Investigating of Well Plan Parameters for Directional Drilling in the Gulf of Thailand

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Abstract

Directional drilling is commonly practiced in a complex structured reservoir in the Gulf of Thailand. Directional well path is planned by different well planner experiences. Torque and drag analysis will be performed to examine drillability of well paths. This process would require time and effort. The scope of this study is based on 2 well profiles; 2 dimensional (2D) build and hold as well as 3 dimensional (3D) build and hold. Each well profile required different well plan parameters i.e. kick of point (KOP), inclination (INC), build rate (BUR). To allow efficiency of well plan parameters varying process, a set of fundamental well construction and reservoir data were constrain based on Gulf of Thailand offshore field data. Derivative torque and drag from each well profile are observed, analyzed and evaluated. The study found that KOP and INC are most affected on torque and drag generating on deviated well. Other well plan parameters show minor effect. 2 deg./100ft. BUR generated significantly low torque and drag in building section. However, it cannot apply to every design due to casing depth restriction. The optimum parameters set and the limitation of well plan parameters for each well profile is presented in this paper.

Keywords: *directional drilling, gulf of Thailand, torque and drag, well planning*

บทคัดย่อ

การเจาะหลุมแบบระบุทิศทางเป็นการเจาะที่มีการปฏิบัติทั่วไปในพื้นที่ที่มีแหล่งกักเก็บปิโตรเลียม ซึ่งมีหน่วยหินและโครงสร้างซับซ้อน เช่นในพื้นที่บริเวณอ่าวไทย ประเทศไทย นักออกแบบหลุมเจาะจะเป็นผู้ออกแบบหลุมเจาะแบบมีทิศทางโดยอาศัยประสบการณ์ของผู้ออกแบบ จากนั้นหลุมที่ถูกออกแบบจะถูกนำไปวิเคราะห์เพื่อหาค่าแรงบิดและแรงลาก เพื่อใช้ในการคัดกรองหลุมเจาะ ว่าสามารถเจาะได้จริงหรือไม่ ซึ่งกระบวนการเหล่านี้ใช้เวลานาน การศึกษานี้ต้องการศึกษาพารามิเตอร์ที่ใช้ในการออกแบบหลุมเจาะแบบมีทิศทาง โดยสังเกตผลกระทบที่มีต่อแรงบิดและแรงลาก เพื่อแนะนำค่าที่เหมาะสมในการออกแบบหลุมเจาะที่มีทิศทาง เช่น จุดเริ่มต้นเจาะมุมเอียง ค่ามุมเอียง อันตราการเพิ่มขึ้นของมุมเอียง ฯลฯ โดยใช้ขีดจำกัดของแรงบิดและแรงลากเป็นเกณฑ์ เพื่อพัฒนากระบวนการออกแบบหลุมเจาะแบบมีทิศทาง โดยจะทำการศึกษาหลุมเจาะแบบมีทิศทาง 2 แบบ โดยหลุมแต่ละแบบจะใช้พารามิเตอร์จำนวนต่างกัน และกำหนดให้องค์ประกอบของหลุมเจาะและลักษณะของแหล่งกักเก็บปิโตรเลียมเหมือนกันทุกประการ และอ้างอิงจากการปฏิบัติงานจริงในพื้นที่อ่าวไทย หลุมเจาะแบบมีทิศทางที่ได้ออกแบบไว้จะถูกนำไปวิเคราะห์หาแรงบิดและแรงลาก จากนั้นสังเกตและวิเคราะห์ผลที่ได้และประเมินผล จากการศึกษาพบว่าค่าจุดเริ่มเจาะมุมเอียง และค่ามุมเอียงส่งผลต่อการเกิดแรงบิดและแรงลากมากที่สุด ส่วนพารามิเตอร์อื่นๆ ส่งผลกระทบน้อย นอกจากนี้ยังพบว่าอัตราการเพิ่มขึ้นของมุมเอียง 2 องศาต่อ100 ฟุต จะทำให้เกิดแรงบิดแรงลากในปริมาณที่น้อยกว่าอัตราการเพิ่มที่สูงกว่าอย่างเห็นได้ชัด แต่อัตรานี้ไม่สามารถนำมาใช้ออกแบบหลุมเจาะทุกหลุมได้เนื่องจากมีข้อจำกัดเรื่องตำแหน่งของท่อกรุ ในส่วนท้ายของการศึกษาได้แนะนำช่วงพารามิเตอร์ที่สามารถใช้ในการออกแบบหลุมเจาะแบบมีทิศทางซึ่งผ่านเกณฑ์แรงบิดและแรงลากสำหรับการขุดเจาะในอ่าวไทย

