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Development of Torque and Drag Calculation Software for Oil Well Planning-Part 1 : 2D Aadnoy Method

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ABSTRACT

With the increasing number of drilled ultra-extended reach wells and complex geometry wells, the drilling limitation caused by excessive torque and drag forces must be further investigated. The wellbore friction being a main limiting factor in extended reach well needs to be studied with the new developed models. The torque and drag software implement two methods: (1) 2D and 3D analytical model developed by Aadnøy (Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001; Aadnoy & Djurhuus, 2008; Aadnoy, et al., 2010; Aadnoy, 2010) and (2) Miska and Mitchel, for 2D wellbore (Mitchell, et al., 2011). This paper presents the theory and implementation of 2D Aadnoy method. Quite diverse wellbore trajectory and depth has been chosen for a better evaluation and comparison of the model with the measured data. In order to investigate the potential and limitation of the model, torque and drag analysis during the different operations such as tripping in, tripping out, rotating off bottom, combined up/down were investigated.

Keywords: torque; drag; friction

I. INTRODUCTION

Both Wellbore profiles and field operation are the two reasons to have a good model for wellbore friction analysis. The reliable model is necessary to be able to give a precise torque and drag analysis during planning, drilling and post operational phases. Especially for the planning phase, the model is useful for optimizing the trajectory design in order to minimize the torque, drag and contact forces between drill string and borehole wall. To build a reliable well trajectory we need accurate torque and drag analysis. The model can be useful for predicting realistic forces, bending moment and contact loads along the wellbore. One of the applications is to support the development of drilling automation (Kuswana, et al., 2019).

Torque and Drag (TND, T&D) in well planning is extremely helpful to predict and prevent problems that might occur during the process of drilling. Application of TND in industry is mostly based on Johancsik's work in 1984 (Johancsik, et al., 1984). Sheppard (Sheppard, et al., 1987) improved the work of Johanschik by formulating the torque and drag models that are implemented in most simulators.

However, it seems that for normal planning, extended-reach and other challenging wells, T&D modeling provides a guideline for performance. This is the reason to get better modelling, especially in complex three-dimensional wellbores. This paper describes a software development that will give more accurate 3D T&D calculations. In the optimization stage of well design, TND modeling should consider some factors such as adapting tubular design, changing annulus fluids and adjusting operating drilling processes. The last one is an important factor for developing tripping control as mentioned above.

One of the mathematical models which were developed to evaluate the mechanical behavior of the drill string inside the wellbore is proposed by Aadnøy. While Johanschic established the basic equations for friction in deviated wellbores, Aadnoy extends the method for generic 3D wellbores. The Johanschic's model makes no distinction between cased and openhole friction coefficients (Fazaelizadeh, et al., 2010).

Specifically, Aadnoy's model provides a new analytical solution to calculate wellbore friction for different well geometers and it can be applied for all the wellbore shapes such as vertical sections, build-up bends, drop-off bends and straight sections. The mathematical model has the capability of calculating torque and drag for rotating and tripping. In that model, the drill string is modeled as a soft string because it neglects any tubular stiffness. By this assumption, the pipe is behaving like a heavy cable lying along the wellbore. This implies that axial tension and torque forces are supported by the string and contact forces are supported along the wellbore.

In this paper, a numerical simulator TND will be developed as an important part of drilling / tripping operations and the results of this simulator calculation will be an important input to axial drill string dynamic modeling. This numerical simulator will verify the results with several standard studies that have been carried out previously and the study focuses on the influence of the side force during tripping-out of the drill string.

The paper is organized as follows. First, we describe the calculation of torque and drag in detail. Next, we present the result of calculation through developed software. The final section shows discussion and conclusion.

II. TORQUE & DRAG MODELING

One of the most critical limitations during hydrocarbon exploration, especially during directional drilling, is torque and drag generated by the contacts between the drill string and the wellbore or casing. Proper modeling is highly important to prevent downhole problems related to drill string and wellbore.

Torque is the power lost due to friction while transferring surface torque to bit and drag is the load difference between the static weight of the drill string and the tripping weight if the drill string is observed (Aarrestad & Bikra, 1994). There are some sources which would result in high drag and torque such as high friction between drill string and borehole, wellbore tortuosity and hole cleaning problems.

Parameters such as drill string components, weights, casing depths, formation types and frictional forces, drilling mud density, well profile (inclination and azimuth) should be considered in every torque and drag model. Torque and drag information during the drilling process are crucial to field personnel in making decisions and detecting anomalies during drilling operation. In any case, a close monitoring and appliance of correct calculations are necessary to keep torque and drag within permissible limits that would maintain the drill string without a failure.

The main contributor for high torque and drag value is wellbore friction. Wellbore friction is affected by two factors such as coefficient of friction between the contact forces (friction factor) and normal force between the tubular and wellbore. Friction factor itself is affected by the drilling mud and formation type and defined as the measure of the degree of resistance to motion of two adjacent elements sliding against each other.

There had been many researches (Fazaelizadeh, et al., 2010; Sheppard, et al., 1987; Fazaelizadeh, 2013; Abughaban, 2017; Abughaban, 2017), (Ismayilov, 2012; Mitchell & Samuel, 2009; Tikhonov, et al., 2014) that were conducted previously to develop an accurate model for torque and drag. This paper focuses on developing software for TND calculations and implemented in PRE's Real-Time Torque & Drag in-house software (Wibowo, 2019).

These studies are mainly based on the Soft String Model and the Stiff String Model to calculate torque and drag in a wellbore. Soft String Model is the common model used in the industry and it has been used extensively for planning and in the field, because of the simplicity and general availability of this model.

The Soft String model assumes the loads on the drill string result only from the effects of gravity and frictional drag occurring due to the contact between the wellbore and drill string. The product of normal force between the wellbore and drill string and the friction coefficient yields to the frictional force. The most important assumption is that the drill string is in continuous contact with the wellbore from bottom to the top; that means the radial clearance effects are ignored and the bending moment is not considered in the Soft String Model.

In order to ensure a realistic approach to torque and drag calculations, friction factors should be considered carefully. Actual friction coefficient values are affected by mud type, formation type, and casing points. These values are generally known before the drill string design process and can be used for torque and drag analysis.

Aadnoy (Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001; Aadnoy & Djurhuus, 2008; Aadnoy, et al., 2010) developed analytical solutions to well friction for different well geometries, as explained in the following section. Analytical expressions for build, drop, hold and side profiles are presented in those papers, and also a new modified catenary profile. Using these equations, friction analysis can be made without requiring a simulator. These solutions gave better insight into the frictional behavior throughout the well.

