INVESTIGATION OF WELL PLAN PARAMETERS FOR DIRECTIONAL DRILLING IN GULF OF THAILAND

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การตรวจสอบพารามิเตอร์สำหรับการออกแบบการเจาะหลุมแบบระบุทิศทางในอ่าวไทย

นางสาวอนุสรา เห็นถูก

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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การเจาะหลุมแบบระบุทิศทางเป็นการเจาะที่มีการปฏิบัติทั่วไปในพื้นที่ที่มีแหล่งกักเก็บปิโตรเลียมซึ่งมีหน่วยหินและโครงสร้างซับซ้อนเช่นใน อ่าวไทย นักออกแบบหลุมเจาะจะเป็นผู้ออกแบบหลุมเจาะโดยอาศัยประสบการณ์ของผู้ออกแบบ จากนั้นหลุมที่ถูกออกแบบจะถูกนำไปวิเคราะห์เพื่อหาค่าแรงบิดและแรงลาก เพื่อใช้ในการคัดกรองหลุมเจาะ ว่าสามารถเจาะได้หรือไม่ กระบวนการเหล่านี้ใช้เวลานาน การศึกษานี้จะทำการศึกษาพารามิเตอร์ที่ใช้ในการออกแบบหลุมเจาะแบบระบุทิศทางและแนะนำค่าที่เหมาะสมในการออกแบบหลุมเจาะ เช่น จุดเริ่มต้นเจาะมุมเอียง ค่ามุมเอียง อัตราการเพิ่มขึ้นของมุมเอียง ฯลฯ โดยใช้ขีดจำกัดของแรงบิดและแรงลากเป็นเกณฑ์ เพื่อพัฒนากระบวนการออกแบบหลุมเจาะแบบระบุทิศทาง โดยทำการศึกษาหลุมเจาะแบบระบุทิศทาง 4 แบบ ทั้งแบบ 2มิติและแบบ 3 มิติ หลุมแต่ละแบบออกแบบโดยใช้พารามิเตอร์ต่างกัน โดยกำหนดให้องค์ประกอบของหลุมและลักษณะแหล่งกักเก็บปิโตรเลียมเหมือนกันทุกประการอ้างอิงจากการปฏิบัติงานจริงในพื้นที่อ่าวไทย หลุมเจาะแบบมีทิศทางที่ได้ออกแบบไว้จะถูกนำไปวิเคราะห์หาแรงบิดและแรงลาก จากนั้นสังเกตและวิเคราะห์ผลที่ได้ แล้วประเมินผล นอกจากนั้นยังศึกษาผลกระทบจากน้ำหนักของน้ำโคลนที่ใช้ในการขุดเจาะ

จากการศึกษาพบว่าค่าจุดเริ่มเจาะมุมเอียง และค่ามุมเอียงส่งผลต่อการเกิดแรงบิดและแรงลากมาที่สุด ส่วนพารามิเตอร์อื่นๆ มีผลกระทบน้อย นอกจากนี้ยังพบว่าอัตราการเพิ่มขึ้นของมุมเอียง 2 องศาต่อ100ฟุต ก่อให้เกิดแรงบิดและแรงลากในปริมาณที่น้อยกว่าในช่วงของการเจาะเพิ่มมุมเอียง แต่นำมาใช้ออกแบบหลุมเจาะทุกแบบไม่ได้เนื่องจากมีข้อจำกัดเรื่องตำแหน่งของท่อกรุ น้ำหนักของน้ำโคลนมีผลกระทบต่อค่าแรงบิดและแรงลากโดยเมื่อเพิ่มน้ำหนักน้ำโคลน 1 ปอนด์ต่อแกลลอน จะทำให้ค่าแรงบิดและแรงลากลดลงประมาณ 1.5 เปอร์เซนต์ ในส่วนท้ายของการศึกษาจะแนะนำช่วงค่าพารามิเตอร์ที่สามารถใช้ในการออกแบบหลุมเจาะแบบระบุทิศทาง ซึ่งผ่านเกณฑ์แรงบิดและแรงลากสำหรับอ่าวไทย

ภาควิชา วิศวกรรมเหมืองแร่และปิโตรเลียม ลายมือชื่อนิสิต ....

สาขาวิชา วิศวกรรมปิโตรเลียม ลายมือชื่อ อ.ที่ปรึกษาหลัก ....

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KEYWORDS: WELL PLANNING / TORQUE AND DRAG / GULF OF THAILAND / DRILLING ENGINEERING

ANUSARA HENTOOG: INVESTIGATION OF WELL PLAN PARAMETERS FOR DIRECTIONAL DRILLING IN GULF OF THAILAND. ADVISOR: ASST. PROF. JIRAWAT CHEWAROUNGROAJ, Ph.D., 249 pp.

Directional drilling is commonly practiced in complex structure reservoir in Gulf of Thailand. Directional well path is planned by different well planner experiences. Torque and drag analysis are performed to examine drillability of well path. This process may take time and effort. This study provides optimum sets of well plan parameters i.e. kick off point (KOP), inclination (INC), build rate (BUR) based on torque and drag as criterion, to improve well planning process. This study is based on 4 well profiles; 2 dimensional (2D) build and hold, 2D build hold and drop, 3D build and hold and 3D build hold and drop. Each well profile requires different well plan parameters. To allow efficiency of well plan parameters varying process, a set of fundamental well construction and reservoir data are assumed. Constrain values are based on Gulf of Thailand field data. Derivative torque and drag from each well profile are observed, analyzed and evaluated. The effect of mud weight also investigates in this study.

The study found that KOP and INC are the most important well plan parameters on torque and drag generated in deviated wells. Other well plan parameters show minor effect. 2 deg./100ft. BUR generates significantly low torque and drag in build section. However, there is a limit to apply. Varied mud weight afftects torque and drag as increase 1 pound per gallon of mud weight yields lower torque and drag as 1.5 percent approximatly. The parameters set and limit of well plan parameters for each well profiles are presented in this paper.

Department:	Mining and Petroleum Engineering	Student's Signature	....
		Advisor's Signature	....
Field of Study:	Petroleum Engineering		
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List of Abbreviation

AGS	Adjustable Gauge Stabilizer
BF	Buoyancy Factor
BHA	Bottom Hole Assembly
BUR	Build Up rate
d	Diameter
DC	Drill Collar
DOR	Drop off Rate
DP	Drill Pipe
E.O.B	End of Build
F.I.T	Formation Integrity Test
GOT	Gulf of Thailand
IF	Internal Flush
INC	Inclination
KOP	Kick off Point
MD	Measure Depth
MOD	Modified
MWD	Measure While Drilling
r	Radius
REG	Regular
RPM	Rotational rate Per Minute
SBM	Synthetic Based Mud
T	Trip Speed
TD	Total Depth
TVD	True Vertical Depth

Nomenclature

F_{AB}	Axial force (Buoyancy Method) (lb.)
F_{AY}	Axial force required generating the yields stress (lb.)
F_D	Drag force (lb.)
F_f	Sliding friction force (lb.)
F_n	Normal force (lb.)
F_t	Axial tension force (lb.)
W_B	Buoyed weight of drillstring (lb.)
σ_{FEL}	Fatigue endurance limit (psi)
σ_{FL}	Fatigue limit (psi)
$\in$	Azimuth angle (deg.)
α	Inclination angle (deg.)
θ	Inclination angle (deg.)
BF	Buoyancy factor
T	Torque (ft.-lb.)
f	Factor of straight line versus curve section
D	True vertical depth (ft.)
L	Horizontal displacement in y axis (ft.)
M	Horizontal displacement in x axis (ft.)
T	Trip speed (in/s)
V	Resultant speed (in/s)
d	Diameter (in.)
A	Azimuth angle (deg.)
β	Dogleg severity (deg./100ft.)
μ	Friction coefficient (frac.)

Chapter 1 : Introduction

1.1 Introduction

Deviated well is practical nowadays. It is created for several applications e.g. multi well drilled from one platform, inaccessible location, complicate geological structure etc.

Gulf of Thailand locates in a western part of South China seas. It has complex fault structured. The reservoir is typically sandstone. Directional drilling is commonly practical in this location. 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 problems. Torque and drag are key factors planning in extended reach and horizontal well and optimized well profiles. Optimization well profile to minimize torque and drag problem has been discussed in many publications. Important conclusion is making smooth well path. Minimizing dogleg severity has been implement in procedure [1]. Excessive torque and drag force have consequence of drilling failure such as twist off, buckling, over draw work capacity, stuck pipe etc.

Nowsday, conventional well planning method can pre-analyze a torque and drag of planning wellbore before drill. Torque and drag simulation through wellbore profile helps eliminate risk and uncertainty at pre-job stage. Typically, it bases on trial and error approach i. e. assume kickoff point, build drop rate, inclination and then repeat in order 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 considering effective, but the selected well design may not be the best one technically or economically [2].

This study provides optimum sets of directional well plan parameters i.e. kick off point, inclination, dogleg severity, build/ drop rate base on torque and drag as criterion. The solution presents for planning various well profile via typical Gulf of Thailand lithology.

1.2 Objectives

1. To investigate well profile parameters i.e. KOP, BUR etc. which are applicable for directional drilling in Gulf of Thailand using torque and drag as criteria.
2. To evaluate sensitive parameters affecting torque and drag in wellbore.

1.3 Scope of Work

This study investigates well plan parameters for 4 following well types;

- 2D, build and hold profile
- 2D, build, hold and drop profile
- 3D, build and hold profile
- 3D, build, hold and drop profile

This study focuses on varying well profile parameters i.e. KOP, BUR, drop rate and degree turn to determine drillability by observing torque and drag limitation. Minimum curvature method will be used for well profile calculation.

1.4 Outline of Methodology

Methodology of this study is outlined as flow chart in Figure1-1. Each step and input parameter will be detailed in Chapter 4.

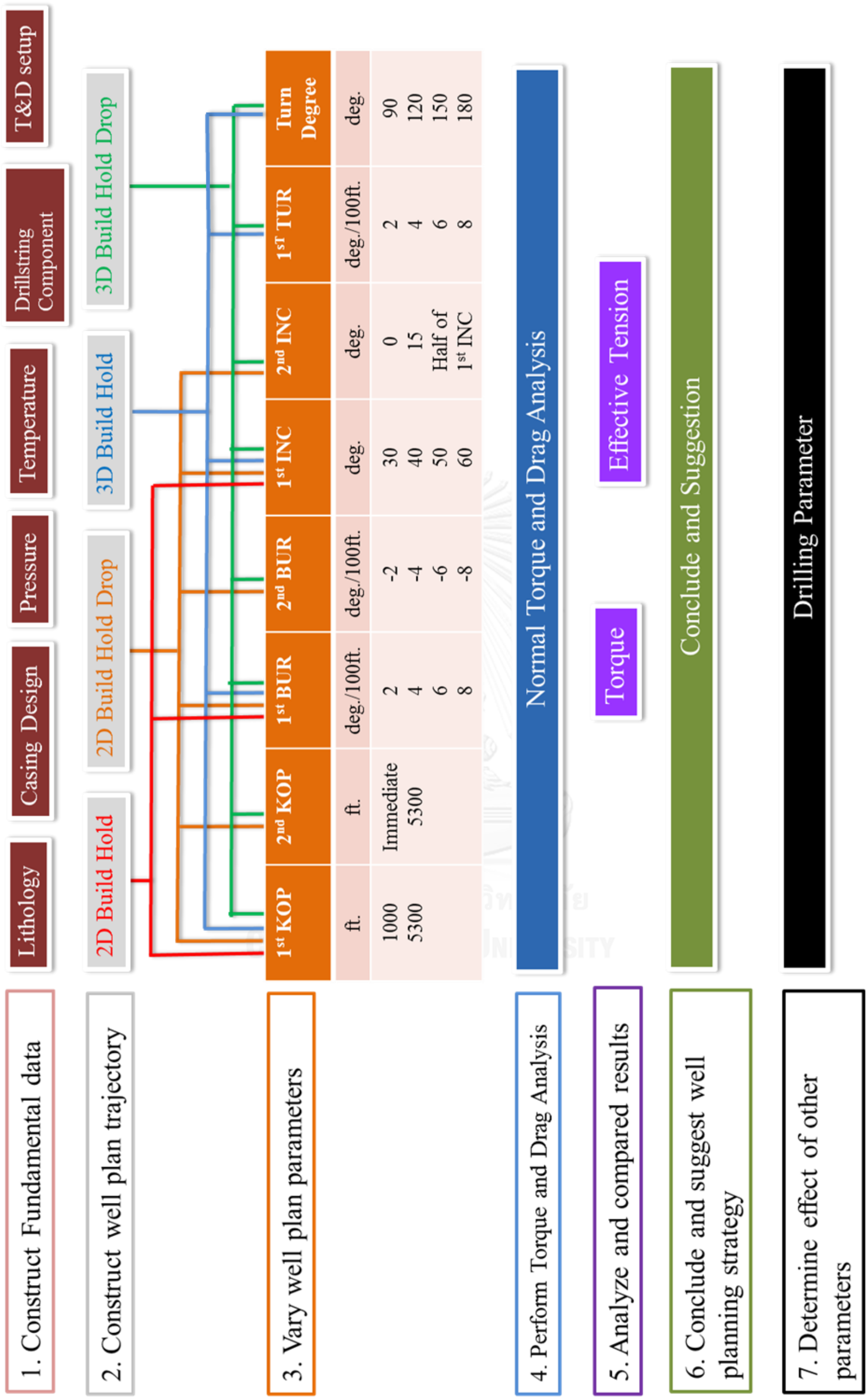


Figure 1-1: Methodology Outline

1.5 Outline of Thesis

This thesis composed of 6 chapters including;

- Chapter 1: Introduction

This chapter provides the challenge of well planning in Gulf of Thailand, objective of this study, scope of work and outline of methodology.

- Chapter 2: Literatures Review

Literatures that relate to this study provide in this section. The topics are related with drilling operation in Gulf of Thailand, torque and drag analysis, well planning for extended reach well and deep well drilled etc.

- Chapter 3: Relevant Theory and Concept

This section provides the theory and concept that relate to well profile well and torque and drag calculation.

- Chapter 4: Methodology

Details and input of this study are described and explained in this section include well plan modeling and torque and drag analysis modeling.

- Chapter 5: Result and Discussion

Result from chapter 4 is analyzed and evaluated, separated by well profile.

- Chapter 6: Conclusion and Recommendations

In this section, author provided conclusion and recommendation for future work.

Chapter 2 : Literature Review

In this chapter, literatures are reviewed as follows topic; Gulf of Thailand geology, general drilling and operation in Gulf of Thailand, directional well planning for deep well and torque and drag analysis and drilling failure by high torque and drag.

2.1 Gulf of Thailand Geology

Reservoir in Gulf of Thailand is typically Miocene gas sand with highly faulted sand shale interbedded (Figure 2-1 and 2-2). Deposition environment is fluvial-deltaic. Formation dip angle is very gently [3].

Gas is dominantly produced from sequence II, III and IV (Figure 2-1 and 2-2). Most pay sands are in range of 5-50ft and 15ft in average. Fault structure lays in north-south trending, graben system. It divides reservoir sand into small units.

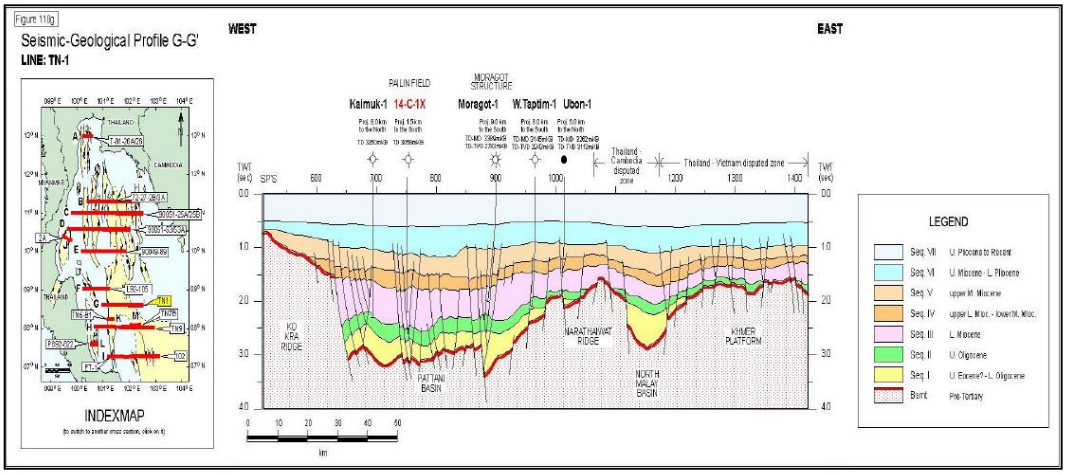


Figure 2-1: GOT Geological Profile [4].

From Figure 2-1, the reservoir is interbedded gray shale with red sandstone and few coal beds. Basement is Cretaceous granite, non-porosity.

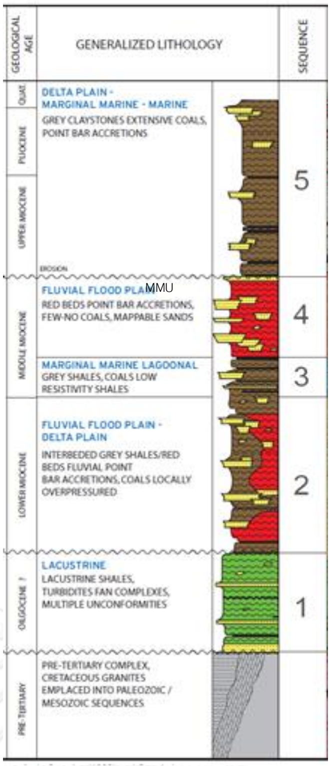


Figure 2-2:The stratigraphy in south Pattani Basin, Gulf of Thailand [5]

Geologic setting in Gulf of Thailand started in Late Cretaceous. Rifting and granite intrusion in Late Cretaceous to early Tertiary time had formed a basin oriented in NS direction. Early of the basin, sediments deposited in lacustrine. Therefore, sequence 1 is lacustrine shale with turbidity fan complex. After a short erosional period, rifting occurred completely and continued subsidence. So, the depositional environment in sequence 2 is fluvial flood plain to delta plain. Most of rock in sequence 2 is interbedded grey shale/red fluvial point bar accretions with some coal locally. After that, there were transgression and slow subsidence resulting in marginal marine lagoon environment in sequence 3. The rock is grey shale with coal. Then, there were regression and regional subsidence, sequence 4 is fluvial red sandstone with few coals. In beginning of upper-Miocene, there was continued rifting and regional subsidence. The depositional environment is delta plain- marginal marine- marine. The main component is grey claystone with extensive coals[5].

MMU in Figure 2-2 stands for Mid Miocene Unconformity. It is the key bed for setting intermediate casing seat. This study assumes that MMU is around 5,000ft TVD.

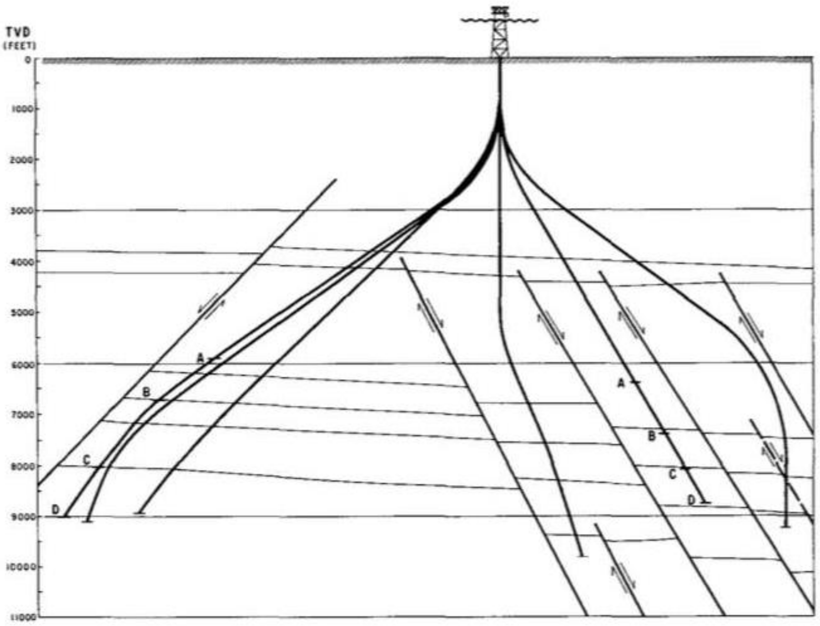


Figure 2-3: General Gulf of Thailand Geological Structure [3]

2.2 General drilling and operation in Gulf of Thailand

Deviated slim hole design had been applied in GOT due to the fact that the reservoir is small unit and has complexity structure as seen in Figure 2-3. The directional work starts in intermediate section with motor BHA. In production section, synthetic based mud (SBM) is used because of torque and drag issue. This section is drilled using rotary steerable with Adjustable Gauge Stabilizer (AGS) instead of motor drive due to high temperature downhole. Length of each section is provided in Table 2-1. General drilling and completion program in GOT is detailed in Table 2-2.

The formation pressure is normal from surface down to 6700ft TVD approximately. Deeper than that to TD, abnormal pressure is presented with high temperature gradient (4^{o}F/100ft). It is consequently difficult to use motor drive. A typical well schematic is deviated well which shows in Figure 2-4. The maximum well angle averages 48 degree [3].

Table 2-1 Unocal Thailand General Operation Environment [4]

Parameter	Value
Water Depth	190-240 ft.
Surface Section	1000 ft. with 9-5/8” Casing
Intermediate Section	4000-5500 ft. TVD with 7” Casing
Production Section	9000-15000 ft. MD 8000-10000 ft. TVD with 2-7/8” Tubing
Pay depth per Well	0-600 ft. between 5000-1000 ft. TVD

Table 2-2 Unocal Thailand General Drilling and Completion Program [4]

Section	Surface	Intermediate	Production
MD Depth	1,000 ft.	4,000-5,000 ft.	9,000-15,000 ft.
Drilling Fluid	Gel Mud	Sea Water	SBM
Inclination	15 deg.	60 deg.	60 deg.
Drill Pipe size	5”	5”	3-1/2” or 4”
Hole Size	11-3/4”	8-1/2”	6-1/8”
F.I.T	12.5 ppg.	14.5 ppg.	
Casing size	9-5/8”	7”	2-7/8” Tubing
Cement	13.5 or 15 ppg. With 100% excess	12.4 ppg. lead, 15.9 tail	13.5 ppg.

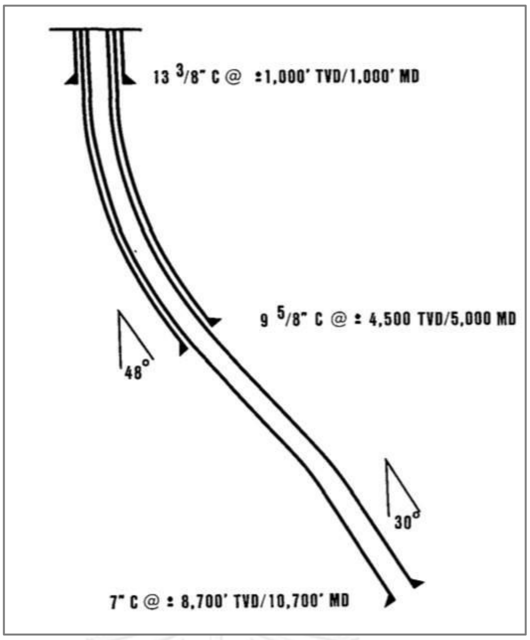


Figure 2-4: Typical Well Schematic in Gulf of Thailand [3]

2.3 Directional Well Planning

Many significant improvements in equipment and techniques used in directional drilling have been made since 1934[6]. Deep directional drilling continues increasing in importance to the industry. Nevertheless, it costs greater than normal. Increase directional drilling efficiency is the way to reducing overall cost.

Once the target has been designed, next step for consideration is the kick-of-point (KOP). The primary consideration in selecting the best point is the amount of angle necessary to obtain the desire deviation and the type of formation and structural of this point. The maximum angle should be greater than formation bedding plain angle [6].

2.4 Torque and Drag Analysis

Torque is a force required for rotate drill pipe, drag is an incremental force to move pipe up or down from hole. Torque and drag are related; high drag force and high torque loads normally occur at the same time. Drillstring torque and drag are primary caused by friction force between string and wellbore [7].

Drag is also related to well trajectory design. Downward drag in directional well can cause excessive axial compression and lead to buckling. Torque and drag behavior depend on local friction factor and specific operational and rig limitation [8].

Excessive torque and drag force can cause by tight hole condition, poor hole cleaning, differential stick. Almost reasons are relating to hole condition. If well is in good condition, the main cause of torque and drag is siding friction. The more deviated well profile creates higher siding friction and excessive torque and drag (Figure 2-5).

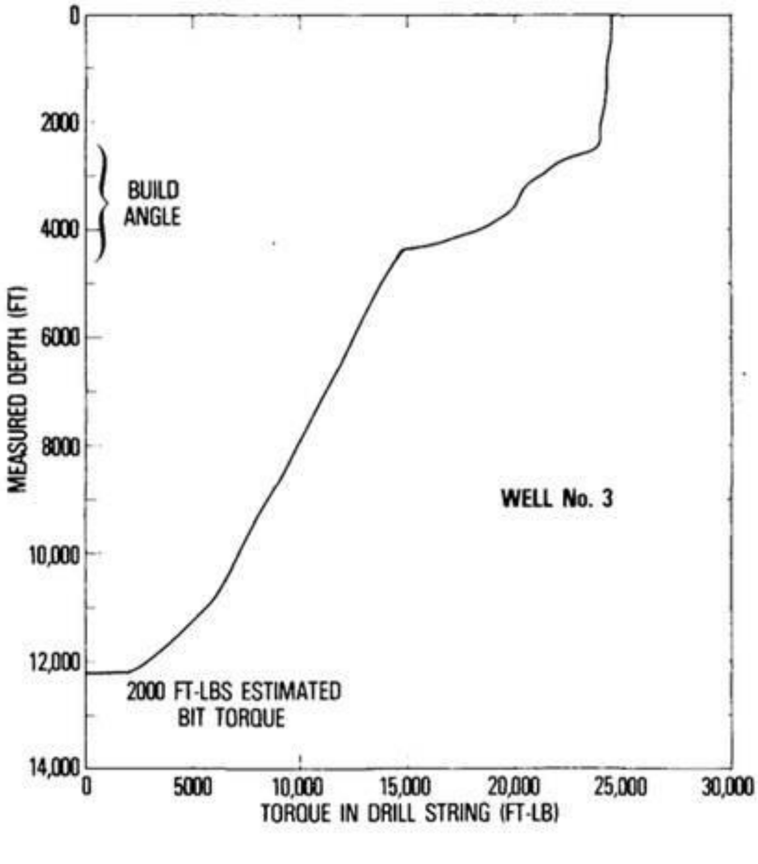


Figure 2-5: Torque in Drillstring Versus Measure Depth [7]

Prediction of frictional loads on drill pipe of deviated well allows driller to select the practical well plan by minimum torque and drag as criteria [7]. Well planning should include torque and drag modeling with worst case friction factor to ensure that drill string can be rotated and pull in-out of hole [9].

Torque and drag simulation using software of well planning stage helps eliminate risk and uncertainty. Software account varies input such as directional plan, drill string data, cased hole data etc. If the modeling shows that there is a critical problem then alter design can be selected. Torque and drag modeling is proven technique for wellbore construction [10].

Optimization well profile to minimize torque and drag problem has been discussed in many publications. Important conclusion is making smooth well path. Minimizing dogleg severity have been implement in procedure [1].

Reduced torque and drag can be achieved by minimize kick off point, build- drop rate, inclination. These result in reduced dogleg severity. Reduced torque and drag represent a significant time and cost saving by reducing chance of operation problem [2].

From overall, directional drilled is general in GOT. To eliminate risk and uncertainty, torque and drag analysis need to be applied with every well plans before drilled. The planning process may take longer time if torque and drag exceed the limited because well plan need to be revised until it would not exceed the safety limited. Hence, this study is performed to investigate well plan parameter for directional drilling in GOT and recommend the well planning limited of design.

Chapter 3 : Relevant Theory and Concept

There are 3 major theories and concepts that related to this study; well profile, survey calculation and torque and drag theory.

3.1 Well Profile

Wellbore profile can be divided into 2 major types; vertical and deviated well. Vertical wellbore is simply drilled vertically to target, or within 5 degree of deviation. Deviated wellbore is more complicated. Deviated wellbore or directional drilling is a well that drilled deviated from vertical.

Deviated well profile is created for several applications; multi well drilled from one platform, inaccessible location, complicate geological structure etc.

Directional well profile can be separated into 3 types (Figure 3-1) followings;

1. Type I Build and Hold
2. Type II Build Hold and Drop
3. Type III Continuous Build or Deep build/ Kick off

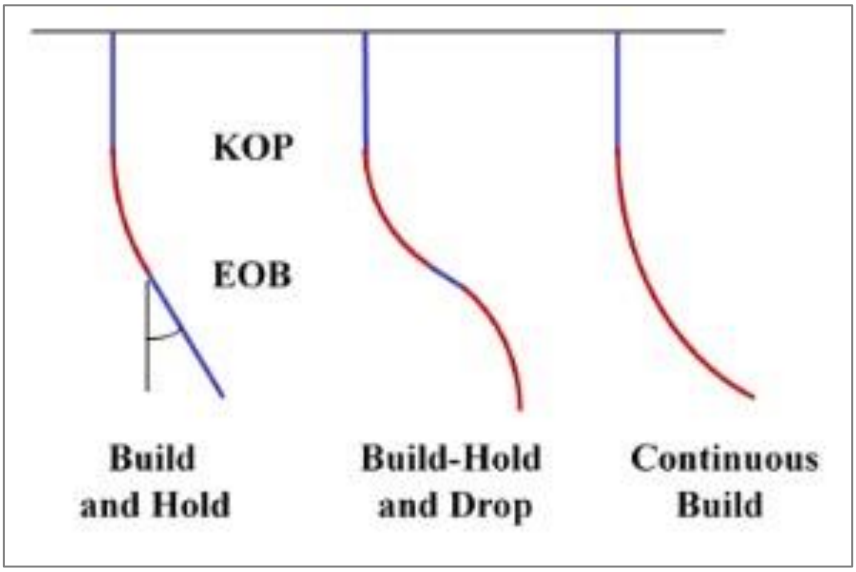


Figure 3-1: General Deviated Well Profile

There are importance parameters that provide desire well path following;

Build up rate (BUR)	a rate of inclination change between two consecutive survey points, expressed in degree per 100ft, measured in vertical plane. If build up rate is minus value, it will call drop off rate (DOR).
Dimension	a category of well profile. If differential degree turn of start point and end of section is over 90 degrees, this well profile is 3D profile. If not, it is 2D profile.
Direction	an angle that associate with departure in X plane.
Dog Leg Severity (DLS)	an overall angle change. It accounts changing bot inclination and azimuth, expressed in two- dimensional degree per 100ft High dogleg occurs when there is quickly change or azimuth and/or inclination.
Inclination Angle	an angle that deviated from vertical line or Y plane.
Kick off point (KOP)	a depth of hole where start directional drilling.
Total Depth (TD)	the final depth of wellbore in MD or TVD.
Turn Degree	a reversal of direction, relate to azimuth change
Turn Rate (TUR)	a rate of azimuth change between two consecutive survey points, expressed in degree per 100ft, measured in horizontal plane.

3.2 Well Trajectory Calculation

Well trajectory calculation is importance for well planning process. There are six calculation methods which have been widely used in directional drilling application; tangential, Mercury, average angle, balance tangential, minimum curvature and radius curvature method. Minimum curvature method is often use in order to maximize survey calculation accurately [11].

Hence in this study, the calculation is based on Minimum Curvature method. This method assumes a curve well trajectory at deviated interval. It also includes overall angle change of drill pipe between deviated intervals from point to point as seen in Figure 3-2. Well path is described by depth or TVD, displacement in x and y axis. It can be calculated by;

$$M_i = \frac{D_i}{2} \times [sin(\alpha_{i-1}) \times sin(\epsilon_{i-1}) + sin(\alpha_i) \times sin(\epsilon_i)] \times f \quad 3\text{-}1)$$

$$L_i = \frac{D_i}{2} \times [sin(\alpha_{i-1}) \times sin(\epsilon_{i-1}) + sin(\alpha_i) \times cos(\epsilon_i)] \times f \quad 3\text{-}2)$$

$$D_i = \frac{D_i}{2} \times [cos(\alpha_{i-1}) + cos(\alpha_i)] \times f \quad 3\text{-}3)$$

Where,

	M	=	Horizontal displacement in x axis (ft.)
	L	=	Horizontal displacement in y axis (ft.)
	D	=	True Vertical Depth (ft.)
	A	=	Inclination Angle (deg.)
	∈	=	Azimuth angle (deg.)
	f	=	A factor of straight line versus curve ratio

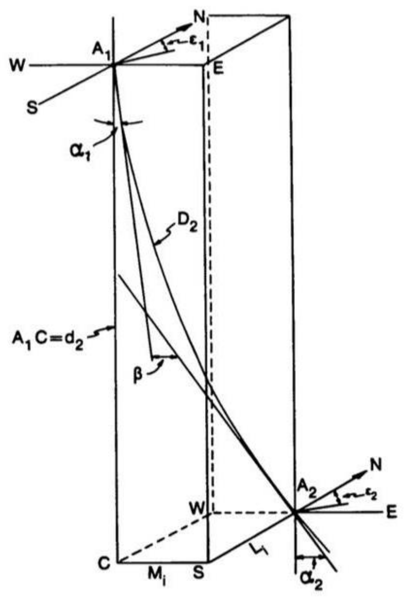


Figure 3-2: A Curve Represents a Wellbore Path Between Point A1 and A2 [12]

Given β as a dogleg in degree per 100ft, the overall angle can be written for the minimum curvature method as;

$$\cos\beta = \cos\big((\alpha_2 - \alpha_1) - \{\sin(\alpha_1) \times \sin(\alpha_2) \times (1 - \cos(\epsilon_2 - \epsilon_1))\}\big) \qquad 3\text{-}4)$$

Where, α = Inclination angle (deg.)

ϵ = Azimuth angle (deg.)