คำสำคัญ: *การขุดเจาะแบบมีทิศทาง อ่าวไทย แรงบิดและแรงลาก การออกแบบหลุมเจาะ*

1. Introduction

Deviated well drilled is practical nowadays. It is created for several applications; multi well drilled from one platform, inaccessible location, complicate geological structure etc. The Gulf of Thailand (GOT) has complex structured fields in a western part of South China seas. The reservoir is typically sandstone (Ridd et al., 2011). Directional drilling is commonly practical in this location with a limited number of doglegs at 8 deg. /100ft (Yodinlom et al., 2003). Several wells had been planned and revised for drilling by using conventional software.

Optimistic well plan helps eliminate severe drilling issue especially torque and drag analysis. Torque and drag are key factors in planning extended reach well and horizontal well. It is a proven technique for wellbore construction. Optimizations of a well profile to minimize torque and drag problems have been discussed in many publications. Important conclusion is making smooth well path. Minimizing dogleg severity has been implemented in procedure (Aarrestad, 1994). Excessive torque and drag force have consequences cause by drilling failure such as twisted off, buckling, over drawn work capacity, stucked pipe etc.

Nowadays, conventional well planning method can pre-analyze stress, torque and drag of planning wellbore before drilling. Torque and drag simulation through wellbore profile helps eliminate risk and uncertainty at pre-job stage. However, it is still based on trial and error approach, i. e. assumed kickoff point, build drop rate, inclination and then repeats to get the reasonable result. Well planning is perhaps the most demanding aspect of drilling engineering. It requires the integration of engineering principles, corporate or personal philosophies, and experience factors.

Although the method is still considered effective, but the selected well design may not be the best one technically or economically (Helmy et al., 1998)

This study will provide optimum sets of directional well plan parameters i.e. kick off point (KOP), inclination (INC), dogleg severity, build rate (BUR) base on torque and drag as criterion. The solution presented is for planning various well profiles via the typical Gulf of Thailand lithology.

2. Objectives

Objective of this study is to investigate well profile parameters i.e. KOP, BUR etc. which applicable for directional drilling in the Gulf of Thailand using torque and drag as criteria.

3. Materials and methods

3.1 Well planning model

Well planning will be performed in a commercial software. To allow efficiency of well parameters varying process, a constrain set of well construction and reservoir data are defined.

3.1.1 Construct a fundamental data

Reservoir data i.e. lithology, pressure data, are required. The data represent typical properties of reservoir in GOT. Reservoir in GOT typically consists of Miocene gas sand with highly faulted sand shale interbedded. Deposition environment is fluvial-deltaic. Formation dip angle is very gentle.

Also, general operations in GOT are applied i.e. hole geometry, casing design, drillstring components. A 3 string hole design has been applied in GOT due to small reservoir unit and structure complexity with 2 casing sections which was surfaced and intermediated casing. The directional work starts in intermediate section with motor drive. In production section, synthetic based mud is used because of torque and drag, and high temperature problem (Charnvit et al., 2014). This section is drilled using rotary steerable with adjustable gauge stabilizer instead of motor drive due to high temperature downhole.