Torque & Drag Model for 2D Well Profile Modeling

2.1. Model Overview

Aadnoy T&D method, and also Mitchel and Miska T&D method based on "soft string" model. It is so called because it ignores any tubular stiffness effects. This means that the pipe is behaving like a heavy cable lying along the wellbore which implies that axial tension and torque forces are supported by the string and contact forces are supported along the wellbore (Fazaelizadeh, et al., 2010; Aadnoy, et al., 2010). Opposed to the *soft-string model* is the *stiff-string model* that accounts for pipe bending stiffness.

At first, the *soft-string model* may look like an unrealistic assumption, but field practice indicates that the results obtained using this approach are acceptable for many practical applications (Mitchell, et al., 2011).

Ho (Ho, 1988; Fazaelizadeh, 2013) improved the previous soft-string model into a somehow *stiff-string* and showed that for most parts of the drill string the stiffness effect for drill pipe and heavy-wall drill pipe is minor and while for drill collars is major and has to be taken into account.

2.2. Aadnoy Method (Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001; Aadnoy & Djurhuus, 2008; Aadnoy, 2010)

2.2.1. *Drag and Torque Along Straight Sections*

Before proceeding with various frictional models, the basic principles for well friction are defined. All equations that follow are based on the soft string model . String stiffness is neglected because it contributes a negligible amount to the tension. Figure 1a defines the forces acting on an inclined drillstring. The force required to pull a drill string along an inclined plane is: $F = mg\cos\alpha + \mu mg \sin\alpha$. If the drillpipe is lowered instead, the friction acts opposite to the direction of motion, resulting in a top force of: $F = mg\cos\alpha - \mu mg\sin\alpha$. This is a Coulomb friction model. From a stationary position, increasing or decreasing the load, an equal amount will lead to upward or downward movement of the drill string. For a drill string of weight mg (= $w\Delta s$) and an inclination a, the axial weight and the drag force in a straight section is (Figure 1b).

$$F_2 = F_1 + w\Delta s(\cos\alpha \pm \mu \sin\alpha) \tag{1}$$

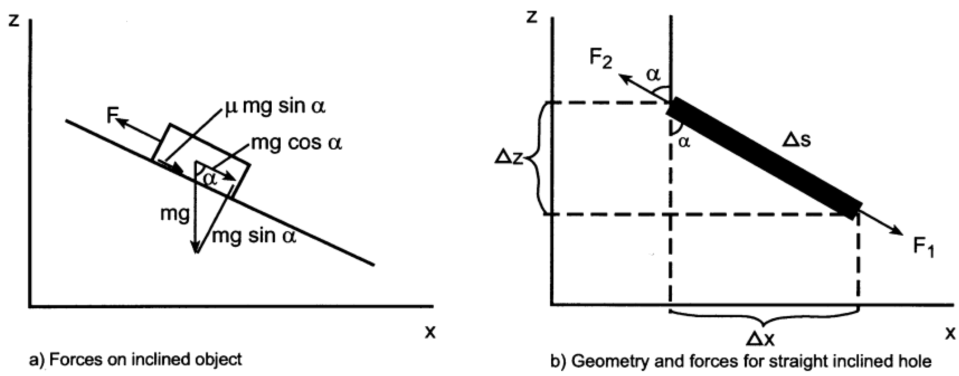

Figure 1. Forces and geometry in straight hole sections
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

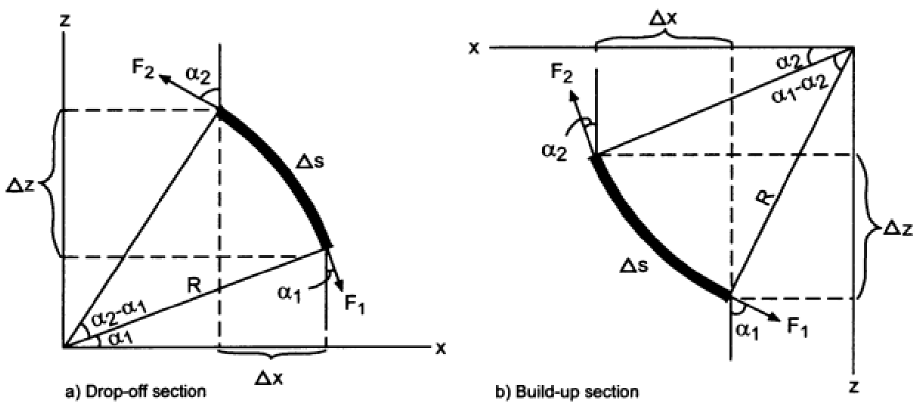

Figure 2. Forces and geometries of various curved hole profiles
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

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Vol.3 No. 2 2022

The plus sign defines pulling of the pipe, whereas a minus sign defines lowering of the pipe. The first term inside the brackets defines the weight of the string, the second term defines the additional frictional force required to move the pipe. The change in force when initiating motion either up or down is found by subtracting the weight from the forces defined above.

2.2.2. *Drag and Torque Curved well*

Figure 2 shows a number of different well geometries and the inclinations at top and bottom are also shown well. Gu et al. (1993) derived some of the equations, whereas Aadnøy and Andersen (1998) presented the complete derivations. The equations for the well geometries shown in Figure 2 are given in Table 1 and Table 2 for the construction of the well geometry. All equations required to compute the torque and drag friction of each geometry are summarized in Table 3 and Table 4. The equation for a straight section is given in Table 3 and Table 4 section (a). The friction is additive, which implies that the friction depends on the weight of the pipe itself and not on the total axial force. The friction is independent of whether a high or a low pulling force is applied at the end of the pipe.

Table 1. Geometrical projections for various section profiles, Part 1
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

Section profile	Section length Δs	Vertical projection Δz
(a) Straight inclined	Δs	$\Delta s \cos\alpha$
(b) Drop-off	$R(\alpha_2-\alpha_1)$	$R(\sin\alpha_2-\sin\alpha_1)$
(c) Build-up	$R(\alpha_2-\alpha_1)$	$-R(\sin\alpha_2-\sin\alpha_1)$
(d) Right side-bend	$R(\phi_2-\phi_1)$	0
(e) Left side-bend	$R(\phi_2-\phi_1)$	0
(f) Modified catenary	$\frac{F_1}{w}(\sin\alpha_1 \sinh A-\cos\alpha_1)$	$\frac{F_1 \sin\alpha_1}{w}(\sinh A-B)$
(g) Entrance modified catenary	$R^*\alpha_2^*$	$R^*\sin\alpha_2^*$

Where:

$$A=\frac{wx}{F_1}+\sinh^{-1}(\cot\alpha_1) \qquad B=\cosh[\sinh^{-1}(\cot\alpha_1)]$$

$$R^*=\frac{F_0+(w\Delta s)^2+2w\Delta sF_0\cos\alpha_1}{wF_0\sin\alpha_1} \qquad \alpha_2^*=\tan^{-1}\left(\frac{w\Delta s+F_1\cos\alpha_1}{F_1\sin\alpha_1}\right)$$

