Egyptian Journal of Petroleum (2016) xxx, xxx–xxx

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Egyptian Journal of Petroleum

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FULL LENGTH ARTICLE

A study of friction factor model for directional wells

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Received 31 January 2016; revised 15 June 2016; accepted 4 July 2016

KEYWORDS

Wellbore friction;
Modeling;
Directional drilling;
Torque and drag;
Aadnoy's friction model

Abstract High torque and drag is one of the main problems in the directional wells. Friction models can be used for analysis during planning, drilling and after finishing the well. To have an accurate model it is very important to have the correct friction factor. This paper studies one of these models called Aadnoy's friction model. The purpose of this paper is to make an investigation on the limitations of the model, and also to find out how much the model can help for detecting the downhole problems. The author used an Aadnoy's based excel sheet done by TL Longbow Prime company for studying the model. The model has shown reliable results for slant wells which helped to estimate the downhole issue (Bitumen – high viscous oil). Also good torque results had been obtained for horizontal section despite the poor drag results. In the paper three different well profiles has been used during the study.

1. Introduction

Torque and drag result from the friction between the drill string and the wellbore. Torque and drag calculations are very important during planning phase and operating phase of the well. The success of the well can be affected by torque and drag presence especially in deep and complex wells. For instance, high torque and drag forces are important limitations in extended reach drilling because they prevent to reach drilling targets [14]. Therefore, the focus on torque and drag model has been increased by increasing the number of extended reach drilling [7,8].

Running torque and drag model is a very important factor to drill the wells successfully. Usually a model based on frictional analysis is used to study the effect of friction on torque and drag readings. The friction factor is maybe the most uncertain factor in the calculations. This is because the friction fac-

☆ This paper was prepared for presentation at the Final discussion for Partial Fulfillment of M.Sc. in Petroleum Engineering held in Suez University, Suez, Egypt, 22 Feb, 2016.

Abbreviations: 2D, two-dimensional; 3D, three-dimensional; BHA, bottom hole assembly; ECD, equivalent circulation density; ERD, extended reach drilling; ERW, extended reach wells; HD, horizontal departure; HL, the hook load. Displayed by the weight indicator; HKL, the hook load. Signature in real time data file; MD, measured depth; POOH, pulling out of hole; PRS, pick up/rotate/slack off; RIH, running in hole; ROP, rate of penetration; RPM, revolutions per minute; SPP, stand pipe pressure; TVD, true vertical depth; TRQ, torque. Signature in real time data file; WBM, water-based mud; WOB, Weight on bit; RSS, rotary steerable system; PDM, positive displacement mud motor; MW, mud weight; PDC, polycrystalline diamond compact; DD, directional driller; TL, Trant-Logistics Company; PWD, pressure while drilling.

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Peer review under responsibility of Egyptian Petroleum Research Institute.

http://dx.doi.org/10.1016/j.ejpe.2016.07.004
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Nomenclature

α	wellbore inclination, radians	H_r	hook load while rising, calculated in analysis, tons
$\Delta\alpha$	change in inclination over section length, radians	HKL	the hook load, tons [kN]
Φ	wellbore azimuth, radians	L	length of element, m
$\Delta\Phi$	change in azimuth over the section length, radians	MF	mud flow, l/min
θ	absolute change in direction/dogleg, radians	r	radial clearance between wellbore and work string, m
μ	friction factor	R	radius of curvature, m
β	buoyancy factor	RPMB	revolutions per minute or average rotary speed, (–)
F_1	the bottom force of a pipe element, N	s	length of the section, m
F_2	the top force of a pipe element, N	SPP	stand pipe pressure, bar
F_{down}	slacking force, N	T	torque, kNm
F_F	frictional force, N	TJ	tool joint, m [inch]
F_N	side or normal force, N	W	buoyed weight of the pipe, N
F_{up}	pulling force, N	w	unit weight of pipe, kN/m
ΔF	difference in Fup and Fdown, N	W_{tb}	weight of traveling block, tons
H_l	hook load while lowering, calculated in analysis, tons		

tor is not a measured parameter but it is a fudge factor. This fudge factor depends on other effects including mud system lubricity, pipe stiffness, cuttings beds, hydraulic piston effects and tortuosity [18]. To have an accurate model, it is very important to find appropriate friction factors for different drilling situation. To judge any model whether it is good or bad, we have to judge the model quality and how much easy it is to use.

In the present paper, the author will study Aadnoy's friction model by applying real well data for different hole conditions and will compare the model with field data. The main objective of the paper is to study the validity and limitations of Aadnoy's model. Because the fudge factor or the friction factor is one of the important factor for any torque and drag model, the main goal is to model the friction factor for different hole conditions to find out if the model can be used to predict the downhole condition.

2. Literature review

In this section, a short review on the previous work has been done for torque and drag models.

2.1. Torque and drag models review

The first contribution to understand the friction in the well was developed by Johansick [22]. He has developed a torque and drag model based on basic equations for friction in deviated wellbores. In 1987 Sheppard et al. improved Johansick model by changing the model into standard differential equations [21]. In 1993 a well has been drilled in the Wytch Field in England by British Petroleum (BP). The well profile was ERD well with 10.1 km horizontal displacement from the onshore platform. Drilling this well proved to the industry that the targets were earlier seen as out of reach became accessible. From this time extended reach drilling wells increased globally. One of these wells was in Al Shaheen field in Qater with 12.3 km MD drilled by Maersk in 2008 [9]. From these types of wells a more understanding of downhole forces improved the torque and drag models, because they limit distant drilling objects and decide the success of the well [4,12]. In 2001 Aadony and Andersen developed a new analytical solution to present the wellbore frictions [19]. These geometries include straight, drop-off and build up sections. In 2008, Aadnoy et al. [15] made the analytical model simpler and entered the movement of the drill pipes up or down. In 2010 Aadony et al. improved this model for different geometries [12]. The Author had used an excel sheet based on the model done by Aadnoy et al. [15].

Torque and drag analysis has proven to be useful in well planning/design, real time analysis and post analysis. Practically torque & drag model's analyses are a combination of study of historical behavior, improves the experience, utilize engineering models and use of that analysis, to be able to study the well bore condition and reduce the downhole problems. Every time we use the model we have to calibrate the model at the beginning of each section.

2.2. Friction factor

In Coulomb friction model, the friction coefficient between an object and a surface is defined as the ratio of the friction force F between the object and the surface and the normal force N of the object on the surface. The situation is called static, if a force acts on a body, until the maximum friction force is reached. At this moment in time the body starts moving.

The Coulomb friction model can be described in the following Eq. (1) and Fig. 1, can be expressed as.

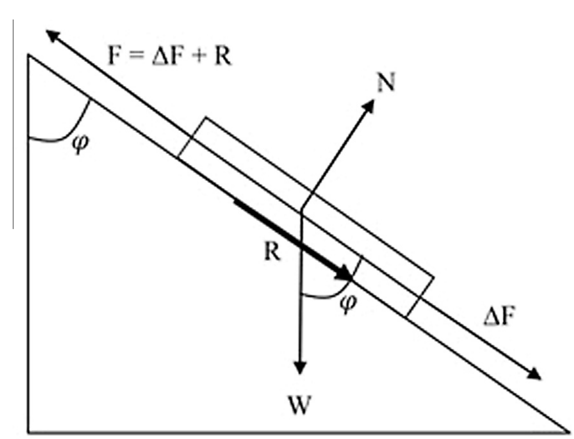

Figure 1 Friction in a deviated well.

$$\mu = \frac{F_f}{F_n} \quad (1)$$

where μ is the Coulomb friction coefficient. In Eq. (1) the inequality sign is valid as long as the body is stationary (static friction), while the equality holds once the body starts moving (dynamic friction). The friction coefficient is a property of the two surfaces in contact with each other. During the drilling operation the drill string is always in contact with the inside of the hole. For any torque and drag model, the friction force and the weight of a drill string element affect in the total load of the drill string. A high value of μ means the material needs to overcome a large resistance to start motion. Once there is motion, the friction force reduces, and acceleration takes place. At this threshold of motion, the static friction coefficient, μ_{static}, changes to the dynamic friction coefficient, μ_{dynamic}. This dynamic is lower than the static friction coefficient.

In the drilling process this phenomenon can cause a vibration in the drill string called "stick-slip". As the drill string rotates there is friction between the bit and the formation and between the formations. When the bit is encountering too much friction, it will remain stationary on bottom and will not rotate. Subsequently, the friction force increases as the drill string torques up. When the friction force reaches a threshold value the bit starts to accelerate and exceed the drill string neutral position. In effect, the drill string acts like a giant dampened spring and the bit angular velocity will decrease till the motion stops. The drill string exceeds the bit rotating speed again and starts to wind up until it reaches the threshold value once more.

3. Mathematical model

Torque and drag models have the following benefits:

- During planning trajectory we can adjust or change it for minimum torque and drag.
- During drilling we can predict the down hole problems before major problem happens.
- Torque and drag model can help us to select better BHA.
- During drilling we can monitor the hole cleaning performance.
- Can help us for better casing run.
- During planning phase, the model can help us to select the proper BHA weight to prevent pipe buckling.
- To select the right pipe grade to handle the pre-calculated torque and drag.
- The torque and drag model can help us for mud drilling program and hydraulics calculations.