3.1.2 Planning a well

A well is planned by a commercial software using minimum curvature method calculation. Minimum curvature method is often used in order to maximize survey calculation accuracy (Adewuya & Pham, 1998). Two typical well profiles will be planned; 2 dimensional (2D) build and hold profile and 3 dimensional (3D) build and hold profile. Each profile requires different well planning parameters. 3 parameters will be varied for 2D build and hold profile, namely kick of point (KOP), build rate (BUR), and inclination deviation (INC). For 3D build and hold profile, 5 parameters will be varied following; KOP, BUR, INC, turn rate (TUR), and “Turn Degree”. Each parameter will be varied as designed in Table 1.

Table 1 Varying well plan parameters

Type	Unit	Value	Value	Value	Value
KOP	ft.	1000	5300		
BUR	deg./100ft.	2	4	6	8
INC	deg.	30	40	50	60
TUR	deg./100ft.	2	4	6	8
Turn Degree	deg.	90	120	150	180

The values in Table 1 are typical well planning parameters that applied in GOT. KOP values are designed following casing seat. Turn degree, which is lower than 90 deg. is not considered to be 3D well profile. If turn degree is higher than 180 deg., TUR will be applied with the same value with a minus sign. Hence, this range of turn degree is set for this study.

3.2 Torque and drag model

Torque and drag analysis is performed in commercial software. Soft string model is applied in this study to allow drillstring to bend along the curve path (Miska et al., 2015). The general frictional factor for cased hole is 0.25. For open hole section, frictional factor is depended on local geological lithology. Fr interested field, frictional factor for open hole section is 0.28-0.35. The severe frictional factors are applied in this study (Samuel, 2010), which are 0.25 for cased hole, and 0.35 for open hole.

Torque is a turning force that is applied to a rotary mechanism to make drillstring rotate, measured in foot-pound. Additional torque occurs during drillings due to wellbore friction and interaction with formation. Torque while drillstring is rotating can be calculated from;

$$T = F_n * \frac{d}{2} * sin\theta = \mu * W * \frac{d}{2} * sin\theta \qquad \textbf{Eq. 1}$$

Where,

T	=	Torque (ft.-lbs.)
F_n	=	Normal Force (lbs.)
d	=	diameter (in.)
W	=	Weight of segment (lbs.)
θ	=	Inclination angle (deg.)
μ	=	friction coefficient (frac.)

Drag is friction between a moving device and other moving or nonmoving part such as formation. Downward drag in directional well can cause excessive axial compression and lead to buckling. Drag force is calculated using the following equation;

$$F_D = F_n * \mu * \frac{T}{V} \qquad \textbf{Eq. 2}$$

Where,

F_D	=	Drag Force (lbs.)
F_n	=	Normal Force (lbs.)
μ	=	friction coefficient (frac.)
T	=	Trip speed (in/s)
V	=	Resultant speed (in/s)

The derivative torque while rotating on bottom and effective tension while tripping out are observed from the analysis. The criterion of torque is based on drillstring's makeup torque. The criterion of effective tension is based on drillstring's tensional yield stress property.

Torque at bit is depending on a bit model. This value needs to be identified. For this study torque at bit is set as 2500 ft-lbft. according to field data.

4. Results and discussion

Results of each well profile type are compared and discuss separately. The effects of each varied parameter will be investigated and described in this section.

4.1 2D Build and Hold

Results of varying 3 well plan parameters and its derivative torque and effective tension along the drillstring are displayed in Figure 1 and 2 respectively. The graph color relates to well profile. The vertical red line in graph represents the limit.

According to Figure 1, derivative torque can be identified by slope into 4 sections which are; from bottom hole to a top of bottomhole assembly (BHA), tangent or hold section, build section and vertical section to surface.

From observing, from bottom hole to top of BHA, torque is gently increasing. Refer to Eq. 1, high torque in this section is affected by heavy weight drillstring component. In tangent section, slope is steeper, this means the torque increase slower along the drillstring. This consequence occurs because the drillstring's weight is lighter than previous section. Also, it can be observed that INC is the most affected in this section. Higher INC provides steeper slope, which means it can generates higher torque. There is a correlation between increasing of INC and torque, where higher INC generates higher magnitude of torque.

