ANALYSIS OF THE OIL WELL IMPACTOR MECHANISM UNDER DIFFERENT CONDITIONS

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ANALYSIS OF THE OIL WELL IMPACTOR MECHANISM UNDER DIFFERENT CONDITIONS

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ABSTRACT

ANALYSIS OF THE OIL WELL IMPACTOR MECHANISM UNDER DIFFERENT CONDITIONS

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Drilling process is one of vastly used manufacturing in oil and gas industry, there are plenty of studies that are looking for this complex process in academic and industry world. PDC drill bit is an important petroleum equipment in this process, therefore predictions of significant process variable such as torque, cutting force and stress distributions play an important role to keep the equipment life and the safety of the lives of workers. The researchers have found these variables by using experimental techniques which makes the investigation need long period time and have expensive cost. At this point, finite element modeling and simulation become the main to investigate these parameters. It can be expected that finite element Simulations can be used without conducting any experimental studies.

This thesis covers a study investigating the effect of parameters on the drill bit, PDC modelling and simulation during the drilling process by using finite element method with software ABAQUS. For this purpose, drilling simulations of the PDC are performed.

At the first step, the effect of drilling speed on torque and cutting force is investigated by comparing simulation result with experimental results that are found in the literature review. The effect of load force on torque and the values of rotary speed depend on data from experimental working from field NOOR WELL in south of Iraq are found. In addition, comparison of two different mesh sizes of element is performed and the results are compared with that of the literature. Then the effect of applied pressure on the drill bit is shown. Also the effect of kinetic energy and internal energy are considered. Lastly, element point in drill bit is set and the maximum stress results are listed from the beginning of the process to the end. The results corresponding to all of these parameters related with the process of the drill bit are taken as a reference point and then comparison for other impactors are conducted using ABAQUS.

Keywords: Finite element method, Drucker Prager damage, PDC

ÖZ

PETROL KUYUSU İMPAKTÖR MEKANİZMASININ FARKLI KOŞULLAR ALTINDA ANALİZİ

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Sondaj işlemi petrol ve gaz imalatında çokca kullanılır. Bu yüzden akademi ve endüstri dünyasında bu kompleks prosesi araştıran yeterli derecede çalışma bulunmaktadır. PDC matkap ucu bu proseste önemli bir ekipmandır. Bu yüzden tork, kesme kuvveti ve stres dağılımı gibi önemli proses değişkenlerinin bulunması, hem çalışanların hayatları açısından hem de ekipmanların kullanım süresi açısından önemli bir rol oynamaktadır. Araştırmacılar bu degişkenleri hem uzun zaman alan hem de pahalıya mal olan deneysel teknikleri kullanarak bulmuşlardır. Bu noktada sonlu eleman modeli ve simülasyon ana aracımız olmaktadır. Bu sayede, sistemdeki değişimler herhangi bir deney yapmadan sonlu elemanlar yöntemiyle belirlenebilir.

Bu tez, ABAQUS programıyla birlikte sonlu elemanlar metodu kullanarak sondaj işlemi süresince PDC modelleme ve simülasyonla önemli etken parametrelerin incelenmesini içerir.

Bu amaçla PDC sondaj simülasyonları yapılmış ve simülasyonlarda kullanılan model doğrulanmıştır. İlk aşamada; matkap hızının kesme kuvveti ve tork üzerindeki etkisi , literatürlerde bulunan deneysel sonuçlarla simülasyon sonuçlarının karşılaştırılmasıyla araştırılmıştır. Daha sonra yük kuvvetinin tork üzerindeki etkisine bakılmış ve Irak'ın güneyindeki NOOR WELL bölgesindeki deneysel çalışmalardan elde edilen verilere bağlı olarak dönme hız degerleri bulunmuştur. Elementlerin iki farklı mesh ölçüleri karşılaştırılmıştır. Bazı simulasyonlarda matkap ucuna basınç uygulayarak stress degerleri üzerindeki etkisinin gösterilmesine gerek duyulmuştur. Aynı zamanda kinetik enerji ve iç enerjinin de etkisi düşünülmüştür. Son olarak matkap ucundaki temel nokta ayarlanarak başlangıctan sona kadar maksimum stres sonuçları gösterilmiştir. Matkap ucu üzerinde referans nokta belirleyerek bütün bu degişkenlerin incelenmesi işlemi ve bütün etkileyen faktörlerin ölçümü ABAQUS programıyla yapılmıştır.

Anahtar Kelimeler: Sonlu elemanlar yöntemi, Drucker Prager Hasar Modeli, PDC

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LIST OF ABBREVIATIONS

PDC	**polycrystalline diamond compact**
D	**Bit diameter**
T	**Torque**
MSE	**Mechanical Specific Energy**
E_m	**Mechanical Efficiency.**
WOB	**Weight on Bit**
RPM	**Rotational Speed**
ROP	**Rate of Penetration**
σ_i	**The incident stress waves**
σ_r	**Reflected stress waves**
E	**Elastic module**
A	**Cross section area**
C	**Elastic wave speed**
Wf	**Wear function**
F	**Friction Coefficient between the cutter and rock**
c	**Number of face cutters of PDC bit**
α	**PDC cutter back rake angle**
D c	**Diameter of PDC cutter**
ΔBG	**Cumulative bit wear**
A_w	**Wear flat area underneath the PDC cutter**
F	**Feed Rate**

A	**Initial yield strength of the material**
B	**Hardening factor**
$\dot{\varepsilon}^{-pl}$	**Equivalent plastic strain rate**
$\dot{\varepsilon}_{\circ}$	**strain rate**
T_c	**Current temperature**
T_{melt}	**Melting temperature**
T_{room}	**Room temperature**
n	**Coefficient of strain hardening**
m	**Coefficient of thermal softening**
C	**Coefficient of strain rate**
d1-d5	**Damage parameters of Johnson-Cook model**
p	**Stress**
q	**Mises stress**
w_D	**Johnson Cook Damage criterion**
ε_D^{-pL}	**Equivalent plastic strain at the beginning of damage**

CHAPTER 1

INTRODUCTION

In this chapter, the general idea about the drill bit and drilling percussion will be summarized.

1.1 Drill Bits

A drill bit is one of the most important petroleum equipment in oil well during the drilling process [1]. A drill is a cutting tool which is attached to the end of drilling machines. Also the drill bit drills the rock and make some process for example chipping, grinding and scraping at the bottom of the hole. Likewise, there are many different variations in the design of drill bits which are shown in figure (1). One of the other important things is the selection of drilling bit depend on requiring information for drilling.

The mechanical engineer should have an idea about the design variations to be able to control for selecting bit for the appropriate drilling. For example, there are three types of bits which used in oil well. These type bits are roller cone bits (rock bits), polycrystalline diamond compact (PDC) bits and natural or thermally stable diamond bits. On the other hand, the engineer must also be aware of the effect of the operating parameters on the performance of the bit [2].

Figure 1 Type of drill bit [2]

1.1.1 The component of diamond drill bit.

The component of a PDC cutter consists of a study which covered by an artificial diamond layer bonded in a high pressure and high temperature sintering process.

1.1.2 Type of body materials of PDC drill bit.

There are two types of body material for PDC [3]. These types are steel body and tungsten carbide matrix.

Steel body: Most common bit body material is heat treated steel. These steel body bits are usually used in conjunction with PDC "studs" which are diamond compacts on tungsten carbide posts. These stud cutters are typically secured to the bit body by interference fit or shrink fit into a hole located in the bit body. **Matrix Body**: is a second type of bit body which is much more abrasion and erosion resistant than the steel body. The matrix bit body is composed of a combination of copper and tungsten carbide to provide durable wear resistance can be noticed figure (2).

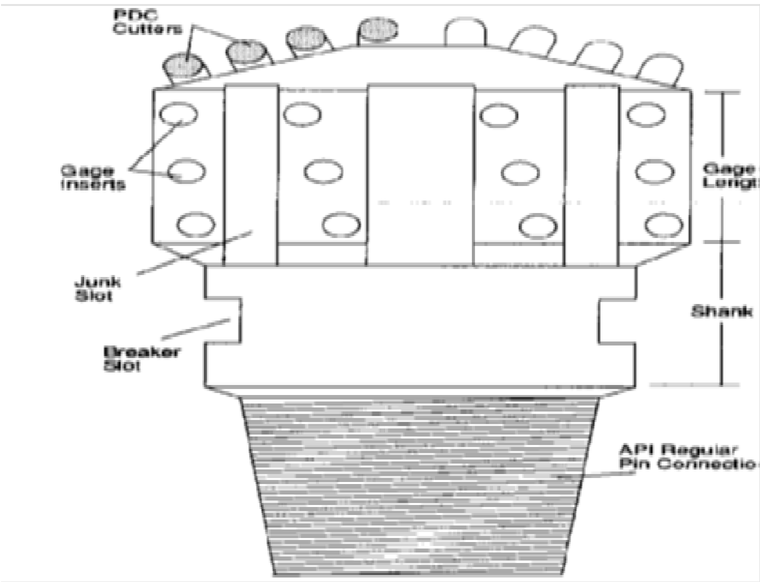


Figure 2 Isometric view of PDC drill bit [3]

Circular cutting is widely used in the drilling process to get good result, especially in the oil well. This study had extended from a lot of previous studies. This study formed as the basis of a full drilling bit modeling that presented at the end.

1.2 Percussive drilling.

Percussive drilling is a process with high force and short duration blows which are applied in rapid sequence to the rock shown in figure (3). The blows are normally generated by the impact of an accelerated piston [4]. The acceleration can be carried out air or hydraulic pressure, or even gravity in more initial tools [7].

Figure 3 Schematic of a percussive system [7]

Also the percussive drilling is used in different applications such as drilling the hole and breaking the rock. In the field of oil industry rock drilling are usually used to drill 70-300 mm diameter holes with different depth from few to hundred meters. On the other hand, the type of percussive drilling can be divided into three method such as down the hole (DTH), hammer drilling and churn drilling [6]. These methods are shown in figure (4). The first one (DTH) can be distinguished by the length ratio of the hammer and bit, then, the second method, drilling hammer the length of the hammer smaller than bit, finally churn drilling is not a hammer but the bit itself accelerates to the work piece.

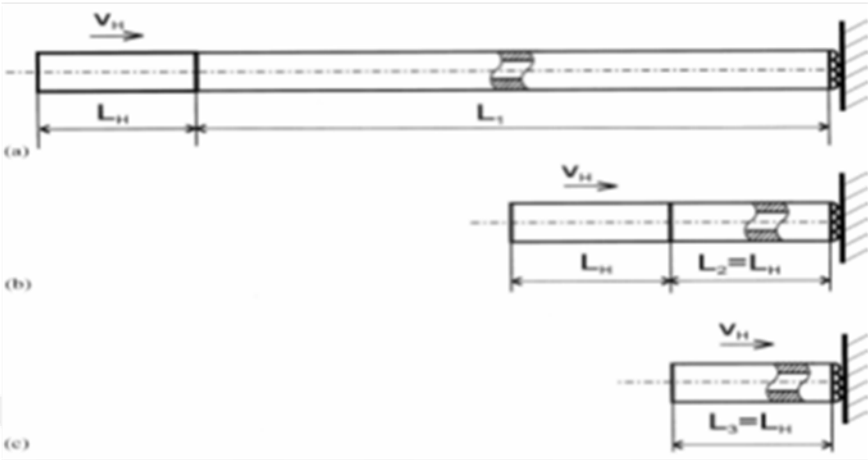


Figure 4 Method of percussive drilling [6]

a. Hammer drilling b. Down the hole drilling c. Churn drilling

It is an impossible to fragment rock when weight is applied on bit only. When Piston impacts on the drill bit the rock begins to break quickly, therefore the velocity thrust of the force and pressure statics cause an effect on the bit. Yongtao Fan et al. [7] defined the drilling percussion as a process which is mainly used in mining in oil and gas industry for fragmentation from the medium to hard rock such as limestone sandstone, granite and others. It has important advantages such as improving penetration rate and reducing cost per foot and decrease the damage. Finally, a number of important parameters needed to be considered such as energy, transport, methods of drilling, fragmentation of rock, velocities and beam displacement in the direction of the piston. The transfer of certain energy from the piston to bit is not high enough, therefore it must be improved.

1.3 Aim and Scope of thesis

The main objective of this research is to conduct simulations to achieve improvement of the drill bits during the drilling process that includes:

1. To analysis the mechanism of the impactor-bit-rock during percussion drilling by finding the relation between force and velocity and torque.
2. To model the interaction between drilling bit and rock.
3. To investigate the relation between the weight on bit and torque and revolution per minute is investigated.
4. To create a steady mesh.
5. To compare ratio between ALLIE and ALLKE.
6. To consider the changes in the stresses of the drill bit in different region of rock.
7. To use 3D finite element methods with the help of an analysis software (ABAQUS).
8. Finally, compare between the simulations results and experiment results, they can be carried out from the oil well field in the south of Iraq.

1.4 Overview of the Thesis:

This thesis has been implemented into six chapters. Chapter one introduces the concept of the drill bit (PDC) and drilling process which needs to model. Chapter two discusses literature review related to the history of the drilling process and parameter effect on the behavior of drill bit that prediction from early FEM model to the last development in this field. Chapter three explains the CAD approach for finding out the different parameters effect on the drill bit during the drilling process. Chapter four provides the simulation of different cases to inter parameters and predict the segment encourage values which will get good results for the drilling process. Chapter Five provides the results to discuss the simulation and comparing some of them with data from field and others from the literature review. Chapter six includes conclusions and future development.

CHAPTER 2

LITERATURE SURVEY

In this chapter, previous studies on the PDC drill bit during percussive drilling by using 3D finite element are going to be summarized**.**

Tarpaulin [8], investigated experimental studies between conventional and percussion drilling carried out and the author compared them to conclude percussion better than conventional drilling in penetration rate with very high percentage rate when measured in meters penetration per hour. An issue that was addressed in this paper, the penetration rates increases while frequency decreases.

Hartman, [9] focuses on a single parameter between kinetic energy and velocity Firstly, he changes kinetic energy values while the velocity is constant. Secondly, he changes velocity and remain energy constant. He claims to depend on one parameter, then shows the effect of these parameters on depth of penetration and volume of the crater created. The results can be noticed in Figures (5 & 6).

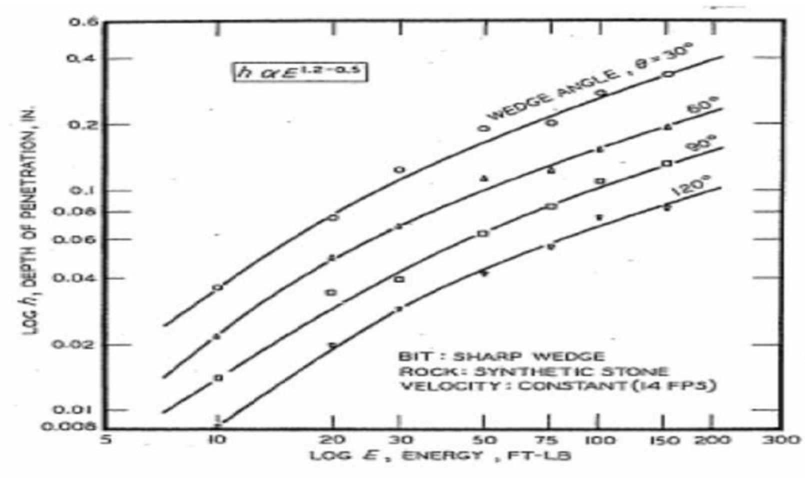


Figure 5 Effect of energy on penetration rate [9]

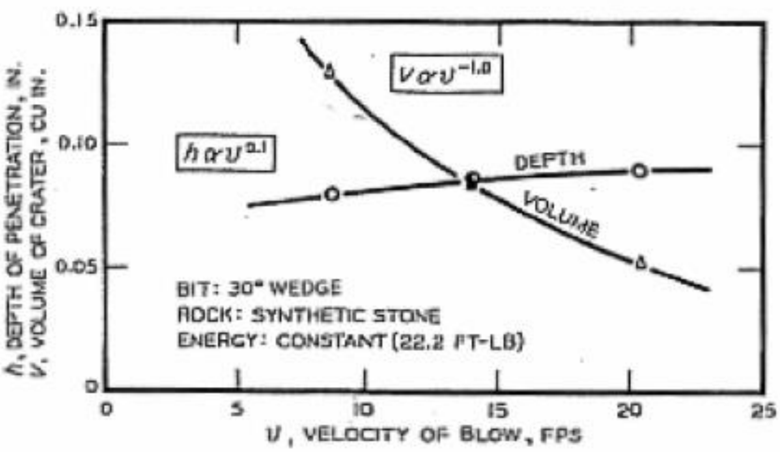


Figure 6 Effect energy on penetration rate and volume of hole[9]

Figure (5) shows the penetration depth for a single a few increase with below energy and wedge angle of the bit while the figure (6) showing the volume of the crater created a decrease with velocity increase. In the final of this study, the author concludes the probability of optimum energy and velocity for any combination of bit shape and rock.

Teale [10] has driven an equation (2.1) which calculate the torsional and axial work performed by bit, then divided this by the volume of rock drilled. Also performed an experimental test that explained the energy per volume of rock damaged to be relatively constant regardless the changes in the rate of penetration (ROP) weight on bit (WOB) and revolutions per minute (RPM). Finally, he suggested the numerical relation between specific energy is equal to rock compressive strength in pounds per square inch as can be shown in the equation (2.1) and used it in his evaluation of laboratory data.

$$MSE = E_M * \left(\frac{4WOB}{D^2 * 100} + \frac{480RPMT}{D^2 ROP * 1000} \right) \tag{2.1}$$

Where:

WOB is the weight on bit

RPM is the revolution per minute

MSE is the specific mechanical energy

D is the diameter of the bit

ROP is the rate of drilling

In his study, the author conformed the specific energy cannot be represented single because of the non-homogeneous rock formation and the wide variation of the drilling variables.

2.1 Characterization of the rock

Fairhurst [4] found the fact gained from the resultant force on the drill head must equal to the force F on the workpiece as shown in equation (2.2).

$$A.(\sigma_i + \sigma_r) = F \qquad (2.2)$$

Where

A is defined the cross section area of the bit.

σ_i The incident stress

σ_r The reflected stress waves.

The relation between the stress amplitude, σ, and the particle velocity, ν, of a one dimensional (1-D) stress pulse is investigated from equation below.

$$V = \frac{C.\sigma}{E} \quad \text{Or} \quad \sigma = \rho.C.V \qquad (2.3)$$

Where E is the elastic modulus, ρ is the density of the media and $c = \sqrt{\frac{E}{\rho}}$ (elastic wave speed).