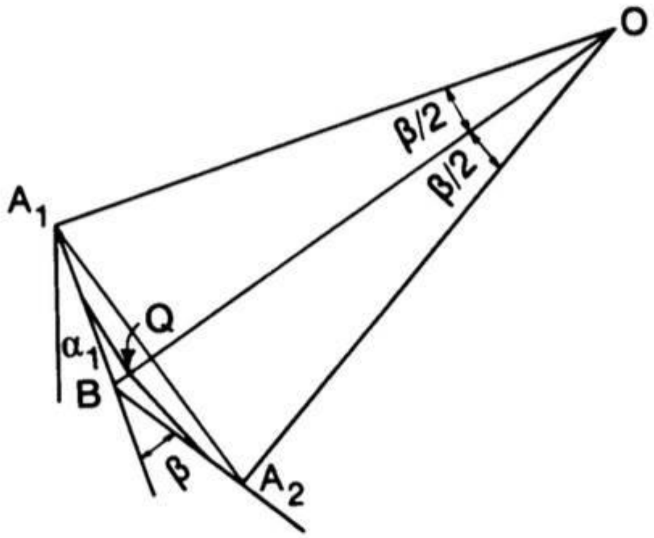


Figure 3-3: Minimum Curvature Parameter [12]

As seen in Figure 3-3, the straight line A_1B+BA_2 adjoin the curve segment A_1Q+QA_2 at point A_1 and A_2.

$$A_1Q = OA_1 \times \frac{\beta}{2} \qquad 3\text{-}5)$$

$$QA_2 = OA_2 \times \frac{\beta}{2} \qquad 3\text{-}6)$$

$$A_1B = OA_1 \times \tan(\frac{\beta}{2}) \qquad 3\text{-}7)$$

$$BA_2 = OA_2 \times \tan(\frac{\beta}{2}) \qquad 3\text{-}8)$$

Then (3-4)/ (3-2) is

$$\frac{A_1B}{A_1Q} = \frac{OA_1 \times \tan(\frac{\beta}{2})}{OA_1 \times \frac{\beta}{2}} = \tan\left(\frac{\beta}{2}\right) \times \frac{2}{\beta} \quad \text{3-9)}$$

And (3-5)/ (3-3) is

$$\frac{BA_1}{QA_1} = \frac{OA_2 \times \tan(\frac{\beta}{2})}{OA_2 \times \frac{\beta}{2}} = \tan\left(\frac{\beta}{2}\right) \times \frac{2}{\beta} \quad \text{3-10)}$$

A factor of straight line section versus curve section ratio is defined as f where;

$$f = \tan\left(\frac{\beta_i}{2}\right) \times \frac{2}{\beta_i} \quad \text{3-11)}$$

If β is less than 0.25 radians, it can assume that f is 1.0.

3.3 Well Planning Process

Before planning well trajectory, there are general data required as see in Figure 3-4, especially hole geometry and casing design. After, well plan is generating to achieve the desired target. Kick off point is the first parameter to be determined. Next, the amount of deviation or inclination and dogleg are considering.

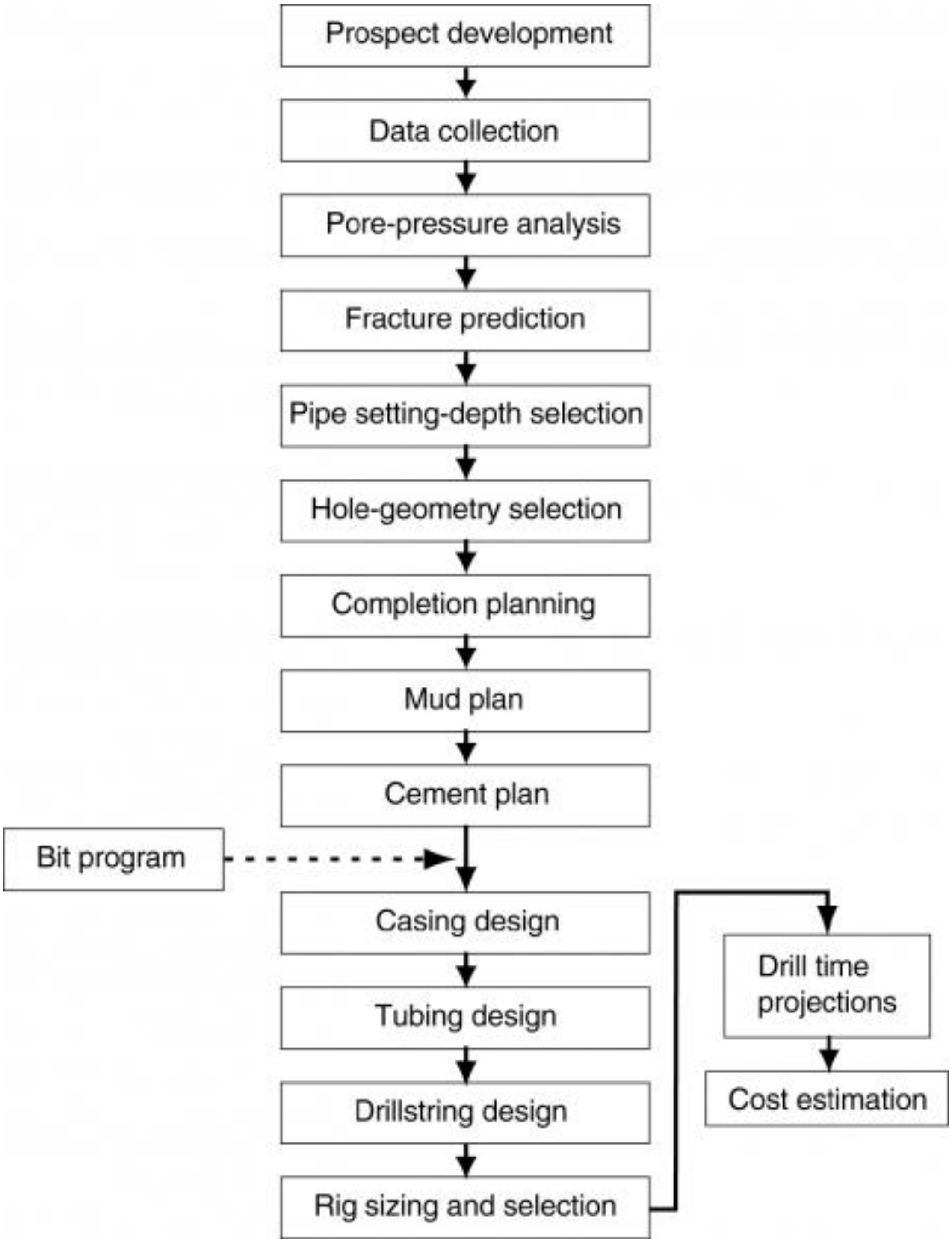


Figure 3-4: General Well Planning Process (ref. Petrowiki.org)

3.4 Torque and Drag

3.4.1 Torque

Torque is a turning force that is applied to a rotary mechanism to make it rotate (Figure 3-5). It is measured in foot-pound. Additional torque occurs during drillings due to wellbore friction and interaction with formation. It is also used for make up a connection. This study focuses on torque while drilling.

Frictional torque is generated by contact loads between the drillstring and casing or open hole. The magnitude of contact loads is determined from drillstring tension, compression, dogleg severities, drill pipe size, drillstring weight and inclination. Hence, friction torque is directly related to well profile.

Required torque to rotate drillstring can calculate from;

$$T = F_n \times \frac{d}{2} \times sin\theta = \mu \times W \times \frac{d}{2} \times sin\theta \qquad 3\text{-}12)$$

Where,

	T	=	Torque (ft.-lb.)
	F_n	=	Normal force (lb.)
	d	=	Diameter (in.)
	W	=	Weight of segment (lb.)
	θ	=	Inclination angle (deg.)
	μ	=	Friction coefficient (frac.)

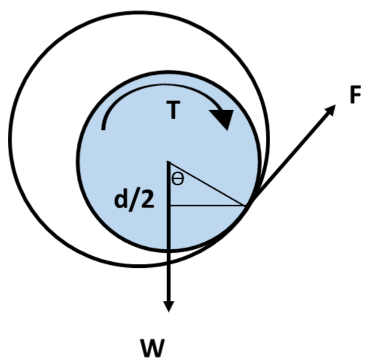


Figure 3-5: Torque while rotating pipe

Excessive torque leads to torsion of the tubular both body and connection part. It often results in a twist off; a torsional failure due to a break in subsurface drillstring. A body normally has higher yield strength than the connection part. Drillstring torsional failure is mostly likely to occur in drillstring during normal drilling operation where there are combined tension and torsion load. Drill pipe under tension load is likely to fail due to yield strength reduction. Connection torsional failure can occur while drilling too. If there is too much torques, it will damage connection.

In commercial software, there are 2 torque analysis models; stiff string and soft string model. Soft string model is account for drillstring motion and neglected the string bending stiffness. This model is widely used in oil and gas industry[13].

3.4.2 Torque Limitation

Torque limit that applied in this study relates to make up torque of drillstring. Make up torque is a torque that applied to make a joint connection. This value relates to drillstring property, because near surface is the highest torque generated area, which is the drill pipe section. Hence, drill pipe's make up torque is used as a criterion, which is 22,200 ft.-lbs.

3.4.3 Drag

Drag is a friction between a moving device and other moving or nonmoving part such as formation. It acts opposite side of object movement (Figure 3-6). It is related to well trajectory profile and wellbore smoothness. Downward drag in directional well can cause excessive axial compression and lead to buckling. Buckling issue often occurs while trip in or sliding a tubular.

Drag force is calculated using the following equation;

$$F_D = F_n \times \mu \times \frac{T}{V} \qquad \text{3-13)}$$

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)

Resultant speed is calculated from;

$$V = \sqrt{T^2 + (d \times \pi \times \frac{RPM}{60})} \qquad 3\text{-}14)$$

Where, d = Drillstring diameter (in.)

RPM = Rotational speed per minute (rpm.)

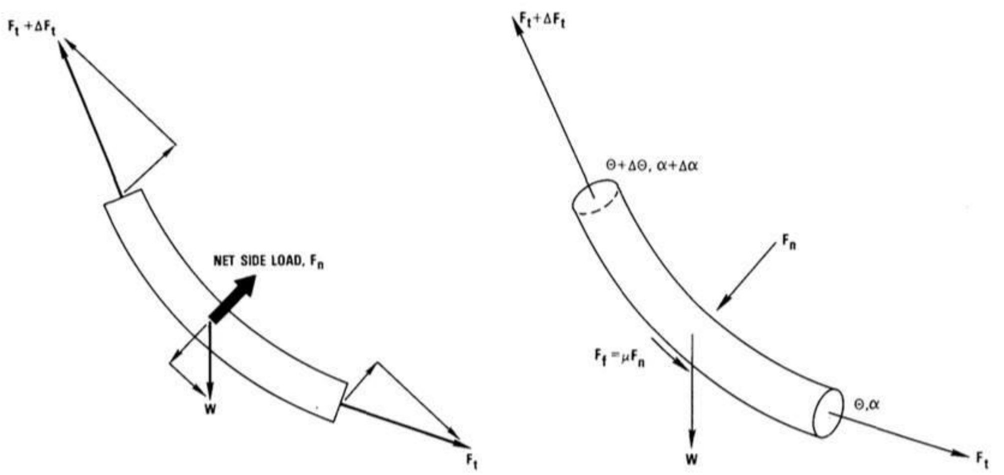


Figure 3-6: Force Balance on Drillstring (left), Force Acting on Drillstring (right)[14]

Normal force act on a curve of the drillstring. The magnitude of normal force is;

$$F_n = [(F_t \Delta\alpha sin\theta)^2 + (F_t \Delta W sin\theta)^2]^{1/2} \qquad 3\text{-}15)$$

Where, F_n = Normal Force (lbs.)

F_t = Axial tension force (lbs.)

W = Weight of segment (lbs.)

θ = Inclination angle (deg.)

α = Azimuth angle (deg.)

While drillstring curved, there is tension force. Tension force increment is;

$$\Delta F_t = Wcos\theta + \mu F_n \quad \text{3-16)}$$

And torsional increment (M) is;

$$\Delta M = \mu F_n r \quad \text{3-17)}$$

In this study, effective tension is analyzed instead of dragging. Unlike tension, this value accounts for weight in drilling fluid.

3.4.4 Effective Tension Limitation

Effective tension limit belongs to drillstring property. If effective tension exceeds the limit, drillstring has potentially a part. Tension limit calculated from drillstring property. This commercial software applies the Goodman relation to define effective tension limit. It can express as an equation following;

$$\sigma_{\mathrm{FL}} = \sigma_{\mathrm{FEL}}\left(1 - \frac{\mathrm{F_{AB}}}{\mathrm{F_{AY}}}\right) \quad \text{3-18)}$$

Where, σ_{FL} = Fatigue limit (psi)

σ_{FEL} = Fatigue endurance limit (psi)

F_{AB} = Axial force (Buoyancy Method) (lb.)

F_{AY} = Axial force required to generate the yields stress (lb.)

Near surface location has high effective tension, which is the drill pipe section. Hence, drillpipe property is used as an effective tension limit, which is 314.9 kip.

3.4.5 Frictional Factor

Coefficient of friction is defined as the ratio of frictional force to normal force acting at the point of contact which can calculated by;

$$\mu = \frac{F_f}{F_n} \qquad 3\text{-}19)$$

There are two types of coefficient of frictional factors; case hole frictional factor and open hole frictional factor. This factor accounts for hole cleaning quality and micro tortuosity. Friction factor while drilling relates to drilling fluid, pipe type and cutting concentration.

3.4.6 Drillstring failure

In directional drilling, drillstring rotates in the curve path. It generates tensile and compressive loads or call stress. Shear stress is due to torque applied. Axial stress is generated due to drillstring tension [14]. This section focuses on drillstring failure cause by exceeding torque and drag limit.

- Buckling is a lateral deformation of drillstring when there is exceed compress loads.
- Parting is a parted of drillstring. It occurs when the induced tensile stress exceeds the pipe-material ultimate tensile stress or its tension limit.
- Twist- off is a parting or breaking of the drillstring downhole due to fatigue or excessive torque.

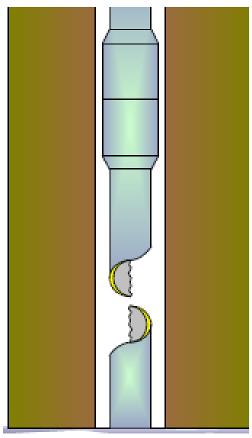


Figure 3-7: Twist off

Chapter 4 : Methodology

This chapter details methodology includes; well plan modeling and torque and drag modeling. These two models are performed in commercial software; Compass and Well plan; by Halliburton. The modeling input is also specified in this Chapter. Most input data relied on literatures review in Chapter 2.

Methodology

1. Gather data

   To start planning a well, essential data must be determined;

   - Pressure; pore pressure, fracture pressure
   - Drilling and operation plan; mud plan, casing plan etc.
   - Formation drilled

2. Construct typical formations and associated reservoir properties.

3. Create well trajectory

   In this study, 4 main well profiles are planned following;

   - 2D build and hold profile
   - 2D build, hold and drop profile
   - 3D build, and hold profile
   - 3D build, hold and drop profile

4. Vary well plan parameters

   Well plan parameter is varied as shown in Table 4-1 and Figure 4-2.

5. Perform torque and drag analysis

6. Perform sensitivity analysis

   Mud weigh and formation pressure are varied as detailed in section

7. Analyze and evaluate result

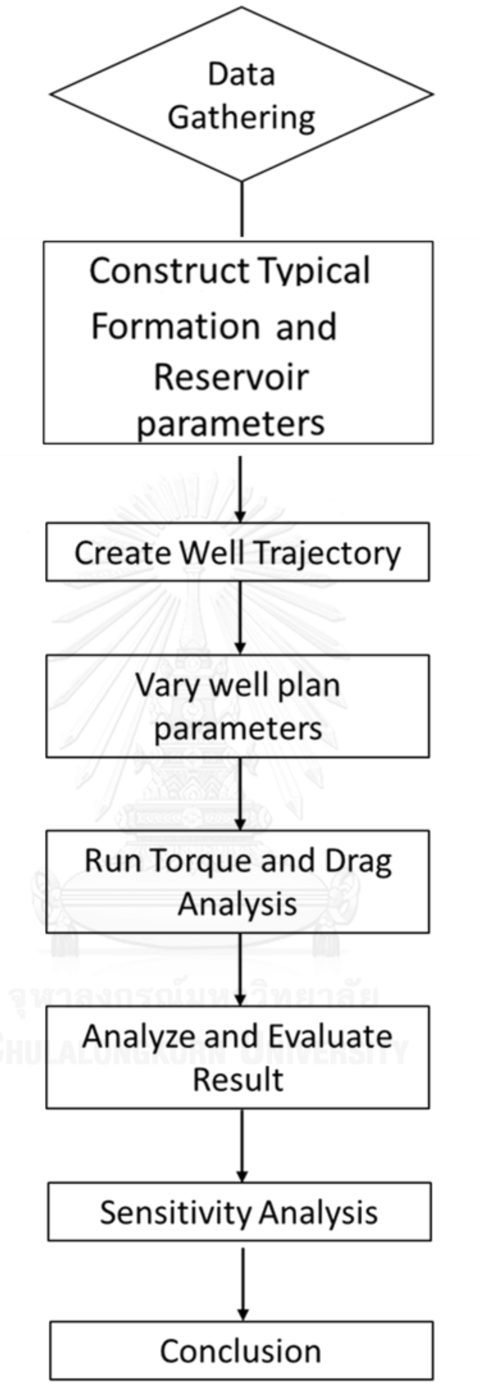


Figure 4-1: Study Work Flow

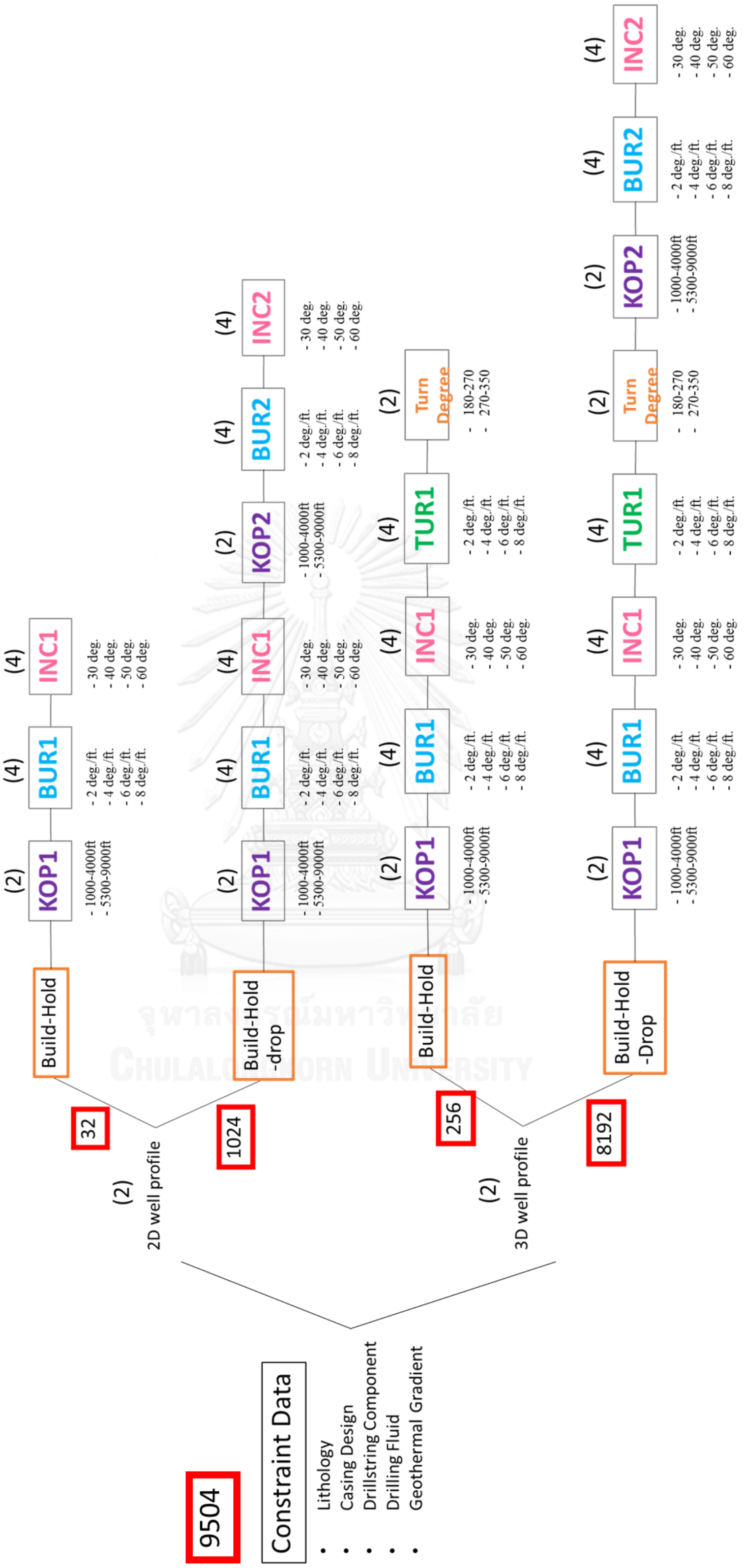


Figure 4-2: Case matrix.

Table 4-1: Well plan parameters variation for each well profile type.

Well Profile				Parameter	Value			
3D Build-Hold-Drop	3D Build-Hold	2D Build-Hold-Drop	2D Build-Hold	1st Kick off point (TVD ft.)	1000	5300		
				1st Build up rate (deg./100ft.)	2	4	6	8
				1st Inclination (deg.)	30	40	50	60
				2nd Kick off point (TVD ft.)	immediately	5300		
				2nd Build up rate (deg./100ft.)	-2	-4	-6	-8
				2nd Inclination (deg.)	0	15	Half of 1st INC	
				1st Turn Rate (deg./100ft.)	2	4	6	8
				1st Turn Degree (deg.)	90	120	150	180

From Table 4-1 and Figure 4-2, the maximum cases are 9,504 cases. Some cases maybe not designable due to it is not followed casing regulation. Typical design should not have a curve path pass casing seat area because it can cause of casing shoe damaged. The success plans are further investigated for torque and drag analysis to determine drillability and results are discussed in chapter 5.

Kick off Point or KOP are corresponding to given lithology. In this study, 1st and 2nd KOP are varied as follow; 1,000ft TVD and 5,300ft TVD. 1,000ft TVD is at the depth below surface casing depth and at 5,300ft TVD is after intermediate casing. In this section, it cannot kick off immediately after casing depth because of tool limitations. Hence, Deep KOP is set on 5,300ft TVD while casing depth is 5,000ft TVD.

Build up rate is named as 1st BUR and it is varied from 2, 4, 6 and 8 deg./100ft. Second build up rate is named as 2nd BUR which is drop off rate. It is varied from -2, -4, -6 and -8 deg/100ft. These rates are generally applied for well planning.

Inclination is named as INC. 1st INC is varied from 30, 40, 50 and 60 deg. As the literature review, limit of design in GOT is at 45 deg. However, the technology and equipment are improved day by day, hence degree of inclination are pushed to the upper boundary to observe possibility. Second inclination or 2nd INC, is varied from 0, 15 and half of 1st INC.

Turn rate (TUR) and turn degree are applied along the same depth with build trajectory. TUR is varied from 2, 4, 6 and 8 deg/100ft.

Turn degree is varied from 90, 120, 150 and 180 deg. If the degree turn is higher than 180 deg, turn rate will be the same value with minus sign. Hence, these parameter set are designed for this study.

4.1 Well Plan Modeling

To allow efficiency of well plan parameters varying process, a constrain set of well construction and reservoir data are defined in list below.

1. General Information
2. Lithology
3. Casing Design
4. Pressure Data

4.1.1 General Information

Rig location is not specified in this study. Rig type is mobile offshore drilling unit (MODU). Mean sea level is 100ft below rig floor. Data references are detailed in Table 4-2 and Figure 4-3.

Table 4-2: Typical data for well planning construction

Parameters	Values	Unit
Mean Sea Level	100	ft. TVD
Mudline Depth	350	ft. TVD

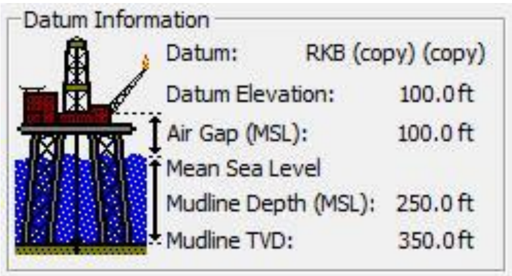


Figure 4-3: Datum information

4.1.2 Lithology

Before plan a well path, formation or lithology description needs to be detailed. Formation top is the key to recognize where the well drill through. Hence, formation description and formation top depth are required. Lithology input which used in this study is summarized in Table 4-3.

Table 4-3: Lithology Detailed

TVD (ft.)	Formation Top Name	Lithology Description	Dip angle (deg.)
Sea floor	Seq.5	Claystone	5
4700	Seq.4 *MMU	Sand	5
7000	Seq.3	Shale	5
7700	Seq.2	Shale, Sandy	5
8300	Seq.1	Shale	5
13500	Basement	Granite	0

4.1.3 Casing Design

Casing design in this study follow typical operation in Gulf of Thailand. There are 2 casing; surface casing and intermediated casing. Surface casing is set on formation sequence 5. Intermediated casing is set after drilled thought MMU, which is in sequence4. Detailed of casing design is displayed in Table 4-4. Casing depth in measure depth (MD) will change relatively with well path.

Table 4-4: Typical casing design

TVD (ft.)	Casing size (in.)	Hole size (in)	String Type
1000	9.625	12.250	Casing
5000	7.000	8.500	Casing

4.1.4 Pressure Data

Pressure data; formation pressure, fracture pressure and drilling fluid weight; are required for well plan modeling. The input is detailed in Table 4-5 and Figure 4-4.

Table 4-5: Pressure data for well plan modeling

TVD (ft.)	Formation Pressure (ppg.)	Fracture Pressure (ppg.)	Mud Weight (ppg.)
350	8.6	9.0	8.6
5000	9.2	14.5	9.5
10000	10.1	17.8	10.5
13000	9.5	18.0	10.9

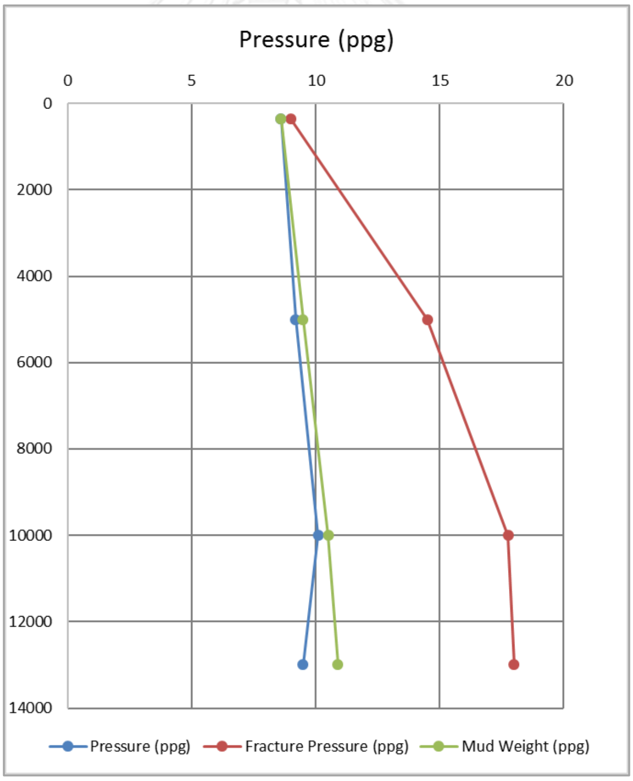


Figure 4-4: Constraint of Pressure Profile in ppg.

4.1.5 Pressure Data for sensitivity analysis

Refer to Eq. 3-12 and 3-15, weight is account in torque and drag calculation. Mud weight affected on buoyancy weight. Therefore, mud weight is interested parameter to observe its sensitivity over torque and drag. The well that has torque and drag result nearly exceed the limit is selected to perform sensitivity analysis with variety of mud weight as detailed in Table 4-6.

Table 4-6: Varied minor effective parameter over torque and drag

Parameter	Area A	Area B	Area C	Area D	Area E
Mud Weight (ppg.)	9.0	10.0	12.0	13.0	14.0

Mud weight parameter is selected to observe the effected over torque and effective tension. The value is optimized from formation pressure data in difference area as detailed in Figure 4-5 and Table 4-7 to 4-11.

Table 4-7: Pressure data from area A

TVD (ft.)	Pressure (ppg)	Fracture Pressure (ppg)	Mud Weight (ppg)
350	8.6	9.0	8.6
5000	8.6	14.5	9.0
7500	6.7	16.0	9.0
10000	8.3	17.8	9.0
10800	8.3	18.0	9.0
13000	8.3	18.0	9.0

Table 4-8: Pressure data from area B

TVD (ft.)	Pressure (ppg)	Fracture Pressure (ppg)	Mud Weight (ppg)
350	8.6	9.0	8.6
5000	8.7	14.5	9.2
7500	9.2	16.0	9.2
10000	9.6	17.8	10.0
10800	9.9	18.0	10.0
13000	9.9	18.0	10.0

Table 4-9: Pressure data from area C

TVD (ft.)	Pressure (ppg)	Fracture Pressure (ppg)	Mud Weight (ppg)
350	8.6	9.0	8.6
5000	9.2	14.5	9.5
8000	11.5	16.0	12.0
10000	11.9	17.8	12.0
10800	9.5	18.0	12.0
13000	9.5	18.0	12.0

Table 4-10: Pressure data from area D

TVD (ft.)	Pressure (ppg)	Fracture Pressure (ppg)	Mud Weight (ppg)
350	8.6	9.0	8.6
5000	9.2	14.5	9.5
7500	12.0	16.0	12.5
10000	12.7	17.8	13.0
10800	12.5	18.0	13.0
13000	12.5	18.0	13.0

Table 4-11: Pressure data from area E

TVD (ft.)	Pressure (ppg)	Fracture Pressure (ppg)	Mud Weight (ppg)
350	8.6	9.0	8.6
5000	9.2	14.5	9.5
7500	12.0	16.0	13.0
10000	12.5	17.8	14.0
10800	13.2	18.0	14.0
13000	13.2	18.0	14.0

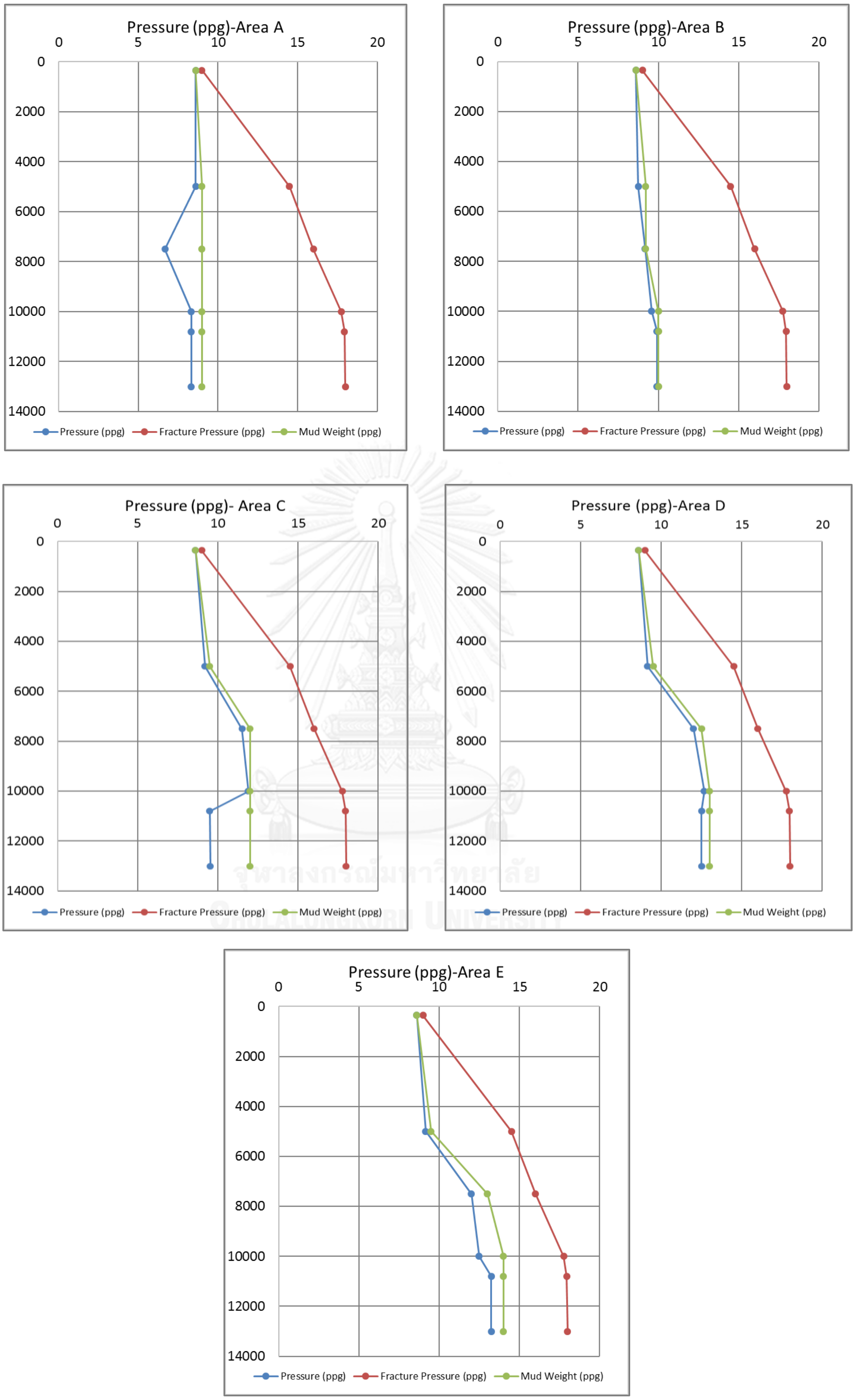


Figure 4-5: Pressure Profile

4.1.6 Well Planning

Well plan parameters are varied to observe torque and drag analysis result as mentioned in Table 4-1. There are maximum 8 parameters to vary depend on well profile type which are 1st and 2nd kick off point, 1st and 2nd inclination, 1st and 2nd build up rate, turn rate and turn degree. Each parameter is varied while other parameters are fixed in order to observe its effect.

While planning process, the curvature trajectory must be finished before casing seat. If not, these well designs are considering as incompetent drill design.

4.2 Torque and Drag Modeling

To perform torque and drag analysis, there are 5 data required as follow;

1. Hole section
2. Drillstring component
3. Drilling fluid property
4. Geothermal property
5. Torque and drag set up data

These parameters will be detailed in next section.

4.2.1 Hole Section

Hole section is detailed in Table 4-12. This data corresponds to casing design in previous section. Measure depth of casing seat and TD must be input accurately. These data can be gathered from well plan section.

Table 4-12: Hole section input

Section Type	Length (ft.)	Length (ft. TVD)	Item Description
Casing	As per well plan	Surface -5000	7 in, 26ppf, L-80
Open Hole	As per well plan	5000-13000	

4.2.2 Drillstring Component

In Chapter 2, general operation in GOT is 3 strings well; 12.25, 8.5 and 6.125 sections drilled respectively. This study is focusing on torque and drag while drilling in production section as it rotates through curved well path. Drillstring component is constrained. Drill pipe length changes corresponding to measure depth changes with different well trajectories.

