CHAPTER IV
RESULTS AND DISCUSSION

4.1 Well Planning User-Friendly Software

4.1.1 Introduction of the Software

A task introduces a user-friendly way _for the analytical model application by creating a torque and drag software. The developed software created in GUI with MATLAB is shown in Figure 4.1. The software is based on the three-dimensional torque and drag, which it is rather simple tool to use. The software consists of three parts: input, calculation, and results.

The input panel (Figure 4.2), which is well description, can be separated into three sections: well section, drillpipe and BHA, and the table of well description for each section (Figure 4.2 (a)). All the required inputs are summarized below:

Well section:

- well type (vertical, build, hold, drop, and horizontal)

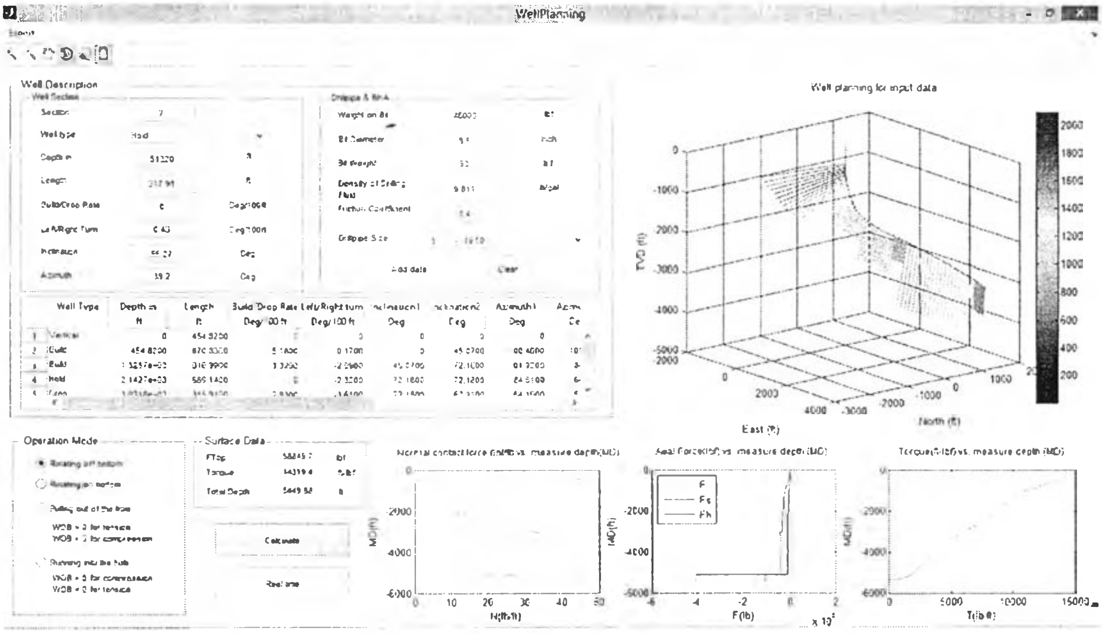


Figure 4.1 The developed of the user-friendly software.

- depth in (ft)
- length (ft)
- build/drop rate, BUR (degree/100 ft)
- left/right turn, BURLR (degree/100 ft)
- inclination, Inc (degree)
- azimuth, Az (degree)

Drillpipe and BHA:

- weight on bit, WOB (lbf)
- bit diameter (inches)
- bit weight (lbf)
- density of drilling fluids, DF (lbm/gal)
- friction coefficient, FF
- drillpipe size (inches)

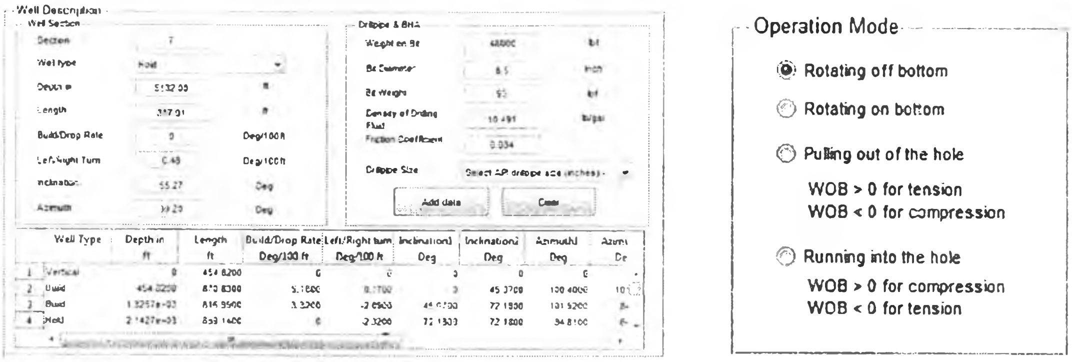
Drillpipe size in a popup menu contains a drillpipe configuration consisting of five parameters:

- nominal weight (lbf/ft)
- drillpipe outer diameter (inches)
- drillpipe inner diameter (inches)
- drillpipe material density (lbm/gal)
- elasticity of drillpipe material (psi)

The operation mode is also one of the input parameter that can be selected by radio button as shown in Figure 4.2(b).

The inputs are the exact values, except build/drop rate and left/right turn summarized in Table 4.1. WOB is also affected to the RonB operation by the positive value (+) is a compressive force, whereas the negative value (−) is a tensile force.

In the calculation part, a user cannot only adjust variables inputting to the software via the edit box in the GUI, but also comprehend a graphic of outputs from processing of the software in the form of three-dimensional well trajectory cooperated with normal contact force along the well profile (Figure 4.3(a)). The calculated values of the surface parameters from the software are expressed in the panel of text box in the GUI composed of axial force, torque, and measured depth at



● Rotating off bottom

○ Rotating on bottom

○ Pulling out of the hole

WOB > 0 for tension
WOB < 0 for compression

○ Running into the hole

WOB > 0 for compression
WOB < 0 for tension

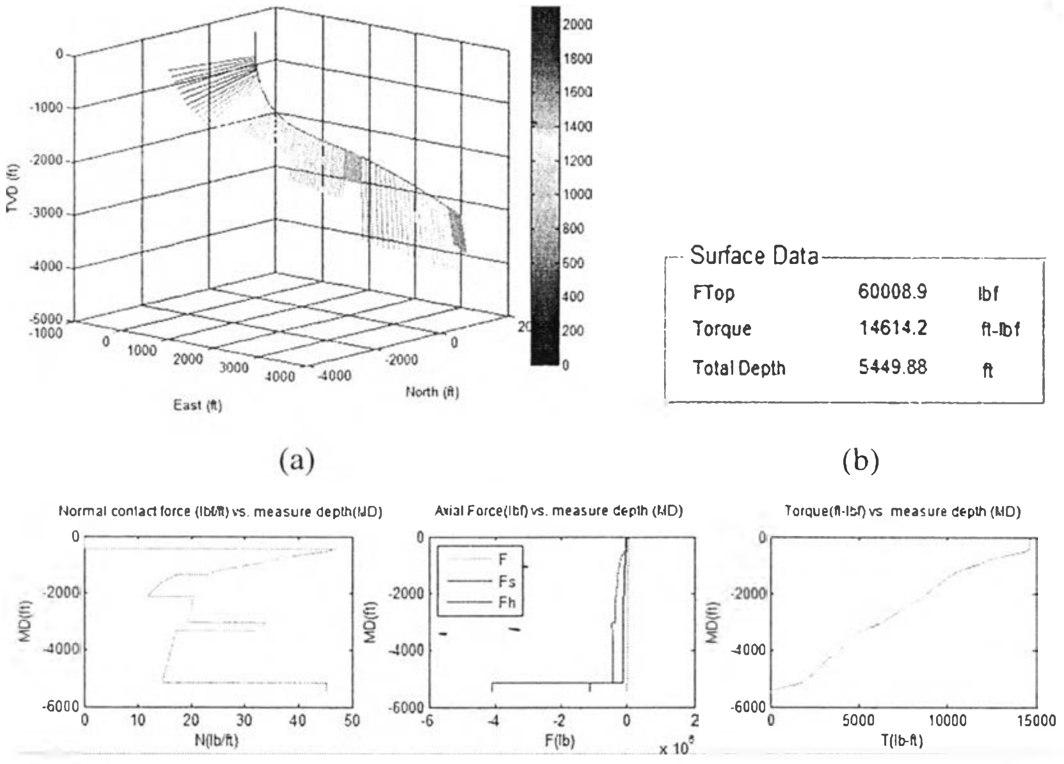
(a) (b)

Figure 4.2 Input panel of the user-friendly software consist of (a) well description, drillpipe, BHA, and (b) operation mode.

Table 4.1 Characterization of well trajectory in 3D and the input sign

Type of Section	Inclination	Azimuth	Software input	
			Build/Drop rate	Left/Right turn
Vertical	Constant	Constant	0	0
Build	+	Constant	+	0
Build Left Turn	+	–	+	–
Build Right Turn	+	+	+	+
Hold	Constant	Constant	0	0
Hold Left Turn	Constant	–	0	–
Hold Right Turn	Constant	+	0	+
Drop	–	Constant	+	0
Drop Left Turn	–	–	+	–
Drop Right Turn	–	+	+	+
Horizontal	Constant	Constant	0	0
Horizontal Left Turn	Constant	–	0	–
Horizontal Right Turn	Constant	+	0	+

In the calculation part, a user cannot only adjust variables inputting to the software via the edit box in the GUI, but also comprehend a graphic of outputs from processing of the software in the form of three-dimensional well trajectory cooperated with normal contact force along the well profile (Figure 4.3(a)). The calculated values of the surface parameters from the software are expressed in the panel of text box in the GUI composed of axial force, torque, and measured depth at a bit goes (Figure 4.3(b)). In the result parts, the output of the value of normal contact force, axial force, and torque are shown in the graph versus measured depth in Figure 4.3(c).