In the following section we will try to summarize Aadnoy's model equations

3.1. Drag

3.1.1. Drag in straight sections

In the straight sections the friction is based on the normal weight component. If we divide the drill string to elements the top force for each element is given by Eq. (2), where the cos α-term is representing the weight if the element, while the sin α-term represents the additional friction force required to move the pipe element. The plus sign in Eq. (2) is for pulling while minus is for slacking, and the equation is valid for both the 2D model and the 3D model [12].

$$F_2 = F_1 + \beta \Delta L w(\cos\alpha \pm \mu \sin\alpha) \quad (2)$$

3.1.2. Drag in curved sections

For curved section, the friction is based on the tension on the string more than the weight component. In some cases the tension could be more than the weight of the string element. For curved sections there are different equations for the 2D model and the 3D model, where the first four equations are for the 2D model, and Eq. (7) is for the 3D model [12].

Eq. (3) is for POOH and Eq. (4) is for RIH in a drop-off bend.

$$F_2 = F_1 e^{\mu(\alpha_2-\alpha_1)} + \frac{wR}{1+\mu^2}\begin{bmatrix}(1-\mu^2)(\sin\alpha_2 - e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1) \\ -2\mu(\cos\alpha_2 - e^{\mu(\alpha_2-\alpha_1)}\cos\alpha_1)\end{bmatrix} \quad (3)$$

$$F_2 = F_1 e^{-\mu(\alpha_2-\alpha_1)} + wR\left[\sin\alpha_2 - e^{-\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right] \quad (4)$$

The following two equations; Eqs. (5) and (6), are sequentially for POOH and RIH in a build-up bend.

$$F_2 = F_1 e^{-\mu(\alpha_2-\alpha_1)} - wR\left[\sin\alpha_2 - e^{-\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right] \quad (5)$$

$$F_2 = F_1 e^{\mu(\alpha_2-\alpha_1)} - \frac{wR}{1+\mu^2}\begin{bmatrix}(1-\mu^2)(\sin\alpha_2 - e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1) \\ -2\mu(\cos\alpha_2 - e^{\mu(\alpha_2-\alpha_1)}\cos\alpha_1)\end{bmatrix} \quad (6)$$

For the 3D model Aadnoy generate two equations; one for POOH and one for RIH, where the plus sign is for pulling while minus is for slacking [12]:

$$F_2 = F_1 e^{\pm\mu|\Delta\theta|} + \beta\Delta L w\left(\frac{\sin\alpha_2 - \sin\alpha_1}{\alpha_2 - \alpha_1}\right) \quad (7)$$

3.2. Torque

3.2.1. Torque in straight sections

For straight section the torque is normal moment multiplied with the friction factor, Eq. (8). This equation is valid for both 2D and 3D model [12].

$$T = \mu r w \Delta s \quad \sin\alpha \quad (8)$$

From Eq. (8), torque will be zero when a vertical bend (α equal to zero), while the torque will be maximum when a horizontal section (α equal to 90 degree). In case the drill pipe only in rotation, the axial friction has no effect, and the direction of the motion has no effect on the torque.

3.2.2. Torque in curved sections

Torque with no drill string axial motion with a drop-off bend the in 2D model is presented by Eq. (9), while torque based on the 2D model in a build-up bend is given by Eq. (10) model [12].

$$T = \mu r(F_1 + wR\sin\alpha_1)(\alpha_2 - \alpha_1) - 2\mu r w R(\cos\alpha_2 - \cos\alpha_1) \quad (9)$$

$$T = \mu r(F_1 + wR\sin\alpha_1)|\alpha_2 - \alpha_1| + 2\mu r w R(\cos\alpha_2 - \cos\alpha_1) \quad (10)$$

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For 3D model Eq. (11) is applicable for torque with the 3D model the drill string is on stationary no movement up or down.

$$T = \mu r F_N = \mu r F_1 |\theta_2 - \theta_1| \quad (11)$$

3.3. Combined axial and rotational motion

The current model still can't be used for estimating frictions in combined axial and rotational motion cases. However the experience from the field showed that the drag will be less when the drill string is rotating [16]. So this case is not included in the current study.

3.4. Model selection and input data

Selecting the model type whether 2D or 3D depends on the well geometry. We normally select the 2D model in case the well is in a single plane in other words azimuth is negligible however we can select the 3D model. Studies have shown that either procedure should give approximately the same solution [10]. As a general rule of thumb; the friction is considered higher for more side-bends throughout the wellbore trajectory [13]. There are different forces applied on the drill string including axial, bending, friction and hydraulic loads Fig. 2 [20].

For 2D and 3D models; to describe the inclination change or azimuth change normally use the sing + or – to describe this change Tables 1 and 2. In the tables sign "+" means increasing in an angle, "–" means decreasing, while "constant" means that the angle didn't change [6].

As a good practice, the model calibration is very important during drilling operation, based on trial and error method to calibrate and find the proper friction factor Fig. 3 [5]. The following data have been used during running the model using the TL Longbow Prime excel sheet, the excel sheet can accept English or Metric units:

- Rig data (travel block weight)
- Fluid properties (Buoyancy factor)
- The unit weight of the drill pipe
- The length of the drill pipe [m]
- BHA unit weight
- Largest radius on the BHA (bit radius)

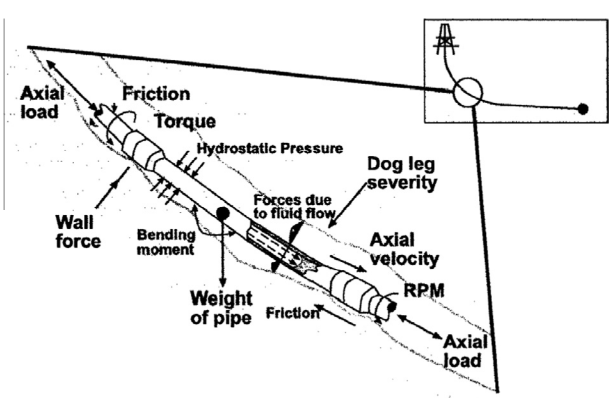

Figure 2 Forces acting in a downhole bend [20].

Table 1 Characterizing different sections in the 2D model [6].

Type of section	Inclination	Azimuth
Straight/vertical	"Constant"	"Constant"
Build-up	"+"	"Constant"
Drop-off	"–"	"Constant"
Side bend	"Constant"	"+" or "–"
Horizontal	"Constant"	"Constant"

Table 2 Characterizing different sections in the 3D model [6].

Type of section	Inclination	Azimuth
Build-up with right side bend	"+"	"+"
Build-up with left side bend	"+"	"–"
Drop-off with right side bend	"–"	"+"

- Measured depth
- Measured inclination
- The friction coefficient
- Weight on bit used during drilling
- Bit torque during drilling

3.5. Quality control for real time data

Pickup/rotate/slack off test (PRS test) is very important test for torque and drag calibration and during daily drilling operation. Normally we have to do the PRS test to calibrate the model at the casing shoe to determine the correct friction factor. Also during drilling operation we use this test to record free rotating weight, free rotating torque, pick up weight and slack of weight after drilling each stand. Also we can record that reading when the pumps are off is an optional [17].

For better and accurate reading a clear procedures must be followed and also with the same parameters (RPM and hoisting system speed). This procedure making readings before connection has been used successfully Fig. 4 [11]:

Pumps are ON for all these measurements:

- After stand down, Drills off the weight.
- Back ream pulling up at a fix speed, and according to DD-approved back reaming RPM and DD-approved interval: 1 single, 2 singles or complete stand of DP.
- At the top of the back ream interval, stop and rotate freely at 80 RPM for 30 s.
- Record the free rotating weight and free rotating torque. Then, continue by reaming down with same back reaming RPM.
- Pull up at a consistent speed to DD-approved interval without rotary. Make sure we are above stretch distance.
- Record pickup weight.
- Work back down at consistent speed. Record slackoff weight.
- Set slips.

By following these procedures the accuracy of the results will be increased. Some clients prefer to measure off bottom rotating weight before turning on the pumps after the connection is made. An important point is to achieve a good clean

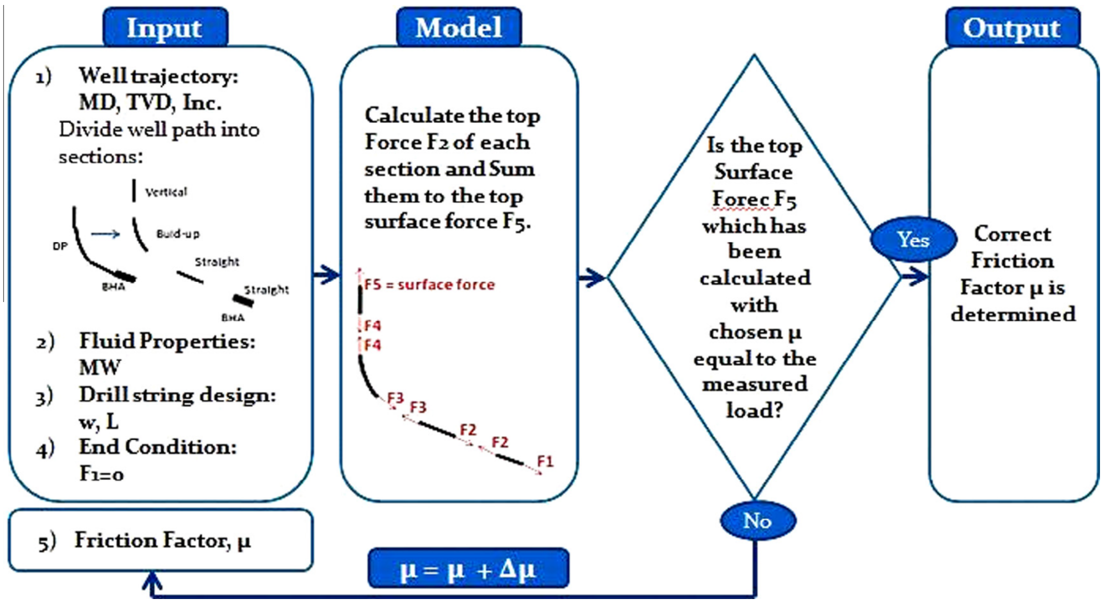

Figure 3 Flow diagram for finding a proper friction factor that match the estimated surface load with the measured surface load [5].

