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Drillstring Buckling and Drilling Fluid Density Effect on Torque and Drag in Iraqi Oil Wells

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Abstract— Drillstring buckling phenomena in oil and gas wells is considered as a critical problem in drilling engineering while it negatively affects the drilling operations. While drilling, drillstring buckling may cause inefficient load transfer to the bit, excessive torque magnitudes, decreases the life of the drillstring significantly and even drillstring failures due to fatigue. In this study, Halliburton's Landmark software (WellPlan) was utilized and two wells; Well-BU (horizontal well) in Buzurgan oilfield, Missan oilfields and Well-Ga (deviated well) in Garraf oilfield, Thi-Qar oilfields were selected. Three main processes are used in torque and drag modeling application. First, utilizing offset wells data, the second process is correcting hookload weight and the third process comprises friction coefficient calibration with actual field data. Calculation of minimum weight on bit (WOB) to initiate buckling and effect of drilling fluid density during different drilling operations in 5 5/8 and 17 1/2 inch open hole sections in the two wells were studied.The most important conclusion is minimum WOB to initiate buckling is reduced at different drilling operations (sliding and rotating) while drilling operation progresses and both the diameter of the wellbore and drillstring decreases (depth of the well increases). While rotating operation, minimum WOB that caused sinusoidal buckling in 17 ½ and 5 5/8 inch hole diameter were 17.88 and 10.4 tonne respectively. In contrast, during sliding operation, the minimum WOB is less than rotating operation. Significant values of hookload were exhibited in BU-Well and Ga-Well whenever density of drilling fluid was varied, in contrast less effect on torque values were observed. The variations in drilling fluids were 1.21 g/cc to 1.23 g/cc in Well-BU and 1.114 g/cc to 1.138 g/cc in Well-Ga. Not every reduction or rising in torque and hookload means there is a problem.

Keywords— Minimum Weight On Bit, Hookload, Buckling, Landmark Software.

1. Introduction

The contact between the drillstring and wellbore generates frictional forces and normal loads against the direction of drillstring movement and causes an increase in drag and torque [1]. In complex geometry wells, ultra-extended reach wells and drilling deep wells, drilling limitations cannot be ignored due to high drag forces and torque. Excessive drag and torque, specially unplanned drilling operations may be detrimental. Numerous ways have been developed to defiance the drilling limitations by decreasing torque and drag forces so as to drill more and deeper. Solutions to problematic drag and torque in highly inclined wells are important in order to complete the drilling well and completion operations. Since many limitations are imposed by the drilling rig, top drive, well trajectory and drilling equipments, engineers have come up with methods to decrease drag and torque while drilling. There are weight restrictions that a rig may provide; especially in operations without rotating for instance slide drilling. Besides, if the compressive loads in the drillstring are too high, buckling will occured, therefore, it is important for engineers to calculate the drag, torque and buckling loads accurately and attempt to decrease them to prohibit these scenarios from happening. Simultaneously, it is an engineer's accountability to ensure that the design is not exaggerated to meet unwarranted needs[2].

1.1 *Torque and Drag*

Increasing torque and drag ultimately induces losses in drilling energy which will affect the drilling process[2]. There are two major sources of drag and torque [3]:

a- ***Side forces***

Side forces occur between every element of the drillstring and the wellbore wall. They are the normal forces created by the drillstring to the wellbore wall. There are a few main factors that can cause side forces that include the weight of the drill string, tension due to dogleg severity, buckling, and stiffness of the drill string.

b- ***Friction***

It is the resistance to motion (due to drillstring movement). The roughness between the drillstring and borehole wall is intended to represent the friction coefficient [3]. Though, because of the complex nature of drilling, coefficient of friction is not only symbolizes real mechanical friction but also involves a multitude of further downhole effects [4]

The rotation friction coefficient during drilling operation is main source of concern as it affects the ultimate torque output. It is the friction between the drillstring and the wellbore while drillstring rotation. When tripping in and out of borehole, the translation friction coefficient is an issue since rotation is not a factor while tripping. Both the rotation and translation friction factors while back-reaming are of concern because both axial movement and rotation take place. Inaccurate designs may occur when incorrect friction factors are utilized [5].

1.2 *Buckling Phenomena*

Buckling occurs when the drillstring is in compression, where lost in the original rectilinear status due to axial compression load is the definition of tubular buckling [6]. Sinusoidal buckling is the first state when the drillstring is in compression, where the drillstring goes from side to side in a snaky manner (Figure 1) [7]. However, further increase in the drillstring axial compressive load is, the drillstring will go into helical buckling, where the drillstring locks up in a spiraling manner against the borehole sides (Figure 1) [7]. The contact surface area between the drill string and the wellbore is increased due to buckling, this lead to an increase in side forces [5]. In general, a damage/loss to drillstring may be caused due to buckling.

In a horizontal section of wells, problems may be caused by tubular buckled for instance: severe drag and torque, failure or wear of casing , eliminates the transmission of axial force to the bit, fatigue of drillpipe, change in bit direction, failure of tubing seal, failure of connection [6].

The beginning of buckling will depend on the stiffness of the drillstring components and the outer diameter of components associations with casing and wellbore. This is essential for modeling of drag and torque since helical buckling will cause a large increase in the side force between wellbore walls and drillstring. In small diameter pipe sizes and coiled tubing, buckling is often seen [7].

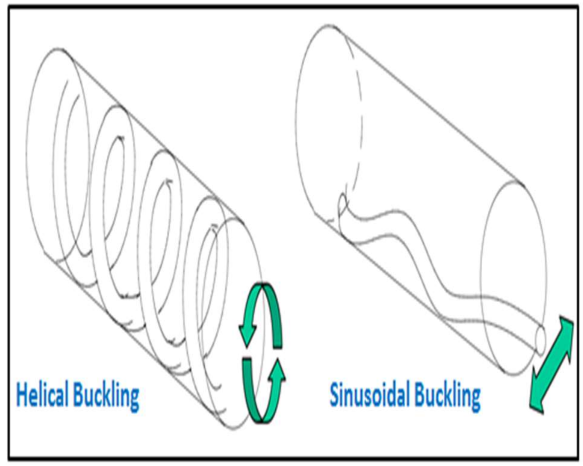

Figure 1: Sinusoidal and Helical Buckling [7]

Continuous rotation of buckled drill string (when bending forces are applied) suffers both compression and tension for each rotation of the drillstring. This type of loading on drillstring makes stresses that are named fluctuating stresses. These fluctuating stresses reduce the life of the drillstring significantly and cause early fatigue failure. Moreover, since buckled drill string gets in contact with wellbore, it may result in insufficient bit weight due to excessive frictional drag between drill string and wellbore [8].

Buckling models predict the forces required for the initiation of two modes of buckling: sinusoidal and helical. The models provide different predictions for vertical section (Table A.1) [9,10], curved section (Table A.2) [9,11]and inclined section (Table A.3) [9,12] in the Appendix respectively. All these models are in non-rotating buckling conditions.

A model for critical buckling loads under presence of torque (rotating condition) on the tubing was developed by He et al. (1995) (Equation 1) [6]. The critical buckling load (F) in the presence of the applied torque (τ) is lower than the buckling load in the absence of the applied torque (F_c). The torque (τ) application results in a decrease in the buckling load [6].

$$F = F_c \left[1 - \frac{\tau}{\sqrt{\frac{E\,I\,F_c}{2}}} \right] \quad (1)$$

1.3 *Hook Load*

The sum of all the drillstring weight (drillpipe and other bottom hole assembly) suspending on the hook through a drilling operation is defined as the hookload. The hook holds the actual weight of the drillstring as measured at the surface which is the drilling load (Figure 2). When all the weights attached to the hook are hanged freely in air (at surface) without any support, the hookload would be at its maximum magnitude. The hookload will be reduced when any manner of support for the weight hanged on the hook [13]. Knowing the hookload assists and provides information to the driller for controlling weight on bit. The driller can be decided to reduce or raise the impact weight on the drill bit by monitoring the hookload [14].

Due to the following support for the weights attached to the hook results in hookload reduction [13]:

- During drilling, the drillstring would have to be submerged in the drilling fluid in the borehole. So, some of this load will be conveyed to the drilling fluid, thereby decreasing the hookload magnitude. This support is as a result of buoyancy force (upward) extended from the drilling fluid on the drillstring.
- In vertical wells, a reduction in hookload is observed when the bit touches the bottom of the hole as some of the weight is transferred to bottom. In high angle wells, a reduction in hookload is observed due to friction between the drill string and wellbore wall as the contact or rests of the drillstring on one side of the borehole.

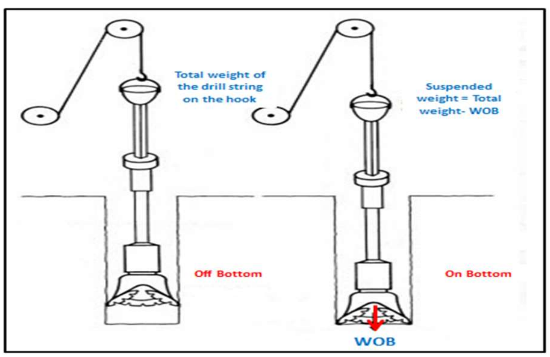

Figure 2: Weight on the Hook Off Bottom and On Bottom [14].

