SIMULATION STUDY REGARDING DRILLSTRING VIBRATIONS AND BOTTOM HOLE ASSEMBLY MECHANICS OF DIRECTIONAL WELLS IN ZUBAIR FIELD

STUDIU DE SIMULARE PRIVIND VIBRAȚIILE GARNITURII DE FORAJ ȘI MECANICA DE ANSAMBLUL GĂURII DE FUND ALE PUȚURILOR DIRECȚIONALE DIN CÂMPUL ZUBAIR

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Abstract: *Drillstring vibrations and BHA mechanics are considered two important factors during making well planning. This is due to the importance of the drillstring selection, its components and its related optimum drilling parameters as well. Therefore, the main objective of this paper is to simulate a deviated well (ZB-349) drilled in Zubair field which is situated in Southern Iraq. This simulation study is done by Landmark to study the behavior of the drillstring of 8 ½" hole section. In addition, the general well data are taken from Zubair field, well 349. The well was built on well plan section of the Landmark using well profile, geological data, casing and drillstring data, mud properties, and the required drilling parameters such as WOB, ROP, RPM, SPP, Flow Rate, ..etc. Torque and drag components are simulated and analyzed. Also, the BHA mechanics and vibration analysis are presented and discussed.*

Keywords: Vibrations, Landmark, stress, torque & drag, forces, displacements, well plan.

Rezumat: *Vibrațiile gărniturii de foraj și mecanica BHA sunt considerate doi factori importanți în timpul planificării puțurilor. Acest lucru se datorează importanței selecției gărniturii de foraj, a componentelor sale și a parametrilor optimi de foraj aferenti acestuia. Prin urmare, obiectivul*

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principal al acestei lucrări este de a simula o sondă deviată (ZB-349) forată în câmpul Zubair care este situat în sudul Irakului. Acest studiu de simulare este realizat de Landmark pentru a studia comportamentul gărnitura de foraj cu secțiune de gaură de 8 ½”. În plus, datele generale ale sondei sunt preluate din câmpul Zubair, sondă 349. Sonda a fost construită pe secțiunea în plan de sondă a Landmark-ului folosind profilul sondei, datele geologice, datele de tubaj și cordonul de foraj, proprietățile noroiului și parametrii necesari de foraj, cum ar fi WOB. , ROP, RPM, SPP, Debit, ..etc. Componentele cuplului și rezistenței sunt simulate și analizate. De asemenea, sunt prezentate și discutate mecanica BHA și analiza vibrațiilor.

Cuvinte cheie: Vibrații, Landmark, stres, cuplu și rezistență, forțe, deplasări, plan de sondă.

1. Introduction

Drill pipes, drill collars and bits make up the bulk of a drill string (D/S) on the onshore and marine drilling rigs. Its purpose is to supply torque and drilling fluid to the drill through a top drive. The D/S is a cylindrical shape with a internally-externally communication to provide space between the D/S and the casing or/and open hole, allowing drilling fluid to pass through and circulate back to the annulus [1-6]. A standard D/S may be several kilometers long.

Heavy-weight drill pipe, drill collars, stabilizers, cross-overs, bottom-hole subs, bits, and other D/S accessories are referred to as a bottom hole assembly (BHA). In order to reach the desired reservoir pay zones, all wellbores: vertical or directional; require the precise design of the BHA to regulate the borehole direction. The primary tools utilized to govern well direction are collars and stabilizers. The BHA is made up of a bit for breaking up rock formations, a drill collar, which is thick wall pipe, and a drill stabilizer for keeping the whole thing in the center of the hole. Additional parts, including as rotary steering systems (RSS), measurement while drilling (MWD), bottom-hole motors (DHM), and logging while drilling (LWD) equipment, may be included in a BHA. Strong screw connections are used to connect the parts. Elements are connected to several threads using short "BHA subs" [1-7]. The drill pipe makes up the majority of the D/S close to the surface; either segment contains a wide diameter portion with a pin-box component. It takes three displacements and three rotations to fully describe the dynamic behavior of a BHA at each node. In comparison to other simplistic models that simply explain a few vibration patterns, this model is more accurate. However, a full finite-element model requires more processing power. Only lateral and torsional vibrations are looked at here [7] in order to simplify calculation and make it easier to grasp the numerical findings.

D/S dynamics have been the subject of much theoretical and experimental study in recent years with the goal of developing control and optimization solutions for D/Ss [8]. According to the findings in [9,10], the frictional forces acting on the drill bit at the bit-rock contact are the primary source of stick-slip occurrences. Furthermore, it is suggested by [10] that one of the reasons of these dangerous vibrations is the negative damping in the frictional forces brought on by the contacts between the bit and the rock.

To continue this review of the D/S and BHA mechanics and analysis, the following table shows a background of some basic researches and studies development from 1950 till 2016. Years after that show highly advanced researches and their applications.

Table 1. **Reviewing of D/S and BHA studies**

Author/Year	**Method/Approach/Study/Experiment**
Lubinski,1950 [11]	Making the 1st comprehensive study on D/S buckling, exposing the process by which rotary D/Ss buckle in vertical boreholes, then presenting the essential buckling conditions and D/S post-buckling behavior Providing the critical buckling forces for the lowest 2 types of buckling solutions after studying the 2D lateral buckling issue with the beam approach.
Althouse et al., 1962 [12]	Presenting one significant cause of well deviation which is thought to be the D/S's curved structure, considering as a 2nd order function and the D/S tends to touch the inner surface of the borehole wall on both sides as the axial force grows further and reaches the second critical value.
Johansick, 1984 [13]	Building directional well drag and torque computation models based on Johansick's soft model in 1984
He, 1988 [14]	Presenting an updated tensile torque model that, for the 1st time, takes into account the stiffness of the D/S and is based on the idea of massive deformation.
Bai et al., 1985 [15] & Yushi et al., 1989 [16]	Advancing the study to 3D in 1989 and putting out the beam-column theory to address the 2D model of BHA deformation
Zifeng et al. 1992 [17]	Constructing a steady state model of tensile torque while investigating D/S movement and drilling fluid effect
Abbassian et al., 1998 [18]	Investigating how different D/Ss affect the stability of the drilling operation, specifically with reference to unwanted torsional vibrations.

Table 1 (continued)

Author/Year	**Method/Approach/Study/Experiment**
Dekun et al.,1998 [19] & Zhong et al.,2000 [20]	Constructing D/S models for longitudinal & torsional vibrations and then solving them utilizing the finite difference method
Harris, 2001 [21]	Presenting contact surface stress as well as variations in the quantity and distribution of the contact stress as a result of the contact area's shape alteration.
Leine et al., 2002 [22]	Understanding the complicated behavior of the D/S system and analyzing the local contact and friction between the D/S and casing, as well as the compressed BHA.
Melakhessou et al., 2003 [23]	Creating reduced-order models of a D/S system that incorporate stick-slip interactions between the D/S and the outer shell as well as radial, bending, and torsion motions of a flexible drill-string Also, calculating and testing quantitative variations in system motion with regard to rotational speed and the amount of friction between the D/S and the outer shell.
Veggel et al., 2004 [24]	Developing a D/S model with 3degrees of freedom that may concurrently monitor stick-slip and whirl vibrations.
Song et al., 2006 [25]	Presenting a novel computation model for torque and drag
Tong et al., 2007 [26]	Constructing D/S dynamics simulation software
Qingyou et al., 2008 [27]	Doing a dynamics modeling of a complete hole D/S system with 3D trajectory based on Hamilton's theory and the finite element approach
Mitchell et al., 2009 [28]	Making a roughly full stiff rod taking into account the D/S's position in relation to the borehole.
Balachandran et al., 2011[29]	Establishing an experimental drilling rig that was utilized to simulate all significant D/S vibrations and in which the D/S's nonlinear features were modeled using finite element techniques and experimentally confirmed.
Kamel et al., 2014 [30]	Studying the impacts of altering drilling operation parameters and coming to the conclusion that increasing the axial rate during operation also increases ROP and applied WOB.
Kapitaniak, 2015 [31] & Navarro-López, 2010 [32]	Studying the impact of changing the control torque on the rotary speed and WOB on the stick-slip vibrations and confirmed the Tang et al., [14]'s conclusion
Tang et al., 2015 [33]	Looking at how the speed of a rotary table affected stick-slip, they discovered that doing so had an impact on the time of the stick phase in stick-slip vibrations.
Liu, 2015 [34]	Recommending a sliding approach control strategy to reduce stick-slip vibrations while presuming that the D/S's physical characteristics were unknown.
Huang et al., 2015 [35]	Studying the phenomena of D/S buckling, theory, equations, influences and its behavior under various loads.

Table 1 (continued)

Author/Year	Method/Approach/Study/Experiment
Zhu et al., 2015 [36]	Creating a dynamic drag and torque approach based on the dynamics of the entire hole D/S system for highly inclined wells
Hong et al., 2016 [37]	Suggesting using a Kalman estimator to handle downhole parameters that are not measured and utilizing numerical simulations, this estimator helps in measuring downhole friction torque and recognizing stick-slip vibrations
Besselink et al., 2016 [38]	Demonstrating an effective feedback control production/result to prevent stick-slip in a D/S system.