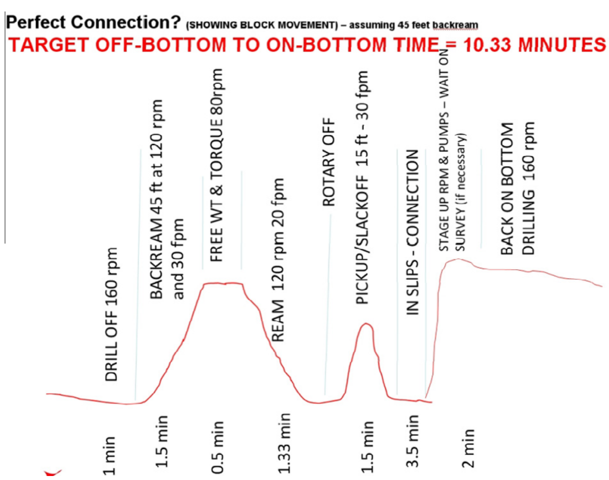

Figure 4 Connection procedures and PRS test [11].

baseline before the casing shoe is drilled, and then friction factors can be adjusted in for a clean well. This makes it easier to later diagnose drilling problems.

4. Field case

In this paper the friction model will be applied on real wells. First relevant data of the applied wells are presented in this section followed by results and discussion from modeling friction in the next section.

To cover different hole conditions Three wells; Well-A, Well-B and Well-C, will be presented with relevant field data to run the friction model.

4.1. Field data of Well-A

The presented dataset of Well-A is taken from the final well report. Well-A is an appraisal well in the Field located in the Federal Region of Kurdistan, and was completed to a TD of 5175 m measured depth (MD).

The well has been drilled to 12.25″ section where encountered a BHA lost in hole. Decision was to side track in 12.25″ section and hit the original targets. For bad trajectory control they had high DLs which caused the too much torque and drag. So another side track has been decided to do and a slant well was drilled based on the well plot Fig. 5 [3].

After a successful side track and drilling 12.25″ hole section to a depth of 2903 m, the 9 5/8″ Intermediate 3 Casing has been set. The 8.5″ section has been drilled with a concern with Jurassic target reservoirs – Barsarin (4346-4588 m MD), Sargelu (Naokelekan) (4588–4765 m MD) and Sekhaniyan (4765–4819 m MD) formation. The potential risks for this section were well control, H2S, Loss circulation, differential sticking and drill string fatigue.

The 8 1/2″ hole section has been drilled with non-damaging Polymer/KCl based drilling fluid with mud weight 9.5 ppg. The mud rheological properties and flow rate have been optimized to provide superior hole cleaning and suspension, to prevent washouts and fulfill overall hydraulic requirements.

The 8 1/2″ directional BHA included an NOV PDC Bit 6×15 jets and NOV PDM with 1.15 deg and Jar, new MWD tools have used Table 3 [3].

The 8 1/2″ section has been drilled where encountered a torque and drag issue in 4500 m MD will be discussed in the next section in detail.

4.2. Field data of Well-B

The second well we are going to include in the paper is a horizontal well (WELL-B). Well-B is a production well in a Field located in the Federal Region of Kurdistan, and was completed to a TD of 3016 m measured depth (MD).

The objective for Well-B is to be landed at 90 degrees in Shiranish S1 target and drill 1000 m of Horizontal section to

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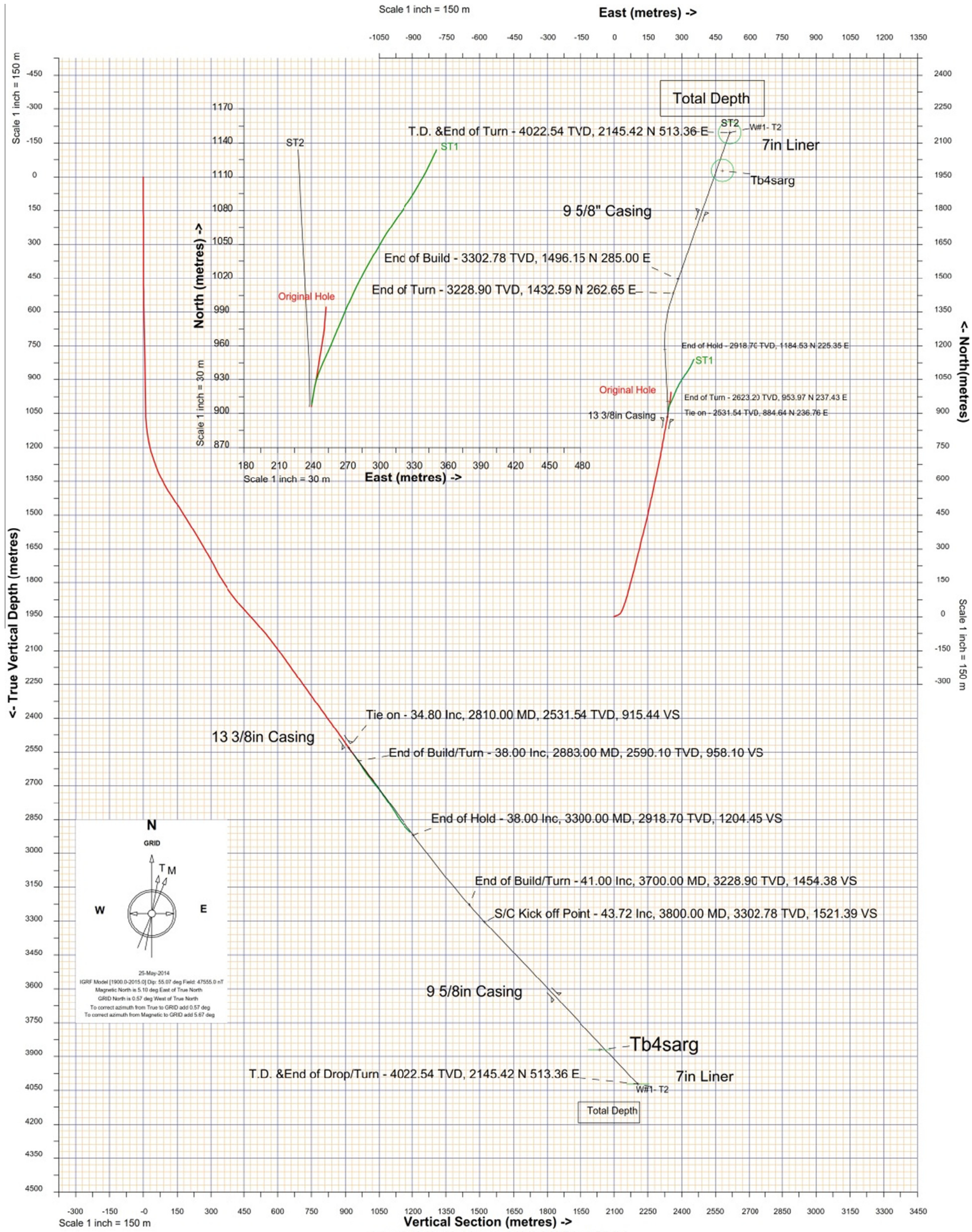

Figure 5 Well-A well plot [3].

TD and complete the well as a horizontal producer by draining oil from the Cretaceous reservoir. Also objective was to increase the productivity of the well.

After setting the 95/8″ casing the well has been drilled to TD using two BHAs. The first BHA was PDM BHA used to land the well to 90 degree inclination from 1900 m MD to

Table 3 8 1/2″ hole section BHA for Well-A [3].

Name	Overall length (m)	Accumulated length	ID (in)	OD (in)	Acc. weight (klb)
Assembly description					
5″ 19.5# G-105 NC50	4478.400	4767.840	4.276	5.000	383.010
5″ Hevi-Wate DP (15 jts)	136.760	289.440	3.000	5.000	57.570
6–1/2″ HM Drilling Jar S/N CW-770874–2	6.070	152.680	2 5/8	6 5/8	34.330
5“ Hevi-Wate DP (12 jts)	109.410	146.610	3.000	5.000	30.990
6 3/4″ PBL Circulating Sub SN: WES 675 SBP 511	2.830	37.200	2 3/4	6 3/4	12.400
6–3/4″ NMDC SN: 556412-6A	8.550	34.370	3 1/4	6 3/4	10.460
6–3/4″ MWD Flow Sub SN: 24667–7	0.930	25.820	3 1/4	6 3/4	7.710
6–3/4″ MWD (DNI & GR) SN: 556412-4A	9.410	24.890	3 1/4	6 3/4	7.410
6–3/4″ Pony NMDC SN: 563348-5A-2	4.290	15.480	3 1/4	6 3/4	4.200
8″ String Stabilizer SN: 0413379–356	1.770	11.190	2 3/4	6 3/4	2.820
6 3/4″ PDM 5/6 6.8S w/8 3/8″ S.Stab/1.15 bend w/Float Valve	9.170	9.420	2.000	6 3/4	2.260
8 1/2″ PDC Bit Haliburton	0.250	0.250		8 1/2	0.080

2109 m MD, and the second BHA was RSS BHA which has been used to drill the horizontal section Table 4 [2]. The second BHA was used with the required well data to evaluate the model for horizontal section. The well has been drilled based on the plan and the actual surveys have been used during the study Fig. 6 [2].