Subscript 1 is the deepest position, subscript 2 is the highest

Table 2. Geometrical projections for various section profiles, Part 2
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

Section profile	Horizontal projection Δx	Horizontal projection Δy
(a) Straight inclined	$\Delta s \sin\alpha$	
(b) Drop-off	$-R(\cos\alpha_2-\cos\alpha_1)$	
(c) Build-up	$R(\cos\alpha_2-\cos\alpha_1)$	
(d) Right side-bend	$-R(\cos\phi_2-\cos\phi_1)$	$R(\sin\phi_2-\sin\phi_1)$
(e) Left side-bend	$-R(\cos\phi_2-\cos\phi_1)$	$R(\sin\phi_2-\sin\phi_1)$
(f) Modified catenary	Δx	
(g) Entrance modified catenary	$R^*(1-\cos\alpha_2^*)$	

Equations for a drop-off section are given in Table 3 and Table 4 section (b). Friction depends on two elements; the weight of the pipe itself and the bottom pulling force multiplied by an exponential expression; hence, friction is no longer additive, but can be considered multiplicative. The side bends defined in Table 3 and Table 4 section (d) and (e) has added complexity. The weight of the pipe forces the pipe to its lowest position, whereas the pulling force attempts to move it to the midpoint of the hole. The exact position along the side-bend depends on the vector sum of these two forces.

Table 3. Torque and drag for various sections, Part 1
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

Section profile	Static weight	Torque
(a) Straight inclined	$w\Delta s\cos\alpha$	$\mu w\Delta sr\sin\alpha$
(b) Drop-off	$wR(\sin\alpha_2-\sin\alpha_1)$	$\mu r[(F_1+C)\lvert\alpha_2-\alpha_1\rvert-D]$
(c) Build-up	$-wR(\sin\alpha_2-\sin\alpha_1)$	$\mu r[(F_1+C)\lvert\alpha_2-\alpha_1\rvert+D]$
(d) Right side-bend	0	$\mu r\lvert\phi_2-\phi_1\rvert(H-F_1)$
(e) Left side-bend	0	$\mu r\lvert\phi_2-\phi_1\rvert(H-F_1)$
(f) Modified catenary	$w\Delta z$	$\mu r\Delta F\tan^{-1}I$
(g) Entrance modified catenary	$wR^*\sin\alpha_1$	$\mu r[(F_1+C)\alpha_1+2wR^*(1-\cos\alpha_1)]$

Where:

$$C = wR\sin\alpha_1 \qquad H = F_1+\sqrt{F_1^2+(wR)^2}$$

$$D = 2wR(\cos\alpha_2-\cos\alpha_1) \qquad I = \frac{w\Delta s+F_1\cos\alpha_1}{F_1\sin\alpha_1}$$

$$E = \frac{wR(1-\mu^2)}{1+\mu^2}\left[\sin\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right] + \frac{2wR\mu}{1+\mu^2}\left[\cos\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\cos\alpha_1\right] \qquad J = \sqrt{F_1^2+(w\Delta s)^2+2\Delta sF_1\cos\alpha_1}$$

$$K = \frac{wR}{1+\mu^2}[(1-\mu^2)\sin\alpha_1+2\mu\cos\alpha_1]$$

$$G = wR\left[\sin\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right]$$

Subscript 1 is the deepest position, subscript 2 is the highest

Table 4. Torque and drag for various sections, Part 2
Source : Aadnoy & Andersen, 1998; Aadnoy & Andersen, 2001

Section profile	Pulling Force	Lowering Force
(a) Straight inclined	$F_1+w\Delta s(\cos\alpha+\mu\sin\alpha)$	$F_1+w\Delta s(\cos\alpha+\mu\sin\alpha)$
(b) Drop-off	$F_1e^{\mu(\alpha_2-\alpha_1)}+E$	$F_1e^{-\mu(\alpha_2-\alpha_1)}+G$
(c) Build-up	$F_1e^{-\mu(\alpha_2-\alpha_1)}-G$	$F_1e^{\mu(\alpha_2-\alpha_1)}-E$
(d) Right side-bend	$\frac{1}{2}\left[He^{\mu(\phi_2-\phi_1)}-\frac{(wR)^2}{He^{\mu(\phi_2-\phi_1)}}\right]$	$\frac{1}{2}\left[\frac{H}{e^{\mu(\phi_2-\phi_1)}}-\frac{(wR)^2}{H}e^{\mu(\phi_2-\phi_1)}\right]$
(e) Left side-bend	$\frac{1}{2}\left[He^{\mu(\phi_2-\phi_1)}-\frac{(wR)^2}{He^{\mu(\phi_2-\phi_1)}}\right]$	$\frac{1}{2}\left[\frac{H}{e^{\mu(\phi_2-\phi_1)}}-\frac{(wR)^2}{H}e^{\mu(\phi_2-\phi_1)}\right]$
(f) Modified catenary	$J+\mu\Delta F\tan^{-1}I$	$J-\mu\Delta F\tan^{-1}I$
(g) Entrance modified catenary	$(F_1+wR^*\sin\alpha_1)e^{\mu\alpha_1}$	$(F_1+K)e^{\mu\alpha_1}+\frac{2\mu}{1+\mu^2}wR^*\cos\alpha_1$

We may rewrite formulas shown in Table 1 to Table 4 as follows. For Drop-off section, static weight W, torque M, pulling force F_P and lowering force F_L, are

$$W = wR(\sin\alpha_2-\sin\alpha_1) \tag{2}$$

$$M = \mu r_p[(F_1+C)\lvert\alpha_2-\alpha_1\rvert-D] \tag{3}$$

$$F_P = F_1e^{\mu(\alpha_2-\alpha_1)}+E \tag{4}$$

$$F_L = F_1e^{-\mu(\alpha_2-\alpha_1)}+G \tag{5}$$

Where R is radius of well curvature, r_p is pipe radius, and

$$C = wR\sin\alpha_1 \tag{6}$$

$$D = 2Rw(\cos\alpha_2-\cos\alpha_1) \tag{7}$$

$$E = \frac{wR(1-\mu^2)}{1+\mu^2}\left[\sin\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right] + \frac{2wR\mu}{1+\mu^2}\left[\cos\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\cos\alpha_1\right] \tag{8}$$

$$G = wR\left[\sin\alpha_2-e^{\mu(\alpha_2-\alpha_1)}\sin\alpha_1\right] \tag{9}$$

Subscript 1 is the deepest position, subscript 2 is the highest.

