Torque and Drag Forces Problems in Highly Deviated Oil Well

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Abstract

Excessive torque and drag can be critical limitation during drilling highly deviated oil wells. Using the modeling is regarded as an invaluable process to assist in well planning and to predict and prevent drilling problems. Identify which problems lead to excessive torque and drag to prevent cost losses and equipment damage. Proper modeling data is highly important for knowing and prediction hole problems may occur due to torque and drag and select the best method to avoid these problems related to well bore and drill string. In this study, Torque and drag well plan program from landmark worldwide programming group (Halliburton Company) used to identify hole problems.one deviated well in Zubair oil fields named, ZB-250 selected for analyses the effect of friction factor on torque and effective `tension of the drill string along well depth, moreover the effect of well bore problems such as; mud losses, accumulation of cutting bed in the well bore, stuck pipe, caving, sloughing, high torque and drag values on drill string components and well trajectory. Wells data which include hole section size, mud properties, well profile survey, casing string depth, rig specification, drill string components, drilling parameters like weight on bit, rotary speed and flow rate were used to compare between planning and drilling stages for these wells and identify the reasons of difference between these stages. The results showed a difference for the drilling phase and increasable in effective tension, torque, pick up and slack off drag, measured string weight, and possibility to occur the buckling if compare with planning phase. Wellbore instability, high friction factor, high tortuosity, high flow rate ,stuck pipe , excessive drag spot, partial to total losses, increase of drilling parameters, hard formations and bad hole cleaning, all these factors yield to this difference between planning and actual phases. When drilling hole section 8.5", the main causes of varying were drilling fluid losses, high value of friction factor, stuck pipe and friction forces when the maximum torque was (16 to 20 klb-ft) and pick up weight (20-40 klb)

Keywords: Torque, Drag, Stuck pipe, Well bore instability

1- Introduction

Directional drilling represents a tool to reduce drilling operations costs of an oil field, due to two concerns; Improve formation production when drill high deviated wells; hence, it can produce from low permeability zones better than vertical drilling, and the cost of rig operations and mobilization will be minimized because drilling more than well in the same land or platform.

There are worldwide achievements of highly deviated drilling wells instead of vertical wells due to some challenge limitations. Facility of reciprocating and rotating drill string in directional wells and large well bores area are two of the major concerns .In spite of drilling high deviated wells have many benefits, but still have limitations along drill deviated sections. The difficulties must be controlled by engineering activities. For examples getting optimum drilling parameters become more difficult in deeper wells especially with complicated well profile. Two of these critical limitations called torque and drag that occur due to roughness between well bore in the cased or open hole and drill string [1].Torque and drag models have proven to be useful in all three stages of highly deviated wells: planning, drilling and post-analyses.

While planning stage the models are used to optimize the well trajectory design to minimize torque, drag and contact forces between drill string and wellbore, during drilling phase it uses for monitoring of hole condition.

Torque and drag models are especially useful in diagnosing hole cleaning problems, impending differential sticking, and severe dogleg in addition to determine the possibility of reciprocating and movement casing and drill string during operation, In post-analyses phase the models help to determine the root causes of hole problems that previously were unexplained or attributed to other factors like mud density, mud chemical or shale problems [2]. There are a number of causes for excessive torque and drag, like tight-spot condition, sloughing and swelling of shale, key seats, differential sticking, build-up of cutting caused by poor hole cleaning and well bore sliding friction. Conversely, in wells with good hole conditions, the primary source of torque and drag is sliding friction [3]. In highly deviated wells, solutions of torque and drag problems are essential to complete the drilling and completion operations because of many limitations are imposed by drilling rig, well path, drill string component, and drilling parameters, the engineering work have discovered methods to reduce torque and drag while drilling and tripping.

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Physical limitations effect how far a well can reach, especially in non-rotating operations such as slide drilling. If the compressive forces in the drill string are too high, pipe will buckle as a result from loss of weight transferred to the bit. If the rotary torque is too high, torsional failure will occur, or if the drag force is too high, the drilling string will become stuck or fail. Therefore, it is essential for engineering to accurate account for the torque and drag forces and attempt to reduce them in order to prevent these scenarios from occurring [4].

1.1. Problem Statement

The torque and drag are generated in the well bore during drilling. The miscalculated and misinterpreted of these parameters values will lead to time and money losses, because the special and expensive equipment and technology are involved in the drilling operations. The torque and drag magnitudes are required to be calculated for complete interval of the well bore as opposed to single depth torque magnitude, therefore these parameters are applying in the planned operations and updating the well bore trajectory in the next wells objectives.

1.2. The Objectives of Study

This analyses study has been performed to get the following objectives:
a. To be able to calculate and predict the frictional forces affecting the drill string and wellbore problems (Torque and drag) by using well plan program from landmark programming group for this purpose in order to planned to keep the torque and drag forces at a minimum and with allowable limit and control this values while drilling highly deviated wells.
b. To calculate the tension, pick up, slack off, minimum weight on bit and compression limits to prevent the buckling behavior belongs the drill string in order to get the opportunity before choosing the drill string components that consider these extra forces involved in the operations with high torque and drag values in deviated sections.
c. To analyses the influence of well bore problem and high values of the torque and drag on planned and actual well trajectory in order to get the lesson learned to consider this consideration in the next planned well profile, as a result the well path must be design to reduce frictional forces and hole problems like; stuck pipe, mud losses, tortuosity and well bore instability.

1.3. Significant and Contribution of Study

a. To assist drilling oil field an engineer to make quick calculations for the torque and drag analysis while drilling directional and horizontal wells.
b. To find the torque, drag, tension, compression, and buckling calculation during the well path design process that could prevent risks and problems before they happen.
c. To get an idea for the drilling an engineer about torque and drag at any interval depth of the well bore section.

1.4. Area of Case Study

Directional drilling performed in Iraqi oil field about 2013 especially in Zubair oil field. It is one of the largest oil fields in the world which located in the southern part of Iraq; it was discovered in 1949 and went on stream in 1951. Which located in 20 km southwest of Basra city, the extension of Zubair oil field is from south-west Safwan passing near Zubair city to al-hammar mishrif zone, the field is an anticline that runs roughly north-west to south-southeast approximately 60 km long and 10-15 km wide. This field consists of four domes from southeast into northeast as the following; Safwan, Rafidhyah Shuaiba, and Al-Hammar. Safwan Dome extends to Kuwaiti territory but it is in communication with the other domes of the Zubair Field through an aquifer.

The Zubair Field includes three production reservoirs that have been appraised and produced; upper Cretaceous Mishrif Limestone, lower Cretaceous Upper Sandstone (3rd Pay), and lower Cretaceous Lower Sandstone (4th Pay) [5].

1.5. Review of Previous Work

Torque and drag modeling has been originally started with Johancsick (1984) he assumed torque and drag to be caused by sliding friction forces that result from contact of wellbore with the drill string, and define this friction force to be a function of the normal contact force and the friction factor between contact surfaces based on Coulomb's friction model. He wrote the force balance for an element of the pipe concerning that the normal component of tensile force acting on the element contributing to the normal force, this force is a different in case for a straight section like in hold section [3].

