Sudan University of Science and Technology

College of Petroleum Engineering an d Technology

Department of Petroleum Engineerring

Project of:

Simulation Study of Tool joint Thread Connection Failure (washout) (Case Study Sudanese well)

محاكاة تشوه اسنان اداة الربط (الانـهيار)(دراسة حالة لبئر سودانية)

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Prepared by:

Ahmed Mohamed Mahmoud

Hossam Hassan Ahmed

Mohaned JamalEldin Mohamed Hamad

Supervisor:

Dr .Yousif Eltahir Bagadi

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الإستهلال

قال تعالى :

بسم الله الرحمن الرحيم

﴿ كَمَا أَرْسَلْنَا فِيكُمْ رَسُولًا مِّنكُمْ يَتْلُوا عَلَيْكُمْ آيَاتِنَا وَيُزَكِّيكُمْ وَيُعَلِّمُكُمُ الْكِتَابَ وَالْحِكْمَةَ وَيُعَلِّمُكُم مَّا لَمْ تَكُونُوا تَعْلَمُونَ ﴾

صدق الله العظيم

سورة البقرة الآية ﴿151﴾

Dedication

To:

Who taught us the meanings of life and values of generosity and faithfulness

Our mothers………….

Who suffered for making the best future to us and growing the flowers in our way,

Our fathers………….

Who supported and helped us,

Our brothers and sisters………….

Who made with us beautiful memories that will never die.

Our dear friends………….

Acknowledgement

We have exerted great efforts in this project, however; it would not been possible without the support and help of many individuals and organizations. We would like to extend our sincere thanks to all of them.

We would like to express our deepest thanks to **Dr. Yosef Eltahir Bagadi** for assistance, encouragement and guidance while we were doing our research.

We are also so indebted to **Eng. Hamza Ahmed Mohamed** for his guidance and providing us necessary information that essential to complete this project.

Our thanks and appreciations also comprise to our colleagues and college staffs those helped us to develop this project.

Abstract:

Thread connections are widely used in oil and gas industry. Determination of under which this thread may leak is very crucial for drilling operation continuity.

In this thesis finite element software (ABAQUS) has been used to simulate the base case scenario of X well tool joint and the conditions, of failure has been determined.

From the analysis, leak was found on thread connection and the main reason were high displacement due to internal pressure and also high deformation strain. And a suggestion has been made according to the results.

التجريد:

أسنان الربط تستخدم بصورة واسعة في صناعة النفط والغاز .تحديدالظروف التي يحدث عندها هروب سائل الحفر خلال الأسنان هو أمر في غاية الأهمية لإستمرارية عملية الحفر.

تم في هذا البحث إستخدام برنامج (ABAQUS) لمحاكاة الوضع الحقيقي لإداة الربط لتوضيح حالة الإنهيار التي حدثت في بئر سودانية.

و من التحليلات وجد أن التسرب في أسنان أداة الربط هو سببه عمليات الإزاحة العالية بسبب الضغط الداخلي بالإضافة إلى التشوه العالي. و الإقتراحات بنيت وفقا لهذه النتائج .

LIST of CONTENTS

List of Figures

List of Tables

Chapter 1

Introduction

Chapter 1

1.1 Introduction:

Drill string failure is due to a lot of reasons, which may occur either individually or in-group. In order to prevent or at least minimize occurring drill string failure, all reasons should be recognized. To do that, one should have a good designed approach to test all factors, affecting drill string failure, to early eliminate the problem. Early studied cases were analyzed without an overall approach and without revealing the actual reasons of the drill string failure (Shokir E. M.,2004).

Thread connections are widely used in the oil and gas industry. The burst and collapse strength of a thread connection often determines the ultimate pressure to which a pipe string or downhole tool can be subjected, and therefore, determination of the collapse and burst pressure of a thread connection is critical in a design process. Calculation of the burst and collapse pressure via FEA is a relatively straight-forward exercise. But, a straight-forward analysis of a helical thread will require a huge FEA model and long computing time. This is especially true when pre-stress has to be accounted for in a thread connection for an accurate determination of collapse strength of a tightened thread connection. Using a straight groove representation of a helical thread is a common practice, and it enables an axis-symmetric model for the analysis of thread connections under critical load. To determine a thread connection under burst pressure, we use a similar approach, but we introduce a suitable interference between the pin and box thread to account for the pre-stress in the thread connection due to make-up torque. The response to collapsing pressure, however, usually requires a full 3D model, even when a straight groove model is used, since symmetry is lost under collapse buckling. For this case, an efficient technique based on symmetric results transfer capability in (ABAQUS 2005) has been applied for calculation of critical collapsing pressure. The symmetric results transfer capability is widely used in tire analysis (e.g. (ABAQUS 2005), (Zhong, 2006), but less so in other types of analysis. An issue for the numerical prediction of the collapse or burst of a thread connection is the definition of collapse and burst. This is because in the oil and gas industry (per American Petroleum Institute (API) standard), a component burst or collapse occurs when stress in the component reaches yield stress under pressure, but a thread connection typically reached yield stress already during make-up.

1.2 Problem Statement:

Thread connections are widely used in oil and gas industry. But the thread may fail under washout; this research focus on determination of causes of this failure and suggest a solution of this problem in a cost effective manner.

1.3 Objectives:

- Investigate the joint washout failure causes.
- Try to find a perfect solution to avoid this problem in the future.
- Design a model using ABAQUS software for a drill string in X well.
- Investigate the internal pressure causes thread connection failure
- Investigate the compression and torque, causes deformation and the displacement,

1.4 Methodology:

The objectives of this research will be achieved by deep investigation in the literature; also the ABAQUS software will be used to design a model.

Chapter 2

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Literature Review and Theoretical Background

Chapter 2

Literature Review and Theoretical Background

2.1 Literature Review:

The drilling pipe used in slim-borehole drilling performs well due to its lower cost and higher efficiency (Zhang et al., 2015). Due to it being the most fragile component of the whole driving pipe string (Zhou, 2009), the joint thread has attracted many researchers’ interest to improve its sealing quality (Li et al., 2014) and connection stress, which are the key characteristics and areas conducted on the joint thread according to American Petroleum Institute (API) standards (American Petroleum Institute, 1995). Tafreshi and Dover (1993) analyzed threaded connections using a finite element method (FEM) to find the greatest concentration of stress under the action of axial loading. However, the contact stress was not reported. They optimized the shape of the teeth of the threaded connection according to the load distribution.