For Build-up section, static weight W, torque M, pulling force F_P and lowering force F_L, are

$$W = -wR(\sin\alpha_2 - \sin\alpha_1) \tag{10}$$
$$M = \mu r_p[(F_1 + C)|\alpha_2 - \alpha_1| + D] \tag{11}$$
$$F_P = F_1 e^{-\mu(\alpha_2-\alpha_1)} - G \tag{12}$$
$$F_L = F_1 e^{\mu(\alpha_2-\alpha_1)} - E \tag{13}$$

TND Software Development

TND software developed by PRE was based on the Aadnoy method as explained previously. The algorithm of the software is shown in Figure 3. The User Interface (UI) is shown in Figure 4, Figure 5 and Figure 6. This software is used in this study to generate the drag distribution along the implemented drill string.

Microsoft Visual Studio Community 2015 (VS2015), with C# Programming Language, has been chosen for developing the TND Software. This development tool (VS2015) is chosen because of its stability, speed, real-time performance, accuracy, and manageability. The authors have proven that a computer program (or software) developed by using C# has strong stability, high-speed calculation performance, and very accurate results. As shown in Figure 4 to Figure 6, the TND software has a GUI (Graphical User Interface) with 2D and 3D graphics, tables, and input and output objects.

III. RESULTS AND DISCUSSION

This section will demonstrate the application of the software for calculating torque and drag for 2 cases: (1) a build-sail type well, and (2) S-Type well.

Case 1, 2D Well: Build-Sail Type

This section will demonstrate the application of the software for calculating torque and drag in a build-sail type well, as explained in Aadnoy & Andersen (Aadnoy & Andersen, 2001). The well under consideration is shown in **Figure 7**. It is vertical to the kick-off point, and built with a constant radius to a sail angle, which is kept constant to the bottom of the well. The static weight is just the unit weight multiplied by the projected height, regardless of the inclination of the well.