Next, build section, the slope is very steep, torque raises up dramatically in this section. As seen in Figure 1, small effect of varied BUR is observed. Higher BUR generates higher torque. BUR 2 deg./100ft. yields significantly low torque, whereas BUR 4, 6, and 8 deg./100ft. generated similar rate. Lastly, vertical section, torque is constant in any varied parameters. Set at KOP variation, shallow KOP generates higher torque than deeper KOP. It can be implied that the length of tangent and vertical section impact torque. The well that has longer vertical section generates less torque. The well that has longer tangential section, generates larger torque.

Derivative effective tension can be identified into 4 slopes like torque. From the bottom of the hole to the top of BHA, effective tension is gently increasing according to heavyweight components. Next, tangent section, effective tension is the most affected by INC parameter like torque. Higher INC generates higher effective tension. Build section, higher BUR generates higher effective tension. From vertical section towards the surface, effective tension is gently increased.

Considering by varying parameters, KOP and INC affect torque and effective tension more than BUR. However, its magnitude of effect is less severe than torque. Also with 2 deg./100ft. BUR design, it does not show much difference of effective tension value like torque.

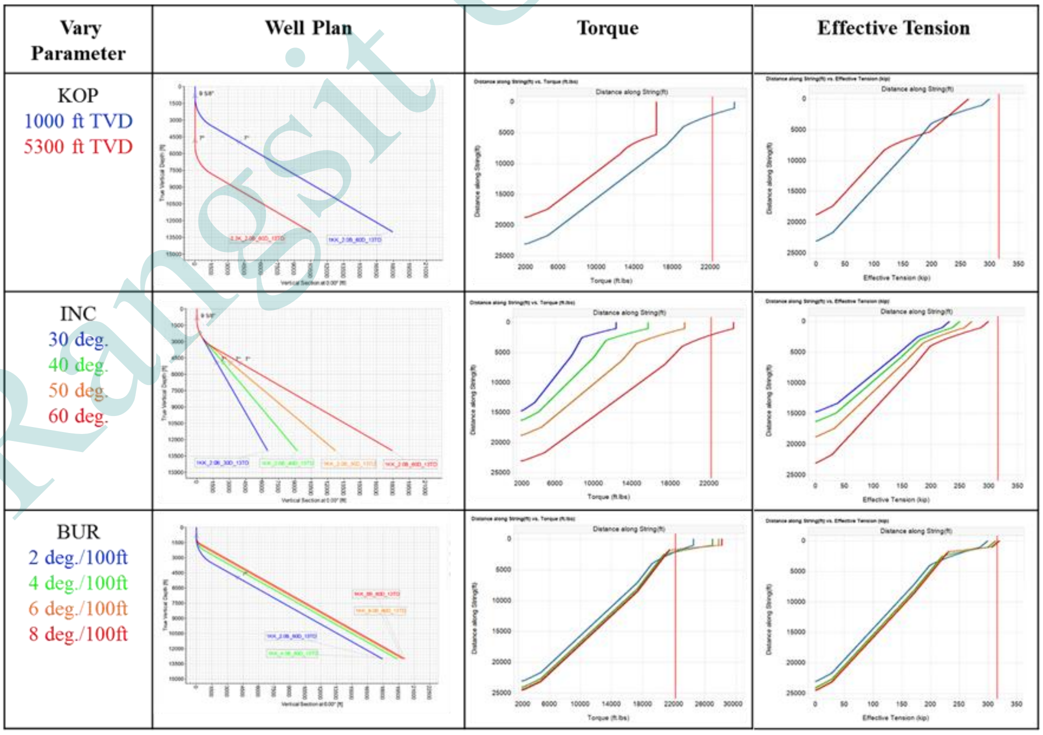

Figure 1 2D Build and Hold Well Profile with varying KOP, INC and BUR, and its derivative torque and effective tension.