Baryshnikov and Baragetti (2001) determined the load bearing percentage of each tooth to calculate allowable loads for API drill string threaded connections under conditions offending and axial and combined loading. Griffin et al. (2004) analyzed the stresses in a specific drill pipe connection under axial loading via FEM. Shahani and Sharifi (2009) built a model contact between mating surfaces of the threads and analyzed this by using ABAQUS 6.6 standard code. The contact pressure on the contact surfaces and the effect of preload on the stress concentration factor and were investigated. Santus et al. (2009) compared the torsional strength between two assembling techniques for connection of an aluminum drill pipe to a steel tool joint. Zhang et al. (2010) studied the taper trapezium joint threads of a drilling rod with a large hole. An improvement scheme for dual taper and cylinder seal has been proposed which has successfully tackled the problem of stress concentration. A double-sealing shoulder was used by Li et al. (2011) to develop a 73mm diameter directly connected drill pipe without friction welding. The angular clearance was enlarged, which can satisfy the logging tool and drill-out tool. Zhu et al. (2013) established a drill pipe thread FEM to aid failure analysis and to study solutions in a horizontal-direction drilling project. An XT-M joint developed by Grant Prideco has reached a high level of technology. Its torsional capability is 70% higher than the API’s ,whose joint airtight capacity can reach 15 000 psi (Zhuang etal., 2015).

The contact model of the drill pipe has been analyzed, and different specifications of the thread have been designed, but these connections are used in a large-sized oil well. Few studies have been conducted with regard to modelling the correlation between the contact stress and tightness. At present, most of the drill pipes which are widely used in API standard are more than 89mm in diameter (Shi et al., 2014; Wang et al., 2010). API seldom performs research on small-diameter drill pipes, as these are unable to meet the requirements of slim-borehole drilling.

2.2 Basic Concepts:

2.2.1 Stress:

Steel is an elastic material, up to a limit. If a tensile load is applied to steel (STRESS), the steel will stretch (STRAIN). If you double the load, you will double the amount that the steel stretches. Stress is defined as load ÷ cross sectional area. Units are usually Pounds per Square Inch. Stress is usually given the symbol σ (Greek symbol Sigma).

2.2.2 Strain:

Strain is defined as the amount of stretch ÷ the original length. Strain does not have any units, being a ratio. Strain is usually given the symbol $\boldsymbol{\varepsilon}$ (Greek symbol Epsilon). Strain can be due to applied stress or it can be due to thermal expansion

2.2.3 Stress-Strain Relationship:

Hooke's Law states that; "Within the Elastic Limit, Stress is proportional to Strain". If Stress $\propto$ Strain, then Stress ÷ Strain must be a constant. This constant is called Young's Modulus of Elasticity. The Greek symbol E (Epsilon) is used to denote Youngs Modulus.

If more stress is imposed above the Limit of Proportionality then the material stretches a little more per unit of force and the graph is no longer a straight line. Another important point is then reached on the graph, which is the Elastic Limit. If the material is stressed up to any point at or below the Elastic Limit, removing the stress restores the metal to it's original dimensions.

After stressing the material to beyond the Elastic Limit and then removing the stress, the metal will have acquired a permanent stretch or "set". In many materials the Limit of Proportionality and the Elastic Limit are so close as to be practically the same. While we refer to the Elastic Limit when discussing oilfield steels, we never refer to the Limit of Proportionality as the two are so close that we do not distinguish between them.

Our drill string, casing and tubing designs are intended to stay within the Elastic Limit to prevent sudden failures in service due to overstressing. Failures can still occur well within the elastic limit due to Fatigue, which is discussed later in this Module.

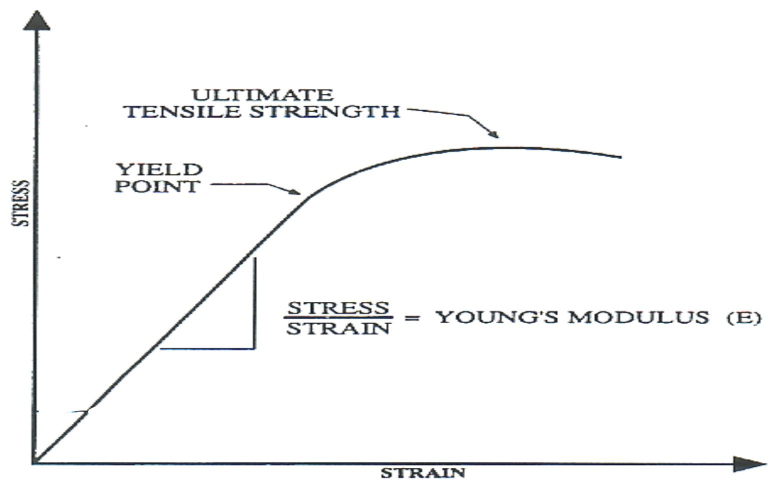

Figure 2.1: Stress-Strain Relationship

2.2.4 Yield Strength and Tensile Strength:

Yield Strength is the level at which the material changes from predominately elastic to predominately plastic strain behavior. Unit for this measure is PSI.

Tensile Strength is the highest stress level a material achieves before it breaks. The unit for this measure is Lbs.

API calculates a Minimum Yield Strength in tension for tubulars. A particular grade of steel is tested to obtain the stress-strain graph. The stress which gives a stretch of 0.5% (e.g. a strain of 0.005) in normal strength steels (E75 and X95) is taken as the maximum stress that should ever be imposed on that material. The Minimum Yield Strength is simply obtained by multiplying this Minimum Yield Stress by the cross sectional area of the pipe and these figures are then published by API. Note also that the Minimum Yield Stress is referred to in the name of the grade; thus E75 grade steel has a Minimum Yield Stress of 75,000 psi, G105 has a Minimum Yield Stress of 105,000 psi.

For high tensile drill string steels, a higher strain is used to calculate Minimum Yield Stress. For G105 it is 0.006 and for S135 it is 0.007 (defined in API Specification 5D).

The Minimum Yield Stress, if applied to the steel, will result in a small amount (2%) of permanent deformation. If a pipe is loaded to the Minimum Yield Strength, some permanent stretch will have occurred and that pipe might not remain straight. API therefore recommends that pipe is never actually loaded to more than 90% of Minimum Yield.

Chapter 3

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Methodology

Methodology

3.1 Drill String Design:

During the design, a good knowledge of drill string performance properties (available sizes, grades, etc.), previous history of drilling in similar conditions, and also costs associated with drill string components. The following design criteria should be considered while designing the drill string:

1. Design involves the determination of:

a. Length

b. Weight

c. Grades

2. Factors affecting the design:

a. Hole or depth size

b. Mud weight

c. Safety factor

d. Length/weight of DC

e. DC sizes

3. Design should be tested for the following criteria:

a. Tension

b. Collapse

c. Critical speed

d. Shock loading

e. Torsion

f. Stretch

4. Design should follow the following procedure

a. Tension

b. Collapse

c. Others (if necessarily)

However, there are some other major standards that need to be satisfied at the final stage of the design. These criteria are:

i) The load capacity divided by a SF of any drill string component should be greater than or equal to the maximum permissible load.

ii) The neighboring elements must be well-suited which is accomplished by selecting elements with an appropriate bending-stress ratio.

iii) The drill string geometric properties should be selected in conjunction with an optimal hydraulic and casing program.

iv) In deviated wells, drill string rotation should not produce excessive wall and casing damage, and

v) A minimum level of the cost of the string should be maintained.