From Equation (2.3), the penetration velocity can be derived by assuming the bit initially stationary and it writes like equation below.

$$\frac{c}{E}.(\sigma_i - \sigma_r) = V_c \qquad (2.4)$$

Where V_c is the velocity of the drilling bit to the workpiece, or equally, the penetration velocity. Here it must be noticed that the compressive stresses are taken to be positive.

By using Equation (2.1), Equation (2.3) and the known time variations of the incident and reflected stress waves, one can find the force and velocity variations of the bit, which can yield the *F-P* relationship easily. The author conducted that the incident and reflected waves on the hammer drill, systems were affected by strain gauges s, and derives the force-displacement characteristic of an 18 in cubic rocks of the impact piston single at 2 ft. long, 1 in. diameter piston is used to strike a 10 ft. Long, 1 in. Diameter rod in the measurements. The resulting F-P curve as shown in Figure (7).

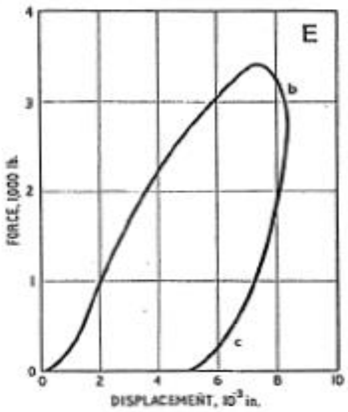


Figure 7 F-P Characteristic of rock [4]

The relation between dynamic tests and direct determination technique to show the relation of *F-P characteristics* of rock that have been investigated by Hustrulid and Fairhurst [4]. They had used a drop tester in which the bit is attached to a heavy mass and allowed to free fall onto the rock. The *F-P* results of 16 successive drops are given in Figure (8).

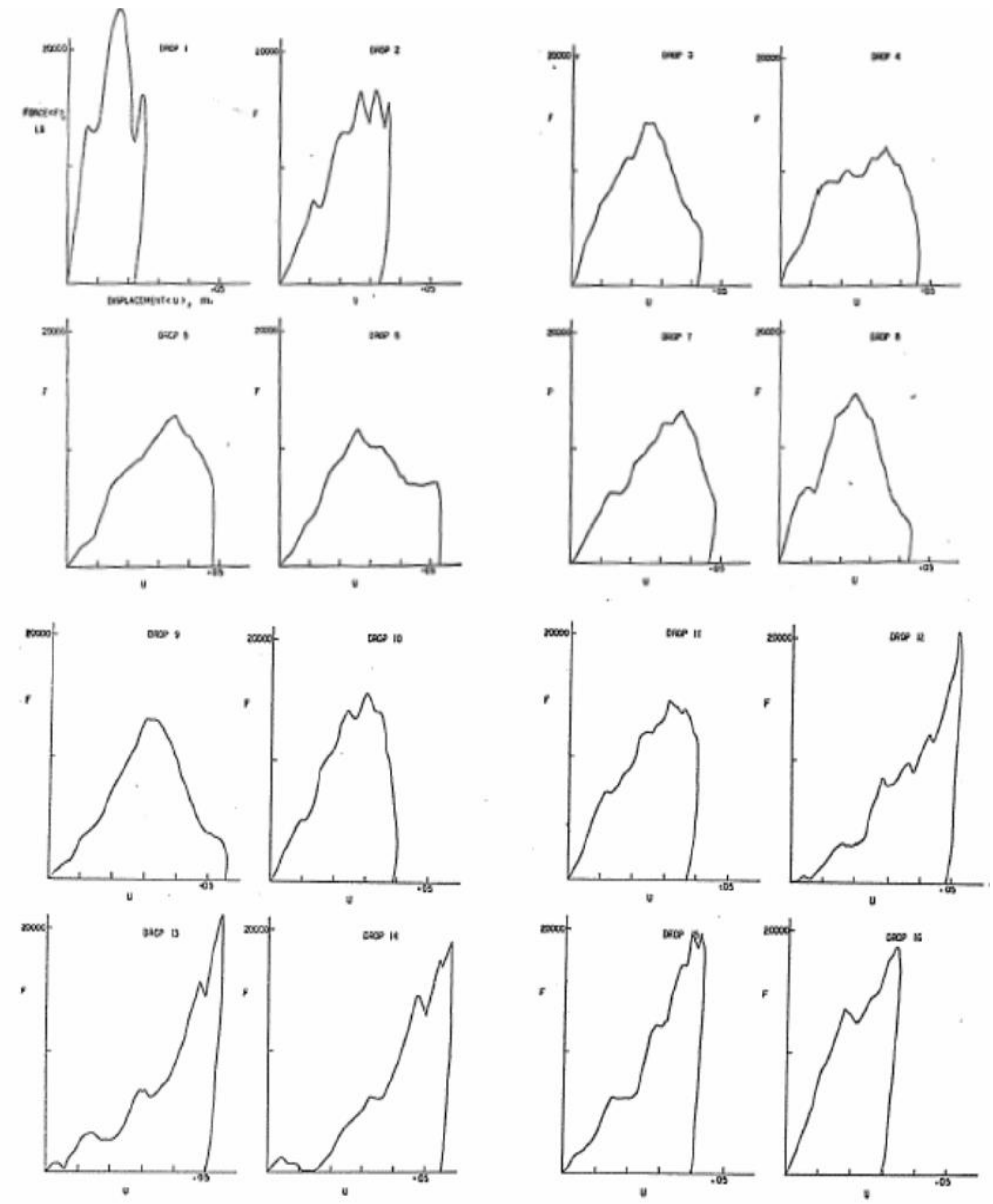


Figure 8 Dynamic F-P curves of granite for 16 drops [11]

Lundberg and Henchoz [12] have recently developed the methodology which is used by Fairhurst [4] where stress can be measured at one cross section because of the minimum requirement for the length of the drill bit and, the stress have not overlapped at the point of strain measurement. Finally the waves do not separate during measuring and it separates in analysis of strain. This develop method is called two point strain measurement. Lundberg et al. [13] modulate the method to include non-uniform rods.

Carlsson et al. [14] used DTH drilling system to measure the F-P curve used by Their results can be seen in Figure (9). They refer to the studies that are mentioned up to this point and reveal a general shape for the F-P behavior of stones under percussive drilling. A typical one is given in Figure (10).

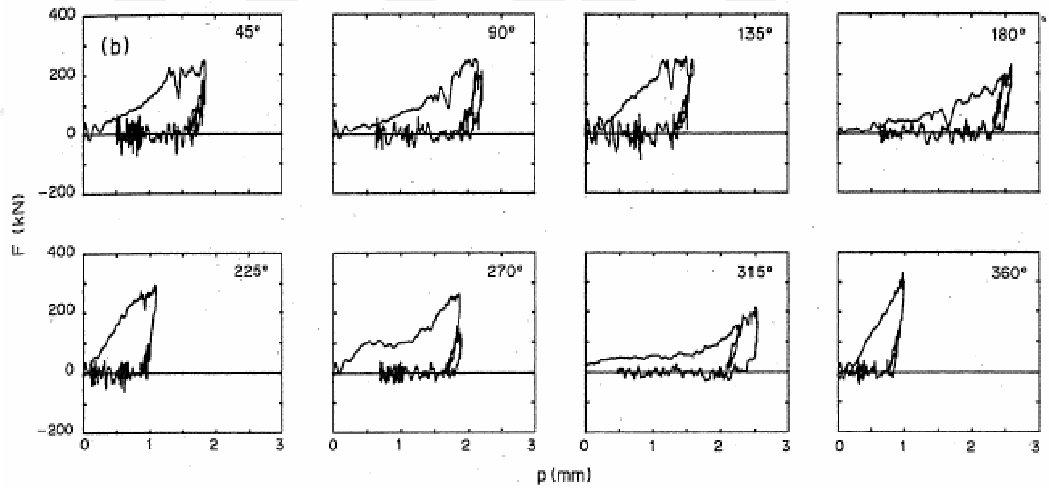


Figure 9 F-P relations obtained for 8 hits by two strain measurement [14]

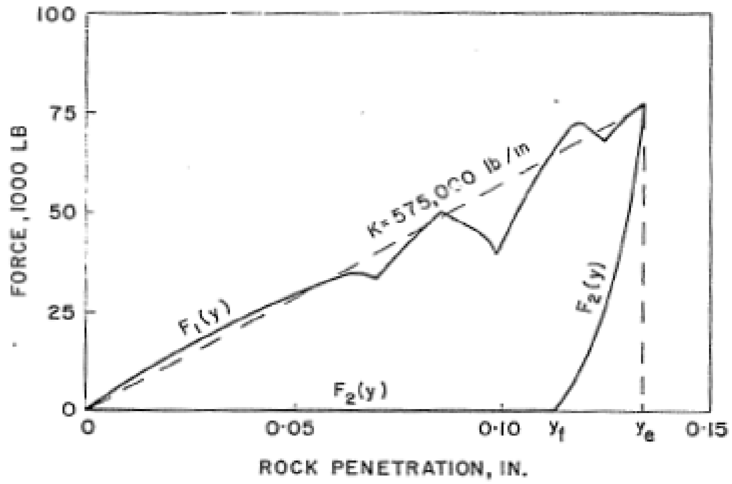


Figure 10 Force curve in stone percussive drilling [14]

From figure (10) it can be conducted that F_1(y) represents a closed hysteresis loop in the appositive quadrant of the force penetration. The $F_1(y)$ elastic deformation and crushing of the workpiece is represented by the curves of positive slope and regions of chip formation or sudden fractures by those of negative slope which is represented by $F_2(y)$, the y_e is less than y_f by the amount of this elastic expansion. The slopes in *F-P* curve of any drilling system depend on amount of factors like the stone type (hardness, brittleness, homogeneity, elastic behavior), bit head geometry (wedge angle), fluids used in the drill hole, and the amount of stone debris at the bottom of the hole. The typical *F-P* relationship is generally represented by a bilinear curve with loading and unloading phases, which can be seen in Figure (11).

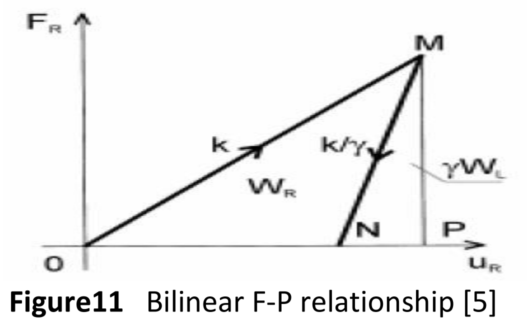


Figure11 Bilinear F-P relationship [5]

In Figure (11) line OM is the loading phase characterized by the penetration resistance k, and line MN is the unloading phase. The slope in the unloading phase depends on γ, which is generally called the unloading parameter. γ takes values between (0 & 1), which makes the workpiece perfectly inelastic or elastic, respectively. After the loading and unloading phases, the total work done on the workpiece W_R can be calculated by equation (2.5).

$$w_R = w_L - w_U \tag{2.5}$$

Where w_L is the work done during the loading phase, and w_U is the energy returned to the drill during the unloading phase. w_U Can be found by equation (2.6).

$$W_u = \gamma . W_L \tag{2.6}$$

2.2 Polycrystalline Diamond (PDC) Bits

Polycrystalline Diamond Compact really effective cut compared to roller cone. Moreover, it may be twice PDC drill bit faster and longer than the roller cone even in hard form [6].

2.3 Parameters important for a PDC Drill Bit

Polycrystalline diamond compacts (PDC) drill bit belong to the category of drag bits, which consists of fixed cutter blades integrated with the body of the bit and rotate as a single unit along with drill string[15]. A schematic view of a PDC drill bit and its major components is shown in Figure (12).

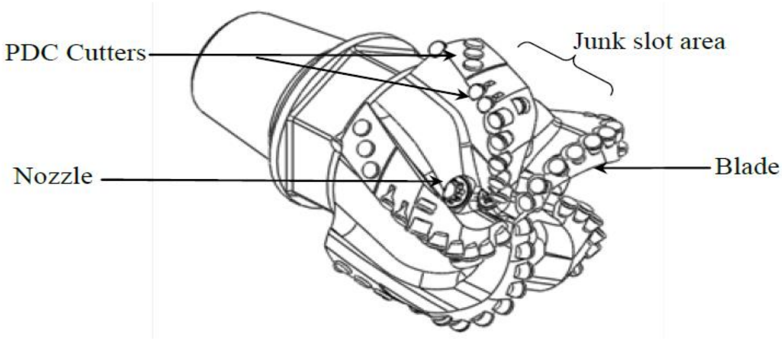


Figure 12 Isometric view of PDC drill bit [15]

Balkenbush & Onisko [16]; Cerkovnik,.[17] confirm these drill bits have been used for the soft, medium, and hard formations of rocks and shale with appropriate design and features it can improve drilling performance and lower the associated cost. Moslemi & Ahmadi [18], Offenbacher et al. [19], have also shown that by increasing the drilling rate this bit may reduce drilling cost by 50% or 11%, respectively. Akin et al. [20], confirm the factors that have an effect on drilling rate and bit life are the weight on bit (WOB), rotary speed and bit hydraulics. Bit balling is the phenomena of sticky shale getting trapped in the face of the drill bit flow path, which in turn causes serious drag on the bit and obstructs the fluid flow in the flow path (Figure 13).

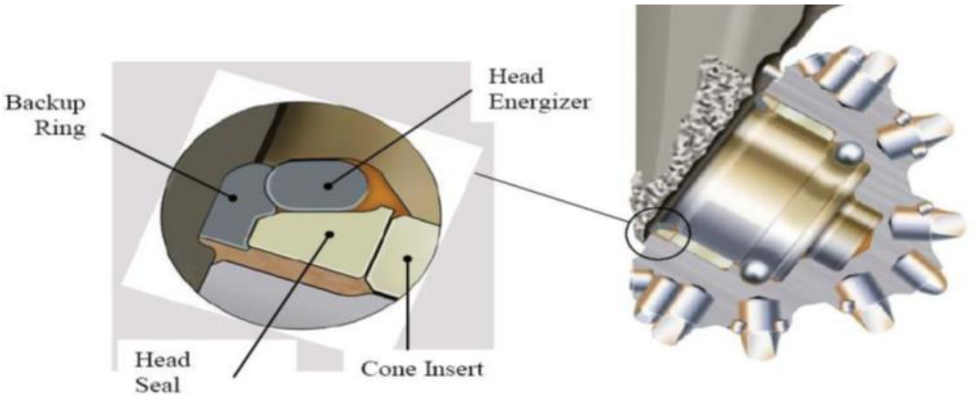
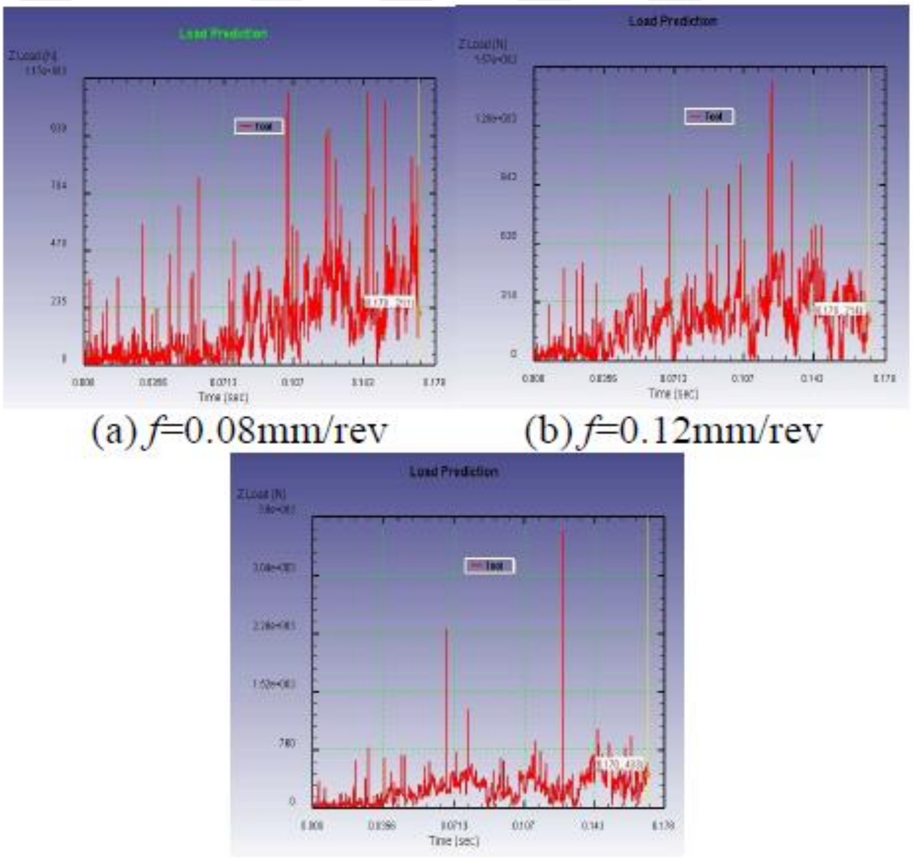


Figure 13 Bit baling in PDC drill bit [21]

2.4 Trust force

Drilling force not only determines the power consumption of drilling, but also directly affects the cutting heat generated during the drilling process. One of the big problems is the thrust force. Typical roller cone bits use a combination of thrust force and radial bearings to withstand external forces. Su et al. [22] confirmed that the drilling rate is more effective on drilling force (Z load). They experiment nine simulations with different drilling rate and speeds to show the effect of each one on the drilling force and Torque as shown in figure (14).



(a) f=0.08mm/rev (b) f=0.12mm/rev

(c) f=0.16mm/rev

Figure 14 The values of the force against time [22]

.

Olschewski et al. [23] used a combination of tapered and cylindrical roller bearings. Some designs have also used partially-tapered cylindrical rollers to include such an effect.

Lin and Nguyen. [24], show a dynamic seal made of a relatively soft material which has also been added between two metal seals. Then finally they conducted, the use of two elastomeric seals back to back is another proposed method known as dual-seal method and the configuration was modified to replace one of the metal seals with cone insert to prevent debris entering the cone cavity as shown in figure (15).