From observing, the total of 10 samples, there are 6 wells that exceed torque limit. Within these wells, there are only 3 samples that exceed effective tension limit. Hence, torque makes a main criterion in determining drillability of well better than effective tension in this well profile type.

After, maximum torque from each well profiles are used to evaluate a limitation of the design. As mentioned above, KOP and INC are the most affected parameters to torque. Because KOP is designed by formation properties, which is difficult to change, hence the limit of INC is evaluated and summarized in Table 2.

Table 2 Well planning guideline 2D build and hold

KOP\BUR	2	4	6	8
1000	55	51	51	50
5300	60	60	60	60

Table 2, the detail of the maximum INC that can be used in planning a drillable well with each KOP and BUR. For example, if a well was planned to kick at 1000ft. with 2 BUR the maximum INC that can be used in designing is 55.39 deg.

4.2 3D build and hold

Results of 5 well plan parameters varying with its derivative torque and effective tension are displayed in Figure 2. The graph color relates to well profile. The vertical red line in the graph represents the limit.

In well planning step, several cases that plan with TUR 2 deg./100ft with 1000ft KOP, cannot designed due to the fact that it cannot achieve the desired turn degree before casing seat, which is represented in Table 3-6 as -*.

From Figure 2, derivative torque and effective tension can be identified by the slope which is divided into 5 sections; from the bottom hole to BHA, tangent or hold section, turn section, build section and vertical section to surface. From the bottom hole to BHA section, torque and effective tension are gently increased along the drillstring. In tangent section, both two derivatives are clearly affected by INC. Higher INC generates higher torque.

Torque and effective tension rise rapidly in turn section and build section. In turn section, high TUR generates lower torque than lower TUR rate. Because the well with high TUR can achieve a certain turn degree better than low TUR as seen in Figure 2, which 8 deg./100ft TUR yields low torque and effective tension more than 6 and 4 deg./100ft. TUR respectively. Turn degree also shows its effect only in this section. High turn degree generates high torque and drag because it requires more drill depth to achieve with the same TUR. In build section, lower BUR generates lower torque.

Final, vertical section, deeper KOP generates significantly low torque and slightly low in effective tension. Comparing result of varied KOP, after casing seat, KOP at 5300ft generates slightly lower torque and drag than KOP at 1000ft. In contrast, the above casing seat, KOP at 5300ft generates much higher torque and drag than KOP at 1000ft. It is an effected of BUR, TUR, and turn degree.

It can be concluded that in 3D well profile, KOP and INC affected torque and effective tension of the whole section along the well path. Turn degree, TUR and BUR are affected less on torque and drag respectively.

Unlike 2D build and hold profile, effective tension limit makes a main criterion to determined drillability of the well better than torque in this well type as displayed in Figure 2. From 18 cases, there are 11 cases that are not exceeded torque limit and 4 cases that do not exceed effective tension limit. Therefore, a maximum effective tension from each well is plotted as a function of 5 well plan parameters to evaluate a well planning guideline in Table 3- 6 separated by turn degree.

Some of design with KOP 1000ft. with TUR 2 deg./100 ft. represented in the table by “*-”, cannot be evaluated since it is not following the casing design.

Some of the well that is planed with KOP 5300ft. with TUR 2 deg./100 ft. cannot be evaluated due to it cannot achieve INC and Turn degree within the final target depth.

Other designs that cannot be evaluated which represented in "-", it could be drilled with INC lower than 30 deg. All designs with 60 deg. INC and KOP at 1000ft. are exceed torque or effective tension limit, which mean they are undrillable.