Because of a drilling fluid property identifies as buoyancy, drillstring load is more in air than in weighted fluids. Thus, what is observed as the hookload is actually the drillstring buoyed weight. The buoyancy force is equal to the weight of the fluid displaced which is Archimedes' principle states. A buoyancy force is equal to the pressure at the bottom of the drillstring multiplied by the cross sectional area of the pipe as the buoyancy force is not a body force as gravity, but it is a surface force [15].

Total drillstring weight in air is:

$$\text{Total Air Weight} = \text{drillstring weight per foot x length} \quad (2)$$

Hook load while drillstring is submerged in the drilling fluid in the borehole is:

$$\text{Hookload}=\text{Air Weight - Buoyancy Force} \quad (3)$$

$$\text{Buoyancy Force}=\text{Pressure at the bottom x Area} \quad (4)$$

Instead, the following formula, which incorporates a buoyancy factor, is used and recommended by the API.

$$\text{Hookload} = \text{Air Weight x Buoyancy Factor} \quad (5)$$

$$\text{Buoyancy Factor} = 1 - \frac{\text{MW,ppg}}{\text{65.5,ppg}} \quad (6)$$

Where, MW is drilling fluid density in ppg and 65.5 ppg is a steel density. Hookload in equation 5 does not use into account of axial drag, it is the estimated static hookload at surface that would be exhibition by the weight indicator in a vertical borehole without drag; exclusive of the traveling block weight, drill line etc.

Actually, because of motion and borehole drag, the hookload magnitude would vary. While pulling drillstring upwards out the borehole, Pick-Up Load refers to the hookload. When an attempt to pick up the drillstring, the highest hookload occured. While lowering the drillstring in the borehole, Slack-Off Load refers to the hookload. During drilling in the oriented manner, Drag Load refers to the hookload. Other situations to the hookload are Rotating Drilling Load and Rotating Off-Bottom Load [15].

In directional wells, the conditions are changed due to deeper drilling and build angle. In these conditions, the friction is a main contributor to vary the weight in the hook [16] . Weight acting along an inclined interval of the well where the inclination is constant is presented in equation 7 [15] .

$$\text{Weight acting along borehole} = \text{Air Weight x cos (avg. Inc.)} \quad (7)$$

2. Case Study

Two wells in two Iraqi oilfields were selected one of them in Missan oilfields (Buzurgan oilfield) and the second one in Garraf oilfield. The choice for these wells depended on the availability of data. Landmark software (WellPlan) was used to develope torque and drag model to determine minimum weight on bit (WOB), drillstring buckling and study the impact of drilling fluid density on two important parameters which are torque and hookload

2.1 *Buzurgan oilfield*

Missan oilfields are located in the Missan province in southeastern Iraq and close to the Iraq-Iran border. It is about 175km north to the Basra city. Missan oilfields comprise three subfields, namely Abu Ghirab, Buzurgan and Fauqi oilfields.

Buzurgan oilfield is a NW-SE axis anticline which ranges about 353.4 km^2 showing two domes one in the north, the second one in the south. Cretaceous Mishrif carbonate reservoir is the main target interval in Buzurgan oilfield, the Mishrif is divided into seven pay zones; MA, MB11, MB12, MB21, MB22, MC1 and MC2. The main pay zone is MB21[17].Top of MB21 of Mishrif reservoir in southern Buzurgan oilfield and wells location is shown in Figure 3.

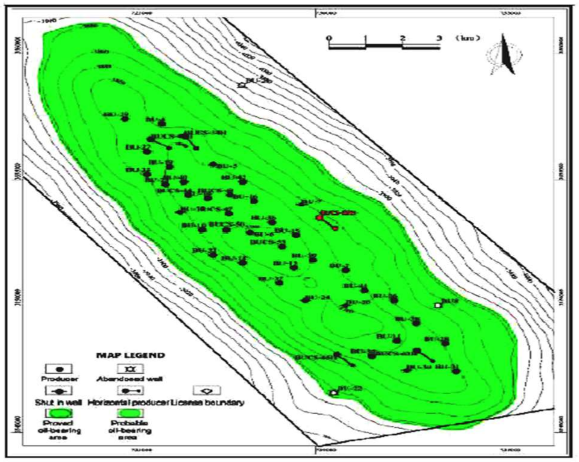

Figure 3: Well Location on Top of MB21 of Mishrif Reservoir in Southern Buzurgan Oilfield [17].

2.2 *Garraf Oilfield*

Garraf oilfield is located in the province of Thi-Qar, approximately 5km north-west of Al-Refaei city and 85 km north of Nasiriyah city. The field is 17.5km long and 5.5km wide. Garraf oilfield was discovered in 1984 where three exploration wells were drilled in 1984, 1987 and 1988 respectively and two appraisal wells were drilled: in 2011 and 2012. Well Locations on Top Mishrif Formation in Garraf Oilfield is illustrated in Figure 4 where the reservoir is located on the low relief gentle anticline structure in NW-SE. Mishrif and Yamama formations were containing the most oil accumulation within the field area. The second accumulation zones are found within the Ratawi and Zubair formations [18].

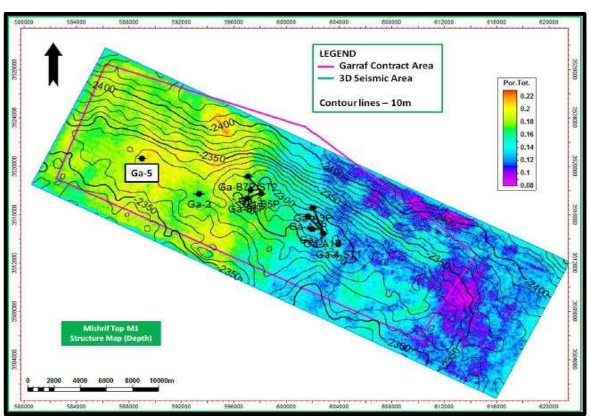

Figure 4: Wells Location on Top Mishrif Formation in Garraf Oilfield [19].

2.3 *Study Methodology*

Landmark (WellPlan) software is used where extends and simplifies the science through dramatic advancements in ease-of-use and data visualization.The following field data were collected for torque and drag model application:

- Final Well Report (FWR)
- Slide and Rotary Drilling Report
- Drilling Program
- Directional Well Report
- Casing Tally
- BHA Report
- Daily Drilling Report (DDR)

2.3.1 Torque and Drag modeling:

The construction of torque and drag model by Landmark (WellPlan) software can be summerized as following:

a. ***Creating the Data Hierarchy***

b. ***Open the Case and Follow the Next Steps:***

- Create a WellPath of Well.
- Create the Hole Section.
- Create a Drillstring
- Create Mud (Drilling Fluid)
- Add Subsurface Properties
- Add Operations Parameters

c. ***Analysis Settings***

This analysis can be made by common options which include the following:

- Active fluid
- Pump rate
- The Run Parameters

d. ***Hook-Load /Weight-Indicator Corrections by:***

- Block Weight
- Use Stiff String
- Use Viscous Torque and Drag
- Use Maximum Overpull

e. ***Calibration the Model using Actual Load Data***

Actual loads data (Hookload and Torque) were obtained from rotary and sliding drilling report which can be used in friction factor calibration.

3. Results and Discussions

3.1 *BU-Well*

The first horizontal well, BU-Well (Buzurgan-Well) was drilled to 4766 m total depth (TD). A casing of 9 5/8 inch OD was set at 2823.1 m MD. Liner of 6 5/8 inch OD was started from 2580.48m to 4079.83m MD and 5 5/8 inch OD open hole section was started from 4079.83 m to 4766 m MD as shown in Figure 5.

Inclination in this well was increased with measured depth (MD) and reached 91.33 degree at depth 4341.59 m MD. Also, this well has high value of dogleg severity; it reached maximum value of 4.896 degree/30m at 4061.42m MD.

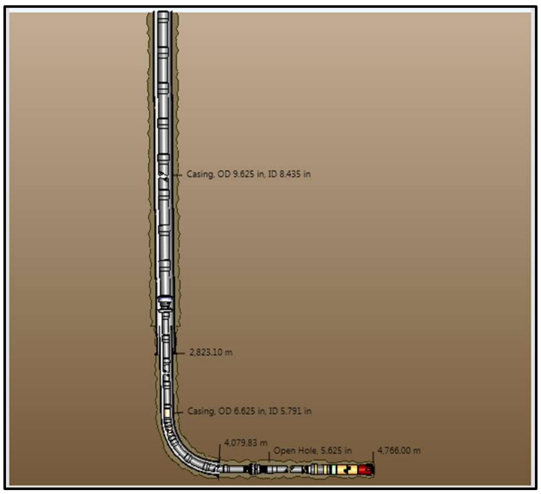

Figure 5: BU-Well Schematic

3.1.1 Minimum Weight on Bit

Minimum WOB to initiate helical or sinusoidal or helical buckling is shown in Figure 6 for two operations; rotating and sliding drilling. Extreme care should be developed during drilling 5 5/8 inch open hole section from 4079 m (CSG Shoe) to 4766 m (TD) in horizontal BU-Well to ensure that the WOB is kept less than the present values at the corresponding bit depth. Once the WOB exceeds the minimum WOB at the corresponding bit depths, the drillstring will begin buckling according to the corresponding buckling mode (sinusoidally or helically).

During rotating operation, the minimum WOB of 10.4 tonne at 4750 m MD may cause sinusoidal buckling (green line) and minimum WOB value of 11.74 tonne at 4537 m MD to be helical buckling (red line). Also the smallest difference of 1.14 tonne is between minimum WOB sinusoidal buckling and helical buckling at 4232 m MD, therefore, the driller should be careful at this depth because of the small change in WOB may lead to transition from sinusoidal to helical buckling.