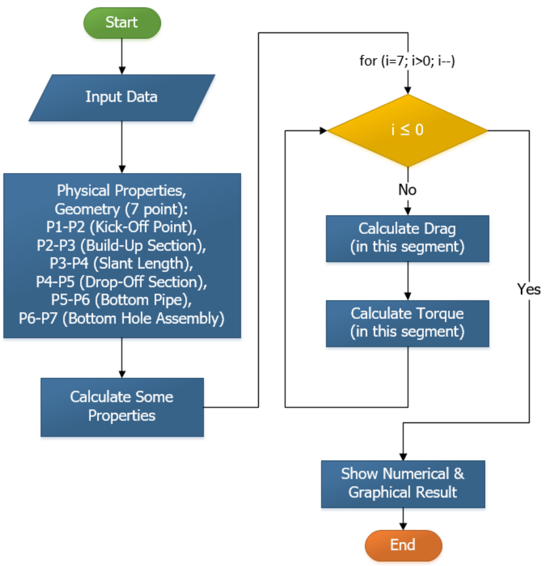

Figure 3. TND Flow Chart

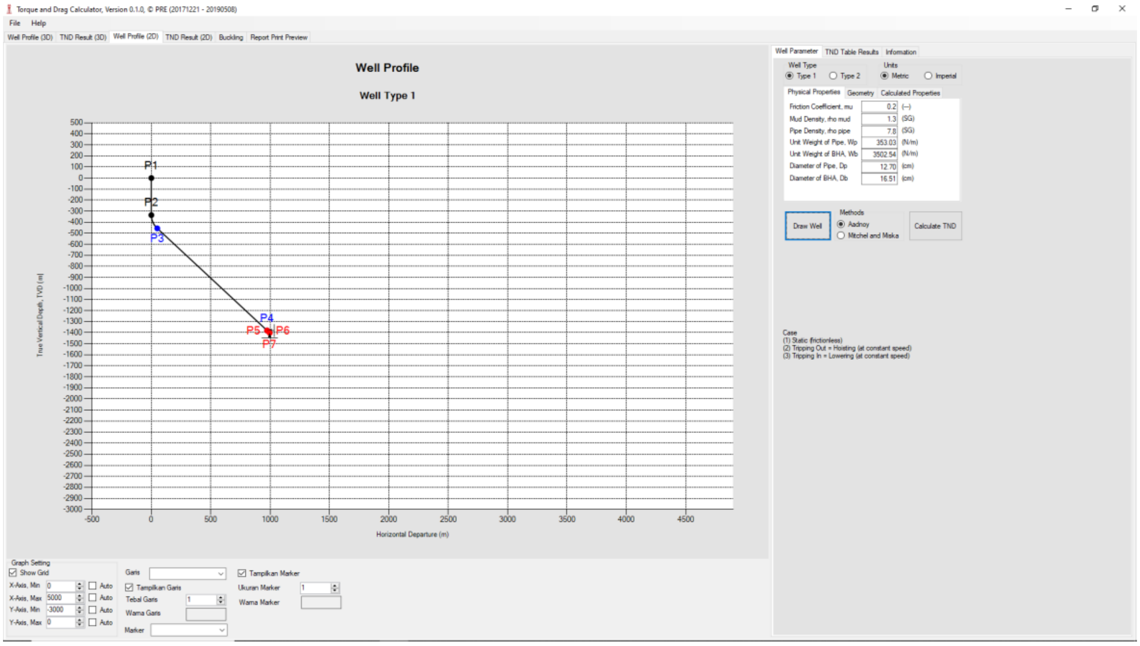

Figure 4. Default Input of Type-1 2D Well Profile

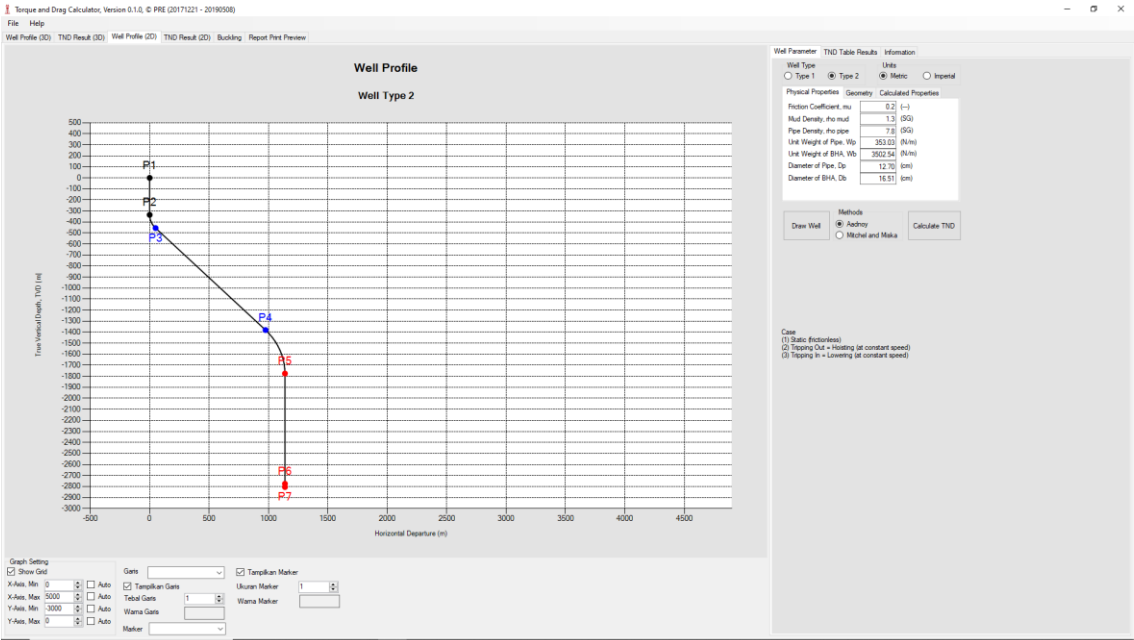

Figure 5. Default Input of Type-2 2D Well Profile

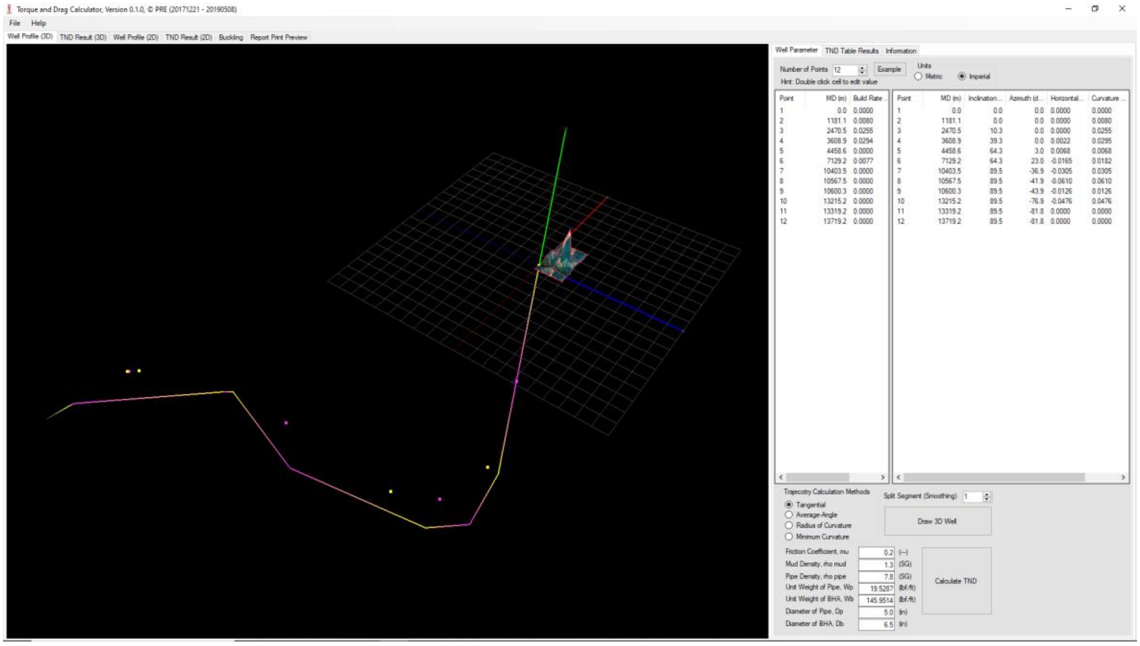

Figure 6. Default Input of 3D Well Profile

For this example, assume a unit weight of the bottom-hole-assembly of 3 kN/m (200 m long), drillpipe of 0.3 kN/m (2000 m from BHA to end build section), a 60° inclination, a build radius of 500 m, a kick-off-depth of 1500 m and a mud weight of 1.56 s.g. which leads to a buoyancy factor of 0.8. The friction coefficient is 0.15. The torque is computed both with the bit off bottom, and with a bit force of 150 kN, resulting in a bit torque of 6 kN/m. With these numbers, the target is located at 3033 m vertical depth, and the horizontal departure is 2155 m. The drag forces at each point of interest have been calculated in (Aadnoy & Andersen, 2001), and the results are shown in **Table 5**. The related graph, **Figure 8**, shows the same results.

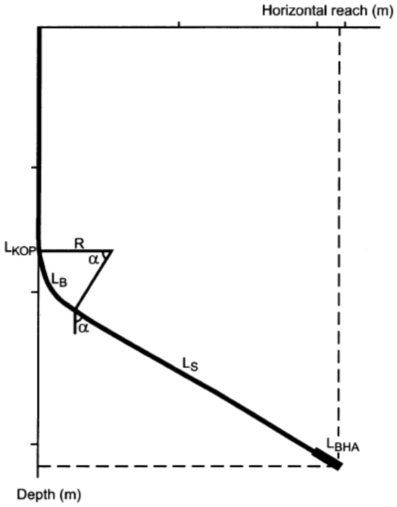

Figure 7. Build-Sail Type Wellbore Profile
Source : Aadnoy & Andersen, 2001

Table 5. Drag in Drillstring, Build-Sail Well
Source : Aadnoy & Andersen, 2001

Position	Static weight, bit off (kN)	Pulling (kN)	Lowering (kN)
Bit	0	0	0
Top BHA	240	302	178
Top of sail section	480	604	356
Kick-off-position	584	828	374
Top well	944	1188	734
Note: Pulling = hoisting = tripping out, Lowering = tripping in (kN)			

JOURNAL OF PETROLEUM AND GEOTHERMAL TECHNOLOGY
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Vol.3 No. 2 2022

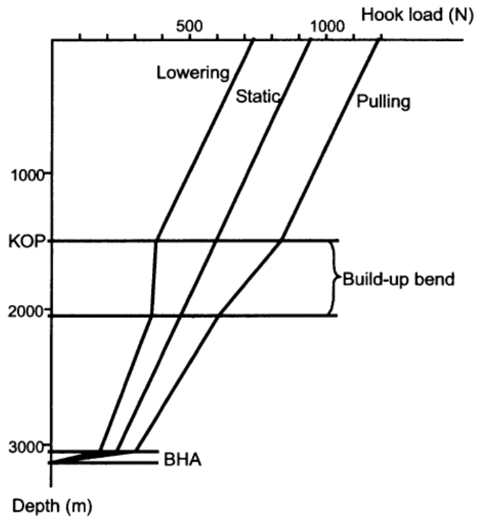

Figure 8. Drag Forces, Build-Sail Well
Soucer : Aadnoy & Andersen, 2001

The torques at each point of interest have also been calculated in (Aadnoy & Andersen, 2001), and the results are shown in **Table 6**. The related graph, **Figure 9**, shows the same results.