Surface Data

FTop 60008.9 lbf

Torque 14614.2 ft-lbf

Total Depth 5449.88 ft

(a)

(b)

(c)

Figure 4.3 Output panels of the user-friendly software consist of (a) well trajectory in three dimensions, (b) the data of axial force, torque, and total measured depth at the rig floor, and (c) the graph of normal contact force, axial force, and torque versus measured depth.

4.1.2 Calculation of Solving Torque and Drag Equations

The software checks inputs that user feed into the software by a constraint of each parameter. Inclination and azimuth by each well type is the first value of the calculation in the table of the well description panel (Figure 4.2(a)) before the user can add information of the next section. All sections of the well are feed into the software, and then the calculation is beginning with the measured depth followed by an alpha angle (α), which related to inclination, the step size, as well as well trajectory. For the case of vertical, hold and horizontal section, a step size of the measured depth are divided by the length into nineteen points as default value of the software. The step sizes of calculated measured depth in case of build and drop section are also divided the alpha angle which is calculated from the length of that section into nineteen points as others well type. The measured depth accumulates from top at the rig floor to the bottom.

The software diagnoses the torque and axial force in three-dimensional wellbore that can be expected during RoffB, RonB, POOH, and RIH. In each well type, the calculation begins with the normal contact force followed by axial force, as well as torque which appears only rotating operation (RoffB and RonB). These are accumulated from bottom to the top with an initial condition. The initial condition of torque at the bottom is zero due to an idealistic value, which is torque applied at the surface vanished by the friction torque till the bit, and the initial condition of axial force of RoffB, POOH, and RIH is a bit weight, otherwise in case of RonB, WOB is used. Torque and drag equation are solved by Euler's method to solve T&D differential equation using step sizes as calculated by the measured depth presented in Appendix A.

4.2 Actual Field Well

4.2.1 Well A

This example demonstrates the developed software for well A, and also verifies the T&D equations. Well A is an old field example on-shored in the central of Thailand and one of the complex wells as described in Table 4.2.

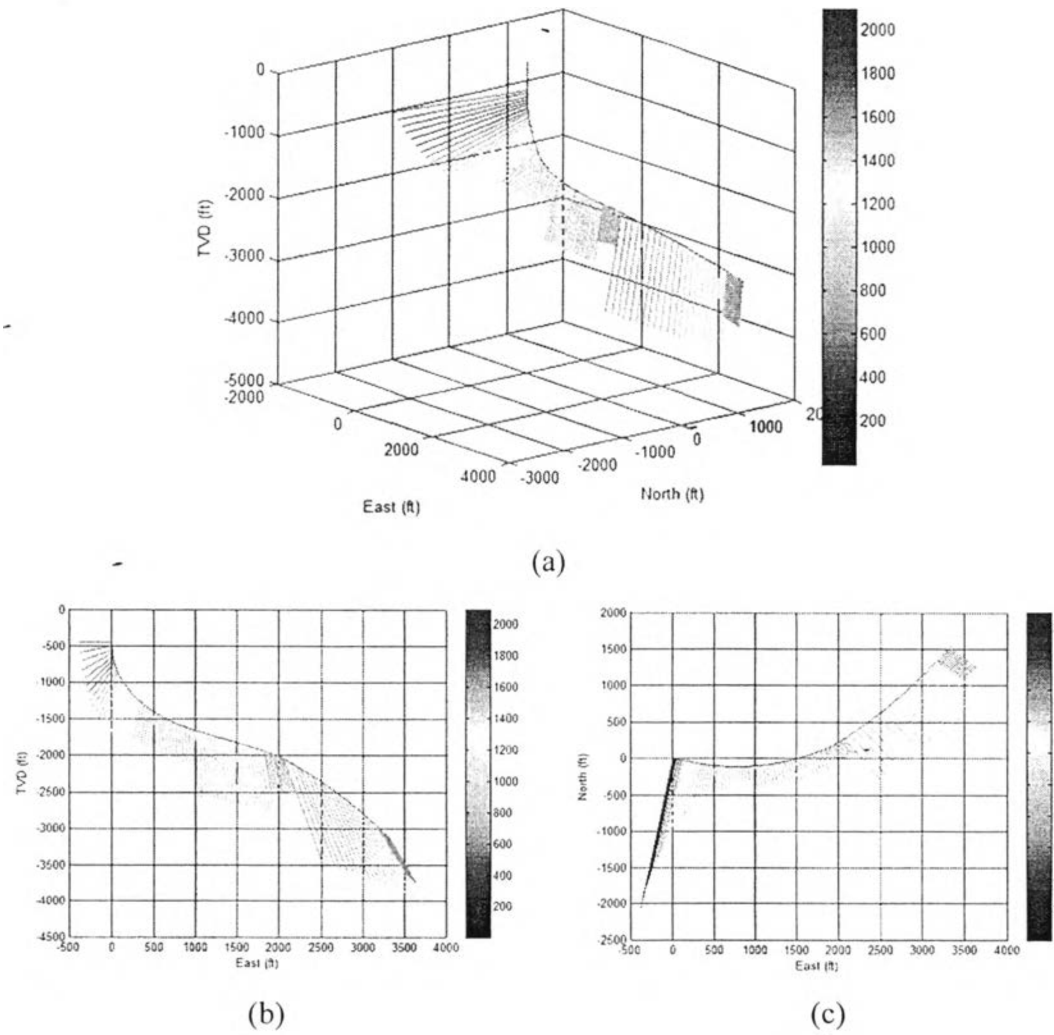
Table 4.2 Well description of well A as the inputs to the software

Well type	Depth in (ft)	Length (ft)	BUR (deg/ 100ft)	BURLR (deg/ 100ft)	Inc1 (deg)	Inc2 (deg)	Az1 (deg)	Az2 (deg)	WOB (lbf)	Bit diameter (inches)	DF (lb/gal)	FF	Bit Weight (lbf)
Vertical	0.00	454.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	18.746	9.089	0.1-0.4	0.00
Build	454.66	870.00	5.18	0.17	0.00	45.07	100.40	101.92	0.00	12.298	9.509	0.1-0.4	0.00
Build	1325.66	816.99	3.32	-2.09	45.07	72.18	101.92	84.81	0.00	12.250	9.721	0.1-0.4	0.00
Hold	2142.65	889.14	0.00	-2.32	72.18	72.18	84.81	64.19	0.00	10.556	9.918	0.1-0.4	0.00
Drop	3031.79	315.91	3.86	-3.61	72.18	62.91	64.19	52.80	0.00	8.5	10.029	0.1-0.4	0.00
Drop	3347.70	1784.28	0.43	-0.76	62.91	55.27	52.80	39.20	0.00	8.5	10.288	0.1-0.4	0.00
Hold	5131.99	317.91	0.00	0.48	55.27	55.27	39.20	40.72	48000	8.5	10.491	0.1-0.4	93.00

Table 4.3 The drillpipe description of well A as the database of the software

Drillpipe diameter (inches)	Elasticity (psi)	OD (inches)	ID (inches)	Density of steel (lbm/gal)	Nominal weight (lbf/ft)
5.00	30,000,000	5.00	4.28	65.5	19.5
5.00	30,000,000	5.00	4.28	65.5	19.5
5.00	30,000,000	5.00	4.28	65.5	19.5
5.00	30,000,000	5.00	4.28	65.5	19.5
5.00	30,000,000	5.00	4.28	65.5	19.5
5.00	30,000,000	5.00	4.28	65.5	19.5
7.32	30,000,000	7.32	3.16	65.5	64.8

The target depth of well A is 5,450 ft, and the drillstring consists of 5,145 ft of 5"-19.5 lbs/ft drillpipe as well as 305 ft of BHA (component shown in Table A3). The drill pipe configuration is provided in the database of the software shown in Table 4.3. The well trajectory in 3D of well A from the software as shown in Figure 4.4 (a), and Figure 4.4 (b) shows the vertical view of well A which is a combination of four well types, vertical, build, hold, and drop. This is an s-shaped well with turned direction to east (horizontal view) compared with the rig floor as shown in Figure 4.4 (c). The well is filled with various drilling fluid densities and the coefficient of friction along the well path. Top drive and traveling block weight are 25,000 lb.



(a)

(b)

(c)

Figure 4.4 Well Trajectory of well A (a) 3D view, (b) vertical view, and (c) horizontal view.

T&D analysis of well A was performed by various the coefficient of friction since this factor is extremely involved in T&D equations, but it is rarely indicated the actual values along the well path as a single value. The friction factor can express the fact that a problem is existing in the wellbore (Brett *et al.*, 1989) which could be either to hole geometry (inclination and azimuth changes) or to some other factors (problems with cuttings accumulations, tight hole, and type of rock formation). Moreover, the coefficient of friction can be separated into two types: the rotating friction factor for conventional drilling (RoffB and RonB) or wiper trips and sliding friction factor for turbine/downhole motor drilling or POOH/RIH (Lesage *et al.*, 1988). Thus, this T&D well-planning software used a single average friction factor for the entire wellbore interval, which is very common in available torque and drag simulators, for both rotational and axial motion.