In summary design of drill string means determination of length, weight, grades of drill pipe to be used during drilling, coring or any other operation which depends on hole depth, hole size, mud weight, safety factor and/or margin of pull (MOP), length and weight of DCs, and drill pipe size. **The design factors** such as tension, collapse, and other factors – shock loading, torsion, stretch of pipe, and critical rotating speed need to be considered. The main factors considered in the selection of drill strings are:

i) The collapse load, and.

ii) The tensile load on the drill pipe.

Burst pressures are not generally considered since these only occur when pressuring up the string on a plugged bit nozzle or during a DST. However, it is very unlikely that the burst resistance of the pipe will be exceeded. Torsion is not needed to be considered except in a highly deviated well. Once the collapse and tension loads have been quantified, the appropriated weight and grade of the drill pipe can be selected. In general, a graphical approach to drill string design is recommended. If one section of the string does not meet requirements, it must be upgraded. The procedure can be listed as:

i) choose a weight and grade of pipe to satisfy the collapse conditions,

ii) Using the pipe chosen in (i), calculate the tension loading, including buoyancy effects,

iii) Draw the tension loading line and also the maximum allowable load line,

iv) Modify the tension load as given in (ii) by applying a design factor, MOP etc.,

v) Generate three design lines,

vi) If any of these design lines exceed the maximum allowable load, a higher rated drill pipe must be used for that section of pipe,

vii) Calculate the new tension loading line for the new drill string and repeat steps (v) and (vi).

Failure Types

- Tension
- Torsion
- Sulfide Stress Cracking
- Fatigue
- Other Causes

3.2 Tensile Failures:

Tensile failures occur when the tensile load exceeds the capacity of the weakest component in the drill stem. This is usually a drill pipe at the top of the hole. Occasionally the tool joint will fail if the connection was made up beyond recommended torque. Tensile load is greater than ultimate tensile strength. Surface of break is jagged and at 45 degrees to axis of pipe.

Concepts of Stress and Strain:

To compare specimens of different sizes, the load is calculated per unit area engineering

3.3 Stress:

$$\sigma = \mathbf{F / A} \qquad \mathbf{(3.1)}$$

F is load applied perpendicular to specimen cross-section; A_0 is cross-sectional area (perpendicular to the force) **before** application of the load. **engineering strain:**

$$\varepsilon = \mathbf{\Delta l / lo\ (\times\ 100)} \qquad \mathbf{(3.2)}$$

Where:

Δl is change in length, lo is the original length.

These definitions of stress and strain allow one to compare test results for specimens of different cross-sectional area A_0 and of different length l_0. **Stress and strain are positive for tensile loads, negative for compressive loads**

3.3.1Shear stress:

$$\tau = \mathbf{F / Ao} \qquad \mathbf{(3.3)}$$

Where:

F is load applied parallel to the upper and lower faces each of which has an area A_0.

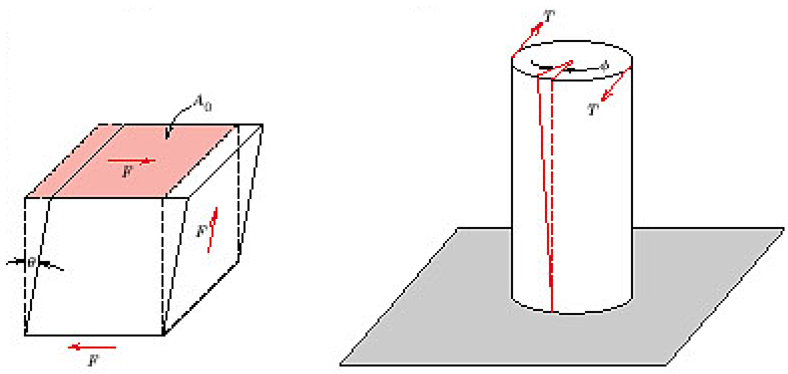
3.4Shear strain:

$$\gamma = \mathbf{tan}\ \theta\ \mathbf{(\times\ 100\ \%)} \qquad \mathbf{(3.4)}$$

where:

θ is the strain angle

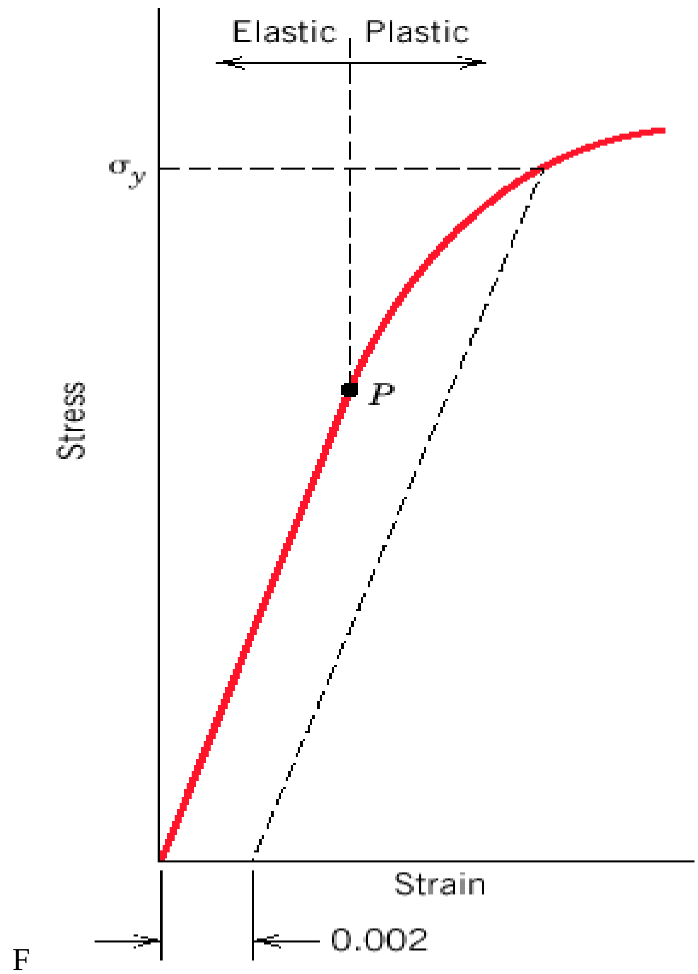
Torsion is variation of pure shear. A shear stress in this case is a function of applied torque T, shear strain is related to the angle of twist, φ.