During sliding operation, the Minimum WOB value of 2.34 tonne at 4537 m MD may result in sinusoidal buckling (orange line) and minimum WOB of 5.82 tonne at 4537 m measured depth to be helical buckling (blue line) but the difference between two values is considered small to change from sinusoidal to helical buckling approximately of 3.48 tonne. Also this figure illustrates that the smallest difference of 3.2 tonne is between minimum WOB sinusoidal buckling helical buckling at 4476 m (MD), therefore, the driller would be careful at this depth because this values is considered small to change from sinusoidal to helical buckling.

Generally, the minimum WOB values versus measured depth during rotating and sliding drilling operations are continued to decrease to 4537 m MD. The critical force causing tubular buckling is higher than that at measured depth above 4537 m. Due to the drillstring lying on the wellbore wall of 5 5/8 inch open hole section with an inclination above 88°, a higher forces enable to buckle the drillstring and higher frictional force between the drillstring and the borehole wall should be overcome.

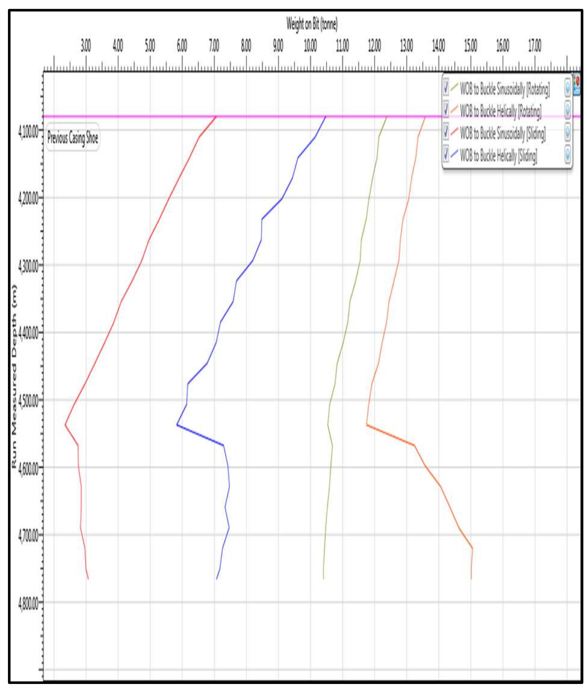

Figure 6: Minimum Weight on Bit of Two Operations (Rotating and Sliding) of BU-Well.

3.1.2 Effect of Drilling Fluid Density

Effect of Drilling Fluid Density on Hookload

Hookload (HKLD) is the drillstring weight on the surface. The effect of drilling fluid density on this parameter during running in the hole (RIH) and pulling out the hole (POOH) was applied depending on the actual drilling fluid densities; 1.21, 1.22 and 1.23 g/cc that were used in 5 5/8 inch open hole section.

- ***Hookload during Running in Hole (RIH) Operation***

The measured HKLD from 4079 m (CSG shoe) to 4766 m (TD) measured depth during RIH operation is shown in Figure 7. The Hookload is decreased as the density of drilling fluid increases because the side force that is generated while RIH the drillstring is fall and the effect of buoyancy is clear as shown in Figure 8 and Figure 9.

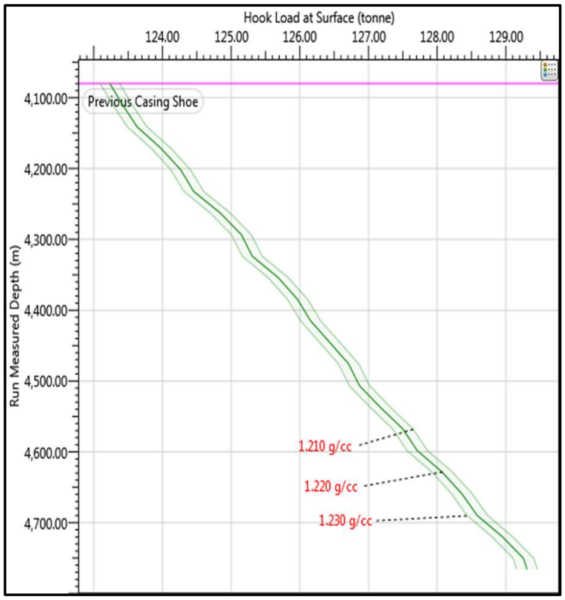

Figure 7: Hookload during RIH Drillstring in 5 5/8" Open Hole Section of BU-Well.

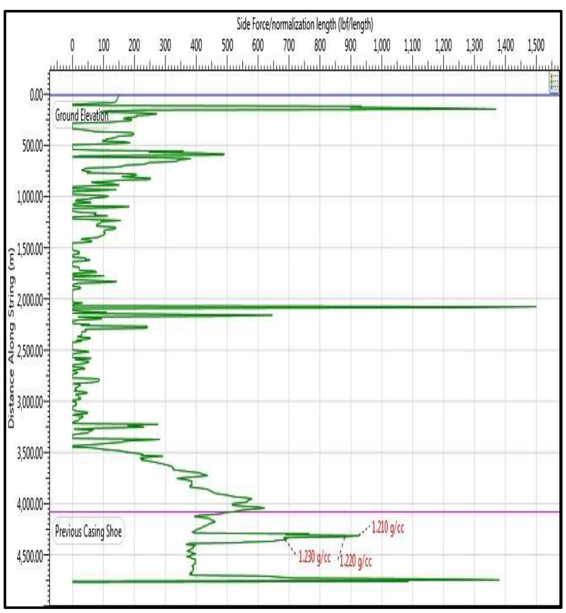

Figure 8: Side Force Generation during RIH Drillstring in 5 5/8" Open Hole Section of BU-Well

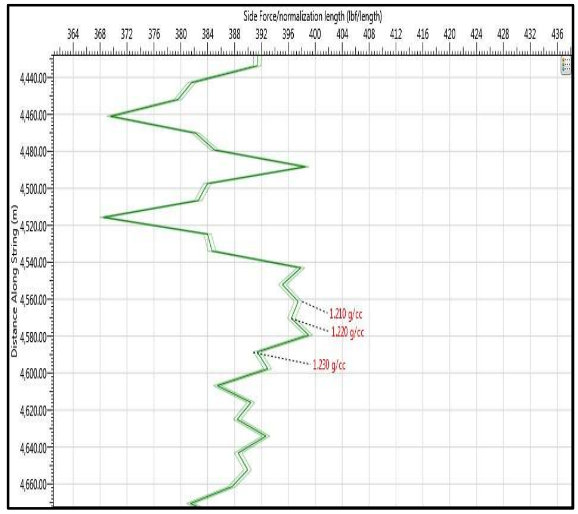

Figure 9: Zoom Graph of Side Force Generation during RIH Drillstring in 5 5/8" Open Hole Section of BU-Well

- ***Hookload during Pulling Out of Hole (POOH) Operation***

The measured HKLD from 4079 m (CSG shoe) to 4766 m (TD) measured depth during POOH operation is shown in Figure 10. The Hookload is decreased as the density of drilling fluid is increased because the side force that is created when POOH the drillstring is fall and buoyancy effect appears as shown in Figure 11 and Figure 12.

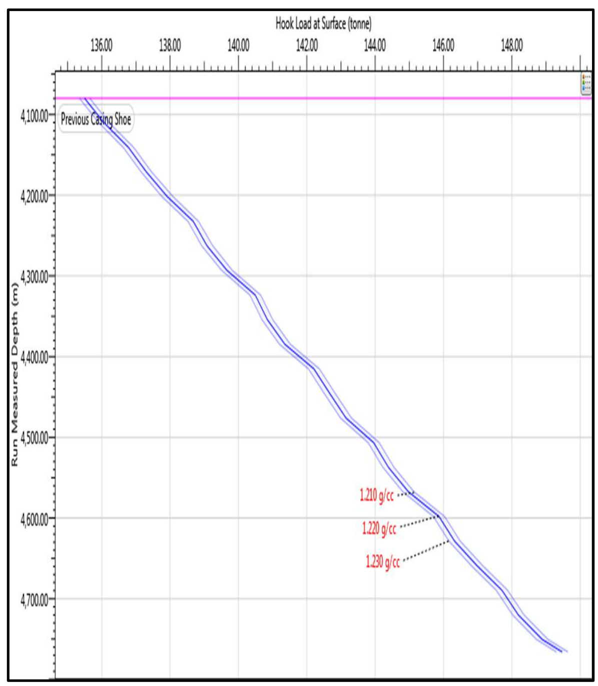

Figure 10: Hookload during POOH Drillstring in 5 5/8" Open Hole Section of BU-Well.

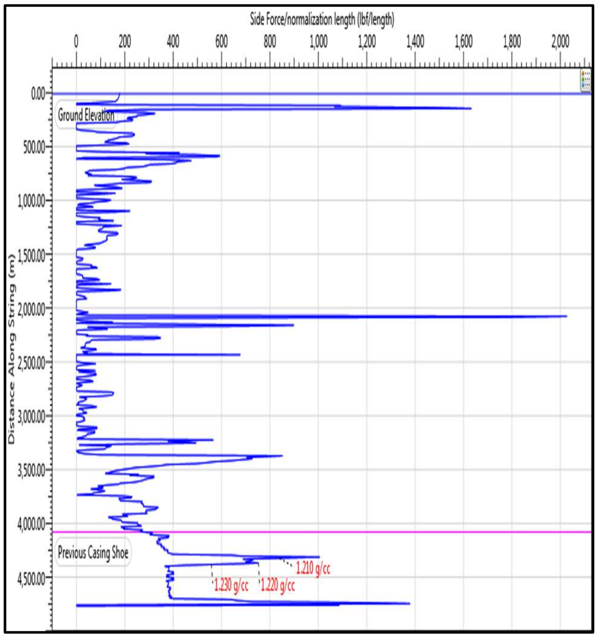

Figure 11: Side force Generation during POOH Drillstring in 5 5/8" Open Hole Section of BU-Well.