4.2.1.1 Torque

The equations used in calculating torque in the well planning consisting of two operation modes, RoffB and RonB are based on a soft string model in three-dimensional wellbore presented by Prurapark (2009). The torque was performed starting bottom-up at each section with the bottom-end boundary conditions to be weight on bit and torque on the bit for RonB which torque on bit equals to zero due to the ideal no loss of torque at bit. The different well geometry will show the different torque behavior due to the different friction drag acting on the drillstring.

Beginning from the bottom hold section (Figure 4.5), the torque is linear trend compared with the upper section which is drop-off section because the normal contact force acting on the drillstring is relatively the same values either left/right turn or no turn direction entries hold section, while in the drop section, the normal contact force extremely depend on the alteration of inclination. For higher drop rate, the torque slope represented the change of measured depth with respect to torque, is less due to the high angle alteration at the same depth interval. As the higher inclination in hold section, the higher normal contact force will be increased in torque mainly that means the torque slope is high for the lower inclination. For the higher build rate in build section, the torque tendency is leaner

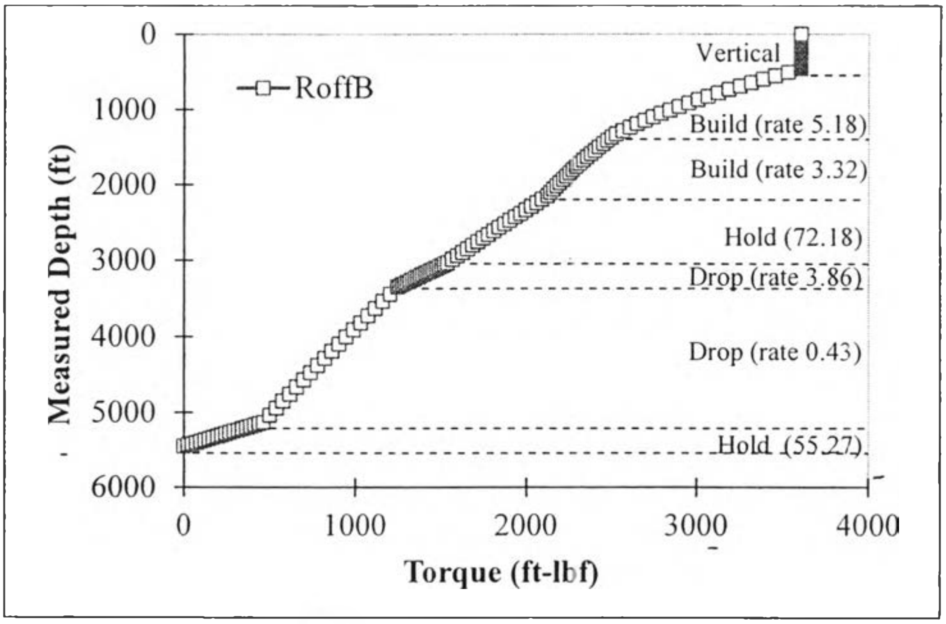


Figure 4.5 Calculated torque of RoffB of well A from the software at the coefficient of friction of 0.1 in each section.

than the lower build rate since the higher normal contact force by alternation of inclination will be increased in torque. Finally, there is no torque different in the vertical section due to the T&D equations assumption.

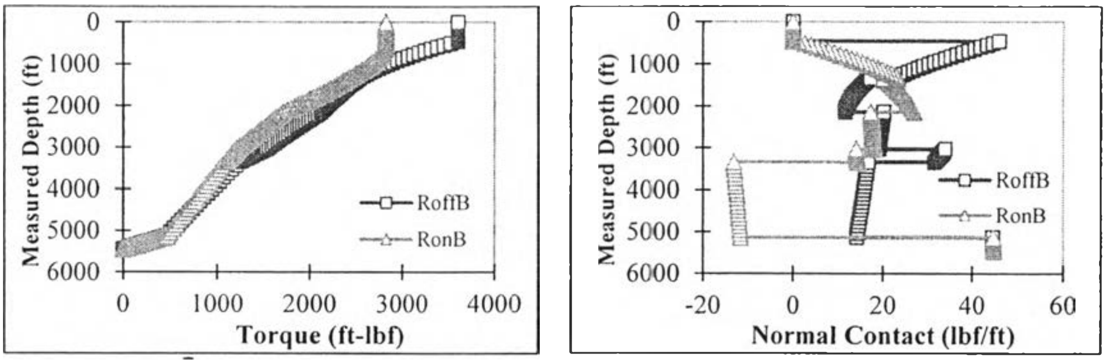
The RoffB, which is the drillpipe rotated without axial movement gives the lower surface torque (at the measured depth of zero) than the RonB shown in Figure 4.6 (a). The difference is about 21.74 % (Table 4.4) due to the magnitude of the normal contact force (Figure 4.6 (b), the positive value is set to be upside contact and the negative value is set to be downside contact of the drillstring) which is affected to the torque value directly as shown in equation (2.7) of Chapter 2. The magnitude of the normal contact force begins to be different in drop section (at above 5,000 ft MD in Figure 4.7) because the effect of WOB acting axially on the drillstring and the surface of the drillstring is a tendency to attach the wellbore wall in the deviated zone, especially the high inclination (at about 2,000 ft MD) in the build section. The normal contact force of the RonB is trends to decrease in the low inclination that gives the low torque near the vertical section (at about 450 ft MD). Finally, there is no torque different in the vertical section because the drillstring is lined in the center of the wellbore, so that the normal contact force is assumed to be zero (no contact between the drillstring and wellbore wall).

In addition, the torque from the software is considered only the frictional torque, but the surface torque comprises of the frictional torque, dynamic torque, mechanical torque, and bit torque. Therefore, the bit torque, which is generated by the engagement of the bit and the formation of the RonB operation, is not taken into account. The addition of this downhole bit torque of RonB will increase the surface torque that is larger than RoffB. Meanwhile, the bit torque can be minimized by focusing on bit optimization program (Payne and Abbassian, 1997) that caused the surface torque of RonB could be larger than RoffB.

Comparison between the calculated torque and the actual field data was performed by various coefficient of frictions (Figure 4.8) because it is always challenging to interpret the torque values, as the actual field data are very sensitive to many factors, such as the poor hole cleaning, wellbore instability, and tight hole (Mason and Chen, 2007). The torque has an influence on the surface contact between wellbore and drillstring, so that the calculated torque was integrated a correction factor to the model by multiplying by various coefficient of frictions from 0.1 to 0.4. The lower coefficient of friction will give the lower torque value as expressing in equation (2.7).

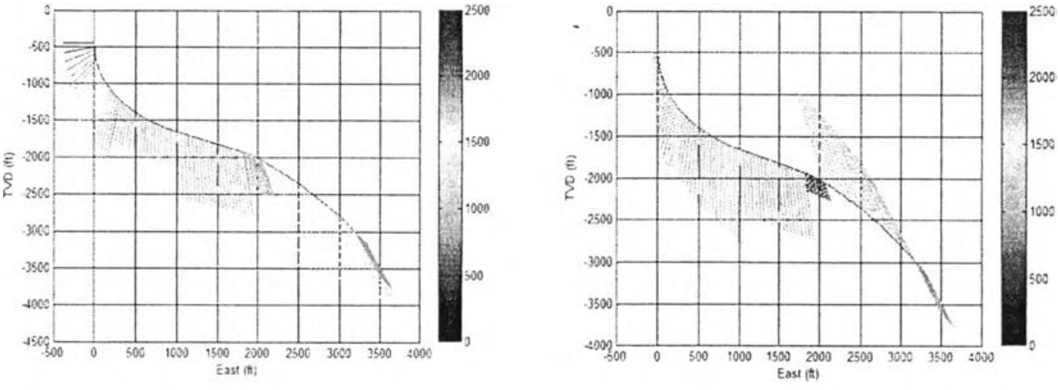
Table 4.4 Calculated torque of well A with various coefficient of frictions

FF	Torque (ft-lbf)		Difference (%)
	RoffB	RonB	
0.1	3,610.12	2,825.45	21.74
0.2	7,220.25	5,994.13	16.98
0.3	10,830.37	9,570.95	11.63
0.4	14,440.49	13,632.64	5.59



(a) (b)

Figure 4.6 Comparison of the RoffB and RonB of (a) the calculated torque and (b) the normal contact force of well A from the software at the coefficient of friction of 0.1.



(a) (b)

Figure 4.7 Comparison of the normal contact force distributed along the drillstring of (a) RoffB and (b) RonB of well A from the software at the coefficient of friction of 0.1.

When the well planning is given the same input data as the actual field data for the 5" drillpipe section (above 5,000 ft MD), the compared results in Table 4.5 show that the calculated torque value at the surface is almost the same at the coefficient of friction of 0.3 with the percentage of difference of 5.07 %. The actual surface torque is affected by many factors; however, the small discrepancy is probably due to small rounding errors in specifying the wellbore and pipe diameter at each measured depth. Moreover, the input data of a bottom hole assembly component is not accurate since it lacks of information. Above 5,000 ft MD, the actual torques is greater than the calculated torque due to the tight hole, or the hard formation, or poor hole cleaning, including the further deep drilling, it is required high torque applied at the surface to overcome the friction in order to reach the target depth, and then it leans back to the lower zone (above 3,000 ft MD), that seems like the calculated torque at the coefficient of friction of 0.3. All the calculated torques with various coefficient of frictions are lower than the torque limit which is the maximum make-up torque of the tool joint of the drillpipe.