Therefore, the aim of our study is to simulate D/S and BHA behavior in one of the deviated wells drilled in Zubair field which is located in Iraq. This simulation is done by Landmark software package developed by Halliburton Company. So as to implement this study, it is better to review shortly the theoretical part and describe the well data used in our simulation.

2. Drillstring vibrations and bha mechanics: theories and analysis

The BHA and the drillpipe are considered as an integrated D/S and most of theories, that were developed, are for both of them. Each is influenced by the other and vice versa. DCs and surrounding DPs are recognized to be the sections that experience the most dangerous vibrations. Therefore, the BHA not only influences the assembly's overall dynamic response, but also acts as the primary location for D/S failures. Therefore, vibration mitigation requires an understanding of the dynamic behavior of the BHA. Bottom well vibrations, however, may be a valuable source of information that reveals bit wear, formation geographies, and D/S/borehole interactions. According to certain studies, they might perhaps be used as a seismic source. Additionally, it has been proposed that drillstring vibrations might increase the power available to the bit, hence increasing drilling efficiency [1]. The D/S and BHA mechanics have been presented in several textbooks [1-5] and scientific papers [6-38] since the fifties. However, here we present the parts that will be used in our study. Firstly, stress determination is the one in which the following equations are used in the study to make several stress estimations. The effects of axial stress caused by hydrostatic and mechanical loading are taken into account in these computations. Torsional tension from twist, transverse shear stress from contact, and approximately calculated bending stress from wellbore curvature Internal and exterior pressure-related hoop stress and pressure-related radial stress are subsequently presented [39].

a. Von Mises stress

$$\sigma_{VM} = \sqrt{\frac{\left(\sigma_{rj}-\sigma_{hj}\right)^2+\left(\sigma_{aj}-\sigma_{rj}\right)^2+\left(\sigma_{hj}-\sigma_{aj}\right)^2+6\sigma_{sj}^2+6\,\sigma_{tj}^2}{2}} \quad (1)$$

b. Radial stress

$$\sigma_{r1} = -\,P_e \quad \& \quad \sigma_{r2} = -\,P_i \quad (2)$$

c. Transverse shear stress

$$\sigma_{s1} = \sigma_{s2} = \frac{2\,F_n}{A} \quad (3)$$

d. Hoop stress

$$\sigma_{h1} = \frac{\left[2\,r_i^2 P_i - \left(r_i^2 + r_o^2\right)P_e\right]}{\left(r_o^2 - r_i^2\right)} \quad (4)$$

$$\sigma_{h2} = \left[\left(r_i^2 + r_o^2\right)P_i - \frac{2r_o^2\,P_e}{\left(r_o^2 - r_i^2\right)}\right] \quad (5)$$

e. Torsional stress

$$\sigma_{t1} = 12\,r_o\frac{T}{J} \quad \& \quad \sigma_{t1} = 12\,r_i\frac{T}{J} \quad (6)$$

f. Bending stress

$$\sigma_{bend1} = r_o\frac{E\kappa M}{68754.9} \quad \& \quad \sigma_{bend2} = r_i\frac{E\kappa M}{68754.9} \quad (7)$$

g. Buckling stress in case of occurring buckling

$$\sigma_{buck1} = \frac{r_o R_c |F_a|}{2I} \quad \& \quad \sigma_{buck1} = \frac{r_i R_c |F_a|}{2I} \quad (8)$$

h. Axial Stress including tension, bending and buckling

$$\sigma_{a1} = \frac{F_a}{A} + \sigma_{bend1} + \sigma_{buck1} \quad \& \quad \sigma_{a2} = \frac{F_a}{A} + \sigma_{bend2} + \sigma_{buck2} \quad (9)$$

where:

A = Cross sectional area of component
E = Modulus of elasticity, psi
Fa = Axial force, lb
Fn = Normal (side) force, lb
I = Moment of inertia

J = Polar moment of inertia, $J = \frac{\pi}{32}\left(OD_{body/joint}^{4} - ID_{body/joint}^{4}\right)$
M = Bending Stress Magnification Factor
Pe = External pressure of pipe, psi
Pi = Internal pressure of pipe, psi
Rc = Maximum distance from workstring to wellbore wall, in
ri = Inside pipe radius, in
ro = Outside pipe radius, in
T = Torque, ft-lb
κ = Dogleg severity for a soft string model expressed as wellbore curvature, deg/100 ft

BHA. Directional penetration execution of a BHA is anticipated by its mechanics. The strengths of the assembly, as it is located inside the probe, are precisely delineated by this analysis. This review could be useful to find out the reasons behind the disappointment of the machines or to clarify the astonishing execution. Uses of the BHA simulations are [39]:

1. Analyze the bit tilt, side forces, and wellbore contact locations as well as the contact forces and displaced form of a BHA.
2. Examine prior failures in a particular direction by analyzing contact pressures on tools.
3. Predict how a BHA will move in a certain direction when it drills through a given interval, including how it will build, walk, and drop.
4. Foresee the momentary impact of running a fresh assembly through a hole.
5. Modify operation settings to impact the effectiveness of the BHA.
6. To achieve optimum performance, consider the impacts of bent assemblies, collar size, stabilizer location, eccentric stabilizers, stabilizer wear, hole enlargement, and operating conditions.
7. Choose the right bent sub to get the build or drop rate you want.
8. Calculate the increased torque required from a motor as a result of bit lateral forces.
9. Discover the mechanism operating the BHA downhole.
10. Choose a BHA's orientation (0–180 degrees to the left or right of the high side) for the best results in a well deflection situation.
11. Evaluate the performance of a steerable vs a rotary assembly for a particular well trajectory study.
12. Through modeling of the number of bends and eccentric contact points in the BHA, optimize the design of a steerable system.

Details, equations and correlation of the drillstring BHA used to do the previous simulations and studies are presented by Halafawi and Avram [40] and Robert [5]. In addition, they have presented the following [5,40]:

1. Explicit mathematical formulae and equations for BHA mechanics
2. BHAs mechanics direct mathematics
3. Slick BHA in an inclined hole mechanics
4. Slick BHA in a curved borehole mechanics and analysis
5. A BHA with one stabilizer in an inclined hole: mechanics and analysis
6. A BHA with a single stabilizer in a curved wellbore: mechanics and analysis
7. BHA mechanics with rotary steering
8. Complex mechanics of BHA

For D/S vibration analysis, it is preferable to review the basic equations that describe the behavior of the D/S during various types of vibrations. Three main types of vibration can be brought on by drilling: axial, torsional, and lateral. The phenomena bit bounce, stick/slip, and spinning are related to these modes, respectively [1-6]. The following equations are presented so as to express the preceded kinds of the D/S vibrations [1,41]:

i. Axial Vibrations

$$\frac{\partial^2 \xi(x,t)}{\partial x^2} = \frac{1}{c^2}\,\frac{\partial^2 \xi(x,t)}{\partial t^2} \tag{10}$$

$$\xi_n(x,t) = \left(A_n \sin\frac{\omega_n}{c}\ x + B_n \cos\frac{\omega_n}{c}\ x\right).$$

$$.\,(C_n \sin\omega_n\ t + D_n \cos\omega_n\ t), n = 1,2, \tag{11}$$

$$c^2 = \frac{E}{\rho} \tag{12}$$

$$\rho\frac{\partial^2 \xi}{\partial t^2} + c_a\frac{\partial \xi}{\partial t} - E\frac{\partial^2 \xi}{\partial x^2} + \rho g_z = g_a\left(x, t, \xi, \frac{\partial \xi}{\partial x}, \frac{\partial \xi}{\partial t}\right) \tag{13}$$

Bit bounce

$$S(r,\phi) = \ S_o\, sin\left(\frac{r}{\Delta r_b}\ \frac{\pi}{2}\right)\sin(3\phi)\,, 0 \le r \le \Delta r_b$$

$$and\ 0 \le \phi \le 2\pi$$

$$S_o\, sin\left(\frac{r}{\Delta r_b}\ \frac{\pi}{2}\right)\sin(3\phi)\,, \Delta r_b \le r \le r_b \tag{14}$$

ii. Torsional Vibrations

$$\rho J \frac{\partial^2 \phi}{\partial t^2} - JG\ \frac{\partial^2 \phi}{\partial x^2} = g_T(x, \phi, t) \tag{15}$$

A Stick/Slip Model

$$I\ \ddot{\phi} + c_r \dot{\phi} + F\left(\dot{\phi}\right) + k\phi = k\Omega t \tag{16}$$

iii. Lateral Vibrations

$$\rho \frac{\partial^2 \phi}{\partial t^2} - \frac{\partial^2}{\partial x^2}\left(EI_z \frac{\partial^2 u}{\partial x^2}\right) = g(x, t) \tag{17}$$

A Whirling Model

$$m\ddot{y} + c_w \dot{y} + k_w\ y = me_0\ \Omega^2 cos(\Omega t) \tag{18}$$

$$m\ddot{z} + c_w \dot{z} + k_w\ y = me_0\ \Omega^2 sin(\Omega t) \tag{19}$$

More details about solving these equations and their forms can be found in Aadnoy et al. [1].