The normal force is given by the following equation:

$$F_n = \sqrt{[(F_t \Delta\theta \ \sin\theta)^2 + (F_t \Delta\theta + W \sin\theta)^2]} \qquad (1)$$

Where:
F_n : Net normal force acting on element, Ibf [N]
F_t : Axial tension acting at lower end of element, Ibf [N]
$\Delta\theta$: Increase in inclination angle over length of element, degrees [rad]
θ : Inclination angle at lower end of drill string element, degrees [rad]
W : Buoyed weight of drill string element, Ibf [N]
$W_{buoy} = W_{air} - W_{fluid}$ lbf [N]

The above equation is then used to derive the tension increment tension which is used for drag calculations:

$$\Delta F_t = W \cos\theta \pm \ \mu \, F_t \qquad (2)$$

ΔF_t : Increase in tension over length of element $Ibf \ [N]$
W : Buoyed weight of drill string element, $Ibf \ [N]$
μ : Sliding friction coefficient between drill string and well bore

The plus and minus sign depends on pipe movement direction whether tripping in or pulling out of hole.
And for the torsion increment which is used for torque calculations:

$$\Delta M = \mu \, F_n \, r \tag{3}$$

ΔM : Increase in torsion over length of element $\text{ft} - \text{lbf} \, [\text{N. m}]$
r = Characteristic radius of drill string element, ft [m]

Aston (1998) addressed techniques to minimize torque and drag in the wellbore by mechanical and chemical methods. Mechanical methods are like using special equipment or tubular in the wellbore to reduce torque and drag and chemicals methods are those which use lubricants [6].

Opeyemi et al. (1998) perform well planning and drill string design by using a torque and drag analysis with considering all constrains might be encountered while planning stage such as, surface location and target coordinates, geometric specification, casing program, geological obstacles. It also suggests that the torque and drag model which is used for planning and modeling processes must be updated with the dynamics of the field operation by performing drilling, tripping and frictional sensitivity analyses. This will ensure more precise and clearer understanding of drill string and well bore interactions from surface to total depth [7].

Rae et al.(2005) used torque and drag simulator to firstly plan a drilling well and then use it to calculate surface torque and hook load with the model has been used for planning after that comparing the values with surface hook load and torque field data. If they match this means that the well is drilling as it planned otherwise either a problem in the modeling or this is a warning sign of a problem in the well bore [8].

Schamp et al. (2006) suggested some industrial methods to reduced torque in the well bore while drilling. He explained two sources of torque in the wellbore: the frictional resistance between the drill string and casing or open hole and the bit/stabilizer torque and proposed some methods to mitigate the frictional resistance which containing enhancing drilling mud properties, using lubricants, adequate hole cleaning, promoting surface roughness and reducing side loads as much as possible by reducing the number of unnecessary dogleg or using rotary steerable system(RSS) which gives a smother well path, applying a catenary well path if possible [9].

Mason et al. (2007) pointed out different major effects that should be considered in the soft string model. One of these factors is the drag force as a result of pipe movement in opposite direction of the drilling fluid flow. Another effect is tortuosity. Although the planned well is a smooth path, the crooked profile will be resulted in reality. For this reason the model has to take this factor into account.

A crooked well profile shows higher torque and drag values. The buckling of the tubular should also be taken as a major factor in order to have a sense of excessive drag limit which may put the string in compression. Aadnoy (2008) generalized the equations for different sections of the well bore and the status of the pipe either moving up or down to be applied simpler [10].

Mirhaj et. al. (2010) has analyzed a field case study that back-calculated the friction factor during drilling from field hook load and the result showed a friction factor of 0.05 for drilling interval while it was 0.2 for lowering and hoisting in that well. In this field, study also is in agreement with the angle and previous case study and a friction coefficient of 0.01 is needed to give a good match of the field and models data. The model used in this study by well plan program is soft-string model, in other words the drill string is assumed to be like a cable and forces due to bending moments have not been considered to affect the normal forces and thus friction. This is fairly good assumption as it may contribute small normal forces on the overall force balance [2].

2- Research Methodology

Well Plan program can define as drilling operation, completion activities, and production service operations engineering programing. Its might be used at the office engineering work and well site activity to provide a tool for solving problems between engineering functions and oil field operations. It is based on a database and data structure common to many of Landmark's drilling applications.

This database is called the Engineer's Drilling Data Model (EDM) and supports the different levels of data that required using the drilling software. The significant advantage while using the software because of improved integration between drilling software products,currently, well Plan, compass, stress check, casing seat, well cat, and casing wear software use the common data base and data structure. The competitive environment companies are facing increasing numbers of technician difficulties such as; Deep wells drilling, extended-drilling wells, thin-hole drilling, underbalanced drilling operations, and environmentally effect of drilling zones [11].

The results from using well plan that offers more efficient analysis using only necessary inputs, saving time, and minimizing analysis steps. Well Plan is integrated with the other engineering data training (EDT) applications enabling you to install it on the same computer or server in multi-user environments, and share data with other EDT software applications.

The Torque and Drag options represent one from well plan application can be used to calculate and predict effective tension weights, buckling limit, allowable pick up and slack off forces, minimum WOB can exerted without get buckling, over pull margin, drill string analyses, and torque that can be phases while the operating conditions[12]; Running in the hole, Pulling out of the hole, Rotating on bottom, Rotating off bottom

while pulling out of the hole, Slide drilling without rotary table rotation , and   Back reaming after drilling.

The Construction of well plan model which includes the input data as follows:

1- Datum information for a land well: as shown in Fig. 1 the datum information for well ZB-250.

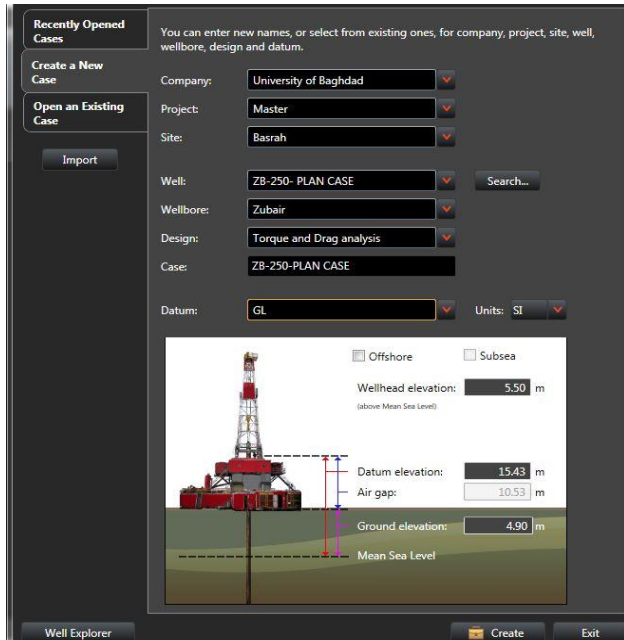
Fig. 1. Datum information for well ZB-250

2- Fluids editor type: data entry that is used to define drilling fluid properties such as; mud based type, rheology model, density, viscosity, and yield point, as shown in Fig. 2.
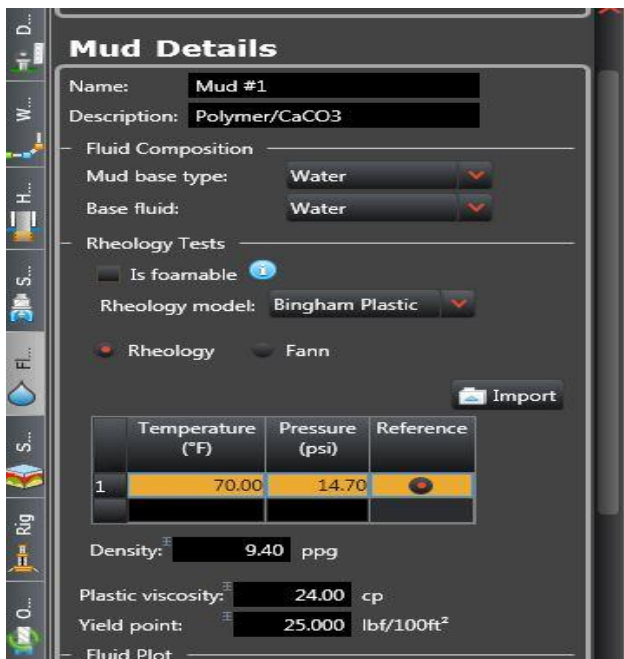