The drilling mud which has been used to drill this section was a reservoir drill in fluid with 9.5 ppg.

4.3. Field data of Well-C

This section contains a description of another well applied with the model, Well-C. The Shakal structure is located approximately 100 km southeast of the Kirkuk city, the city of Kifri lays on the SW flank of the structure and the city of Kalar is at the SE end. The structure trends NW-SE and is one of several anticlines in the area; it is on trend with Pulkhana structure where nine wells have been drilled to date.

Well-C is the second exploration well to the JERIBE and DHIBAN formation with a proposed total depth of 3100 m.

The major objective of the Well-C is to determine the presence of hydrocarbons in the Jeribe–Dhiban carbonates and collect data on the reservoir rock and fluids. Additional information on the overburden rocks will be collected to aid future drilling planning.

Due to the uncertainty of an exploration well and of the data available, a five string design was proposed. Also a contingency 5″ string is included in the plan in case well demands deepening down to Oligocene 3500 m.

After setting the 20″ Intermediate casing the well has been drilled to 18.5″ section where it encountered a drag issue. Which casued a drill string stuck problem and therefore caused BHA lost in Hole. We had used the data to evaluate the model including the acutal surveys and well plot Fig. 7 [4].

As our concern in this well is the 18 1/2″ hole section and we will display the data for that section. The purpose of selecting that section is studying the shallow hole depth results using Aadony's model.

The well profile is vertical. The drilling fluid used was The KCl/NaCl polymer system will be utilized. Salt and

Table 4 8 1/2″ hole section RSS BHA of Well-B [2].

Name	Count	Accumlength	ID (in)	OD (in)	Acc. weight (klb)
Assembly description					
5″ Hevi-Wate DP (15 jts)	15.000	1598.66	3.000	5.000	169.800
5″ 19.5# G-105 NC50 (138 jts)	138.000	1458.62	4.276	5.000	146.010
5″ Hevi-Wate DP (5 jts)	5.000	128.050	3.000	5.000	49.310
6–3/4″ Double Act Hyd Jar. SN kJ 14352	1.000	81.350	2.500	6.750	41.380
5″ Hevi-Wate DP (3 jts)	3.000	72.260	3.000	5.000	36.320
6 1/2″ Float Sub SN:PST-8864	1.000	44.120	2.678	6.500	31.540
6–3/4″ NMDC SN:556412-4A	1.000	43.190	2.810	6.750	31.090
6–3/4″ MWD Flow Sub SN:566977-2A-1A	1.000	34.030	2.810	6.750	28.150
6–3/4″ MWD SN:566080-3A	1.000	33.080	3.250	6.750	27.840
6–3/4″ LWD (GR/PWD) SN:270	1.000	23.690	3.250	6.750	24.640
8 1/4″ Non Mag String stab SN:SDT 8624	1.000	14.540	3.000	6.250	20.230
Pony non Mag Drill Collar SN:563348-5A-2	1.000	12.490	3.250	6.750	19.260
7″ RSS Tool (2 × Stabs) SN:144	1.000	8.210	1.938	7.000	17.950
RSS PIT Bull Stab SN:BBX812-05	1.000	0.570	2.000	8.375	0.400
Bit BH PDC Q506X, SN:7132501, Jets 3 × 14, 1 × 12, 2 × 15	1.000	0.350		8.500	0.290

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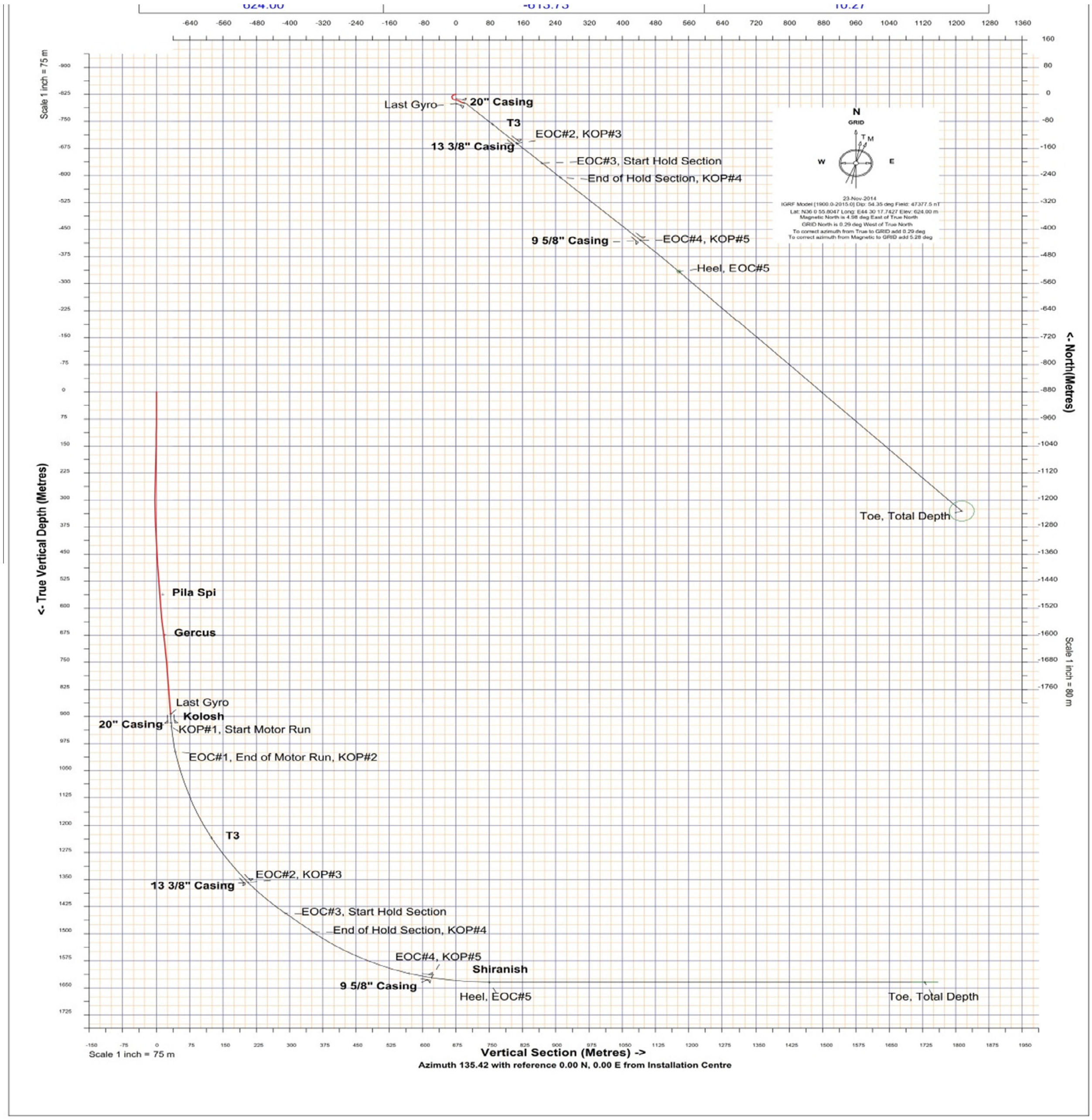


Figure 6 Well-A well plot [2].

shale inhibitors were used in the system for shale inhibition. The mud weight used to drill this section was 11 ppg.

A RSS/packed BHA is proposed to drill the 18 1/2″ hole to section TD. The BHA is designed to prevent hole deviation and ensure hole straightness. It is also designed to provide the required Weight on Bit (WOB) and improves bit performance in Tables 5 and 6 [4].

RSS is included to improve bit performance, A PWD tool was used to provide annular pressure measurements while drilling and will help to determine the back pressure during connections for the MPD system and MWD inclinometer is deemed necessary to assist in keeping verticality of the well.

The 18 1/2″ section has been drilled where it encountered a drag issue in 1907 m MD which will be discussed in the next section in detail [4].

5. Results and discussion

This section contains results from field cases with the selected friction model. The same procedure as discussed in Mathematical Model section is applied to model friction factor for the field wells.