3. General well data description

A deviated/oil producer well (ZB–349) is drilled in Zubair oil field located in Iraq. It is drilled to reach the 3rd and 4th sandstone pay zones at depth of 3564.86 m TVD RT / 3706 m MD RT inside the lower shale member. These pay reservoirs in the field's northern region are the objectives of ZB-349 (Figure 1). General well data are described in Table 2. The reservoir properties are:

- For the 1st target
  - Gross thickness: 100 - 110 m, N/G ratio: 60 - 80%, Porosity: 16 - 20%.
  - Permeability range: 100 - 200 with peaks that can exceed 1,500 mD, API gravity range: 30 – 36 with GOR of 690 scf/stb.
- For The 2nd target
  - Gross thickness: 70 m, N/G ratios: 30 - 40%, Porosity average: 18%.
  - Permeability around 100 mD, with peaks of about 500 mD, average API gravity average: 38°

The offset wells surrounding this well are: ZB–095 N 722m, ZB–103 N 990m, ZB–287 E 11790m, ZB–347 S 190m, and ZB–310 E 250m. The map location showing the position of well ZB–349 is appeared in Figure 1. The well ZB-349 Directional is located in the Northern part of Zubair Field on the Hammar Dome. The closest DGS is Hammar-Mishrif. The well drilled with several sections: 23”, 17 ½”, 12 ¼”, 8 ½”, and 6”. The recorded drilling parameters such as ROP, WOB, Surface RPM, Total RPM, Torque, Flow Rate and SPP are expressed and shown beside geological column in Figure 2. There are various BHAs used to drill each section, however, Tables 3&4 show the BHA of 8 ½” hole section which will be simulated in our study. Similar to the preceding phase, the starting MW in 8 12" will be increased to 1.35sg before to Upper Shale formation. Depending on the hole conditions and the availability of cavings, MW might be increased to 1.40 sg; however, further increases would require approval. While drilling the upper, middle, and lower shale formations, additional additives such as salinity (Cl-) 120 K mg/l, BXR-L 3 percent, BARO-TROL PLUS 2 lb/bbl, and BAROLUBE 1% will be used. However, the addition of lubricant will rely on a case-by-case analysis. For the 12 14" and 8 12" portions, the only acceptable weighing agents were CaCO3 and salt.

Table 2. **General well data**

Data/ Well Name	**ZB-349**
Location	Dir. (AG-18 Dir)
Well Classification	Oil Producer / Deviated
Expected Total Depth	3542 m TVDSS / 3529 m TVD RT / 3709 m MD RT
License	Zubair Field
Closest DGS	Hammar-Mishrif
GL – MSL	2.36 m
RT Elevation (GL)	10.5 m
RT Elevation (MSL)	12.86 m
Lithology of the targets	Sandstone
Targets Formation	3rd Pay & 4th Pay
Targets Depth	3rd Pay -3263 m TVD SS / 3276 m TVD RT / 3421 m MD RT 4th Pay -3415 m TVD SS / 3428 m TVD RT / 3585 m MD RT
Tolerance Radius @ 1st Target	50 m
Coordinates Reference System	WGS-84
Surface Coordinates (metric)	X = 745,594.18, Y = 3,383,598.19
3rd Pay Target Coordinates (metric)	X = 744,893.00,Y = 3,383,293.00
4th Pay Target Coordinates (metric)	X = 744,836.08, Y = 3,383,268.54
Project Units	Metric
Estimated Reservoir Pressure of Targets	**H layers:** 3000 – 3100 psi @ 3,261 mTVDss **L layers:** 4850 - 5050 psi @ 3,261 mTVDss **Reference well:** ZB-325 (RFT acquired)
Estimated Time	54.4 Days

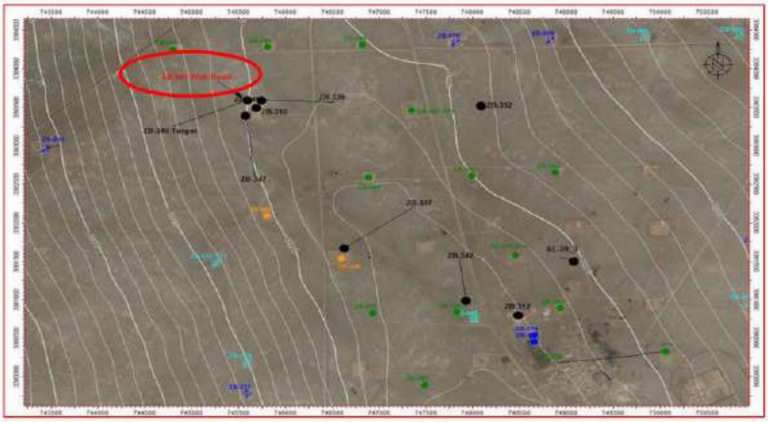


Figure 1. Location map of ZB-349.

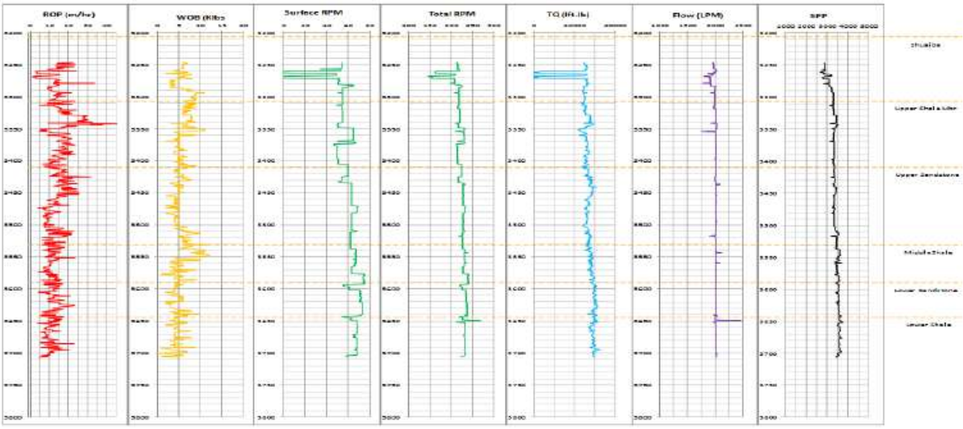
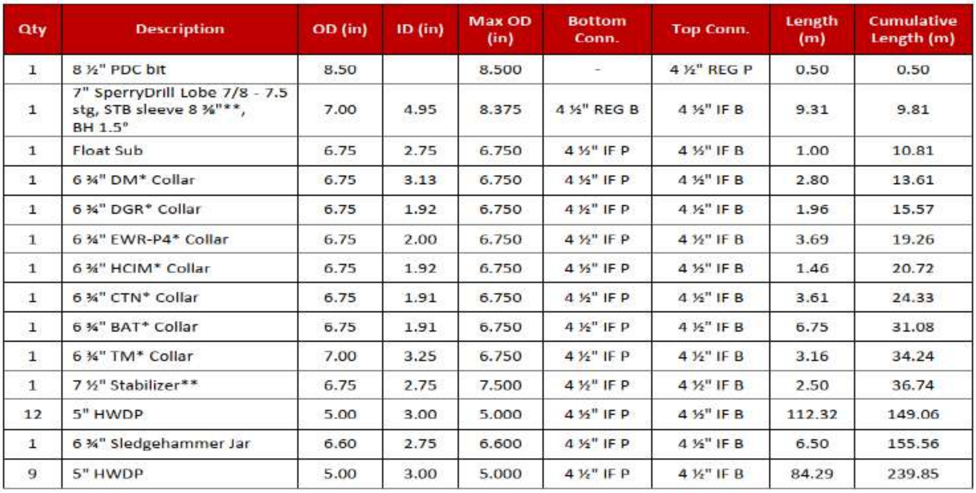


Figure 2. Recorded drilling parameters of 8 1/2" hole section (3214m- 3706m).