Torque and drag analysis required a detail of drillstring components as follow; component length, total length, outer diameter, inner diameter, tool joint length, joint outer diameter, joint inner diameter, weight, material, grade and class. The input is summarized in Table 4-13 and Figure 4-6.

Table 4-13: Drillstring components input from top to bottom

Section Type	OD (in)	ID (in)	Length (ft.)	Item Description
Drill Pipe	4.000	3.340		4.000 in, 15.91 ppf, S, XT39
Heavy Weight Drill Pipe	4.000	2.563	1196.40	4.000 in, 30.48 ppf, 1340 MOD, XT39
Cross Over Sub	5.000	2.250	1.940	5.000 in, 43.66 ppf, 4145H MOD, 4 1/2 REG
Drill Collar	4.750	2.250	119.62	4.750 in, 46.84 ppf, 4145H MOD, 3 1/2 IF
Stabilizer	5.000	2.250	4.92	5.000 in, 46.84 ppf, 4145H MOD, 3 1/2 REG
MWD Tool	5.000	2.250	30.02	4.750 in, 46.10 ppf, 15-15LC MOD (1), 4 1/2" IF
Cross Over Sub	5.000	2.250	2.26	5.000 in, 53.37 ppf, 4145H MOD, 4 1/2" IF
AGS	5.000	1.638	10.96	5.000 in, 63.03 ppf, 4145H MOD, 3 1/2 IF
Bit Sub	5.000	2.250	0.98	1' extension sub
AGS	5.000	2.250	2.43	5.000 in, 53.37 ppf, 4145H MOD, 3 1/2 IF
Bit	6.125		0.72	Polycrystalline Diamond Bit, 4x12, 0.440 in^2

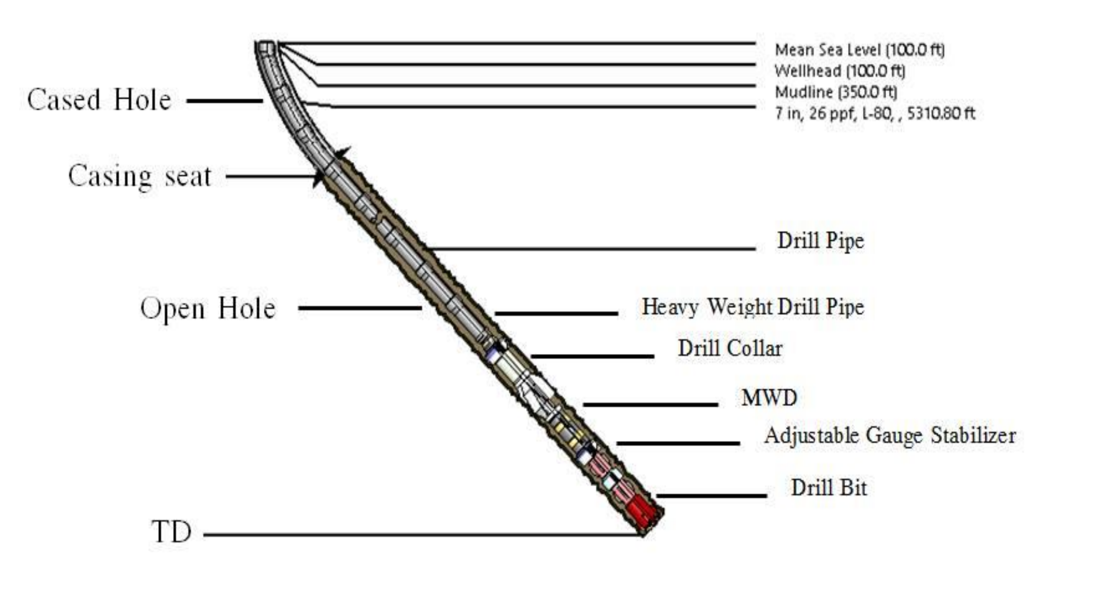


Figure 4-6: Sample of drillstring component

4.2.3 Drilling fluid

Drilling fluid helps improve frictional between borehole and drillstring or casing and drillstring while drilling. From fanning data input, drilling fluid shows as Bingham plastic model property. Drilling fluid properties are detailed in Table 4-14.

Table 4-14: Drilling fluid properties

Parameter	Value	Unit
Mud Density	10.90	ppg.
Rheology Model	Bingham Plastic	
Mud Temperature	150	^{O}F
Plastic Viscosity	25	cp.
Yield point	15	lb/100ft^2

4.2.4 Geothermal gradient

Related to literature review, geothermal gradient of GOT is 4 ^{o}F./100ft.[4]

4.2.5 Torque and drag set up data

Set up data is detailed in Table 4-15. Refer to section 3.4.1; soft string model is applied in this study. Torque at bit is a torque that generated when a bit drilling or rotating at bottom hole. From field data, bit torque is estimated at 2500 ft-lb corresponding to bit type and formation drilled. The general frictional factor for cased hole is 0.25 and 0.28-0.35 for open hole section depending on formation drilled. Refer to Samuel-2015, the severe frictional factors should be applied in the analysis, hence 0.35 open hole's frictional factor is applied in this study.

Table 4-15: Set up data for torque and drag analysis

Data	Value	Unit
Hook load travelling	55	kip.
Analytical methods	Bending Stress Magnification	
Contact force normalize length	31.0	ft.
Mechanical limitations	Maximum WOB with no buckling	
Maximum overpull	90.00	% of yield
Friction Factor (open hole)	0.35	frac.
Friction Factor (cased hole)	0.25	frac.
Torque at bit	2500	ft.-lbs.
Drilling WOB/overpull	15	kip.
Trip speed	100	ft./min.

Chapter 5 : Result and Discussion

This chapter provides results of well plan, torque and effective tension from study cases. Result evaluation also discussed as a well planning guideline in this chapter.

Wells are planned as designed in Chapter 4 in order to investigate the effect of well plan parameters on torque and drag and also to determine drillability of the well designs. Several cases cannot be design due to casing seat regulation. In practice, casing seat preferably set in no curve well path because it can be damaged by rotating of drillstring.

Result and discussion are divided into 4 parts; 2D Build and Hold Well profile, 2D Build, Hold and Drop Well profile, 3D Build and Hold Well profile and 2D Build, Hold and Drop Well profile by well profile type, sub section by well plan parameters.

Torque and drag are applied as criteria. Torque limit is corresponding to makeup torque. Drag limit or tension limit is corresponding to tensional yield stress of drillstring. Torque and effective tension from simulation is used for drillability consideration. Moreover, the maximum torque and the maximum effective tension are used for evaluated the well planning guideline.

5.1 2D Build and Hold Well Profile

3 parameters were varied namely; kick off point (1st KOP) build up rate (1st BUR) and inclination angle (1st INC). Well plan of varying 3 parameters and its torque and effective tension along the drillstring are displayed in Figure 5-1 to 5-3 respectively.

5.1.1 Kick off point Effect

KOP is varied at 1000ft TVD and 5300ft TVD, which are below surface casing and intermediated casing depth respectively. Meanwhile other parameters are constrained as 2deg./100ft BUR and 60 deg. INC. Side views of well profiles are displayed in Figure 5-1 a). Torque and effective tension are also displayed in Figure 5-1 b) and c) respectively.

The graph color relates to well profile. The vertical red line in torque and effective tension graph represents the limit of torque and effective tension.

In Figure 5-1 a) the well that has shallower KOP provides longer measure depth and it can reach further horizontal distance away from the surface location. If target is far from the rig, planning KOP at early section could be considered.

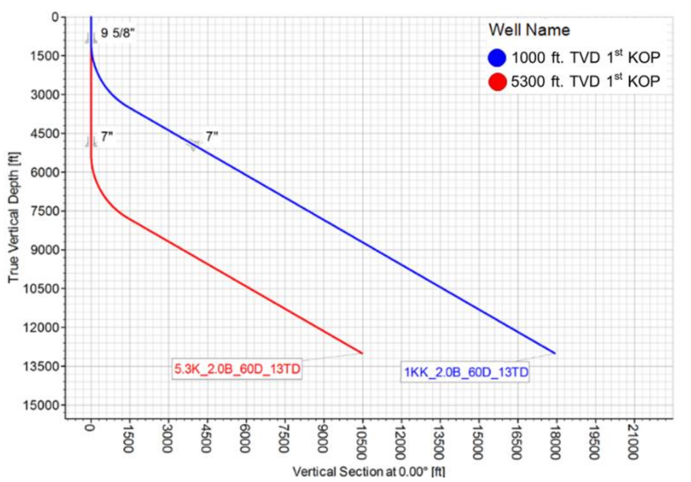
Figure 5-1 b) displays torque results along the drillstring from two different KOP. KOP at 1000ft TVD results in exceeding torque limit, meanwhile result of KOP at 5300ft TVD is within the limit.

Torque from both wells can be identified into 4 slopes which are; from bottom hole to a top of bottom hole assembly (BHA), tangent section, build section and vertical section to surface. From bottom of the hole to a certain section or called BHA section, torque is gently increasing from the bit along the drillstring. Both well have the same torque generated per foot.

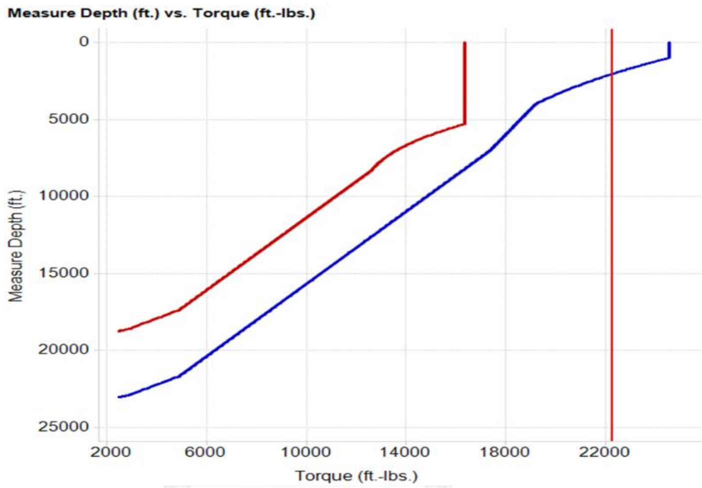
Entered tangent section, slope is flatter, which means torque is slowly increase. It changes from previous section because BHA section composed of heavy weight drill strings such a drill collar and heavy weight drillpipe, while this section composes of drill pipe, which has lighter weight. As Eq.3-12) higher weight of segment yields higher torque.

In tangent section, both cases have the same slope but shallower KOP has longer interval. Therefore, shallower KOP generates higher torque. It can imply that the length of tangent section impact torque. The well that has longer tangential section generates larger torque. In build section, torque raises up rapidly. After, a vertical section to surface, torque is constant. It can conclude that torque is affected by KOP in all section.

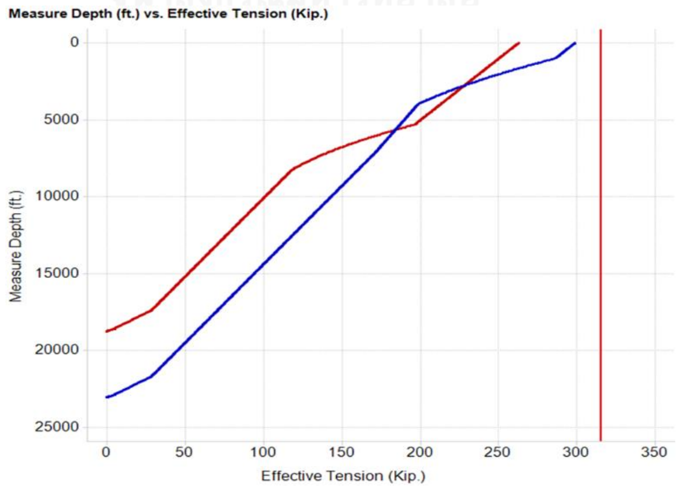
Effective tension results are illustrated in Figure 5-1 c). KOP at 1000ft TVD generated higher effective tension than 5000ft TVD KOP. It can imply that shallower KOP generates higher torque and effective tension with constraint BUR and INC.



a) well profiles



b) Torque



c) Effective Tension

Figure 5-1: 2D build and hold well profile with varied 1st KOP parameter, 2 deg./100ft 1st BUR, 60 Deg. 1st INC

Like torque, there are 4 slopes identified belong to 4 sections; BHA section, tangent section, builds section and vertical section. First is BHA section, effective tension increases gently. Next, tangent section, effective tension is raised with the same slope for both cases. The design that has longer tangent section generated higher effective tension. Length of drillstring is related to weight. Refer to Eq.3-12 and Eq. 3-15, heavier weight yields higher torque and effective tension. Next, build section, effective tension raises rapidly in this section due to more contact point in curve well path. Unlike torque, effective tension at vertical section is not constant. It is increasing as lower rate than build section, but slightly higher rate than tangent section. It is because drillstring at near surface location is stretched and loaded by heavy weight component downhole.

To summarized, Figure 5-1 shows that the well with 60 deg. INC, 2 deg./100ft BUR having KOP at 5300ft TVD can be drilled as both torque and effective tension stay within the limit. The well that designs with 60 deg. INC, 2 deg./100ft. BUR having KOP at 1000ft TVD cannot be drilled as torque exceeds the limit.

However, KOP depth selection is depended on other critical factors such as formation strength. It also has benefit of shallow KOP i.e. reaching far target. In order to design a shallow KOP, other well plan parameters should be adjusted to achieve the desire target. On the other hand, we would increase KOP depth below 1000ft TVD, in order to keep both torque and effective tension within the limit and maintain the same BUR and INC parameters.

5.1.2 Inclination Effect

In this section is continued observed on 1000ft TVD KOP design, which is not previously drillable. This section discusses on wells that planned with varying INC; 30, 40, 50 and 60deg with fixed KOP at 1000ft TVD, and 2 deg./100ft BUR as displayed in Figure 5-2 a). Its torque and drag results are illustrated in Figure 5-2 b) and c) respectively.

Higher INC provides longer measure depth and long horizontal displacement as seen in Figure 5-2 a).

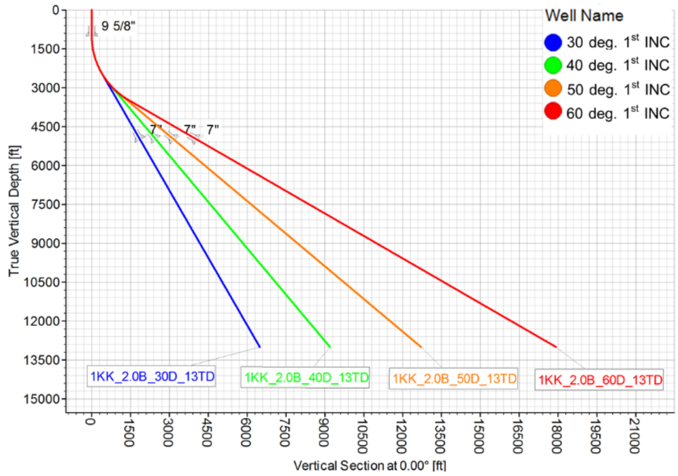
Figure 5-2 b) shows that increasing INC affected torque nonlinearly but corresponding to measure depth generated. From observation, higher INC generates higher magnitude of torque from bottom to top. Also, the increment is larger near build section.

In more detailed, torque can be divided in to 4 sections. First, BHA section, all cases have similar slope. The well with lower INC design shows slightly low torque than higher INC in this section. Then, torque raises gently with different slope per INC design in tangent section. Higher INC yields higher increasing rate.

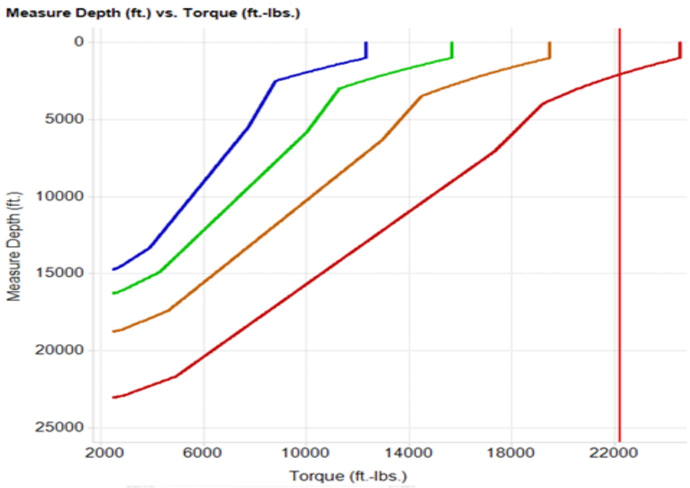
Entering build section, torque increases rapidly. In this section, higher INC generates slightly higher increasing rate. Considering at varied INC with constant BUR, higher INC requires longer measure depth to achieve. Also, the contact area of higher INC is more than lower INC design. From the investigation, changing INC affected torque of the whole well. Higher INC generates higher torque corresponding to Eq. 3-12.

Unlike torque, effective tension generates higher magnitude of change near bottom hole as seen in Figure 5-2 c). Corresponding to Eq.3-16, cosθ accounts for tension force calculation. Hence, lower section where it has higher deviation angle than surface section has more severe effective tension. 4 different slopes can be identified from effective tension in Figure 5-2 c). Foremost, BHA section, effective tension rises from zero. Compared between varied INC, lower INC generates higher torque at increasing rate. In tangent section, increasing rate is in the same direction as previous section but with lower increasing rate. In build section, these 4 wells have similar torque generated per foot. However, the length of this section is different because higher INC required longer measure depth to achieve with the same BUR. Hence, higher INC yields higher effective tension. Final, a vertical section, effective tension is gently increased with the same rate and the same interval for all cases due to the fact that KOP is fixed at 1000ft TVD.

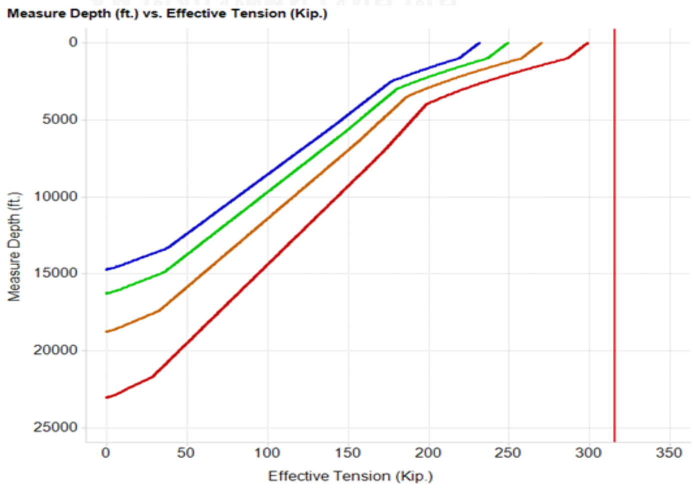
Summary, INC affected all sections. Figure 5-2 shows that the well with 60 deg. INC, 2 deg./100ft BUR having KOP at 1000ft TVD cannot drill as torque exceeds the limit. The rest of the well can be drilled, as both torque and effective tension within the limit. To keep both torque and effective tension are within the limit and maintain the same KOP and BUR parameters, we would decrease INC below 60 deg. in order to drill the design target depth, which is 13,000ft TVD.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-2: 2D build and hold well profile with varied 1st INC parameter, 1000 ft. 1st KOP and 2 deg./100ft. 1st BUR

5.1.3 Build up rate Effect

From section 5.1.1 well that planned with 1000ft TVD KOP at 60 deg. INC and 2 deg./100ft BUR is not drillable. This section, BUR is varied with constrain 1000ft TVD KOP at 60 deg. The well profile is illustrated in Figure 5-3 a). Its torque and effective tension results are displayed in Figure 5-3 b) and c) respectively.

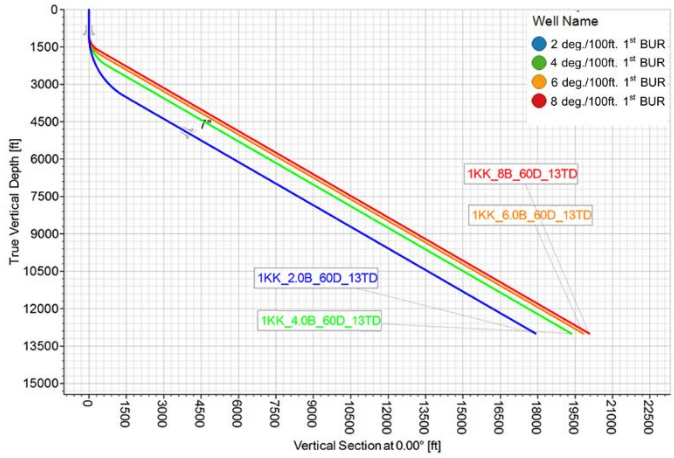
It can be observed from Figure 5-3 a) that 2 deg./100ft BUR generated shorter measure depth and horizontal displacement than other. On the other hand, higher BUR generates longer measure depth and horizontal displacement nonlinearly.

Like section 5.1.2, torque characteristic in Figure 5-3 b) can be classified into 4 sections. BHA section has torque increasing rate higher than tangent section. All 4 cases have the same rate in these 2 sections. Later, build section has different torque increasing rate per varying BUR. Higher build up rate generates higher torque per depth. The magnitude of increasing torque by changing BUR is greater, when BUR is higher. After build section, torque is constant. In addition, it is clearly observed that 2 deg./100ft BUR yields significantly low torque, whereas BUR 4, 6, and 8 deg./100ft generates similar rate. It is because 2 deg/100ft BUR designed has shortest measure depth.

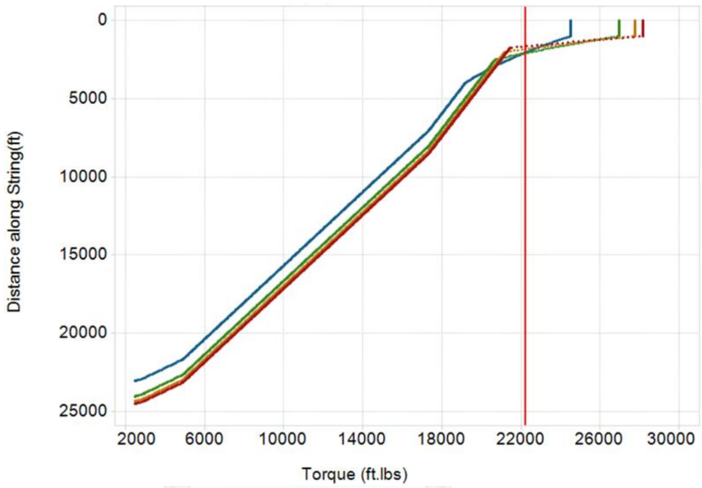
In Figure 5-3 c) characteristic of effective tension can be identified as 4 sections like torque. Effective tension's increasing rates are in the same direction as torque except vertical section. Effective tension is gently increased in vertical section to surface meanwhile torque is constant in this section. Higher BUR generates higher effective tension. 2 deg./100ft BUR yields significantly low effective tension compared to the higher BUR. Varied BUR affected all sections, but in lower magnitude than KOP and INC

From Figure 5-3 it can be summarized that, there are 4 cases, all exceed torque limit, but 3 cases exceed effective tension limit. The well that has KOP at 1000ft TVD and 60 deg. INC with any BUR cannot drill as torque exceeds the limit. In this case, we should consider either increasing KOP or decreasing INC to keep both torque and effective tension within the limit.

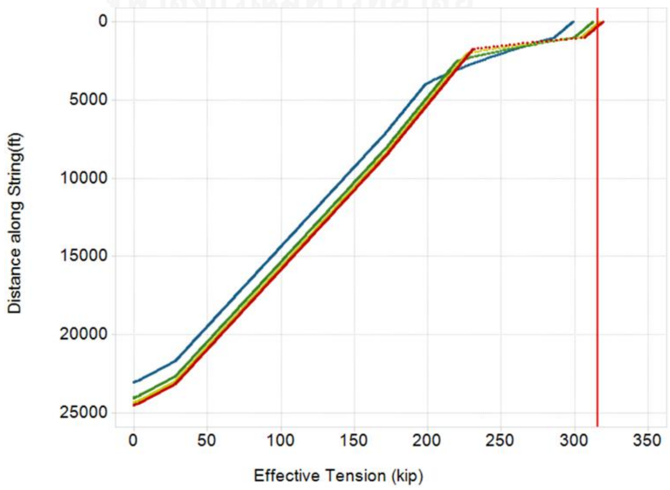
From total 8 cases in Figure 5-1 to 5-3 there are 4 cases that exceed torque limit. Among these wells there are only one case that exceeds effective tension limit.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-3: 2D build and hold well profile with varied 1st BUR parameter, 1000 ft. 1st KOP and 60 Deg. 1st INC

Moreover, the maximum torque and effective tension is plot versus each well plan parameter in Figure 5-4. The red line represents limit.

It is clearly observed that torque limit makes a main criterion to determine drillability of well than effective tension in this well profile type. After investigating 3 well plan parameters, it can conclude that KOP and INC are the most affected parameter to torque and effective tension followed by BUR.

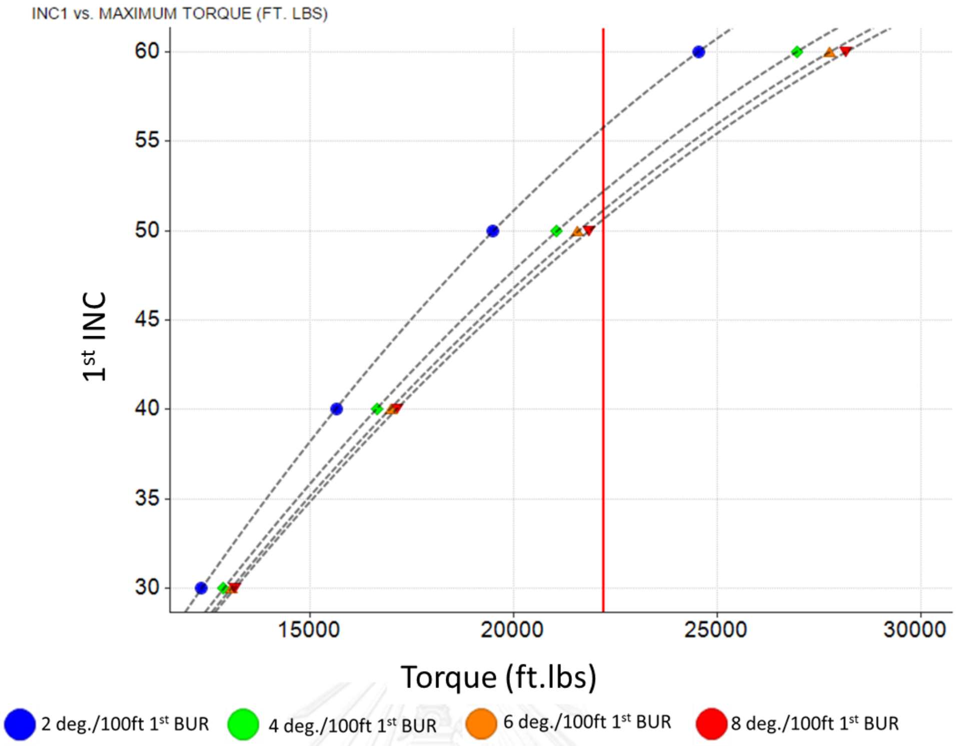
As mention above KOP and INC are the most affected parameter to torque but KOP is constrained by another factor. Therefore, the maximum INC is determined. The maximum torque from each well profiles are used to evaluate a limit of design. Straight line equation is identified from data point in Figure 5-4. Because KOP is designed by formation properties, which is difficult to change, hence the limit of INC is evaluated and summarized in Table 5-1.

Table 5-1: Well planning guideline 2D build and hold. Maximum INC

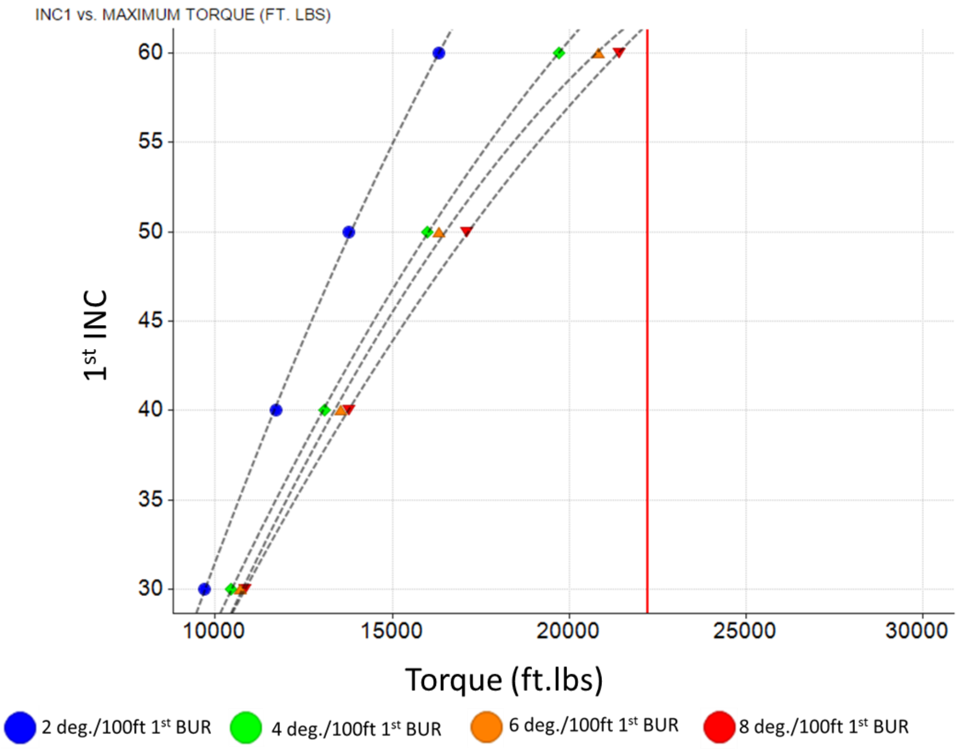
KOP\BUR	2	4	6	8
1000	55	51	49	49
5300	60	60	60	60

The maximum inclination design is provided as a guideline. For example, the maximum INC for 2D Build and Hold design with KOP at 1000ft. and 2 deg/100ft BUR designed is 55 deg.

It also can be evaluated that the maximum measure depth that 2D build and hold well profile can reach which is within torque and drag limit is 21000ft approximately.



a) KOP at 1000ft TVD



b) KOP at 5300ft TVD

Figure 5-4: Maximum torque versus INC plot, color by BUR.

5.2 2D Build, Hold and Drop Well Profile

5 parameters are varied namely; 1st KOP, 2nd KOP, 1st BUR, 2nd BUR (Drop off rate), 1st INC, and 2nd INC. Well plan of varying 5 well plans and its torque and effective tension results along the drillstring are displayed in Figure 5-5 to 5-9 respectively.

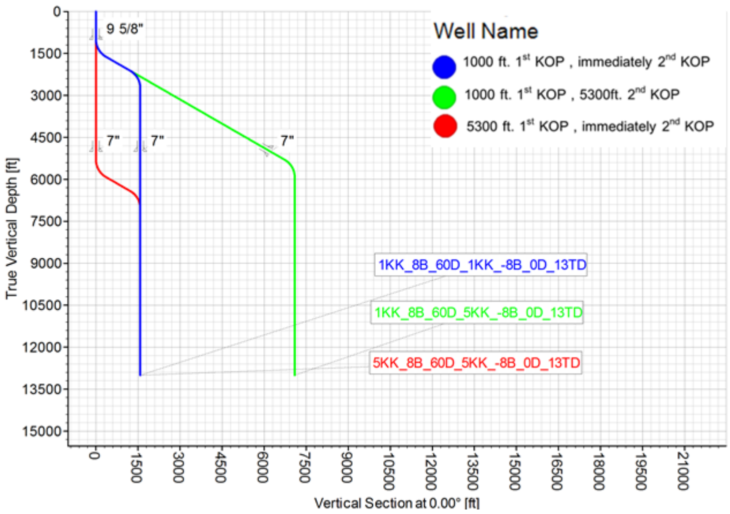
5.2.1 Kick off point Effect

1st KOP and 2nd KOP, which are kick off point and drop of point responsively, are varied to observe their effected over torque and drag. 1st KOP is varied at 1000ft TVD and 5300ft TVD. 2nd KOP is varied at immediate kick off after 1st KOP and 5300ft TVD. Other parameters are constrained as follow; 8 deg./100ft 1st BUR, 60 deg. 1st INC, -8 deg./100ft 2nd BUR, and 0 deg. 2nd INC. A side view of well profile of KOP variation is displayed in Figure 5-5 a). torque and effective tension as a function of varying KOP are displayed in Figure 5-5 b) and c) respectively. The graph color relates to well profile. The vertical red line in torque and effective tension graph represents the limit of torque and effective tension.

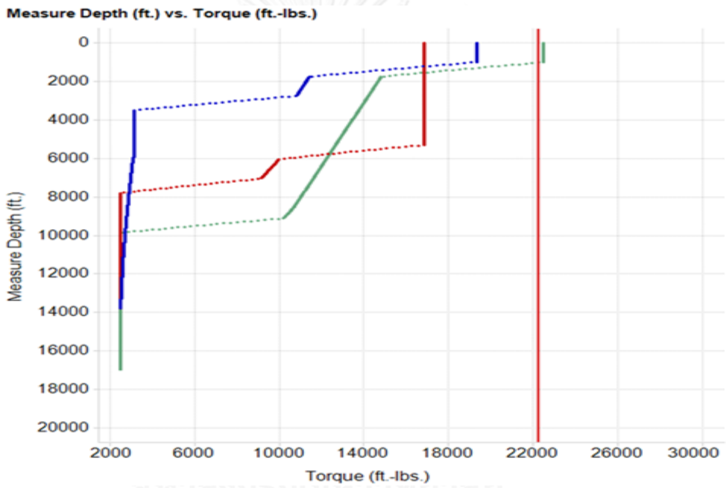
In Figure 5-5 a), the well that kick at difference section; 1st KOP is inside intermediated casing and 2nd KOP is in open hole section; has longest measure depth and large horizontal displacement. The wells that have KOP in the same section provide the same measure depth and horizontal displacement.

From Figure 5-5 b), 1st KOP at 1000ft TVD and 2nd KOP at 5300ft TVD generates highest torque and effective tension. The well that has at 5300ft 1st KOP and immediate 2nd KOP, generates lowest torque. This well profile is unable to drill because of exceeding torque and effective tension.