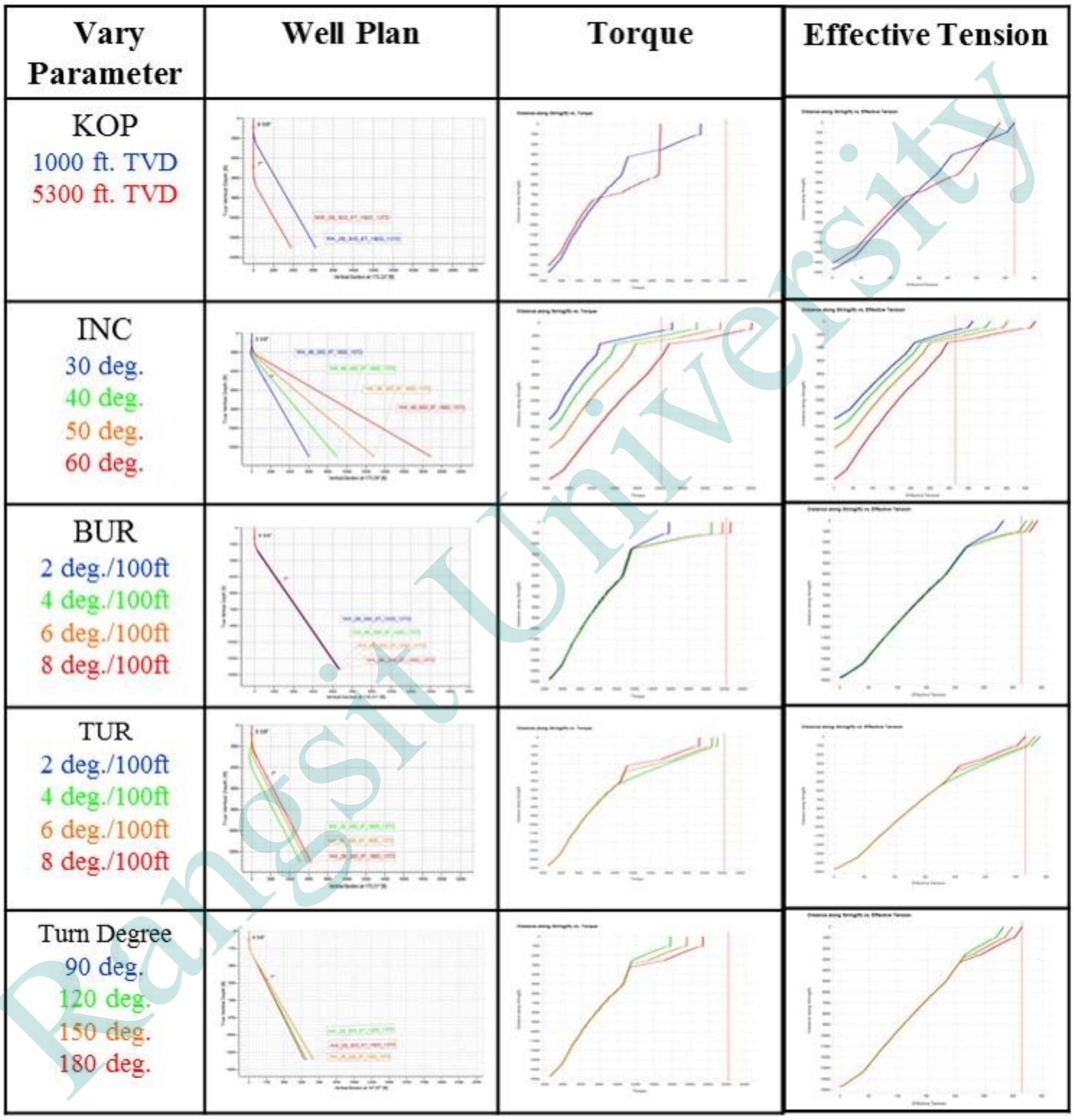

Figure 2 Sample of derivative torque and effective tension along the drillstring as a function of 3D Well Profile with varying KOP, INC, BUR, TUR, and Turn degree.

From Table 3-6, the maximum of INC is determined for planning a drillable well with each KOP, BUR, TUR, and Turn degree.