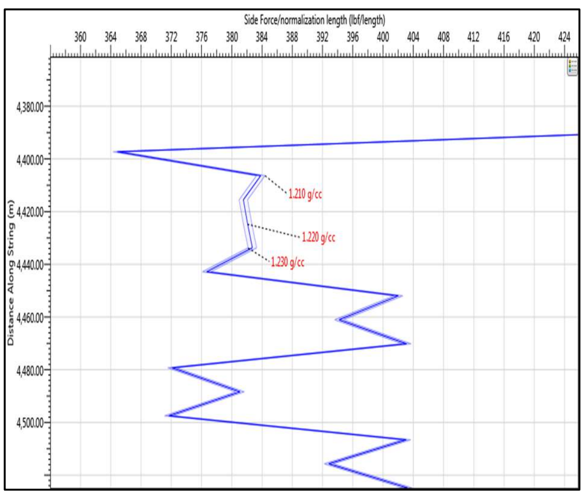

Figure 12: Zoom Graph of Side Force Generation during POOH Drillstring in 5 5/8" Open Hole Section of BU-Well.

Effect of Drilling Fluid Density on Torque

Torque is the moment required to rotate the entire drillstring and the bit on the bottom of the hole. The effect of fluid density on this parameter was applied depending on the actual drilling fluid densities 1.21, 1.22 and 1.23 g/cc that were used in 5 5/8 inch open hole section during three types of operations, which are Backreaming, Rotate Off Bottom and Rotate On Bottom.

- ***Torque during Backreaming Operation***

The torque during backreaming operation from 4079 m (CSG shoe) to 4766 m (TD) measured depth is shown in Figure 13. When the density of drilling fluid is increased the torque decreases because the side force that is created during backreaming 5 5/8 inch open hole section decreases and the buoyancy effect is clear as shown in Figure 14 and Figure 15.

Generally, the effect of drilling fluid density on torque is considered to be small in comparison with hookload.

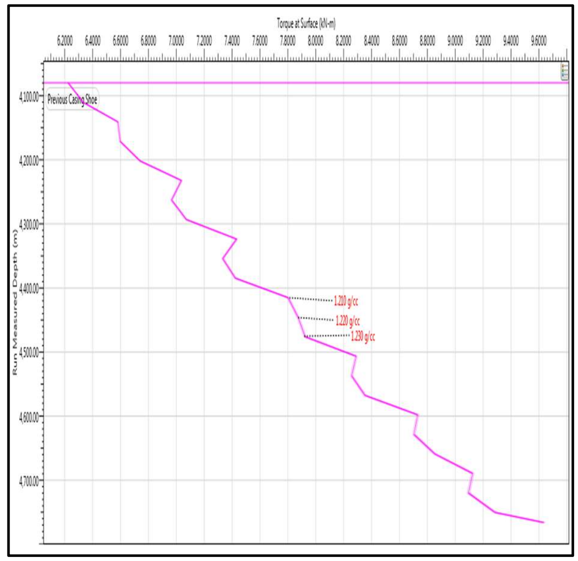

Figure 13: Torque during Backreaming Operation in 5 5/8" Open Hole Section of BU-Well.

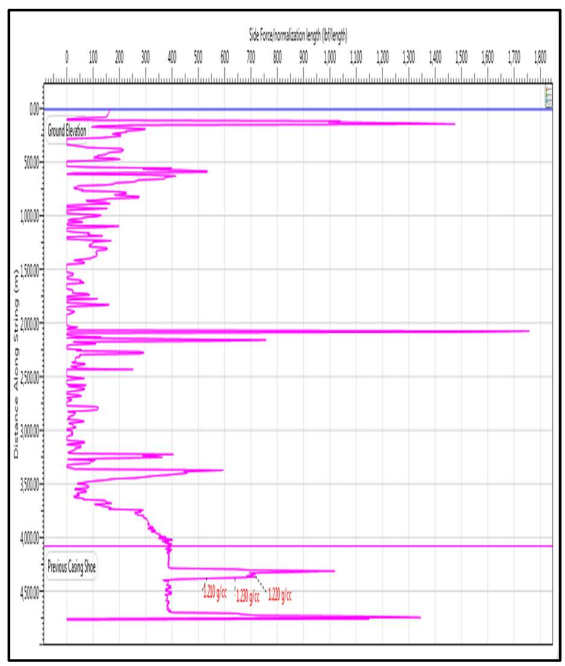

Figure 14: Side Force Generation during Backreaming Operation in 5 5/8" Open Hole Section of BU-Well.

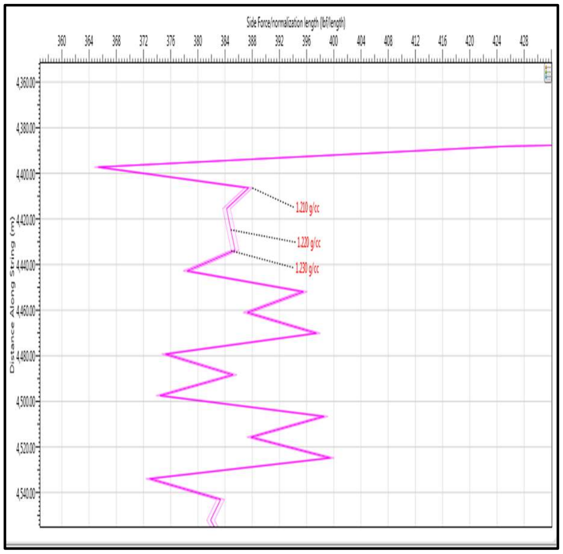

Figure 15: Zoom Graph of Side Force Generation during Backreaming Operation in 5 5/8" Open Hole Section of BU-Well.

- ***Torque during Rotating off Bottom (ROOFB) Operation***

During rotating off bottom operation, the torque from 4079 m (CSG shoe) to 4766m (TD) measured depth is shown in Figure 16. Torque decreases when the drilling fluid density increases due to the reduction in side force that is created during rotating off bottom in 5 5/8 inch open hole section and buoyancy effect appears as shown in Figure 17 and Figure 18. Drilling fluid density effect on torque is considered to be small in comparison with hookload.

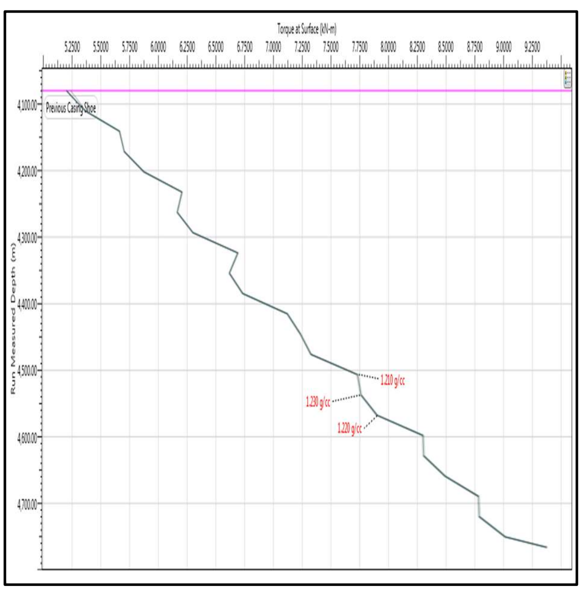

Figure 16: Torque during Rotate Off Bottom Operation in 5 5/8" Open Hole Section of BU-Well.

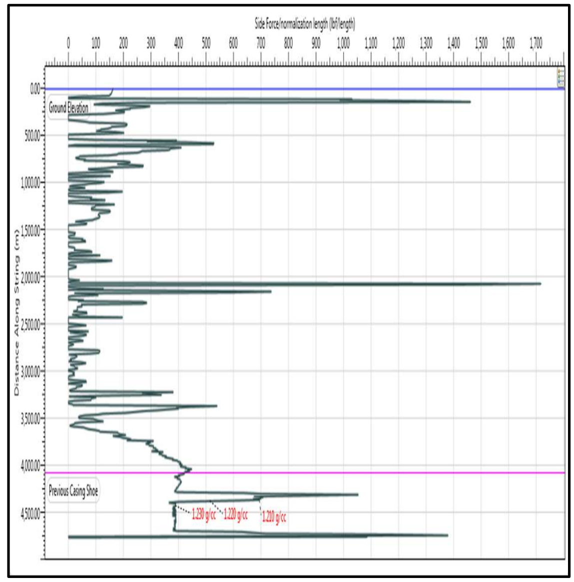

Figure 17: Side Force Generation during Rotate Off Bottom Operation in 5 5/8" Open Hole Section of BU-Well.