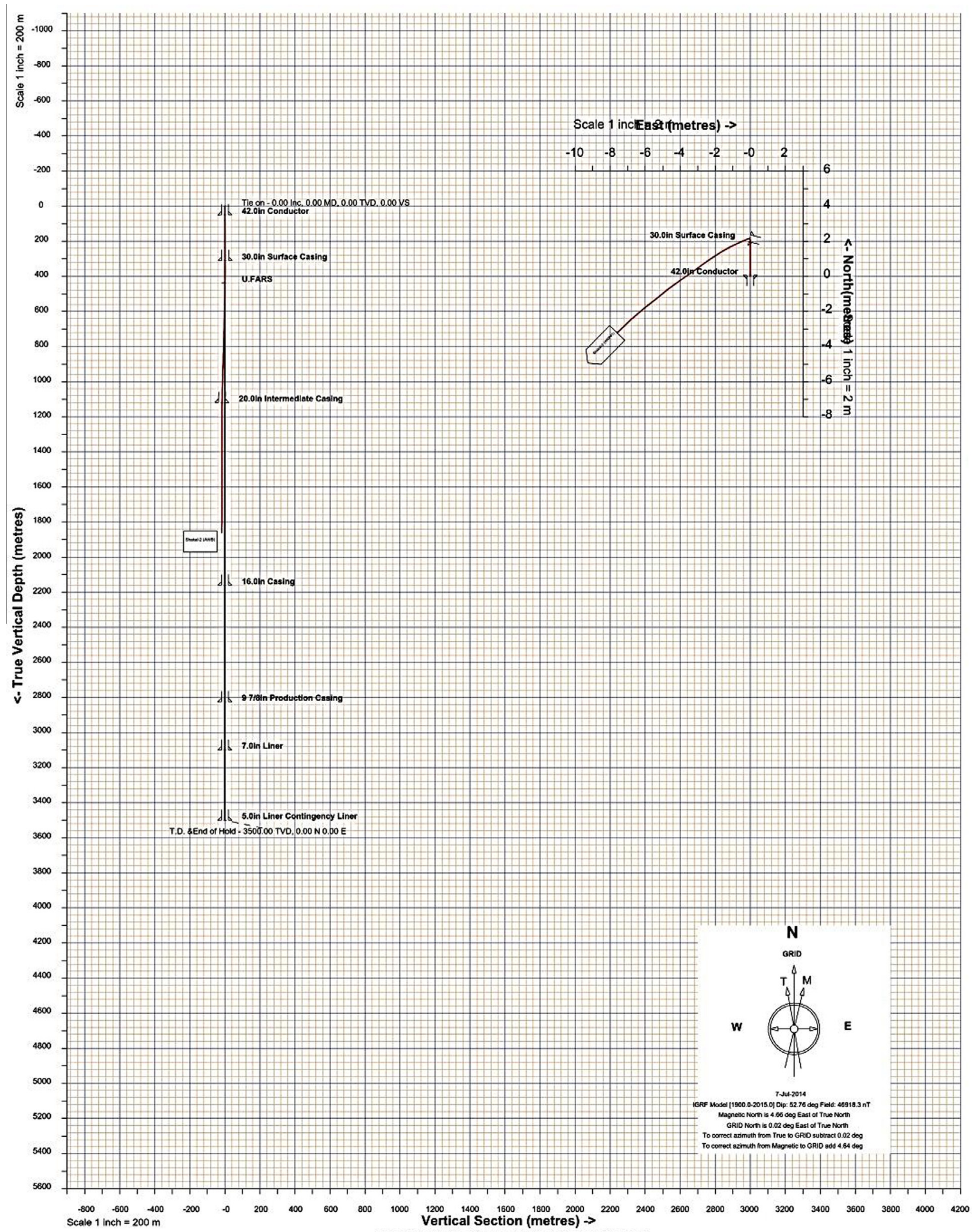


Figure 7 Well-C well plot [4].

5.1. Results and discussion of Well-A

The required input data which have been discussed in Section 3 are described on the model snapshot in Fig. 8. The well data had been converted to English unit and run the model. I had used friction coefficient as I had calibrated the model at the beginning of the section. However in software result we still can have results based on two other friction factors.

Table 5 18 1/2″ hole section RSS BHA for Well-C [4].

Name	Count	Accum length	OD (in)	ID (in)	Acc. weight (klb)
Assembly description					
5″ 19.5# G-105 NC50	170.000	1940.020	5.000	4.276	223.220
5″ Hevi-Wate DP (21 jts)	21.000	333.730	5.000	3.000	106.490
CrossOver 6 5/8 Reg to NC50 SER # – Rig CrossOver GreyWorf	1.000	131.560	8.000	2.813	72.140
8–1/2″ Drill Collar (1 jts)	1.000	130.780	8 1/2	3.000	71.880
8″ HM Drilling Jar – SER # – 800-186	1.000	121.320	8.000	2 3/4	67.340
8–1/2″ Drill Collar (6 jts)	6.000	115.810	8 1/2	3.000	65.890
CrossOver 7–5/8 Reg to 6–5/8 Reg SER# –Rig CrossOver GreyWorf	1.000	59.240	8.000	2 3/4	38.760
9 1/2″ Drill Collar (2 jts)	2.000	58.450	9 1/2	3.000	38.190
9–1/2″ PBL Circulating Sub – SER # – WES 950 BP175 = 2800 SHEARING PSI	1.000	39.590	9 1/2	2.270	24.600
18 1/4″ String Stab – SER # – 0413379-240	1.000	36.840	9 1/2	3.000	22.720
9 1/2″ Drill Collar (1 jts)	1.000	34.940	9 1/2	4.000	21.230
18 1/4″ String Stab – SER # – 0413379-238	1.000	25.760	9 1/2	3.000	14.810
MWD (DNI) – GAMMA - PWD – SER # – 565286-1A + 48557-4 + 48557-1	1.000	23.840	9 1/2	4.000	13.310
Float Sub (Ported) – SER # – NM-1043-014-2	1.000	12.430	9 1/2	2 3/4	6.240
(XO) SUB - SER # – 0413379-72	1.000	11.330	8.000	2 3/4	6.060
10″ WG RSS w/ two Stab's - SER # – 022	1.000	10.540	10 3/16	2 13/16	5.670
18 1/4″ WG Anti Spiral Sub SER # – 011	1.000	1.070	9 1/2	3.000	0.980
18 1/2″ PDC Bit – SER # – E161381	1.000	0.380	18 1/2		0.440

Table 6 18 1/2″ hole section RSS BHA parameters [4].

BHA weight in air, klbs	121.3
BHA buoyed weight, klbs – 10.5 ppg mud	101.8
Maximum available WOB, klbs	65.0 – with 85% of weight below jar
Maximum allowable Pull, klbs	370 – with 85% of new pipe tensile capacity

The results showed that the torque we have is around 18 kft-lbs however we had during drilling 23 kft-lbs. and also the actual drag we had during drilling was more than 60 klbs drag. Decision was POOH and check the BHA found marks of Bitumen (high viscous oil) Fig. 9.

The model helped us to determine the presence of downhole problem and avoid any Drilling problem ex. Lost BHA in hole. Decision was run drill pipe non rotating protectors to reduce the torque and drag generated from friction between DP and casing Fig. 10 [1].