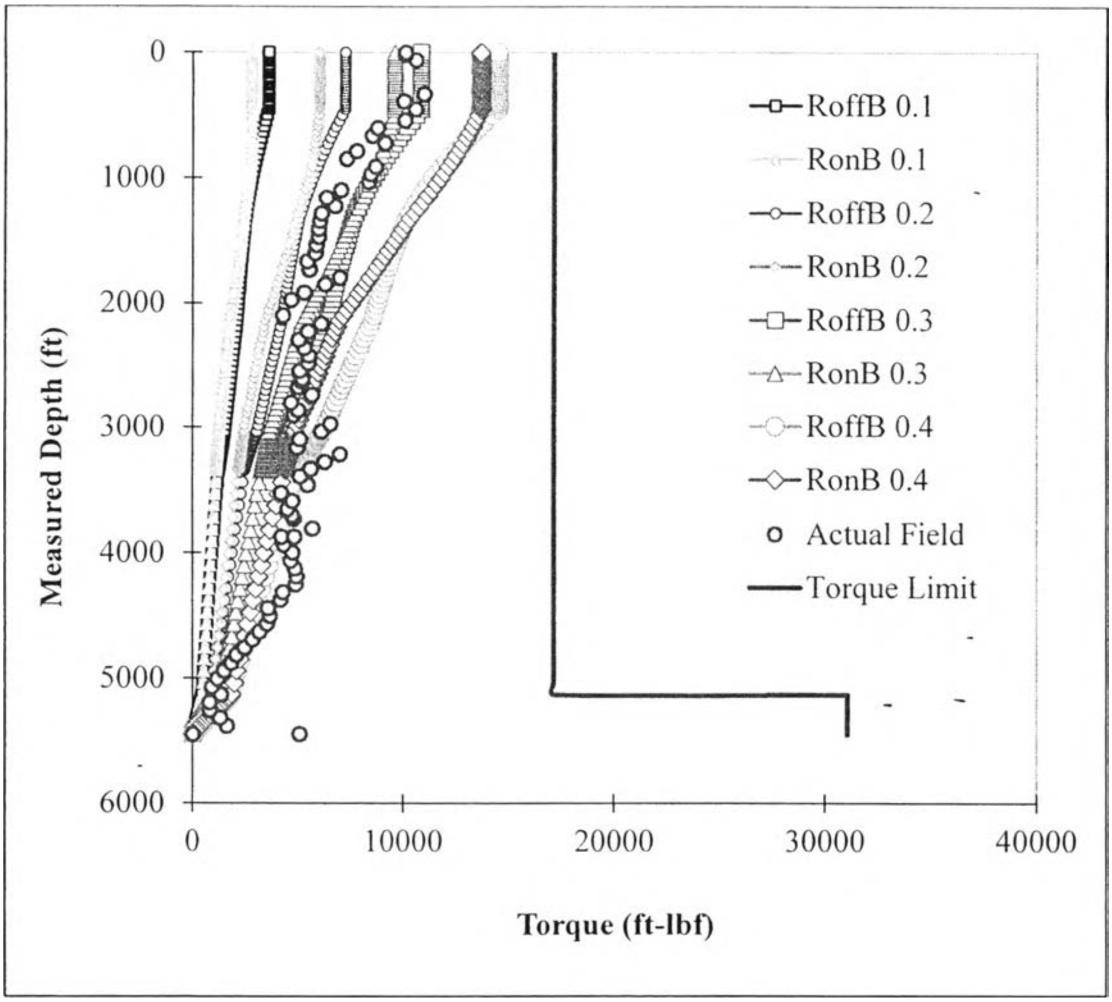


Figure 4.8 Comparison of the actual field torque of well A and the calculated torque at RoffB and RonB from the software with various coefficient of frictions from 0.1 to 0.4.

Table 4.5 Actual field torque and calculated torque of well A at the surface

FF	Torque (ft-lbf)		Actual RonB Torque (ft-lbf)	Difference (%)
	RoffB	RonB		
0.1	3,610.12	2,825.45	10,082.07	-71.98
0.2	7,220.25	5,994.13		-40.55
0.3	10,830.37	9,570.95		-5.07
0.4	14,440.49	13,632.64		35.22

4.2.1.2 Axial Force and Hookload

The axial force is the force along the drillstring comprising of the tensile force (positive value, +) and compressive force (negative value, –). The axial forces along the drillstring were calculated gathering from bottom to top for different well type, such as hold, drop-off, build-up, and vertical section.

The calculated axial force was achieved by various coefficient of frictions from 0.1 to 0.4 with different operation mode, RoffB, RonB, POOH, and RIH as shown in Table 4.6 compared with the actual field data. The highest axial force at the surface face comes from the POOH since it is affected by the friction drag that against the movement in the desired direction, while the RonB is given the lowest axial force at the surface due to the assist of the friction drag. The RoffB is a static weight of the buoyed weight of the drillstring, which is not affected by the friction drag due to no axially movement, and it is usually between the axial value of POOH and RIH.

The axial force in the deviated zone i.e. build-up and drop-off is broadened by the loads of the normal contact force leading to high drag force as expressing in equation (2.5). According to the increasing in the coefficient of friction, the axial force of POOH and RIH will also spread out of RoffB (Figure 4.9).

The axial force can be presented in the measured hookload (HK) as the following:

$$HK = Axial\,force + Top - WOB \qquad (4.1)$$

Table 4.6 Actual axial force and calculated axial force at the surface of well A

FF	Axial Force (lbf)				Actual RIH Axial Force (lbf)	Difference (%)
	RoffB	RonB	POOH	RIH		
0.1	59,325.96	6,986.98	72,048.00	54,203.76	38,790.39	-39.74
0.2	59,325.96	1,785.95	88,573.06	48,961.04		-26.22
0.3	59,325.96	-4,549.88	110,130.74	42,947.70		-10.72
0.4	59,325.96	-12,233.13	138,310.07	28,695.17		26.03

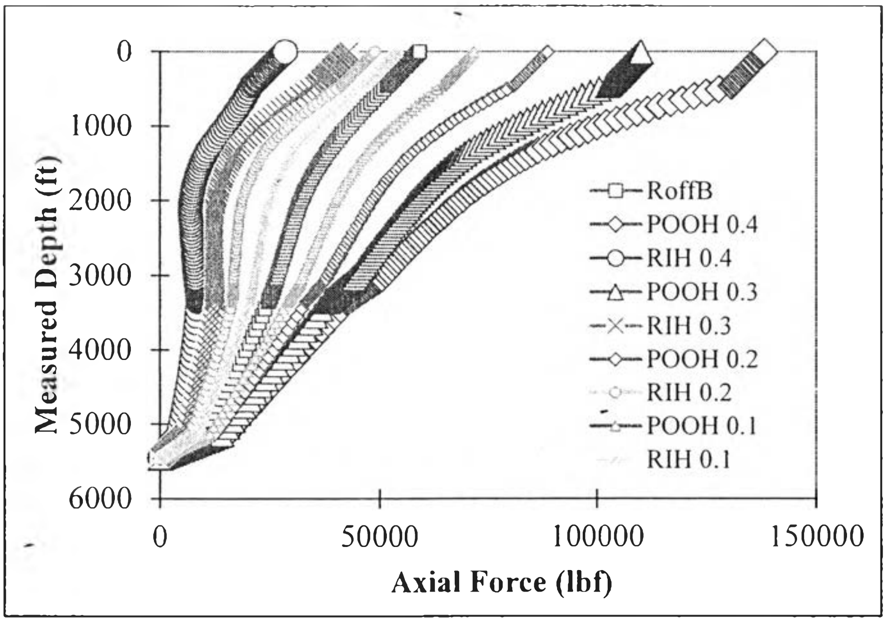
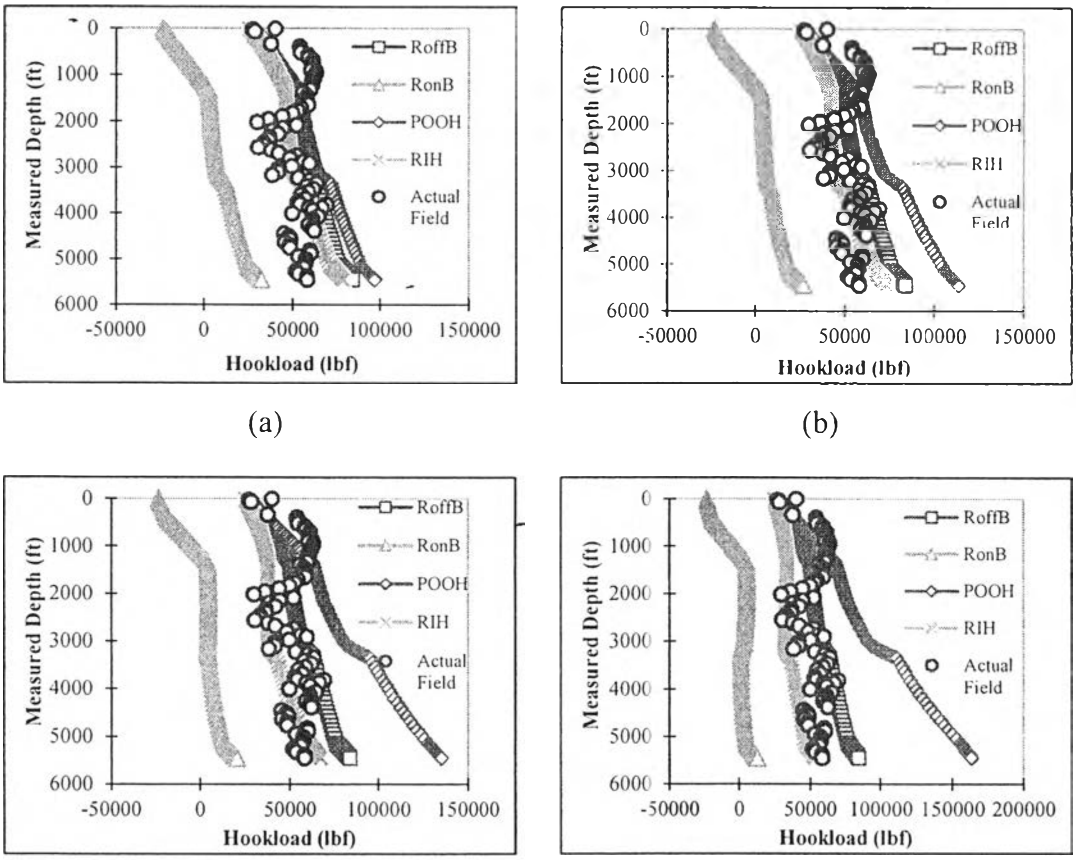