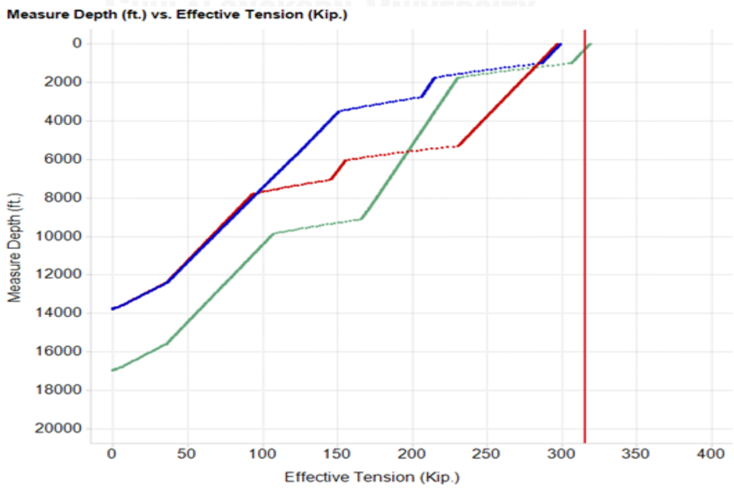
From observing, torque of this well profile type can be identified into 5 sections which are; tangent section, drop section, second tangent section, build section and vertical section to surface. Foremost, tangent section, there are small torque generates per foot. Next, drop section, torque is nearly constant, because this section has 0 deg inclination drop.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-5: 2D build hold and drop well profile with varied 1st KOP, 2nd KOP parameter, 8 deg./100ft. 1st BUR, 60 deg. 1st INC, -8 deg./100ft. 2nd BUR, and 0 deg. 2nd INC

Torque in BHA section is not constant due to effect of 2^{nd} BUR and length of drop section. Shorter drop section generates nearly constant torque than longer interval. Torque raises rapidly in build and drop section with the same slope for all cases, because 1^{st} BUR, 2^{nd} BUR, 1^{st} INC and 2^{nd} INC are constrained. At tangent section, torque is gently increased. In these cases, a slope change at heavyweight components is not observed because it is in vertical section, where axial load applied directly to the bit.

Effective tension is illustrated in Figure 5-5 c). Its characteristic can be identified into 6 sections; BHA section, tangent section, drop section, second tangent section, build section and vertical section. Effected of KOP over BHA section is observed in effective tension. Refer to Eq.3-13, drag force accounts for tripping speed hence moving in axial direction is count.

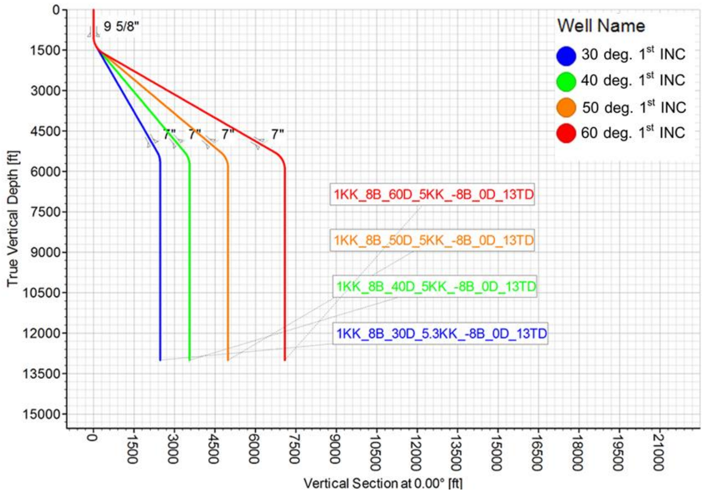
Each section has the same torque generate per foot. However, the length of each section is different because of difference KOP. It can be concluded that KOP affects torque and drag of the whole section.

From Figure 5-5 b) and c), case that exceeded both torque and effective tension limit is 1000ft TVD 1^{st} KOP and 5300ft TVD 2^{nd} KOP. KOP at deeper point still generates lower torque over shallow KOP. Major effect of KOP over torque and effective tension is observed from entire section.

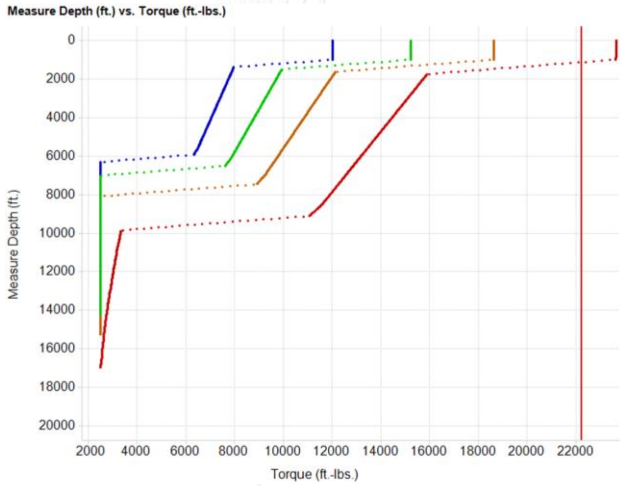
5.2.2 Inclination Effect

From section 5.2.1 case of 1^{st} KOP at 1000ft TVD and 2^{nd} KOP at 5300ft TVD is not drillable. This case is used as a basis to observe affected of INC in this section. 1^{st} INC is varied from 30, 40, 50 and 60 deg. 2^{nd} INC is varied from 0, 15 and half of 1^{st} INC. These 2 parameters are discussed separately.

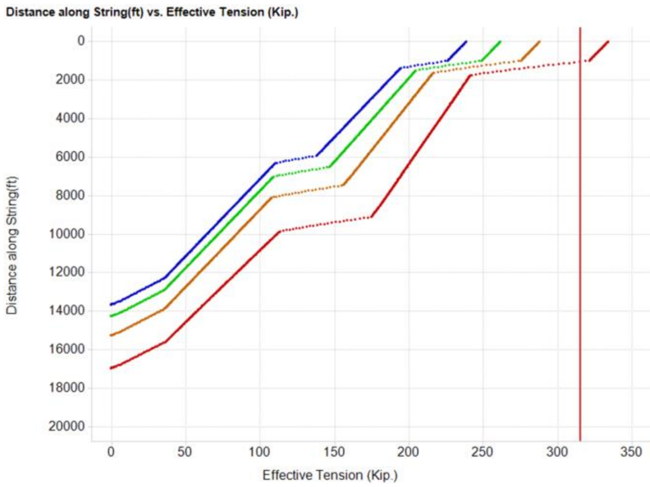
In order to observe 1^{st} INC effect, other parameters are constrained as 1000ft TVD 1^{st} KOP, 5300ft TVD 2^{nd} KOP 8 deg. /100ft 1^{st} BUR, -8 deg./100ft 2^{nd} BUR, and 0 deg. 2^{nd} INC. Well profile and its torque and effective tension results of varied 1^{st} INC and 2^{nd} INC are displayed in Figure 5-6.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-6: 2D build hold and drop well profile with varied 1st INC parameter, 1000ft. 1stKOP, 5300ft. 2nd KOP, 8 deg./100ft. 1st BUR, -8 deg./100ft. 2nd BUR, and 0 deg. 2nd INC.

In Figure 5-6 a) higher 1st INC provided longer measure depth and farer horizontal displacement. torque can be identified to 5 section similar to section 5.1.3. From Figure 5-6 b) at tangent section, lower 1st INC has lower increasing torque rate than the higher one.

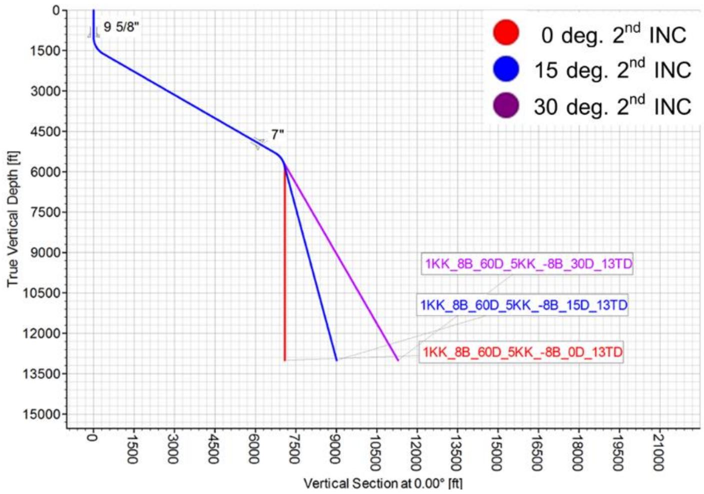
At vertical section, torque is constant. At build secton, torque increases with the same rate for each case due to fix 2nd BUR and 2nd INC. However, high 1st INC has higher magnitude of afftected torque than lower one because of the differnce of 1st INC and 2nd INC. At lower 1st INC, it requires less hole length to reduce angle to 2nd INC. At first build section, torque increases with the same rate for all cases and it is constant in vertical section. From this graph, it crealy sees that 1st INC affects most of the well section toward surface, except vertical section at bottom hole.

Effective tension character is similar to section 5.1.3. In Figure 5-6 c) the magnitude of 1st INC effect is larger toward bottom hole due to more weight load in inclined path toward bottom. From Figure 5-6 60 deg. 1st INC exceeds the limit. This case is applied in the next variation.

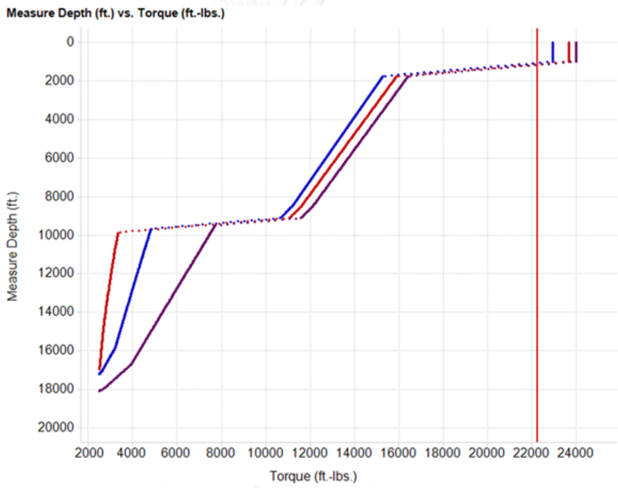
In order to observe 2nd INC effect, other parameters are constrained as 1000ft TVD 1st KOP, 5300ft TVD 2nd KOP, 60 deg 1st INC, 8 deg./100ft 1st BUR and -8 deg./100ft 2nd BUR well profile, its torque and effective tension of varied 1st INC and 2nd INC are displayed in Figure 5-10.

In Figure 5-7 a) applying high 2nd INC applied results in larger horizontal displacement. Also, high 2nd INC requires less measure depth to achieve with the same 2nd BUR.

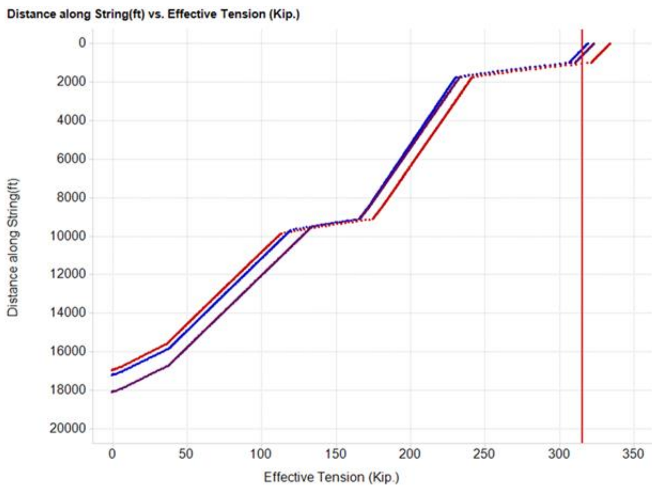
Figure 5-7 b) illustrated torque results which can be identified into 6 sections by its slope; BHA section, tangent section, drop section, second tangent section, build section and vertical section. Effected on BHA section cannot be observed in cases of 0 degree because it is drilled in vertical plane. Like 1st INC, higher INC yields higher torque. In tangent section torque is affected by 2nd INC in the same direction. It is clearly observed that 30 deg. 2nd INC yields significantly high torque.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-7: 2D build hold and drop well profile with varied 2nd INC parameter, 1000ft. 1st KOP, 5300ft. 2nd KOP, 60 deg. 1st INC, 8 deg./100ft. 1st BUR, -8 deg./100ft. 2nd BUR.

Next, drop section, all cases have same slope, but lower 2^{nd} INC generates higher torque because it required longer MD to achieve with the same 2^{nd} BUR. The lowest torque is generated in well with 15 deg. 2^{nd} INC. This phenomenal continues observed toward surface. It can be explained by 2 reasons. Firstly, 15 deg. 2^{nd} INC is medium inclination which not too high, hence torque at BHA section to tangent section is around the middle value. Secondly, the difference from 1^{st} INC is not severe. Hence torque generate at build section toward surface is lower than the other two.

From results, all 3 cases exceed torque limit.

Considering at effective tension result in Figure 5-7 c), 6 sections is identified similar to torque. From BHA section to drop section, all variations have the same slope. Higher 2^{nd} INC generates higher torque because it has longer MD.

In contrast, from drop section to surface, lower 2^{nd} INC yielded higher effective tension. The low drop inclination means more drop direction work from first inclination. It is a consequence of increase contact point to the well bore, and then drag force rises. In Figure 5-10, all cases exceed limit.

In summary, 1^{st} INC dominantly affects overall torque and drag. 2^{nd} INC affects torque and drag in different way. High 2^{nd} INC yields high torque, meanwhile, low 2^{nd} INC yields high effective tension. 2^{nd} INC which is between 0 to half of 1^{st} INC is recommend because it yields low torque and effective tension. 60 deg. 1^{st} INC with varied 2^{nd} INC well designs cannot be drilled.

5.2.3 Build up rate Deviation Effect

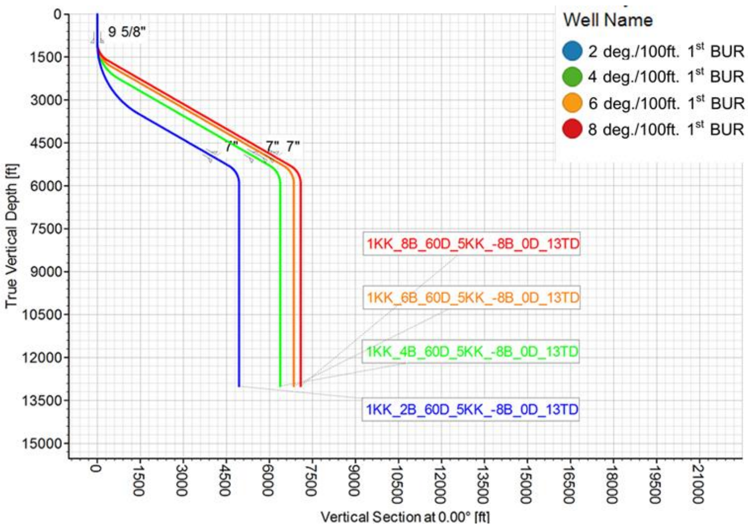
From 5.2.2 all cases that designed with 60 deg 1st INC are not drillable. In this section, 1st BUR and 2nd BUR which are build up rate and drop rate respectively, are varied from 2, 4, 6 and 8 deg./100ft to observe their affect. Results of varied 1st BUR and 2nd BUR are illustrated in Figure 5-8 and 5-9 respectively. Vertical red lines in torque and effective tension graphs represent limit.

For 1st BUR variation of well design, other parameters are constrained as 1000ft 1st KOP, 5300ft 2nd KOP, 60 deg. 1st INC 0 deg. 2nd INC and -8 deg. /100ft 2nd BUR. Well profile of 1st BUR variation is displayed in Figure 5-8 a). 2 deg./100ft BUR generates significantly short measure depth. It is consequence of significantly low torque and drag produced. Larger 1st BUR provides long measure depth and also further horizontal displacement.

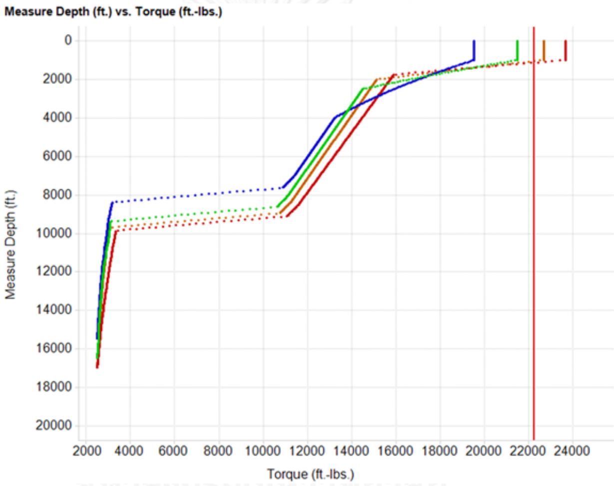
Torque of varied 1st BUR is displayed in Figure 5-8 b). Torque is identified into 5 sections. First is tangent section, torque is generated slowly along the depth. Second, generated torque is dramatically high in drop section. Clearly, 2 deg/100ft 1st BUR shows low torque over the other. Third, second tangent section, all cases have the same slope. 2 deg/100ft 1st BUR case has shortest intervals. Hence it generates lower amount of torque in this section. Forth, in build section, dominantly effect of 1st BUR on torque is observed. Low 1st BUR has flatter slope than higher 1st BUR. Finally, torque in vertical section is constant. 2 deg/100ft 1st BUR yields significantly low torque. It is a benefit of longer build section and shorter tangent section generated.

Effective tension in Figure 5-8 c) shows similar character as described in 2D build and hole profile. There are 6 sections identified. Each section of each case has the same slope. 2 deg./100ft 1st BUR generates outstanding low effective tension as well as torque, because it has short MD.

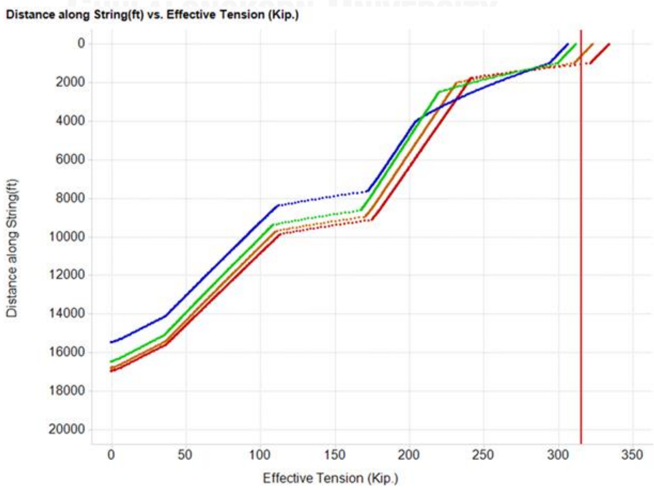
From Figure 5-8) there are 2 cases exceeding both torque and effective tension limits, which are 6 and 8 deg/100ft 1st BUR.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-8: 2D build hold and drop well profile with varied 1st BUR parameter, 1000ft. 1st KOP, 5300ft. 2nd KOP, 60 deg. 1st INC 0 deg. 2nd INC and -8 deg./100ft. 2nd BUR.

2^{nd} BUR is varied from -2, -4, -6 and -8 deg./100ft with 1000ft 1^{st} KOP, 5300ft 2^{nd} KOP, 60 deg. 1^{st} INC 0 deg. 2^{nd} INC and 4 deg./100ft 1^{st} BUR.

4 deg./100ft 1^{st} BUR case is selected to observe in this section because this well nearly exceeds torque and exceed effective tension. Results are illustrated in Figure 5-9 a), b) and c), which are well profile, torque and effective tension.

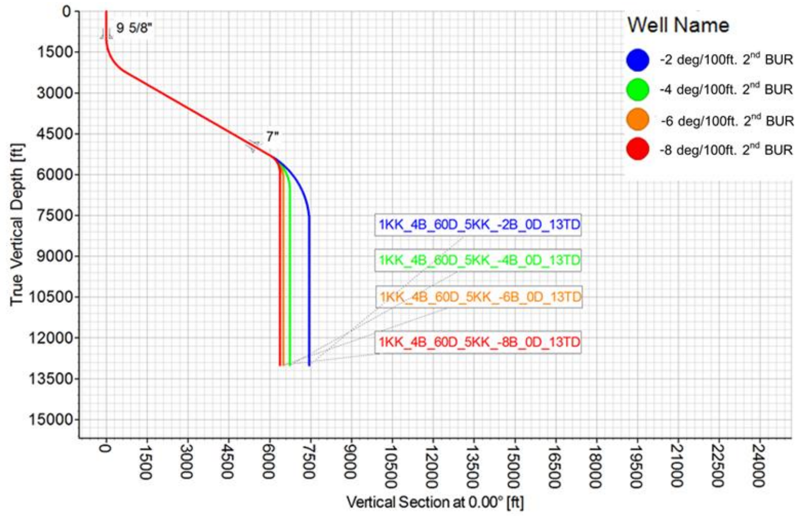
Unlike 1^{st} BUR, lower 2^{nd} BUR generates longer measure depth and further horizontal displacement.

Considering at this Figure 5-9 b) effect of varied 2^{nd} BUR on torque is very small. There are 5 sections identified; tangent section, drop section, second tangent section, build section and vertical section. Tangent section is nearly constant. Drop section shows the most affected from varied 2^{nd} BUR. High 2^{nd} BUR yields higher torque along the depth. 2 deg./100ft 2^{nd} BUR generates significantly low torque.

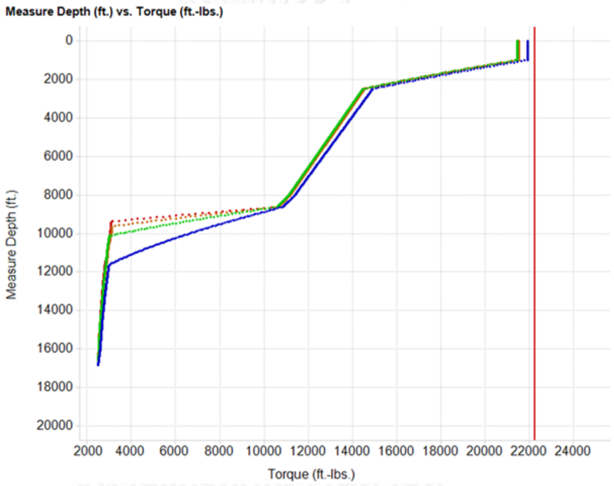
Effective tension result is in the same direction as torque. Varying 2^{nd} BUR shows small effect and the most affected section is drop section as Figure 5-9 c). Higher 2^{nd} BUR generates higher effective tension. However, 2^{nd} BUR generates shorter drop interval. Finally, the effective tension results did not show much difference.

From Figure 5-9 b) and 5-9 c), -2 deg/100ft 2^{nd} BUR case exceeds effective tension limit.

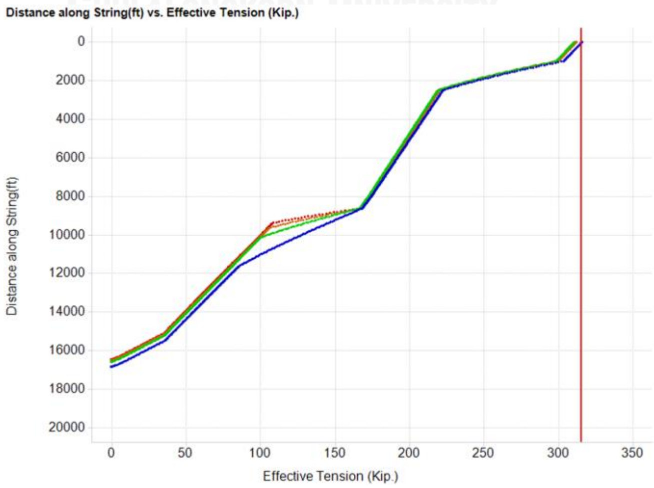
In summary, varied 1^{st} BUR 1 affected torque and drag of all section. 2^{nd} BUR affects all sections as well, but it dominantly affects drop section. 2 deg./100ft BUR generates significantly low torque. It can be applied for both 1^{st} BUR and 2^{nd} BUR. Low 2^{nd} BUR is recommended when target is at extended reach.



a) Well profiles



b) Torque



c) Effective Tension

Figure 5-9: 2D build hold and drop well profile with varied 2nd BUR parameter, 1000ft. 1st KOP, 5300ft. 2nd KOP, 60 deg. 1st INC 0 deg. 2nd INC and 2 deg./100ft. 1st BUR.

From 16 cases in Figure 5-8 to 5-9, there are 4 wells that exceed torque limit and 5 wells exceed effective tension limit. It could be concluded that effective tension makes a main criterion to determine drillability of this well type. The maximum effective tension from each well profile is used to evaluate a limit of design like previous case study. The limit of design is displayed in Table 5-2.

Although 2 deg./100ft 1st BUR design generates lowest torque, but it suffers to achieve high 1st INC within intermediated casing. "*" in Table 5-2 means that the case cannot be design with inclination lower than 30 deg.

For example, if a well is planned to kick off at 1000ft and 5300ft 2nd KOP with 60 deg. 1st INC, 0 deg. 2nd INC. It could be planned with 2nd BUR from 4-8 deg./100ft when 1st BUR is less than 4 deg./100ft.

It also can be evaluated that the maximum measure depth that 2D build hold and drop well profile can reach which is within torque and drag limit is 18000ft approximately.

Table 5-2: Well Planning Guideline 2D Build Hold and Drop

			2nd INC			
			0			
		2nd BUR	-2	-4	-6	-8
1st KOP	2nd KOP	1st BUR				
1000	immediately	2	30*	60	60	60
1000	immediately	4	60	60	60	60
1000	immediately	6	60	60	60	60
1000	immediately	8	60	60	60	60
1000	5300	2	60	60	60	60
1000	5300	4	59	60	60	60
1000	5300	6	57	59	60	60
1000	5300	8	56	57	56	56
5300	immediately	2	60	60	60	60
5300	immediately	4	60	60	60	60
5300	immediately	6	60	60	60	60
5300	immediately	8	60	60	60	60

5.3 3D Build and Hold Well Profile

There are 5 varying parameters for 3D build and hold well profile namely; kick off point (1^{st} KOP), build up rate (1^{st} BUR), inclination angle (1^{st} INC), turn rate (1^{st} TUR) and Turn degree. Well plans and its torque and effective tension along the drillstring are displayed in Figure 5-10 to 5-14 respectively. The graph color relates to well profile. The vertical red line in graph represents the limit.

In a well planning step several cases that planned with 1^{st} TUR 2 deg./100ft and 1000ft 1^{st} KOP, cannot design due to the fact that it cannot achieve desired turn degree before casing seat.

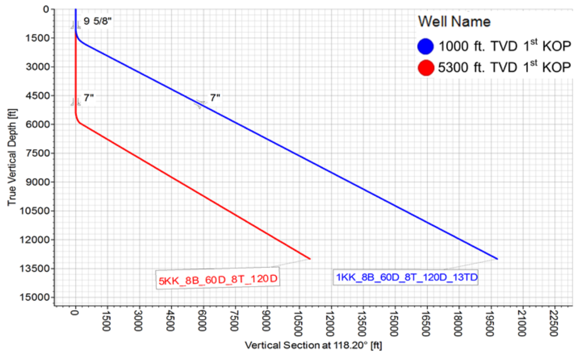
5.3.1 Kick off point Effect

1^{st} KOP and 2^{nd} KOP are varied from 1000ft TVD and 5300ft TVD to observe its effected over torque and drag. Other parameters are constrained as 8 deg./100ft 1^{st} BUR, 60 deg. 1^{st} INC, 8 deg./100ft TUR, and 120 deg. Turn degree. Well plans and its torque and effective tension are illustrated in Figure 5-10.

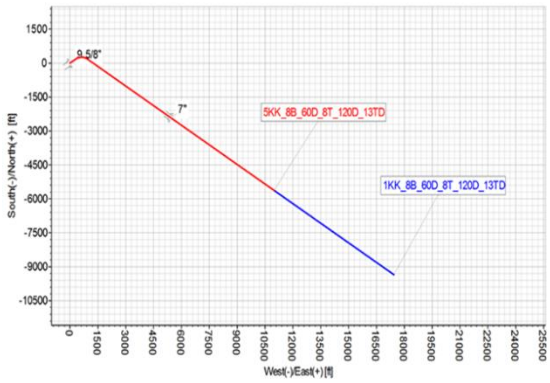
Figure 5-10 a) shows that shallower KOP allows to reach further horizontal distance than deep KOP.

Torques are plotted versus measure depth in Figure 5-10 b). Result can be identified into 4 sections by its slopes following; BHA section, tangent section, build section and vertical section. Torque is most generated in build section compared to other sections. Kick off at shallow depth provided longer tangent section. It is consequence of high torque generated.

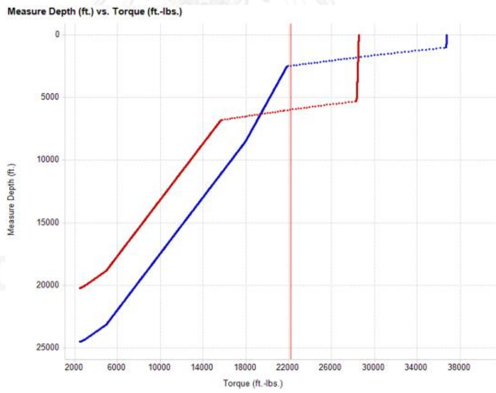
Effective tension result shows similar direction to torque result.



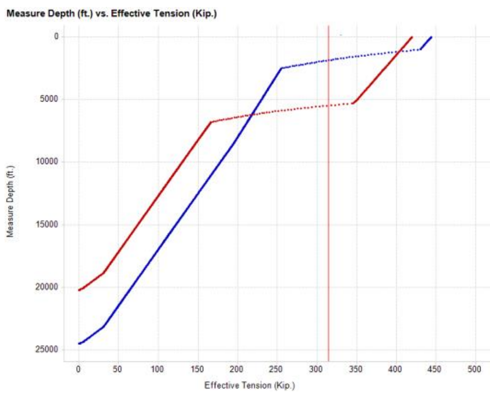
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-10: 3D build and hold well profile with varied 1st KOP parameter, 8 deg./100ft 1st BUR, 60 Deg. 1st INC

5.3.2 Inclination Effect

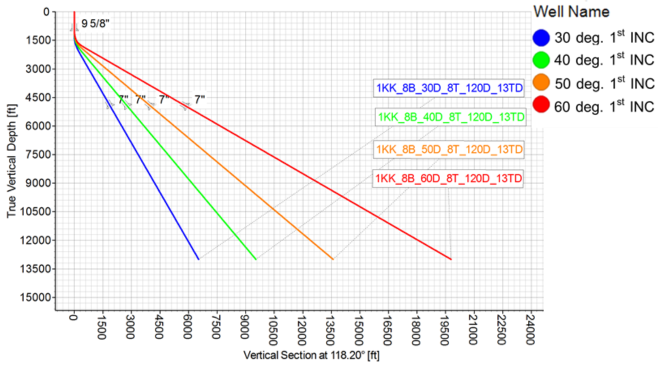
1st INC is varied from 30, 40, 50 and 60 deg. Other parameters are constrained as follow; 1st KOP at 1000ft TVD, 8 deg./100ft 1st BUR, 8 deg./100ft 1st TUR, and 120 deg. Turn degree. Results are displayed in Figure 5-11.

In Figure 5-11 c) torque can be identified into 4 sections following; BHA section, tangent section, build and turn section and vertical section to surface. It is clearly observed that varied 1st INC affected most on tangent, and build and turn section.

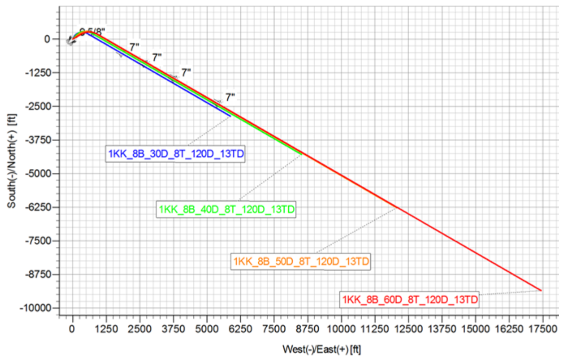
In tangent section, High INC generates high torque with higher magnitude because higher INC provides longer measure depth. Slightly changing slope is observed in this section. It has a consequence of cased hole frictional factor. Next, build and turn section, there is no different slope with difference 1st INC. However, the increment is different. Higher INC generates larger increment of torque increasing rate, corresponding to larger curve path generated.

Effective tension results in Fig 5-11 d) can be identified into 4 sections by its slope; BHA, tangent section, build and turn section and vertical to surface section.1st INC parameter affected most on tangent section and build and turn section.

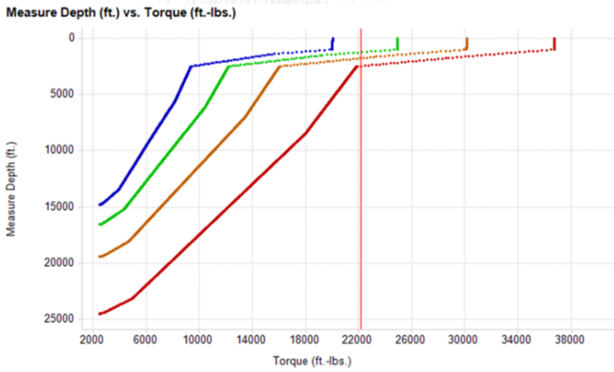
From section 5.3.1 well that has 1st KOP at 1000ft TVD and 60 1st INC is not drillable. In this section, it can be concluded that the well that has 1st KOP at 1000ft TVD is drillable when applied 30 deg. 1st INC.



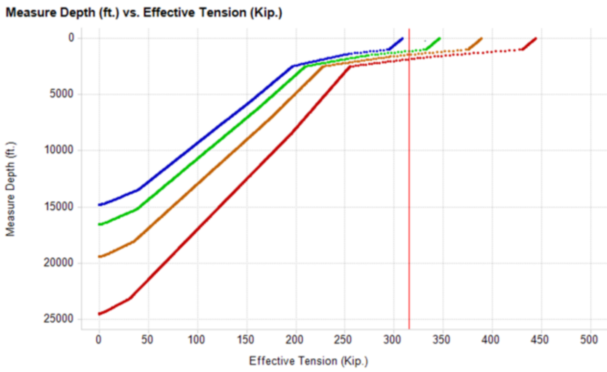
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-11: 3D build and hold well profile with varied 1st INC parameter with 1st KOP at 1000ft TVD, 8 deg./100ft 1st BUR, 8 deg./100ft 1st TUR and Turn degree 120 deg.

5.3.3 Build up rate Effect

From section 5.3.2 case 1000ft TVD 1^{st} KOP with 40 deg. 1^{st} INC design is slightly exceeded torque and drag limit. Therefore, this case is used to evaluate BUR affected.