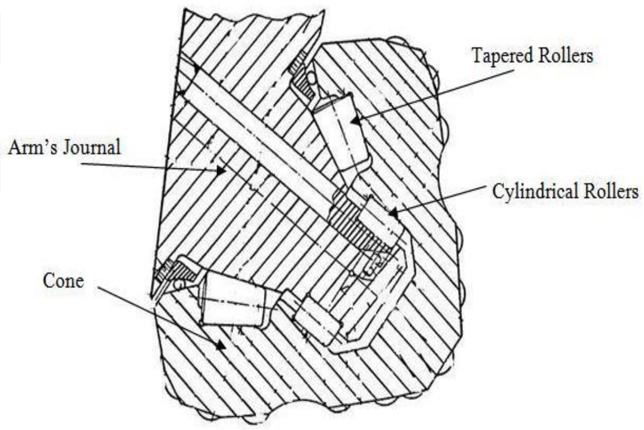


Figure 15 The sealing package [24]

Rampersad et al, [25] have developed a model to evaluate the ability of drilling rate of drag bits, then, they performed equation to estimate it.

$$Rop = \frac{14.4 * WOB * RPm * \cos\alpha}{\sigma * D * \tan\theta} * \frac{a}{Rpm^{b} * Woc^{c}} \qquad (2\text{-}7)$$

Where:

ROP Drilling Rate (Ft/Hr)

WOB weight on bit (Ton)

Rpm Rotary speed

α The angle of cutter side –rake range (degree) a, b, c confined compressive strength (psi)

D the diameter of the bit (inch)

θ cutter half wedge angle (degree)

Motahhari et al. [26] developed this model and they considered two parameters, the first one is the back rake angle shown in equation (2.8) and the others is wear flat as be noticed in equation (2.9). The back rake angle “is the angle between the leading edge of a cutting tool perpendicular to the surface being cut chip flow”. The wear flat area is the area formed under the cutter due to friction between the cutting edge and the surface being cut. From equation (2.8) and equation (2.9) equation (2.10) can be concluded.

$$ROP = Wf * \frac{14.4 * WoB * Rpm^{b} * \cos\theta}{\sigma * D * (\tan\theta)} \tag{2.8}$$

$$Wf = a * \frac{WoB^{c}}{N_c^{d} * \sigma^{c} * A_w^{f}} * (1 + \frac{\mu}{\tan\theta'}) \tag{2.9}$$

$$A_w = \frac{D_c^2}{4\sin\theta'} * \arccos(1 - \frac{\Delta BG}{4}) - \frac{D_c^2(4 - \Delta BG)}{64\sin\theta'} * \sqrt{8 * \Delta BG * \Delta BG^2}$$

(2.10)

Where:

Wf Wear function

μ Viscosity (cp)

F Friction Coefficient between the cutter and rock

N_c Number of face cutters of PDC bit

D diameter of bit

θ' PDC cutter back rake angle (degree)

D_c PDC cutter diameter (inch)

ΔBG Cumulative bit wears function

A_w Wear flat area underneath the PDC cutter ($inch^2$)

But this model does not consider the effect of cumulative cutters wear on ROP therefore, Wu et al. [27] integrated the effect of cumulative cutters wear on the ROP of PDC drill bits and they got an equation (2.11) and finally, described equation (2.12):

$$G_b = \frac{t_c * N_c}{\cos\alpha} * \sqrt{\frac{\Delta BG * D_c^2}{2\cos^3\theta}(1-\frac{\Delta BG}{8\cos\theta})} \qquad (2.11)$$

$$\Delta BG = \frac{C_c}{G_B} * \sum_{i=1}^{n} WoB_i * Rpm_i * CCS_i * Abr_i \qquad (2.12)$$

Where:

G_B Geometric function

t_c PDC layer thickness (m)

C_c The Bit wear coefficient

CCS is the Confined of the compressive strength (Mpa)

Abr Formation abrasiveness

RPM Rotary speed of the bit

WOB Weight on bit (Tone)

In this model, the cumulative bit wear was recognized to be a function of the geometry and the orientation of the cutter.

2.5 Efficiency

According to Fairhurst [4] the efficiency of energy transfer from drill bit to the rock is recognized by the boundary condition at bit rock interface and the completed transmission can occur only if the penetration of the rock matches the characteristic of the bit. Simon. [28] describes that it is impossible to decrease the force between drill and rock by increasing the penetration, but the increasing penetration may be occurring momentarily because of the rock feature as shown in figure (16).

Lundberg [29], like Simon [28] calculates the efficiency of the energy transfer from drill bit to the rock depend upon the stress wave and the F-P relationship. But Simon noticed that Lundberg does not neglect the unloading phase and he includes the dimension less parameter as seen in figure (11).

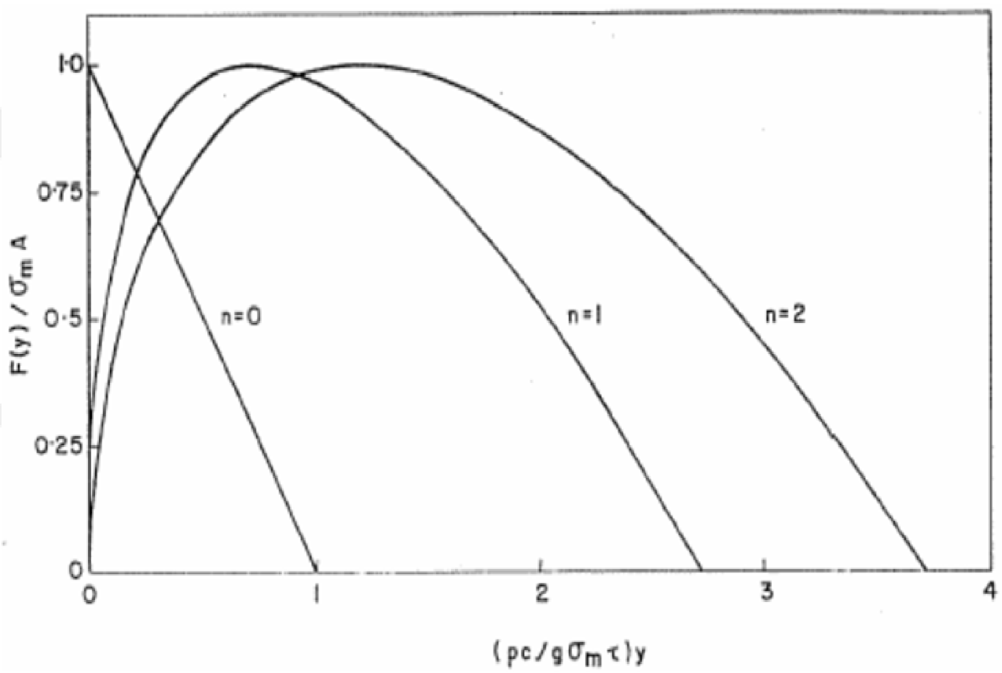


Figure 16 Incident stress wave forms [20]

2.6 Finite element method in the drilling process

The study of the basic ideas of the finite element method specified in the beginning of the 1940s. In (1943) Courant [30] developed finite element method. Then, he used a multi-parametric function definition to meet the sub-regions of the triangle model torsion problems. The term “finite element” is firstly used by Clough [31]. Zienkiewicz [32] wrote the first book on the theory of finite element. Also other development on this theory of this book by

Cook, et al. [33] and Mohr [34]. Finally, Chandrupatla and Belegundu [35] develop this study on FEM.

Finite element method is a powerful tool that is used to study the way of the drilling process which can provide approach for drilling and then it has been developed by Hitchings [36] to study the spread of delamination in composites by using finite element method. Shuttle and Altan [37] used the approach to determine the effect of torque and thrust force. Also, they predict the values of temperature and thermal distribution of drill holes by using finite element method. Finally, Streakowski [38] developed an analytical finite element technique to assess the momentum and torque in the drilling process.

Chiang et al. [39] propose a model to study the impact between the bodies in terms of the impulse-momentum principle and applied iteratively at each node and at each element assuming constant wave speeds. Modeling of the bit interaction with the rock is done by the same scheme used by Lundberg. Finally, the author believes that this method makes it simpler to study the interaction of many bodies during impact under a different case of boundary conditions.

Chiang compares the results with the Finite Element Method (FEM). A 1-D model composed of elements, and a three-dimensional (3-D) model with 8-node brick elements are used for comparison. Then the research achieves a good result as shown in figure (17).

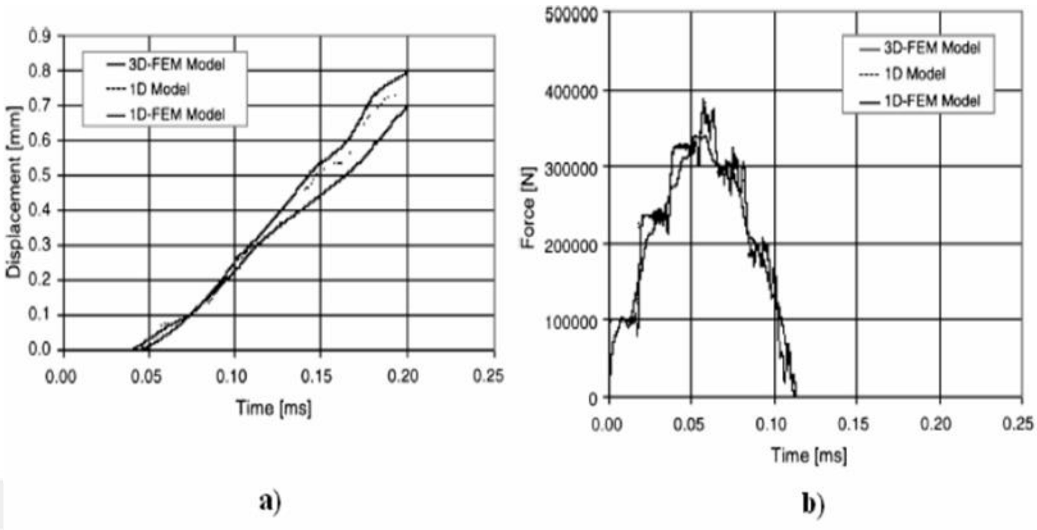


Figure 17 (a) Bit penetration by time. (b) force by time at piston-bit interface [39].

In this study, he analyzes down-the-hole drilling process on different type of rock that are differentiated in the *F-P* curves. The rocks modeled are mortar, endesite and granite from the softer to the harder type. According to the results, the author concludes the remained energy in the piston after the hit is independent of rock being impacted. Only for the case of the rigid rock, there is significantly more energy remained, as can be seen in Figure (18). According to the authors result, it reveals that the piston separates from the drill bit before the rock can reflect any stress wave back into the piston.

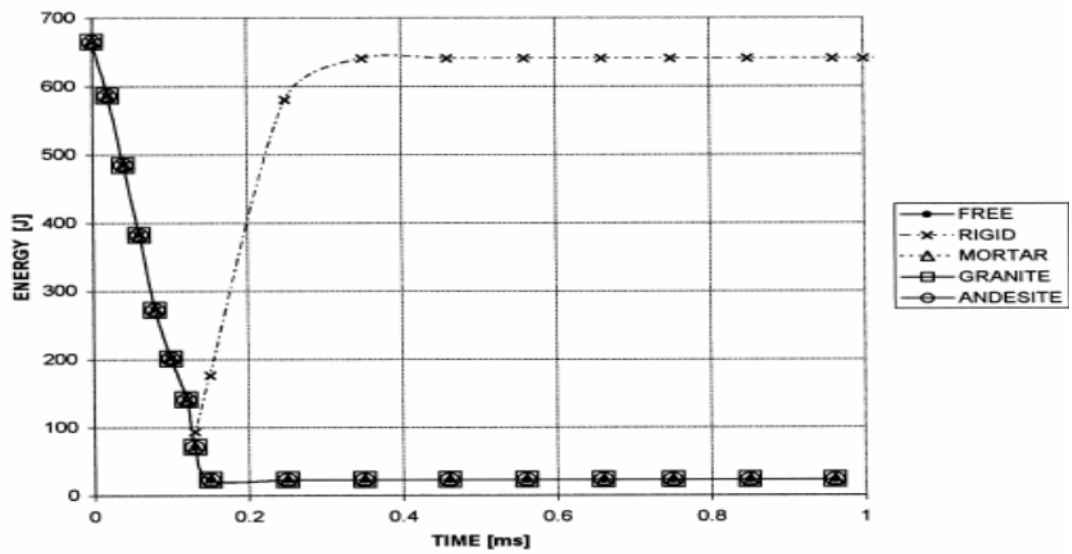


Figure 18 Energy via time history of the piston for DTH drilling [39].

This analysis can be demonstrated as follows: if rigid body is used as the workpiece, the first reflected wave is a compressive wave, the energy can transfer to the piston. However, when rock is used, the first reflected wave has a tensile leading portion [40]. The tensile portion, when reached the piston interface, pulls the end of the bit away from the piston [11]. If the following compressive tail cannot maintain the contact again, no energy can be transmitted to the piston, which is the case for the three rock types in Figure (18) The author also shows that the different rock types, the energy absorbed by the rock is similar, and is a large portion of the initial piston energy for DTH drilling as can be seen in Figure (19). The main difference is the time that the rock takes to absorb the energy, as well as the penetration depth [42].

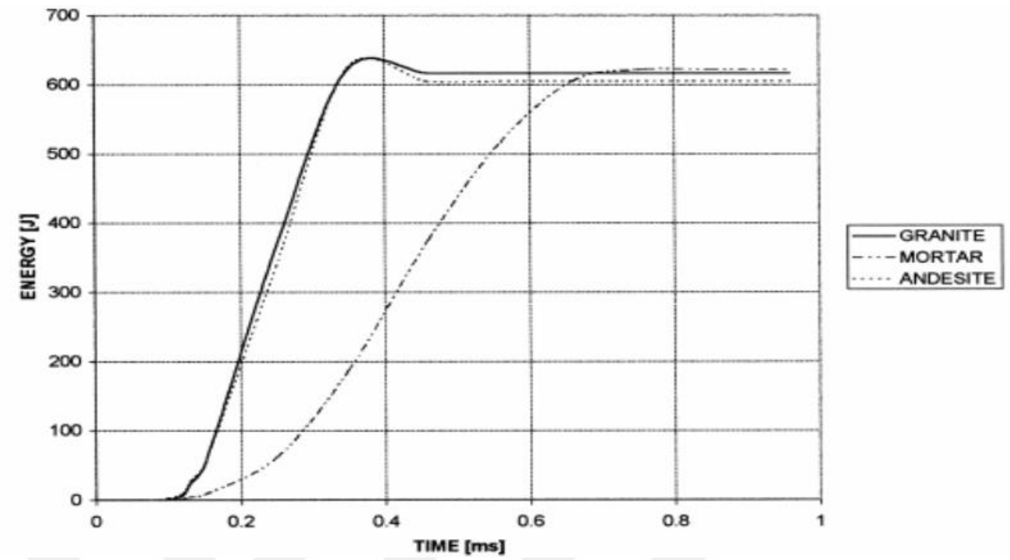


Figure 19 Rock energy by time absorption in DTH drilling [42]

Lundberg et al. [6] have used finite element method to check the validity of the 1-D stress wave. Assumption used in the drilling of percussion for three types of percussion drilling. These types are DTH, churn and hammer drilling. Author, use hollow drill rods for drilling and that the effect of 3-D, which is more efficient. In this study of the FE model, hammer is not the include, but are created a wave of initial effort by Appling pressure on the drill tip leg. In addition, the *F-P* characteristic of the workpiece is considered by means of elastic springs.. According to the results, the 3-D effects which are more effective in hammer drilling than other processes tend to decrease the efficiency of the drilling process because of the relative difference between the efficiencies obtained from 1-D and 3-D analyses is 4% for hammer drilling, 1% for DTH drilling and negligible in churn drilling. Lundberg et al. [42] use churn drilling with axisymmetric FEM. The model can be seen in Figure (20).

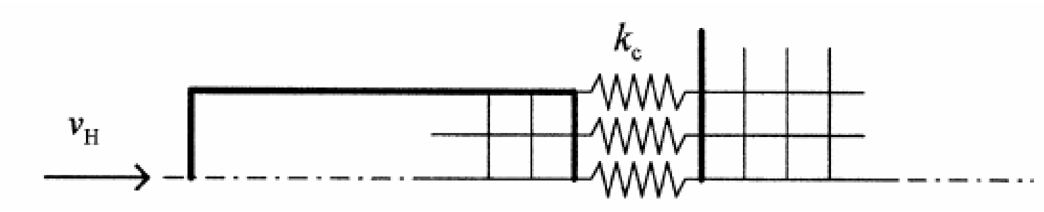


Figure 20 3D model of churn drilling [6].

As indicated in Figure (20) the springs are attached to the nodes. Because of this, the end of the unloading phase, the unloading springs have to be disconnected one by one at the instants when the load tries to change from compression to tension. The springs are also attached to the rock nodes.

The rock is modeled as a half space with a linear elastic or rigid material model. The author notices the impact of the elastic response of the rock by switching between rigid and non-rigid models of the rock.

2.7 Process of the drill bits during the drilling process

Pawar and Jadhav {43] point out the objective of their work as to optimize the geometry of twist drill and investigate to measure the tool load under conditions of drilling and try to analyze if changes of the cutting edge shape and profile effect on the edge stresses. The authors also tried to demonstrate the machining processes (Turning, Milling and Drilling are most commonly used in cutting process and drilling plays an important role as it is always the last step at the end of the value chain). Two types of drills can be used for drilling process, first one is the straight fluted drill and other is twist drill. Then, the drilling processes are carried out by using twist drill. Twist drill has cutting edge divided into two parts, firstly chisel cutting edge and the others are main cutting edge. The shape and profile of cutting edge of twist drill significantly influence stresses developed during machining. They had made an experiment in the study and use the finite element method, then they show in drilling process thrust force and torque are important parameter than cross feed and longitudinal feed force. Also, they notice mechanical load is calculated in terms of thrust force and torque as can be seen in figure (21).

Figure 21 The model with boundary condition [43]

According to the results shown in figure (22), geometry of twist drill effect on the drilling process. Can be seen shape and profile of cutting edge of twist drill effect on stress developed, heat in chip and chip formation and they refer to the Stress developed with cutting edge by finite element method.

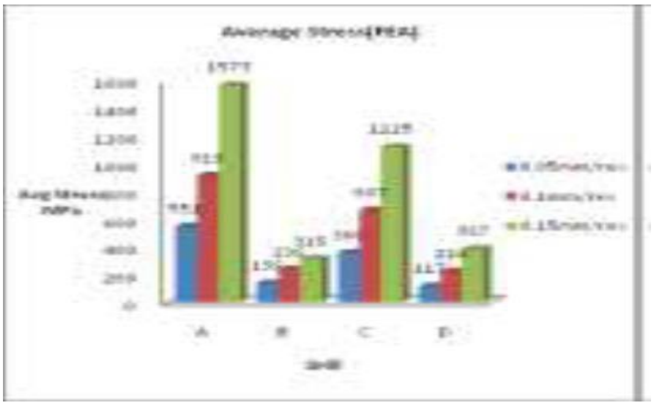


Figure 22 Compression of experiment and FEM[43]

Ozden Isbilir, Elaheh Ghassemieh [44], have developed 3D finite element method with ABAQUS program. This model is designed to simulate the drilling process as seen in figure (23), to calculate the initial and the evolution of the workpiece material damage. Including the prediction of drilling forces, torque, and pressure distribution in the workpiece during the digging process. Bites on both sides of the input and output expected to rise.