Table 3. **Drilling parameters used in simulation study**

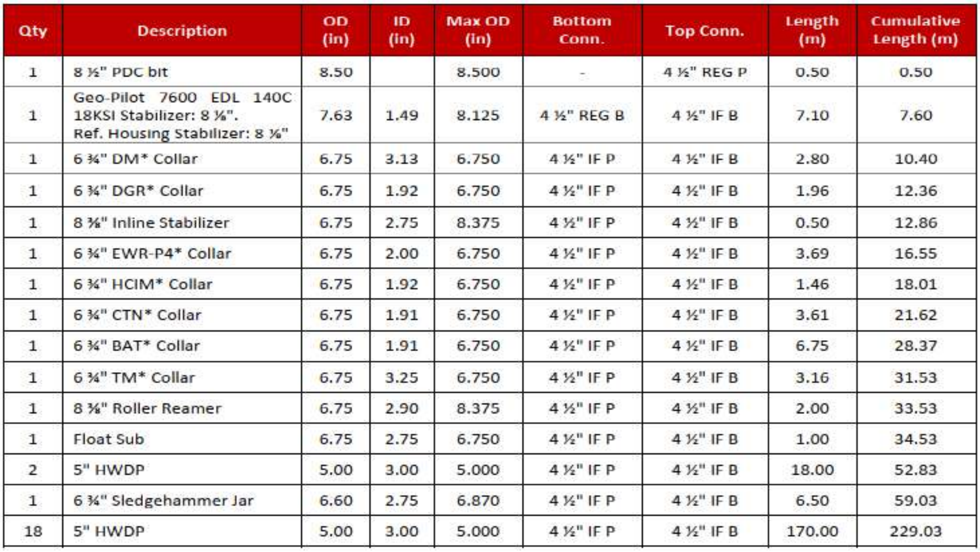
Torque & Drag		
WOB	12ton (26.455)kip	
Block weight	1,500,000 lbs (680t) (1500)kip	
Hook Load	1,300,000 lbs with 14 lines (589.67t) (1300)kip	
Torque at bit	63,000 ft-lbs (85,000 N-m)	
Surface Torque	63,000 ft-lbs (85,000 N-m)	
Tripping in (speed/Rpm)	10.44 m/h (0.174 m/min)	60 rpm
Tripping out (speed/Rpm)	10.51 m/h (0.175 m/min)	70 rpm
Bit Rpm(Rotary on bottom)	65 rpm	
BHA Dynamic		
Pump rate(mud #5)	720 gpm	
Start speed	60 rpm	
End speed	70 rpm	
Speed increment	2 rpm	

Table 4. **Directional BHA of 8 ½” with Motor**



Qty	Description	OD (in)	ID (in)	Max OD (in)	Bottom Conn.	Top Conn.	Length (m)	Cumulative Length (m)
1	8 ½" PDC bit	8.50		8.500	-	4 ½" REG P	0.50	0.50
1	7" SperryDrill Lobe 7/8 - 7.5 stg, STB sleeve 8 ⅜"**, BH 1.5°	7.00	4.95	8.375	4 ½" REG B	4 ½" IF B	9.31	9.81
1	Float Sub	6.75	2.75	6.750	4 ½" IF P	4 ½" IF B	1.00	10.81
1	6 ¾" DM* Collar	6.75	3.13	6.750	4 ½" IF P	4 ½" IF B	2.80	13.61
1	6 ¾" DGR* Collar	6.75	1.92	6.750	4 ½" IF P	4 ½" IF B	1.96	15.57
1	6 ¾" EWR-P4* Collar	6.75	2.00	6.750	4 ½" IF P	4 ½" IF B	3.69	19.26
1	6 ¾" HCIM* Collar	6.75	1.92	6.750	4 ½" IF P	4 ½" IF B	1.46	20.72
1	6 ¾" CTN* Collar	6.75	1.91	6.750	4 ½" IF P	4 ½" IF B	3.61	24.33
1	6 ¾" BAT* Collar	6.75	1.91	6.750	4 ½" IF P	4 ½" IF B	6.75	31.08
1	6 ¾" TM* Collar	7.00	3.25	6.750	4 ½" IF P	4 ½" IF B	3.16	34.24
1	7 ½" Stabilizer**	6.75	2.75	7.500	4 ½" IF P	4 ½" IF B	2.50	36.74
12	5" HWDP	5.00	3.00	5.000	4 ½" IF P	4 ½" IF B	112.32	149.06
1	6 ¾" Sledgehammer Jar	6.60	2.75	6.600	4 ½" IF P	4 ½" IF B	6.50	155.56
9	5" HWDP	5.00	3.00	5.000	4 ½" IF P	4 ½" IF B	84.29	239.85

Table 5. **Directional BHA of 8 ½” with with Geopilot/ RSS**



Qty	Description	OD (in)	ID (in)	Max OD (in)	Bottom Conn.	Top Conn.	Length (m)	Cumulative Length (m)
1	8 ½" PDC bit	8.50		8.500	-	4 ½" REG P	0.50	0.50
1	Geo-Pilot 7600 EDL 140C 18KSI Stabilizer: 8 ⅛". Ref. Housing Stabilizer: 8 ⅛"	7.63	1.49	8.125	4 ½" REG B	4 ½" IF B	7.10	7.60
1	6 ¾" DM* Collar	6.75	3.13	6.750	4 ½" IF P	4 ½" IF B	2.80	10.40
1	6 ¾" DGR* Collar	6.75	1.92	6.750	4 ½" IF P	4 ½" IF B	1.96	12.36
1	8 ⅜" Inline Stabilizer	6.75	2.75	8.375	4 ½" IF P	4 ½" IF B	0.50	12.86
1	6 ¾" EWR-P4* Collar	6.75	2.00	6.750	4 ½" IF P	4 ½" IF B	3.69	16.55
1	6 ¾" HCIM* Collar	6.75	1.92	6.750	4 ½" IF P	4 ½" IF B	1.46	18.01
1	6 ¾" CTN* Collar	6.75	1.91	6.750	4 ½" IF P	4 ½" IF B	3.61	21.62
1	6 ¾" BAT* Collar	6.75	1.91	6.750	4 ½" IF P	4 ½" IF B	6.75	28.37
1	6 ¾" TM* Collar	6.75	3.25	6.750	4 ½" IF P	4 ½" IF B	3.16	31.53
1	8 ⅜" Roller Reamer	6.75	2.90	8.375	4 ½" IF P	4 ½" IF B	2.00	33.53
1	Float Sub	6.75	2.75	6.750	4 ½" IF P	4 ½" IF B	1.00	34.53
2	5" HWDP	5.00	3.00	5.000	4 ½" IF P	4 ½" IF B	18.00	52.83
1	6 ¾" Sledgehammer Jar	6.60	2.75	6.870	4 ½" IF P	4 ½" IF B	6.50	59.03
18	5" HWDP	5.00	3.00	5.000	4 ½" IF P	4 ½" IF B	170.00	229.03

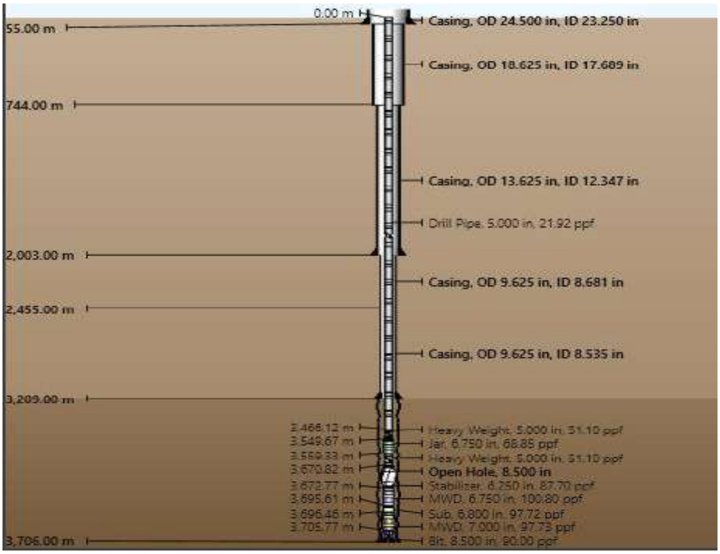


Figure 3. Well schematic and D/S components built in software.

4. Simulation results and discussions

ZB-349 is an onshore well which will be used in our simulation study. It is a deviated well of 3564.84 m TVD RT and 3706 m MD RT reaching to an oil targets called pay zones 3&4. Table 2 shows the general well data while Tables 3 through 5 show the parameters and D/S components used for 8.5 in hole section in which our simulation study will be performed. Moreover, the drillstring and BHA components used in 8.5 in section are appeared in Tables 2 through 5. Figure 2 shows the drilling parameters registered in 8.5 in section, such as ROP, WOB, Surface RPM, Total RPM, Torque, Flow Rate and SPP variations through the entire well section. The Landmark software package is used through its well plan part to simulate the performance of the D/S and BHA during drilling the deviated well drilled in Zubair field located in Iraq. Firstly, the stress estimation and the generating torque and drag are simulated, using data in Table 3, as shown in Figures 4 through 14. It is found that all the torque and drag components such as tension, torque, fatigue, and string positions are located within limits during various drilling operations like rotation and tripping (Figs. 4 through 11). However, the string rotation on bottom shows higher tension than limit so it is recommend to use lower RPM value. Furthermore, it is clear that all types of stresses generated on the D/S are below the stress limit during tripping in and out (Figs. 12 through 14). However, the Von Mises is higher than the limit in the cased section during rotation on bottom.