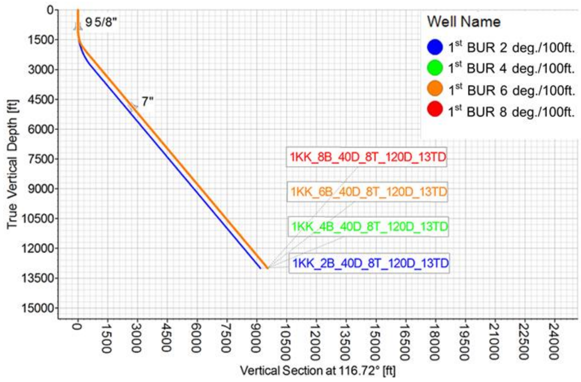
1^{st} BUR was varied from 2, 4, 6 and 8 deg./100ft while other parameters are constrained as follow; 1^{st} KOP at 1000ft TVD, 40 deg. 1^{st} INC, 8 deg./100ft 1^{st} TUR, and 120 deg. Turn degree as illustrated in Fig 5-12. Well profiles of varied 1^{st} BUR in Figure 5-12 a) and b) show that it provided same MD.

From Figure 5-12 c) torque can be identified into 4 slopes; BHA section, tangent section, build and turn section and vertical section. All wells have similar torques at BHA and tangent sections.

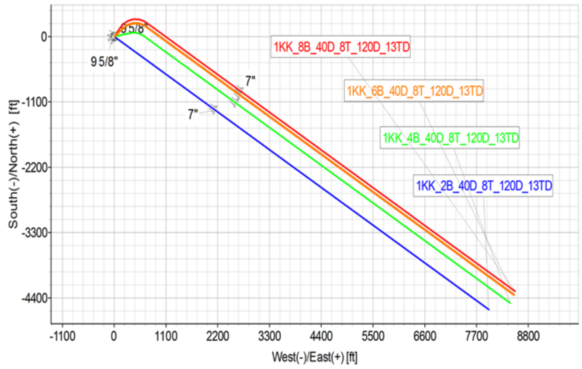
Next, in build and turn section 2 deg./100ft 1^{st} BUR generates significantly lower torque than the other. 4, 6 and 8 deg./100ft 1^{st} BUR has similar torque generate per foot in build and turn section, but difference interval. Higher BUR generated higher torque.

This phenomenon can be explained by the differential between TUR and BUR. If the well design with TUR that lower than BUR, it will reach desired INC before Turn Degree. Then, it is drilling with only TUR to achieve desired Turn degree. Following Eq. 3-1 TUR has less dominated in DLS. Hence, the well design with TUR lower than BUR will generate lower torque than the reverse. Considering at Figure 5-12 b) well profile of 4, 6 and 8 deg./100ft 1^{st} BUR have similar curve length. 8 deg./100ft 1^{st} BUR provided larger curve in build and turn section following by 6 and 4 deg./100ft 1^{st} BUR. Unlike, 2 deg./100ft 1^{st} BUR has no curve path from top view. Hence, it has longer interval to generate torque with the same slope as 4 and 6 deg./100ft .1^{st} BUR in tangent section and build and hold section.

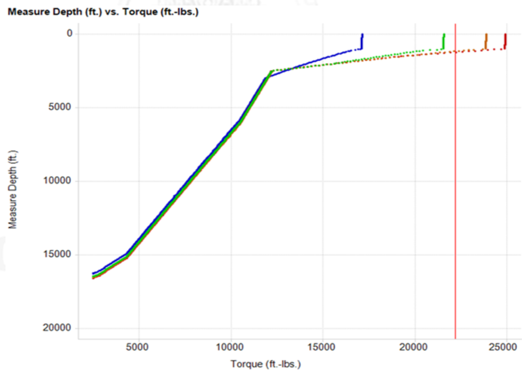
Effective tension result that illustrated in Figure 5-12 d) can be identified into 4 sections; BHA section, tangent section, build and turn section and vertical section. It shows the similar effect as torque. It can be summarized that BUR affects torque and drag most in build and turn section.



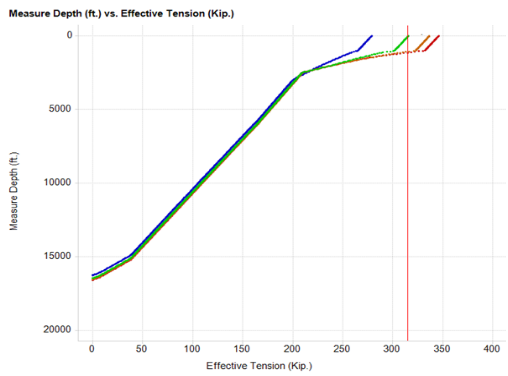
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-12: 3D build and hold well profile with varied 1st BUR parameter with 1st KOP at 1000ft TVD, 1st INC 40 deg., 1st TUR 8 deg./100ft and Turn degree 120 deg.

5.3.4 Turn Rate Effect

1^{st} TUR is varied from 2, 4, 6 and 8 deg./100ft while other parameters are constrained as follow; 1^{st} KOP at 1000ft TVD, 30 deg. 1^{st} INC, 8 deg./100ft 1^{st} BUR, and 120 deg. Turn degree. Well plan and torque and effective tension are showed in Figure 5-13.

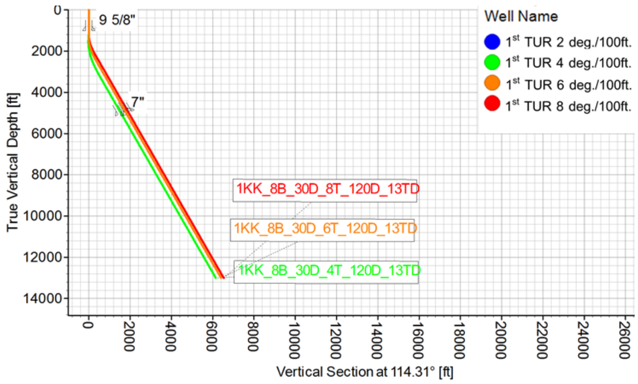
In planning process 2 deg./100ft 1^{st} TUR cannot be designed, because curve path exceeded intermediate casing depth. Available results are displayed in Figure 5-13.

As observed from Figure 5-13 a) and b), low TUR provides slightly shorter horizontal distance and larger curve path than higher TUR. However, all cases generate the same MD.

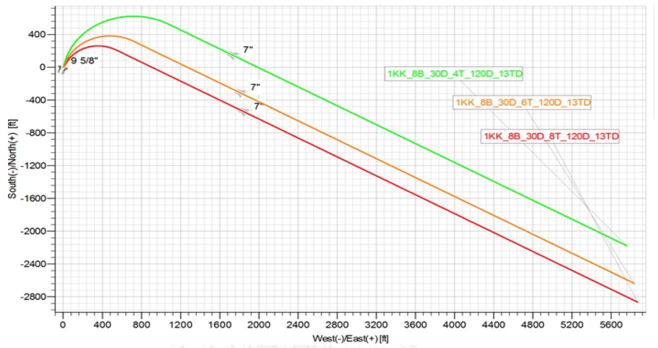
Torque from varied 1^{st} TUR is illustrated in Figure 5-13 c). The graph can be separated into 5 sections as BHA section, tangent section, turn section, build and turn section and vertical section. There is no affected observe in BHA section and tangent section.

In turn section the well that design with 8 deg./100ft 1^{st} TUR has higher torque increasing along the drillstring than 4 and 6 deg./100ft 1^{st} TUR. It is difficult to observe the difference of slope between turn section and build and turn section of 8 deg/100ft 1^{st} TUR case. Meanwhile, it is clearly seen that the difference slopes of 2 section in 4 and 6 deg./100ft 1^{st} TUR cases. 6 deg./100ft 1^{st} TUR generates slightly higher torque than 4 deg./100ft 1^{st} TUR. Although, higher 1^{st} TUR yields higher torque at turn section, it yields lower torque at early of build and turn section. Finally, lower 1^{st} TUR generates lower torque than the higher one. Effective tension has the same character as torque.

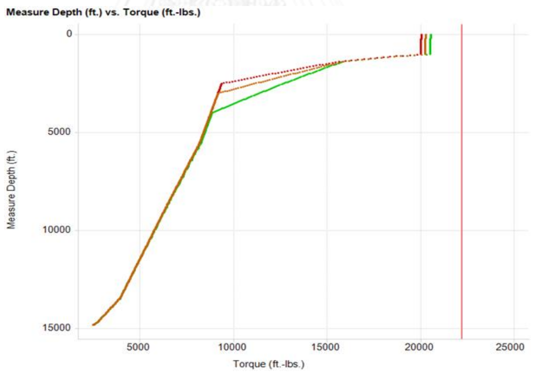
In summary, higher 1^{st} TUR generated lower torque and effective tension. From section 5.3.3, the well with 8 deg/100ft 1^{st} BUR design is not drillable. In this section found that 8 deg/100ft BUR case is drillable with 6 and 8 deg/100ft TUR designs.



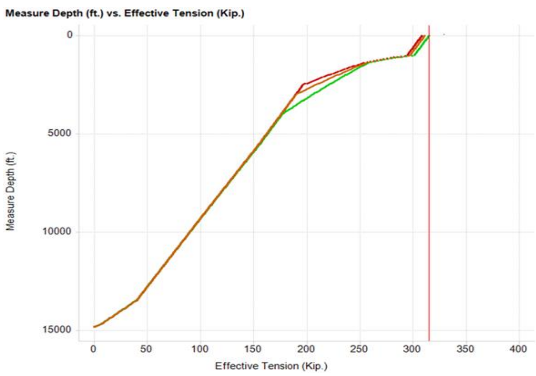
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-13: 3D build and hold well profile with varied 1st TUR parameter with 1st KOP at 1000ft TVD, 1st INC 30 deg., 1st BUR 8 deg./100ft and Turn degree 120 deg.

5.3.5 Turn Degree Effect

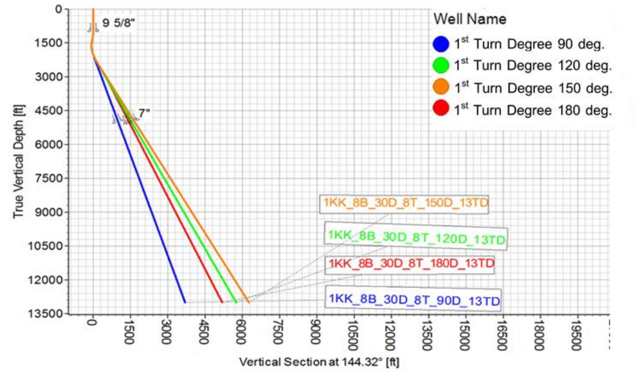
From previous section, the well that designed with 1000ft TVD 1st KOP, 30 deg. 1st INC, 8 deg./100ft 1st BUR, 8 deg./100ft 1st TUR and 120 deg. Turn degree is not drillable. In this section turn degrees are varied from 90, 120, 150 and 180 deg. with 1000ft. 1st KOP, 30 deg. 1st INC, 8 deg./100ft 1st BUR and 8 deg./100ft TUR. To observe its effected torque and effective tension. The results are displayed in Figure 5-14. Turn degree variation provided difference horizontal displacement and azimuth direction as displayed in Fig 5-14 a) and b). Larger Turn degree can reach farer, but not always.

Torque in Figure 5-14 c) can be identified into 4 sections by slope; BHA section, tangent section, build and turn section and vertical section. From BHA section to tangent section, there is no affected from Turn degree changed observed. In turn section, torque is rapidly increased. Due to fix 1st TUR, a slope is the same. However, interval of turn section affects by turn degree. Higher turn degree consequence of larger turn section and it allow generating more torque. It can imply that higher Turn degree generates high torque. After, torque increases more severe than previous section due to it has higher DLS. The interval and slope of each case is similar. Final, vertical section dilled generated constant torque. It can be concluded that Turn degree affected torque in build and turn section the most.

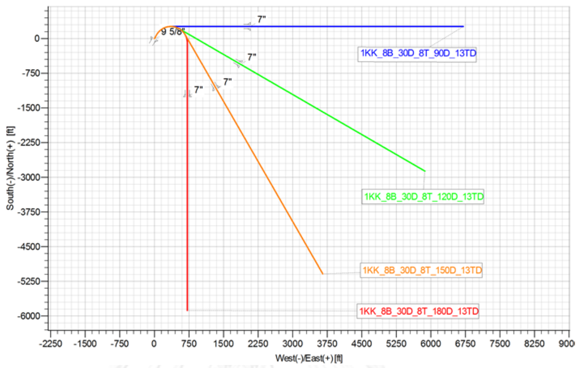
Effective tension results are depicted in Figure 5-14 d). It can be separated into 5 sections as; BHA section, tangent section, turn section, build and turn section and vertical section. There is similar result in BHA and tangent section.

In build and turn section, all cases have the same slope but difference interval. High turn degree generates longer interval respectively. Therefore, higher turn degree generates higher effective tension in this section.

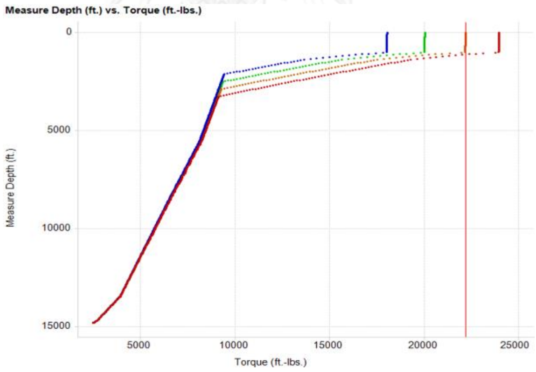
There are 2 cases exceeding both torque and drag limits which are 150 and 180 degrees turn.



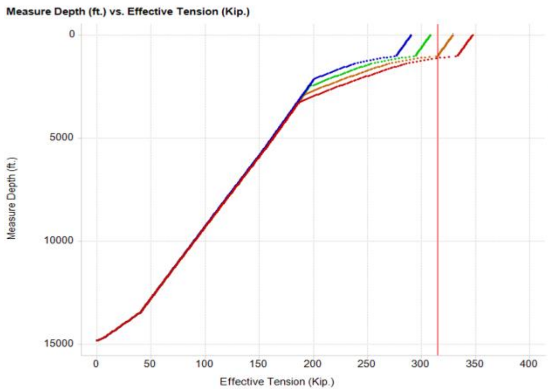
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-14: 3D build and hold well profile with varied Turn degree with 1st KOP at 1000ft TVD, 1st INC 30 deg., 1st BUR 8 deg./100ft and 1st TUR 8 deg./100ft.

To sum up, KOP and INC affect torque and effective tension of whole section along the well path. Turn degree affect most in tangent section. Meanwhile, BUR, TUR affect build and turn section only. The magnitude of change is slightly different. Within build and turn section, the increment of torque and effective tension are affected most by TUR then BUR respectively.

Unlike 2D build and hold profile, effective tension limit makes a main criterion to determined drillability than torque in this well type as displayed in Figure 5-10 to 5-14. As per 16 cases in Figure 5-10 to 5-14, there are 7 cases that exceed torque limit, whereas, there are 9 cases that exceed effective tension limit. Therefore, the maximum effective tension from each well is plotted as a function of 5 well plan parameters to evaluate well planning guideline in Table 5-3 to 5-6 at different turn degree.

Some of design with 1st KOP 1000ft TUR 2 deg./100ft represent in the Table by “x” which means the well cannot be planned with INC lower than 30 deg due to casing regulation.

The symbol “-“ represents the well that cannot be drilled due to exceeding torque and effective tension limits.

Table 5-3: Well Planning Guideline 3D Build and Hold, 90 Turn Degree

		Turn Degree 90			
1st BUR	1st KOP/1st TUR	2	4	6	8
2	1000	43	49	53	53
4	1000	36	38	43	49
6	1000	36	36	38	41
8	1000	35	34	35	37
2	5300	56	58	60	59
4	5300	43	45	53	58
6	5300	41	40	42	47
8	5300	39	38	39	41

Table 5-4: Well Planning Guideline 3D Build and Hold, 120 Turn Degree

		Turn Degree 120			
1st BUR	1st KOP/1st TUR	2	4	6	8
2	1000	x-	46	55	53
4	1000	x-	33	35	40
6	1000	x-	31	32	33
8	1000	x-	30	31	32
2	5300	49	60	60	60
4	5300	39	38	41	52
6	5300	38	35	35	37
8	5300	36	33	33	34

Table 5-5: Well Planning Guideline 3D Build and Hold, 150 Turn Degree

		Turn Degree 150			
1st BUR	1st KOP/1st TUR	2	4	6	8
2	1000	x	37	54	54
4	1000	x	-	-	-
6	1000	x	-	-	-
8	1000	x	-	-	-
2	5300	46	50	60	60
4	5300	37	33	34	39
6	5300	36	31	30	31
8	5300	35	30	x	30

Table 5-6: Well Planning Guideline 3D Build and Hold, 180 Turn Degree

		Turn Degree 180			
1st BUR	1st KOP/1st TUR	2	4	6	8
2	1000	x	x	38	-
4	1000	x	-	-	-
6	1000	x	-	-	-
8	1000	x	-	-	-
2	5300	44	41	60	60
4	5300	38	30	-	31
6	5300	36	-	-	-
8	5300	36	-	-	-

For example, the well is planned to kick off at 1000ft TVD with 2 deg./100ft 1st BUR, 4 deg./100ft 1st TUR and 90 deg. Turn degree. From Table 5-3, the maximum 1st INC that can be designed is 49 deg.

Refer to Table 5-4 If the well is planned to kick off at 5300ft with 6 deg/100ft 1st BUR, 4 deg./100ft 1st TUR, and Turn degree 120 deg., the maximum INC that can be designed is 31 deg.

Refer to Table 5-5 if the well is planned to kick off at 5300ft TVD with 60 deg. INC and 150 deg Turn, 1st BUR should be 2 deg/100ft with TUR from 6-8 deg/100ft.

Refer to Table 5-6 if a desired target requires 60 deg. 1st INC and 180degree turn, a well could be planned using KOP at 5300ft, 2 deg./100ft 1st BUR and 6-8 deg./100ft 1st TUR.

From the results, small TUR cannot satisfy large turn degree especially when kick off at shallow depth. Hence, high TUR is recommended.

It also can be evaluated that the maximum measure depth that 3D build and hold well profile can reach which is within torque and drag limit is 18700ft approximately.

5.4 3D Build, Hold and Drop Well Profile

There are 7 varying parameters for 3D build hold and drop well profile namely; 1^{st} KOP, 2^{nd} KOP, 1^{st} BUR, 2^{nd} BUR, 1^{st} INC, 2^{nd} INC, 1^{st} TUR and turn degree. Well plan of varying 3 parameters and its torque and effective tension along the drillstring are displayed in Figure 5-15 to 5-21 respectively.

5.4.1 Kick off point Effect

1^{st} and 2^{nd} KOP are varied as 1000ft and 5300ft respectively, with 2 deg./100ft 1^{st} BUR, 60 deg. 1^{st} INC, -8 deg./100ft 2^{nd} BUR, 0 Deg 2^{nd} INC, 2 deg./100ft 1^{st} TUR and 90 deg Turn degree. Results are displayed in Figure 5-15.

According to Figure 5-15 a) and b) shallower 1^{st} KOP can reach further horizontal displacement. 1^{st} KOP at 1000ft. and 2^{nd} KOP at 5300ft yield longest MD and the longest horizontal displacement follow by 1^{st} KOP at 1000ft with immediate 2^{nd} KOP, and 1^{st} KOP at 5300ft with immediate 2^{nd} KOP respectively.

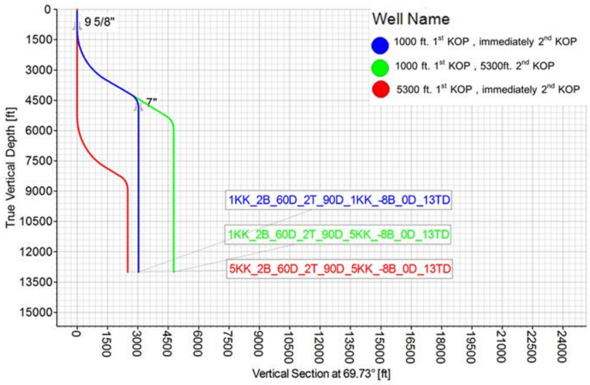
The effected of varied KOP on torque is displayed in Figure 5-15 c). The results can be separated into 5 sections as; tangent section, drop section, second tangent section, build and turn section and vertical section. It clearly sees that varied KOP affected overall section. Starting at tangent section, torque increases slowly along the distance. It increases rapidly in drop and turn section. Slope is nearly horizontal, means this section generated highest torque per foot.

Next is second tangent section. Correspond to the well path, only a case that kicks off at difference section, shows this section (green line). Small amount of torque was generated in this section. In build and turn section, because build and turn is not end at the same depth, results in not constant of torque per foot generated. Finally, vertical section, torque is constant.

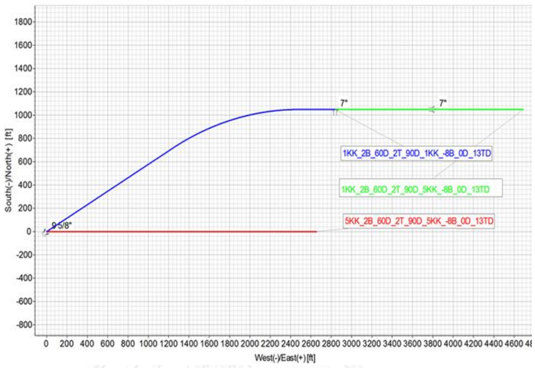
Effective tension is displayed in Figure 5-15 d). Its slope can be separated into 6 sections namely; BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Foremost, BHA section generates small effective tension along the depth. Secondly, tangent section, all cases generate effective tension with the same rate per depth, but difference in intervals. 1^{st} KOP at 1000ft TVD yields longer tangent interval, hence it generates higher effective tension than deep 1^{st} KOP. In drop section, effective tension has faster rate per foot corresponding to high dogleg area and effected area relates to well path.

Like torque, second tangent section can be observed only in the case that does not kick off 2^{nd} KOP immediately (green line). It yields small amount of effective tension. Next, build and turn section, effective tension rate change is no constant. Lastly, vertical section, effective tension is constant.

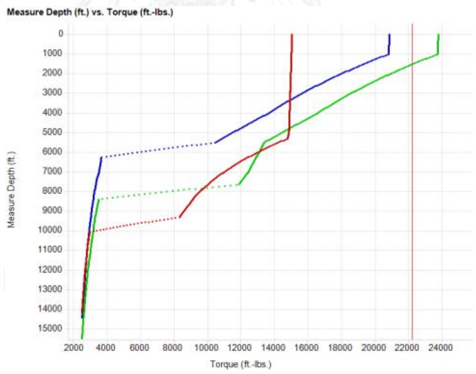
There are two cases that are within torque limit and only 1 case that is within effective tension limit. The worst case is kicking off at different sections. This case is continued applied in the next varied parameter. It can be concluded that 1^{st} KOP dominantly affects torque from surface to bottom hole. Also, it affects effective tension of entire well length, but with smaller magnitude. 2^{nd} KOP affects both torque and effective tension, especially at the second tangent section. The magnitude of effect depends on the tangent length. Longer tangent section generates more torque and effective tension.



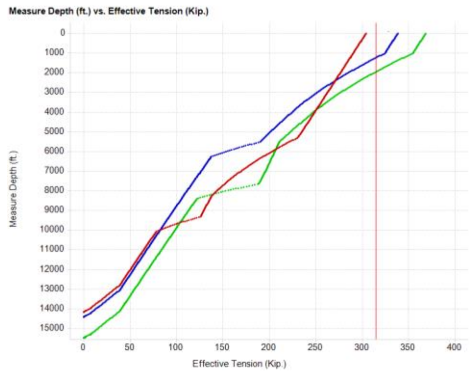
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-15: 3D build and hold well profile with varied 1st and 2nd KOP parameters, 2 deg./100ft 1st BUR, 60 Deg. INC, -8 deg./100ft. 2nd BUR, 0 Deg 2nd INC, 2 deg./100ft. TUR and 90 deg Turn degree.

5.4.2 Inclination Effect

1st and 2nd INC are varied as 30, 40, 50 and 60 deg. with 1000ft TVD 1st KOP, 5300ft TVD 2nd KOP, 2 deg./100ft 1st BUR, -8 deg./100ft 2nd BUR, 0 Deg 2nd INC, 2 deg./100ft 1st TUR and 90 deg Turn degree. Results are displayed in Figure 5-16 and 5-17.

Effect of 1st INC is discussed first. Higher 1st INC generates longer curved path and further horizontal displacement with the same MD and TVD as seen in Figure 5-16 a) and b). 50 and 60 deg. 1st INC generates the same azimuth deviation.

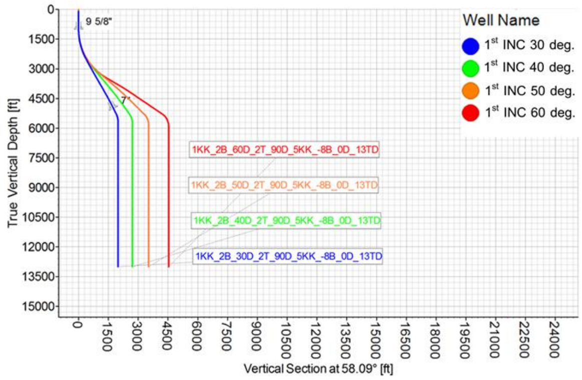
Torque can be separated into 5 sections by its slope (Figure 15-6 c)). They are tangent section, drop section, second tangent section build and turn section and vertical section. Firstly, torque gradually increases in tangent section. Different slope can be observed at nearly the end of this section.

Next, drop section is dominantly affected by varied 1st INC. All cases have the same slope. The length of drop section makes it severed. Higher 1st INC required longer interval to drop to 0 deg. 2nd INC. It has consequence of higher torque generated. After, second tangent section, all cases have the same rate of torque generating per, but the interval is different. Higher 1st INC has longer interval.

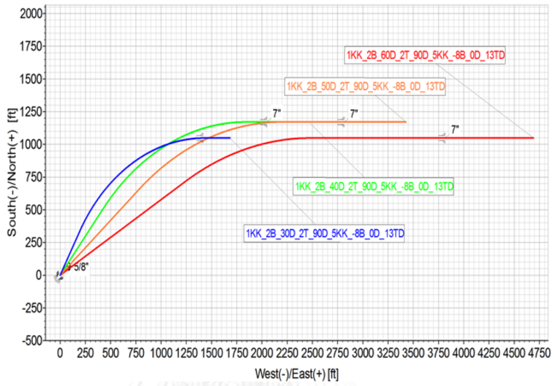
In build and turn section, all cases have the same slope, a torque increases slowly in this section. In vertical section, torque is constant. To sum up, higher 1st INC generates higher torque.

Effective tension has 5 sections; BHA section, tangent section, drop section, build and turn section and vertical section. There is no effect of 1st INC observed in BHA section and tangent section. Drop section has flat slope, which means that effective tension generates higher torque per foot. Like torque, length of drop section affects severity. Higher 1st INC provides longer interval and yields higher effective tension. Build and turn section shows slightly affected effective tension from varied 1st INC. Higher 1st INC has flatter slope, meaning it yields higher magnitude of effective tension changes. In vertical section, effective tension is constant.

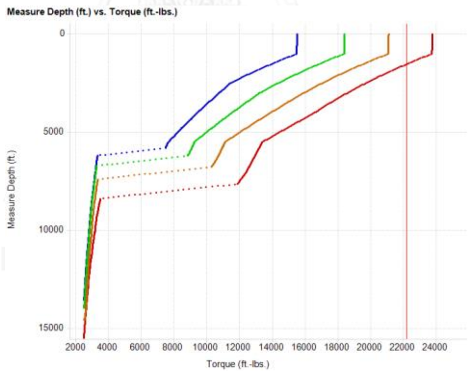
From 4 cases, there is one case exceeds torque limit which is case 60 deg 1st INC and 2 cases exceed effective tension limit which are 50 and 60 deg 1st INC.



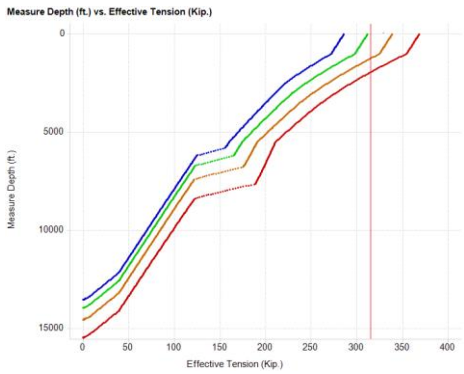
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-16: 3D build and hold well profile with varied 1st INC parameters, 1000ft TVD 1st KOP, 5300ft TVD 2nd KOP, 2 deg./100ft 1st BUR, -8 deg./100ft. 2nd BUR, 0 Deg 2nd INC, 4 deg./100ft. TUR and 90 deg Turn degree.

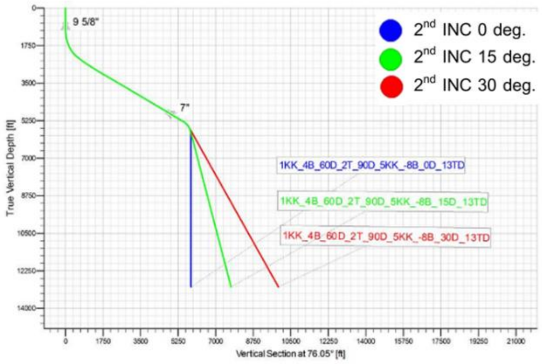
Effect of varied 2nd INC is observed and interpreted next. It's well profiles and both s is illustrated in Figure 5-17. From Figure 5-17 a) and b) it can be observed that higher 2nd INC provides further horizontal displacement.

Torque is illustrated in Figure 5-17 c). It can be divided into 6 sections by its slopes. First is BHA section, followed by tangent section, drop section, second tangent section, build and turn section and vertical section. Varied 2nd INC affects torque most in drop section and tangent section.

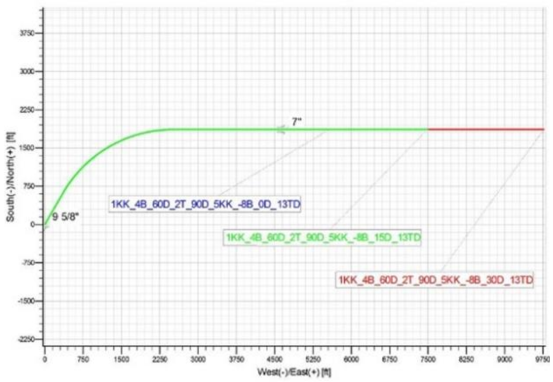
Starting from BHA section, case that has 0 deg. 2nd INC is similar to tangent section. Because the well path is vertical, hence it has constant torque generated like tangent section. In tangent section, torque generates at difference rates. Higher 2nd INC yields higher torque per foot. Also, higher 2nd INC provides longer measure depth, it is more severe torque generated comparing to other cases.

Next, drop section shows most affected torque from varied 2nd INC. All cases have the same slope because 2nd BUR is fixed. The interval of each case is difference. Lower 2nd INC has longer drop interval. It is referred to attempt to drop the angle. It can be d that more difference between 1st and 2nd INC, more torque per foot generates.

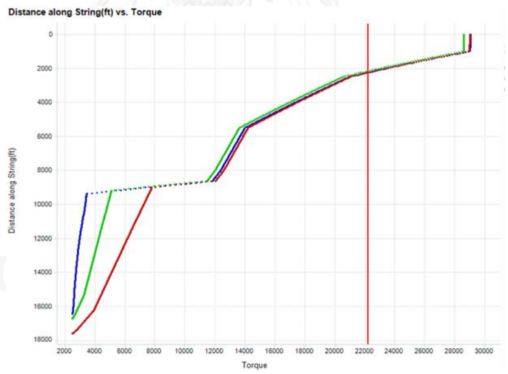
From results all cases exceed both torque and effective tension limit. It may be concluded that Higher 2nd INC generates higher torque but lower effective tension.



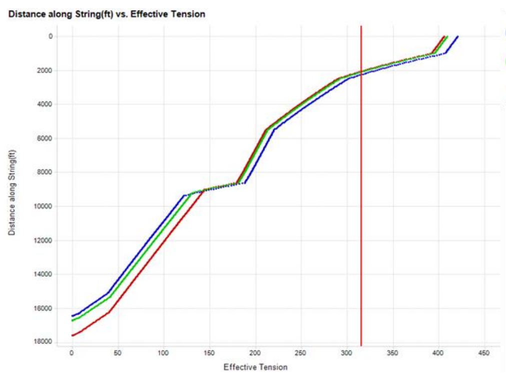
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-17: 3D build and hold well profile with varied 2^{nd} INC parameters, 1000ft TVD 1^{st} KOP, 5300ft TVD 2^{nd} KOP, 60 deg 1^{st} INC, 2 deg./100ft 1^{st} BUR, -8 deg./100ft. 2^{nd} BUR, 4 deg./100ft. TUR and 90 deg Turn degree.

5.4.3 Build up rate Effect

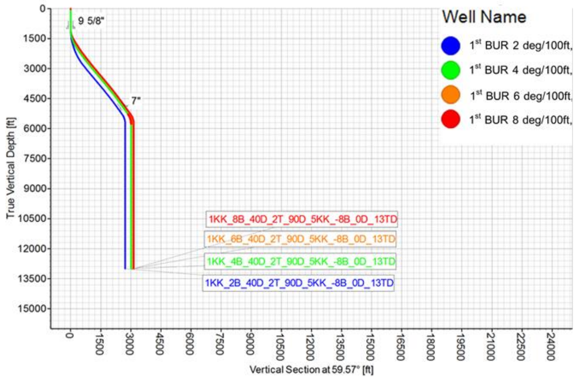
1st and 2nd BUR are varied as 2, 4, 6 and 8 deg./100ft with 1000ft TVD 1st KOP, 5300ft TVD 2nd KOP, 40 deg. 1st INC, 0 deg. 2nd INC, 2 deg./100ft 1st TUR and 90 deg Turn degree. Results are displayed in Figure 5-18 and 5-19 respectively.

Well path from varied 1st BUR is illustrated in Figure 5-18 a) and b). Higher 1st BUR provides high curvature path and long horizontal displacement with similar MD to lower 1st BUR.

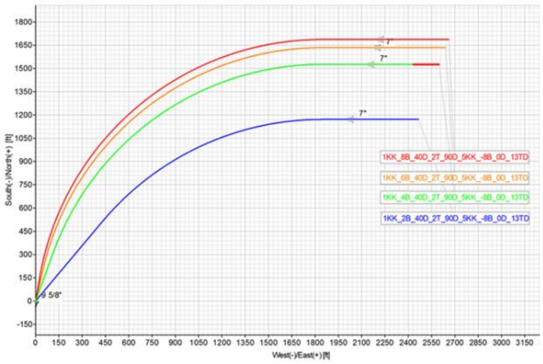
In Figure 5-18 a) torque results can be divided into 5 sections; tangent section, drop section, second tangent section, build and turn section and vertical section. The effect of varied 1st BUR is mostly seen at build and turn section. From Figure 5-18 c) torque increases dramatically at early of build and hold section. However, this characteristic is not seen in 2 deg./100ft 1st BUR case (blue line). This case yields significantly low torque than the others.