Figure(3.1) :Shear and torque

3.5 Stress-Strain Behavior:

Elastic deformation Reversible: when the stress is removed, the material returns to the dimension it had before the loading.



Figure(3.2): Elastic deformation

3.5.1 Plastic deformation:

Irreversible: when the stress is removed, the material does not return to its previous dimension.

3.5.2 Stress-Strain Behavior:

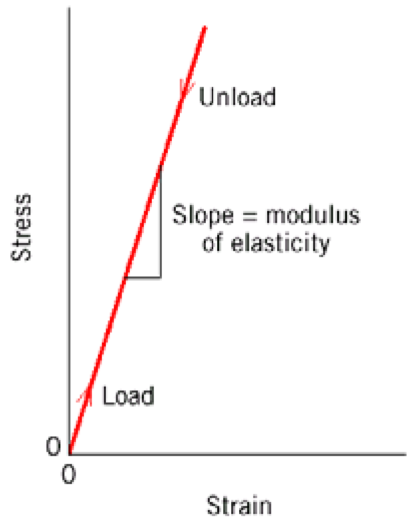
Elastic deformation:

In tensile tests, if the deformation is elastic, the stress strain relationship is called Hooke's law:

$\sigma = \mathbf{E}\, \varepsilon$ (3.5)

Where:

E is **Young's modulus** or **modulus of elasticity**, has the same units as σ, N/m2 or Pa



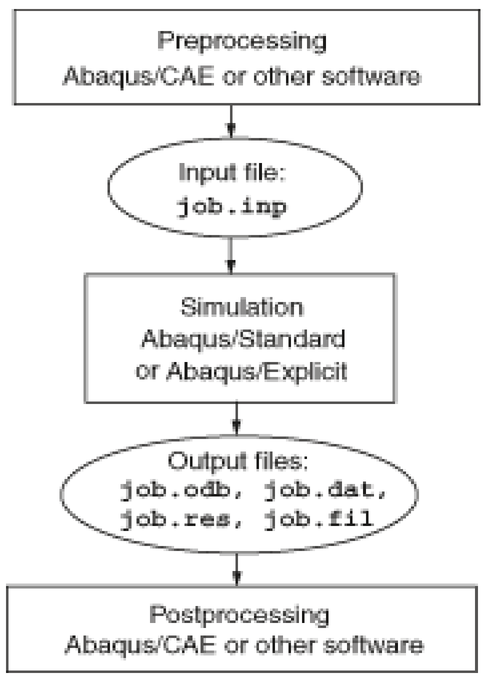
Figure(3.3): stress strain behavior

3.6 Abaqus Software Background:

Abaqus is a suite of powerful engineering simulation programs, based on the finite element method, that can solve problems ranging from relatively simple linear analyses to the most challenging nonlinear simulations. Abaqus contains an extensive library of elements that can model virtually any geometry. It has an equally extensive list of material models that can simulate the behavior of most typical engineering materials including metals, rubber, polymers, composites, reinforced concrete, crushable and resilient foams, and geotechnical materials such as soils and rock. Designed as a general-purpose simulation tool, Abaqus can be used to study more than just structural (stress/displacement) problems. It can simulate problems in such diverse areas as heat transfer, mass diffusion, thermal management of electrical components (coupled thermal-electrical analyses), acoustics, soil mechanics (coupled pore fluid-stress analyses), piezoelectric analysis, electromagnetic analysis, and fluid dynamics.

Abaqus offers a wide range of capabilities for simulation of linear and nonlinear applications. Problems with multiple components are modeled by associating the geometry defining each component with the appropriate material models and specifying component interactions. In a nonlinear analysis Abaqus automatically chooses appropriate load increments and convergence tolerances and continually adjusts them during the analysis to ensure that an accurate solution is obtained efficiently.

A complete Abaqus analysis usually consists of three distinct stages: preprocessing, simulation, and post processing. These three stages are linked together by files as shown below:



Figure(3.4): Analysis Stages.

3.7 Preprocessing (Abaqus/CAE)

In this stage you must define the model of the physical problem and create an Abaqus input file. The model is usually created graphically using Abaqus/CAE or another preprocessor, although the Abaqus input file for a simple analysis can be created directly using a text editor.

3.8 Simulation (Abaqus/Standard or Abaqus/Explicit)

The simulation, which normally is run as a background process, is the stage in which Abaqus/Standard or Abaqus/Explicit solves the numerical problem defined in the model. Examples of output from a stress analysis include displacements and stresses that are stored in binary files ready for post processing. Depending on the complexity of the problem being analyzed and the power of the computer being used, it may take anywhere from seconds to days to complete an analysis run.

3.9 Postprocessing (Abaqus/Viewer)

You can evaluate the results once the simulation has been completed and the displacements, stresses, or other fundamental variables have been calculated. The evaluation is generally done interactively using Abaqus/Viewer or another postprocessor. Abaqus/Viewer, which reads the neutral binary output database file, has a variety of options for displaying the results, including color contour plots, animations, deformed shape plots, and *X*–*Y* plots.

Each simulation process consist of the following tasks as shown in figure (3.2):