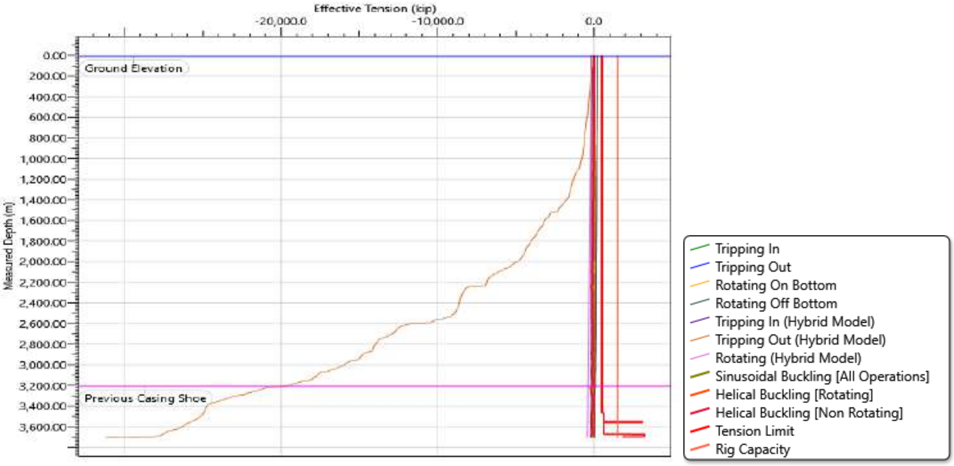


Figure 4. Variation of effective tension with depth.

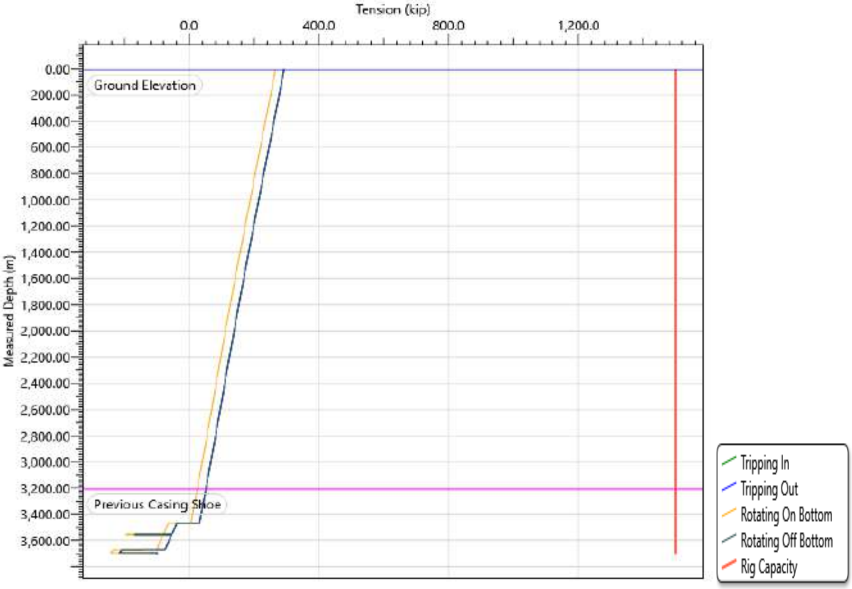


Figure 5. Variation of true tension with depth.

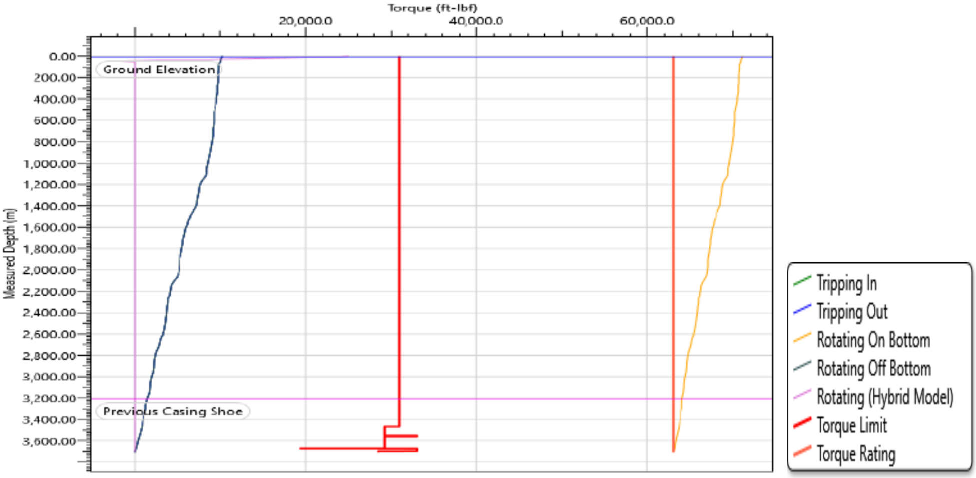


Figure 6. Variation of torque with depth.

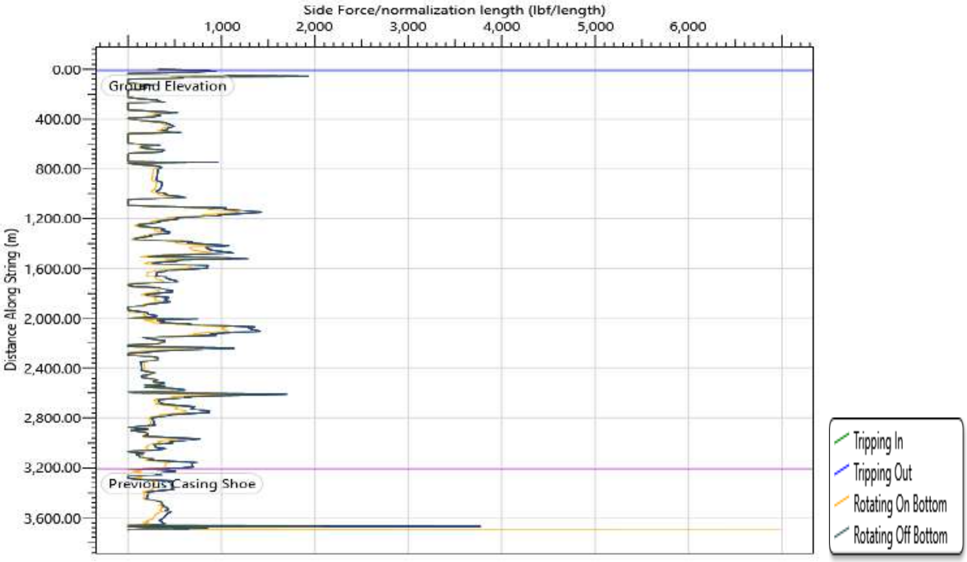


Figure 7. Variation of side force along the drillstring.

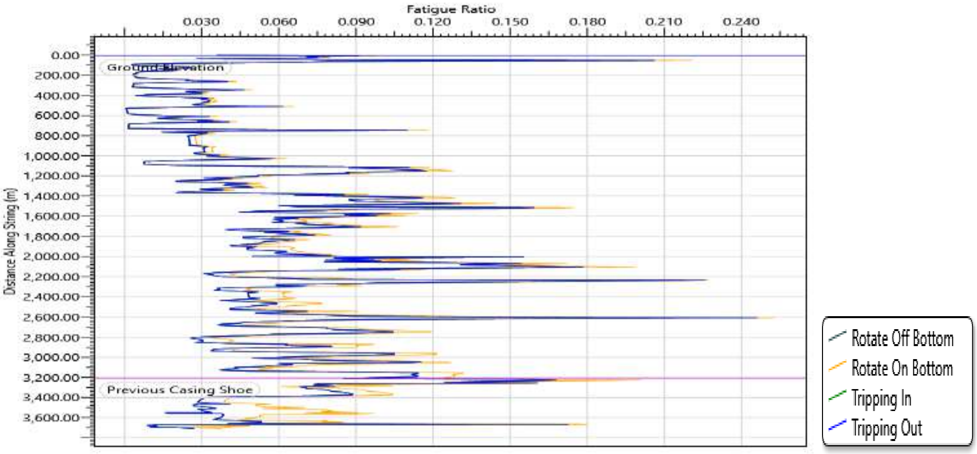


Figure 8. Variation of fatigue along the drillstring.

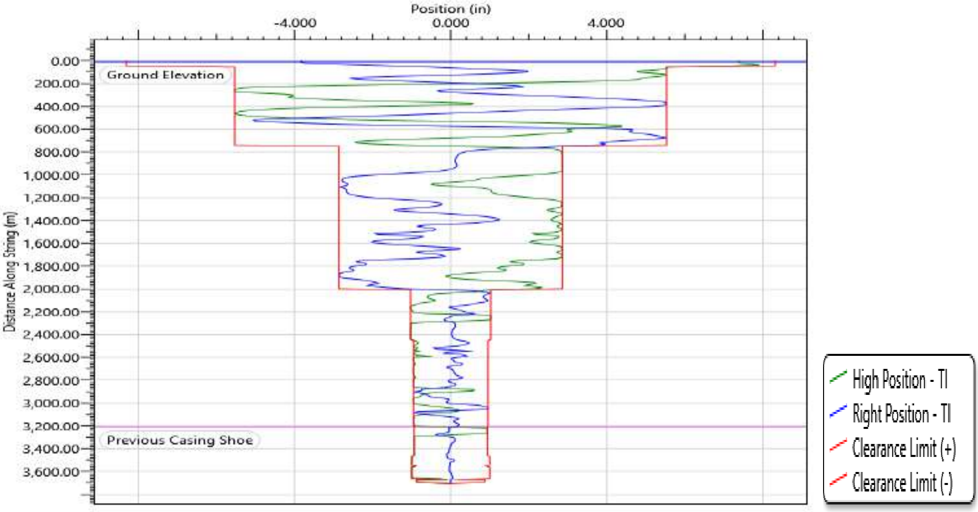


Figure 9. Variation of string clearance along the drillstring during tripping in.