The finite element Lagrange equation with explicit integration model carried out all drilling experience to remove heat by using coolant. It is supposed that the heat produced by drilling is terminated by the radiator, but thermal issues are not counted in the form. While the effects of weight and inertia in this form, are not taken into account the overall mechanisms of comprehensive mechanisms in mind when analysis. The base is supposed completely flexible material, and the tool is supposed as a rigid body. Contact the parameters influenced by friction between the rock and the tool by a number of factors, such as drilling speed, feed rate, the geometry of the tool and surface properties of the workpieces. This study consider that the chip is due to the cost, neglected account, and therefore the friction between the chip and drilling. Coulomb friction is the model used in this analysis and static coefficient of friction 0.5. The interaction between the tool and the workpiece using surface to surface contact.

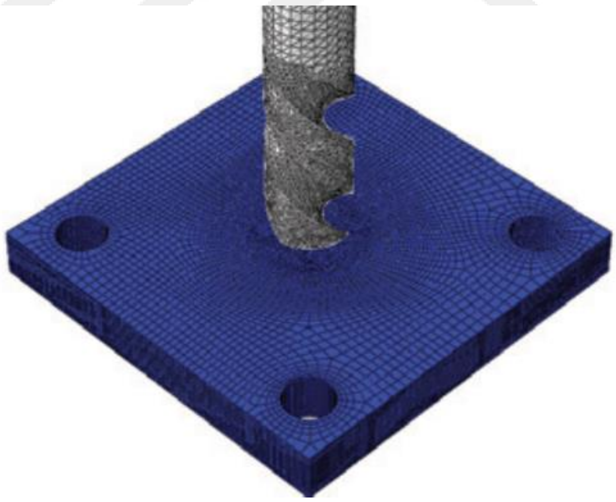


Figure 23 Drill bit and works piece with FEM [44]

Also, they calculated the effect of stress by using the equation of Johnson- Cook model in equation 2.13.

$$\bar{\sigma} = (A + B[\varepsilon^{n}])(1 + (n[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{\circ}}])(1 - [\frac{T - T_{room}}{T_{melt} - T_{room}}]^{m}) \quad (2.13)$$

The damage began when it arrived at the plastic strain equivalent to the value of the criteria. The onset damage is calculated by plastic strain equivalent which can be shown from Eq 2.14.

$$\varepsilon_{D}^{-pL} = \varepsilon_{D}^{-pL} = \left[d_{1} + d_{2} * \exp(d_{3} * \frac{p}{q})\right]\left[1 + d_{4} \ln\left(\frac{\dot{\varepsilon}^{-pl}}{\dot{\varepsilon}_{\circ}}\right)\right]\left(1 + d_{5} * \frac{T - T_{room}}{T_{melt} - T_{room}}\right) \quad (2.14)$$

In this study, the authors predicate the thrust force by Z direction and find the values of force against depth as can be seen from figure (24) then, the result is near the experimental data from the curve and they conclude the finite element method as more accurate.

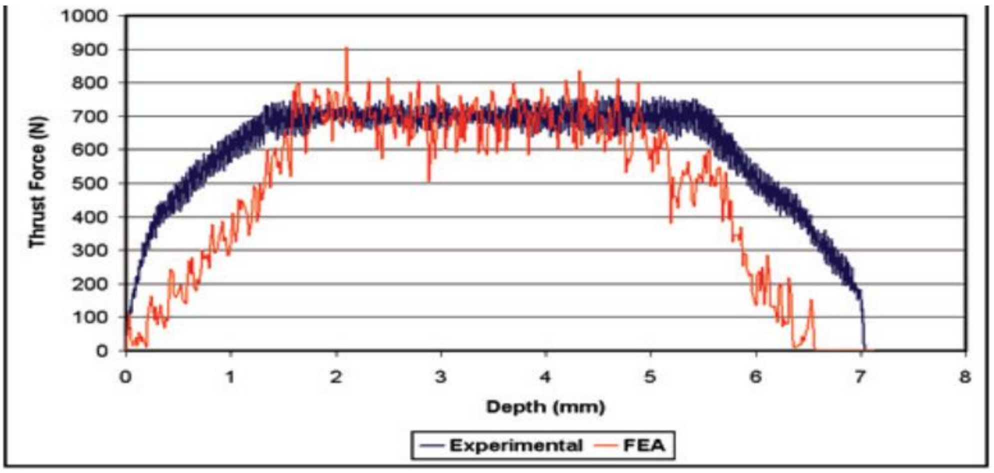


Figure 24 The values of thrust force against depth with FEM and Experiment data [44].

Here the author uses Johnson Cook model to evaluate the initial damage and the parameter Johnson Cook of Ti6 Figure 24 The values of thrust force against depth with FEM and Experiment data [44]. Ti6Al4V parameters can be seen in the table below:

Table 1 Johnson- cook coefficient parameters of Ti6Al4V [44].

A	B	C	n	m	D1	D2	D3	D4	D5
862 Mpas	331 Mpas	0.012	0.8	0.34	-0.09	0.25	-0.5	0.014	3.85

According to the result as shown in figure (24) the axial force resulted from experiment and FEM were performed at 95 mm / min, then the figure shows the finite element method is very good results thrust forces estimate Also the author shows the drilling process divided into three stages which are entrancing, stable and finally exit. Tulu and Heasley [45] depend on three dimension FDM (FLAC) model to simulate the cutting of the circular groove as shown in figure (25). They proposed a special null element to reach the failure depend upon Mohr-coulomb criterion this method based on the interaction between the drill bit and rock during ductile range and it assumed there is no chip formation and crack propagation.

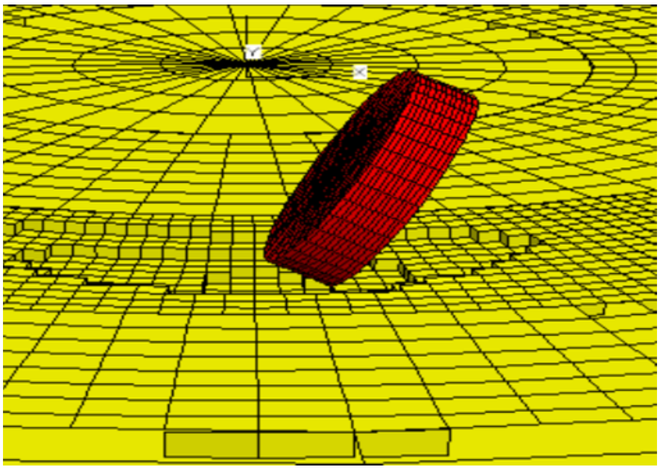
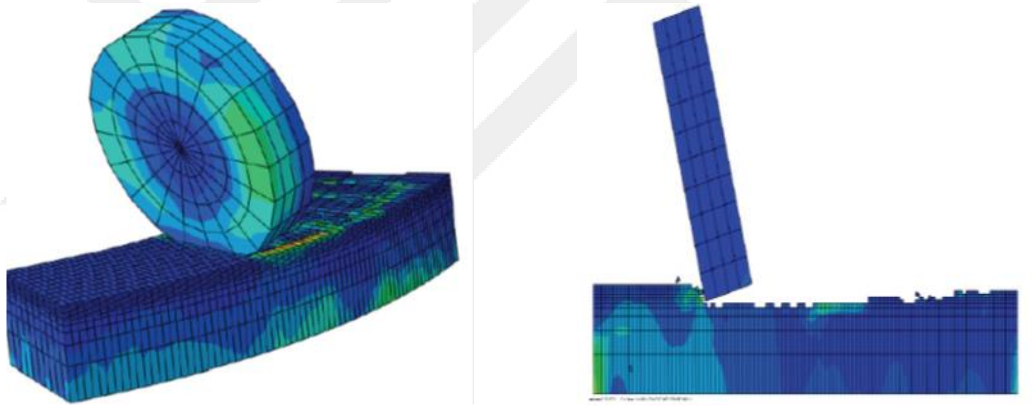


Figure 25 Circular groove by using model FDM [45]

Fontoura *et al*. [61] depend on the basis of the standard model erosion cuttings using software ABAQUS. The implementation of each of the linear cutting 2D slab and 3 D circular groove is performed, then Figure (26) was used. Corrosive element algorithm in this study was limited to the development of ductile. The expected pattern of strength and size deviated significantly from the experimental forces. Mechanical modeling of the rock drill bit with full drill. As well as, they used fine mesh and coarse meshes in this study to find which one is better. They conclude from curve fine mesh is better than coarse mesh from the relation between force and displacement.



a.2D linear slab cutting b. 3D Circular groove cutting

Figure 26 Cutting in ductile mode with FEM [61]

Jaime et al. [47, 48] carried out the two failure modes in linear cutting and circular groove using 3D FEM with software LS-DYNA. They also modeled successfully crushing failure in the shallow cut, and configuration crack, dynamic and fragmented in a deep cut, as shown in Figure (27). Their study integrated continuum damage material model MAT159 [49], capable of modeling the elastic and plastic deformation, In addition to the damage under static and dynamic load case. The researchers also found forces expected and compared with the result of the laboratory. However, in the retractable failure mode, and the study showed was almost continuously MSE, but far less than the value of uniaxial compressive strength. This can be attributed to the fact that the erosion of rocks algorithm, delete items after the failure, and the presence of the wreckage of crushed rock in the front cutter [50] cannot be a good technique, resulting in lower than estimates forces.

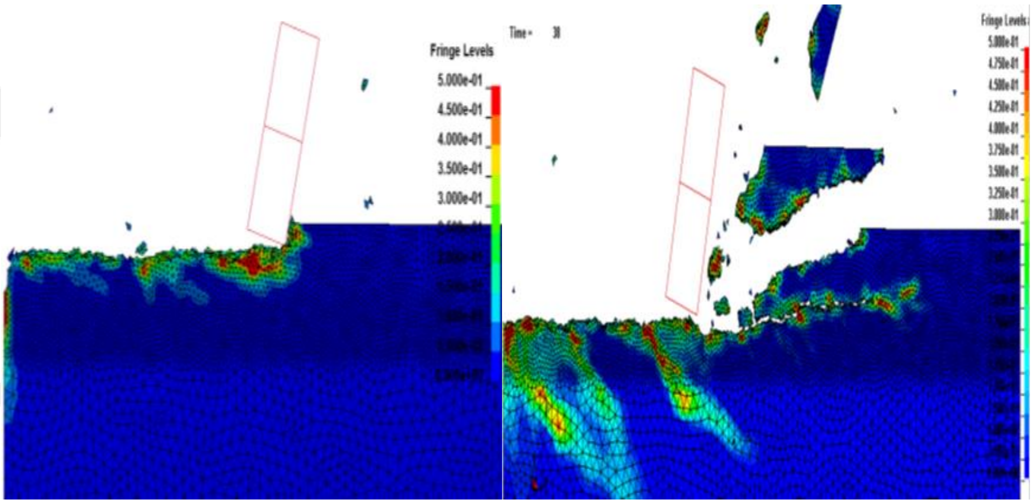


Figure 27 Linear slab cutting [47,48]

a. Ductile mode b. Brittle mode

Figure 27 Linear slab cutting [47,48]

Pryhorovska, et al. [51] simulate a rock linear and circular cutting process for different shape of the PDC drill bit by using finite element method. They also study the effect of the cutter shapes on the cutting force. As well as they show the same shape of the cutter which causes the lower change of cutting force so that to minimize the cutting force changes in the drill bit.

According to the result the authors perform there is no basically difference between curricular cutting and linear cutting but all the obtained relations of cutting forces were wobbling and unevenly for all types of cutters and also they show cutting depth increasing causes oscillation capacity increasing.

The relation between cutting depth and fluctuation amplitude can be observed from figures (28) and (29).

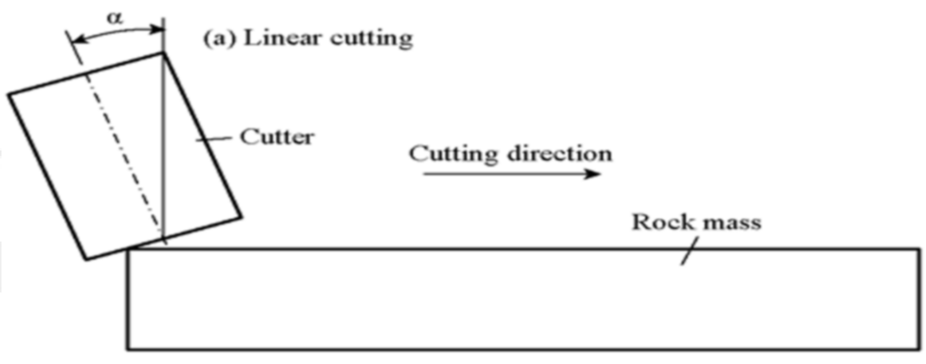


Figure 28 Linear cutting[51]

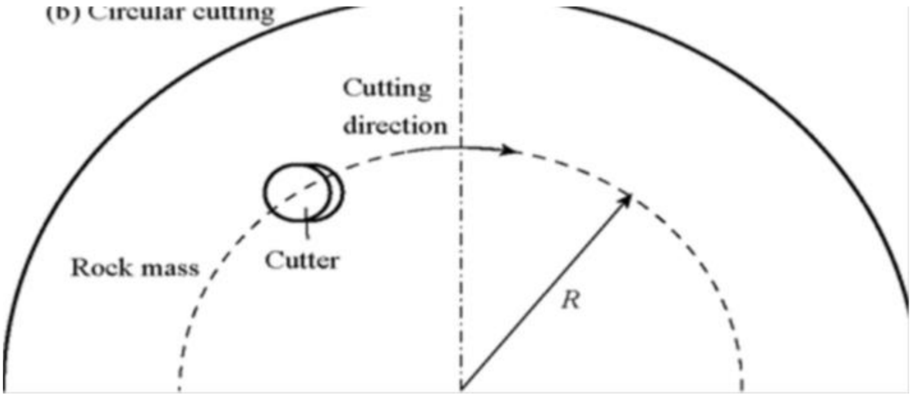


Figure 29 Circular cutting[51]

Finally, they also refer to the propagation of plastic deformations under the cut surface and the gap between the cut parts are observed. And the separation of units consisting of finite elements and increasing of the rock layer displacement is observed through the cutting process.

Navid Bahrani et al. [52], used 3D FEM elastic model to show continuum and discontinue. Codes were used to investigate the effect of the stress path on drilling induced core damage. It contains different cases such as stress increase, decrease and rotation. They refer the details of stress depend on bore hole orientation. The author perform for two bore hole orientation the first one is the borehole parallel to the direction of the principle stress and the others is borehole parallel to the minimum principle stress.

According to the simulation results presented in this paper drilling in a high stress environment may result in core damage in the form of micro-cracks as can be shown in figure (30). The drilling-induced core damage has been known to influence the mechanical properties of rocks specimens measured in the laboratory.

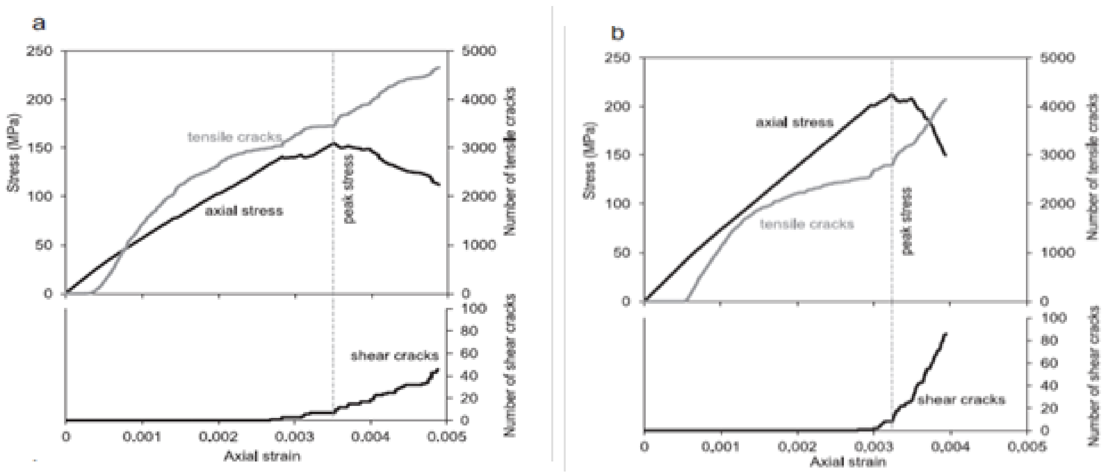


Figure 30 Bore hole parallel to maximum

Bourgoyne and Young [53,54] Submitted a model to measure the penetration rate with the equation expressed as a function of multiple contains 8 items can be expressed in equation 2.15.

R = f {f1, f2 , f3, f4, f5 ,f6 ,f7, f8 } (2. 15)

The factors f1 - f8 express the different values on the rate of penetration (R in Equation 2.15) by the strength of the formation, weight on bit, the speed of drilling string, differential pressure, effect force on a bit.

f1 effects of the formation of the strength factor and the type of the penetration rate model, which is fixed to certain conditions, drilling, and the type of thing. It is included to increase the impact strength due to the formation of normal pressure with depth in the f2, While the effect of f3 under pressure information models press abnormally in. f2 and f3 factors are also continuing for a particular formation. Factor f4 effects over or under the balance of the penetration rate in the equation 2.16.

Bourgoyne and Young [53,54] also note that the f5 and f6 factors are linked to weight on bit (WOB) and the speed of rotation of the bit, and represented in the equations 2.17 and 2.18. Then, Similar to the effect of tooth wear in f7 coefficient, but is assumed to be a constant steady state model. Finally, f8 is served factor in the equation 2.19 and models the impact force of the impact of hydraulic jet drilling mud penetration rate. Originally published equations using engineering units, but was changed to SI units for this work.

$$f_4 = e^{a_4(p_f - p_{bh})} \tag{2.16}$$

$$f_5 = \left[\frac{\left(\frac{w}{d_b}\right) - \left(\frac{w}{d_b}\right)_t}{71.4 - \left(\frac{w}{db}\right)_t} \right]^{a_5} \tag{2.17}$$

$$f_6 = \left(\frac{N}{60}\right)^{a_6} \tag{2.18}$$

$$f_8 = \left(\frac{f_j}{4482}\right)^{a_8} \tag{2.19}$$

The weight on bit (WOB) represents in metric tons, while rotational speed (N) represents the revolutions per minute (RPM). Diameter drilling (and thus also the well at a certain depth) is expressed in decibels represents a threshold WOB in diameter bit what is required to penetrate a given surface, and is therefore dependent on the characteristics of the formation. pf represents the formation pressure at the bottom of the wellbore while PBH representing the bottom hole pressure in the wellbore. Fj represents the hydraulic jet impact force in Newton.