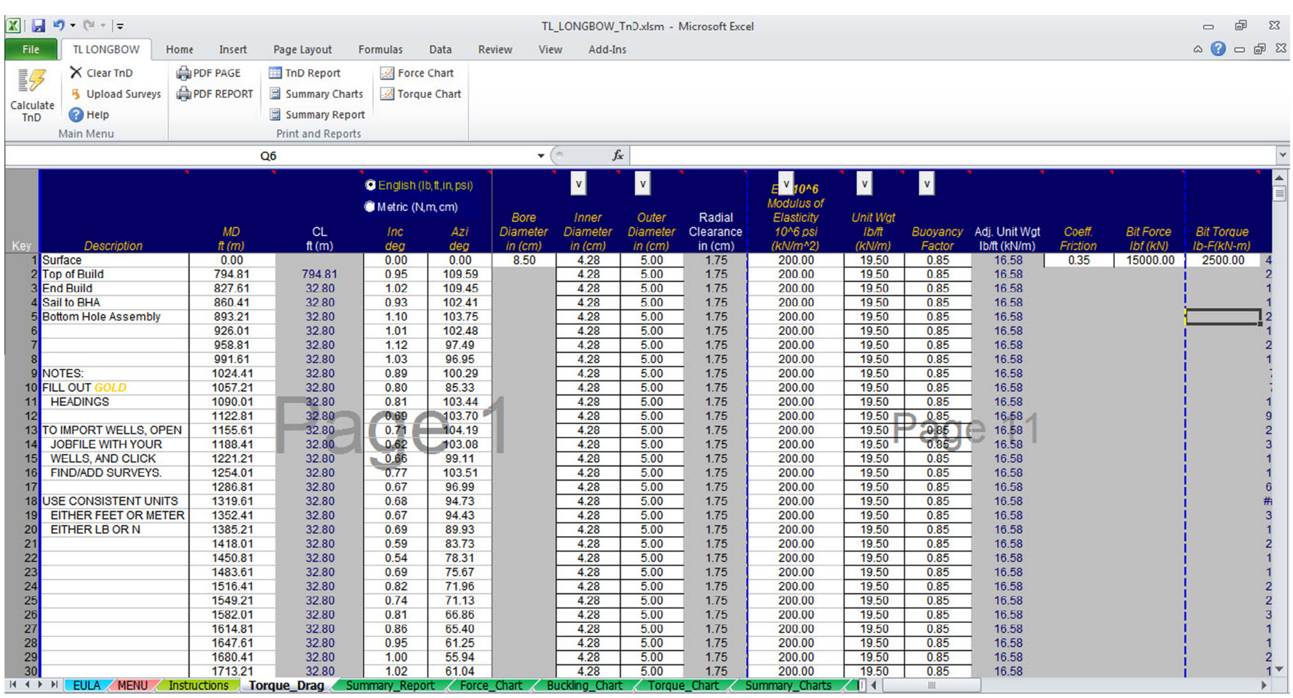
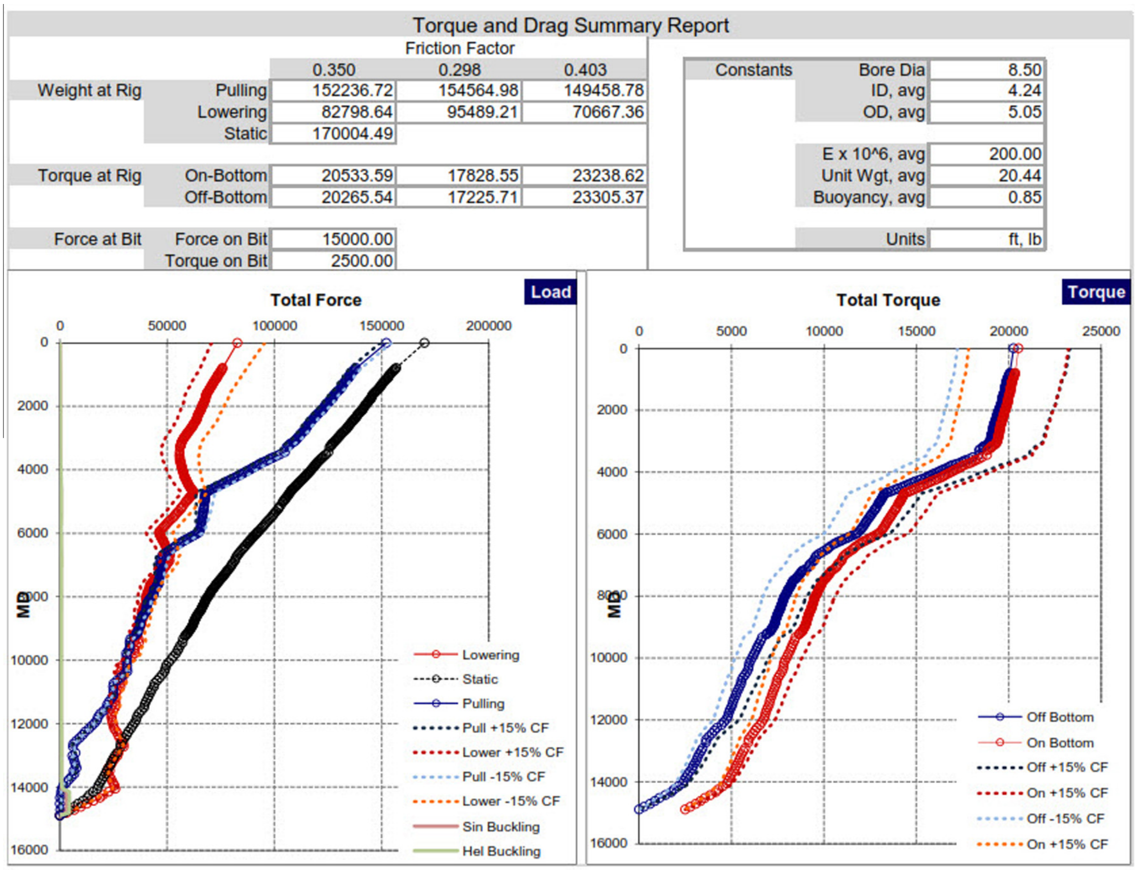


Figure 8 Snapshot for the model excel sheet.


Torque and Drag Summary Report

		Friction Factor		
		0.350	0.298	0.403
Weight at Rig	Pulling	152236.72	154564.98	149458.78
	Lowering	82798.64	95489.21	70667.36
	Static	170004.49		
Torque at Rig	On-Bottom	20533.59	17828.55	23238.62
	Off-Bottom	20265.54	17225.71	23305.37
Force at Bit	Force on Bit	15000.00		
	Torque on Bit	2500.00		

Constants		
	Bore Dia	8.50
	ID, avg	4.24
	OD, avg	5.05
	E x 10^6, avg	200.00
	Unit Wgt, avg	20.44
	Buoyancy, avg	0.85
	Units	ft, lb

Figure 9 Torque and drag results for 8.5″ hole section Well-A well.

5.2. Results and discussion of Well-B

The purpose for selecting this well /section was to find out Aadony's model performance in the deep holes 8 1/2″ and also in the horizontal section. Using the data displayed in previous section will have results for well TD with RSS BHA. The PDM BHA had been used to land the well to 90 deg inclination and the RSS BHA had been used to drill the horizontal section.

Using the TL Longbow Prime company excel sheet we had calibrate the software at the heel and applying the data displayed in the previous section for the RSS BHA.

The torque model shows good results by comparing it with the actual well data which were around 13–14 kft-lbs as in Fig. 11. However, the Drag result which is described in Fig. 12 shows high difference between rotating weights, slack off and pickup weights. And this is clear by comparing the calculated results with the actual field data described in Table 7 [2]. This is because of horizontal section with considering the

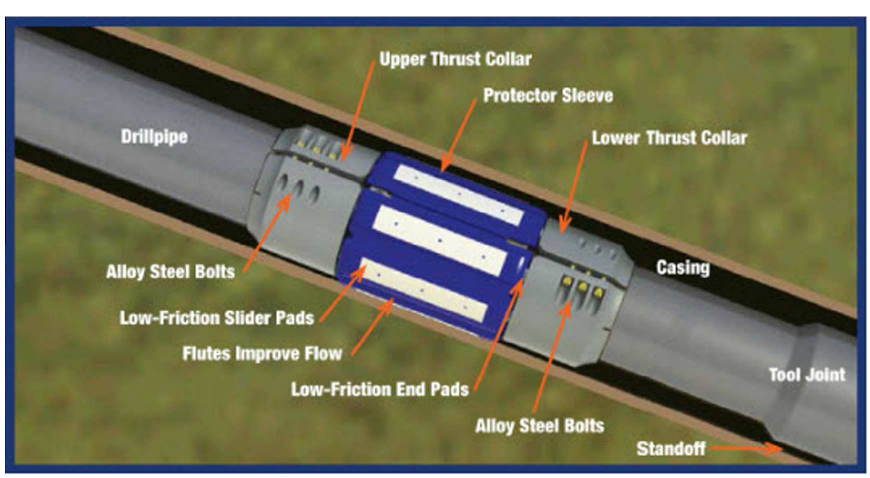


Figure 10 Picture for one job using non rotating protectors [1].

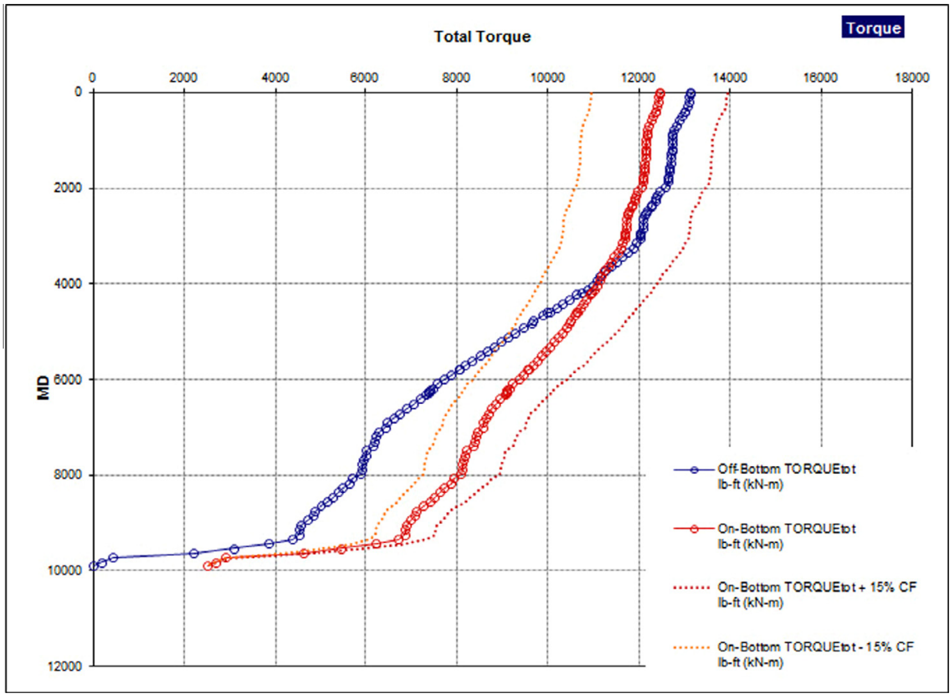


Figure 11 Describe the results of toque for 8.5″ section RSS BHA.