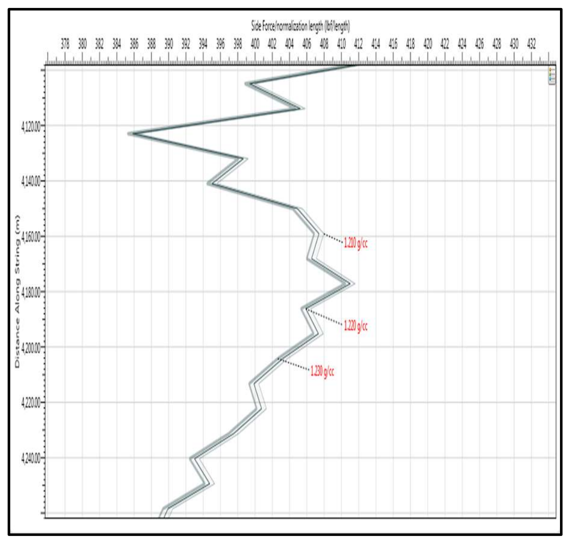

Figure 18: Zoom Graph of Side Force Generation during Rotate Off Bottom Operation in 5 5/8" Open Hole Section of BU-Well.

- ***Torque during Rotating On Bottom Operation***

During rotating on bottom (RONB) operation, the torque from 4079 m (CSG shoe) to 4766 m (TD) measured depth is shown in Figure 19. Torque decreases when the drilling fluid density increases due to the reduction in side force that is created during drillstring rotating on bottom operation in 5 5/8 inch hole section and buoyancy effect appears as shown in Figure 20 and Figure 21. Drilling fluid density effect on torque is considered to be small in comparison with hookload.

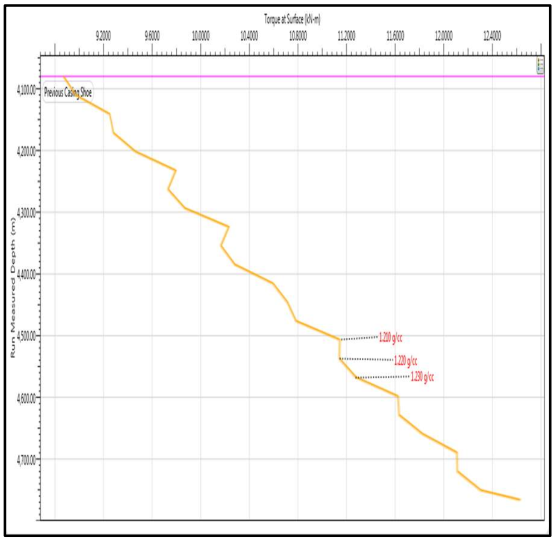

Figure 19: Torque during Rotate On Bottom Operation in 5 5/8" Open Hole Section of BU-Well.

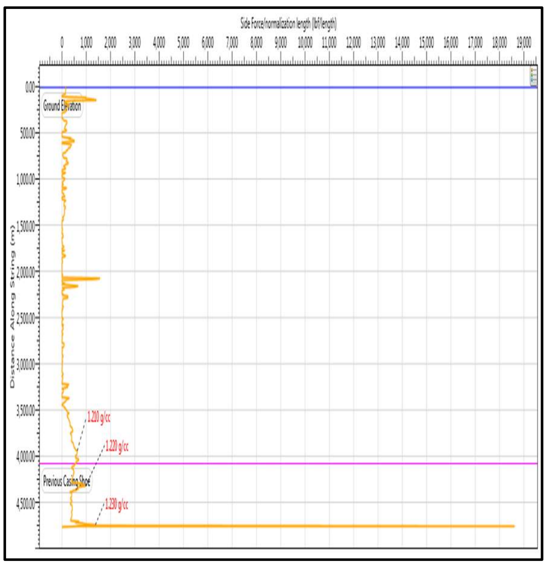

Figure 20: Side Force Generation during Rotate On Bottom in 5 5/8" Open Hole Section of BU-Well.

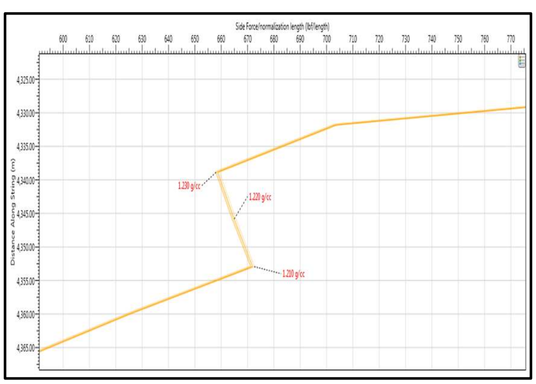

Figure 21: Zoom Graph of Side Force Generation during Rotate On Bottom in 5 5/8" Open Hole Section of BU-Well.

3.2 *Ga-Well*

Deviated (J-shape) GA-Well is the second selected well. It was drilled from surface to 2937 m. Casing of 18 5/8 inch OD was set at 5043 m and 17 1/2 inch open hole section is began from 504.3 m to 1725m MD as shown in Figure 22. The inclination of this well increase as measured depth increases and reached 43.6 degree at 1727.36 m MD. Also, this well has high value of dogleg severity; it reached maximum value of 4.569 degree/30m at depth 666.19 m MD.

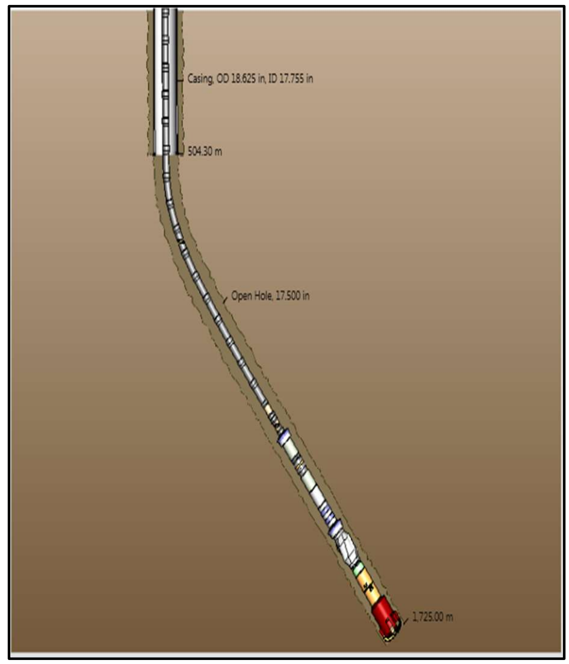

Figure 22: Ga-Well Schematic.

3.2.1 Minimum Weight on Bit

Minimum WOB to initiate sinusoidal or helical buckling is shown in Figure 23 for two operations (rotating and slide drilling). Extreme care should be developed during drilling 17 1/2 inch open hole section from 504 m (18 5/8" CSG shoe) to 1725 m (TD) in Ga-Well Deviated well to ensure that the WOB is kept less than the present values at the corresponding bit depth (Figure 23). Once the WOB exceeds the minimum WOB at the corresponding bit depths, the drillstring will start buckling according to the corresponding buckling mode (Sinusoidal or helical).

During rotating operation, the minimum WOB value of 17.88 tonne at 538.48 m measured depth may result in sinusoidal buckling (green line) and minimum WOB value of 19.25 tonne at the same measured depth to be helical buckling (red line) as shown in Figure 23. The difference between these two values of 1.37 tonne is considered to be large change from sinusoidal to helical buckling. Also, the smallest difference of 0.8 tonne is between minimum WOB sinusoidal buckling and helical buckling at 751.84 m measured depth. Therefore, the driller should be careful at this depth because of the small increase in WOB, the mode of buckling would transition from sinusoidal to helical.

During sliding operation, the minimum WOB of 17.4 tonne at 508 m measured depth may cause sinusoidal buckling (orange line) and the minimum WOB of 23.78 tonne at 538.48 m measured depth to be helical buckling (blue line) as shown in Figure 23. Also this figure illustrates that the smallest difference of 3.04 tonne is between minimum WOB sinusoidal buckling and helical buckling at 1117 m measured depth, therefore, care must be taken during sliding operation at these depths.

Generally, the minimum WOB values versus measured depth during rotating and sliding operations are continued to increase to 1230 m measured depth as shown in Figure 23. Approximately, the critical force causing tubular buckling is higher than that measured depth above 1230 m MD. Due to the drillstring lying on the wellbore wall of 17 1/2 inch open hole section with an inclination above 39°, higher forces enable to buckle the drillstring and higher frictional force between the drillstring and the borehole wall should be overcome.

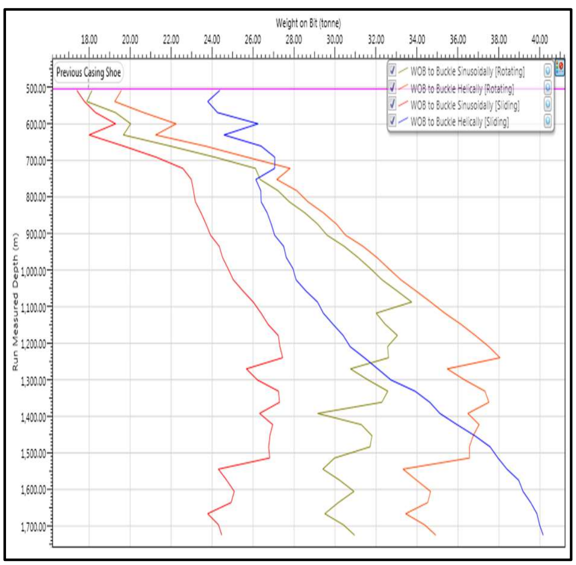

Figure 23: Minimum Weight on Bit during Two Operations (Rotating and Sliding) of Ga-Well.