Combining F3 and F7 at a fixed one R0. This represents a constant drilling ability of forming units m = hours. Given the equation resulting from the rate of penetration in table (2). It has been selected foundations A4, A5, A6, A8 based on the typical values in the literature, and are contained in the above equations

Table 2 The parameter of the rate of penetration [53]

Parameters	A_4	A_5	A_6	A_8
Value	0.01	1	0.7	0.3

$$R = R_o e^{0.01(p_f - p_{bh})} \left[\frac{\left(\frac{w}{d_b}\right) - \left(\frac{w}{d_b}\right)_t}{71.4 - \left(\frac{w}{db}\right)_t} \right]^{a_5} \left(\frac{N}{60}\right)^{0.7} \left(\frac{f_j}{4482}\right)^{0.3} \qquad (2.20)$$

Equation 2.20 shows that the increase in the penetration rate is linear with increasing (WOB), while the increase is less than linear with N, bit rotational speed. The increase in ROP.

Detection of the interaction mechanism bit rock there are four hypotheses. It does not consider. 1. The initial damage of the rock. 2. Limit the pressure and temperature at the bottom of the hole. 3. The effect of the body, interaction tooth bit 4. Is taken away from the rock debris live [53].

Han et al [55,56], put 3D numerical simulations of air percussion drilling to better understand the physics of drilling and predict hammer performance with the aid of a 3D FLAC program.

Yongtao Fan et al [7] consider the effects of coupling static pressure, impact strength and cutting force using 3D analysis, interaction bit with rock found on three outcomes: transfer of energy in the drilling of percussion, rocks splitting, quickly and radial displacement of the piston trend analysis.

According to the result, the efficiency of energy transfer from the piston to the bit is not high and must be improved. Bit cannot break up the rocks when only loads WOB on it. After a little affected by the piston, it begins to break up the rocks quickly. Better air pressure is 1.0 MPa when using the impactor and bit to drill granite, according to the size and depth of the hole fragmented rock. Quickly and radial displacement on the trends of the piston can be reduced by measures mentioned. This study suggests that 3D FEM interaction impactor bit rock model can be used to further understand the energy transfer, determining operating drilling and improve the structure of the standards a bit. Figure (31) concludes curves a, b, c, d represents the depth of the bore hole when the compressed air pressure is 0.8 , 0.9 , 1.0 , 1.1 and 1.2 MPa, respectively. It shows that the depth of the hole gradually decreases with the air pressure becomes smaller.

Height of the teeth is exposed to a flat is 7.0 mm. When the air pressure is 0.8 MPa and 0.9 MPa, and the peak value of the slot depth is very small, and the speed is too great little return, leading to vibration easily. When the air pressure is 1.2 MPa, and the peak value of the depth of a very large hole that the surface of the small end may affect the rock which leads to energy waste and damage to the instruments. What distinguishes a similar curve when the air pressure is 1.0 MPa and 1.1 MPa. So the best air pressure of 1.0 MPa when the probe hammer bits, which is used in this study to dig granite.

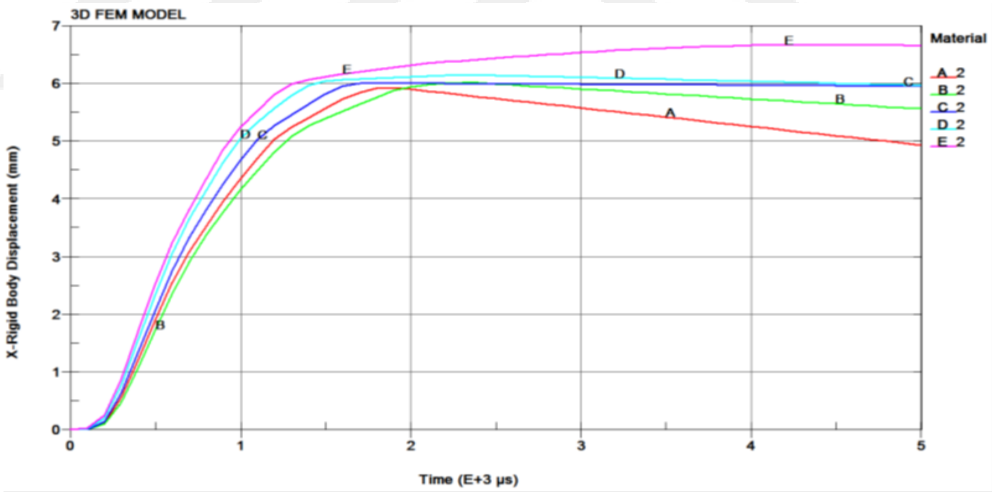


Figure 31 The displacement via time by X axes [7]

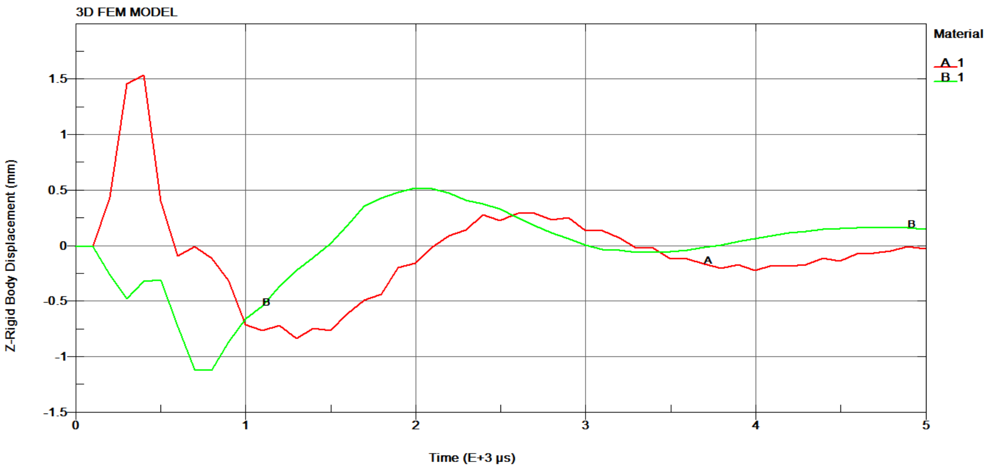
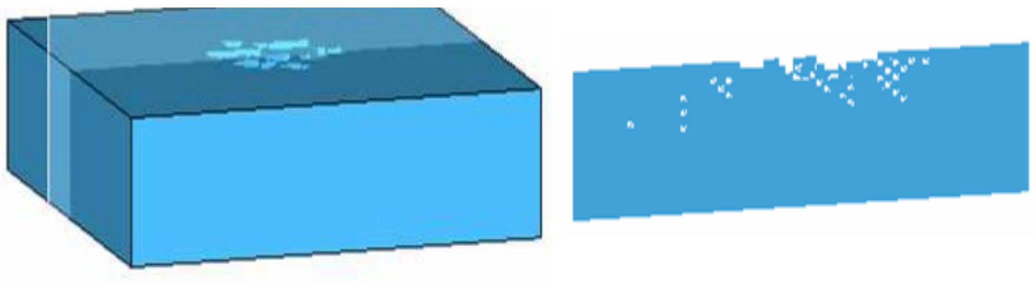


Figure 32 The displacement via time by z axes [7]

Figure (32) illustrates the speeds and displacements along the direction of the piston then, when the compressed air pressure is 1.0 MPa there are two curves which show above first one A curve is formed Y direction and the second B is formed Z. Also the value of the displacement is zero before time equal 0.1 μs After the piston impacts bit, the speeds and displacements increase sharply in the radial direction of the piston. Finally, they conclude fragmented rock size is increased with air pressure. The rocks begin to break up quickly when affected by a little before pressing. After 2.0ms, Rock is no longer about the fragments, but E curve counts slowly because of the rotational motion of the beat. The Rock influence of impact damage, There are many cracks and gaps that are useful for more rock part in the figure (33).



a. Normal position section and crack

b. Section with gaps

Figure 33 Axial partition of rock [7]

CHAPTER 3

FINITE ELEMENT METHOD FOR DRILLING PROCESS

Researchers at the center for drilling tried to determine the best drilling conditions and geometry tool for efficient operation. In recent years, finite element method (FEM) has been a more general option to use in cutting process analysis [45]. Because of high cost experimental data as well as time consumption the research trend to focus on finite element method. In addition to this, simplified analytical methods have limited application areas and they cannot be used for complex drilling processes. At this point numerical methods become more important.

Without doing any experiment, different type of parameters can be predicted by using Finite element method such as torque, drilling force, temperature and others. Also, there are many developmental processes to investigate the efficiency of this process. For example, material constitutive model, material failure, contact and friction

In this chapter, some basic aspects of presentation of the finite element simulation of the drilling process are shown.

3.1 FEM-Basic Principles

In FEM structure divided into several elements (pieces of the structure). The reconnection elements at the nodes used as if the nodes were pinned or dropped of glue that hold the elements together. This process results in the development of algebraic equations simultaneously. For a general linear and/or nonlinear static problem the equations for a finite element analysis are expressed in equation (3.1) [57].

$$\{F\} = [K]\{U\} \qquad (3.1)$$

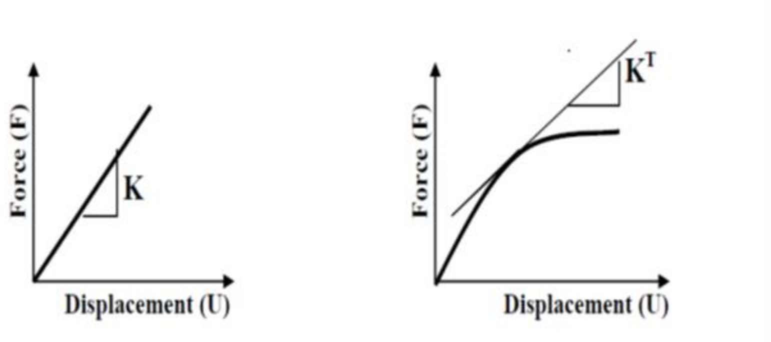


Figure 34 Linear and on linear stiffness chart [57]

Where F is the vector matrix of the forces on the element, K is the stiffness matrix Figure (34) shows the relation linear and nonlinear stiffness, where **U** is the vector of nodal displacements to be determined. However, Hooks law cannot be used in the nonlinear solution of problems since the plot of F (force) and U (displacement) is not a straight line. The stiffness is no longer constant, but it becomes a function of applied load, K^T, then it is called tangent stiffness, In a nonlinear analysis, the response cannot be predicted directly with a set of linear equations.

However, for time dependent dynamic problems the equation requires the form of a dynamic analysis as represented by the equation (3.2)

$$\left\{F_{(t)}\right\} = \left[K\right] \left\{U\right\} + \left[M^1\right] \left\{\dot{U}\right\} + \left[M^2\right] \left\{\ddot{U}\right\} \qquad (3.2)$$

Where K is the stiffness matrix, U is the nodal displacement vector, which is updated as time changes, M^1 is the damping matrix $\dot{U}$, are the nodal displacements with respect to first order time derivative (i.e. Nodes velocity), M^2 is the mass matrix, and $\ddot{U}$ are the nodal displacements with respect to the second order time derivative (i.e. Nodes acceleration).

3.2 Finite Element Solution Approaches

Three approaches have been used for simulation of chip formation process, the first approach (Lagrangian), which is used in the present work, the second one is (Eulerian) approachable, while the third approach is (Arbitrary Lagrangian-Euler).

3.2.1 Lagrangian approach

This approach is more general option used in solid mechanics problems, where the material is modeled by the usual constitutive equations for solid materials. It is the widely used approach for engineering applications, especially in metal cutting. There are two common reasons for the broad usage of this approach Firstly, evaluating the chip from beginning reached to the steady state. Secondly, the geometry is considered as a function of cutting process, plastic deformation and material properties. The body being analyzed. Elements of materials are connected each other by nodes, and the collection of elements produces a mesh. When the body deforms the nodes goes with material while the element is distorting that is indicated in figure (35). In addition, a Lagrangian approach used to evaluate the element of motion with constant mass.

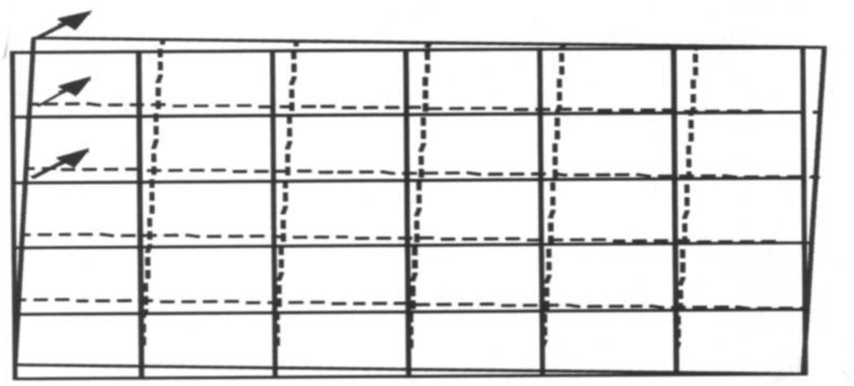


Figure 35 Lagrangian approach principles, used in most drilling simulations [57]

Despite the advantage of Lagrangian there are some disadvantages. Firstly, Lagrangian models may suffer large plastic deformations that occur in drilling process that lead to unacceptable deformed mesh. Secondly, You must provide separation in chip standards. The disadvantage of this approach can be neglected by using the updated Lagrangian formulation with automatic re-meshing technique.

3.2.2 Eulerian approach

This approach is rarely used by other researchers, since it is unable to simulate free surface conditions, therefore, only steady state metal cutting conditions can be simulated with this technique.

Eulerian approach is based on the characteristic matrix as a non-Newtonian fluid this is called a flow formulation. Thus, no elastic strains are included in the material model and residual stresses cannot be obtained directly. In this solution approach, the nodes are fixed in space and the elements are simply partitions of the space defined by connected nodes.

The Eulerian mesh is a "fixed frame of reference". The material of a body under analysis moves during the process; the mass, momentum, and energy of the material are transported from element to element as shown in Figure (36). Besides, few elements remain to analysis, therefore time computation is reduced.

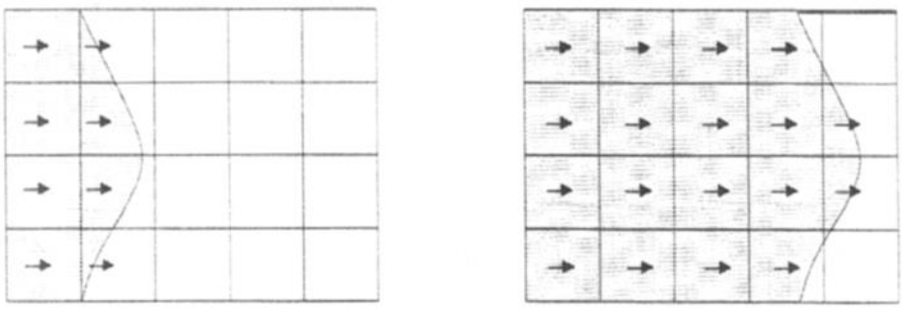


Figure 36 Eulerian approach principles, used with some metal cutting simulation models [57]

Also, there is disadvantages of Eulerian approaches. Firstly, it needs a simulation to define the borders of a chip prior. Secondly, you must keep the chip thickness, length of contact chip and communication between the continuous chip through the analysis tool which makes Eulerian formulation does not get along with the real distortion of the process through the material process.

3.2.3 (ALE) Arbitrary Lagrangian-Eulerian approach

Best Lagrangian and Eulerian features were merged in a formula Arbitrary called Arbitrary Lagrangian-Eulerian (ALE). In ALE formulation. FE mesh is not fixed spatially and not attached to the workpiece material.

Mesh the flow of materials and solve the problem of displacement in the Lagrangian step, while mesh reinstated and solve the problem for speeds in step a Eulerian.The idea used in the simulation of metal cutting is the use of an Eulerian approach for modeling the surrounding area where the tip cutting tool is happening, avoid severe deformation element without the use of contact. It uses an absolute free flow Lagrangian approach. It gives a better shape for the chip.

The alternative way of constructing a fluid-structure interaction is the Arbitrary Lagrange-Euler coupling, which allows Eulerian meshes to move. The structure and the Eulerian region are coupled by means of **ALE** coupling surfaces. The structure serves as a boundary condition for the Eulerian region at the interface. The Eulerian region moves according to an **ALE** motion prescription, in order to follow the motion of the structure. The Eulerian material flows through the Eulerian mesh while the mesh nodes can also have an arbitrary velocity, as shown in Figure (37).

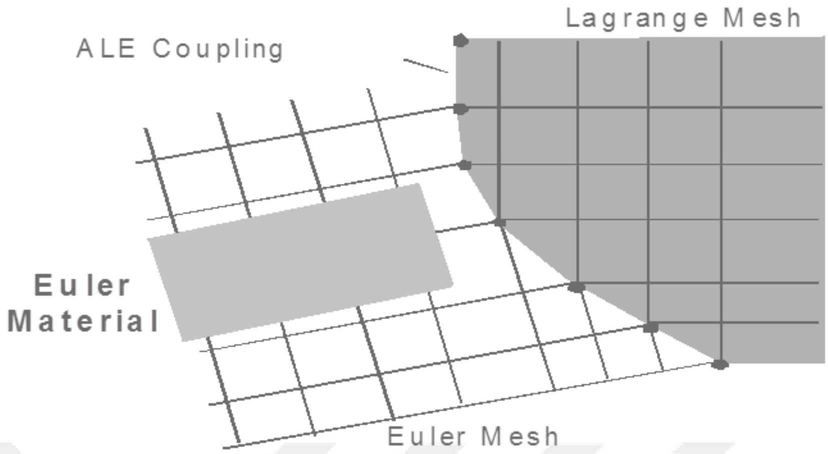


Figure 37 Arbitrary Lagrangian-Eulerian (ALE) approach principles, used with metal cutting simulation models [57]

3.3 General FEM- Packages Used for the Drilling process

The Finite Element Method, as stated in chapter two, was applied through different packages, either specified or oriented towards metal cutting simulation. Some of the common software codes are ABAQUS, LS-DYNA and ANSYS.

ANSYS is an implicit analysis program used to solve structural analysis by using finite element approach and LS-DYNA is an explicit analysis program to solve structural analysis while ABAQUS is an implicit ad explicit analysis structural program which is used in this study. Finally, each program different to others in time running and integration.