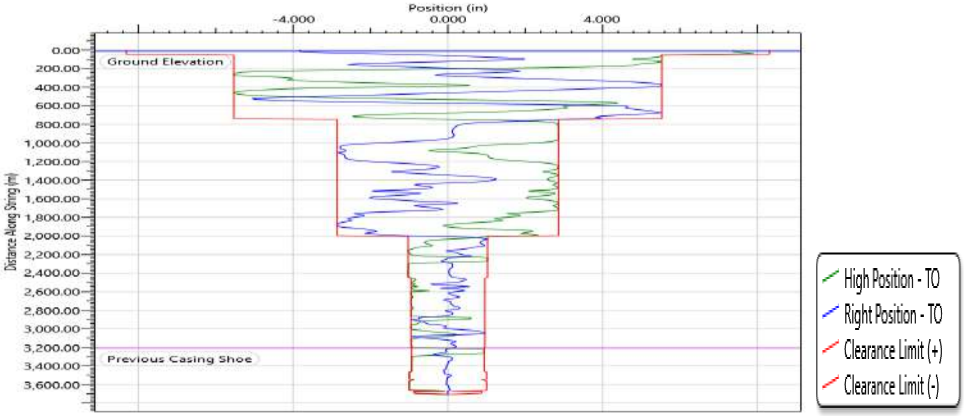


Figure 10. Variation of string clearance along the drillstring during tripping out.

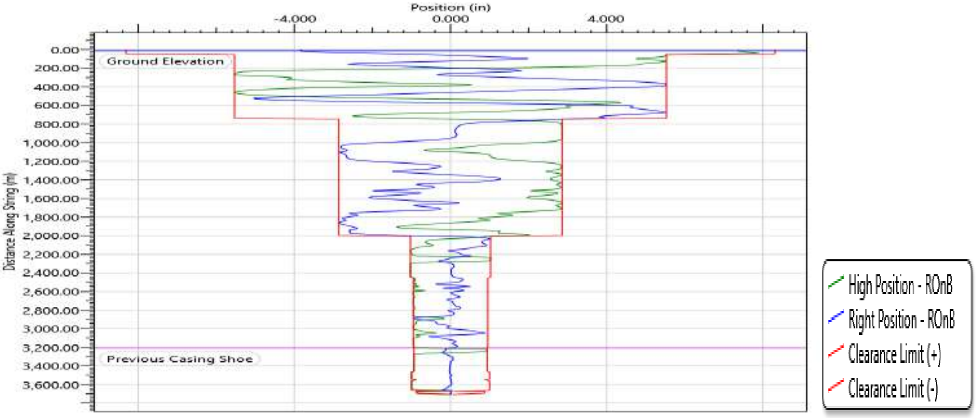


Figure 11. Variation of string clearance along the drillstring during rotation on bottom.

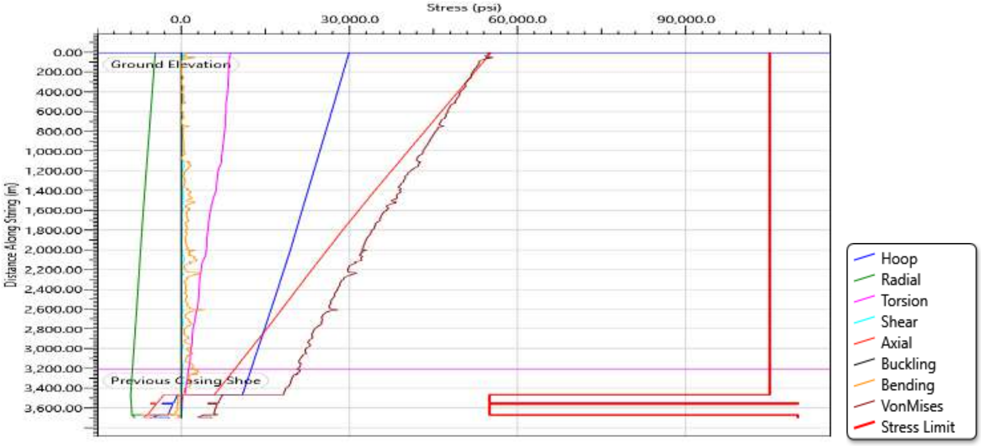


Figure 12. Stresses variation along the D/S during tripping in.

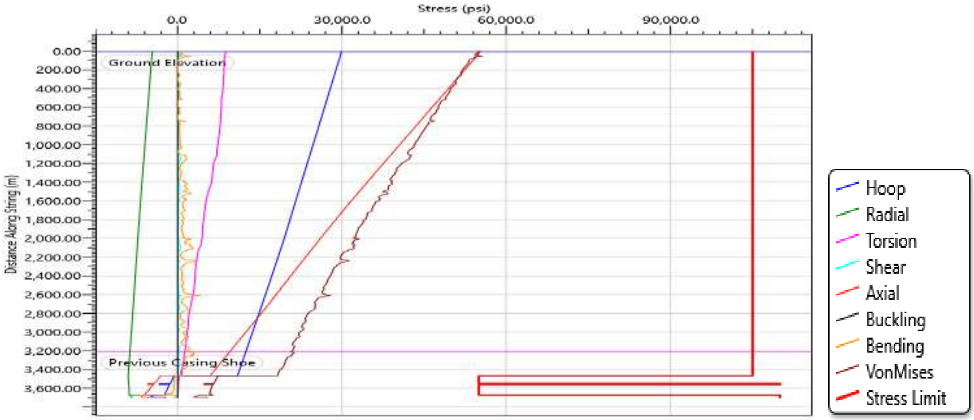


Figure 13. Stresses variation along the D/S during tripping out.

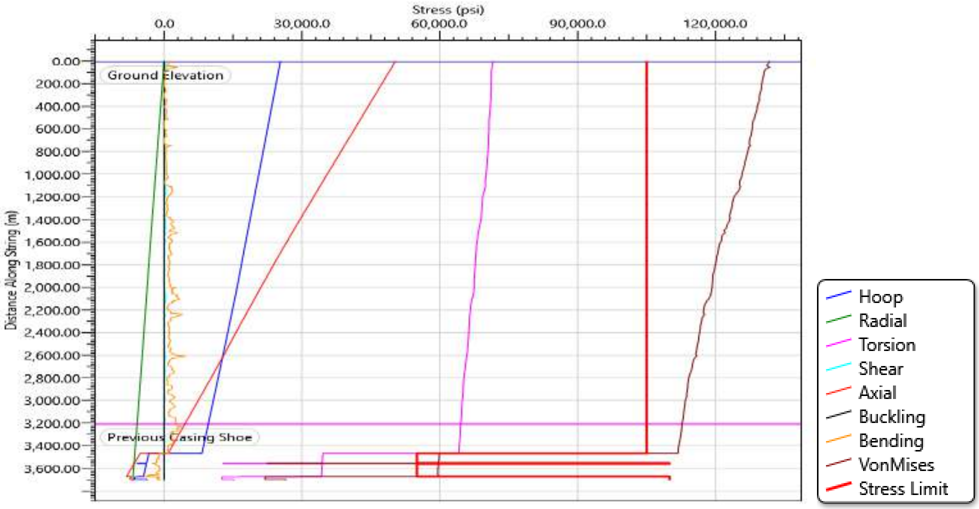


Figure 14. Stresses variation along the D/S during rotating on bottom.

For BHA Dynamics, the BHA Flow display allows a 3D inspection of the inactive foot gap assembly that has been constructed in compliance with various wellbore geometries at varying slants and bearings. A complex module that combines the earlier BHA investigation and basic speed investigation is the BHA Flow. This module gives you the ability to foresee a run of rpms that may cause vibratory issues. Additionally, it's critical to predict how foot gap congregations will execute their directed digging. The construct, hold, and drop inclinations of various groups, as well as the directional inclinations for anticipating cleaned out or right hand walk rate and carrying out Basic Speed Investigation, may all be calculated using the plots made accessible under this module. Contact powers at the bit, stabilizers, and collars are also measured, and these results may be used to estimate how much stabilization is required. A common cause limited component program is used in the scheme. A relatively recent and exceptionally effective method for resolving practical problems in a range of engineering fields is finite element analysis (FEA). Here is a high-level description of the solution scheme because the theory behind FEA is extremely complex [--]:

1. A discrete nodal point separation of the Bottom Hole Assembly is performed using a finite element grid generator. The user's lengths, structural characteristics, and all diameters are used in this procedure.
2. The wellbore diameter and wellpath (MD, INCL, AZIMUTH) data are utilized to define the hole shape.