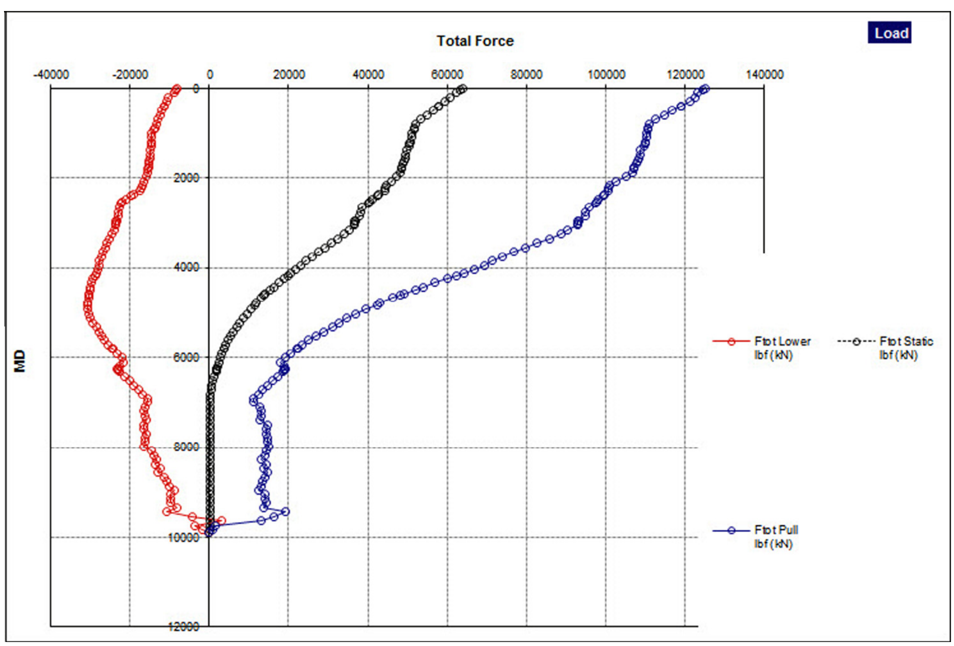


Figure 12 Describe the results of drag for 8.5″ section RSS BHA.

string lying on the low side of the hole. Same as drag the buckling results show Sinusoidal buckling 9 klbs and Helical buckling 14 klbs however the section has been drilled with average 20 klbs WOB, Fig. 13.

5.3. Results and discussion of Well-C

The purpose for selecting this well/section was to find out the Aadony's model performance in the shallow and big holes 18 1/2″ using the data displayed in previous section.

Table 7 Describe the actual readings of drag in klbs for 8.5″ section RSS BHA [2].

Pick up weight, klbs	Slack of weight, klbs	Rotation weight, klbs
205	115	155

However using friction factor 0.4 we had torque reading around 3.5 kft-lbs Fig. 14. The actual reading during drilling

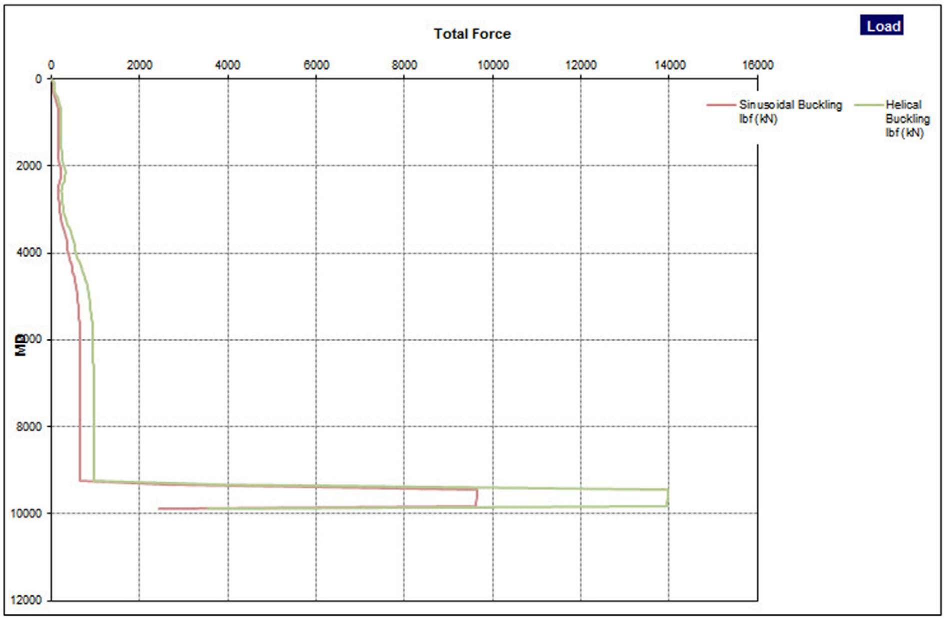


Figure 13 Describe the results of buckling for 8.5″ section RSS BHA.

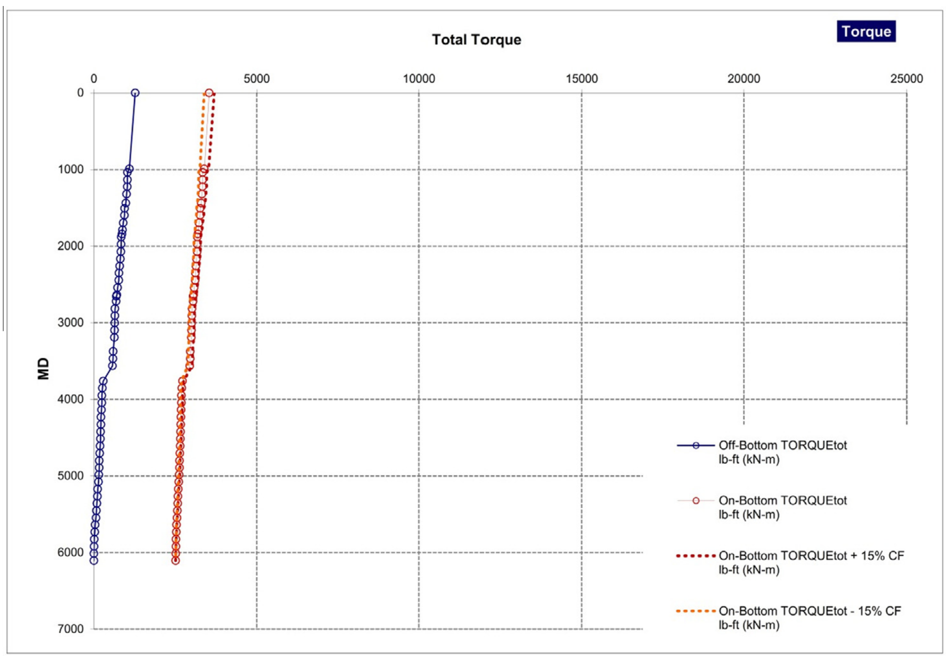


Figure 14 Describe the results of toque for 18.5″ section RSS BHA of Well-C.

was around 10 kft-lbs. The big difference in torque calculated and actual reflects the weakness of the soft string analytical model. The soft string model considers the string is in the center of the hole however it is not in reality. Even the well is vertical still there are torque results from the side forces coming from the contact between the drill string and the bore hole.

The drag results including pickup weight, slack of weight and rotation weight Fig. 15 showed that reading is less than the actual reading Table 8 [4] and this is as torque reading because of not considering the side forces on the calculation. The conformance results of the model didn't help to avoid BHA stuck because of hole collapse issues.

6. Conclusions

Based on the modeled and evaluated results in present paper the following conclusions can be summarized:

Please cite this article in press as: A.A. Elgibaly et al., A study of friction factor model for directional wells, Egypt. J. Petrol. (2016), http://dx.doi.org/10.1016/j.ejpe.2016.07.004

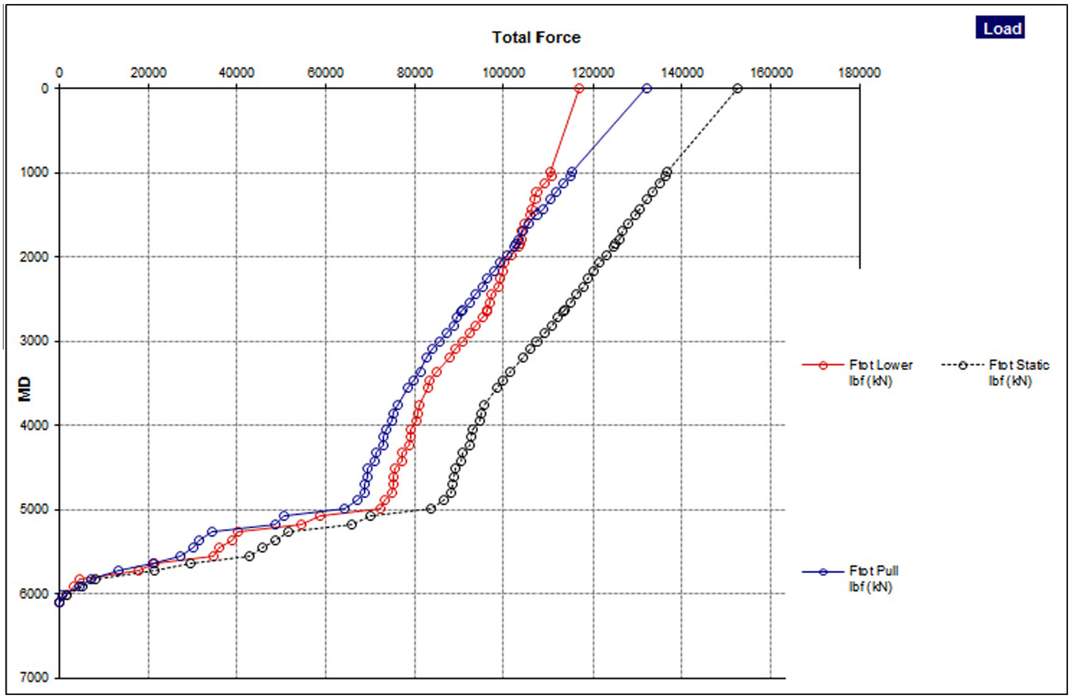


Figure 15 Describe the results of Drag in klbs for 18.5″ section RSS BHA.