In Figure 5-18 d) effective tension results can be divided into 6 sections; BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Effect of varied 1st BUR is observed in build and turn section. Similar to torque result, 2 deg./100ft 1st BUR yields significantly low torque than other.

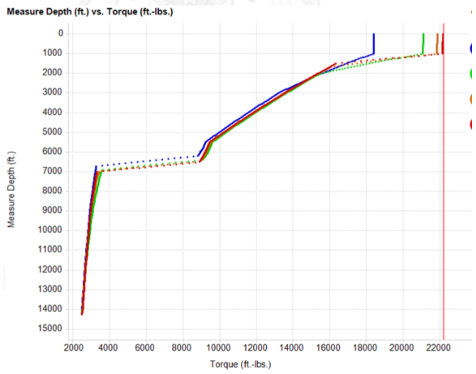
From 4 cases, there are 3 cases stay within torque limit and 1 case stays within effective tension limit. Worst case scenario is at 8 deg./100ft BUR.



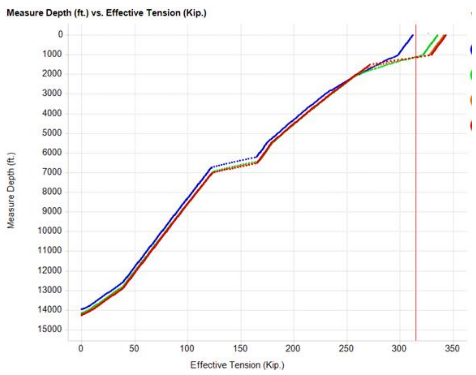
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-18: 3D build and hold well profile with varied 1st BUR parameter, 1st KOP at 1000ft. TVD, 2nd KOP at 5300ft. TVD, 40 Deg. 1st INC, 0 Deg 2nd INC, -8 deg./100ft. 2nd BUR, 2 deg./100ft. TUR and 90 deg Turn degree.

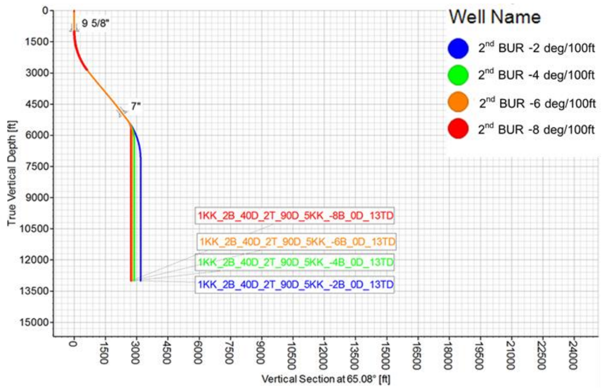
2^{nd} BUR is varied with 2 deg./100ft 1^{st} BUR in order to observe its effect. Well path of different 2^{nd} BUR is displayed in Figure 5-19 a) and b). Unlike 1^{st} BUR result, higher 2^{nd} BUR provides shorter curve and shorter horizontal displacement. It is because high 2^{nd} BUR can achieve desired drop inclination faster than low 2^{nd} INC.

Torque can be divided into 5 sections as followed; tangent section, drop section, second tangent section, build and turn section and vertical section. Varied 2^{nd} BUR affects torque dominantly at drop section. Higher 2^{nd} BUR case generated higher torque per foot as slope is flatter. Other section, torque is generated with similar rate. It can be concluded that varying 1^{st} BUR affects a generated torque generate per foot from drop section to surface. Meanwhile, 2^{nd} BUR affects torque only at drop section.

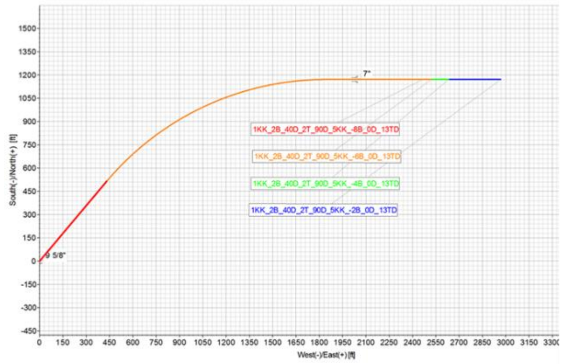
In Figure 5-19 d) effective tension results can be separated into 6 sections; BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Similar to torque, effect of varied 2^{nd} BUR is showed only at drop section.

All cases stay within the limit. Also, there is not much differences in torque and effective tension. It can be concluded that varied 2^{nd} BUR has small effect to torque and drag.

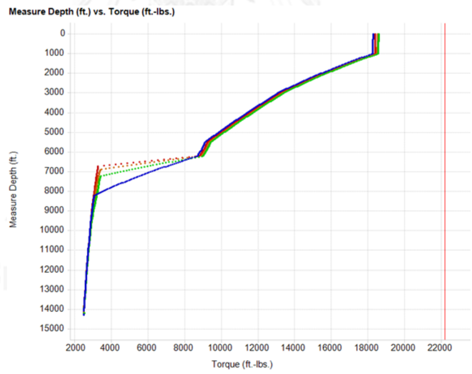
In summary, 1^{st} BUR majorly affects torque and drag from drop section to surface. 2^{nd} BUR slightly affects torque and drag at only drop section.



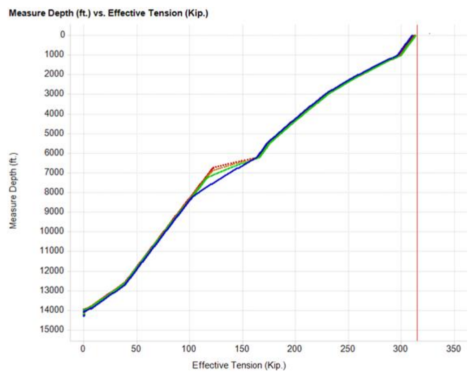
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-19: 3D build and hold well profile with varied 2nd BUR parameter, 1st KOP at 1000ft. TVD, 2nd KOP at 5300ft. TVD, 40 Deg. 1st INC, 0 Deg 2nd INC, 2 deg./100ft. 1st BUR, -2 deg./100ft. 1st TUR and 90 deg Turn degree.

5.4.4 –Turn Rate Effect

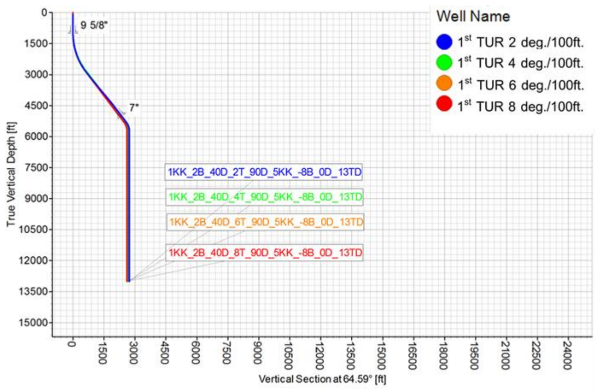
2 deg./100ft 1st BUR and -8 deg./100ft 2nd BUR almost exceeded the limit. This case is continued applied to determine effect of TUR. 1st TUR is varied from 2, 4, 6 and 8 deg./100ft.

Well plan results are displayed in Figure 5-20 a) and b). Varied TUR provides similar horizontal displacement, measure depth, but different direction.

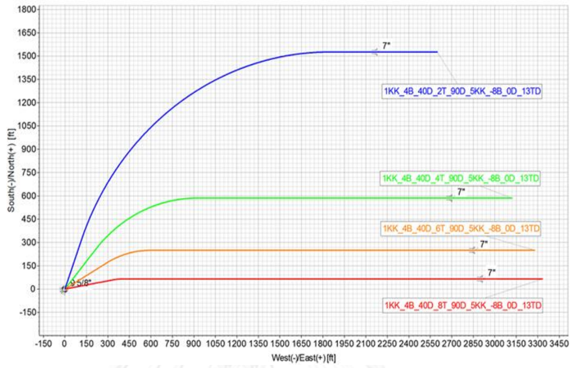
Torque is illustrated in Figure 5-20 c). It can be separated into 5 section as tangent section, drop section, second tangent section, build and turn section and vertical section. Effect of varying TUR is clearly seen from the second tangent section toward vertical section. From the second tangent section, torque generates the same rate for all cases, but at different intervals. Relates to well design lower 1st TUR has longer depth to achieve desired turn degree. Then it has shorter second tangent section, but longer builds and turn section than higher 1st TUR. Also, in build and turn section, there is no constant slope for this case. This characteristic means well path can be achieved with planned inclination before turn degree. It can be concluded that lower 1st TUR generates higher torque.

From Figure 5-20 d) effective tension can be separated into 6 sections as BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Similar to torque, effect of varying TUR is showed from the second tangent section to vertical section. Lower 1st TUR generates higher effective tension due to the fact that it provides large curvature well path and short second tangent section.

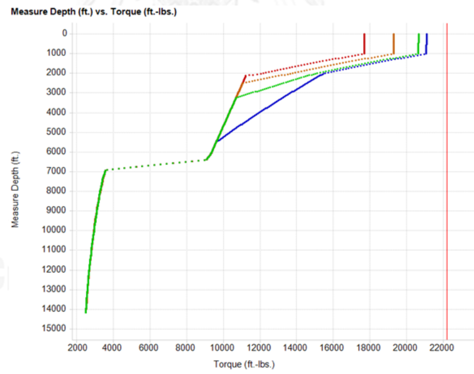
All cases are within torque limit and two cases are within effective tension limit which is 6 and 8 deg./100ft TUR.



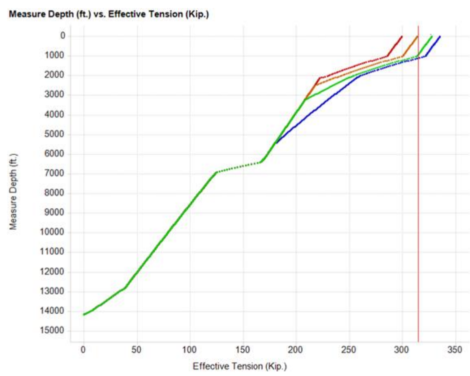
a) Well profiles (Side)



b) Well profiles (Top)



c) Torque



d) Effective Tension

Figure 5-20: 3D build and hold well profile with varied 1st TUR parameter, 1st KOP at 1000ft. TVD, 2nd KOP at 5300ft. TVD, 40 Deg. 1st INC, 0 Deg 2nd INC, 2 deg./100ft. 1stBUR, -8 deg./100ft. 2nd BUR, and 90 deg Turn degree.

5.4.5 Turn Degree Effect

From section 5.4.4, only case of 1^{st} KOP at 1000ft TVD, 2^{nd} KOP at 5300ft TVD, 40 Deg. 1^{st} INC, 0 Deg 2^{nd} INC, 4 deg./100ft 1^{st} BUR, -8 deg./100ft 2^{nd} BUR, 8 deg/100ft 1^{st} TUR and 90 deg Turn degree is slightly exceeded the limit. Therefore, this case is continued to observe in this section.

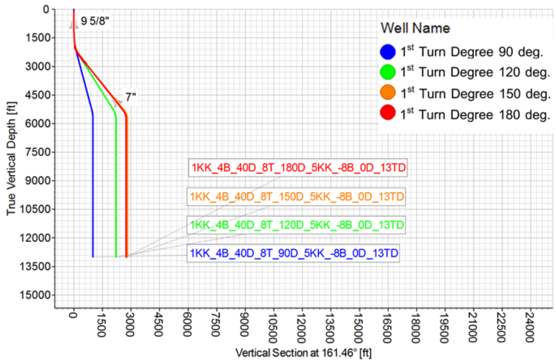
Turn degrees are varied from 90, 120, 150 and 180 deg. while preserving other parameters. Well plans and its torques, effective tensions are displayed in Figure 5-21.

Higher Turn degree provides further horizontal displacement with the same MD with other as seen in Figure 5-21 a) and b).

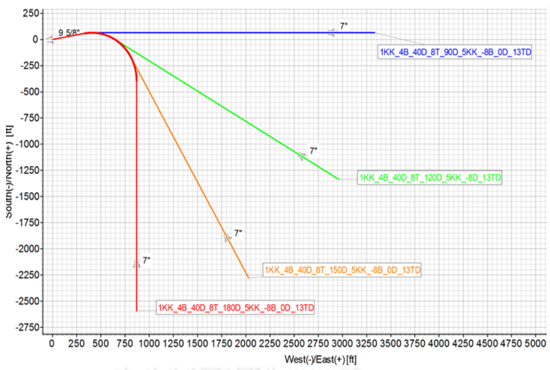
Torque is illustrated in Figure 5-21 c). It can be identified into 5 sections as tangent section, drop section, second tangent section, build and turn section and vertical section. Effect of varied Turn degree is observed in build and turn section. All cases have the same slope, but different in intervals. Related to well path, lower Turn degree has less drill depth to achieve fixed TUR. Hence, lower Turn degree yields lower torque.

In Figure 5-21 d) effective tension has 6 sections; BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Similar to torque, effective tension result is affected from varied Turn degree at build and turn section. Lower Turn degree yields lower effective tension.

There are 2 cases that stay within torque limit and only one case is within effective tension limit. Therefore, the drillable case is 1^{st} KOP at 1000ft TVD, 2^{nd} KOP at 5300ft TVD, 40 Deg. 1^{st} INC, 0 Deg 2^{nd} INC, 4 deg./100ft 1^{st} BUR, -8 deg./100ft 2^{nd} BUR, 8 deg/100ft 1^{st} TUR and 90 deg Turn degree.

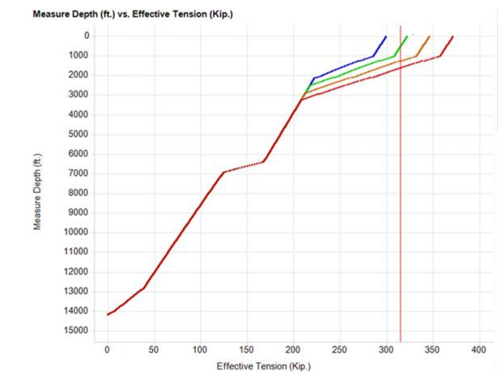


a) Well profiles (Side)



b) Well profiles (Top)

c) Torque



d) Effective Tension

Figure 5-21: 3D build and hold well profile with varied Turn degree parameter, 1st KOP at 1000ft. TVD, 2nd KOP at 5300ft. TVD, 40 Deg. 1st INC, 0 Deg 2nd INC, 4 deg./100ft. 1st BUR, -8 deg./100ft. 2nd BUR, and 8 deg/100ft 1st TUR

In summary, varied well plan parameters affect 3D build hold and drop well profile in the same direction with 3D build and hold well profile. High torque and drag is generated at build and turn section and drop section, where they have high dogleg. KOP and 1^{st} INC parameters dominantly affect torque and drag for entire section. 2^{nd} INC affects torque and drag only at drop section. The combination of 1^{st} and 2^{nd} INC is important. Corresponding to Figure 5-17 c) and d), the best case is the case the has 60 deg./100ft 1^{st} INC and 15 deg./100ft 2^{nd} INC, which are in the middle of varied value.

In addition, effective tension is observed as a criterion for this well profile type. According to 21 cases that illustrated in this section, there are 6 cases exceed torque limit and 13 cases exceed effective tension limit. The maximum effective tension of each well is used for analysis and evaluation of planning guideline as shown in Table 5-7 to 5-10.

For example, the well is planned to kick off at 1000ft TVD with immediate 2^{nd} KOP, 4 deg/100ft 1^{st} BUR, -8 deg/100ft 2^{nd} BUR, 0 deg 2^{nd} INC and 6 deg/100ft TUR and 90 degree Turn. From Table 5-7, the maximum 1^{st} INC is 42 deg.

Refer to Table 5-8, If the well is planned with 5300ft 1^{st} KOP, immediate 2^{nd} KOP, 0 deg 2^{nd} INC, 1^{st} and 2^{nd} BUR 4 deg/100ft, TUR 8 deg/100ft and 120 deg Turn. The maximum 1^{st} INC is 51 deg.

Refer to Table 5-9 if the well is planned to kick off at 1000ft TVD with immediate 2^{nd} KOP, 0 deg. 2^{nd} INC, 2 deg/100ft 1^{st} BUR, -4 deg/100ft. 2^{nd} BUR, 6 deg TUR and 150 deg Turn. The maximum 1^{st} INC is 50 deg.

Refer to Table 5-10, if the well is planned to kick off at 5300ft 1^{st} KOP, immediate 2^{nd} KOP, 0 deg 2^{nd} INC, 1^{st} and 2^{nd} BUR 4 deg/100ft, 4 deg/100ft TUR and 180 deg Turn. The maximum 1^{st} INC is 30 deg.

It also can be evaluated that the maximum measure depth that 3D build hold and drop well profile can reach which is within torque and drag limit is 14900ft approximately.

Table 5-7: Well Planning Guideline 3D Build Hold and Drop, 90 Turn Degree

		2nd INC	0 deg															
		Turn Degree	Turn Deg 90															
		TUR	2				4				6				8			
1st KOP	2nd KOP	1stBUR/2ndBUR	2	4	6	8	2	4	6	8	2	4	6	8	2	4	6	8
1000	immediately	2	x	x	x	-	57	50	60	60	x	x	60*	60	57	60	60	60
1000	immediately	4	x	x	x	-	42	42	42	43	40	53	53	53	56	57	56	57
1000	immediately	6	x	x	x	-	37	38	38	37	41	40	40	41	46	46	45	45
1000	immediately	8	x	x	x	-	36	36	36	36	37	37	37	37	40	40	40	40
1000	5300	2	42	41	41	41	52	51	48	51	53	52	52	52	53	52	52	52
1000	5300	4	37	36	35	35	38	37	36	36	43	43	42	42	47	47	47	47
1000	5300	6	35	35	34	34	34	35	34	34	36	37	36	35	39	39	39	38
1000	5300	8	34	34	34	34	33	33	33	33	34	34	34	34	36	35	35	35
5300	immediately	2	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
5300	immediately	4	42	42	43	43	48	43	48	48	53	54	53	53	58	57	57	57
5300	immediately	6	40	39	39	39	43	38	38	42	46	40	40	39	46	46	45	45
5300	immediately	8	39	39	38	38	41	36	36	40	42	37	37	36	39	39	39	39

Table 5-8: Well Planning Guideline 3D Build Hold and Drop, 120 Turn Degree

		2nd INC	0 deg															
		Turn Degree	Turn Degree 120 deg															
		TUR	2				4				6				8			
1st KOP	2nd KOP	1stBUR/2ndBUR	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8
1000	immediately	2	x	x	x	-x	x	-x	60	60	x	60	60	54	30	50	61	60
1000	immediately	4	x	x	x	-x	x	-x	33	37	x	38	39	39	48	49	53	51
1000	immediately	6	x	x	-x	-x	x	-x	33	34	x	33	33	33	36	35	43	35
1000	immediately	8	x	x	-x	-x	x	-x	32	31	x	32	31	31	33	33	39	33
1000	5300	2	-	-	-	-	45	44	44	44	51	50	50	50	52	51	51	51
1000	5300	4	-	-	-	-	33	32	31	31	33	33	32	32	39	38	37	37
1000	5300	6	-	-	-	-	31	31	-	-	30	30	30	-	31	31	31	30
1000	5300	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
5300	immediately	2	47	47	47	48	60	60	60	60	60	60	60	60	60	60	60	60
5300	immediately	4	39	39	38	38	36	36	35	35	41	40	41	41	52	51	51	51
5300	immediately	6	37	37	37	37	33	32	33	33	35	34	34	34	36	35	35	35
5300	immediately	8	37	36	36	36	32	31	31	31	33	33	33	33	32	32	32	32

Table 5-9: Well Planning Guideline 3D Build Hold and Drop, 150 Turn Degree

		2nd INC	0 deg															
		Turn Degree	Turn Degree 180 deg															
		TUR	2				4				6				8			
1st KOP	2nd KOP	1st BUR/2nd BUR	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8
1000	immediately	2	x	x	x	x	x	x	x	x	x	x	x	50	x	-	-	-
1000	immediately	4	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-
1000	immediately	6	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-
1000	immediately	8	x	x	x	x	x	x	x	x	x	x	x	x	x	-	-	-
1000	5300	2	x	x	x	x	-	-	-	-	35	34	35	38	49	48	48	47
1000	5300	4	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
1000	5300	6	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
1000	5300	8	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
5300	immediately	2	x	x	x	x	38	38	37	37	60	60	60	60	60	60	60	60
5300	immediately	4	x	x	x	x	30	30	30	30	-	-	-	-	-	-	-	-
5300	immediately	6	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
5300	immediately	8	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-

Table 5-10: Well Planning Guideline 3D Build Hold and Drop, 180 Turn Degree

		2nd INC	0 deg															
		Turn Degree	Turn Degree 150 deg															
		TUR	2				4				6				8			
1st KOP	2nd KOP	1st BUR/2nd BUR	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8	-2	-4	-6	-8
1000	immediately	2	x	x	x	x	x	-x	-	-	x	50	60	60	x	50	60	60
1000	immediately	4	x	x	x	x	x	-x	-	-	x	31	31	32	30*	35	35	35
1000	immediately	6	x	x	x	x	x	-x	-	-	x	-	-	-	-	-	-	-
1000	immediately	8	x	x	x	x	x	-x	-	-	x	-	-	-	-	-	-	-
1000	5300	2	x	x	x	x	34	33	34	34	47	47	47	47	51	50	50	50
1000	5300	4	x	x	x	x	-	-	-	-	-	-	-	-	30	-	-	-
1000	5300	6	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
1000	5300	8	x	x	x	x	-	-	-	-	-	-	-	-	-	-	-	-
5300	immediately	2	x	x	x	x	49	47	47	48	60	60	60	60	51	50	50	50
5300	immediately	4	-x	40	43	-x	32	32	32	32	32	32	32	32	30	-	-	-
5300	immediately	6	-x	-x	-x	-x	30	31	30	30	30	-	-	-	-	-	-	-
5300	immediately	8	-x	-x	-x	-x	-	-	-	-	-	-	-	-	-	-	-	-

5.5 Sensitivity Analysis Result

From section 4 drilling fluid weight or mud weigh is varied to observe a sensitive of torque and drag. In this section, the 3D build hold and drop well type is selected to be a case in order to observe the sensitivity of every section. The selected case has 1^{st} KOP at 1000ft TVD with 5300ft TVD 2^{nd} KOP, 2 deg/100ft 1^{st} BUR, -6 deg/100ft 2^{nd} BUR, 30 deg 1^{st} INC, 0 deg 2^{nd} INC, 4 deg/100ft TUR and 150 deg. Turn Degree.

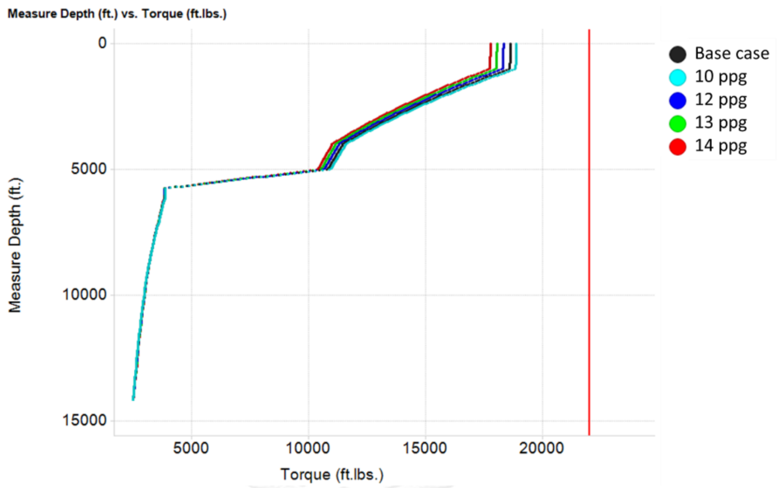
There are 2 methods to observe its affect as followed; varied mud weight with formation pressure change and varied mud weight without formation pressure change as detailed in section 4.1.5.

However, these 2 methods show the same results. It means that torque and drag analyzing mode does not account for formation pressure change. Hence, only result from varied mud weight is discussed and evaluated in this section.

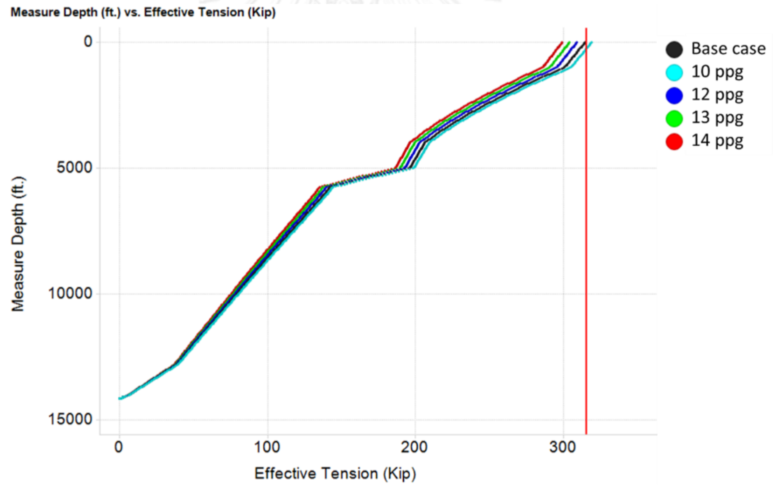
The mud weight is varied from 10, 12, 13 and 14 ppg to observe how it affected torque and drag. Torque and effective tension is displayed in Figure 5-22.

Torque has 5 sections from the bottom of hole to the top; tangent section, drop section, second tangent section, build and turn section and vertical section. From observing, varied mud weight affects torque from drop section to the top. Higher mud weight yields lower torque with similar magnitude of change.

Effective tension has 6 sections from the bottom of hole to top which are BHA section, tangent section, drop section, second tangent section, build and turn section and vertical section. Effect of varied mud weight is shown from tangent section to vertical section. Similar to torque, higher mud weight generates lower effective tension with similar magnitude.



a) Torque

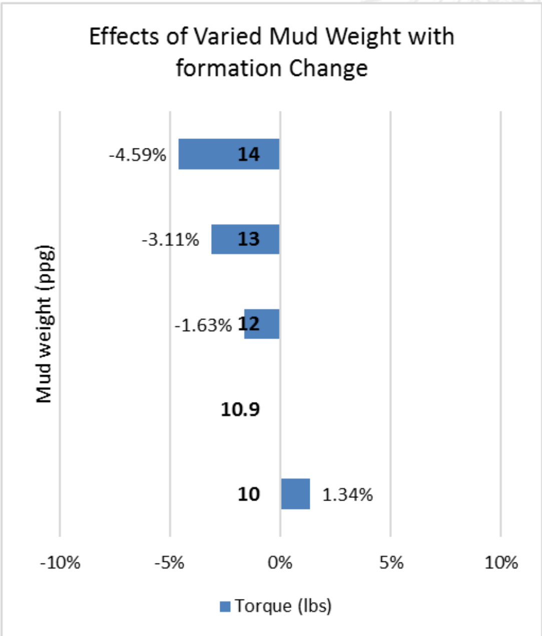


b) Effective Tension

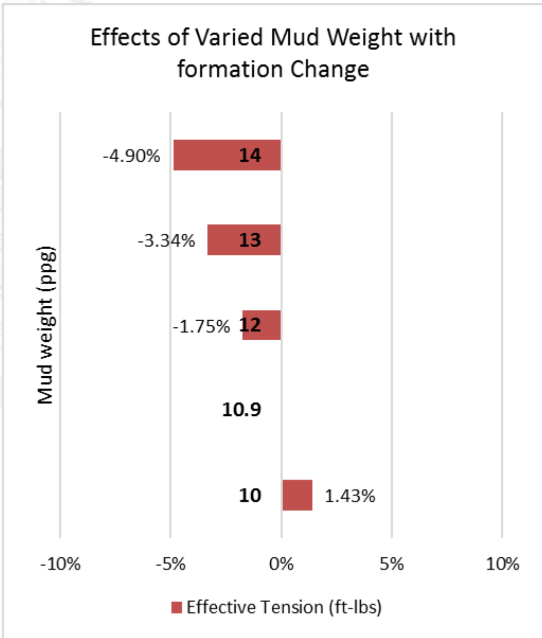
Figure 5-22: Torque and Effective tension as a function of varied mud weight with constrained formation pressure.

Table 5-11: The maximum torque and effective tension from varied mud weight and formation pressure result.

Mud Weight (ppg)	Maximum Torque (lb.)	Maximum Effective Tension (Kip)
10	18902	319
10.9 (Base case)	18653	314
12	18349	309
13	18073	304
14	17797	299



a) Torque



b) Effective Tension

Figure 5-23: Percentage of torque and effective tension change as a function of varied mud weight.

From Table 5-11 and Figure 5-23, mud weight affects torque and effective tension in the same direction. Increasing 1ppg of mud weight generates lower torque and drag by 1.5 percent approximately.

This phenomenon can be explained by buoyancy weight. It can be calculated from;

$$\mathrm{BF} = \frac{65.5 - \text{mudweight (ppg)}}{65.5} \qquad \textit{5-1)}$$

$$\mathrm{W}_{\mathbf{B}} = \mathrm{W} \times \mathrm{BF} \qquad \textit{5-2)}$$

Where BF = Buoyancy Factor

W_B = Buoyancy weight (lbs.)

W = Weight in air (lbs.)

From Eq. 5-1 and 5-2, higher mud weight yields lower buoyancy weight. Moreover, it shows effect on effective tension more than torque. Corresponding to Eq. 3-16), tension force acts in axial axis. Weight of drillstring has direct effect on drag force.

It can be concluded that mud weight influences torque and effective tension as high mud weight help decrease torque and effective tension generated. If the drilling well has a potential to generate torque or drag exceeding the limit, increasing mud weight with a proper design can help decrease torque and drag.

Chapter 6 : Conclusion and Recommendation

Torque and drag are often considered as important factor for drillable well trajectory. This study varied well plan parameters in order to investigate how they effect on torque and drag in different 4 well profile types which are 2D build and hold, 2D build hold and drop, 3D build and hold and 3D build hold and drop. Each well plan parameter affects torque and drag differently.

6.1 Conclusion

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

1. Torque can be preferably used as a criterion for 2D build and hold profile. Effective tension can be preferably used as a criterion for 2D build hold and drop, 3D build and hold and 3D build hold and drop profile.
2. Kick off point and 1^{st} inclination have strong effects on torque and effective tension. Turn degree, 2^{nd} inclination, build up rate and turn rate have weaker effect on torque and effective tension comparable to kick off point and 1^{st} inclination.
3. Deep kick off point benefits on decreasing torque and drag as well as shorten well total depth.
4. 2 deg./100ft. 1^{st} build up rate generates significantly lower torque comparable to 4, 6, and 8 deg./100ft 1^{st} build up rate in both 2D and 3D build and hold well profiles.
5. In 3D well profile, high turn degree is drillable with deep kick off point, low build up rate and high turn rate combined.
6. In this study, a set of well plan parameter guideline for each well type is provided for pre-check a drillability of the design.
7. In this study, the maximum measure depth that can be drilled to reach 13000ft TVD within torque and effective tension limit for 2D build and hold, 2D build hold

and drop, 3D build and hold and 3D build hold and drop is 21000ft, 18000ft, 18700ft and 14900ft respectively.

8. Mud weight has small effect on torque and effective tension in this study as increasing 1 ppg of mud weight help decreasing torque and effective tension generated by approximately 1.5 percent. If the drilling well has a potential to generate torque or effective tension exceeding the limit, increasing mud weight with a proper design can help decrease torque and drag.

6.2 Recommendations

1. Variation of BHA and drillstring design could be further investigated.
2. There exists other 3D well profiles that could be designed and may have different results on torque and effective tension.

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APPENDIX

The maximum torque and the maximum effective tension of every cases are plotted versus 1st INC in order to identify the maximum 1st INC that can be drilled and is within torque and drag limit for each well type.

1.) 2D Build and Hold

1.1) 2D Build and Hold

1.1.1) 1000ft TVD 1st KOP

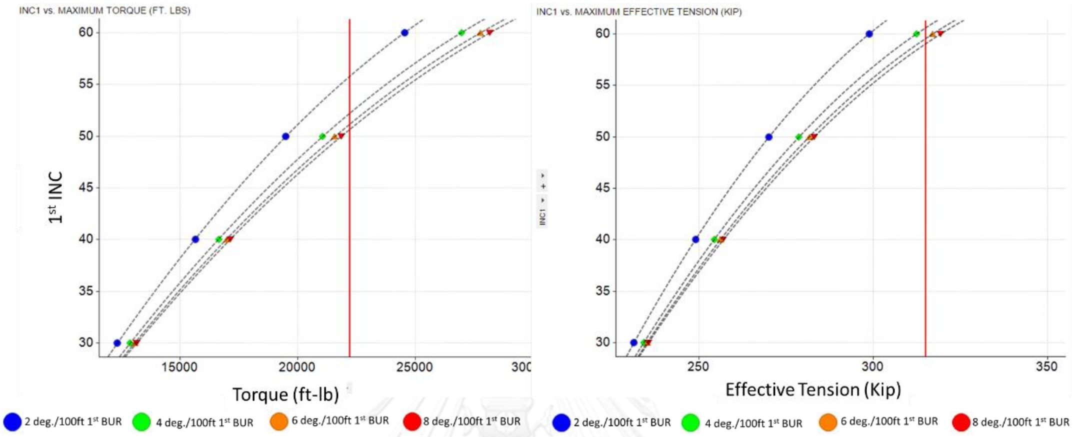


Figure 1: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with varied well plan parameters for 2D build and hole profile.

Table 1: The maximum 1st INC, by torque criteria

Torque Criteria				
1st BUR	2	4	6	8
Eq.	$y=-20.28+4.88*10^{-3}x-6.57*10^{-8}x^2$	$y=-20.28+4.88*10^{-3}x-6.57*10^{-8}x^2$	$y=-20.28+4.88*10^{-3}x-6.57*10^{-8}x^2$	$y=-15.74+4.23*10^{-3}x-5.26*10^{-8}x^2$
Max. INC	55	52	51	50

Table 2: The maximum 1st INC, by effective tension criteria

Effective Tension Criteria				
1st BUR	2	4	6	8
Eq.				$y=-184.18+1.32x-1.73x^2$
Max. INC	60	60	60	59

1.1.2) 5300ft TVD 1st KOP

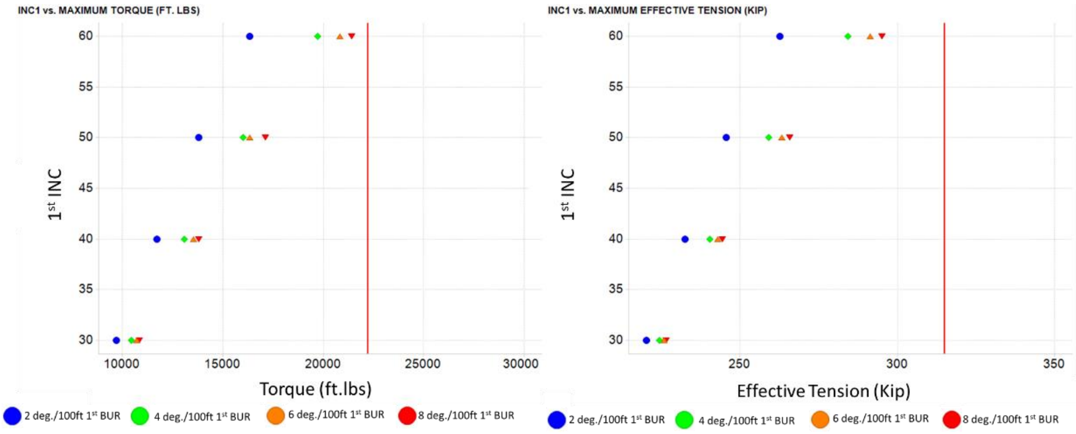


Figure 2: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with varied well plan parameters for 2D build and hole profile.