For example, the well was planned to kick at 1000 ft. with BUR 2 deg./100 ft., TUR 4 deg./100 ft., and Turn Degree of 90 deg., the maximum INC that can be designed is 39.19 deg.

If the well was planned to kick at 1000ft. with BUR 8 deg./100 ft., TUR 4 deg./100 ft., and Turn degree of 90 deg., the maximum INC that can be designed is lower than 30 deg.

Table 3 Well planning guideline for 3D build and hold, 90 degrees turn

KOP	BUR\TUR	2	4	6	8
1000	2	43	49	53	43
1000	4	36	38	43	36
1000	6	36	36	38	36
1000	8	35	34	35	35
5300	2	56	58	60	56
5300	4	43	45	53	43
5300	6	41	40	42	41
5300	8	39	38	39	39

Table 4 Well planning guideline for 3D build and hold, 120 degrees turn

KOP	BUR\TUR	2	4	6	8
1000	2	*-	46	55	*-
1000	4	*-	33	35	*-
1000	6	*-	31	32	*-
1000	8	*-	30	31	*-
5300	2	49	60	60	49
5300	4	39	38	41	39
5300	6	38	35	35	38
5300	8	36	33	33	36

Table 5 Well planning guideline for 3D build and hold, 150 degrees turn

KOP	BUR\TUR	2	4	6	8
1000	2	*	37	54	54
1000	4	*	-	-	-
1000	6	*	-	-	-
1000	8	*	-	-	-
5300	2	46	50	60	60
5300	4	37	33	34	39
5300	6	36	31	30	31
5300	8	35	30	*	30

Table 6 Well planning guideline for 3D build and hold, 180 degrees turn

KOP	BUR\TUR	2	4	6	8
1000	2	*	*	38	-
1000	4	*	-	-	-
1000	6	*	-	-	-
1000	8	*	-	-	-
5300	2	44	41	60	60
5300	4	38	30	-	31
5300	6	36	-	-	-
5300	8	36	-	-	-

If desired target requires 50 deg. INC and 160 degree turn, then a well could be planned using KOP at 5300 ft., BUR 2 deg./100ft. and TUR 6-8 deg./100ft.

The results show that, the turn degree is a designable parameter. The maximum Turn degree which is 180 deg. is drillable with 2 deg./100ft. BUR and deep KOP design. The maximum BUR for shallow KOP is 4 deg./100ft. The maximum BUR for deep KOP is 8 deg./100ft. with INC lower than 32 deg. TUR is a flexible parameter which shows low effects on torque and drag of the well. If TUR is too low, it cannot satisfy large turn degree especially when kicks at shallow point. Dogleg is account for inclination change and azimuth change. In 3D well profile, BUR is more affected on dogleg severity than TUR. Then high BUR design is worse than high TUR design. This study recommends applying high TUR.

5. Conclusion

The important points that observed in this study are summarized in this section as a guideline for well planner.

1. Derivative torque can be used as a criterion for 2D Build and Hold profile. Meanwhile, derivative effective tension can be applied as a criterion for 3D Build and Hold well profile.

2. KOP and INC have more effects on torque and effective tension. Turn degree, TUR and BUR are affected less on torque and drag respectively.

3. Recommend INC for 2D and 3D Build and Hold well designs are provided in Table 2-6. Maximum INC is not exceeding 60 deg.

4. 2 deg./100ft. BUR generates significantly low torque, whereas BUR 4, 6, and 8 deg./100ft. generate similar rate in both 2D and 3D Build and Hold well design.

5. In 3D well profile, high TUR could be applied if turn degree is high. Maximum BUR for shallow KOP is 4 deg./100ft. Maximum BUR for deep KOP is 8 deg./100ft. with INC lower than 32 deg.

6. Turn degree has no limit. Maximum Turn degree which is 180 deg. is drillable with 2 deg./100ft. BUR and deep KOP design.

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