Figure 4.9 Comparison of the calculated axial force of well A with the from the software for coefficient of frictions (a) 0.1, (b) 0.2, (c) 0.3, and (d) 0.4.

Where HK is the hookload, Top is the weight of the hoisting system including travelling block, and top drive, and WOB is account only in RonB operation. The top of the software is set to be 25,000 lb as a default (seen in Appendix A).

The hookloads of the drillstring were calculated for each section, such as hold section, drop-off section, build-up section, and vertical section as shown in Figure 4.10. The results show all the operation accomplished by various coefficient of frictions from 0.1 to 0.4 as summarized in Table 4.7. Since the actual field data came from the drilling depth log provided by the operator, the results were compared only RIH operation, or sliding operation, which is to drill with a mud motor rotating the bit downhole without rotating the drillstring from the surface, and the bit able to penetrate into the formation with the mud motor. Though all results were not match, especially in the upper section (above 2,000 ft MD), it might be either the measured hookload sensor out of calibration or the unit pipe weight not correct. In addition, there was an error from the moving parts of the hoisting system affected by a sheave friction that caused low accuracy of the measured weight a bit



(a) (b)

(c) (d)

Figure 4.10 Comparison of the actual field hookload of well A with the calculated hookload from the software for coefficient of frictions (a) 0.1, (b) 0.2, (c) 0.3, and (d) 0.4.

Table 4.7 Actual field hookload and calculated hookload of well A

FF	Hookload (lbf)				Actual RIH Hookload (lbf)	Difference (%)
	RoffB	RonB	POOH	RIH		
0.1	84,325.96	31,986.98	97,048.00	79,203.76	63,790.39	24.16
0.2	84,325.96	26,785.95	113,573.06	73,961.04		15.94
0.3	84,325.96	20,450.12	135,130.74	67,947.70		6.52
0.4	84,325.96	12,766.87	163,310.07	53,695.17		-15.83

lower for pulling out and higher for running in. Therefore, the sheave friction should be corrected by applying it either to the model or to the actual measured data (Tveitdal, 2011). The approximate the coefficient of friction for well A is 0.3 (Figure 4.8 (c)), which the difference between RIH of the actual data and the calculated results of 6.52 % (Table 4.7). The suitable the coefficient of friction for well A is 0.33 obtaining by interpolation.

Even the measured hookload is accurate, the actual coefficient of friction is not constant along the wellbore. The suitable coefficient of friction of 0.3 was not given the idealistic match of the calculated hookload and the actual hookload for the entire well (Figure 4.11). The actual coefficient of friction can be affected by many environmental factors, such as micro-tortuosity, drilling fluid type and composition, and formation type in the open hole section and casing condition in the cased hole section (Gynor *et al.*, 2002). For this reason, when the coefficient of friction is used in the software, it is often referred to as a bulk coefficient of friction to cover all of the affections. The comparison of the calculated results with the actual field data at different coefficients of friction show that lower coefficient of friction can match the RIH hookload to the actual field data in particularly below 2,000 ft MD. The RIH is shifted to the left of the graph to the zone of the compression force (minus hookload) when the coefficient of friction is increase which indicates high drag during RonB and the tendency for buckling in the drillstring.

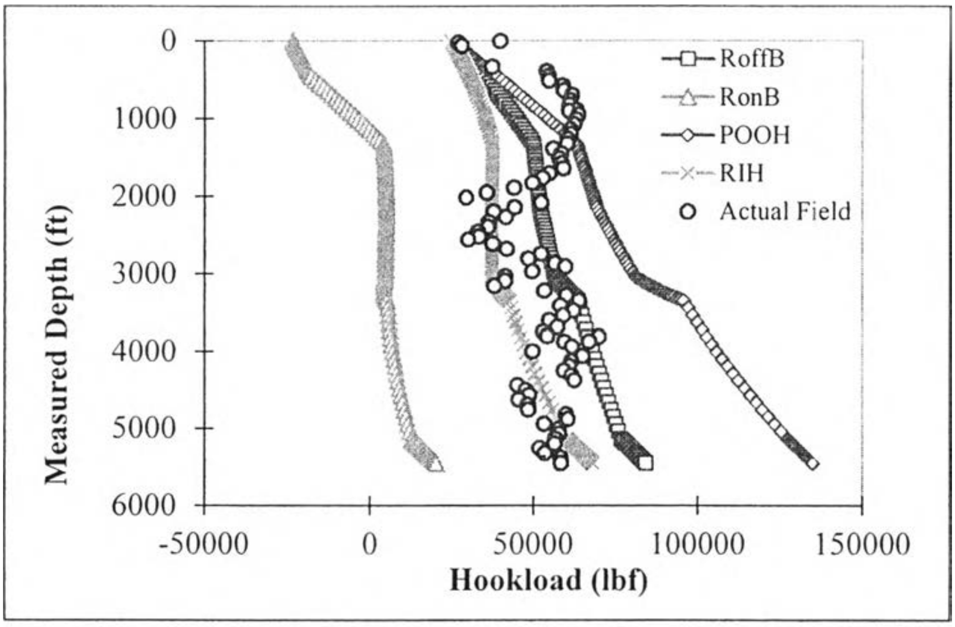


Figure 4.11 Comparison of the actual field hookload of well A with the calculated hookload from the software at the coefficient of friction of 0.3.

The buckling, which is the main T&D problem, is calculated based on the model presented by Wu and Juvkam-Wold (1993). The axial force in each section is calculated (Figure 4.12) as comprised of tensile (positive value) and compressive (negative value) at the coefficient of friction of 0.4. The axial force of POH is shifted to the tensile limit which is tensile strength of the drillpipe material, while the actual force of the RonB is shifted to the high compressive zone greater than the compressive of sinusoidal bucking, F_s (blue line, -), the sinusoidal bucking will be occur and it can continue into the helical bucking, F_h (red line, •) by increasing the compressive force. This situation can happen at high drag and high inclination while running the drillstring into the hole. Therefore, this software could be evaluated to prevent excessive T&D problems before drilling as the following aspects: WOB, density of drilling fluid, and the heavy weight drillpipe.

4.2.1.3 Effect of Weight on Bit on Axial Force and Torque

The axial forces of the RonB were calculated by various the WOB from 30,000 lbf to 50,000 lbf as shown in Figures 4.13 and 4.14. The WOB of

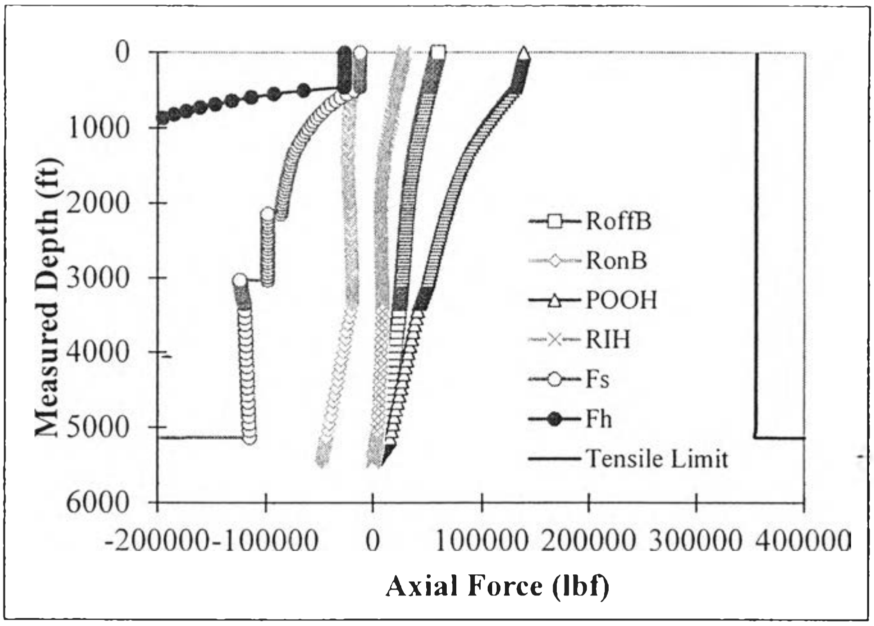


Figure 4.12 Calculated axial force and compressive buckling force of well A from the software at the coefficient of friction of 0.4.

well A is 48,000 lbf, which is shifted the axial force towards the compressive zone (negative value). The drillstring along the well trajectory could be buckled in a snaky manner in the vertical section seen in the Figure 2.17 (a). The potential of buckling could occur as the WOB is increased. In addition, the coefficient of friction is also affected to this situation by the acting of the friction drag in the direction of axial compressive force along the drillstring. Therefore, this situation should be prevented by indicting the allowance of maximum WOB of the RonB operation from the software. The maximum WOB of RonB at the coefficient of friction of 0.3 and 0.4 are 48,250 lbf and 44,200 lbf, respectively (Figure A9 and A10).