Table 3: The maximum 1st INC, by torque criteria

Torque Criteria				
1st BUR	2	4	6	8
Eq.				
Max. INC	60	60	60	60

Table 4: The maximum 1st INC, by effective tension criteria

Torque Criteria				
1st BUR	2	4	6	8
Eq.				
Max. INC	60	60	60	60

2.) 2D Build, Hold and Drop

2.1) 1000ft TVD 1st KOP with immediate 2nd KOP

2.1.1) -2 deg/100ft 2nd BUR

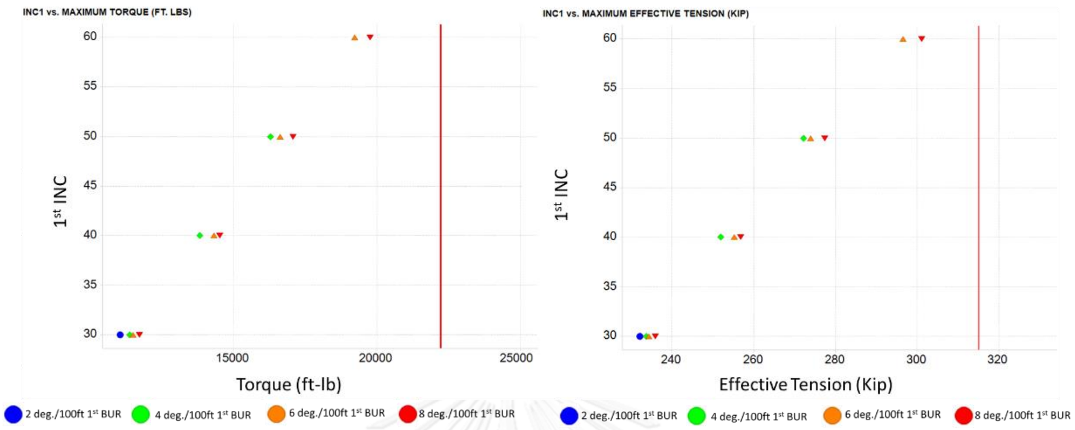


Figure 3: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediate 2nd KOP, -2 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 5: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	30*	60	60	60

Table 6: The maximum 1st INC, by effective tension criteria

Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	30*	60	60	60

Remark

* cannot design with inclination lower than 30 deg.

2.1.2) -4 deg/100ft 2nd BUR

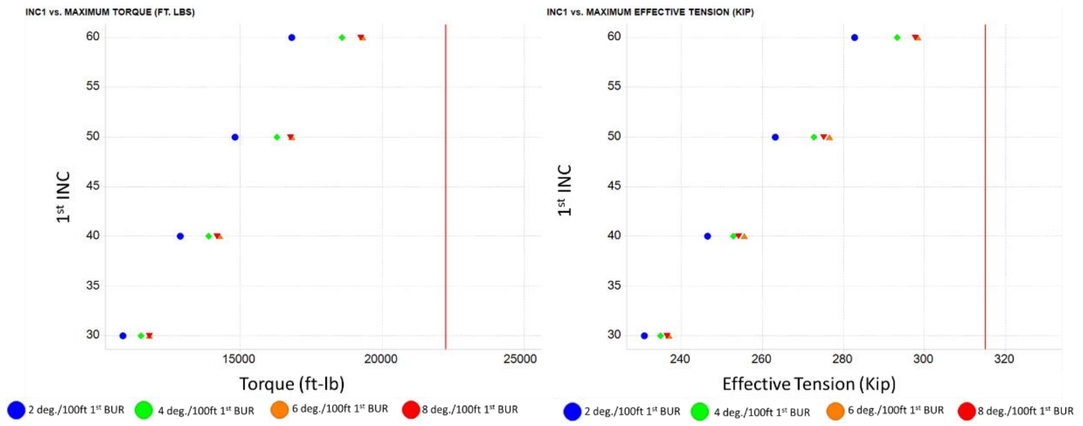


Figure4: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediate 2nd KOP, -4 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 7: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 8: The maximum 1st INC, by effective tension criteria

Tension				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.1.3) -6 deg/100ft 2nd BUR

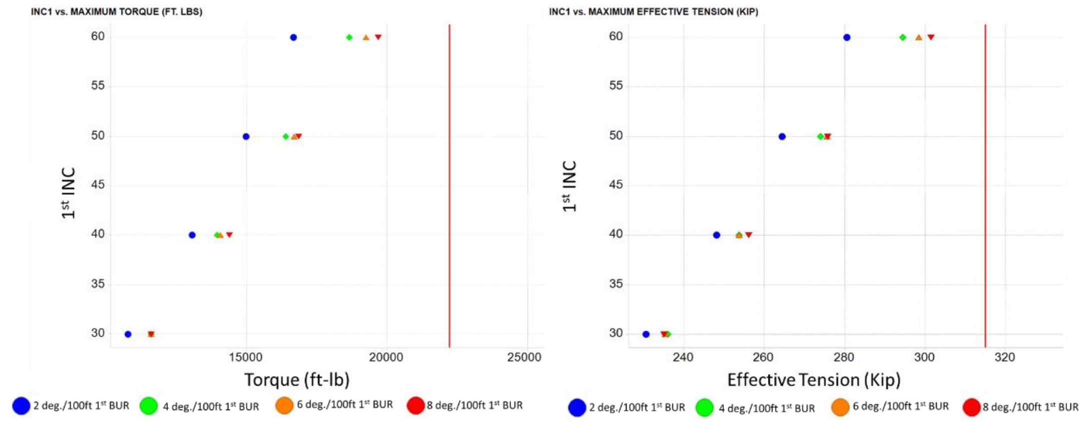


Figure 5: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediate 2nd KOP, -6 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 9: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 10: The maximum 1st INC, by effective tension criteria

Tension				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.1.4) -8 deg/100ft 2nd BUR

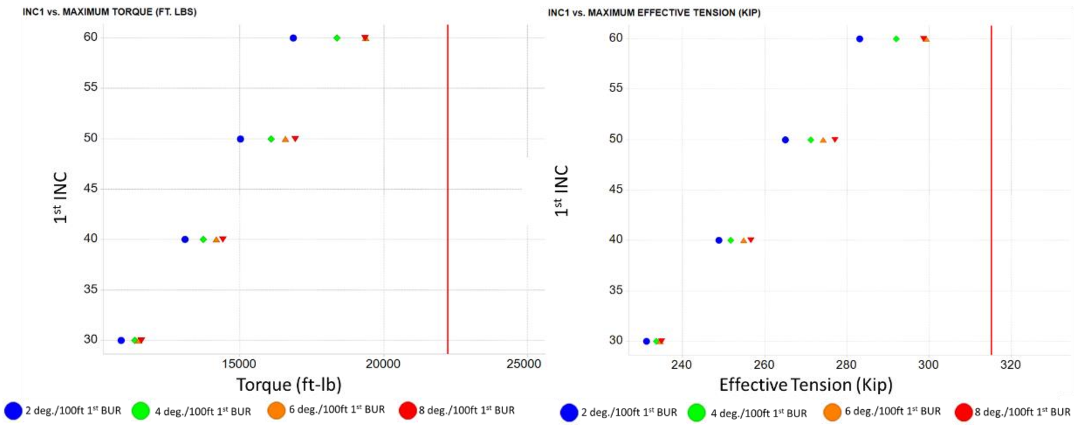


Figure 6: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediate 2nd KOP, -8 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 11: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 12: The maximum 1st INC, by effective tension criteria

Tension				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.2) 1000ft TVD 1st KOP with 5300ft TVD 2nd KOP

2.2.1) -2 deg/100ft 2nd BUR

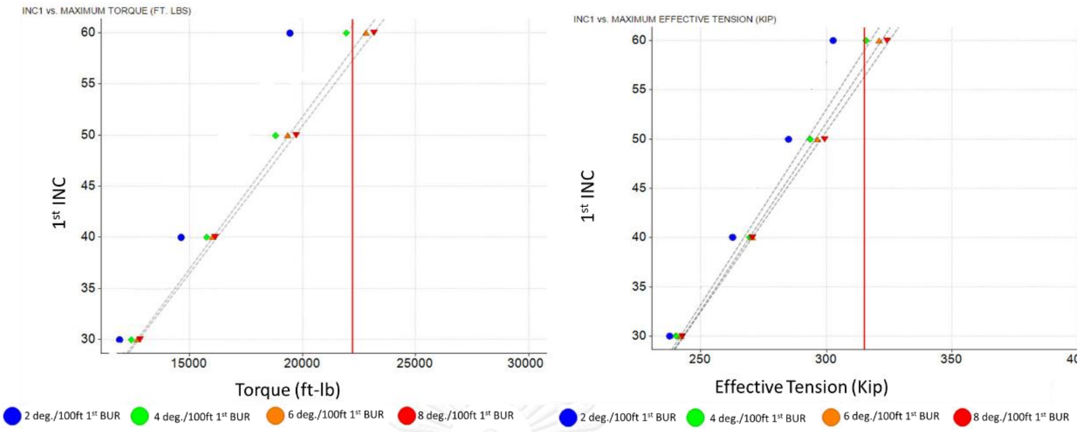


Figure 7: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, -2 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 13: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.			$y=2.97*10^3X-7.72$	$y=2.89*10^3X-6.89$
r^2			1.00	1.00
Max 1st INC	60	60	58	57

Table 14: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.		y=0.40x-66.01	y=0.38x-62.58	y=0.37x-59.18
r^2		1.00	1.00	1.00
Max 1st INC	60	59	57	56

2.2.2) -4 deg/100ft 2^{nd} BUR

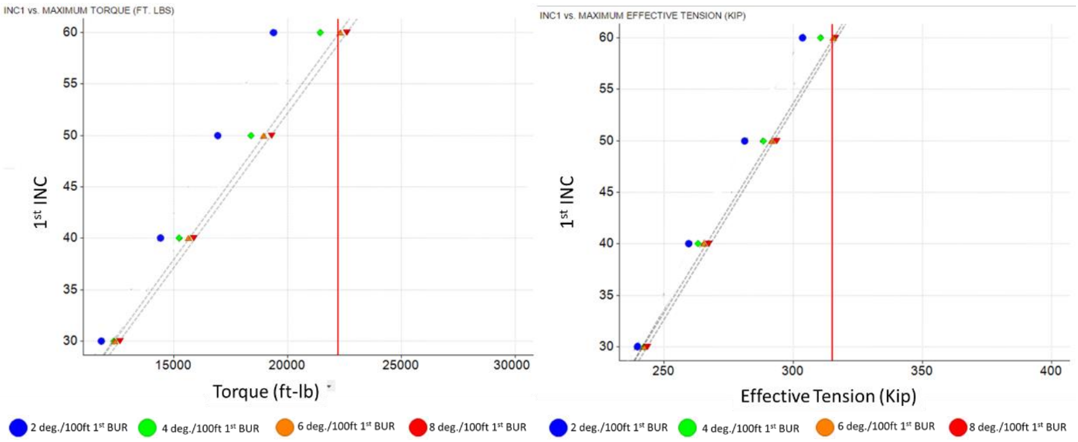


Figure 8: Maximum torque and effective tension versus 1^{st} INC as a function of 1000ft. 1^{st} KOP with 5300ft TVD 2^{nd} KOP, -4 deg/100ft 2^{nd} BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 15: The maximum 1^{st} INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.			$y=3.05*10^3x-7.93$	$y=2.88*10^3x-6.24$
r^2			1.00	1.00
Max 1st INC	60	60	59	57

Table 16: The maximum 1^{st} INC, by effective tension criteria

Effective Tension				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.			y=0.41x-68.03	y=0.37x-60.20
r^2			1.00	1.00
Max 1st INC	60	60	59	57

2.2.3) -6 deg/100ft 2nd BUR

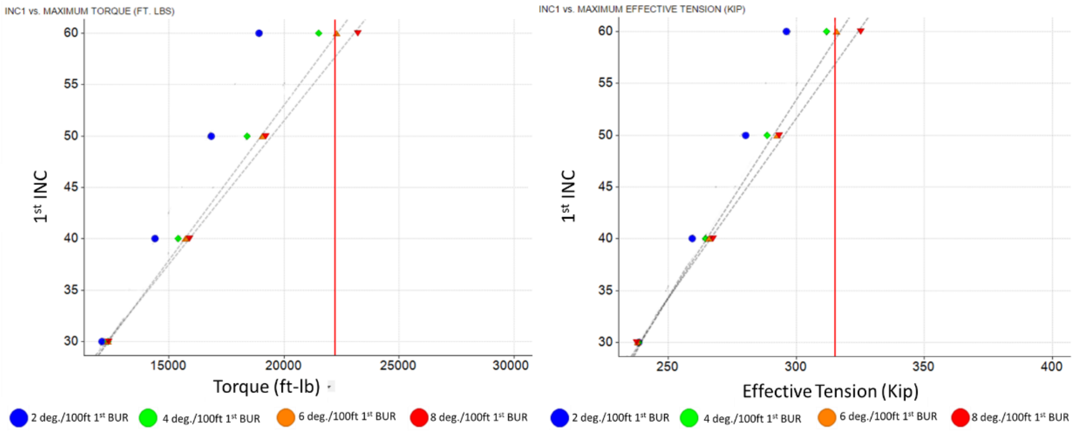


Figure9: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, -6 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 17: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-6			
1st BUR	2	4	6	8
Eq.			$y=3.13*10^3x-9.6$	$y=2.85*10^3x-5.97$
r^2			1.00	1.00
Max 1st INC	60	60	59	57

Table 18: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-6			
1st BUR	2	4	6	8
Eq.				$y=0.36x-56.38$
r^2				1.00
Max 1st INC	60	60	60	56

2.2.4) -8 deg/100ft 2nd BUR

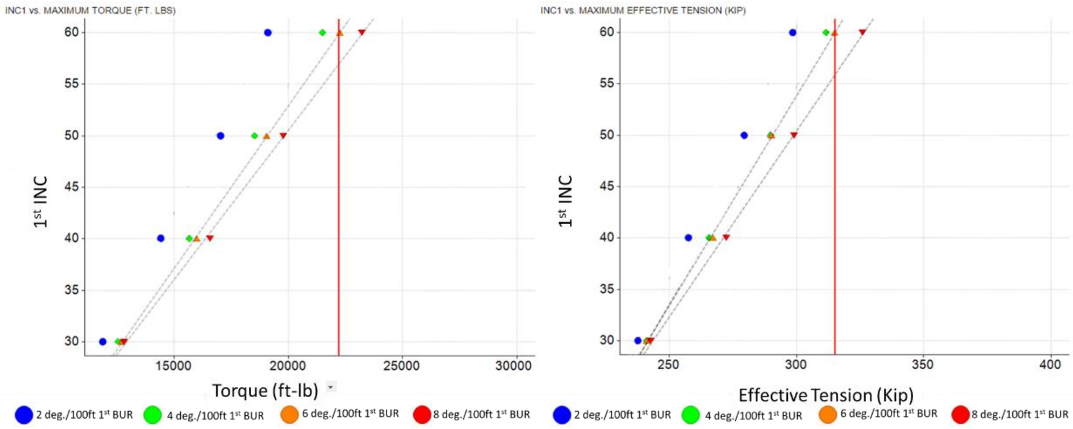


Figure 10: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, -8 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table19: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-8			
1st BUR	2	4	6	8
Eq.			$y=3.15*10^{3}x-10.15$	$y=2.90*10^{3}x-7.42$
r^2			1.00	1.00
Max 1st INC	60	60	59	56

Table 20: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-8			
1st BUR	2	4	6	8
Eq.				$y=0.36x-58.32$
r^2				1.00
Max 1st INC	60	60	60	56

2.3) 5300ft TVD 1st KOP with immediate 2nd KOP

2.3.1) -2 deg/100ft 2nd BUR

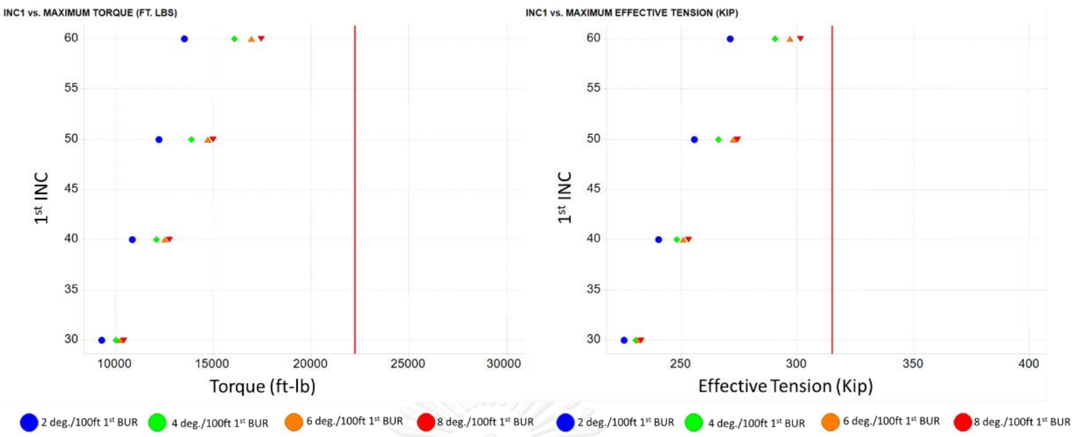


Figure 11: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediate 2nd KOP, -2 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 21: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 22: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.3.2) -4 deg/100ft 2nd BUR

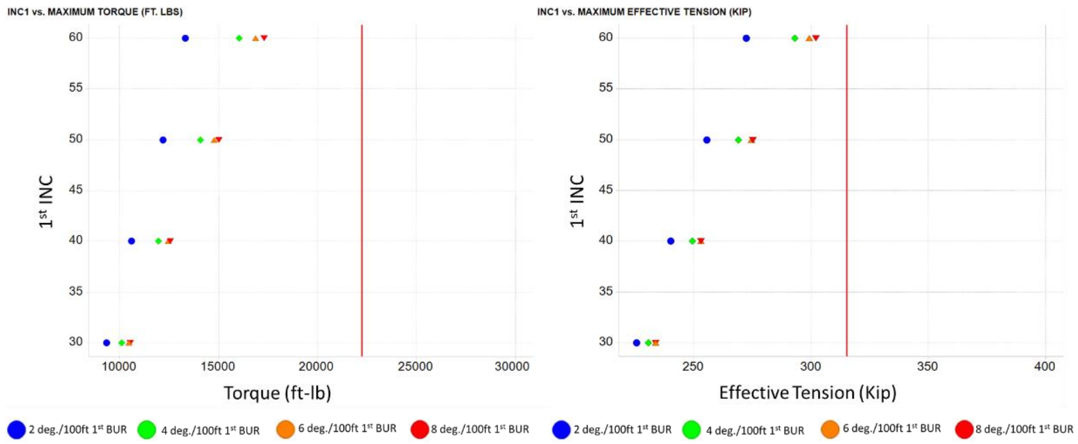


Figure12: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediate 2nd KOP, -4 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 23: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 24: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.3.3) -6 deg/100ft 2nd BUR

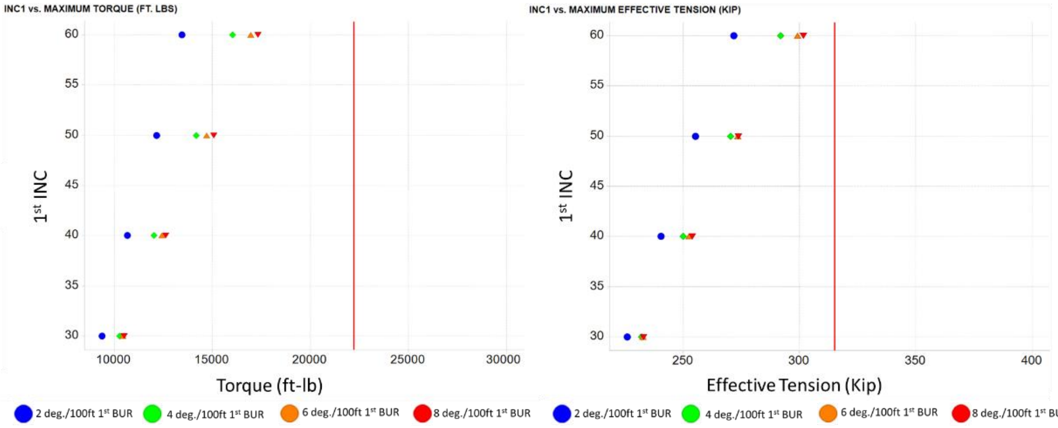


Figure 13: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediate 2nd KOP, -6 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 25: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 26: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

2.3.4) -8 deg/100ft 2nd BUR

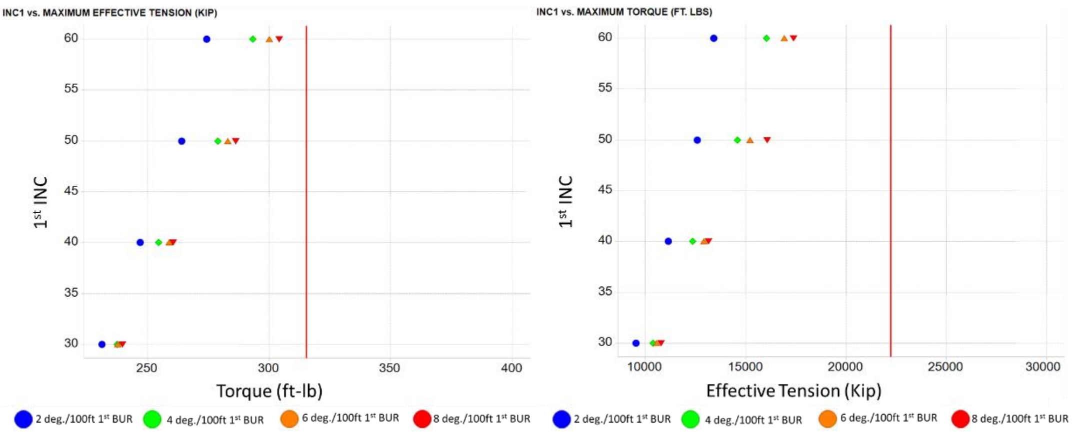


Figure 14: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediate 2nd KOP, -8 deg/100ft 2nd BUR and varied well plan parameters for 2D build, hole and drop profile.

Table 27: The maximum 1st INC, by torque criteria

Torque				
2nd BUR	-4			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

Table 28: The maximum 1st INC, by effective tension criteria

Effective Tension				
2nd BUR	-2			
1st BUR	2	4	6	8
Eq.				
r^2				
Max 1st INC	60	60	60	60

3.) 3D Build and Hold

3.1) 1000ft TVD 1st KOP

3.1.1) 90 deg. Turn degree

3.1.1.1) 2 deg/100ft TUR

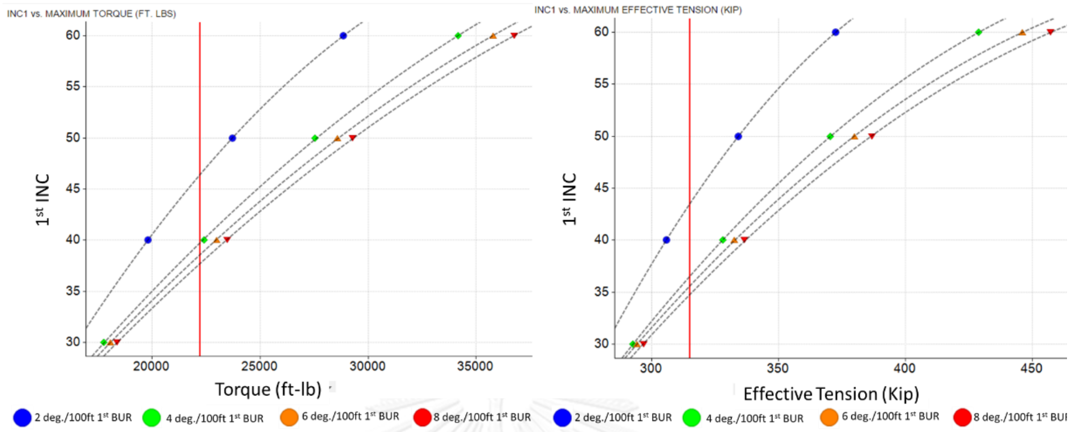


Figure 15: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 90 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 29: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=-42.20+5.49*10^{-3}x -6.74*10^{-8}x^2$	$y=-21.25+3.43*10^{-3}x -3.07*10^{-8}x^2$	$y=-18.61+3.19*10^{-3}x -2.78*10^{-8}x^2$	$y=-17.66+3.07*10^{-3}x -2.61*10^{-8}x^2$
Max 1st INC	46	39	38	37

Table 30: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=-207.13+1.23x -1.36*10^{-3}x^2$	$y=-113.64+0.68x -6.30*10^{-4}x^2$	$y=-100.23+0.60x -5.49*10^{-4}x^2$	$y=-94.29+0.57x -5.08*10^{-4}x^2$
Max 1st INC	43	36	36	35

3.1.1.2) 4 deg/100ft TUR

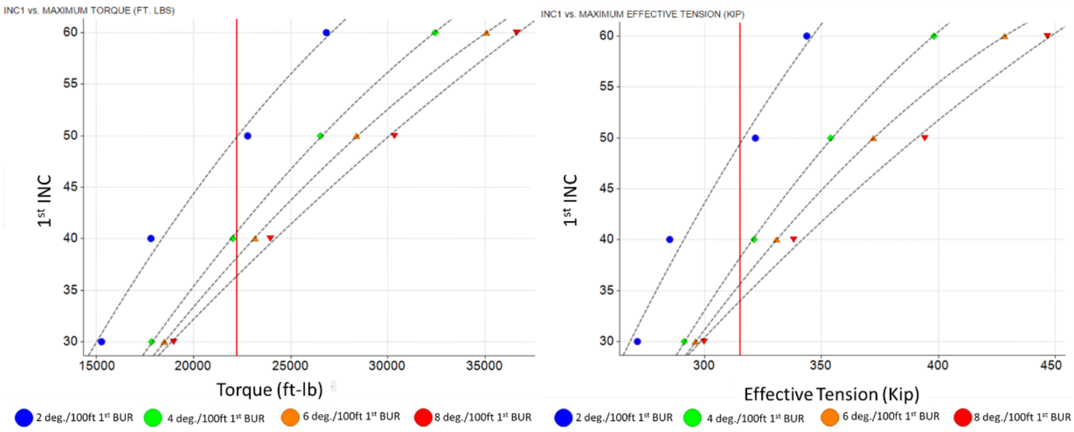


Figure 16: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 90 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 31: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-30.13+4.84*10^{-3}x -5.60*10^{-8}x^{2}$	$y=-29.40+4.01*10^{-3}x -3.86*10^{-8}x^{2}$	$y=-23.28+3.44*10^{-3}x -3.03*10^{-8}x^{2}$	$y=-12.48+2.54*10^{-3}x -1.55*10^{-8}x^{2}$
Max 1st INC	49	40	38	36

Table 32: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-158.66+0.95x -9.22*10^{-4}x^{2}$	$y=-145.89+0.84x -6.34*10^{-4}x^{2}$	$y=-117.77+0.69x -6.34*10^{-4}x^{2}$	$y=-67.44+0.41x -2.82*10^{-4}x^{2}$
Max 1st INC	49	38	36	34

3.1.1.3) 6 deg/100ft TUR

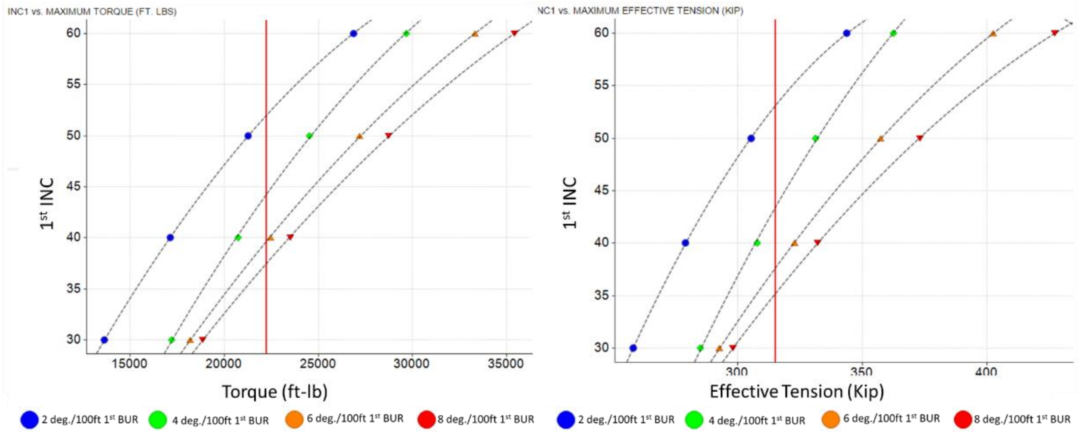


Figure 17: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 90 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 33: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-23.73+4.79*10^{-3}x$ $-6.22*10^{-8}x^2$	$y=-41.40+5.14*10^{-3}x$ $-5.81*10^{-8}x^2$	$y=-28.42+3.88*10^{-3}x$ $-3.67*10^{-8}x^2$	$y=-24.85+3.49*10^{-3}x$ $-3.09*10^{-8}x^2$
Max 1st INC	53	44	39	37

Table 34: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-231.69+1.51x$ $-1.93*10^{-3}x^2$	$y=-215.72+1.23x$ $-1.30*10^{-3}x^2$	$y=-142.83+0.82x$ $-7.87*10^{-4}x^2$	$y=-121.97+0.70x$ $-6.50*10^{-4}x^2$
Max 1st INC	53	43	38	35

3.1.1.4) 8 deg/100ft TUR

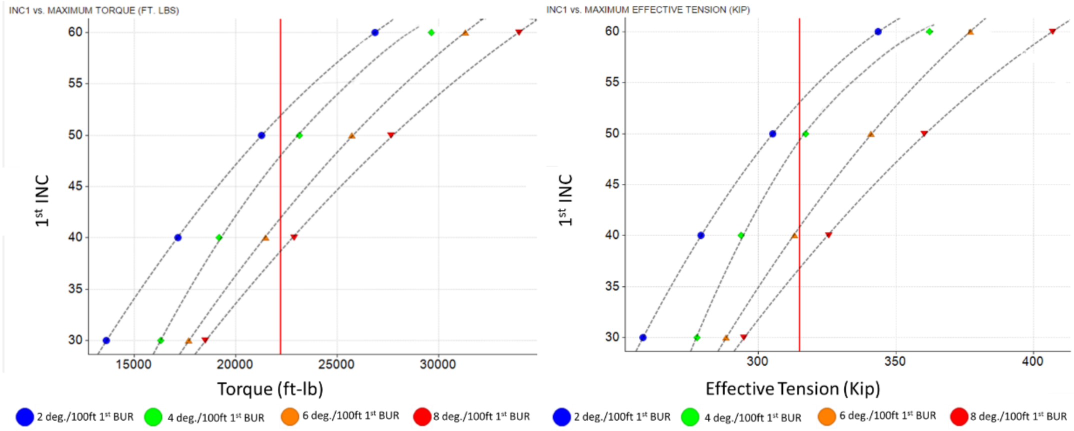


Figure 18: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 90 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 35: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-23.66+4.78*10^{-3}x -6.19*10^{-8}x^2$	$y=-58.76+7.21*10^{-3}x -1.08*10^{-7}x^2$	$y=-35.96+4.59*10^{-3}x -4.85*10^{-8}x^2$	$y=-28.55+3.82*10^{-3}x -3.57*10^{-8}x^2$
Max 1st INC	53	49	41	38

Table 36: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-230.18+1.50x -1.91*10^{-3}x^2$	$y=-414.24+2.56x -3.44*10^{-3}x^2$	$y=-188.21+1.08x -1.11*10^{-3}x^2$	$y=-141.59+0.81x -7.71*10^{-4}x^2$
Max 1st INC	53	49	41	37

3.1.2) 120 deg. Turn degree

3.1.2.1) 2 deg/100ft TUR

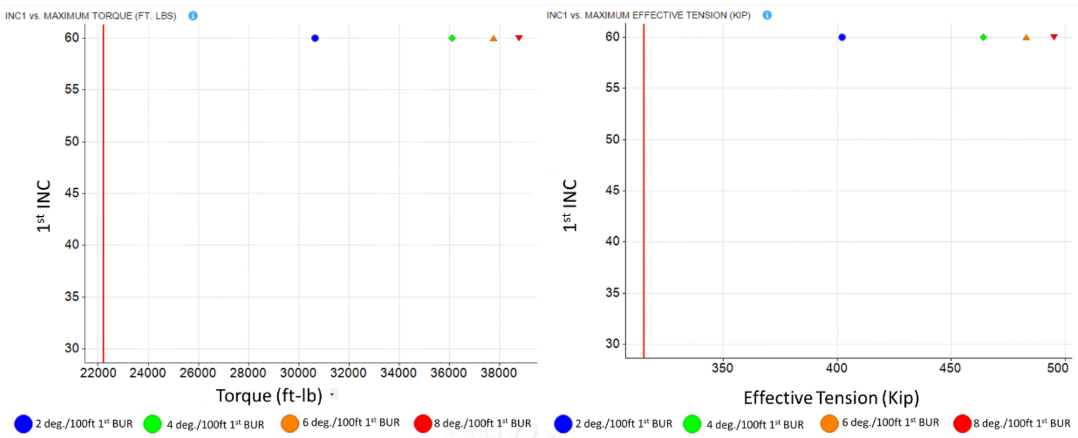


Figure 19: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 120 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 37: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Table 38: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.2.2) 4 deg/100ft TUR