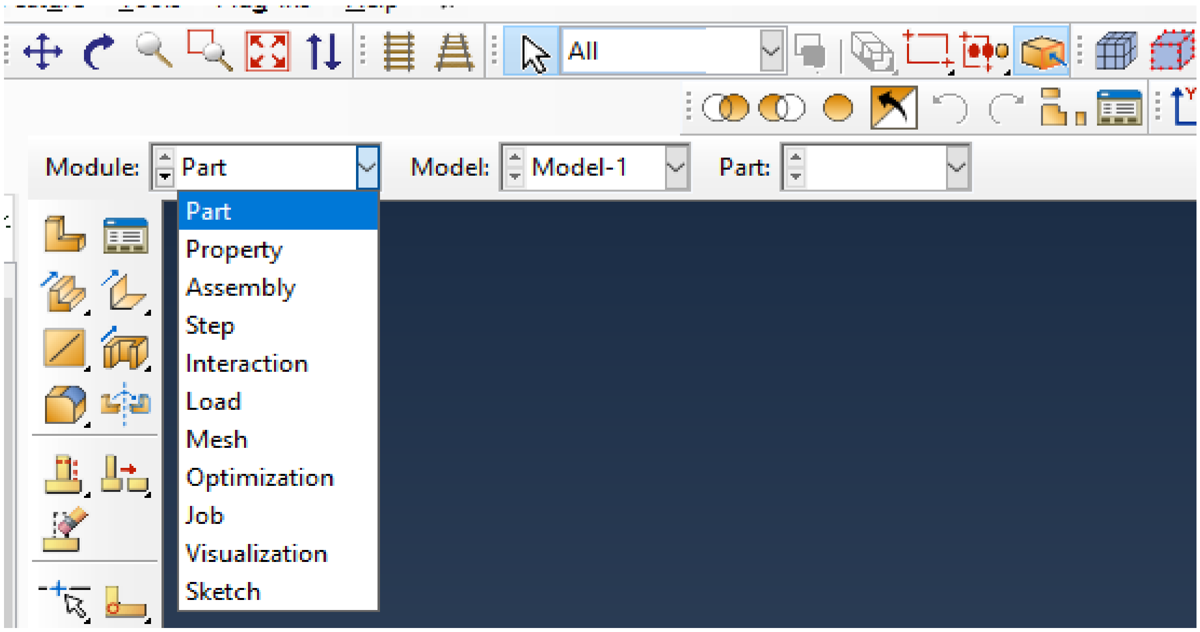


Figure (3.5): ABAQUS screen

Part

Sketch a two−dimensional profile and create a part .

Property

Define the material properties and other section properties of the beam.

Assembly

Assemble the model and create sets.

Step

Configure the analysis procedure and output requests.

Load

Apply loads and boundary conditions to the beam.

Mesh

Mesh the beam.

Job

Create a job and submit it for analysis.

Visualization

View the results of the analysis

Chapter 4

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Results and Discussions

Results and Discussions

4.1 General Introduction:

Thread connections are widely used in oil and gas industry. But the thread may fail under washout; this research focus on determination of causes of this failure and to that a FEM software (ABAQUS) has been used.

4.2 Model Building for Tool joint (Pin and Box):

In order to build a model firstly a part should be created as shown in figure(4.1) , after that a solid 2D deformable model should be choose.

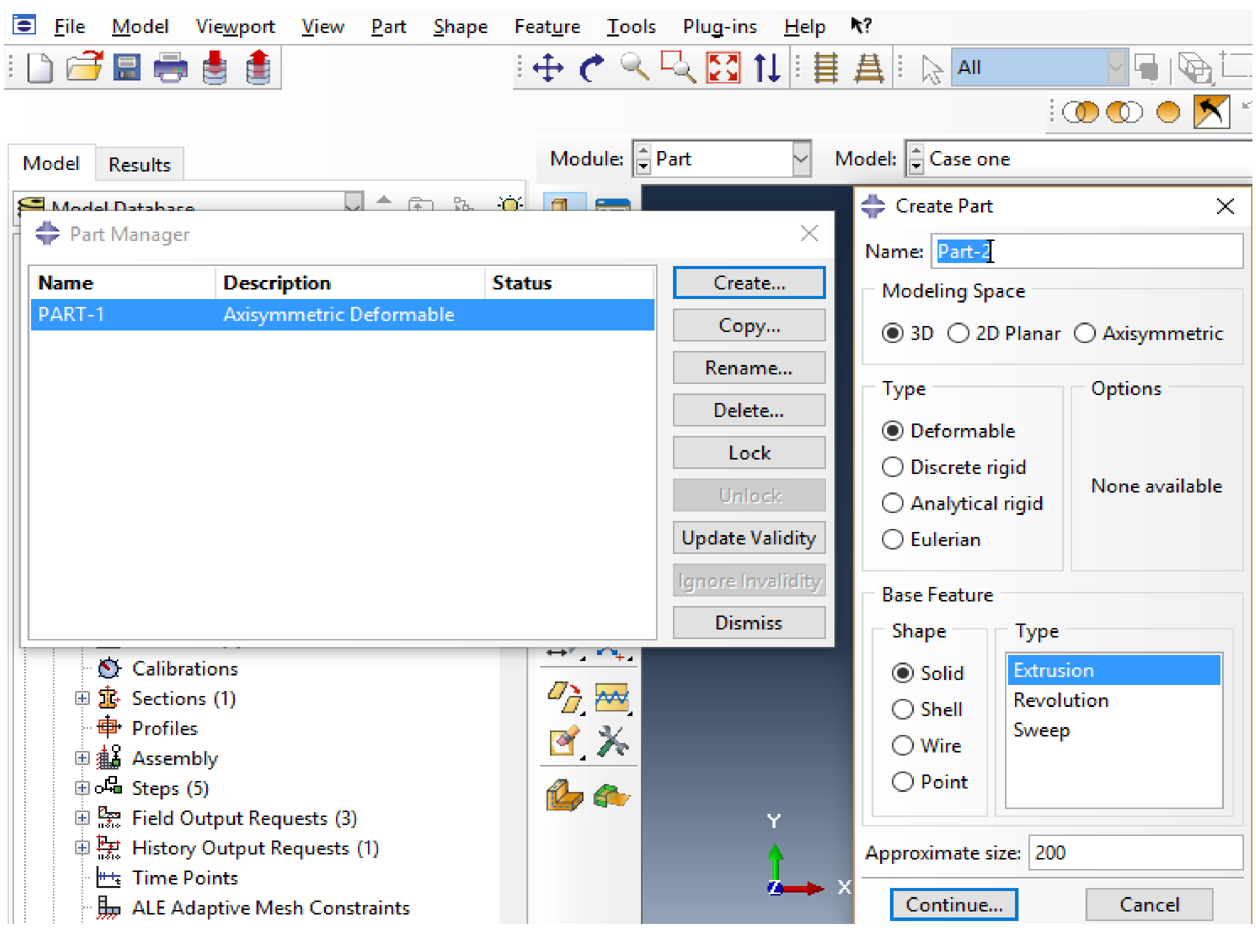


Figure (4.1): Part creation

The second step a tool joint material should be selected from properties step as shown in figure (4.2) ; the material physical properties should be entered as the following table:

Table(4.1): Drillstring properties

Young's Modulus kpa	30000000
Poisson's Ratio	0.3

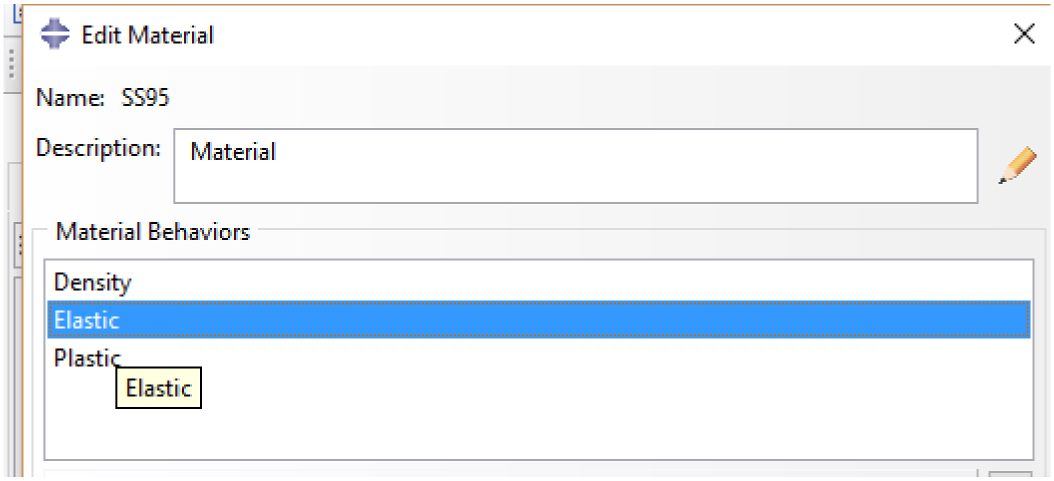
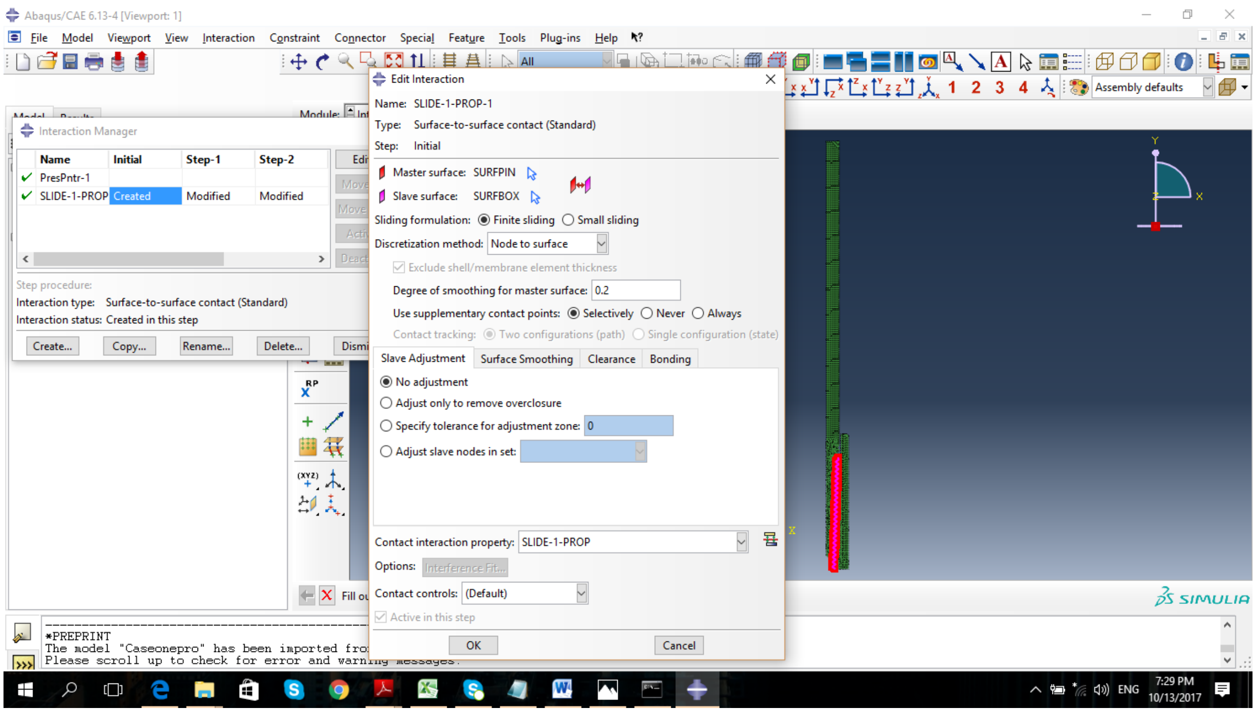


Figure (4.2): Material selection step

In order to define pin and box surface connection the interaction section in CAE should be selected this step shown in figure(4.3).



Figure(4.3): Define pin and box interaction

The next step is to define the weight of BHA which affect upon a tool joint as compression force for the tool joint this value is equal to 26114.67 kilogram force this step shown in figure (4.4).

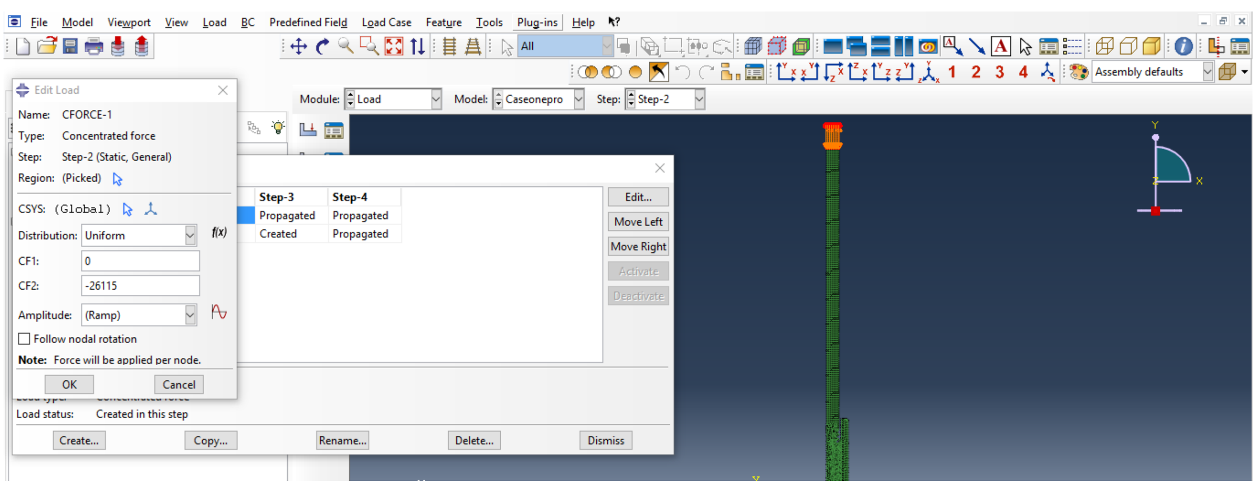


Figure (4.4): Load identification step

In order to solve FEM equation a suitable boundary condition should be applied for endbox of tool joint as the following:

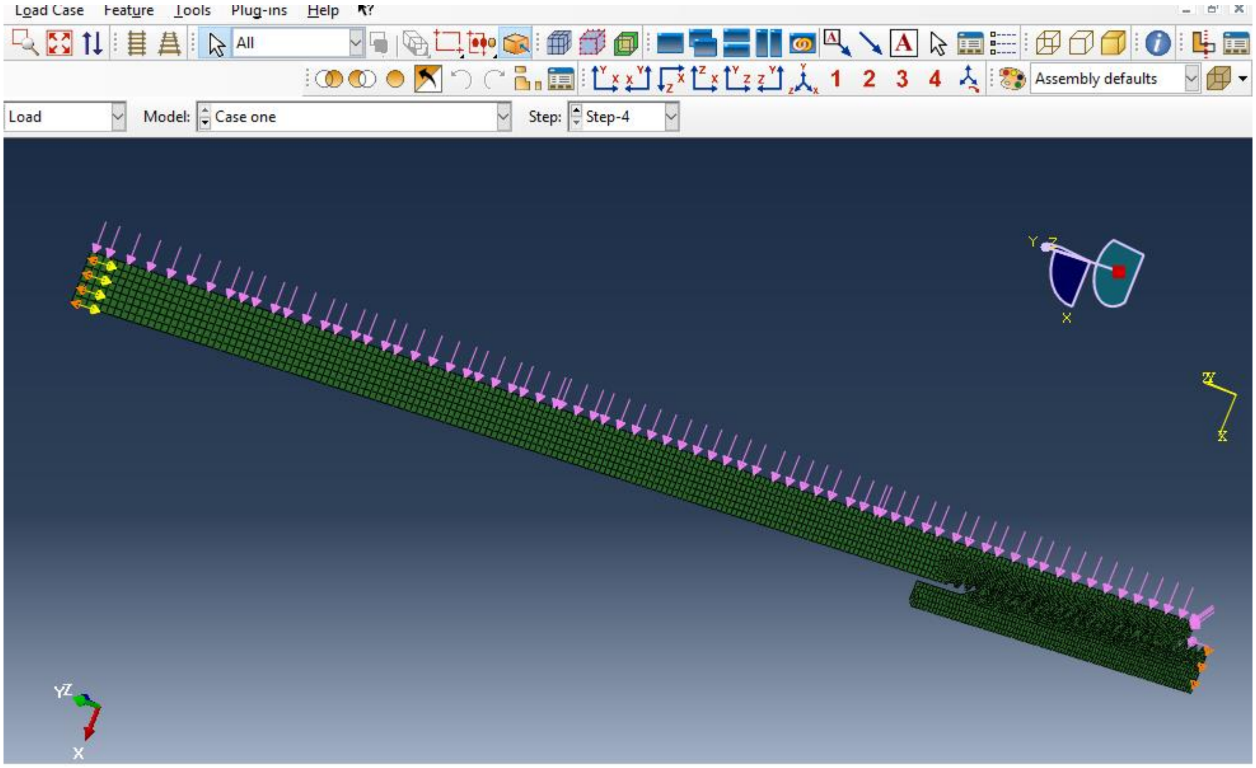


Figure (4.5): Boundary condition for X drillstring

The result of the resulting tool joint failure can be shown after applying all the above steps by creating a job in ABAQUS CAE also the result can be presented in visualized graphs.

4.3 Results and Discussion:

Washout may occur due to leak of mud through the thread in this case a leak happen under the pressure estimated as 4840 kpa (Base Case Pressure) ;at this value a resulting torque is shown in figure(4.6) as red line and the blue line is represent a minimum allowable pressure (5092 kpa) in which no failure occur.

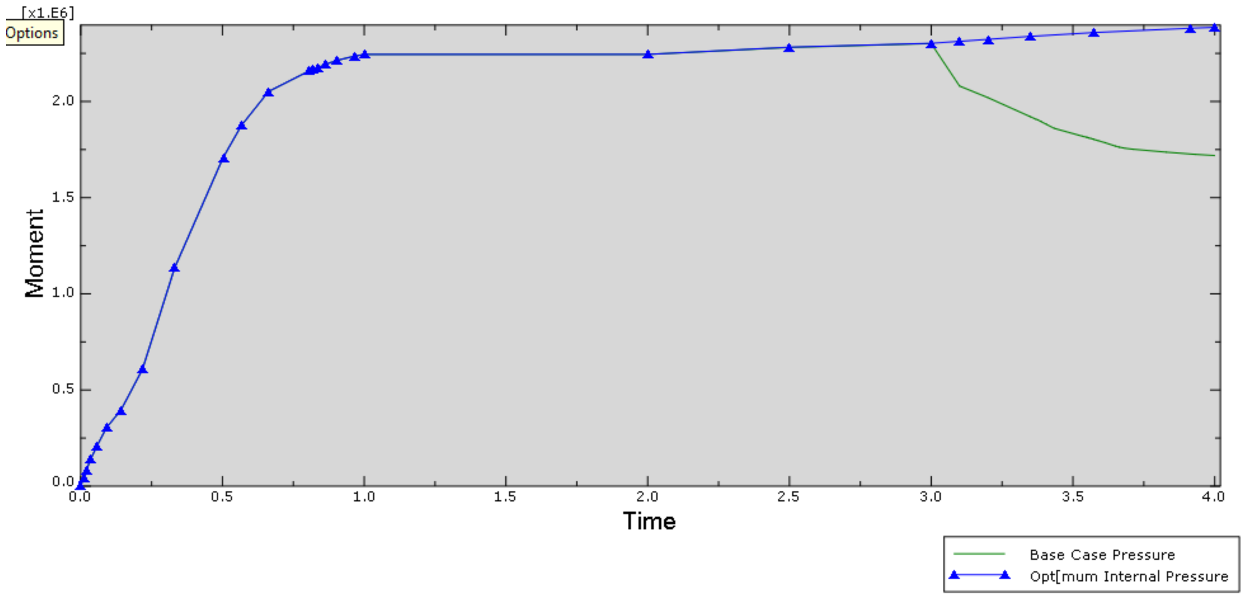


Figure (4.5): Torque at 4840 kpa

In addition to that in case of 4840 kpa the leak is occur due to high displacement as shown in figure(4.6).