3.4 ABAQUS Program

ABAQUS is a FE analysis program which can detail a lot of difficult problems such as drilling process as seen figure (38) [59]. ABAQUS cannot give details with specific forming therefore the user is responsible for the geometric of tool and work specific. The user is responsible for all units that used in this program, drilling process boundary condition and mesh size. In addition, this program has own library therefore the user can get configuration of materials for a variety of models.

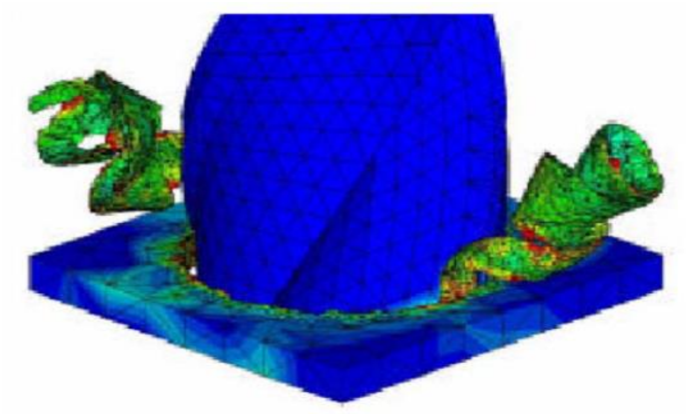


Figure 38 Drilling process [59]

ABAQUS consists of three main products: ABAQUS/Standard, ABAQUS/Explicit and ABAQUS/CAE. Each one has a special purpose to do it for example, users can use ABAQUS /CAE to do graphical environment performance analysis. ABAQUS/Standard is a general-purpose analysis program for solving linear, nonlinear, static and dynamic problems. ABAQUS/Explicit is a special-purpose analysis program that uses an explicit dynamic finite element formulation. It is suitable for modeling dynamic events successfully, such as impact and drilling problems (ABAQUS, 2008a).

3.5 Meshing

A continuous region is divided into discrete region that called element. This discrete region is called meshing. Finite element is involved in mesh. The initial finite element cannot hold on regional shape designed due to several plastic deformation during cutting or drilling process and the distortion causes a numerical error, therefore the user can use adaptive mesh to control this problem. Second-called refining technique which is based on increasing the local element density by reducing the size of local elements as shown in figure (39).

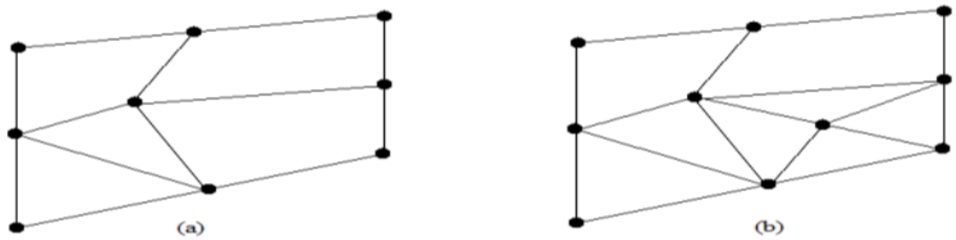


Figure 39 Improvement mesh (a) The preliminary local mesh (b) Reduce the size of the element [59]

Technique, which involves the distribution contract to provide the best element shapes as shown in Figure (40).

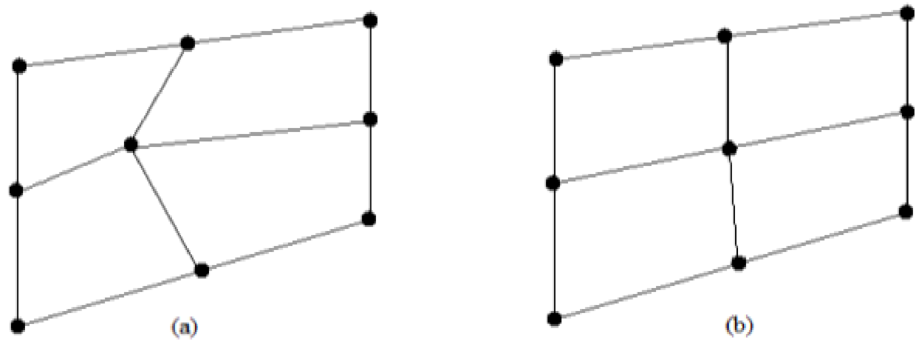


Figure 40 The smooth of meshing: (a) The preliminary local mesh (b) Reduce the size of element [59]

Finally, adaptive mesh can reduce error in numerical simulation. This can make the result of finite element more accurate espacially the adaptive mesh including serving plastic deformation like metal cutting.

3.6 Constituent materials working models

One of the topics of interest in the drilling process simulation is modeling, stress of rock material flow properly in order to get real results. Flow stress is the yield stress of the immediate which depends on the three parameter strain, strain rate and temperature then it is represented by the constituent equations, which were used extensively in metal cutting simulation is Johnson Cook operations mathematical forms.

3.6.1 Johnson - Cook Material Model

Johnson and Cook (1993) based on tape draping materials and Hopkinson dynamic testing on a wide range of temperatures and rates of stress model. This constitutive equation was established as follows:

$$\bar{\sigma} = (A + B[\varepsilon^n])(1 + (c\,Ln[\frac{\dot{\varepsilon}}{\dot{\varepsilon}_{\circ}}])(1 - [\frac{T - T_{room}}{T_{melt} - T_{room}}]^m)$$

The first part is a plastic-term representing the strain hardening. The second is the viscosity range and it shows that stress increases the flow of materials when exposed to materials with high strain rates. The last part is the softening temperature range. A, B, C, N and M physical constants found from the tests of materials. T is the instance temperature. T_{room} is the room temperature and T_{melt} is the melting point of the given material.

3.6.2 Drucker –Prager model.

The model is used in this study to evaluate the rock behavior during process Drucker and Prager model which is provided three dimension yield criteria [58] for this study limestone is a choose for modeling, a rock whose deformation, fracture and drilling properties have been extensively studied for which show triaxle test data at several different of pressure. The model used for the damage initiation of ductility then, according to this standard in the physical beginning to smear once a shear strain reaches a certain rate of the critical value of the plastic strain, and Drucker Prager pressure behavior type of hardening of the yield stress compression uniaxial as a function of uniaxial compression plastic strain. The option was used in the type of displacement to identify and evaluate materials as a function of displacement damage to the plastic from the start up to fail in the end. When the damage reaches a critical level, the element fails and is removed from the mesh.

The drilling process contains a lot of difficult problems. For example, large deformation of material at very high strain rates, contact interaction rock cutting tool large plastic behavior and high friction. All these problems can make the numerical simulation more difficult.

3.7 Structural Modeling in ABAQUS

Each analytical model in ABAQUS includes 10 modules: Part, Property, Assembly, Step, Interaction, Load, Mesh, Job, Visualization, and Sketch. To create a complete analysis model, it is usually necessary to go through most of these modules, as described below:

Build up the geometry of the structure under a set of parts. (Part module, Sketch module, Mesh module)

- Create element sections (Property module).
- Introduce material data (Property module).
- Assign section and material properties to the members (Property module)
- Assemble parts to create the entire structure (Assembly module, Mesh module and Interaction module).
- Create steps and choose analysis method (Step module).
- Introduce load and boundary conditions (Load module).
- Create jobs and submit for analysis (Job module).
- Visualize the result (Visualization module).

3D finite element method with software ABAQUS specific commercial elements of the program. This module aims to analysis the effect of drilling parameter on the drill bit during the drilling process, then calculate the effect of the parameter on drill bit such as damage and begin the development of materials in the rock. Prediction of cutting forces, drilling torque, and the stress distribution on the drill bit during the drilling process. And the expectation of rising bites in the inlet and in the outlet, taking into account both sides of the cutting parameters. This is based on the FE model Lagrangian formulation with an explicit way of integration. The parameters of friction between the workpiece and tool influenced by a number of factors, such as cutting speed, feed rate, and surface properties.

The module uses the constant coefficient of friction of 0.2 for models and the interaction between the rock and tool using surface to surface contact which available in ABAQUS / explicit.

3.8 The Stress and Strain relationship

To know the stress and strain and the relationship between them it should be demonstrated for each one as below.

Stress: is the force which applied in a unites area of material. For this purpose the drilling engineer should consider three basic components of stress.

These components of stress are:

A. Compressive stress
B. Tensile stress
C. Shear stress

Strain: after applying stress on the material there is a deformation can be noticed this deformation is called a strain, and it may take one or two forms depend on the magnitude of the applied stress. If the applied stress is less than the elastic limited of material then, the material returns to the original shape after removing the applied force this behavior is named elastic. If the applied stress overrun the material elastic limited, the material deformation not removing this behavior is named plastic. When stress is limited material will break. The breaking takes place before plastic deformation occurs the material is described as brittle. On the other hand, the material is broken only after expiring significant plastic deformation exhibits ductile or brittle.

CHAPTER 4

SIMULATION

The part is modeled to simulate the drilling process is a very important step to achieve accurate results. In this chapter, the simulation model and the details of the job tool are performed

4.1 Model Geometry and Dimensions: The Finite Element model is built as shown in Fig. (41), which is a general orthogonal drilling process model. The dimension of the workspace is (500x500x300) (mm) and drill bit diameter is 165 mm and height is 363 mm as can be seen in figure (42) with mesh size 18.

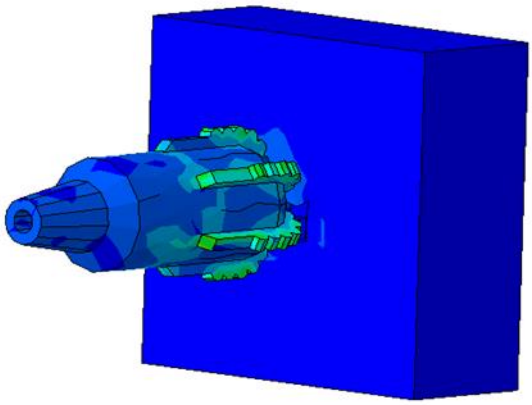


Figure 41 Representation of initial geometry and mesh for the model used in simulated tests

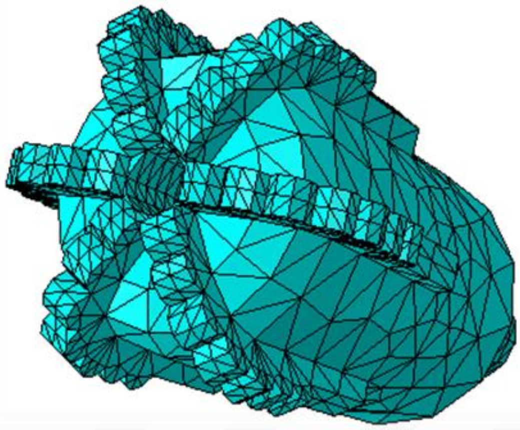


Figure 42 Representation of initial geometry and mesh for drill bit used in simulated tests.

4.2. Material model of the Bit.

During the drilling process the large material distortions, which rate achieves great values subject. The result of the work of the friction and heat plastic deformation is generated. All these factors affect the value of the yield stress of the material. The yield stress can be determined from Johnson-Cook formula for a drill bit.

For elastic properties of steel as shown in the table (3) should be inserted in ABAQUS material properties.

Table 3 Physical parameters of steel [63].

Young Model	210 G pas
Poisson ratio	0.29
Density	7870 Kg/m^3

The used Janson-cook plasticity parameter can be shown from table 4 [63].

Table 4 parameter of Johnson cook model for plasticity [63].

A	B	N	M	m_r	m_t	Strain rate
148Mpas	341MPas	0.183	0.859	0	0	1

4.3 Material model of the work space

In the present work, Drucker-Prager constitutive model parameters from a geological material limestone are obtained experimentally and then introduced into a FE model to simulate the indentation of the material is obtained [61].

In the current study, the commercial finite-element code ABAQUS/Explicit is used for the simulations of the mechanical response of the materials to indentation and the constitutive model adopted, then is Drucker-Prager elastic-plastic model with hardening in the linear form. For elasticity the physical data used in ABAQUS can be shown from the table (5) and for plasticity data from a table (6).

Table 5 physical properties of limestone [61].

Young Models	44.8 Gpas
Poisson Ratio	0.24
Density	2600 Kg/M^3

Table 6 Drucker Prager parameter experiment [61].

Angle of fraction	Flow stress	Dilation angle
39.2	1	28.5

4.4 Influence of the drilling parameter on the drilling bit and the drilling efficiency

Ten jobs are simulated in this study to analyze the behavior of the drill bit by creating a point of reference in the form of the bit and make a coupling to the constraint that all the motivation the body during this point then the impact parameter measured at this point. ABAQUS has the option of creating a data select this option and analyzed data and plotted it. The rock is fixed with ENCASTRE all initial displacement equal zero.

4.4.1 Influence of the drilling parameter on the Torque

Torque is a force that leads to make drilling bit rotates against the resistance to cutting and friction forces [63].

In shallow wells, the torque is the result of the forces wear of the cutting and shearing action generated at the bit/rock contact by the rotation of the bit. In deep wells, additional torque is required to overcome additional forces between the drill rods and the flushing medium. Torque is usually measured in NM. Rotational torque required to rotate bit is very interesting for several reasons. First, it may give clues to the formation being drilled and / or slightly requirement. Second, exercise a little torque a significant impact on the determination of "bit walk" experienced in the direction of the wells. Drilling torque is an important parameter for drill design, then, excessive torque will lead to fracture the drill bit. As can be indicated in figures (43), (44) and (45) the variable parameters of torque against time with different values of drilling speed which obtained from three simulations. Firstly, the relation between torque against time at v=700 mm/min as shown in figure (43).

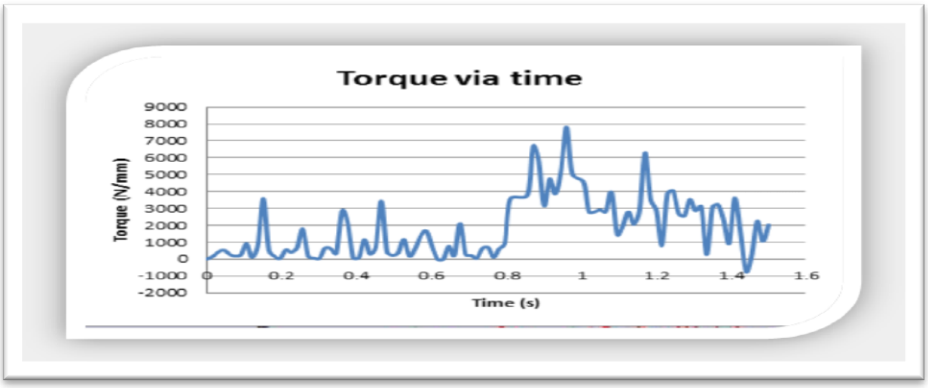


Figure 43 Torque against time at the drilling speed =700mm/min

Then, the next simulation shows the relation between torque and time at drilling rate=900mm /min as seen in figure (44).

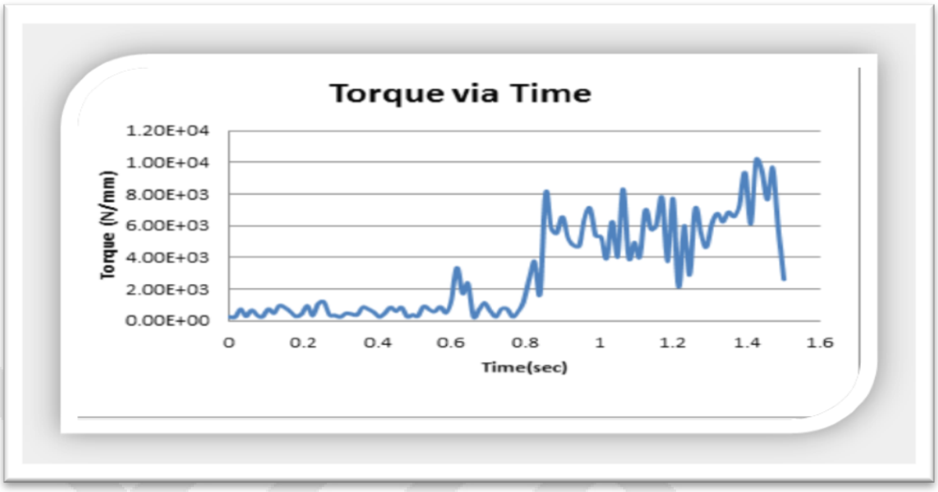


Figure 44 Torque against time at the drilling speed=900 mm/min

The last simulation for this part is also between torque against time at drilling rate=1000mm /min as seen in figure (45).

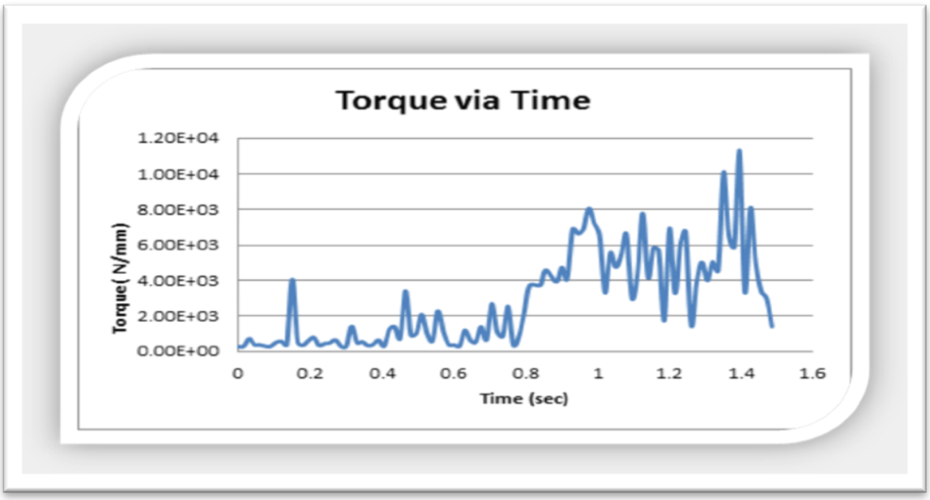


Figure 45 Torque against time at the drilling speed =1000 mm/min

From these simulations maximum torque via velocity can be obtained as shown in table (7) to conclude the maximum torque values increase by increasing the drilling speed and the highest value at the drilling rate (1000 mm /min).