3.2.2 Effect of Drilling Fluid Density

Effect of Drilling Fluid Density on Hookload

As mentioned previously, hookload (HKLD) is the total weight of the drillstring in air (at surface) that affected by buoyancy, friction and other factors in the wellbore. The effect of drilling fluid density on this HKLD during RIH and POOH was applied depending on the actual drilling fluid densities, 1.114, 1.126 and 1.138 g/cc that were used in 17 1/2 inch open hole section.

- ***Hookload during Running in Hole Operation***

The measured HKLD from 504 m (18 5/8" CSG Shoe) to 1725 m (TD) measured depth during RIH operation is shown in Figure 24. The hookload is decreased as the density of drilling fluid increased because the side force that is created when RIH the drillstring decreases and the effect of buoyancy is clear as shown in Figure 25 and Figure 26.

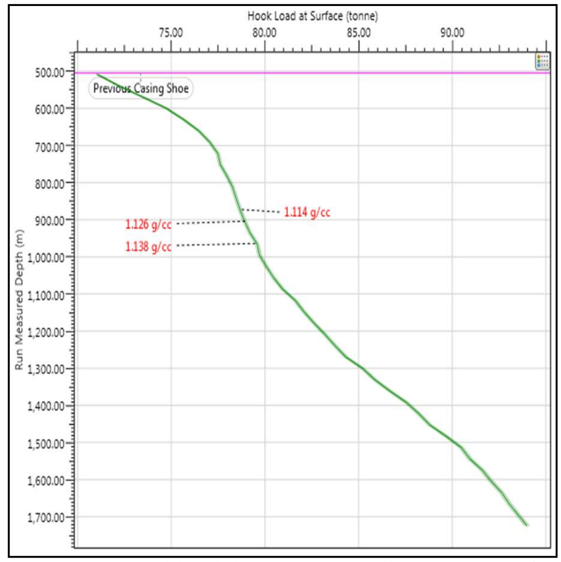

Figure 24: Hookload during RIH Drillstring in 17 1/2" Open Hole Section of Ga-Well.

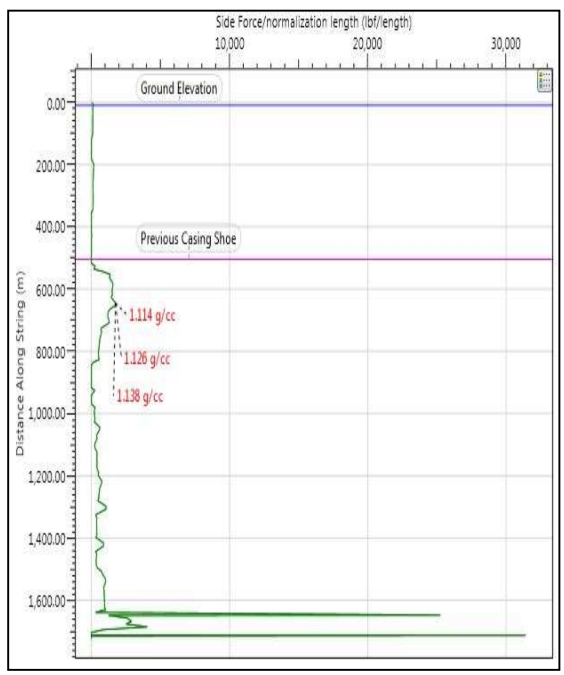

Figure 25: Side Force Generation during RIH Operation in 17 1/2" Open Hole Section of Ga-Well.

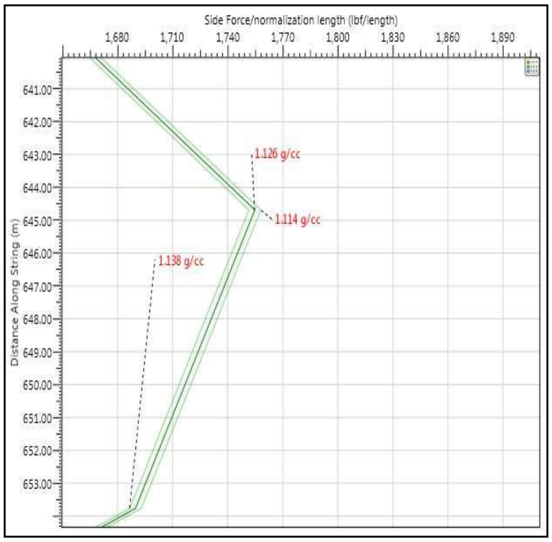

Figure 26: Zoom Graph of Side Force Generation during RIH Operation in 17 1/2" Open Hole Section of Ga-Well.

- ***Hookload during Pulling Out of Hole (POOH) Operation***

The measured HKLD from 504 m (18 5/8" CSG Shoe) to 1725 m (TD) measured depth during POOH operation is shown in Figure 27. The hookload is decreased as the density of drilling fluid is increased. Due to the side force that is created when POOH the drillstring decreases and the buoyancy effect appears as shown in Figure 28 and Figure 29.

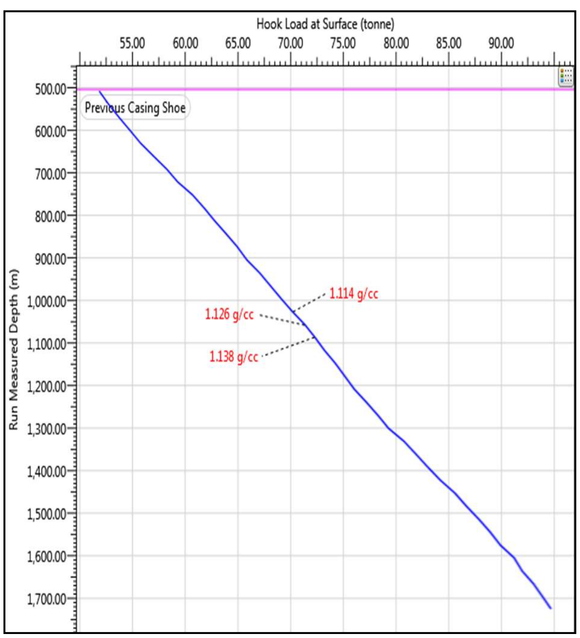

Figure 27: Hookload during POOH Operation in 17 1/2" Open Hole Section of Ga-Well.

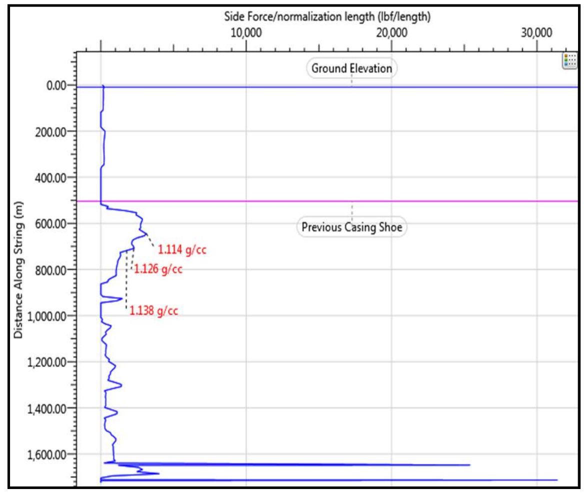

Figure 28: Side Force Generation during POOH Operation in 17 1/2" Open Hole Section of Ga-Well.

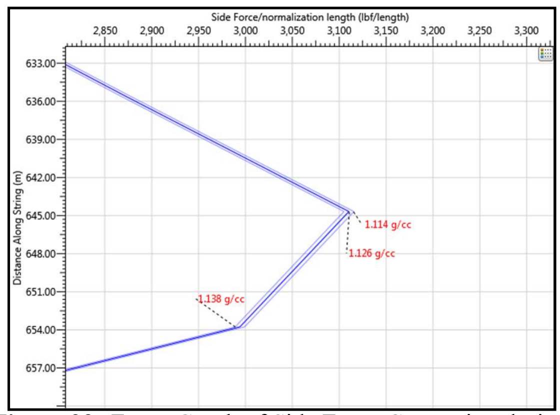

Figure 29: Zoom Graph of Side Force Generation during POOH Operation in 17 1/2" Open Hole Section of Ga-Well.

Effect of Drilling Fluid Density on Torque

The effect of drilling fluid density on torque was applied depending on the actual drilling fluid densities 1.114, 1.126 and 1.138 g/cc that were used in 17 1/2 inch open hole section during backreaming, rotate off bottom and rotate on bottom operations.

- ***Torque at Backreaming Operation***

The torque during backreaming operation from 504 m (18 5/8" CSG Shoe) to 1725 m (TD) measured depth is shown in Figure 30. When the density of drilling fluid is increased, the torque is decrease due the side force that created during backreaming in 17 1/2" open hole section is decreased and the buoyancy effect is clear as shown in Figure 31 and Figure 32. The effect of drilling fluid density on torque is considered to be small in comparison with hookload.

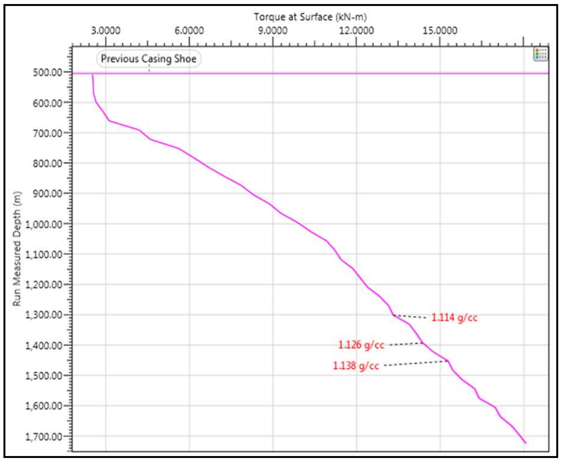

Figure 30: Torque during Backreaming Operation in 17 1/2" Open Hole Section of Ga-Well.