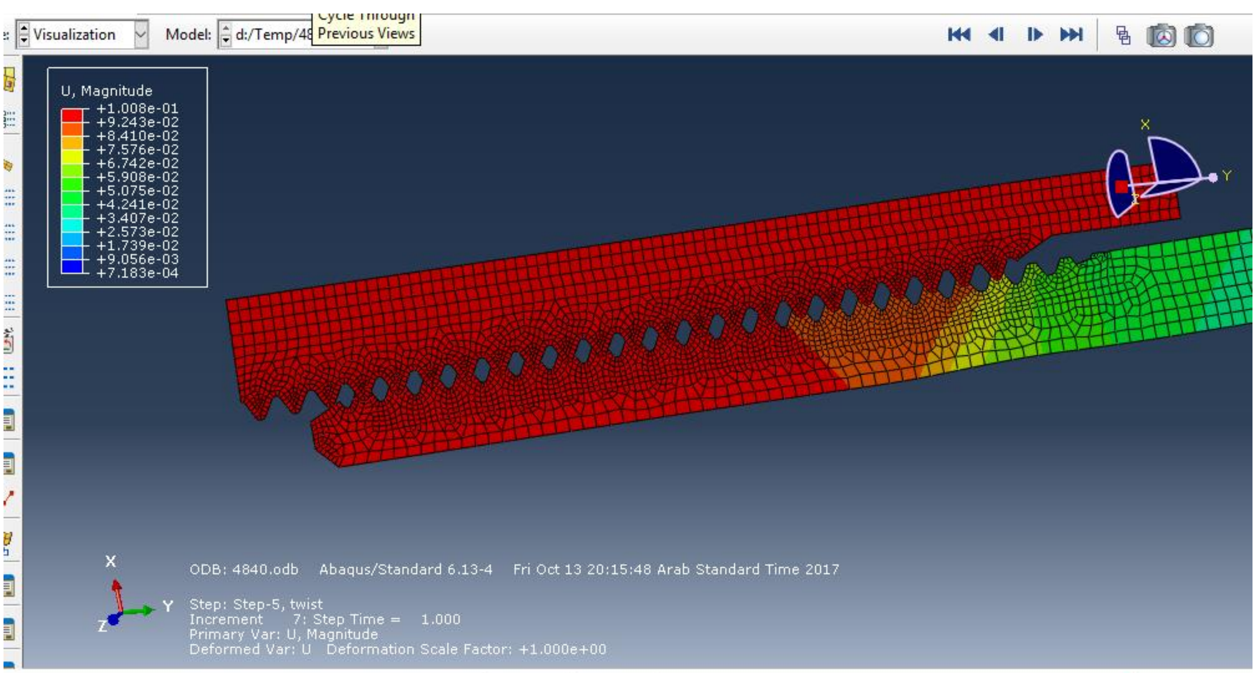


Figure (4.6): Resulting displacement of 4840 kpa

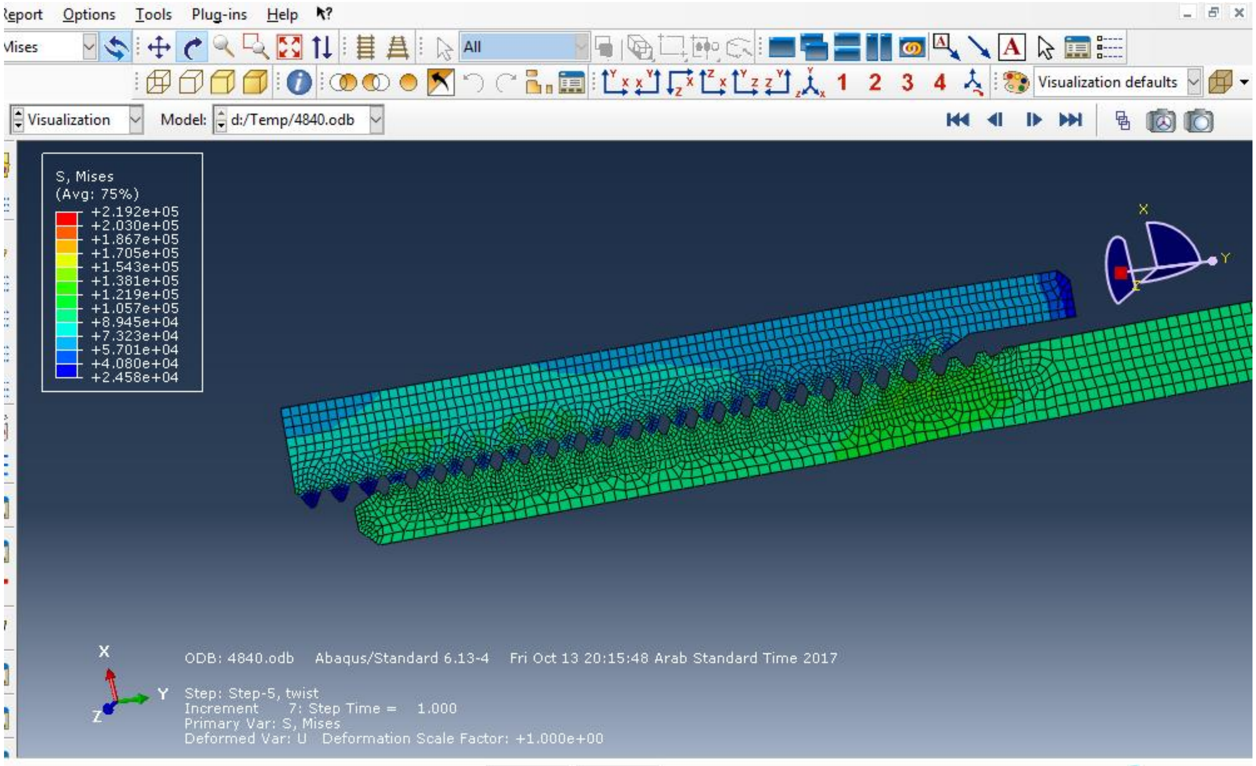


Figure (4.7): Resulting deformation of 4840 kpa

All above results indicate that the actual tool joint failure occurred at approximately 4840 kpa; it was determined that the thread connection should be capable of sustaining more than 4840 kpa internal pressure if no pressure penetrated the threads.

A simple and obvious solution is to add a seal or o ring at inside of the thread as shown in Figure 5 to eliminate pressure penetration. It was also determined that changing the profile of the box and pin at the bearing area would not solve the problem, because under close end conditions, the box would be pulled away from pin axially at that area.

The value of CTRQ is increases as the overclosure is resolved and displacement also due to the change in the contact pressure as the box is pulled away from the pin (see Figure (4.6).

At 4840 high displacement is occur which resulting in flow of mud through pin and box and this lead to leak and this leak is main reason to tool joint washout.

Chapter 5

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Conclusions and Recommendations

Conclusion and Recommendation

5.1Conclusion:

Thread connections are failed under washout; this work manage to determine the causes of thread failure (washout) by simulation of this problem using FEM software (ABAQUS). From the results analysis and discussion we come into the follow conclusions:

- High deformation and displacement was occurred between pin and box of the thread connection at value of internal pressure 4840 kpa.
- A leak was took place due to the high deformation between pin and box.
- Thread connection washout is expected according to the follow of mud through thread.

5.2 Recommendation:

We recommend that more investigation should be done for washout due to thread connection failure, by obtaining more information of the problem and provide solution by suggesting introducing other types of thread connections.

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