Table 6. Torque in Drillstring, Build-Sail Well
Source : Aadnoy & Andersen, 2001

Position	Torque, bit off (kNm)	Torque, bit force 150 kN (kNm)
Bit	0	6
Top BHA	6.24	12.24
Top of sail section	12.48	18.48
Kick-off-position	23.42	27.35
Top well	23.45	27.35

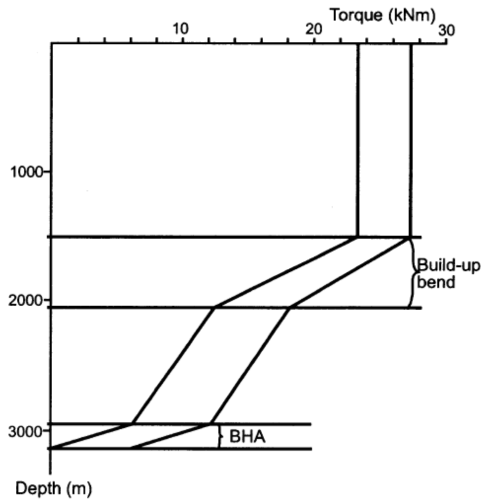

Figure 9. Torques, Build-Sail Well
Source : Aadnoy & Andersen, 2001

This Buil-Sail wellbore was calculated by using T&D software, and the results shown in **Table 7**, **Figure 7**, and **Figure 8**.

JOURNAL OF PETROLEUM AND GEOTHERMAL TECHNOLOGY
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Vol.3 No. 2 2022

Table 7. Drag in Drillstring, Build-Sail Well, T&D Software

Position	Static weight, bit off (kN)	Pulling (kN)	Lowering (kN)
Bit	0	0	0
Top BHA	240.0	302.4	177.6
Top of sail section	480.0	604.7	355.3
Kick-off-position	583.9	811.5	407.6
Top well	943.9	1171.5	767.6

The geometry of this build-sail type wellbore will be plotted automatically by T&D Software from input data, as shown in **Figure 10**. The same geometry, taken from (Aadnoy & Andersen, 2001), is shown in **Figure 7**.

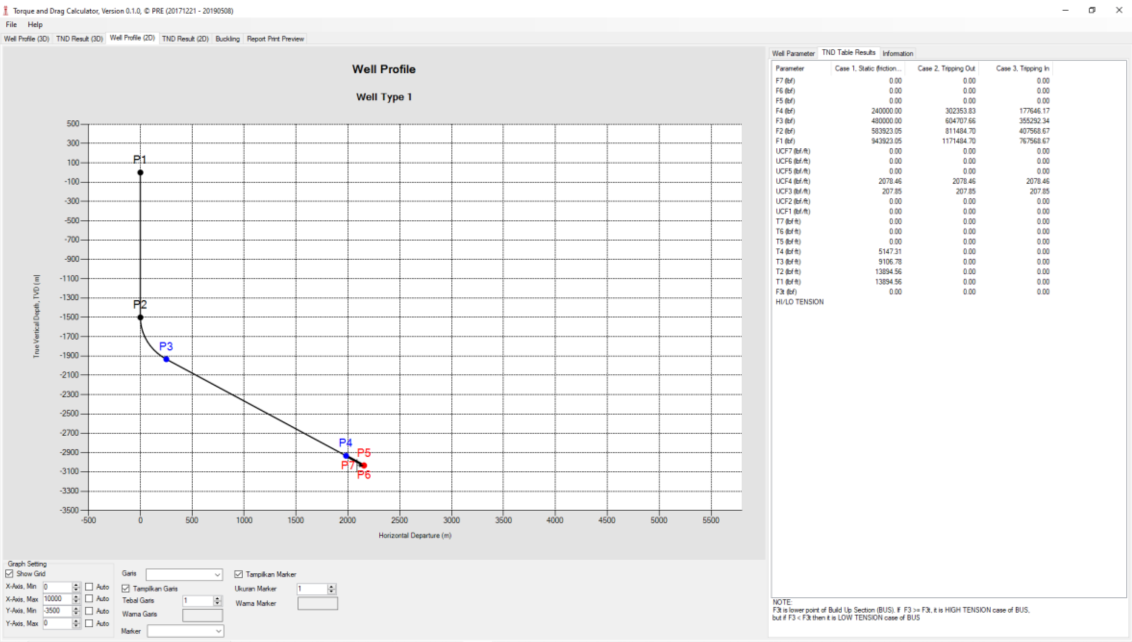

Figure 10. Tabulated Results for Type-1 2D Well Profile, Ex-1: Build-Sail Type, Aadnoy Method

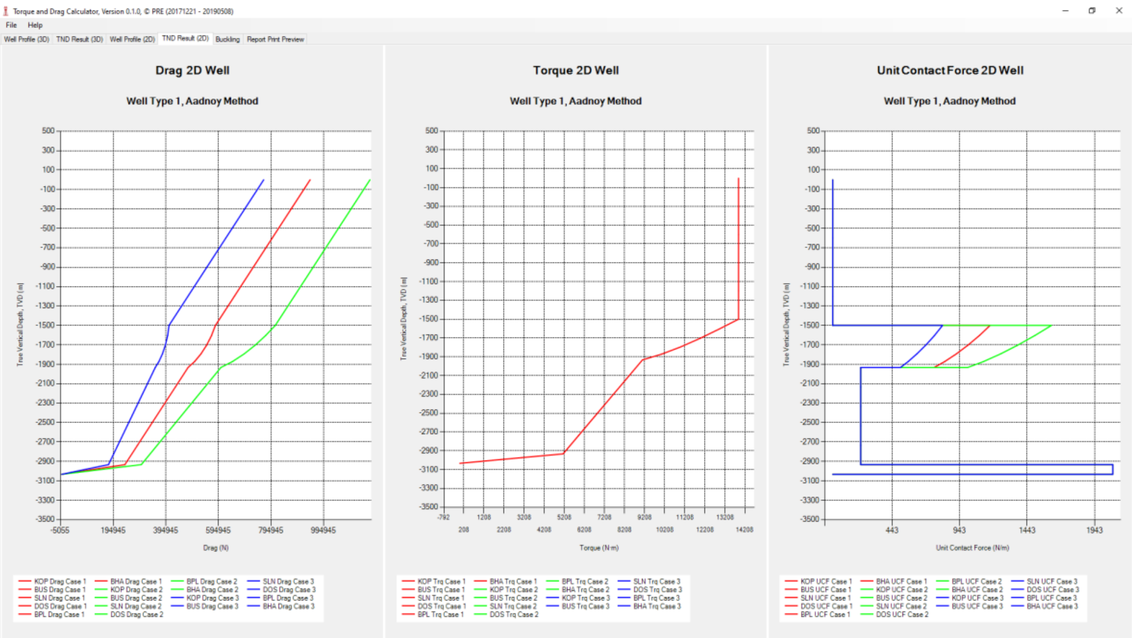

Figure 11. Graphical Results for Type-1 2D Well Profile, Ex-1: Build-Sail Type, Aadnoy Method, case 1: static, case 2: tripping out, case 3: tripping in