Fig. 2. Mud properties for well ZB-250

3- Rig information: The Rig tab is used to define mechanical limits information, including rig hoisting capacity and rotary torque rating. Furthermore, circulating system information including rated working pressure for surface equipment, blow out preventer (BOP), pressure rating, surface pressure loss, mud Pit, and mud pumps specification, as shown in Fig. 3.
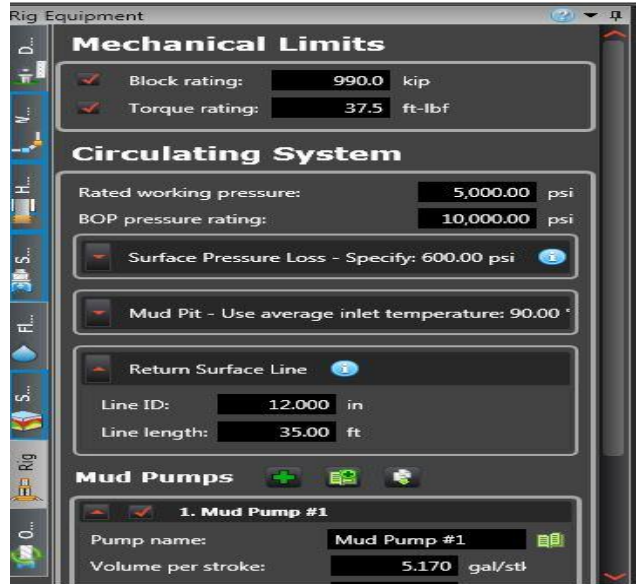

Fig. 3. Rig capacity for well ZB-250

4- Hole section editor: Hole section editor tab to input the riser, casings and liner, open hole sections, friction factors for cased and open hole sections, as shown in Fig. 4.
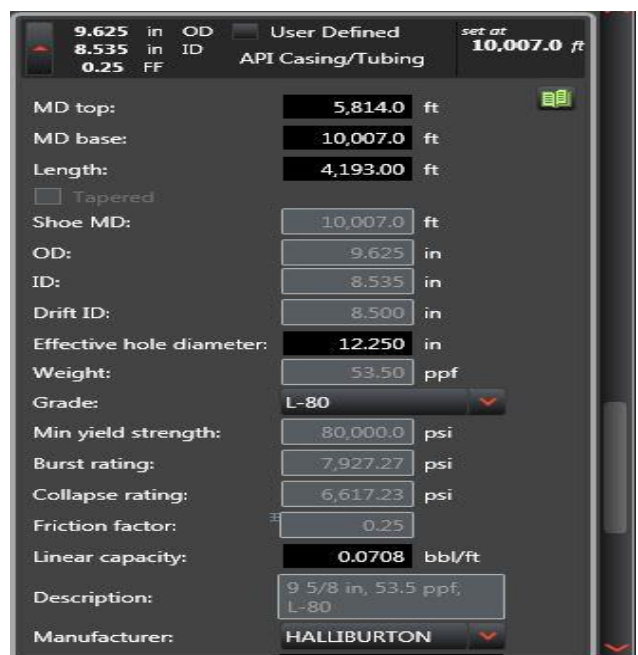

Fig. 4. Casing information for well ZB-250

5- Operation editor: The Operations tab is used to define the operations that appear on various outputs with the parameters needed to generate that output. As shown in Fig. 5, output normal analysis - select the analysis type and enter the parameters to be used in the analysis. The options available are tripping in, tripping out, and rotating on Bottom, slide drilling, back reaming, and rotating off bottom.
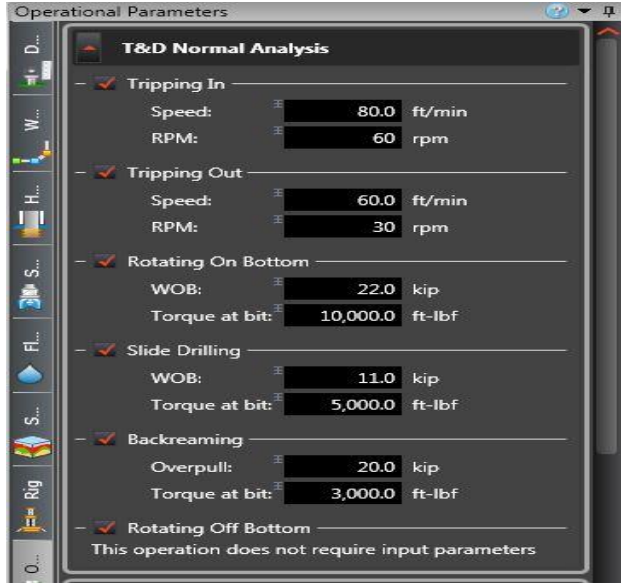
6- Drill string components: The String tab accesses the String Editor that is used to define the drill string component details such as, length, size, weight, make-up torque, minimum yield strength , over pull margin, and depth of BHA, furthermore the length, size, weight, grade , make-up torque, minimum yield strength, and depth of drill pipe, additionally; this details are defined on this panel, as shown in Fig. 6. and the Table 1

Fig. 5. Operation parameters for ZB-250

Fig. 6. Drill string components for ZB-250

Table 1. Drill string components configuration for well ZB-250 [13]

Field Name	ENI_Zubair		Borehole Name	ZB-250(SAF-HOR) PILOT HOLE		Hole Size (in)	8.500
Structure Name	ZB-250(SAF-HOR)Well		BHA Name	8.5in Rotary BHA With MWD -130214		Depth In (m)	3051.00
Well Name	ZB-250(SAF-HOR)Well					Depth Out (m)	3216.00

	Desc.	Manu.	OD (in) / ID (in)	Max OD (in)	Bot Size (in) / Top Size (in)	Bot Type / Top Type	Bot Gender / Top Gender	Length (m)	Cum. Length (m)	Cum. Weight (t)
1	8 1/2 " PDC Bit	Smith International	5.750 / 2.250	8.500	4.500	Regular	Pin	0.25	0.25	0.0
2	8.25NB Stabilizer		6.750 / 2.500	8.250	4.500 / 4.500	REG / NC50 (4 1/2 IF)	Box / Box	1.52	1.77	0.3
3	Float Sub		6.500 / 2.813	6.500	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	1.52	3.30	0.5
4	NMDC		6.750 / 2.250	6.750	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	9.14	12.44	2.0
5	TeleScope 675 NF	Schlumberger	6.750 / 5.109	6.890	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	7.53	19.97	2.9
6	NMDC		6.750 / 2.250	6.750	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	9.14	29.11	4.4
7	8.5 Stabilizer		6.750 / 2.813	8.250	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF	Pin / Box	1.52	30.64	4.6
8	6.5" Collar		6.500 / 2.810	6.500	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	9.14	39.78	6.0
9	Heavy Weight Drill Pipe (2 joints)		5.000 / 3.000	6.500	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	19.70	59.48	7.4
10	Jar	Smith	6.500 / 2.810	6.500	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	6.86	66.34	8.5
11	Heavy Weight Drill Pipe (13 joints)		5.000 / 3.000	6.500	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	130.00	196.34	18.2
12	5" DP (302 joints)		5.000 / 4.000	6.625	4.500 / 4.500	NC50 (4 1/2 IF) / NC50 (4 1/2 IF)	Pin / Box	3020.00	3216.34	145.5

7- Well path: Vertical section, survey data imports and tortuosity are defined on the Well path tab. It can be entered well path data points directly, measured depth values (MD), inclination (Inc), and azimuth (Az) must be entered for each depth, as shown in Fig. 7.

Other common well path information is calculated automatically, it can be viewed using the Well Path table, as shown in the Table 2.