The effect of WOB on the torque value is performed by various the WOB from 30,000 lbf to 50,000 lbf as shown in Figure 4.15 at the coefficient of friction of 0.4 which is the worst case scenario to observe from this forward. The calculated torque of RonB is increased as the WOB is increased because the contact surface between the drillstring and the wellbore wall receives the growing of the magnitude of the normal contact force (Figure 4.16), especially in the

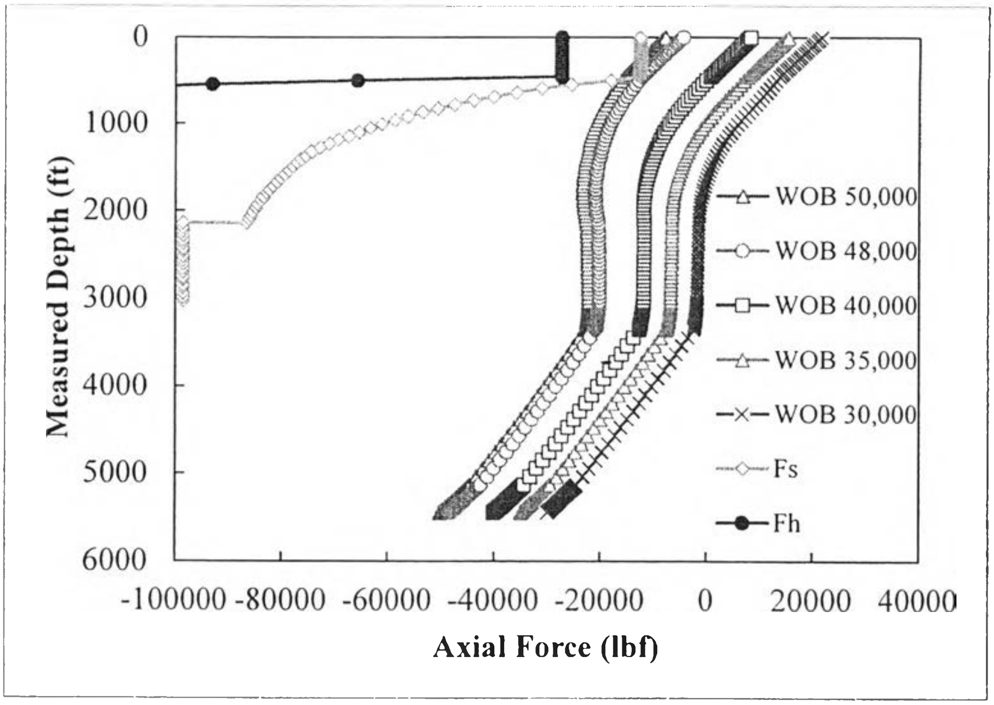


Figure 4.13 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.3 by various WOB.

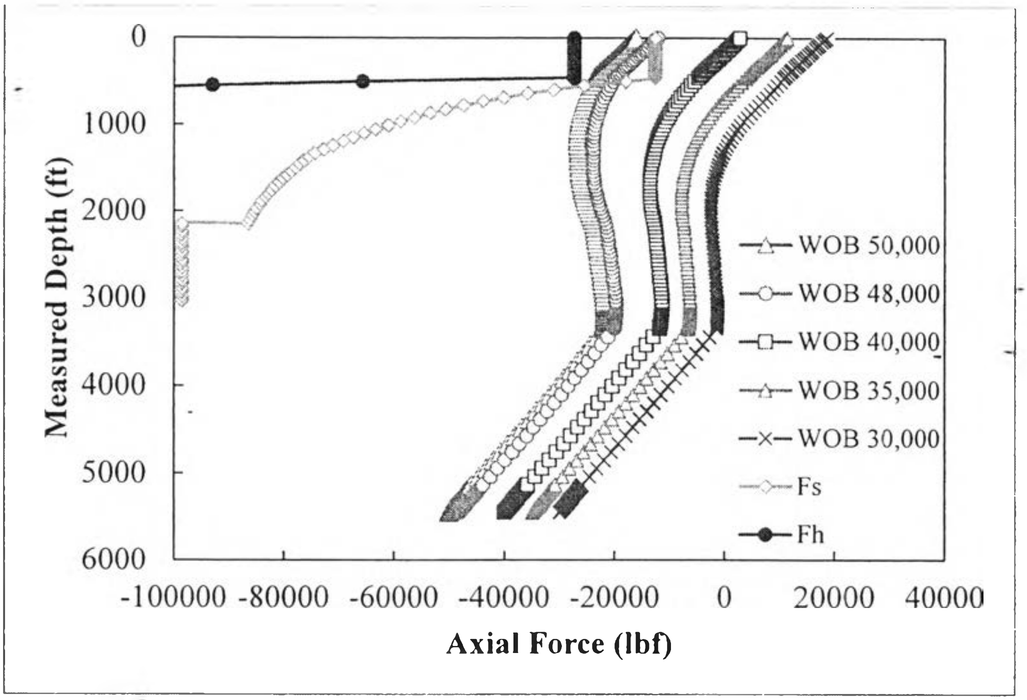


Figure 4.14 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.4 by various WOB.

build section (above 2,000 ft MD). The normal contact force of high inclination in that section acting on the downside of the drillstring is decreased with lowering the inclination. This can be seen in the torque value at that zone near the top of the section. In addition, the RonB at the high WOB, torque can be larger than RoffB, especially in the high inclination of build-up section.

4.2.1.4 Effect of Density of Drilling Fluid on Axial Force and Torque

The density of drilling fluid or mud weight (DF) is one of the factors that can effect on the axial forces and torques. These were calculated by various the DF from 8.500 lb/gal to 9.500 lb/gal as shown in Table 4.8 and 4.9. The new DF is obtained by the difference of the actual DF in each section. The actual DF of well A is 9.089 lb/gal at the top. As the DF increasing, the axial force of the RonB is decreased. When the DF is changed from 9.089 lb/gal to 9.500 lb/gal, the axial tensile force of RonB is reduced by 5.44 % since the buoyancy factor is decreased (as shown in equation (2.3) and (2.4)) and affected directly to the buoyed weight of the drillpipe and also the drag force that acts in the direction of axial compressive force along the drillstring in equation (2.5). The potential of buckling could occur as

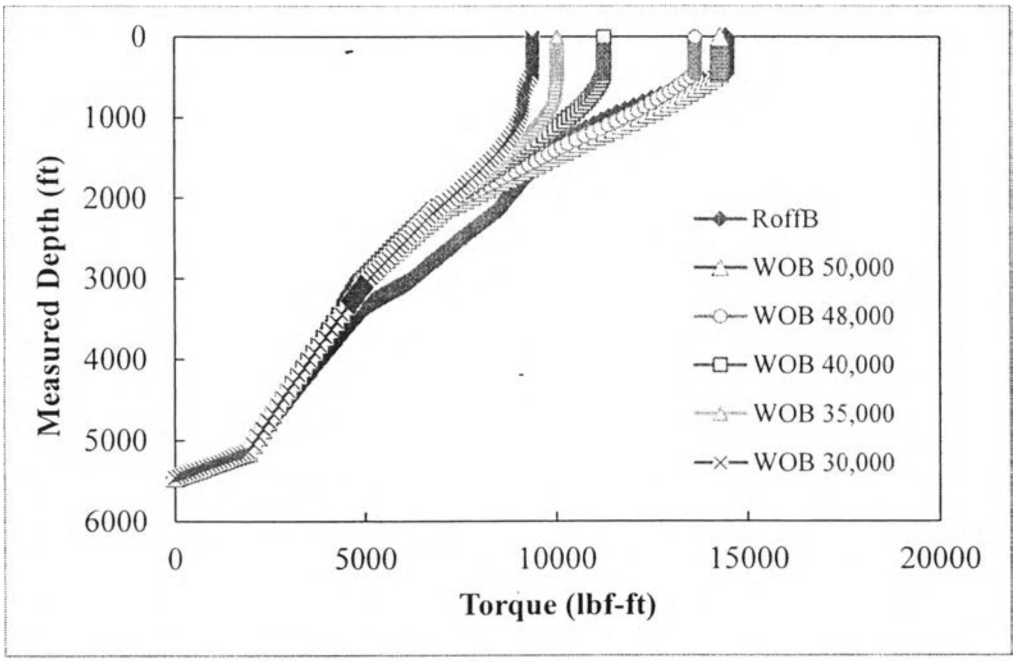


Figure 4.15 Calculated torque of RonB of well A from the software at the coefficient of friction of 0.4 by various WOB.

the DF is increased (Figure 4.17). Therefore, this situation should be prevented by indicting the allowance of maximum DF of the RonB operation from the software, but it is not exceed the fracture pressure of the formation.