Table 7 The maximum values of Torque

Velocity	Maximum Torque
0. 7m/min	8 N/m
0. 9 m/min	11.3 N/m
1 m/min	11.9 N/m

4.4.2 Influence of drilling parameter on the drilling force

Drilling Force not only determines the energy consumption, but also directly the effect on the drilling efficiency of the drilling process that have been created. The figures (46), (47) and (48) show the effect of axial force (Z load) against time with different values of drilling speed. The first simulation shows the drilling force increase by increasing the drilling speed into the entrance until reaching to the steady state, then it is fluctuated to the end of the process. Also predicting the values of thrust force from the first simulation can be seen in figure (46) at drilling rate=700 mm/min.

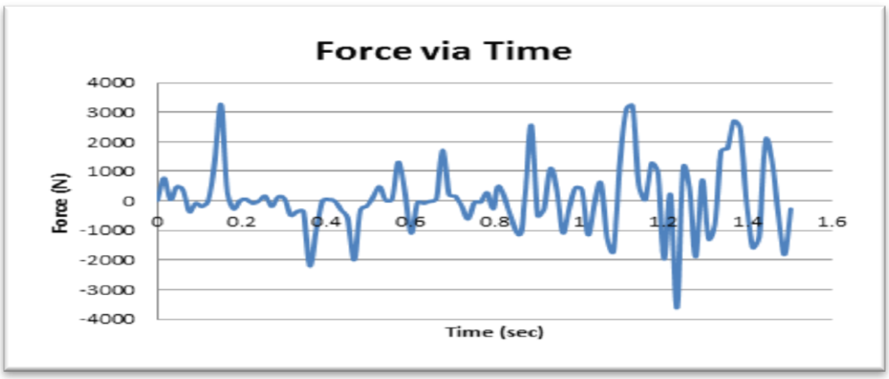


Figure 46 Axial force against time at drilling speed =700 mm/min

Then, the second simulation is predicted the drilling force in Z direction against time at drilling rate=900 mm/min as shown in figure (47).

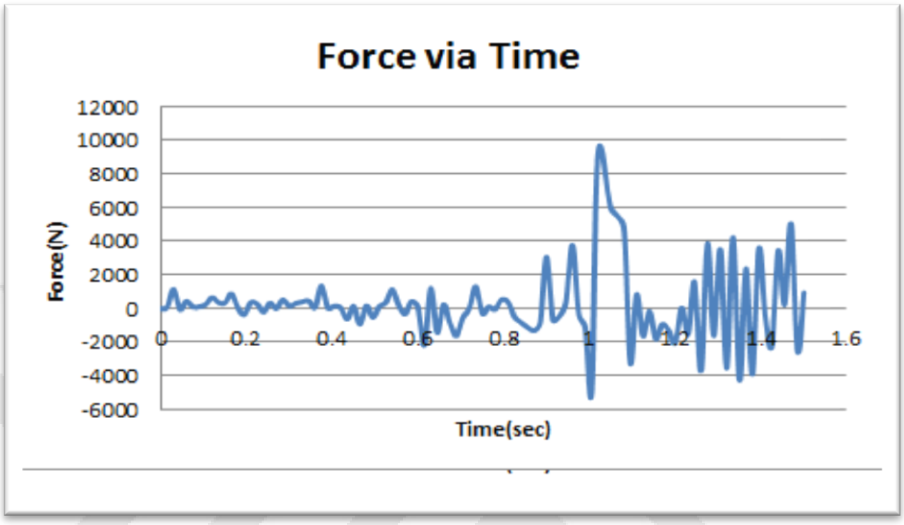


Figure 47 Axial force against time at drilling speed=900 mm/min

From the last simulations, the values of force increase by increasing time as seen in figure (48).

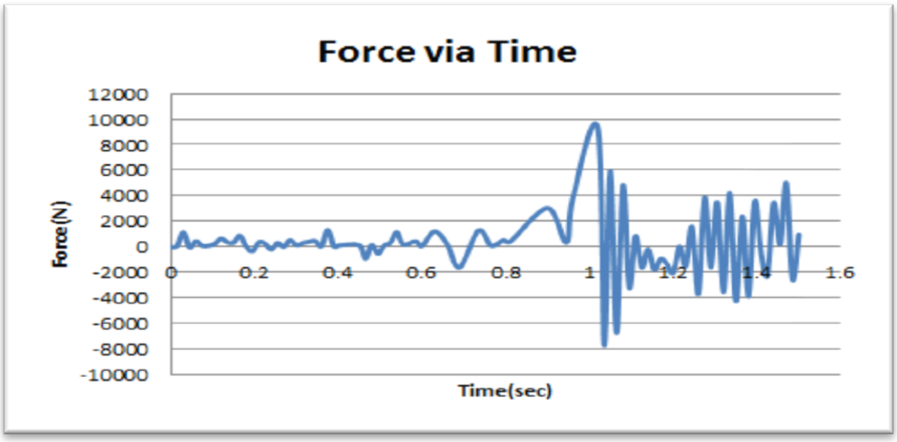


Figure 48 Axial force against time at drilling speed=1000 mm/min

In this figure can be noticed the fluctuation curve at the end of the drilling because high speed in the drilling process completed early, then drilling bit continues to drill till end out of the rock.

According to figures (46), (47) and (48) the values of axial force increase gradually by increasing the time during the drilling process from the entrance. Then steady state and began to decrease at the end of the drilling process. Finally, the behavior of drilling force nearly similar to the behavior of the drilling torque.

4.4.3 Influence of WOB on Torque, RPM

The next study here simulates the effect of WOB which applied on the drilling bit on torque and RPM. WOB is axial force applied on drill bit by Z direction on the bottom of the hole to make rock fragmentation with parameters ROP and RPM. Three simulations conclude the relation between them with increasing WOB. Normally these data are obtained experimentally from field by using a special equations that are found in the literature. The data from the field is shown in table (8). This table is the data as a result of NOOR well, an oil field in southern of Iraq. The workers got this data on the surface of the well and the cases of the drilling process until the completion of the drill hole. It shows a different depth type when applied weight on it with a different in various minute. The result shows how to increase the WOB with increase torque and what is going to increase RPM and then decreased. When a steady increase WOB must be an increase in revolution per minute and ROP, but the increase and decrease values in the table means some error during the drilling process.

Table 8: The experimental data from the field from oil well in the south of Iraq.

Bit size (in)	Well no.	Bit maker	type	S.N	Jets /32	RPM	W.O.B	Mud Weight gm/cc	Flow rate	Depth (m) in	Depth (m) out	meter	hours	ROP	formation
17 1/2	AM-6				NO PDC										U.Farse
	AM-7	Reed	TFR619S	223175	USED										
	AM-8	Best	TS1963SS	222801											
	AM-9	Varel	VB416DGHXU	6010845											
	AM-10	Varel	VTD519SDGHXU	6010853	(8*14)	130	8	1.22	2645	1290	1324	34	5	6.8	
	AM-11	Varel	VB416DGHXU	6010848	(8*14)	124	10	1.23	2700	957	1327	370	41	9.02	
12 1/4	AM-6	Varel	VTD619GX	4000523	(3*14) (3*16)	150	12	2.22	2280	1324	1826	502	133.5	3.76	L. Farse
	AM-7	Varel	VTD619GX	4000535	(5*20) (1*16)	120	8	2.22	2380	1356	1854	498	252.5	1.97	
	AM-8	Varel	VTD619GX	4002665	(3*14) (3*16)	130	8	1.95	2570	1330	1415	85	27.5	3	
		Varel	VB416DGHX	6010665	(2*14) (4*15)	170	12	2.25	2280	1420	1820	400	66.5	6.01	
	AM-9	Varel	VTD519SDGHX	6010705	USED										
	AM-10	Varel	VTD519SDGHX	6010705											
		Varel	VTD519SDGHX	6010704											
	AM-11	Varel	VTD519SDGHX	6010706											
8 3/8	AM-6	Varel	VTD616GX	6000508	(6*13)	120	6	1.23	1500	1826	3680	1854	274.5	6.75	NAHR UMR
	AM-7	Varel	VTD616GX	6000509	(6*13)	140	10	1.25	1400	1857	3564	1707	365	4.6	J,U-L KIR,Aliji, sh, ha Har, sadi, tan, khasi Mish, ru, ahamdi Mau.
	AM-8	Varel	VTD616GX	6000510											KHASIB-MISHRIF
	AM-9	Varel	VTD616SDGHX	6010872											KHASIB-MISHRIF

Figure (49) shows torque against time at WOB =8 and getting the maximum value of torque from this simulation.

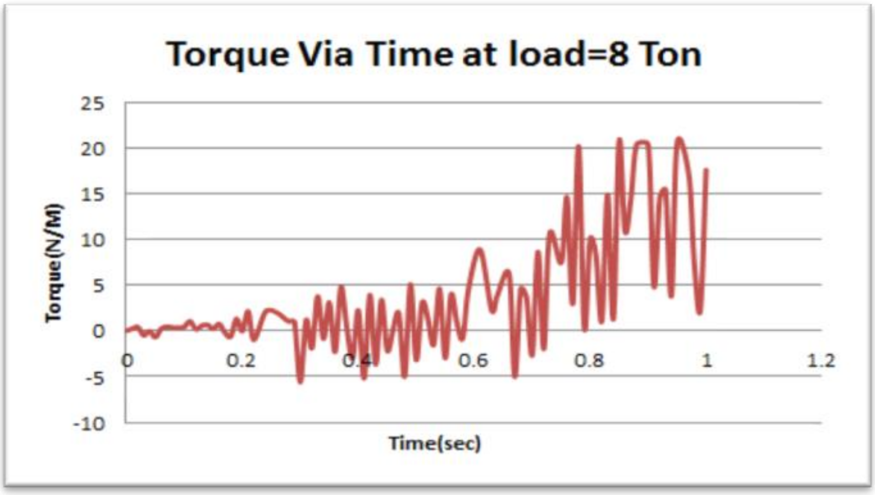


Figure 49 The value of torque against time at load=8 ton

The next simulation applied weight on the bit 10 ton, then the values of torque increase by increasing time as seen in figure (50).

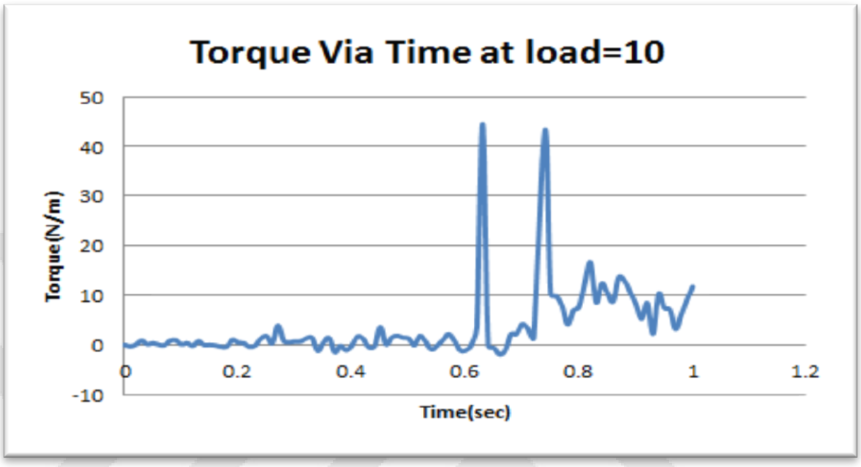


Figure 50 The value of torque against time at load =10 ton

Also making the third attempt with increase WOB to 12 ton to get the relation between torque against time with this load as seen in figure(51). WOB lead to an increase in torque and get maximum in the final. But in this observation point of view of the increasing torque by increasing the weight on bit, and the speed is a step important so as to avoid any fracture or distortion in the drill bit.

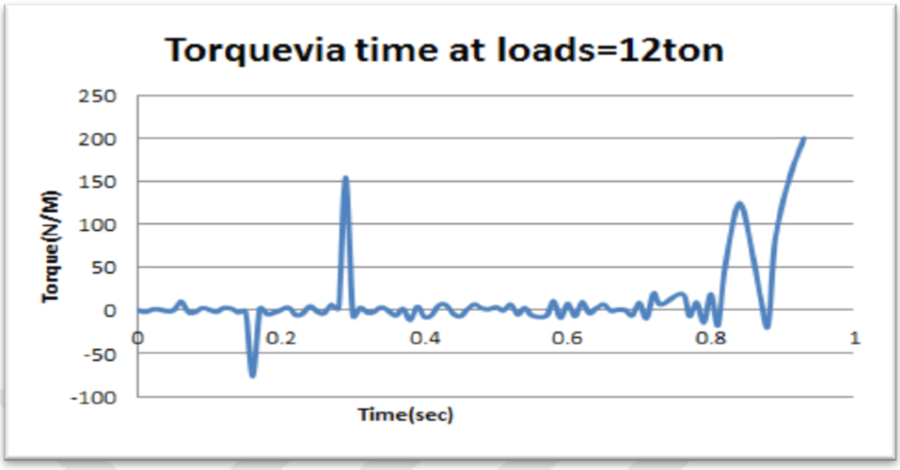


Figure 51 The value of torque against time at load=12 ton

At the same time to get the values of the revolution per minute (RPM). It noticed an increase in the weight on bit can be increased RPM because it is necessary in this area to show increasing between them to avoid any increasing that lead to reduce the RPM. That means the fault of what is happening in the drill bit may be broken or distorted. In ABAQUS inserts data in the boundary condition in step1 to evaluate the value of RPM and the relationship between WOB and RPM as seen in figure (52).

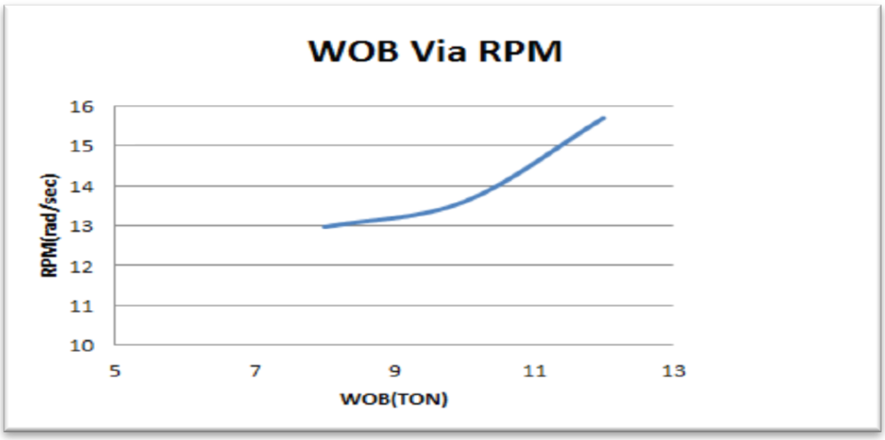


Figure 52 Weight on bit Via RPM

In ABAQUS program/Explicit an option to enter different values of rotational velocity to find the values of each RPM with radians per second depend on data experiment which is given in table (8).

4.5 Bit failure mechanism by applying load pressure.

To induce bit failure, the drill bit selection has to be appropriate with information on the downhole condition and there is a large number of design difference of cutter bit. As well as, the driller engineer should have the first information affect performance drilling to add load according to a study in literature [7]. In this part of study take the effect of stress in the drilling bit by upload pressure on reference point in drill bit to show the effect of it about the drilling process to maintain this equipment. Firstly, taking load pressure 100 mpas, then apply load pressure 500 mpas as seen in figure (53).

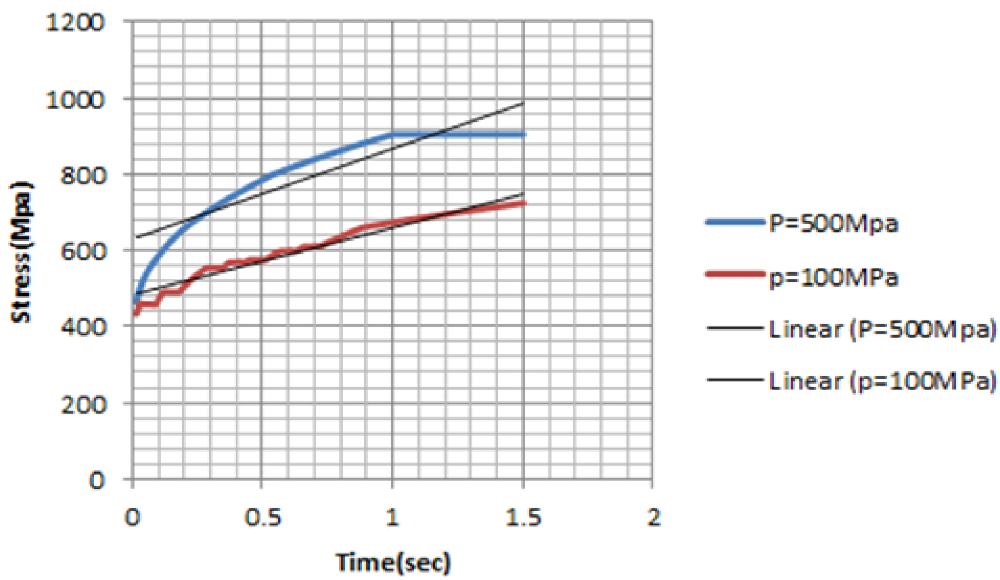


Figure 53 The Von mises stress against time with different load pressure

4.6 Steady mesh

In case of using the coarse mesh at mesh size =25, it has required the use of the model of contact with erosion in this type of the contact mode. The element is detected from the mesh when it reaches specified damage level. Following the removed of an element the tool can remain without contact for a long time as shown in figure (54).

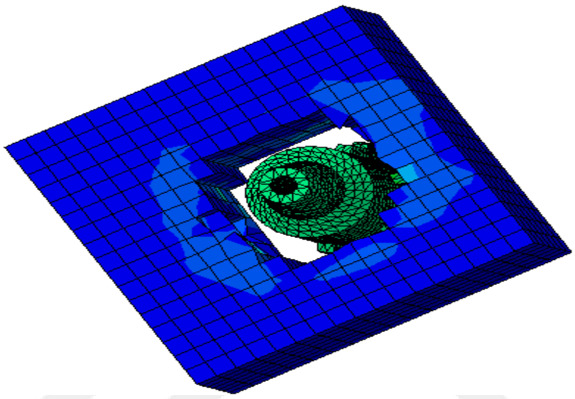


Figure 54 The course mesh of Rock

But when the mesh size used is equal=10, the force increased and the contact with next element of the workspace as seen in figure (55). According to this diagram the curve of mesh size=10 near with each other than mesh size =25 as seen in figure (56), therefore the mesh size=25 is more appropriate than mesh size=10 because the last take more time. In the future, it will be used fine mesh to get a more accurate result.