Fig. 7. Well path information for ZB-250

Table 2. Well path details for well ZB-250

MD	Inc	Azi	TVD	DLS	AbsTort	RelTort	VSect	North	East	Build	Walk
(ft)	(°)	(°)	(ft)	(°/100ft)	(°/100ft)	(°/100ft)	(ft)	(ft)	(ft)	(°/100ft)	(°/100ft)
0	0	0	0	0	0	0	0	0	0	0	0
98.4	0.08	172.73	98.4	0.08	0.08	0	-0.1	-0.1	0	0.08	0
196.9	0.07	194.7	196.9	0.03	0.06	0	-0.2	-0.2	0	-0.01	22.32
295.3	0.04	136.88	295.3	0.06	0.06	0	-0.3	-0.3	0	-0.03	-58.75
393.7	0.1	143.54	393.7	0.06	0.06	0	-0.4	-0.4	0.1	0.06	6.77
492.1	0.11	181.16	492.1	0.07	0.06	0	-0.5	-0.5	0.1	0.01	38.22
590.6	0.02	239.22	590.6	0.1	0.07	0	-0.6	-0.6	0.1	-0.09	58.99
689	0.12	103.58	689	0.14	0.08	0	-0.7	-0.7	00II.2	0.1	-137.81
787.4	0.19	80.77	787.4	0.09	0.08	0	-0.7	-0.7	0.5	0.07	-23.17
885.8	0.21	68.3	885.8	0.05	0.08	0	-0.6	-0.6	0.8	0.02	-12.67
984.3	0.28	64.19	984.2	0.07	0.08	0	-0.4	-0.4	1.2	0.07	-4.18
1,082.70	0.19	84.39	1,082.70	0.12	0.08	0	-0.3	-0.3	1.6	-0.09	20.52
1,181.10	0.14	77.85	1,181.10	0.05	0.08	0	-0.2	-0.2	1.8	-0.05	-6.64
1,279.50	0.19	78.3	1,279.50	0.05	0.08	0	-0.2	-0.2	2.1	0.05	0.46

8- Analyses setting [11]: Analysis Settings tab can be used to configure the analysis parameters settings pertaining to the outputs, only the analysis settings or options required for the selected outputs are displayed on this tab. If the parameters are not required for the displayed plot, the section will not be visible. The settings are divided into many groups,

Common analysis options are not specific to one type of analysis (torque and drag, Hydraulics), for example, the Pump rate specified will be used for any torque and drag or Hydraulics, other analyses options available are torque and drag, it can be used torque and drag parameters to specify analysis options outputs currently have in the output area. Two of the common setting are necessary especially in torque and drag analyses setting, as shown in Fig. 8, operational pump rate and run parameters.

These options allow specifying the depth of the bottom of the string at numerous intervals along the wellbore for the purpose of analysis.

These depths are used to generate output for four torque and drag plots like; effective tension and compression with buckling limit, torque plot along well depth, drill string analyses (include minimum WOB, allowable pick up and slack off weight, and over pull margin), and well path with tortuosity.
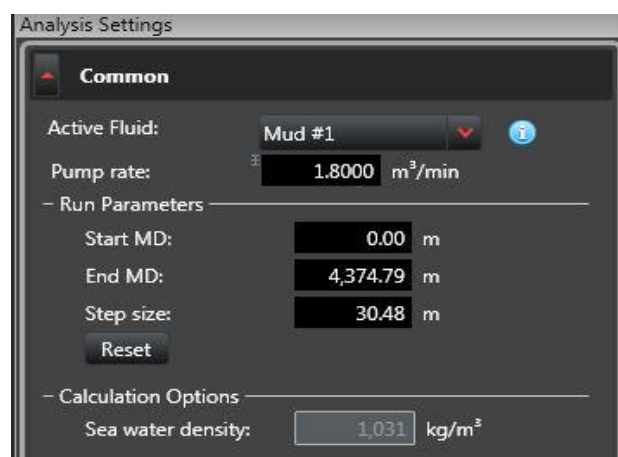

Fig. 8. Analyses setting parameters for well ZB-250

9- Output data: A listing of outputs for Torque and Drag analysis, use torque & drag tab to access plots and tables for torque and drag analysis. These plots can show and calculate the possibility of drilling the well, in addition to indicate what the challenges while drilling the well will occur. Drill strings, casing strings, and liners can be analyzed, as shown in Fig. 9 that shows all torque and drag output plots available can be determine by well plan program.

Fig. 9. All torque and drag output available in well plan software [11]

Appendix- A which gives the summary configuration for the well plan entering data steps and the output which used in this study, as called well plan flow chart.

3- Results And Discussion

In order to analyses the results that resulted from well plan model and study the effect of the friction factor, well path, drill string component on well bore problems, three wells data are examined, namely, ZB-250, This deviated oil well were drilled in Zubair oil field with different hole problems during drilling operations such as; accumulation of cutting bed, pipe sticking, mud losses, tortuosity and well bore instability, then discuss the effect of these problems on drill string tension and compression, torque and drag behavior, well path with tortuosity, and drill string behavior.

All the input data for well ZB-250 in this study, such as; well path survey, BHA details, hole sections, casing string setting depth, drilling fluid properties, and drilling parameters for well planning stage were got from drilling and geological program that prepared by the operator company Zubair field operation division (zfod) and service companies like Halliburton and Schlumberger. Furthermore the wells data for drilling phase, were got from final well report that prepared by zubair field operation division (zfod) after complete drilling operations for this well.

In this chapter a discussion of the output plots such as; effective tension and compression with buckling limit, torque value with different friction factor, the well path inclination with tortuosity and drilling time curve, drill string analyses include minimum WOB to prevent buckling, allowable pick up and slack off weight, and over pull margin for three wells that result from torque and drag model to be calculated and then performed study and analyses the hole problem effect on these parameters in planning and drilling phases.

3.1. Well ZB-250

The well ZB-250 is planned as a horizontal well, it is a part of development plan in Zubair oil field, its objective to develop and produce oil from upper cretaceous Zubair sandstone reservoirs (3rd Pay). The spud date for this well was performed on 10th November 2013, and the date which complete the drilling activity and reached to total depth (TD) was implemented on 18th February 2014 [14].

The first hole section 23" was drilled with only one bit Smith type and spud mud through the following formations, dibdibba , lower Fars, ghar and 4m inside Dammam Formation and the depth for this section was 509 m. The second hole section 17.5" was drilled to 1776 m through the following formation, dammam, rus, umm-er-radhuma, tayarat, shiranish, hartha and 4m inside saadi Formation. The third hole section 12 1/4" was drilled with one bit with Kcl/Polymer Mud through the following formations, Saadi, Tanuma, Khasib, Mishrif, Rumaila, Ahmadi, Mauddud, Nahr Umr to depth 3060m [14].

The objective for this well is the drilling 8 1/2" hole section with salt-polymer mud through nahr umr, shuaiba, upper Shale formations and performed blind drilling (without mud returns) vuggy limestone shuaiba formation through potential loss zone of formation with directional bottom hole assembly (BHA),because in case of total losses the exposure of the stuck pipe will minimize when used directional BHA, and effectively cure losses by pumping losses cure material (LCM) through the bit. The hole section8 1/2" drilled from 3060m to 3228m, while drilling this section observation of mud losses varied to (2 m^3/ hr to total losses) and observed high torque value (15 klb-ft), furthermore high over pull (35 ton) while trying to pull out the drill string back to the casing shoe and pump losses cure material(LCM) to cure the losses [14].

At depth 3110m observed drill string stuck, high torque, hard reaming, the total losses, and rotation stopped while try to pick up the string immediately to casing shoe to pumping LCM, then try to make drill string free by jarring and (25 ton over pull) and slack off 10 tons, combine with rotate at 50 rpm, string went up gradually and get free at 3104 m. Finally, due to the total loss problem from 3108m to 3228m and tried to cure it with pumping LCM , different types of cement plugs and ran Rotary Slick BHA, no success to cure losses zone, decided to set cement plug to temporary abandon for this well, as shown in Fig. 10 well ZB-250 profile [14].