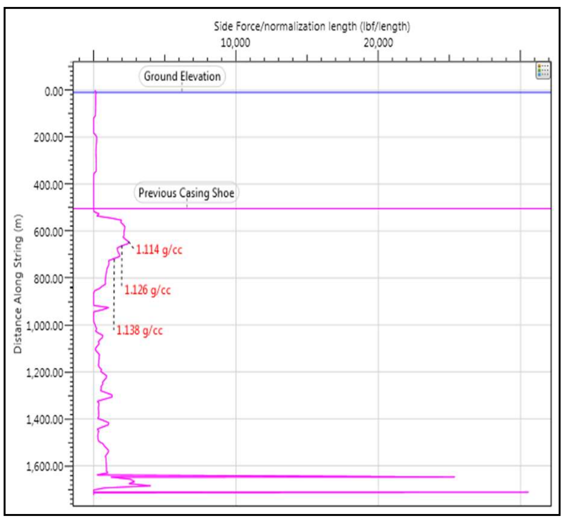

Figure 31: Side Force Generation during Backreaming Operation in 17 1/2" Open Hole Section of Ga-Well.

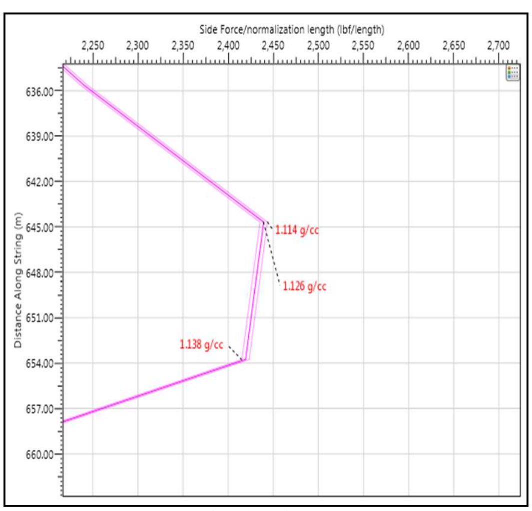

Figure 32: Zoom Graph of Side Force Generation during Backreaming Operation in17 1/2"Open Hole Section of Ga-Well.

- ***Torque during Rotating Off Bottom (ROOFB) Operation***

During rotating off bottom operation, the torque from 504 m (18 5/8" CSG Shoe) to 1725 m (TD) measured depth is shown in Figure 33. Torque is decreased when the drilling fluid density increases due to the reduction in side force that is created during rotating off bottom the in 17 1/2 inch hole section and buoyancy effect appears as shown in Figure 34 and Figure 35. Drilling fluid density effect on torque is considered to be small in comparison with hookload.

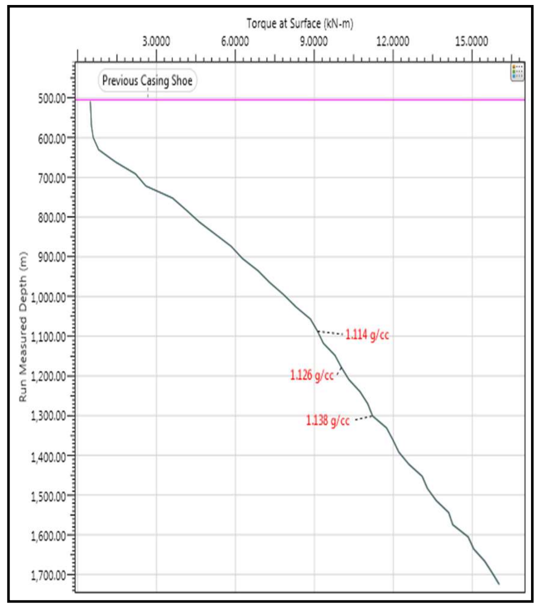

Figure 33: Torque during Rotate Off Bottom Operation in 17 1/2" Open Hole Section of Ga-Well.

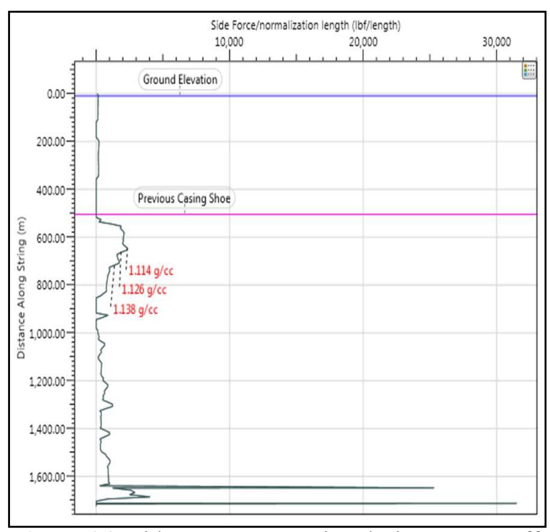

Figure 34: Side Force Generation during Rotate Off Bottom Operation in 17 1/2" Open Hole Section of Ga-Well.

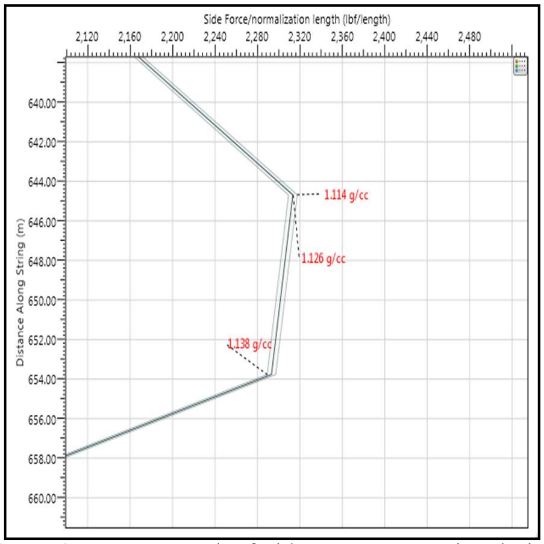

Figure 35: Zoom Graph of Side Force Generation during Rotate Off Bottom Operation in 17 1/2" Open Hole Section of Ga-Well.

- ***Torque during Rotating On Bottom (RONB) Operation***

During rotating on bottom operation, the torque from 504 m (CSG shoe) to 1725 m (TD) measured depth is shown in Figure 36. Torque is decreased when the drilling fluid density increased due to the reduction in side force that is created during rotating on bottom the in 17 1/2 inch open hole section and buoyancy effect appears as shown in Figure 37 and Figure 38. Drilling fluid density effect on torque is considered to be small in comparison with hookload.

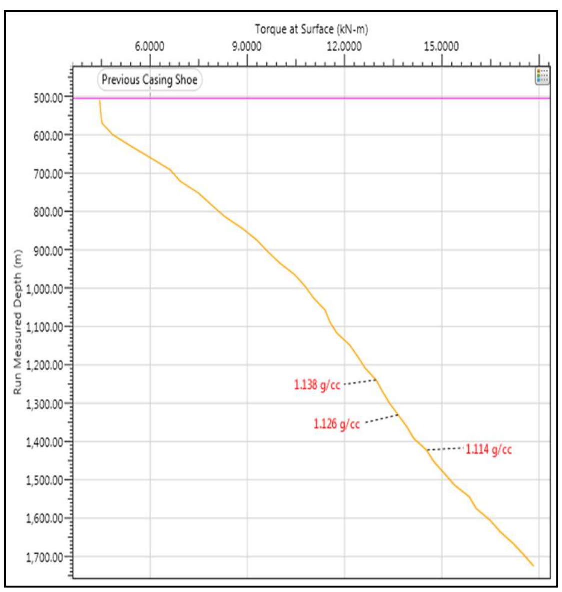

Figure 36: Torque during Rotate On Bottom Operation in 17 1/2" Open Hole Section of Ga-Well

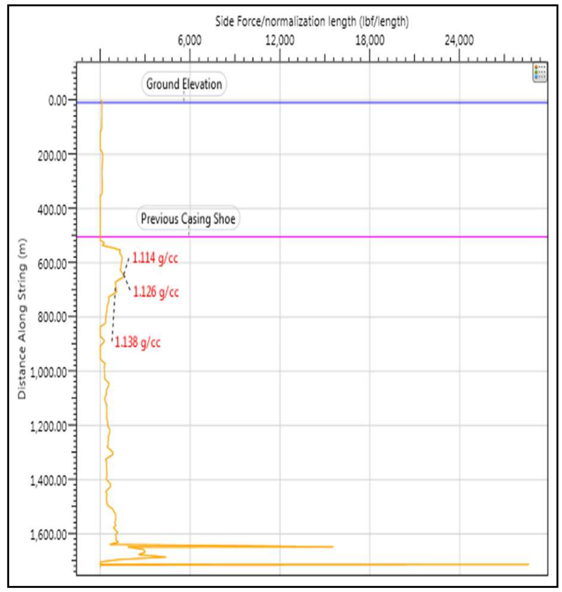

Figure 37: Side Force Generation during Rotate On Bottom Operation in 17 1/2" Open Hole Section of Ga-Well.