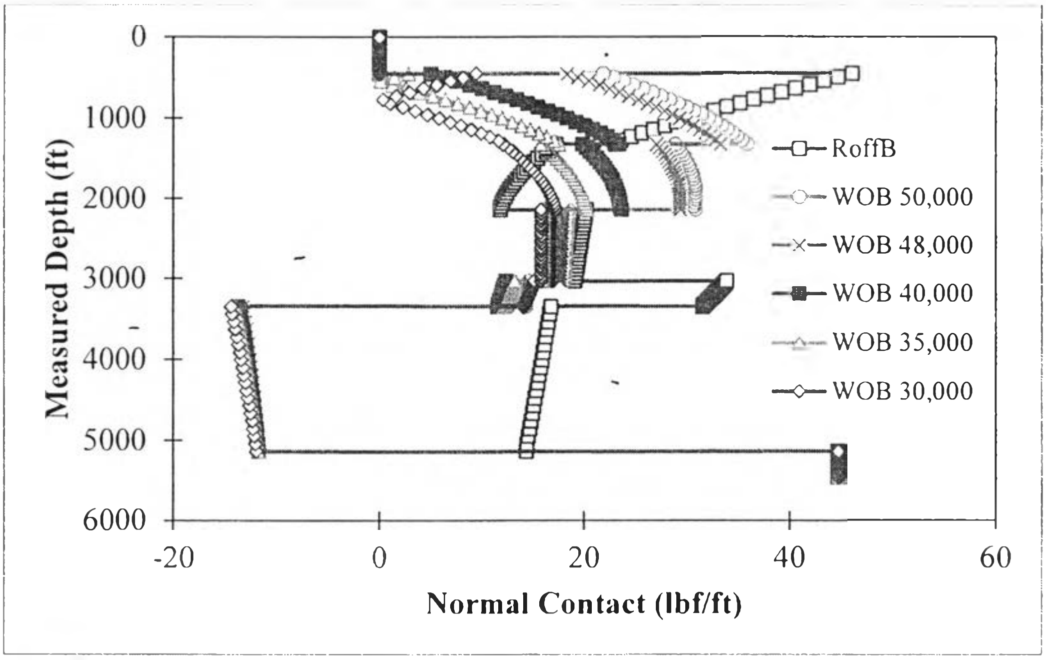


Figure 4.16 Normal contact force of RonB of well A from the software at the coefficient of friction of 0.4 by various WOB.

Table 4.8 Actual DF and new DF of well A

Section	DF Difference (%)	Actual DF (lb/gal)	New DF (lb/gal)	
Vertical	-	9.089	8.500	9.500
Build	4.62	9.509	8.893	9.939
Build	2.23	9.721	9.091	10.160
Hold	2.03	9.918	9.275	10.366
Drop	1.12	10.029	9.379	10.483
Drop	2.58	10.288	9.621	10.753
Hold	1.97	10.491	9.811	10.965

Table 4.9 Calculated axial force and torque at the surface of well A by various DF

DF	Axial Force (lbf)	Difference (%)	Torque (ft-lbf)	Difference (%)
8.500	-11,282.03	7.77	13,609.33	-0.17
9.089	-12,233.13	0.00	13,632.64	0.00
9.500	-12,899.14	-5.44	13,649.91	0.13

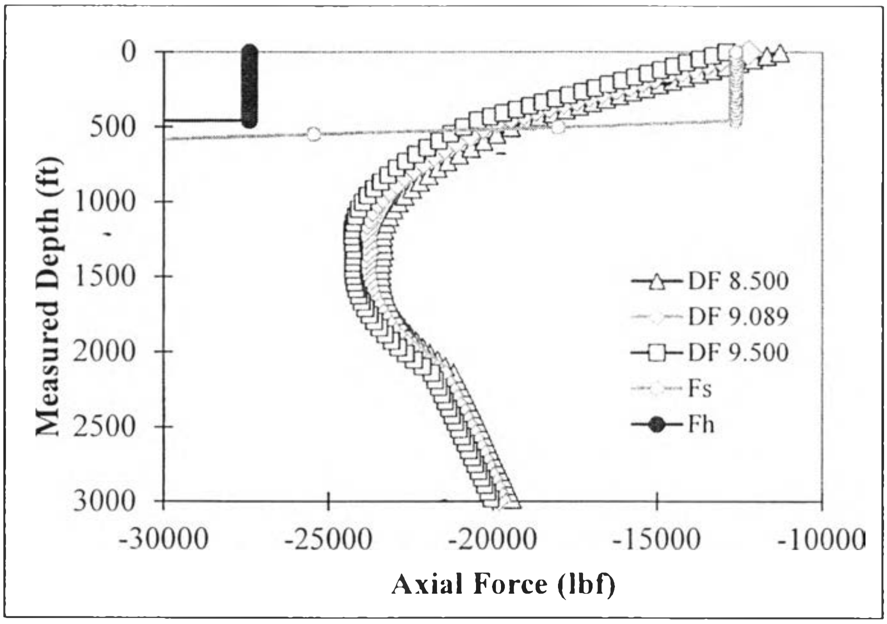


Figure 4.17 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.4 by various DF.

The effect of DF on the torque value was performed by various the DF from 8.500 lb/gal to 9.500 lb/gal as shown in Figure 4.18. The calculated torque of RonB is slightly increased by 0.13 % (in Table 4.10) as the DF is increased by 4.5 % because the normal contact force is slightly increased by affection from the increased axial compressive force (Figure 4.11) as expressing in equation (2.43). On the other hand, the calculated torque of RoffB is slightly decreased, while the DF is increased by 4.5 % because the normal contact force is affected by the decreased axial force as expressing in equation (2.16) from the decreased buoyancy factor directly (equation (2.17)).

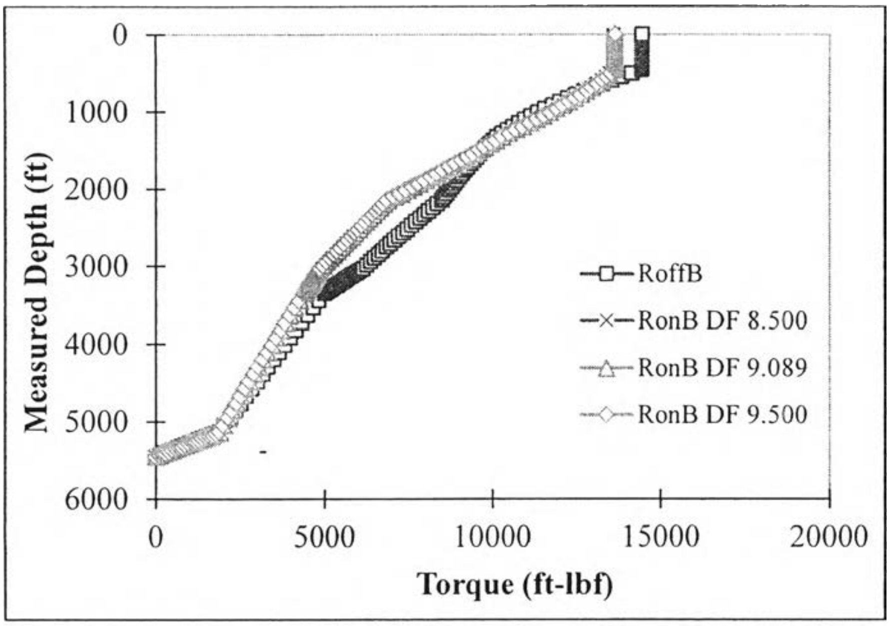


Figure 4.18 Calculated torque of RonB of well A from the software at the coefficient of friction of 0.4 by various DF.

4.3.1.5 Effect of Heavy Weight Drillpipe on Axial Force and Torque

The effect of heavy weight drillpipe (HWDP) was studied on the buckling problem. The HWDP was placed into two cases; vertical (HWDP1) and vertical and build (HWDP2). The axial forces and torques were calculated by applying the HWDP of these cases as shown in Table 4.10. The HWDPs were placed in the vertical section to provide sufficient weight to push the drillstring to keep the tensile force (positive value) along that section to prevent the buckling compressive zone (negative value) as shown in Figures 4.19 and 4.20 because the nominal weight of HWDP (50 lb/ft) is heavier than the drillpipe (DP) (19.5 lb/ft). Not only the axial force is affected directly, but also the buckling compressive force, as expressing in equation (2.10) for F_s and (2.11) for F_h. The different buckling of these two cases is the moment of inertia (I) of the HWDP provided the higher compressive buckling force of the DP in the lowering section (Figure 4.21).