Table 8 describe the actual readings of drag in klbs for 18.5″ section RSS BHA [4].

Pick up weight, klbs	Slack of weight, klbs	Rotation weight, klbs
224	214	218

- The Excel model, which is developed by TL Longbow Prime company and based on Aadnoy's friction theory, has given some reliable results and this appeared on Well-A when estimated the downhole issue (Bitumen – high viscous oil) (Fig. 17).
- The Model showed reliable readings for torque in horizontal section in Well-B however it has some inaccurate readings for drag and buckling calculations.
- In different situations we forced to use high friction factors to reduce the inabilities of the model. However from the deviation calculations the model showed good drilling practices Table 9.
- The model should also be improved to powerful software to enable real time applications
- The model has some inabilities:
  1. Tortuosity and micro-tortuosity: The model considered the actual well path will be perfectly smooth, but in reality it will have natural tortuosity. To correct that; a higher friction factor needs to be used.
  2. Hydrodynamic viscous drag: Hydraulic viscous drag is another effect which is not considered in the calculations. Same as Tortuosity and micro-tortuosity higher fiction factor need to be used to correct the readings.

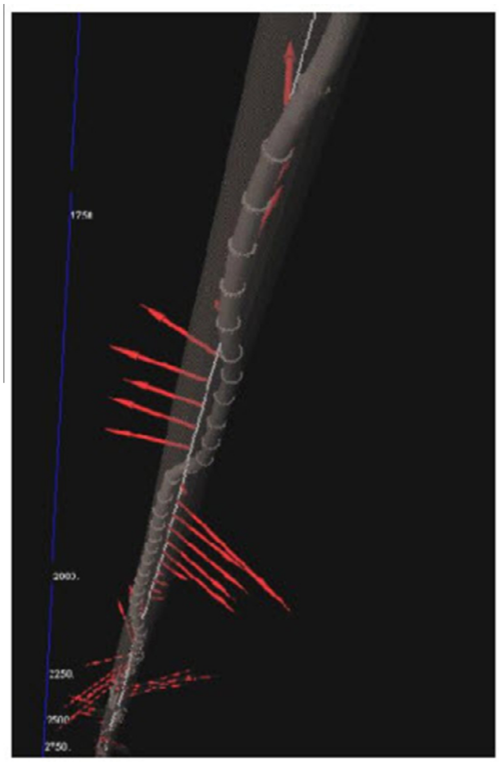


Figure 16 Contact forces in an actual vertical well [16].

  3. Perfect vertical wellbore: The model assumed that perfect wellbore is perfectly vertical and the drill string is in the center of the hole and there is no contact between the drill pipe/BHA and the borehole wall. This leads to

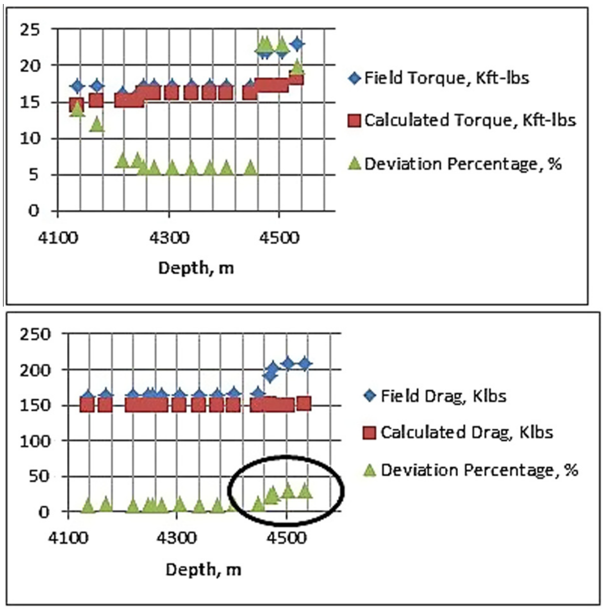


Figure 17 Torque and drag plots Well-A.

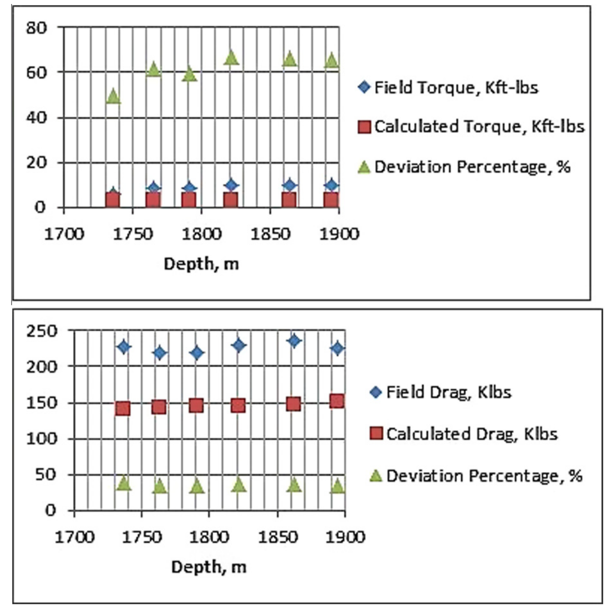


Figure 18 Torque and drag plots Well-C.

have inaccurate results from the torque and drag analysis. This appeared clearly in the Well-C. However the actual position of the drill string in the vertical well is not in the center of the hole Fig. 16 [16] (Fig. 18).

4. Friction loss in the hoisting system is not corrected in the results. To reduce that effect accurate calibration must be done for the hoisting equipment.
5. Buckling results showed some of non-accuracy and this appeared on Well-B (Fig. 19).

7. Recommendations for future work

From the previous conclusions, we can summarize some ideas for future work improvement:

1. Improve tortuosity measurements and add the tortuosity effect to Aadnoy's friction model.
2. Add a hydraulic model to Aadnoy's model to include the hydraulic effect on the torque and drag readings.

Table 9 Summary of results and deviation calculations.

Well name	Field data	Calculated results	Deviation %	Notes
Well-A	Torque = 23 kft-lbs P/U = 210 klbs	Torque = 18 kft-lbs P/U = 150 klbs	21% 28%	During operation noticed that there are a big differences between calculated torque/drag and actual in the field. And this difference is getting bigger with drilling more meters. The Recommendation for the client to increase the hole cleaning performance by increasing the flow rate and use special mud chemicals for lubricity However all this has been done Recommended to client to POOH and check BHA for any indication for formation related problem. After POOH found marks of Botomin (high viscous oil). Decision was run drill pipe non rotating protectors to reduce the torque and drag generated from friction between DP and casing
Well-B	Torque = 13 kft-lbs Weight difference = 45 klbs	Torque = 12.5 kft-lbs Weight difference = 60 kbls	0.04% 30%	The torque model shows good results by comparing it with the actual well data. However the drag result shows high difference. This is because the model considered the string lying on the low side of the hole of the horizontal section. Same as drag the buckling results shows Sinusoidal buckling 9 klbs and Helical buckling 14 klbs however the section has been drilled with average 20 klbs WOB
Well-C	Torque = 10 kft-lbs P/U = 224 klbs	Torque = 3.5 kft-lbs P/U = 150 klbs	65% 30%	However the section was big and shallow, we had used friction factor 0.4. With this friction factor still there is big difference between calculated torque/drag and actual in the field. This big differences reflect the weakness of the soft string analytical Aadnoy's model. The model ignored tortuosity and micro-tortuosity effects and also considered the drill string is centered in the wellbore

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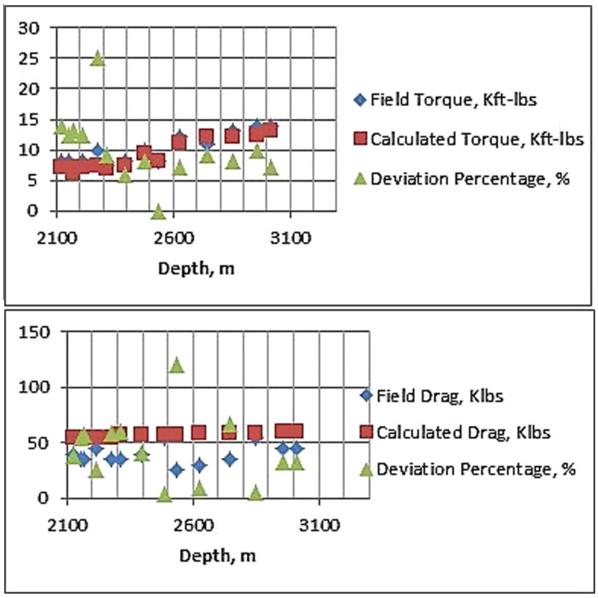

Figure 19 Torque and drag plots Well-B.

3. Improve Aadnoy's model to give more realistic data for buckling calculations.
4. Do more investigation on the friction losses in the sheaves to add its effect on the friction model.
5. Improve the excel sheet to have:
   a. Separate part for BHA effect.
   b. Adding an option to have a real time analysis.
   c. Improving survey input data by adding Sag and Cosag corrections.
   d. Increase the ability to add two friction factors for cased and open hole in the model.

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