3. Calculations have been made for each node's axial force, torque, stresses, and X, Y, and Z coordinates.

The construction and build rates may be anticipated using these presumptions. When the bit travels through the wellbore, forces are generated in three directions: axially (hole axis), vertically (inclination axis), and horizontally (direction axis). Additionally, the bending characteristics of the BHA contained in a wellbore will result in a little tilt in the azimuth and inclination axes. These components will interact to produce the borehole path. The application calculates and displays each of these numbers for a specific place. To identify critical rotational speeds and areas of high stress in the drill string, BHA Dynamics may also be used. The discovered results can be used to stay away from rotational speeds that are too high and lead to catastrophic drill string failure by increasing pipe fatigue. Only utilize the relative (not absolute) estimated stresses to identify critical frequencies. To forecast and study the behavior of the drill string and the BHA dynamics of the well from Lebanon, simulations and modeling studies were carried out. Additionally, the drill string's vibrations were measured and examined. Additionally, the rotating system has been adjusted to identify and forecast the tension, resultant stress, drill string displacement, shear force, torque, axial force, axial displacement, and torque components. In relation to the distance from the screed, all of the aforementioned variables are measured. The outcomes of the simulation research are displayed in Figures 15 through 17. More details are presented in the following section separately.

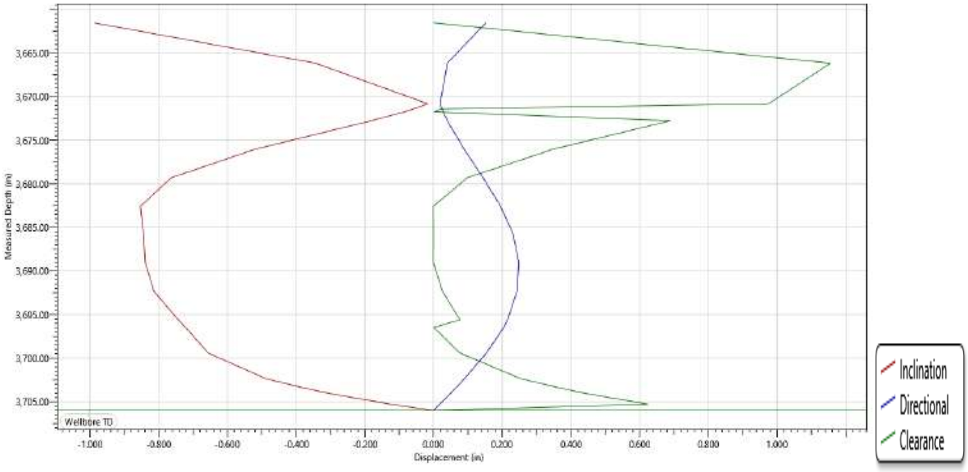


Figure 15. Displacement variation with depth: Inclination, directional and clearance.

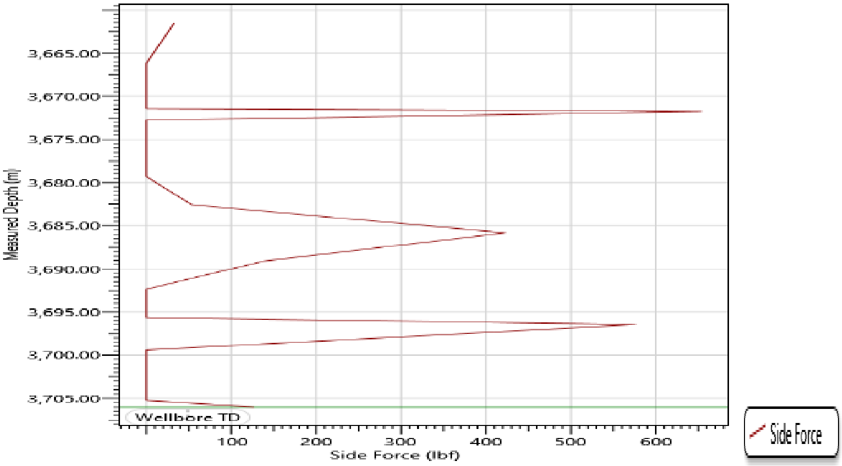


Figure 16. Side force variation with depth.

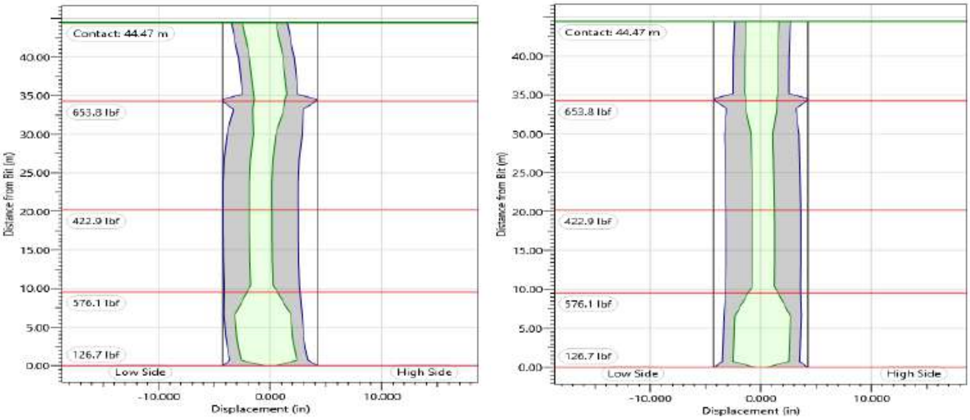


Figure 17. Well profile: (a) Inclination and (b) Directional.

To analyze the resulting vibration in the 8 ½” hole section of well ZB-349, Figures 18 through 26 show the variation of drillstring stresses, forces, displacements and moments due to various vibrations resulting during drilling such as axial, lateral, and torsional. Stress components and their resultant/ equivalent are appeared in Figures 18 &19. It is appeared that the axial stress shows the highest value among the others. Further, the axial and side forces are presented in Figures 20 &21 while the different displacements resulting along the D/S are shown in Figures 22 through 24. The moment and resulting torque are plotted in Figures 25&26.

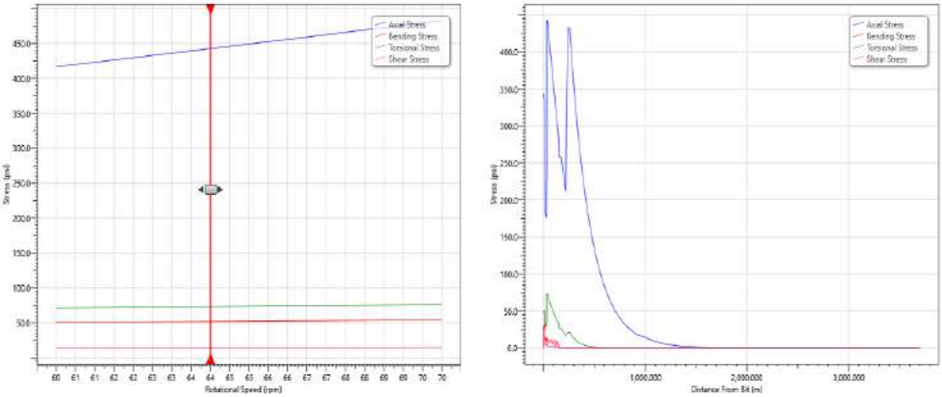


Figure 18. Stress components with D/S speed and distance from bit.

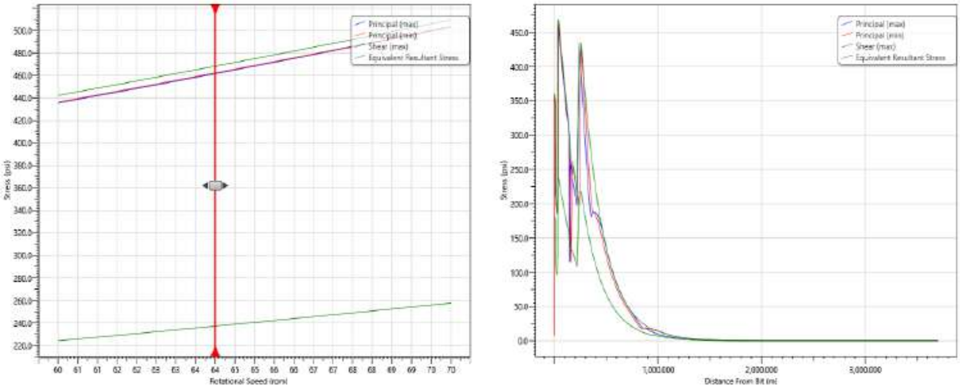


Figure 19. Resultant Stress variation with D/S speed and distance from bit.