In the case of HWDPs being placed in vertical section (Figure 4.19), the axial compressive forces were still in the buckling zone as the

Table 4.10 Calculated axial force and torque at the surface of RonB of well A as the HWDP placed

Drillstring	Axial Force (lbf)	Difference (%)	Torque (ft-lbf)	Difference (%)
DP	-12,233.13	0.00	13,632.64	0.00
HWDP Vertical	-286.04	-97.66	13,632.64	0.00
HWDP Vertical and Build	19,555.06	259.85	14,219.44	4.30

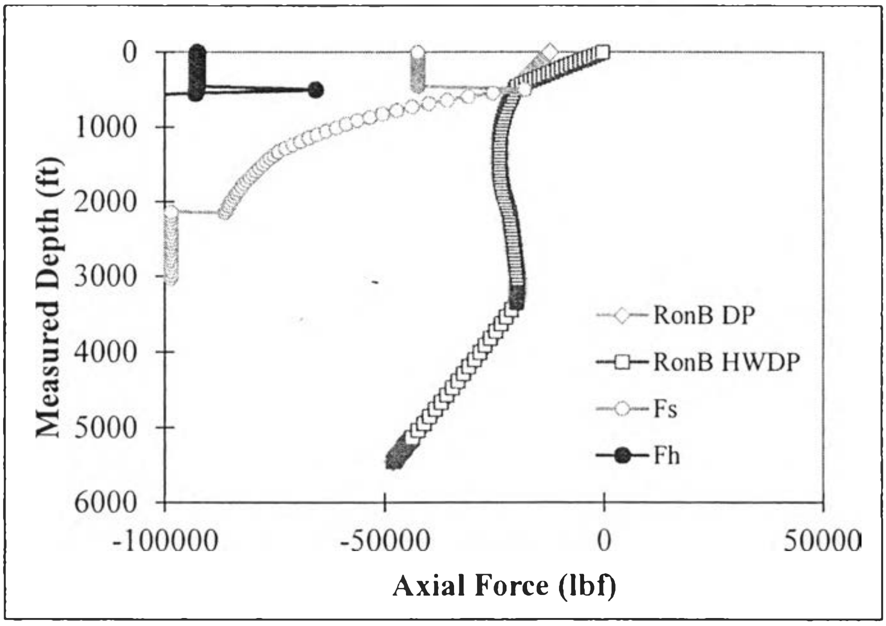


Figure 4.19 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.4 by HWDP placed in vertical section instead of DP.

lowering section is the DP that cannot provide the effective tension force to the drillstring, and also the compressive buckling force is changed only in the vertical section, not to the lowering section. Thus, the HWDPs were placed entirely vertical and build section. For the achievement of this case, the buckling zone keeps away from the axial tension force of the drillstring (Figure 4.20). As the HWDPs increasing, the axial compressive force of the RonB is decreased by 97.66 % of

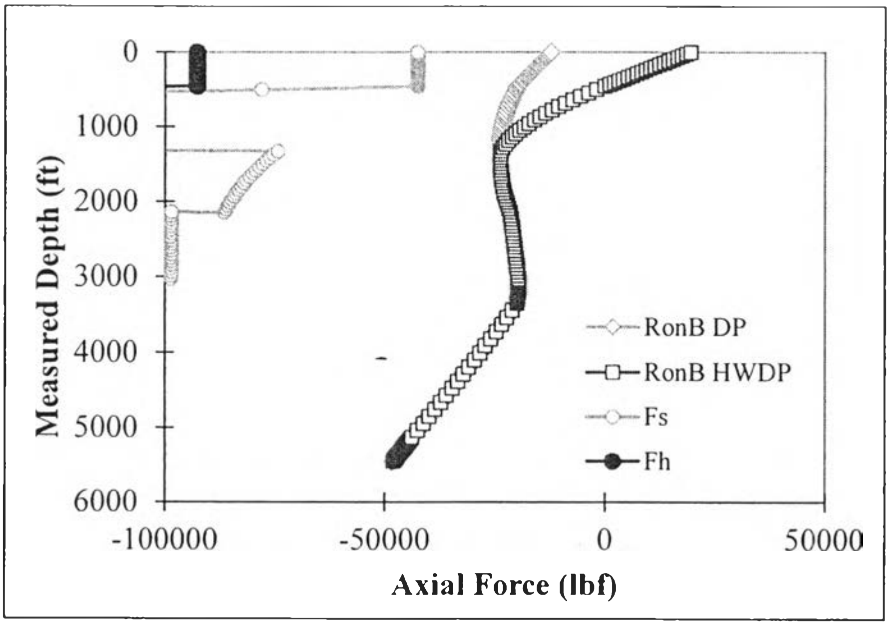


Figure 4.20 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.4 by HWDP placed in vertical and build section instead of DP.

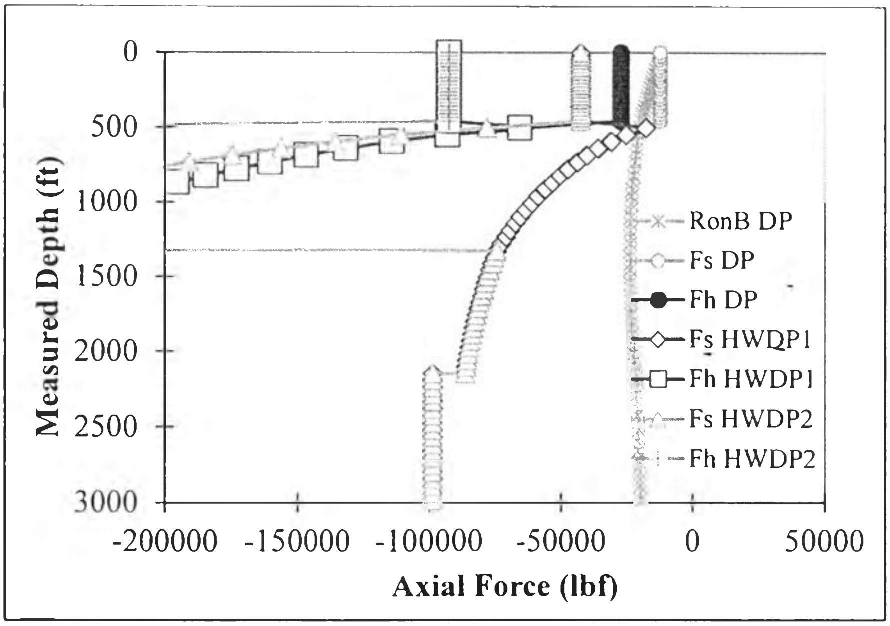


Figure 4.21 Calculated axial force of RonB and compressive buckling force of well A from the software at the coefficient of friction of 0.4 by HWDP1 placed in vertical section and HWDP2 placed in vertical and build section.

placing in the vertical section and by 259.85 % of applying in the vertical and build section. The retardant of buckling could be done as the HWDPs were applied.

The torques of these two cases are different context because the software account for the fictional torque along the drillstring attached with the wellbore wall, so that in case of the HWDPs placed in the vertical section, the torque values are identical with the torque values of the entire drillstring with the DPs (Figure 4.22). While the torques of the HWDPs placed in the vertical and build section gives a bit higher torque at the surface than the other RonB by 4.30 % (Table 4.10) because the HWDPs is affected to the magnitude of the normal contact force through the buoyed weight in that section.

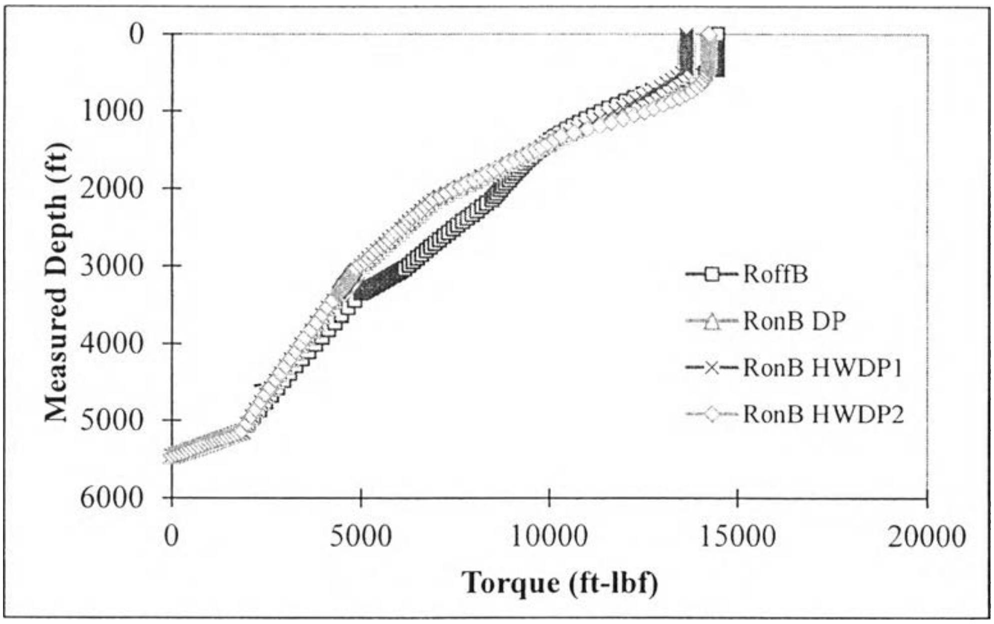


Figure 4.22 Comparison of the torque of RonB of well A from the software by HWDP1 placed in vertical section and HWDP2 placed in vertical and build section.