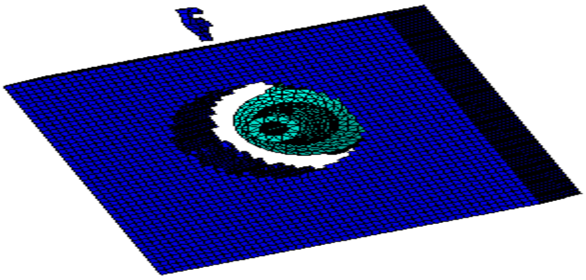


Figure 55 Fine mesh of the Rock

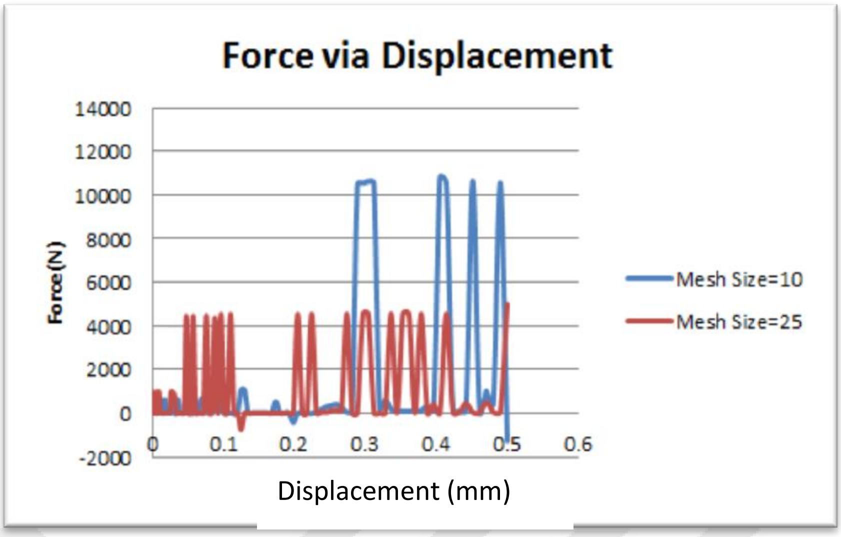


Figure 56 the value of force via displacement

4.7 The effect of internal and kinetic energy to the whole model

To help determine how closely approximates the analysis assuming quasi-static, the history of various energy is helpful. Especially useful is the comparison between the kinetic energy into internal energy. Writes the history of the energy output to a database file as part of the history of preselected output.

The internal energy form Figure (58) shows a smooth increase from zero up to the final value. The ratio of kinetic energy to the internal energy as seen in the figure (57). It is quite small and appears to be acceptable according to ABAQUS manual 6.13.

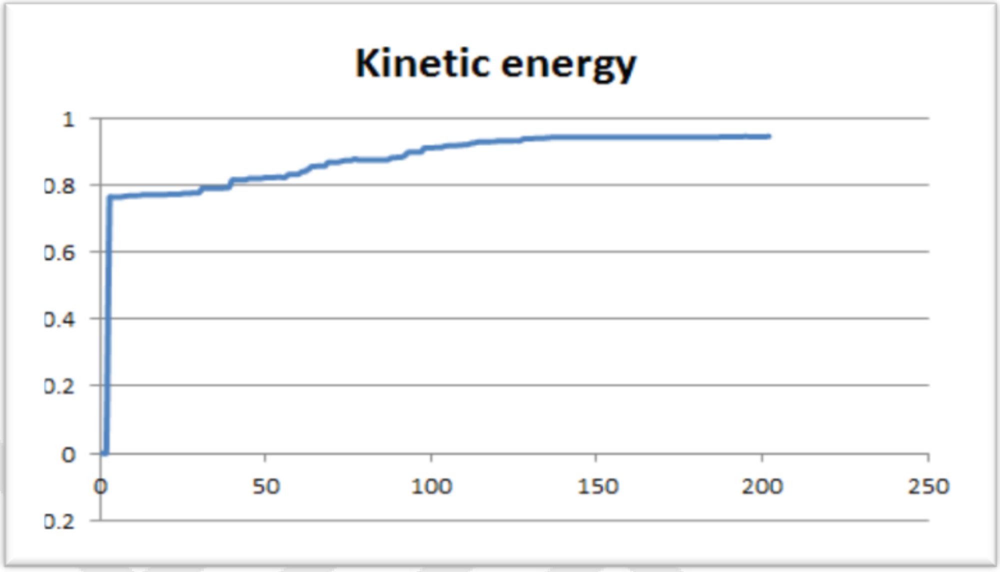


Figure 57 Kinetic energy via time to the whole Model

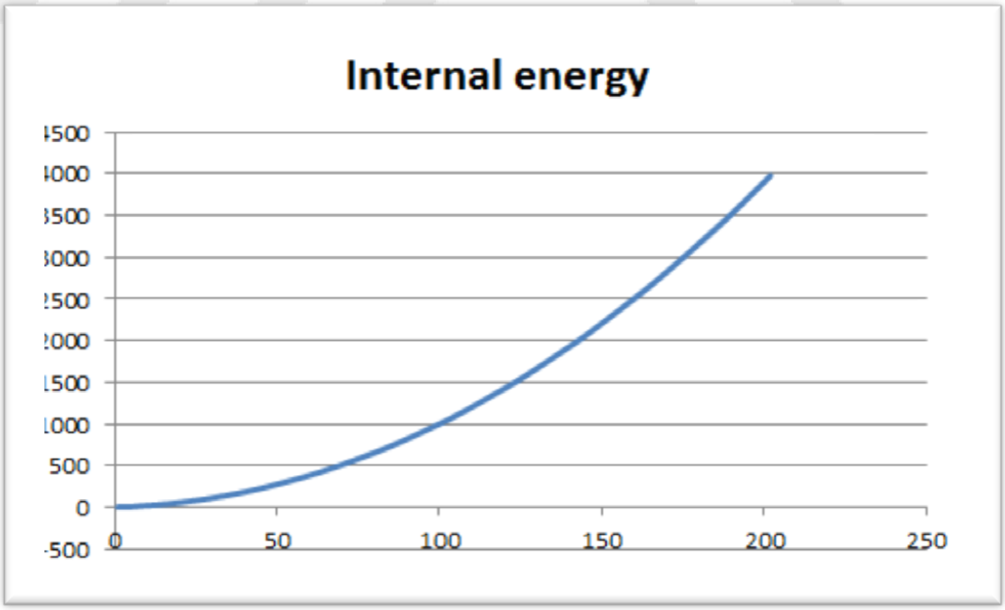


Figure 58 Internal energy via time to the whole Model

4.8 The Stress value of the drilling bit

In this simulation, element point in drill bit is set and the maximum stress results are listed from the beginning of the process to the end. Figure (59) shows the values of stress increased and has become the maximum allowed at the end of the hole.

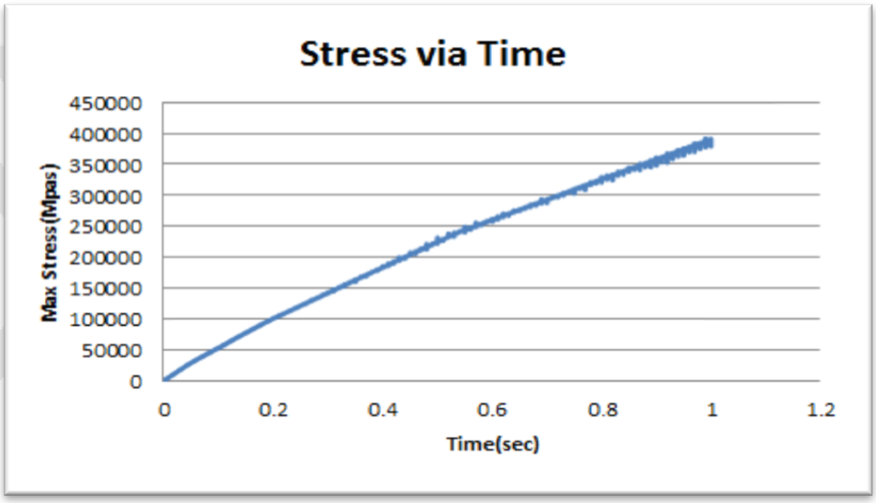


Figure 59 Stress via Time

CHAPTER 5

ANALYSIS AND RESLUT

In this chapter, analysis the effect of drilling parameter on drill bit is discussed.

5.1 Influence drilling speed on Torque and drilling force

In this study, the effect of parameters on the drilling torque and axial force is investigated. Torque is a significant impact on the efficiency of drilling and the biggest impact on the drill bit to avoid any problem that break it. First three simulations carried out with three drilling speed values, and find a relationship between the torque against time non-linear as shown by the Figures (43,44,45). The values of torque increased at the entrance and continue to increase to a steady state then began to fluctuate and become overcome the force to the end of the hole. When applied speed (700 mm / min) got maximum torque (8 N/ m). When applying speed (900), (1000) mm/min the values of torque, which is obtained from simulation are 11.3, 11.9 N/m respectively. Also can be noticed there is no significant difference was found between the result of the application of torque predicted from velocity values 900 mm / min and 1000 mm / min for maximum thus apply torque quickly give progressively engage values and preserve the life of the equipment without any break or distortion, and when compare the chart results that are found in the literature [22]. It fiend the satisfied results that means the value of torque increasing with increase drilling rate and also conclude the fixed increasing is better to get the maximum value of torque without any fracture to the drill bit.

In addition, the same analysis should be backed by cutting force values and compared with the experimental results in a review of the literature [22] show a result that is based increase strength by increasing drilling speed and can get valuable work when drilling speed of 900 and 1000 m / min. Finally, drilling force is the same behavior of drilling torque.

5.2 Influence weight on bit on the Torque

The effect of weight on bit on torque. Torque is a measure of resistance forces opposing a rotation function Friction, cut or shear and friction forces in the bit interface / rock. Thus, with WOB is increased frictional resistance also increase and required greater torque being which is dependent on the strength of the rock, therefore the simulation investigated the linear relationship between (Wob & Tob) seen in figure (60).

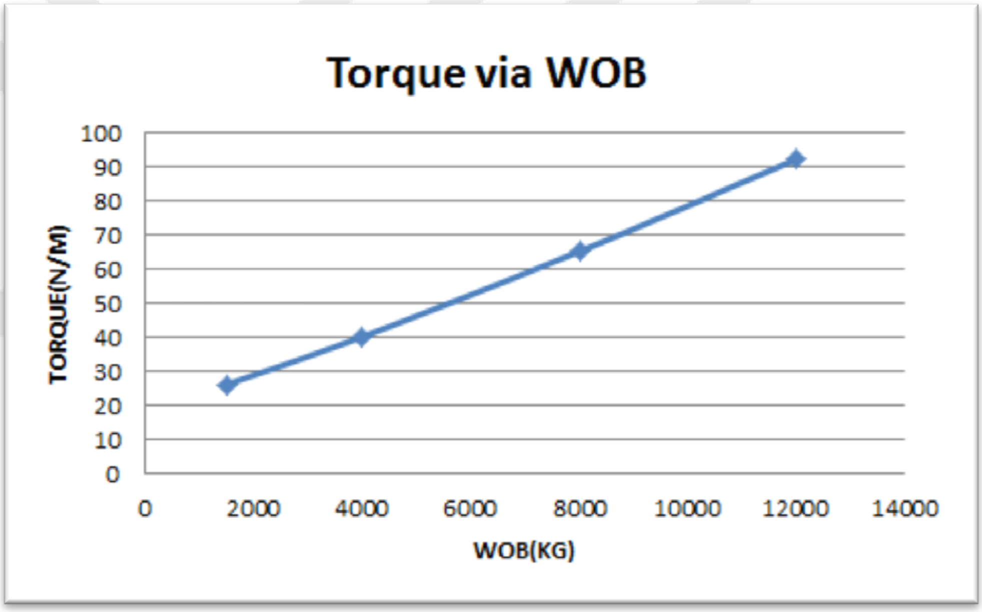


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Figure 60 The values of maximum torque via time with different loads

According to the results from the figure above can be obtained the maximum value of torque which getting from an increase in loads lead to maximum wear to the drill bit.

5.3 Testing bit performance

More than a performance test takes the form of some kind of test step. The second part of the simulation of the application a variety values of loads (WOB) to show the effect loads on torque. Three simulation investigation to show the values of torque via time with different loads.

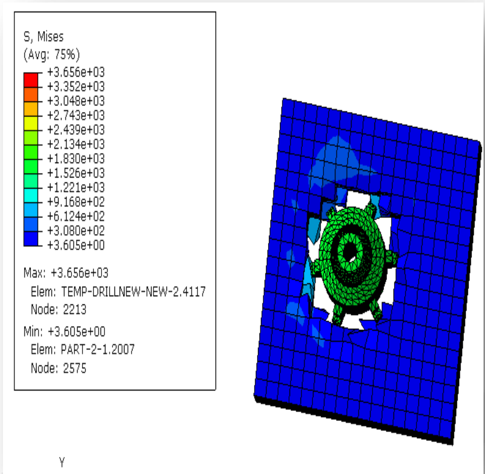
In simulation one in this part applying (8 ton) and the RPM increase to (12.7rad/Sec) if it's efficient The next simulation increase the WOB to (10 ton) and obtain RPM is (13.6 rad/Sec) following this process and monitor the increasing in RPM and loads drill successfully. The last simulation to increase the WOB to (12 Ton) and RPM value is (15.7 rad/Sec).

While RPM continues to increase with an increase WOB and the process normally successful, but if the increase is not appropriate something wrong in the process of the drill bit. The result of the RPM shows in the table below.

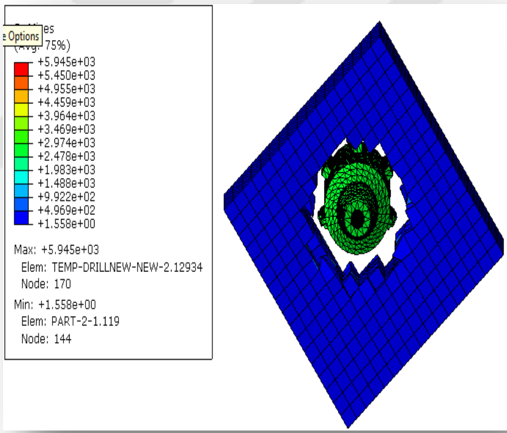
Table 8 Parameter of WOB and RPM

WOB (TON)	RPM (rad/Sec)
8	12.9 (rad/Sec
10	13.6 (rad/Sec)
12	15.7 (rad/Sec)

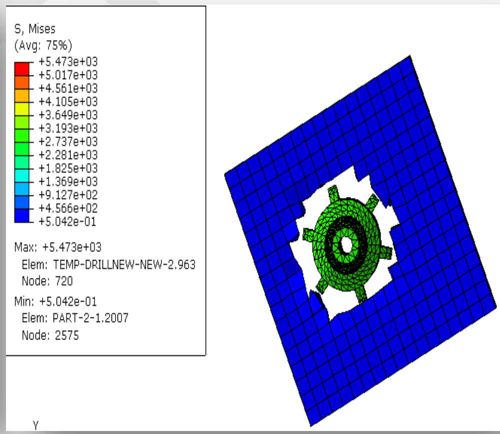
As a consequence of RPM, it appears that WOB alone is not the causative factor make a drill hole without increasing in the drilling rate. The figure (61) shows that there has been increase rise in the size of the hole by increasing the weight on bit that applied on the rock.



a .At load =8Ton



a. At load=10Ton



d. At load =12Ton

Figure 61 The result of every drilling hole with different loads

5.4 Mesh size

The accurate of the results depend on mesh size, therefore, appropriate mesh size for drill and workpiece is more important in this study use mesh size for rock spice is 25 which input in seed in ABAQUS program. Then after complete process experiment to input different size for rock then find which one is the best for analysis. Fine mesh is so bitter than course mesh but, when use the mesh size=10 force increase and the contact next element of the work piece According to this diagram the curve of mesh size=25 is more appropriate than mesh size=10 in this study because the last one needs more time to complete analysis and needs computer with high features.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION FOR FUTURE WORK

Modern day oil and gas well costs are driven by drilling performance as time becomes the dominate capital expense source, therefore the analysis of drilling bit against time during the drilling process is investigated in this study. A 3D finite element model which includes complex tool geometry, constitutive models appropriate for high strain rate, and process parameter is present. Then drilling test is performed to present the efficiency of FE model of the drilling PDC bit. The axial force and torque are evaluated and compared the simulations results with experimental results that are found in the literature [22]. The model offers a good evaluation of axial force and drilling torque as well as it shows the maximum torque increase by increasing velocity and the drilling force also increase by increasing velocity. The study shows that finite element model of drilling process is able to predict changes in drilling force, torque and other parameter. The interaction between the drill bit and rock is modeled by using Dracker Prager model for elastic and plastic are performed. The efficiency of drilling also measured in term of drilling rate. RPM is the most important criteria in drilling economics as it directly influences on time. Time is taken for drilling well base on the relationship between drilling coast and Rpm. The simulations show the maximum RPM can be achieved a good hole drilling with low time. The increasing of WOB lead to increase the torque with linear relationship until the end of the hole. The RPM is also increase with increasing WOB to obtained a best drilling process with at least coast and less time. Monitor the values of torque during application WOB to get the maximum values without any fracture or distortion to the drilling bit. In addition, the effect of applying load pressure on drilling bit was considered to show the development of the stress. Then the increasing pressure leads to increase\ Von mises stress. Two values of applying load pressure on reference point to show the relation between load pressure and stress and this relation lead to be careful when apply pressure to avoid any broken in the drill bit. Also the mesh size is more effective on the accuracy of resultant fine mesh is better than course mesh, but couldn’t use it in this study because it takes more time, so taking normal size mesh 25 is more appropriate for evaluating parameter which is used in this study. Finally, in ABAQUS Explicit the effect of kinetic energy and internal energy are observed in this research to show the quays static equation. Finally, the stress values measured in element point in the tooth. It showed the stress on bit increase from beginning drill process and it measure with element point on the drill bit, therefore applying pressure without monitor can be distorted the drilling bit or finally leads to fracture it. The advantage of this methodology is simple, logical and accuracy in the representation of drilling bit during the drilling process in the oil well industry to predict more accurate parameter influence on the efficiency of PDC drilling bits.

Future Work:

A 3D finite element model that was created in this thesis should be considered the first phase of the modeling effort. There are several aspects of this model, which was simplified preliminary in this model, but it should be investigated in the future. The design of the drill bit should be considered in the future because there is a variety of drilling bit types to compare each one with same condition area to improve the performance of drilling bit.

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APPENDICES A

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EDUCATION

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High School	Al- Huryia Preparatory School	1994

WORKEXPERINCE

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Diyala Univ.	Trainer in the Collage of Engineering	2000-2003
Diyala Univ.	Head of internet unite in the college of Engineering	2004-2007
Diyala Univ.	Trainer in the Collage of Engineering	2007-2013

LANGUAGES
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