JOURNAL OF PETROLEUM AND GEOTHERMAL TECHNOLOGY
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Vol.3 No. 2 2022

Case 2, 2D Well: S-Type

This section will demonstrate the application of the software for calculating torque and drag in a S-shaped well, as explained in Aadnoy (Aadnoy, 2010). Figure 12 shows an S-shaped well that is drilled in a vertical plane. The total length is 2111 m, and the drill string consist of 161m of 8" × 3" drill collars (2.13 kN/m) and 1950 m of 5"-19.5 lbs/ft drill pipe (0.285 kN/m). The drill collar radius is 0.1 m, and the drill string connection radius is 0.09 m. The well is filled with 1.3 s.g. drilling mud and the coefficient of friction is estimated to be 0.2. The bottom-hole-assembly starts out just below the drop-off section, and is vertical. For this case there is no change in azimuth, and the dogleg becomes equal to the change in inclination.

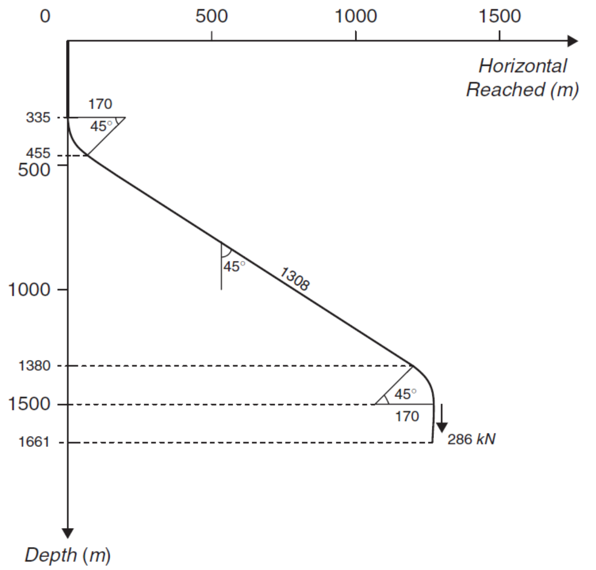

Figure 12. S-Type Wellbore Profile
Source : Aadnoy, 2010

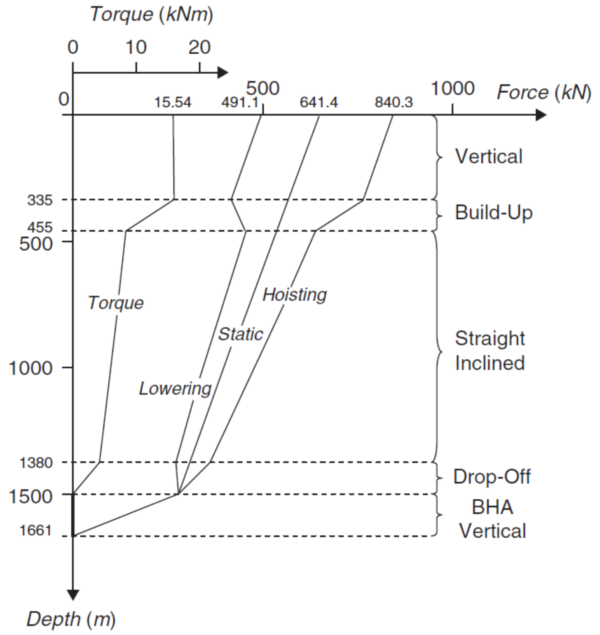

Figure 13. Torque and drag for the S-Type Wellbore
Source : Aadnoy, 2010

Table 8. Drag in Drillstring during Drilling and with Bit Off Bottom, S-Type Well
Source : Aadnoy, 2010

Position	Static weight, Bit off bottom (kN)	Static weight, 90 kN bit force
Well Bottom	0	−90
Bottom dropoff section	286	196
Bottom sail section	314.4	224.4
Top sail section	533.6	443.6
Top buildup section	562	472
Top well	641.4	551.4

Table 9. Torque in Drillstring during Drilling and with Bit Off Bottom, S-Type Well
Source : Aadnoy, 2010

Position	Torque, off bottom (kNm)	Torque, in string (kNm)	Torque in well (kNm)
Well Bottom	0	0	9
Bottom dropoff section	0	0	9
Bottom sail section	4.04	2.77	11.77
Top sail section	8.0	6.72	15.72
Top buildup section	15.54	13.0	22
Top well	15.54	13.0	22

T**able 10. Drag Drillstring during Drilling and with Bit Off Bottom, S-Type Well**
Source : Fazaelizadeh, 2013

Position	Static weight, Bit off bottom (kN)	Pulling, hoisting, tripping out (kN)	Lowering, trinpping in (kN)
Well Bottom	0	0	0
Bottom dropoff section	286	286	286
Bottom sail section	315.5	363	272.9
Top sail section	533.6	626	558.3*
Top buildup section	562	760.9	511.7*
Top well	651.5*	850.3*	591.1*
Note: (*) calculation results are incorrect			

This S-Type wellbore was calculated by using T&D software, and the results shown in **Table 11**, **Figure 12**, and **Figure 13**.