The following Figures (10 to 22) show the following output data (effective tension and torque value with different friction factor, well path inclination with tortuosity and drill string analyses include minimum WOB to prevent buckling, allowable pick up and slack off, over pull margin and drilling time curve) for planning and drilling phases for well ZB-250.
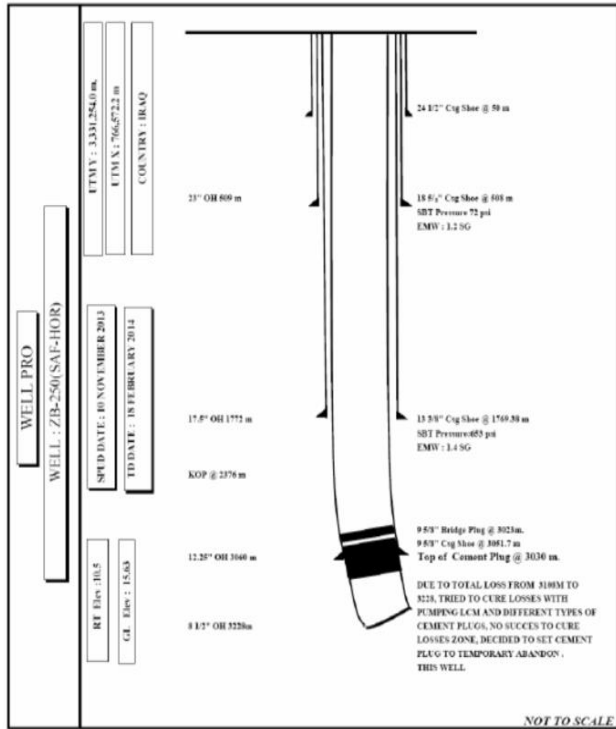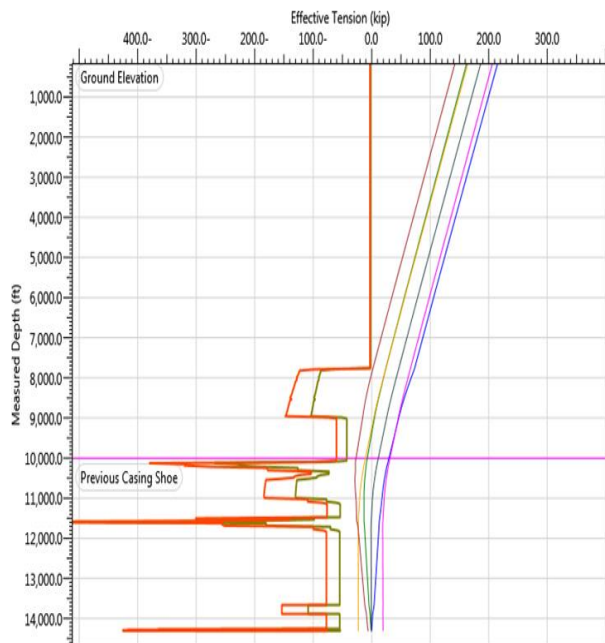

Fig. 10. well ZB-250 profile [14]

Fig. 11. Effective tension with MD, well ZB-250, FF CH/OH 0.25/0.3-planning
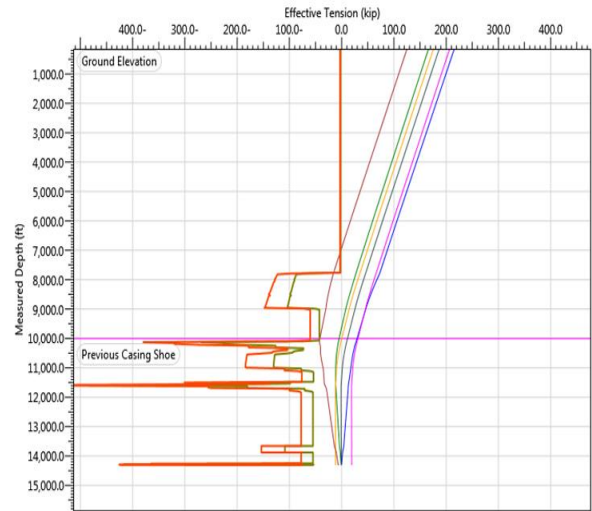
Fig. 12. Effective tension with MD, well ZB-250, FF CH/OH 0.25/0.4,- planning
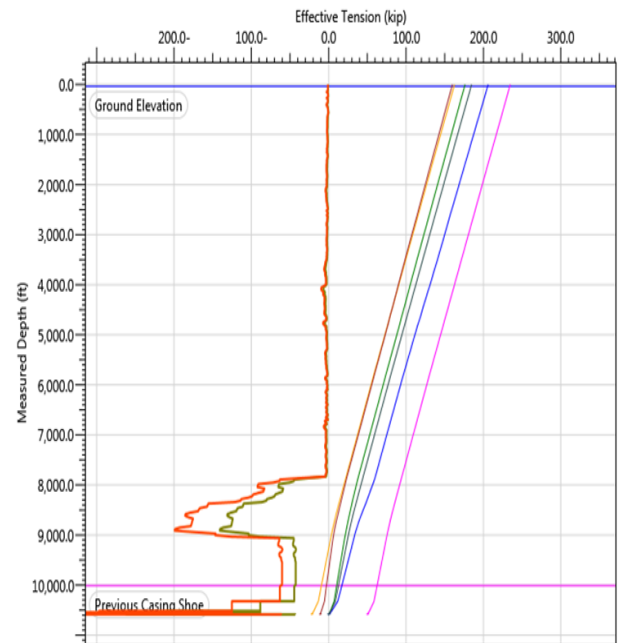
Fig. 13. Effective tension with MD, well ZB-250, FF CH/OH 0.3/0.35- drilling

The Figs.(11 to 13) show the effective tension and compression in the drill string for the operations conditions available in the well plan program (tripping in, tripping out, rotating on bottom, slide drilling, back reaming, and rotating off bottom) with measured depth from surface to drill string depth.

Furthermore these figures indicating the loads required to helically or sinusoidally buckle the drill string.

If an operation curve crosses a buckling load curve, the string will begin to buckle in the buckling mode corresponding to the buckling load line.

These plots show that the tripping out and back reaming conditions effective tension is greater than the other operation conditions because of the direction of the drill string movement for them against the gravity forces, as a

result will get additional tension force added to drill string weight if compare with tripping in condition for same drill string components.

The effective tension increase when friction factor (FF) increase and found the negative effect for this increasable on slide drilling condition and buckling behavior (sinusoidal and helical) from depth (7000 to 10000 ft) will occur when used friction factor 0.4 for open hole, as shown in Fig. 12 for planning phase, so it is not recommended to use this value of the friction factor to prevent drill string buckling.

The effective tension for drilling phase, as shown in Fig. 13 when FF 0.35 for open hole (back reaming operating mode) is greater than the planning phase when FF 0.4 because of stuck pipe behavior, hard back reaming and high over pull observed while try to pulling out the drill string inside 9 5/8" casing shoe.

The compression of the drill string can be found in previous figures as a negative values during tripping in, rotating on bottom, and slide drilling due to axial load exerted on the drill string in these conditions, further more can be noticed this axial load decreased when reached to horizontal section in planning phase, as shown in Fig. 11 and Fig. 12 because of the drill string in the horizontal section embedded on low side of the well bore, as a result for this behavior the WOB will decrease and compression will reduce.