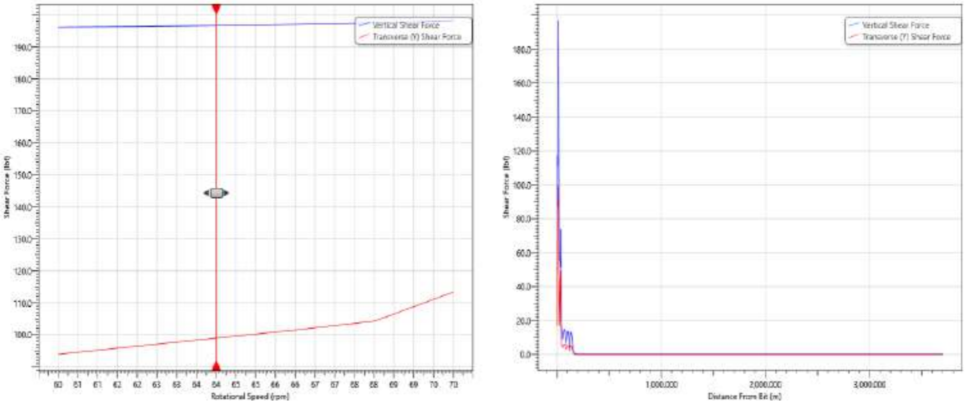


Figure 20. Shear force variation with D/S speed and distance from bit.

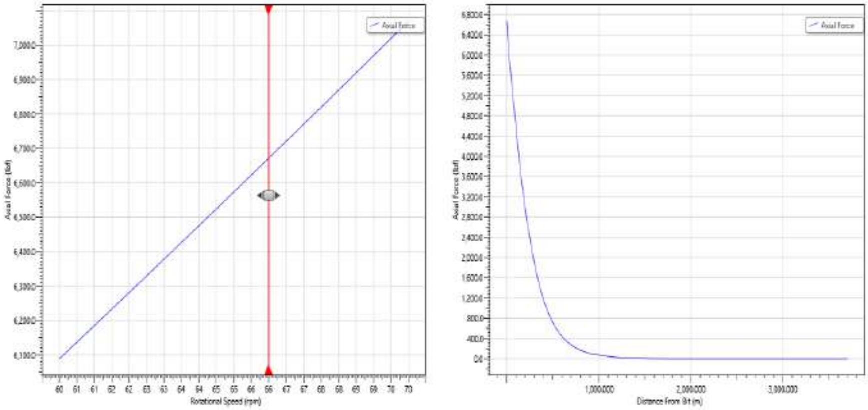


Figure 21. Axial force variation with D/S speed and distance from bit.

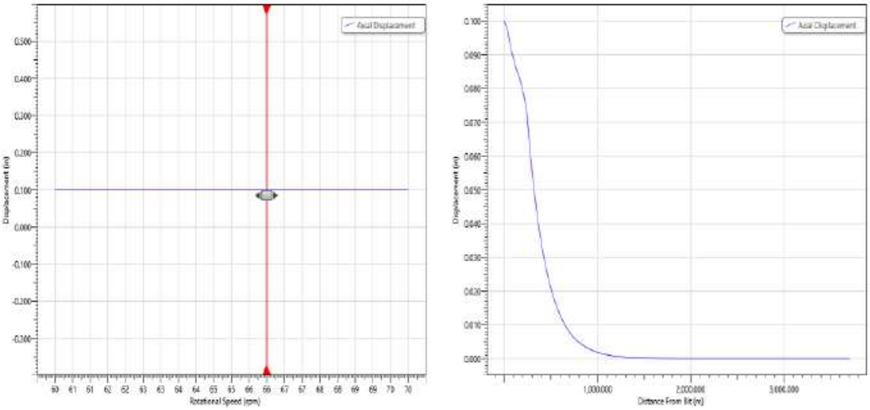


Figure 22. Axial displacement variation with D/S speed and distance from bit.

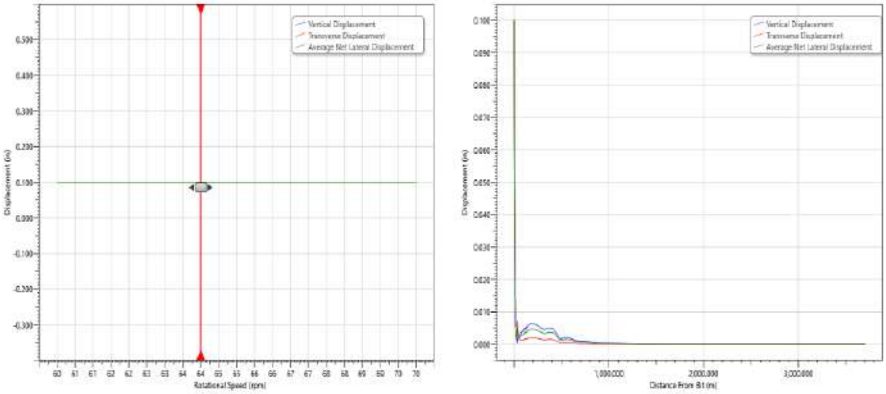


Figure 23. Displacement variation with D/S speed and distance from bit.

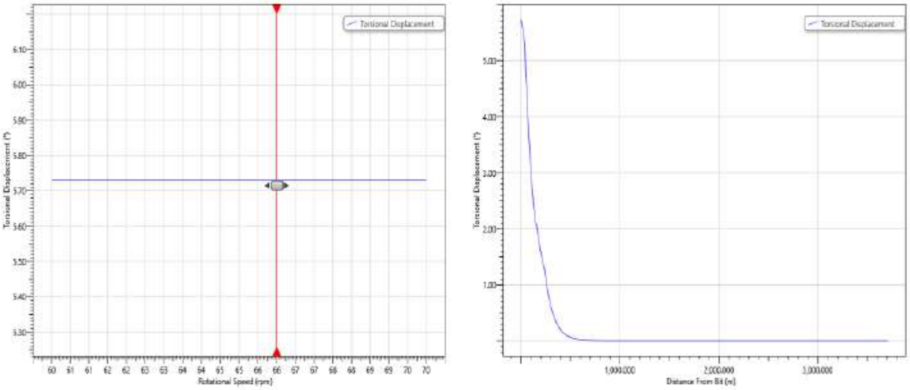


Figure 24. Torsional displacement variation with D/S speed and distance from bit.

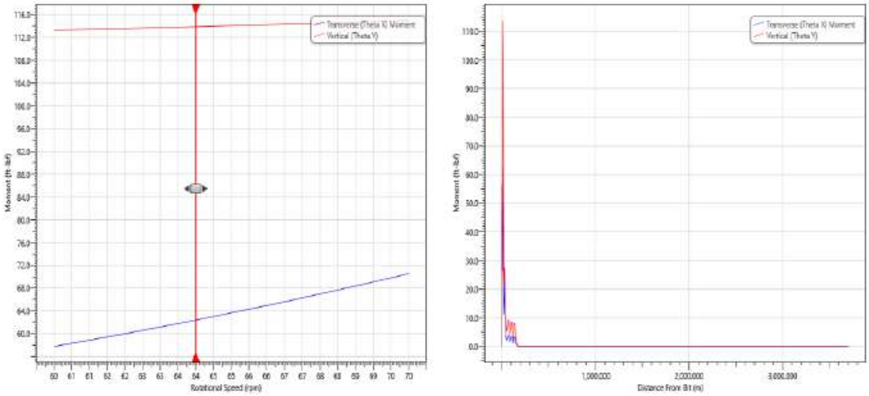


Figure 25. Moments' variation with D/S speed and distance from bit.

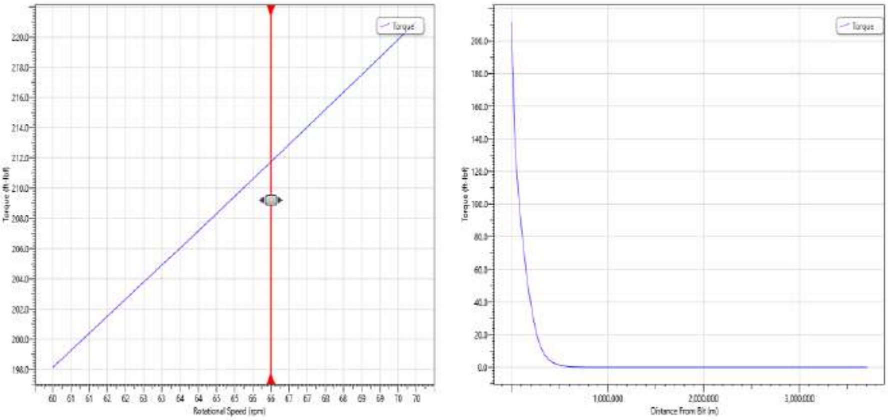


Figure 26. Torque variation with D/S speed and distance from bit

5. Conclusions

A simulation study was performed to analyze the drillstring vibrations and BHA mechanics of the directional well ZB-349 that was drilled in Southern Iraq field called Zubair. Based on the simulation results and discussion, the following extracted points are concluded:

1. It is important to check the drilling parameters range given in the drilling program, maybe, it needs to be changed or modified for the future development wells.
2. Well planning will be improved using the simulation for future activities.
3. Selection of the optimum drilling parameters range is a key-element for enhancing the drilling performance, reducing the well problem and then reducing the non-productive costs.
4. It can be detected from the simulation study which parameter has a great effect on the resulting vibration analysis.
5. It is recommended to this study for each well before and after drilling so as to know from where appear the obstructions.

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