Table 11. Drag in Drillstring, S-Type Well, T&D Software

Position	Static weight, bit off (kN)	Pulling (kN)	Lowering (kN)
Well Bottom	0	0	0
Bottom dropoff section	285.8	285.8	285.8
Bottom sail section	314.3	362.9	272.8
Top sail section	533.9	626.5	448.5
Top buildup section	562.5	761.6	411.9
Top well	642	841.2	491.4

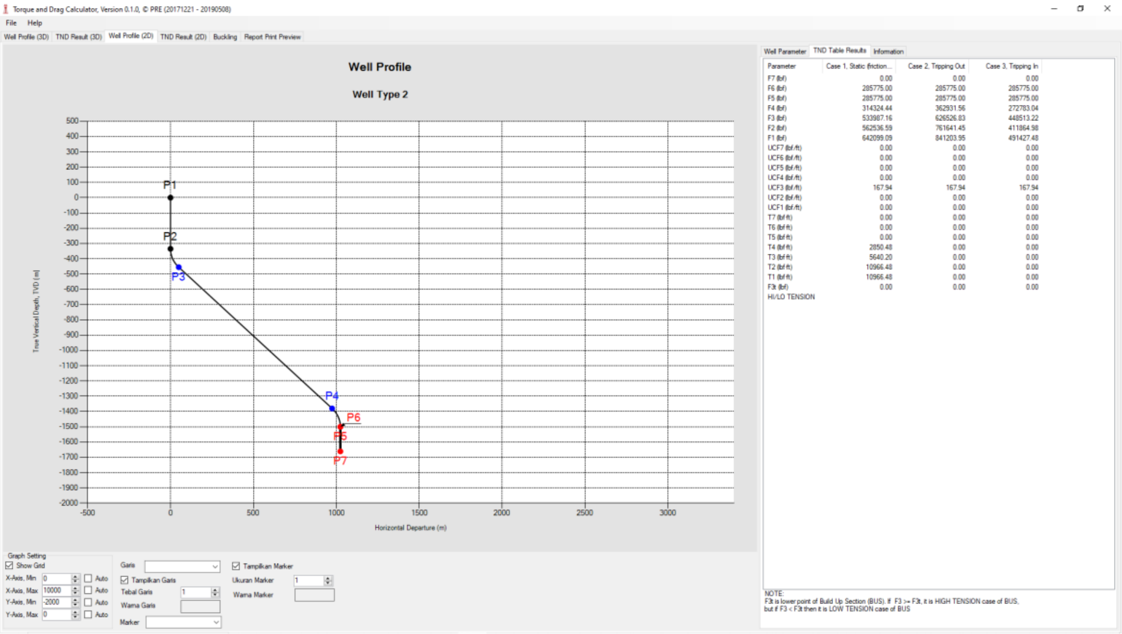

Figure 14. Tabulated Results for Type-1 2D Well Profile, Ex-2: S-Type, Aadnoy Method

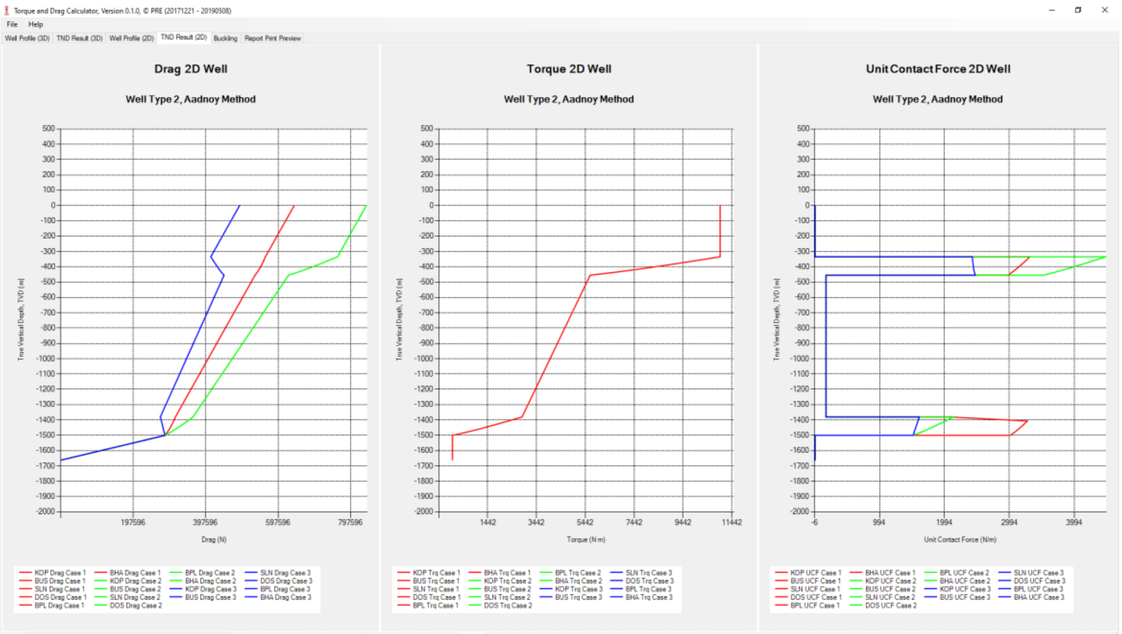

Figure 15. Graphical Results for Type-1 2D Well Profile, Ex-2: S-Type, Aadnoy Method, case 1: static, case 2: tripping out, case 3: tripping in

IV. CONCLUSION

This paper explains the development of torque and drag calculation software. The general development method is as follows: first, modeling drag and torque for 2D and 3D well profile, including straight and curved sections. Secondly, it implements all the models in C# language. Finally, test the software by calculating specific cases taken from Aadnoy (Aadnoy & Andersen, 1998) and Fazaelizadeh (Fazaelizadeh, 2013), and compare the results with those references.

It has been shown that the calculation results from the T&D Software exactly the same with those of (Aadnoy & Andersen, 1998; Fazaelizadeh, 2013). This concludes the software was correct and so can be used as a design tool for oil well design. But of course, these TND results must be validated with field data.

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NOMENCLATURE

x, y	:	coordinates in the horizontal plane	
z	:	vertical coordinate	
D_s	:	measured length along hole section	
D_x, D_y, D_z	:	projected distances	
w	:	unit weight of drillpipe	kg/m
F	:	force along drillstring	kN
F_1	:	force at bottom of section	kN
F_2	:	force at top of section	kN
T	:	torque along drillstring	kN/m
b	:	buoyancy factor	
P	:	power	kW
n	:	rotary speed	rpm
C	:	conversion constant	
α	:	a inclination of string from vertical	rad
$\rho_p, \rho_{\text{pipe}}$	:	Density of pipe,	kg/m³
ρ_o, ρ_m	:	Density of mud (fluid outside pipe)	kg/m³
ϕ	:	azimuth of the section	rad
μ	:	coefficient of friction	
ΔF	:	additional force applied to catenary	
R	:	radius of bend, radius of well curvature	m
r	:	radius of tool joint	m
r_p	:	radius of pipe	m
L	:	length of pipe	m
BHA	:	bottom-hole-assembly	
DL	:	dog-leg; angular change in well path	
DLS	:	dog-leg severity; rate of dog-leg (= 30 (m) × 57.3(°/rad)/R (m))	
HKL	:	Hook Load	
MD	:	measured depth	m
RKB	:	drill floor reference	
RTDD	:	Real Time Drilling Data	
T&D, TND	:	Torque & Drag, Torque aNd Drag	
TVD	:	true vertical depth	m
WOB	:	weight-on-bit	kN

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