In the drilling case not reached to horizontal section due to abandon the well before complete the drilling, so cannot found this behavior, as shown in Fig. 13.
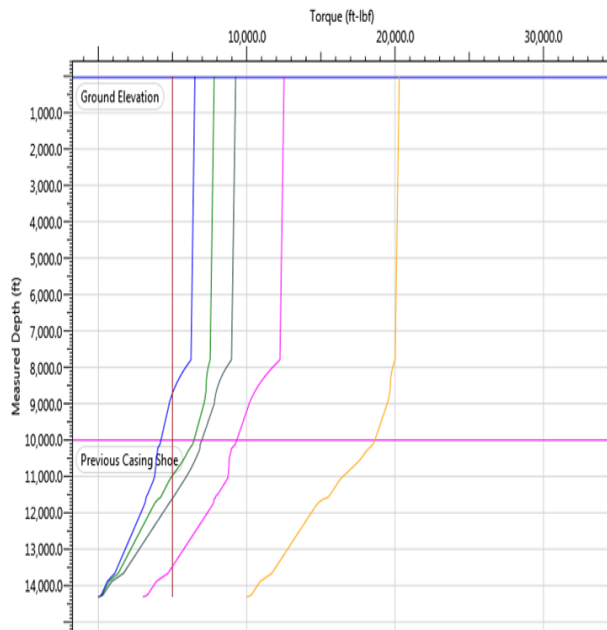
Fig. 14. Torque with MD, well ZB-250, FF CH/OH 0.25/0.3, planning
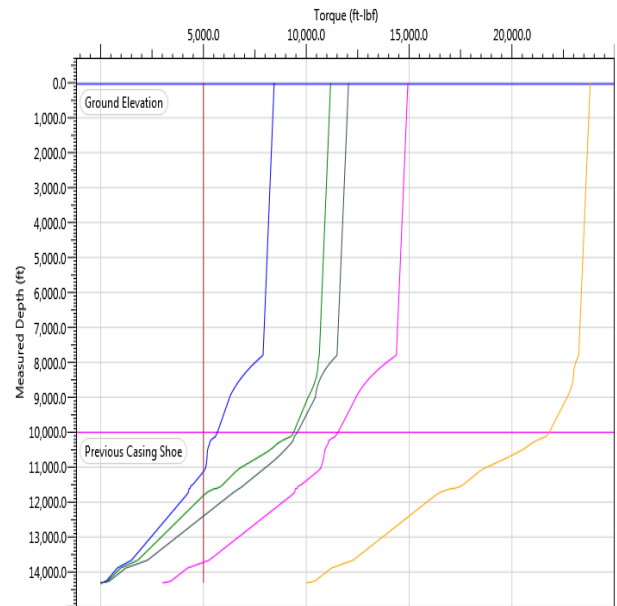
Fig. 15. Torque with MD, well ZB-250, FF CH/OH 0.25/0.4, planning
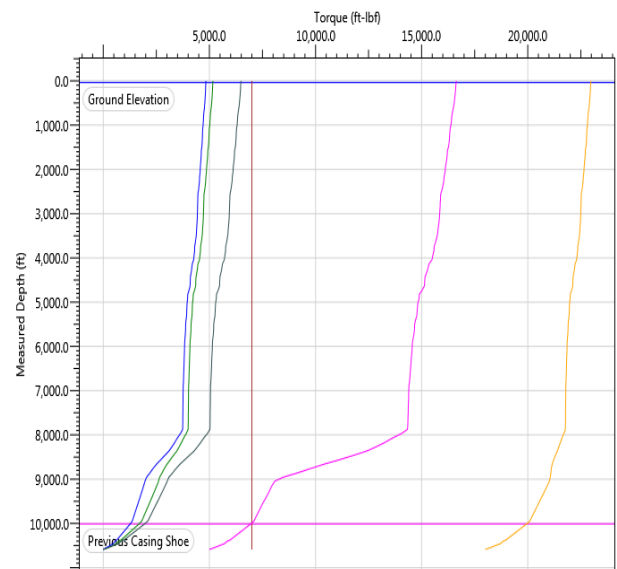
Fig. 16. Torque with MD, well ZB-250 , FF CH/OH 0.3/0.35, drilling.

Figs. (14 to 16) show that the torque in the drill string for the operation conditions corresponding to the measured depth from the surface to the String depth (8.5" hole section). From these figures can be noticed the highest torque values in the surface and start decrease gradually until reach to the minimum values as called torque on bit, Furthermore can be found the torque for drilling on bottom and back reaming conditions increase when FF increased.

Fig. 16 shows the torque for drilling on bottom and back reaming condition for drilling phase FF 0.35 (open hole) are greater than the same conditions with higher FF = 0.4 (open hole) as shown in Fig. 15, especially in the

deviated section after 9 5/8 casing shoe, because of high torque , hard back reaming and high value of over pull due to stuck pipe behavior (no movement, no rotation), high tortuosity and irregular well bore shape, and total mud losses , all these factors caused hard stuck pipe that lead to high torque in the deviated hole section 8.5".

Another two factors effect leaded to high value of torque in the drilling phase as compare with planning phase were built of cutting in the annulus and well bore caving in the deviated section can be indicated that on the shape of cutting on shale shaker as mentioned in the final well report [14].

Minimum WOB (Rotating) to:

Sinusoidal Buckle 48.9 kip begins at 7,759.0 ft

Helical Buckle 49.7 kip begins at 7,759.0 ft

Overpull Margin (Tripping Out): 274.3 kip at 90.00 % of yield

Pick-Up Drag: 28.9 kip

Slack-Off Drag: 24.1 kip

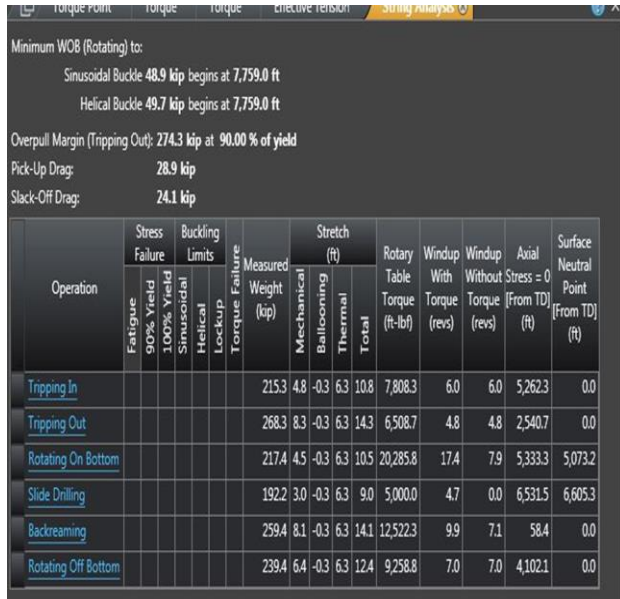| Operation | Stress Failure | | Buckling Limits | | | | Measured Weight (kip) | Stretch (ft) | | | Rotary Table Torque (ft-lbf) | Windup With Torque (revs) | Windup Without Torque (revs) | Axial Stress = 0 [From TD] (ft) | Surface Neutral Point [From TD] (ft) |
	Fatigue	90% Yield	100% Yield	Sinusoidal	Helical	Lockup	Torque Failure		Mechanical	Ballooning	Thermal					
Tripping In								215.3	4.8	-0.3	6.3	10.8	7,808.3	6.0	6.0	5,262.3	0.0
Tripping Out								268.3	8.3	-0.3	6.3	14.3	6,508.7	4.8	4.8	2,540.7	0.0
Rotating On Bottom								217.4	4.5	-0.3	6.3	10.5	20,285.8	17.4	7.9	5,333.3	5,073.2
Slide Drilling								192.2	3.0	-0.3	6.3	9.0	5,000.0	4.7	0.0	6,531.5	6,605.3
Backreaming								259.4	8.1	-0.3	6.3	14.1	12,522.3	9.9	7.1	58.4	0.0
Rotating Off Bottom								239.4	6.4	-0.3	6.3	12.4	9,258.8	7.0	7.0	4,102.1	0.0

Fig. 17. Drill string analyses, FF CH/OH 0.25/0.3 – planning

Minimum WOB (Rotating) to:

Sinusoidal Buckle 48.9 kip begins at 7,759.0 ft

Helical Buckle 49.7 kip begins at 7,759.0 ft

Overpull Margin (Tripping Out): 268.0 kip at 90.00 % of yield

Pick-Up Drag: 35.1 kip

Slack-Off Drag: 31.2 kip

| Operation | Stress Failure | | Buckling Limits | | | | Measured Weight (kip) | Stretch (ft) | | | Rotary Table Torque (ft-lbf) | Windup With Torque (revs) | Windup Without Torque (revs) | Axial Stress = 0 [From TD] (ft) | Surface Neutral Point [From TD] (ft) |
	Fatigue	90% Yield	100% Yield	Sinusoidal	Helical	Lockup	Torque Failure		Mechanical	Ballooning	Thermal					
Tripping In								208.2	4.3	-0.3	6.3	10.2	10,347.5	8.0	8.0	5,674.1	0.0
Tripping Out								274.6	8.8	-0.3	6.3	14.7	7,993.2	6.0	6.0	1,941.6	0.0
Rotating On Bottom								217.4	4.5	-0.3	6.3	10.5	23,106.2	19.6	10.2	5,333.3	5,073.2
Slide Drilling			X	X				166.9	1.2	-0.3	6.3	7.2	5,000.0	4.7	0.0	7,648.5	7,992.9
Backreaming								259.4	8.1	-0.3	6.3	14.1	14,575.0	11.6	8.8	58.4	0.0
Rotating Off Bottom								239.4	6.4	-0.3	6.3	12.4	11,526.0	8.9	8.9	4,102.1	0.0

Fig. 18. Drill string analyses, FF CH/OH 0.25/0.4 – planning

Minimum WOB (Rotating) to:

Sinusoidal Buckle 42.4 kip begins at 10,590.6 ft

Helical Buckle 58.8 kip begins at 7,819.4 ft

Overpull Margin (Tripping Out): 268.6 kip at 90.00 % of yield

Pick-Up Drag: 20.4 kip

Slack-Off Drag: 10.9 kip

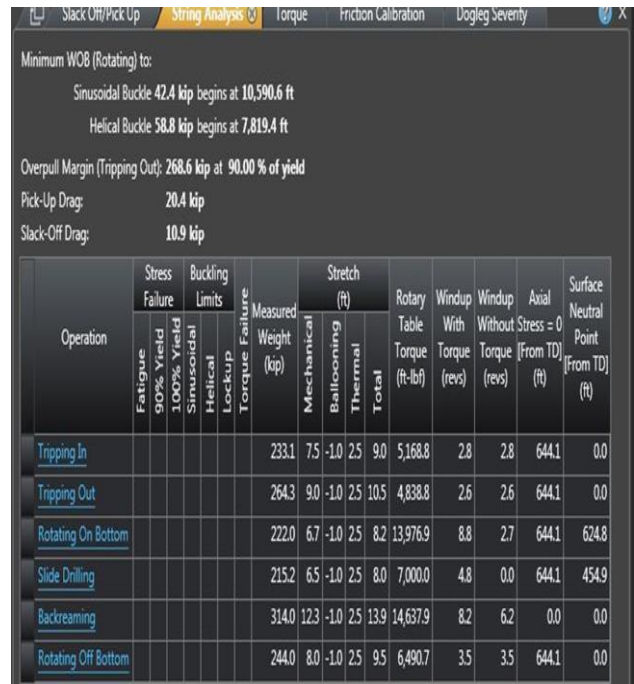| Operation | Stress Failure | | Buckling Limits | | | | Measured Weight (kip) | Stretch (ft) | | | Rotary Table Torque (ft-lbf) | Windup With Torque (revs) | Windup Without Torque (revs) | Axial Stress = 0 [From TD] (ft) | Surface Neutral Point [From TD] (ft) |
	Fatigue	90% Yield	100% Yield	Sinusoidal	Helical	Lockup	Torque Failure		Mechanical	Ballooning	Thermal					
Tripping In								233.1	7.5	-1.0	2.5	9.0	5,168.8	2.8	2.8	644.1	0.0
Tripping Out								264.3	9.0	-1.0	2.5	10.5	4,838.8	2.6	2.6	644.1	0.0
Rotating On Bottom								222.0	6.7	-1.0	2.5	8.2	13,976.9	8.8	2.7	644.1	624.8
Slide Drilling								215.2	6.5	-1.0	2.5	8.0	7,000.0	4.8	0.0	644.1	454.9
Backreaming								314.0	12.3	-1.0	2.5	13.9	14,637.9	8.2	6.2	0.0	0.0
Rotating Off Bottom								244.0	8.0	-1.0	2.5	9.5	6,490.7	3.5	3.5	644.1	0.0

Fig. 19. Drill string analyses, FF CH/OH 0.3/0.35 – drilling

Figs. (17 to 19) show the drill string behavior for selected operating mode, it's include load and stress data, any failures due to stress (fatigue, over maximum yield strength of drill string component), buckling (sinusoidal or helical), and torque failure are indicated depend on data entering to the model.

Minimum WOB while rotating must be not exceeded to prevent buckling and its depth can be found in the previous tables, furthermore allowable (safe) pick up and slack off weight in case of high drag zone and over pull margin within safe operating condition to prevent any drill string failure corresponding to 90% from drill string component minimum yield strength.

As shown in these figures when friction factor increased the measured weight of the drill string will increased as a result from increasable of contact force between drill string and well bore especially in the slide drilling ,back reaming, and tripping out conditions.

As shown in Fig. 18 the slide drilling mode can result buckling behavior (sinusoidal and helical) with FF = 0.4 (open hole) for planning stage and this indicate more certainly as mentioned before and shown in Fig. 12 for effective tension curve which cross buckling limit curve.
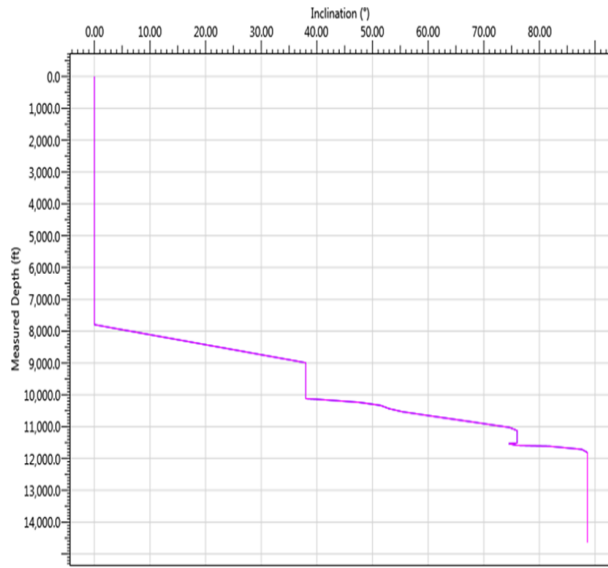
Fig. 20. Well path inclination with MD,ZB-250, planning
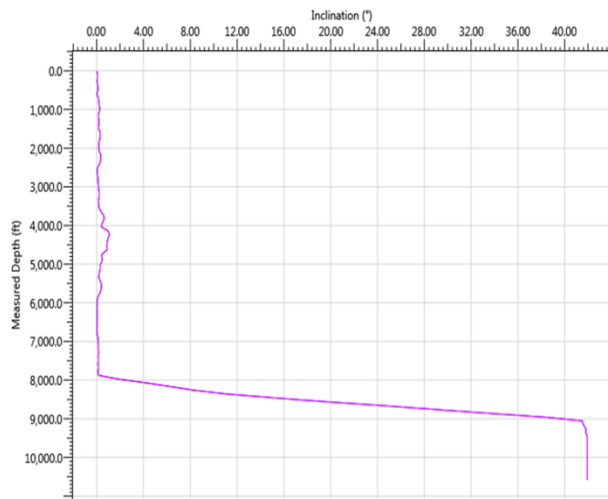