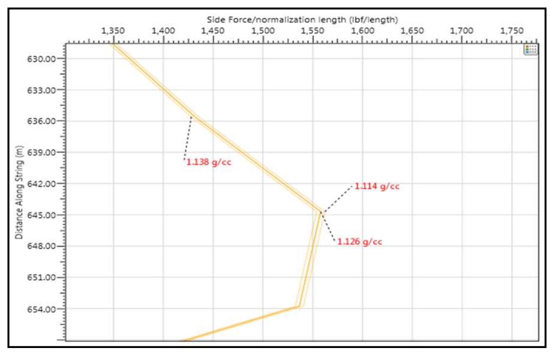

Figure 38: Zoom Graph of Side Force Generation during Rotate On Bottom Operation in 17 1/2" Open Hole Section of Ga-Well.

4. Conclusions

Depending on the results that obtained from this study, the following conclusions have been found:

1. Minimum WOB to initiate buckling was reduced at different drilling operations (sliding and rotating) while drilling operation progresses and both the diameter of the wellbore and drillstring decrease (depth of the well increase). While rotating operation, minimum WOB to cause sinusoidal buckling in 17 ½ and 5 5/8 inch hole diameter are 17.88 and 10.4 tonne respectively. In contrast, during sliding operation, the minimum WOB is less than rotating operation.

2. When the inclination angle was increased above 88° and 39° in BU-Well and Ga-Well respectively, drillstring buckling can be occurred with much higher WOB (compression force) requirement.

3. Significant difference in the values of the hookload was exhibited in BU-Well and Ga-Well whenever density of drilling fluid was varied, in contrast less effect on torque values was observed. The variations in drilling fluid densities were 1.21g/cc to 1.23 g/cc in Well-BU and 1.114g/cc to 1.138 g/cc in Well-Ga.

4. Not every reduction or rising in torque and hookload means there is a problem. Taking into account the modification or variation in drilling fluid density when a complete hole section was drilled due to the range of drilling fluid densities selection which relied on the formation pore pressure and other conditions. As well as drilling fluid properties are very important, especially the lubricating ability is the key factor for deep horizontal wells.

Acknowledgements

The authors wish to express their sincere gratitude to Landmark group in Iraq to get Landmark (WellPlan) software license and training on it at the premises of Halliburton Company. Special thanks to the staff of Missan Oil Company (MOC) and Thi-Qar Oil Company (TOC) for supporting and their effort in providing with regarding required information for this study.

Appendex A

A-1: Buckling in Vertical Sections [9,10].

Section	Buckling	
	Sinusoidal	**Helical**
Vertical	**Lubinski (1962)** $F_{sin} = 1.94(E\,I\,w^2)^{\frac{1}{2}}$ $I = \frac{\pi}{64}(OD^4 - ID^4)$ E = Young's modulus w = Weight per unit length	
	Wu et. al. (1992) $F_{sin} = 2.55(E\,I\,w^2)^{\frac{1}{2}}$	**Wu et. al. (1993)** $F_{hel} = 5.55(E\,I\,w^2)^{\frac{1}{2}}$

Table A-2: Buckling in Curved Sections [9,11] **.**

Section	Buckling	
	Sinusoidal	**Helical**
Curved	Mitchell (1999) $F_{sin} = \frac{2E\,I\,k}{r}\left[1 + \sqrt{\frac{w\sin\theta\,r}{E\,Ik^2}}\right]$ $k = \frac{1}{R}$ (build or drop) $r = \frac{1}{2}(ID_{well/casing} - OD_{tubing})$ r = Radial Clearance θ = Inclination	Mitchell (1999) $F_{hel} = 2.83F_{sin}$

Table A-3: Buckling in Inclined Sections [9,12].

Section	Sinusoidal Buckling
Inclined	Dawson and Paslay (1984) $F_{sin} = 2\left(\frac{E\,I\,w\sin\theta}{r}\right)^{0.5}$ r = Radial Clearance θ = Inclination
	Helical Buckling
	Chen et.al.(1989) $F_{hel} = 2\sqrt{2}\,(E\,I)^{0.5}(w\sin\theta)^{0.5}\left(\frac{1}{r}\right)^{0.5} \times \sqrt{2}\ F_{Dawsons\ Paslay\ Sinusoidal}$
	Wu and Juvkam-Wold (1993) $F_{hel} = 2(2\sqrt{2} - 1)(EI)^{0.5}(w)^{0.5}\left(\frac{\sin\theta}{r}\right)^{0.5}\ 2(2\sqrt{2} - 1) \times F_{Dawson\ Paslay\ sinusoidal}$
	Kyllingstad (1995) $F_{hel} = 2.90(EI)^{0.5}(w)^{0.5}\left(\frac{\sin\theta}{r}\right)^{0.5}\ 1.45 \times F_{Dawson\ Paslay\ sinusoidal}$
	Miska et al. (1996)

	$F_{hel} = 4\sqrt{2}(EI)^{0.5}(w)^{0.5}\left(\frac{\sin\theta}{r}\right)^{0.5} 2\sqrt{2} \times F_{\text{Dawson Paslay sinusoidal}}$
	Aasen and Aadnoy (2002) $F_{hel} = 3.75(EI)^{0.5}(w)^{0.5}\left(\frac{\sin\theta}{r}\right)^{0.5} 1.875 \times F_{\text{Dawson Paslay sinusoidal}}$

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Nomenclature

avg.Inc.	Average inclination angle (degree)
EI	The tubular bending stiffness (Ibs.in^2)
F	Critical buckling load in presence torque (Ibf)
F_c	Critical buckling load in absence torque (Ibf)
MW	Drilling fluid density (ppg)

Greek symbols

τ	torque

Subscripts

c	Critical

Abbreviations

BHA	Bottom Hole Assembly
BU	Buzurgan
CSG	Casing
DDR	Daily Drilling Report
FWR	Final Well Report
Ga	Garraf
HKLD	Hook load
MD	Measured Depth
MOC	Missan Oil Company
OD	Out Side
POOH	Pull Out Of Hole
RIH	Run In Hole
ROFFB	Rotating Off-Bottom
RONB	Rotating On Bottom
TD	Total depth
TOC	Thi-Qar Oil Company
TQ	Torque
WOB	Weight On Bit

التواء خيط الحفر و تاثير كثافة مائع الحفر على عزم الدوران والسحب في الابارالنفطية العراقية

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الخلاصة – تعتبر ظاهرة الالتواء في خيوط الحفر في آبار النفط والغاز من المشاكل الحرجة التي اصبحت موضع اهتمام في هندسة الحفر. يعد تجنب التواء خيط الحفر أمرًا مهمًا لأنه قد يؤثر سلبًا على عمليات الحفر. عندما تحدث ظاهرة الالتواء لخيط الحفر ، قد ينتج عن ذلك مشاكل في التحكم في الانحراف أثناء الحفر ، ونقل غير فعال للوزن إلى الحافرة ، وقيم مفرطة لعزم الدوران ، يقلل من عمر خيط الحفر بشكل كبير وحتى فشل في خيط الحفر بسبب الوهن.في هذا العمل ، تم استخدام برنامج WellPlan) Landmark) الخاص بشركة هاليبرتون على بئرين تم اختيارهما : (بئر-بزركان) بئر أفقي في حقل بزركان النفطي التابع لحقول نفط ميسان و (بئر-غراف) بئر اتجاهي في حقل الغراف النفطي التابع لحقول نفط ذي قار. تم استخدام ثلاث عمليات رئيسية في تطبيق نمذجة عزم الدوران والسحب: أولا, الاستفادة من بيانات الآبارالمجاورة. و في العملية الثانية تم تصحيح وزن الخطاف . اما العملية الثالثة تم فيها معايرة معامل الاحتكاك بواسطة بيانات ميدانية فعلية. تمت دراسة حساب الحد الأدنى للوزن المسلط على الحافرة لحدوث الالتواء وتأثير كثافة سائل الحفر أثناء عمليات الحفر المختلفة في مقاطع التجاويف المفتوحة 5 8/5 بوصة و 17 2/1 بوصة للبئرين الاستنتاجات الاكثر اهمية هي أن الحد الأدنى للوزن المسلط على الحافرة (WOB) لبدء الالتواء يقل في عمليات الحفر المختلفة (الانزلاقي والدوراني) أثناء تقدم عملية الحفر ونقصان قطر تجويف البئر وخيط الحفر (يزداد عمق البئر). أثناء عملية الحفر الدوراني ، الحد الأدنى من (WOB) للتسبب في التواء خيط الحفر بشكل جيبي بقطر 17 2/1 و 5 8/5 بوصة هو 17.88 و 10.4 طن على التوالي. في المقابل ، أثناء عملية الحفر الانزلاقي يكون الحد الأدنى لـ (WOB) أقل من عملية الحفر الدوراني. يحدث تغير ملحوظ في قيم وزن الخطاف في بئر-بزركان و بئر-غراف كلما تغيرت كثافة سائل الحفر ، في المقابل لوحظ تأثير أقل في قيم عزم الدوران. تتراوح الاختلافات في سوائل الحفر(من 1.21 جم / سم مكعب إلى 1.23 جم / سم مكعب) في بئر-بزركان و (1.114 جم / سم مكعب إلى 1.138 جم / سم مكعب) في بئر-غراف. لا يعني كل انخفاض أو ارتفاع في عزم الدوران و وزن الخطاف وجود مشكلة.

الكلمات الرئيسية – الحد الادنى للوزن على الحافرة ,وزن الخطاف,الالتواء,برنامج لاندمارك.