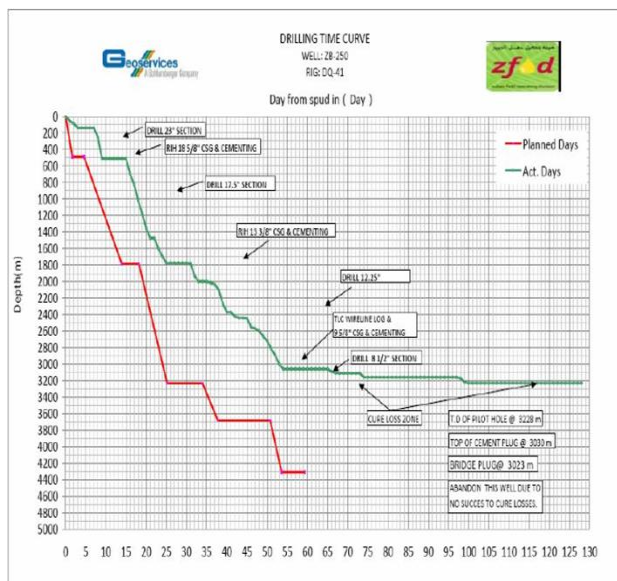Fig. 21. Well path inclination with MD,ZB-250,drilling

Fig. 22. Drilling time curve, ZB-250, drilling [14]

Figs. (20 and 21) show the inclination angle at any depth in the wellbore with tortuosity of the well path for planning and drilling phases depending on well path input data, it can be noticed the inclination angle for planning stage was about 88 degree, but in the drilling phase becomes 42 degree because of abandon the well due to total losses problem and difficulty to cure it.as shown in Fig. 21, for actual drilling days.

Furthermore, it can be showed more tortuosity and deviation from planning survey due to well bore instability and implement sidetrack operation at that time, as a result stuck pipe problem, side track operation, and try to cure mud losses, the extra days was needed for these operation as shown in the Fig. 22, the difference between planning and actual days.

4- Conclusions

1- The study of torque and drag by landmark programming group showed that the friction factor had a highly effect on the friction forces of the drill string and well path.

2- The results show the effect of the following parameters: [1.tension and compression, 2. torque, 3. drill string analyses include minimum WOB to avoid buckling types, 4. allowable pick up and slack off weight, 5. over pull margin] on the drill string component that caused increase the frictional forces [torque and drag] due to the hole problems.

3- The results show that the effect of well bore problem on well trajectory target such as; [mud losses, stuck pipe, well bore instability, shale problems, high torque and drag spots, caused different well path in comparison with planning well path. These problems increased the tortuosity and non-productive time (NPT). Moreover the results indicated the main causes of differences for frictional forces in the planning and actual drilling depend on friction factor and hazards for hole drilling section 8.5", the main causes of varying were drilling fluid losses, high value of friction factor, stuck pipe and friction forces when the maximum torque was (16 to 20 klb-ft) and pick up weight (20-40 klb).

Abbreviations

BHA: Bottom hole assymbly
BOP: Blow out preventer
CH: Cased hole
EDM: Engineering data model
EDT: Engineering data training
KLB: Kilo bound
LCM: Losses cure material
MD: Measured depth
NPT: Non- productive time
OH: Open hole
RPM: Revolution per minute
WOB: Weight on bit

Nomenclature

F_t Axial tension acting at lower end of element, Ibf [N]

$\Delta\theta$ Increase in inclination angle over length of element, degrees [rad]

θ Inclination angle at lower end of drill string element, degrees [rad]

W   Buoyed weight of drill string element, Ibf [N]

ΔFt Increase in tension over length of element Ibf [N]

W   Buoyed weight of drill string element, Ibf [N]

μ Sliding friction coefficient between drill string and well bore

ΔM Increase in torsion over length of element ft − lbf [Nm]

r   Characteristic radius of drill string element, ft [m]

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[14]   Zubair field operation division (ZFOD), Schlumberger, "Geological and Drilling Final   well report for ZB-250 (SAF-HOR), unpublished, February 2014.

Appendix A

APPENDIX –A Well Plan Flow chart
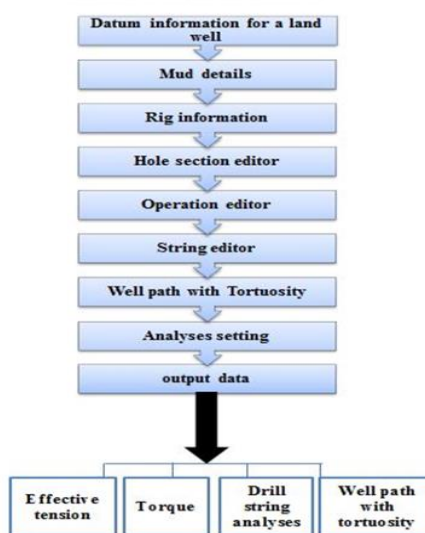
مشاكل قوى عزم الدوران والسحب في الابار النفطية شديدة الميلان

الخلاصة

العزم والسحب الزائد من المحددات الحرجة اثناء حفر الابار شديدة الميلان. استخدام النموذج يعد عملية ذات قيمة للمساعدة في تخطيط البئر والتنبؤ لتجنب مشاكل الحفر. علاوة على ذلك تشخيص اي من مشاكل البئر تؤدي الى العزم والسحب العالي لتجنب خسارة الاموال وتضررالمعدات. استخدام بيانات النموذج المناسبة مهمة جدا لمعرفة وتنبؤ مشاكل البئر التي تحدث نتيجة العزم والسحب واختيار الطريقة الافضل لتجنب هذه المشاكل بالنسبة لمقطع البئر وخيط الحفر.في هذه الدراسة برنامج تخطيط البئر الخاص بالعزم والسحب من مجموعة لاندمارك العالمية للبرمجيات (شركة هاليبرتون) استخدم لتشخيص مشاكل البئر.بئر مائلة في حقل الزبير النفطي باسم- زبير- 250 اختيرت لتحليل تأثير معامل الاحتكاك على العزم والشد المؤثر لخيط الحفر خلال عمق البئر،علاوة على ذلك تأثير مشاكل مقطع البئر مثل فقدان سائل الحفر، تجمع قطع الفتات الصخري في مقطع البئر، استعصاء الانابيب ، التكهف والانسلاخ لجدار البئر اضافة الى قيم العزم الدوراني والسحب العاليين على مكونات خيط الحفر ومسار البئر.

بيانات البئرالتي تشمل حجم مقطع البئر, مواصفات طين الحفر,مسح مقطع البئر,عمق انابيب البطانة,مواصفات جهاز الحفر,مكونات خيط الحفر,معاملات الحفر مثل الوزن على البريمة ,سرعة الدوران و معدل التدفق استخدمت للمقارنة بين حالتي التخطيط والحفر الفعلي لهذه الابار وتحديد اسباب الاختلاف بين المرحلتين.

اظهرت النتائج اختلافا في مرحلة الحفر اي زيادة في الشد الفعلي وكذلك في العزم الدوراني والسحب للاعلى والاسفل ووزن عمود الحفر المقاس واحتمالية حدوث التواء لخيط الحفر اذا ماقورنت مع مرحلة التخطيط.

عدم استقرارية مقطع البئر,معامل الاحتكاك العالي,التعرج العالي للبئر,معدل التدفق العالي,استعصاء الانابيب,مناطق السحب الزائد,الفقدان الجزئي والكلي,الزيادة في متغيرات الحفر,الطبقات الصلبة والتنظيف غير الجيد للبئر.كل هذه الغوامل تؤدي الى هذا الفرق بين المخطط له والحالة الحقيقية.

عند حفر مقطع البئر 8.5 انج كانت الاسباب الرئيسية لهذا الاختلاف هو فقدان سائل الحفر,معامل الاحتكاك العالي,استعصاء الانابيب وقوى الاحتكاك حيث ان اعلى عزم دوراني هو بين (20-16) كيلو باوند – قدم ووزن السحب للاعلى بين (20 – 40) كيلو باوند.