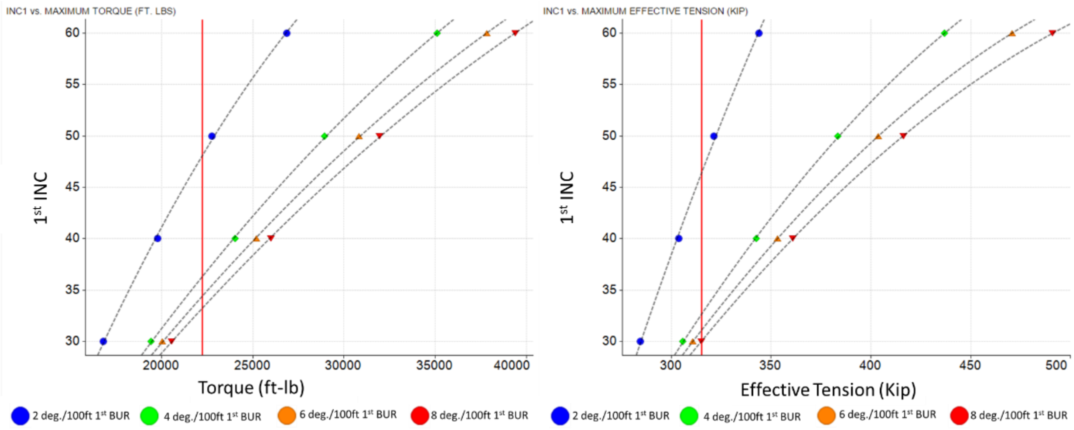


Figure 20: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 120 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 39: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-55.08+6.33*10^{-3}x -7.60*10^{-8}x^2$	$y=-26.48+3.45*10^{-3}x -2.80*10^{-8}x^2$	$y=-21.20+3.01*10^{-3}x -2.27*10^{-8}x^2$	$y=-19.43+2.82*10^{-3}x -2.05*10^{-8}x^2$
Max 1st INC	47	36	34	33

Table 40: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-216.32+1.16x -1.03*10^{-3}x^2$	$y=-108.62+0.61x -5.12*10^{-4}x^2$	$y=-88.39+0.51x -4.11*10^{-4}x^2$	$y=-80.08+0.46x -3.65*10^{-4}x^2$
Max 1st INC	46	33	31	30

3.1.2.3) 6 deg/100ft TUR

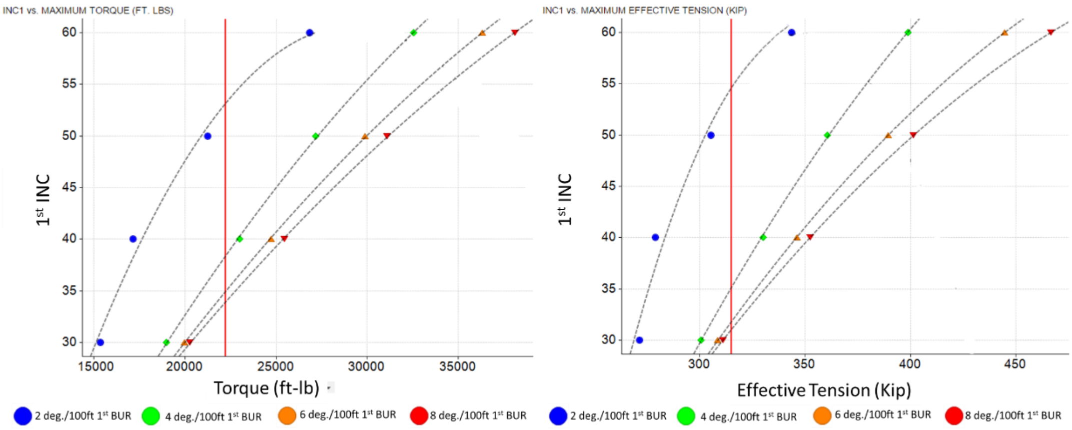


Figure 21: Maximum torque and effective tension versus 1^{st} INC as a function of 1000ft. 1^{st} KOP with, 120 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 41: The maximum 1^{st} INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-71.31+9.05*10^{-3}x$ $-1.55*10^{-7}x^2$	$y=-35.44+4.16*10^{-3}x$ $-3.76*10^{-8}x^2$	$y=-25.73+3.31*10^{-3}x$ $-2.62*10^{-8}x^2$	$y=-21.55+2.99*10^{-3}x$ $-2.24*10^{-8}x^2$
Max 1st INC	55	38	34	33

Table 42: The maximum 1^{st} INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-511.59+3.28x$ $-4.70*10^{-3}x^2$	$y=-139.07+0.75x$ $-6.40*10^{-4}x^2$	$y=-105.15+0.59x$ $-4.88*10^{-4}x^2$	$y=-92.51+0.53x$ $-4.30*10^{-4}x^2$
Max 1st INC	55	35	32	31

3.1.2.4) 8 deg/100ft TUR

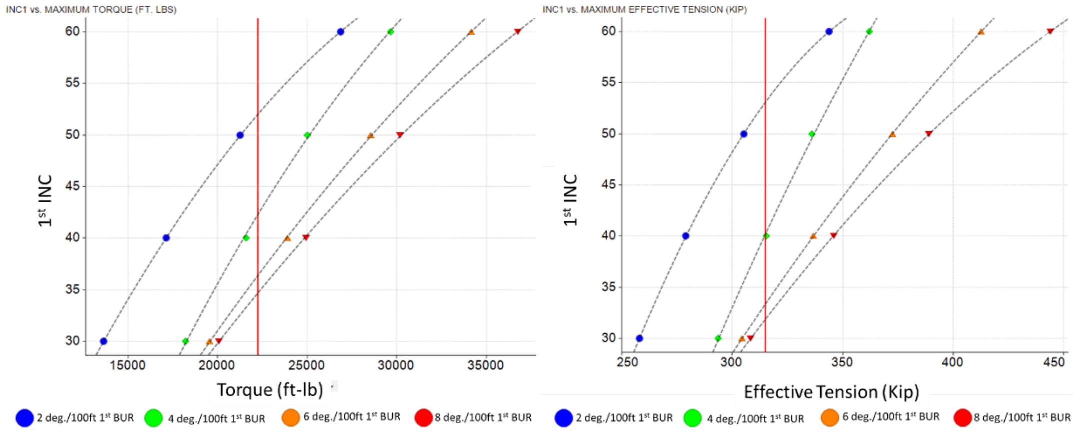


Figure 22: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 120 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 43: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-23.73+4.79*10^{-3}x-6.22*10^{-8}x^2$	$y=-50.56+5.50*10^{-3}x-5.97*10^{-8}x^2$	$y=-29.00+3.56*10^{-3}x-2.80*10^{-8}x^2$	$y=-24.65+3.22*10^{-3}x-2.50*10^{-8}x^2$
Max 1st INC	53	42	36	34

Table 44: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-231.69+1.51x-1.93*10^{-3}x^2$	$y=-193.26+1.02x-8.80*10^{-4}x^2$	$y=-108.30+0.58x-4.28*10^{-4}x^2$	$y=-103.67+0.58x-4.77*10^{-4}x^2$
Max 1st INC	53	40	33	32

3.1.3) 150 deg. Turn degree

3.1.3.1) 2 deg/100ft TUR

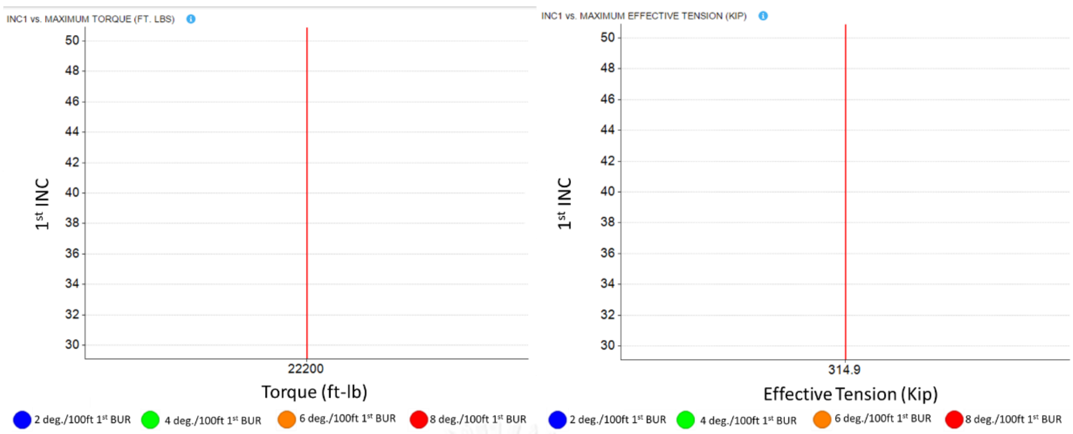


Figure 23: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 150 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 45: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Table 46: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.3.2) 4 deg/100ft TUR

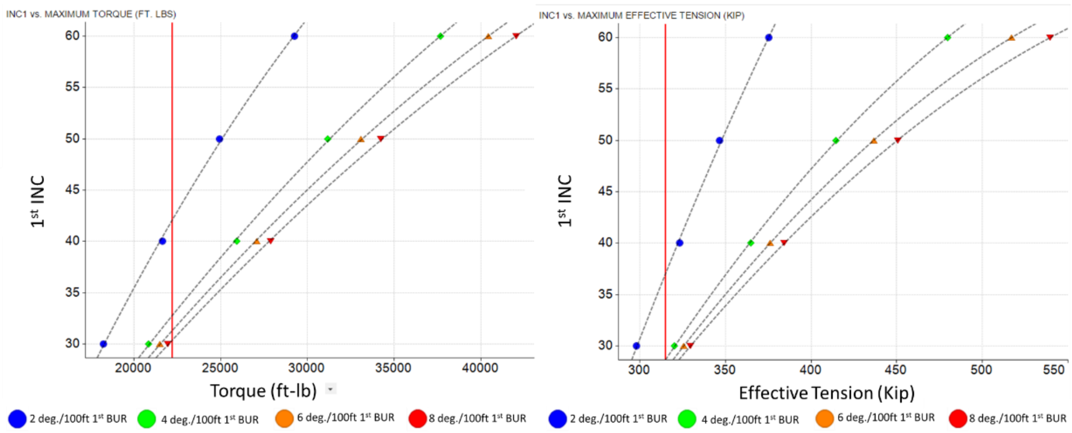


Figure 24: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 150 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 47: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-23.73+4.79*10^{-3}x-6.22*10^{-8}x^2$	$y=-50.56+5.50*10^{-3}x-5.97*10^{-8}x^2$	$y=-29.00+3.56*10^{-3}x-2.80*10^{-8}x^2$	$y=-24.65+3.22*10^{-3}x-2.50*10^{-8}x^2$
Max 1st INC	41	32	31	30

Table 48: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-146.70+0.75x-5.37*10^{-4}x^2$			
Max 1st INC	37	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.3.3) 6 deg/100ft TUR

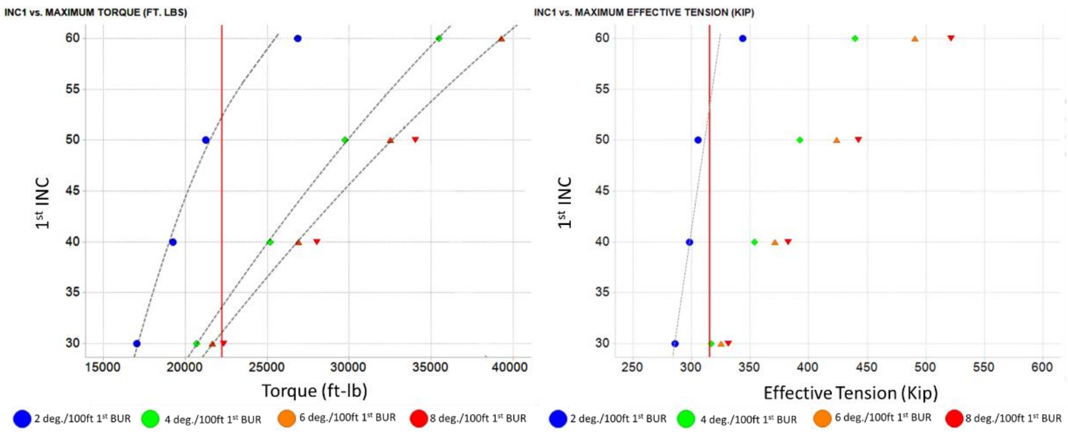


Figure 25: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 150 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 49: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-148.80+1.51*10^{-2}x-2.74*10^{-7}x^2$	$y=-30.92+3.47*10^{-3}x-2.55*10^{-8}x^2$	$y=-23.20+2.87*10^{-3}x-1.90*10^{-8}x^2$	
Max 1st INC	51	33	31	-

Table 50: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-1249.86+7.75x-1.15*10^{-2}x^2$			
Max 1st INC	54	-	-	-

Remark

x cannot design due to unfollow casing regulation

- cannot design due to exceed torque and drag limit

3.1.3.4) 8 deg/100ft TUR

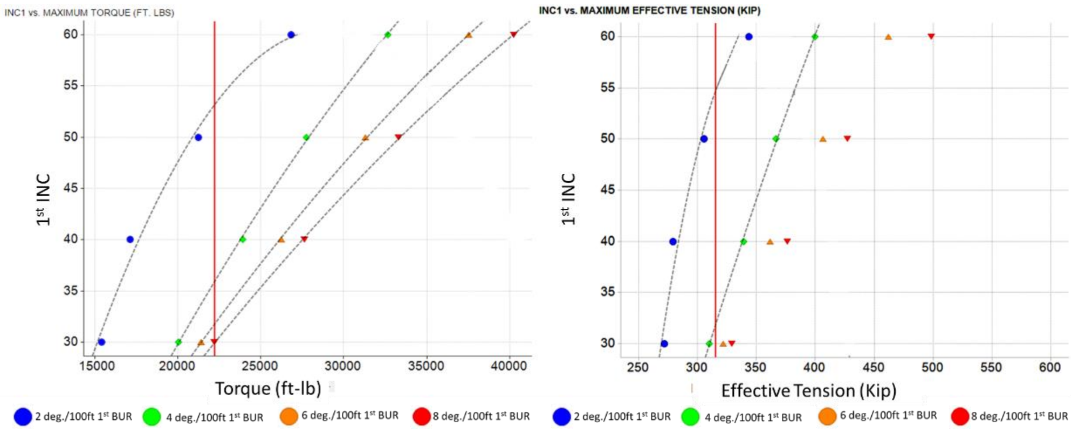


Figure 26: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 150 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 51: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-73.11+9.21*10^{-3}x -1.59*10^{-7}x^{2}$	$y=-40.90+4.23*10^{-3}x -3.49*10^{-8}x^{2}$	$y=-28.01+3.19*10^{-3}x -1.80*10^{-8}x^{2}$	
Max 1st INC	52	35	31	-

Table 52: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-520.52+3.33x -4.79*10^{-3}x^{2}$	$y=-120.70+0.60x -3.73*10^{-4}x^{2}$		
Max 1st INC	54	31	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.4) 180 deg. Turn degree

3.1.4.1) 2 deg/100ft TUR

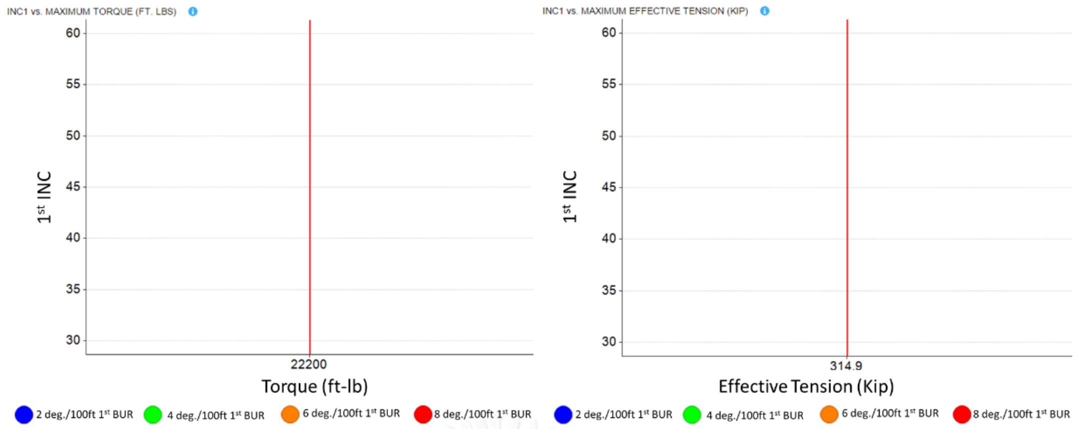


Figure 27: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 53: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Table 54: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x-	x-	x-	x-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.4.2) 4 deg/100ft TUR

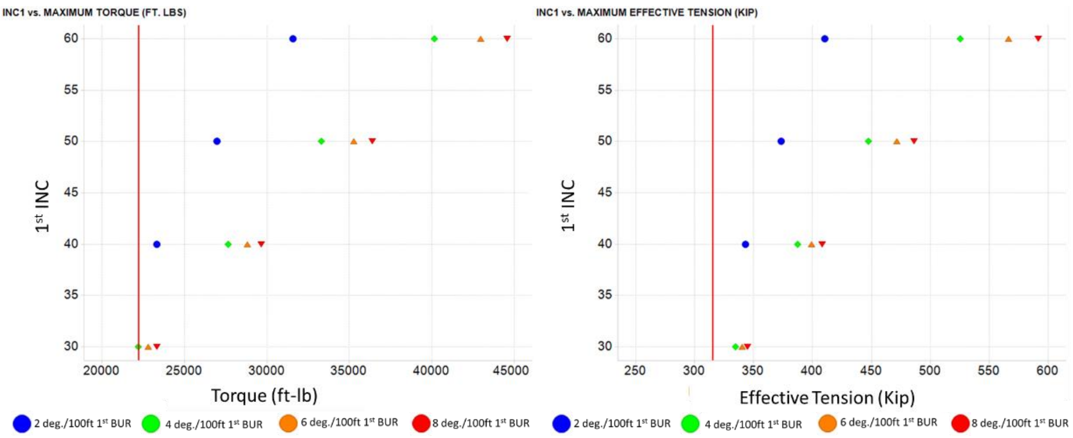


Figure 28: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 180 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 55: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x	30	-	-

Table 56: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	x	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.4.3) 6 deg/100ft TUR

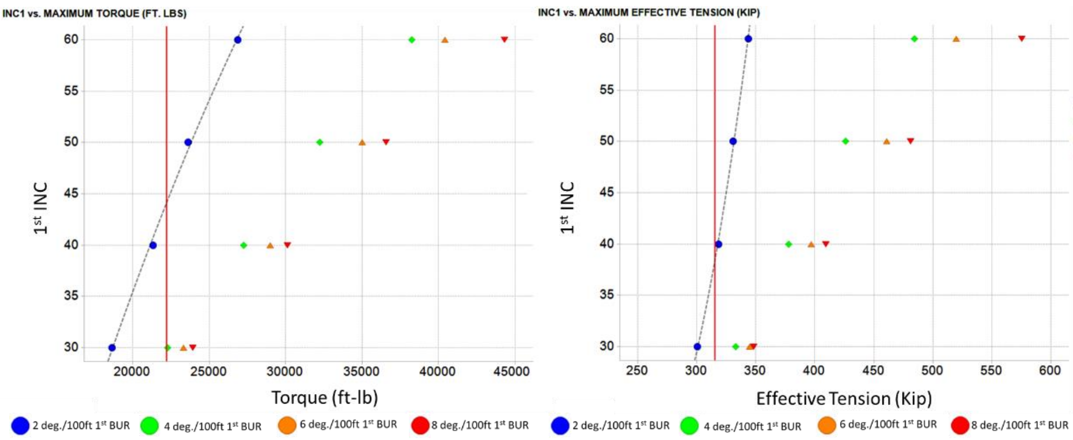


Figure 29: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 180 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 57: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=-73.01+6.77*10^{-3}x-6.76*10^{-7}x^2$			
Max 1st INC	43	-	-	-

Table 58: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.	$y=273.88-2.14x-4.42*10^{-3}x^2$			
Max 1st INC	38	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.1.4.4) 8 deg/100ft TUR

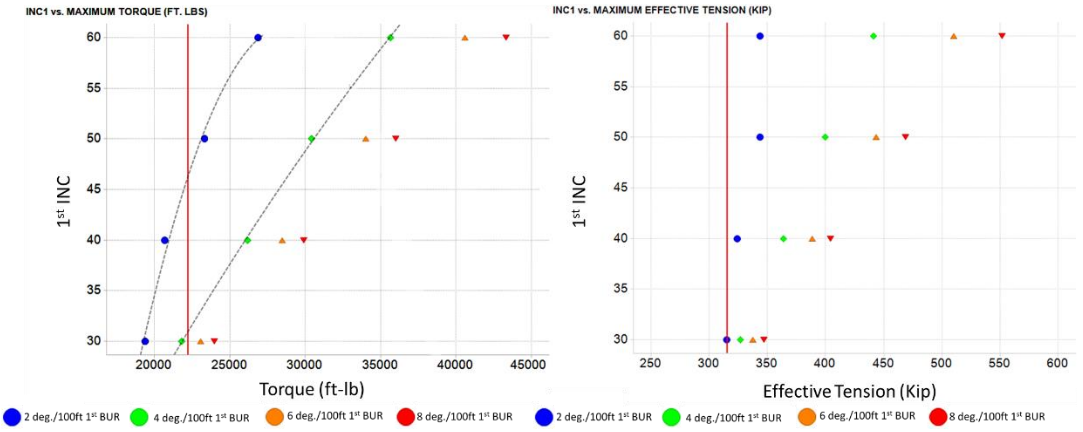


Figure 30: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with, 180 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 59: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-223.62+1.98*10^{-2}x-3.43*10^{-7}x^2$	$y=-34.58+3.43*10^{-3}x-2.18*10^{-8}x^2$		
Max 1st INC	45	30	-	-

Table 60: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	-	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.2) 5300ft TVD 1st KOP

3.2.1) 90 deg. Turn degree

3.2.1.1) 2 deg/100ft TUR

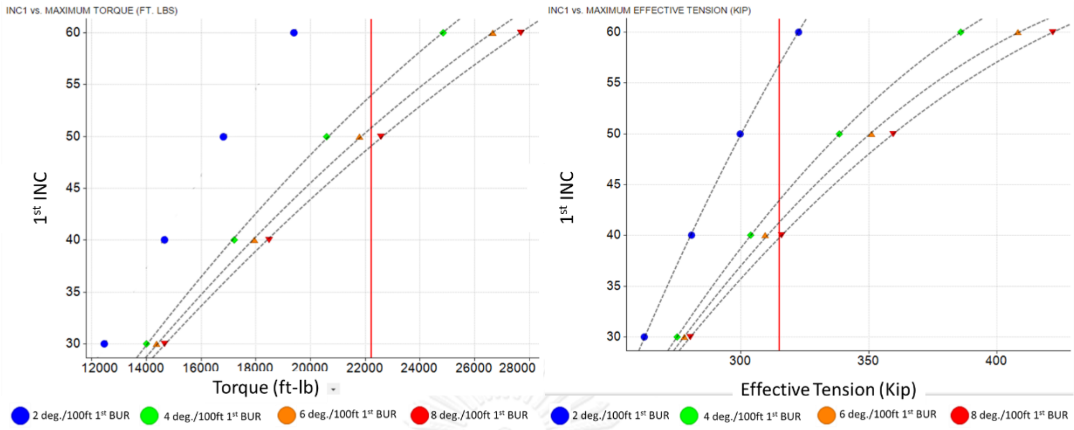


Figure 31: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 90 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 61: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.		$y=-28.97+5.01*10^{-3}x-5.73*10^{-8}x^2$	$y=-23.97+4.45*10^{-3}x-4.87*10^{-8}x^2$	$y=-20.68+4.05*10^{-3}x-4.11*10^{-8}x^2$
Max 1st INC	60	53	50	48

Table 62: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=-215.86+1.29x-3.15*10^{-3}x^2$	$y=-143.47+0.89x-9.32*10^{-4}x^2$	$y=-123.39+0.77x-7.90*10^{-4}x^2$	$y=-106.24+0.67x-6.49*10^{-4}x^2$
Max 1st INC	56	43	41	39

3.2.1.2) 4 deg/100ft TUR

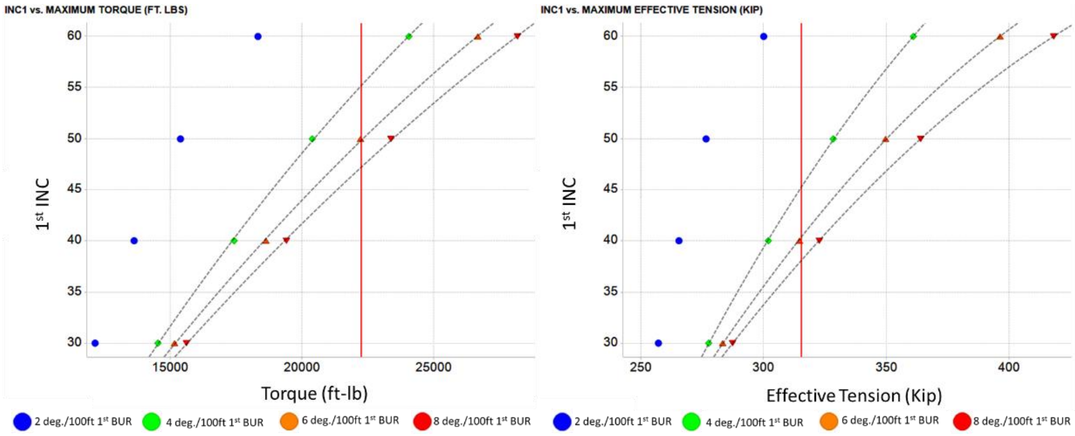


Figure 32: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 90 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 63: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.		$y=-37.66+5.56*10^{-3}x-6.22*10^{-8}x^2$	$y=-27.40+4.45*10^{-3}x-4.37*10^{-8}x^2$	$y=-22.84+3.93*10^{-3}x-3.50*10^{-8}x^2$
Max 1st INC	60	54	49	46

Table 64: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-1212.21+8.38x-1.38*10^{-2}x^2$	$y=-169.42+0.99x-9.91*10^{-4}x^2$	$y=-128.38+0.77x-7.39*10^{-4}x^2$	$y=-105.82+0.64x-5.82*10^{-4}x^2$
Max 1st INC	58	45	40	38

3.2.1.3) 6 deg/100ft TUR

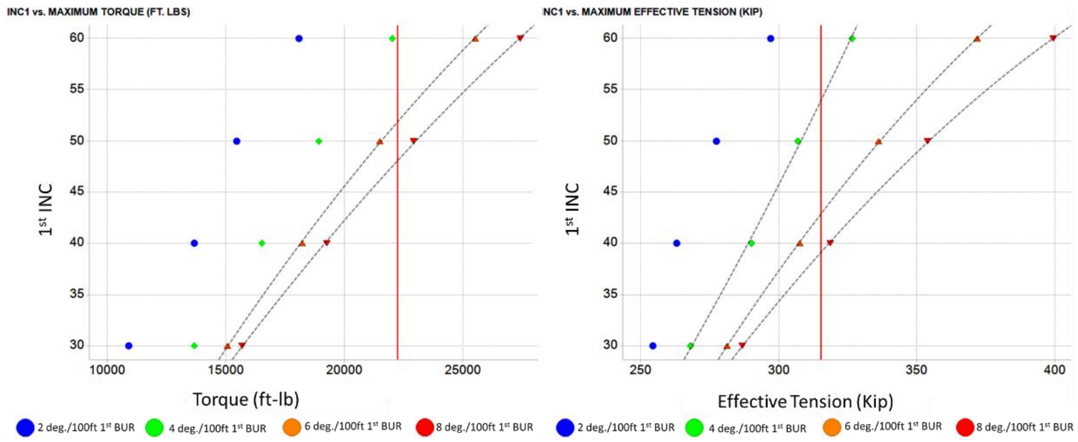


Figure 33: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 90 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 65: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.			$y=-33.55+5.00*10^{-3}x-5.21*10^{-8}x^2$	$y=-26.76+4.22*10^{-3}x-3.82*10^{-8}x^2$
Max 1st INC	60	60	51	47

Table 66: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-38.97+0.04x-8.09*10^{-4}x^2$	$y=-151.29+0.88x-8.42*10^{-4}x^2$	$y=-121.27+0.71x-6.52*10^{-4}x^2$
Max 1st INC	60	53	42	39

3.2.1.4) 8 deg/100ft TUR

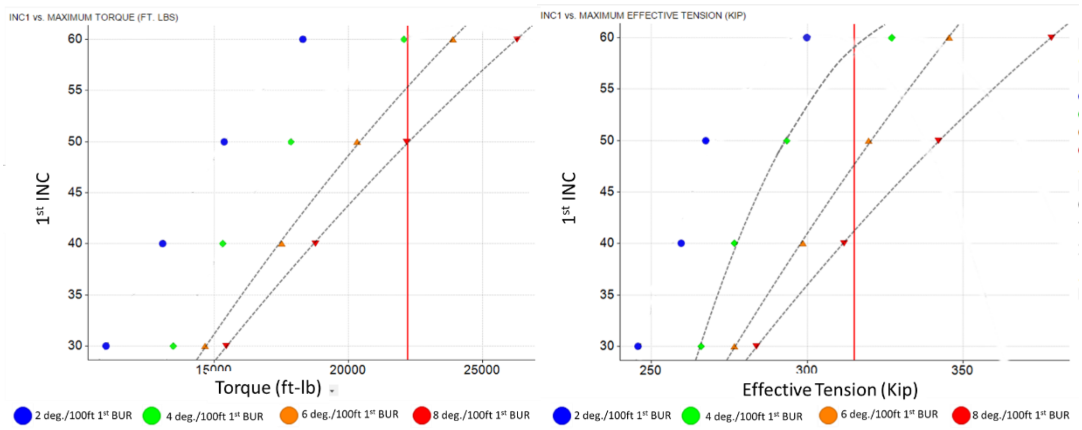


Figure 34: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 90 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 67: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.			$y=-40.02+5.69*10^{-3}x-6.28*10^{-8}x^2$	$y=-29.77+4.51*10^{-3}x-4.15*10^{-8}x^2$
Max 1st INC	60	60	54	49

Table 68: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.	$y=-777.17+5.51x-9.05*10^{-3}x^2$	$y=-728.57+4.78x-7.24*10^{-3}x^2$	$y=-166.39+0.93x-7.83*10^{-4}x^2$	$y=-131.24+0.76x-6.62*10^{-4}x^2$
Max 1st INC	59	58	47	41

3.2.2) 120 deg. Turn degree

3.2.2.1) 2 deg/100ft TUR

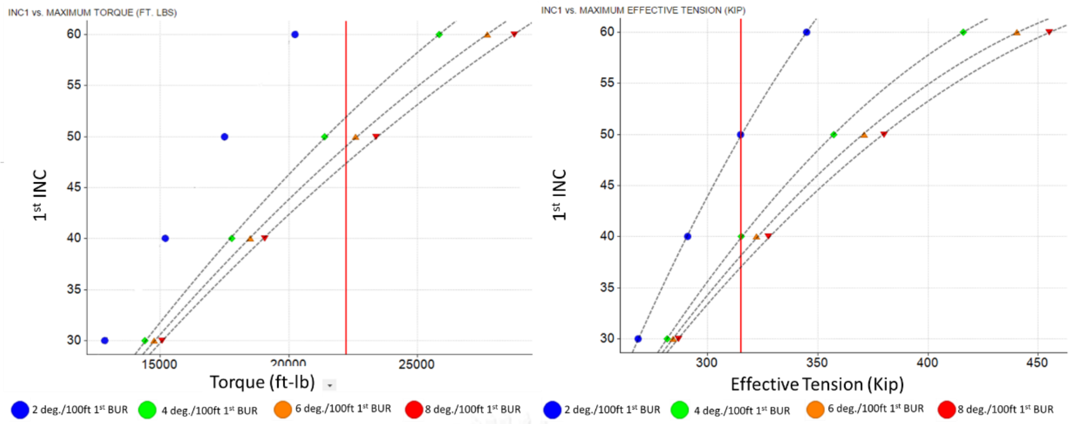


Figure 35: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 120 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 69: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.		$y=-26.85+4.67*10^{-3}x-5.07*10^{-8}x^2$	$y=-22.05+4.16*10^{-3}x-4.32*10^{-8}x^2$	$y=-18.92+3.80*10^{-3}x-3.65*10^{-8}x^2$
Max 1st INC	60	51	48	46

Table 70: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=-181.90+1.10x-1.15*10^{-3}x^2$	$y=-115.25+0.71x-7.04*10^{-4}x^2$	$y=-96.37+0.61x-5.74*10^{-4}x^2$	$y=-85.24+0.54x-4.92*10^{-4}x^2$
Max 1st INC	49	39	38	36

3.2.2.2) 4 deg/100ft TUR

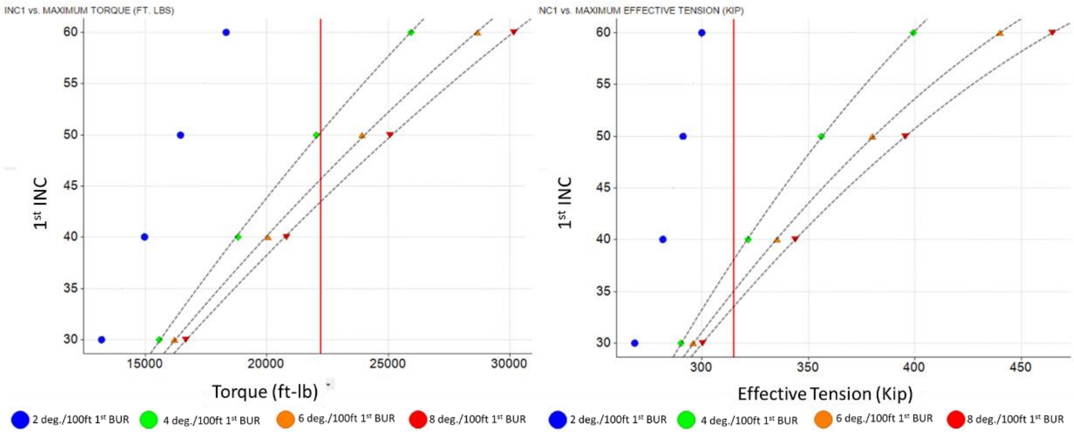


Figure 36: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 120 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 71: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.		$y=-32.38+4.65*10^{-3}x-4.18*10^{-8}x^2$	$y=-23.94+3.83*10^{-3}x-3.14*10^{-8}x^2$	$y=-20.48+3.46*10^{-3}x-2.63*10^{-8}x^2$
Max 1st INC	60	49	45	42

Table 72: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.		$y=-122.15+0.70x-6.22*10^{-4}x^2$	$y=-92.97+0.55x-4.70*10^{-4}x^2$	$y=-79.62+0.48x-3.93*10^{-4}x^2$
Max 1st INC	60	38	35	33

3.2.2.3) 6 deg/100ft TUR

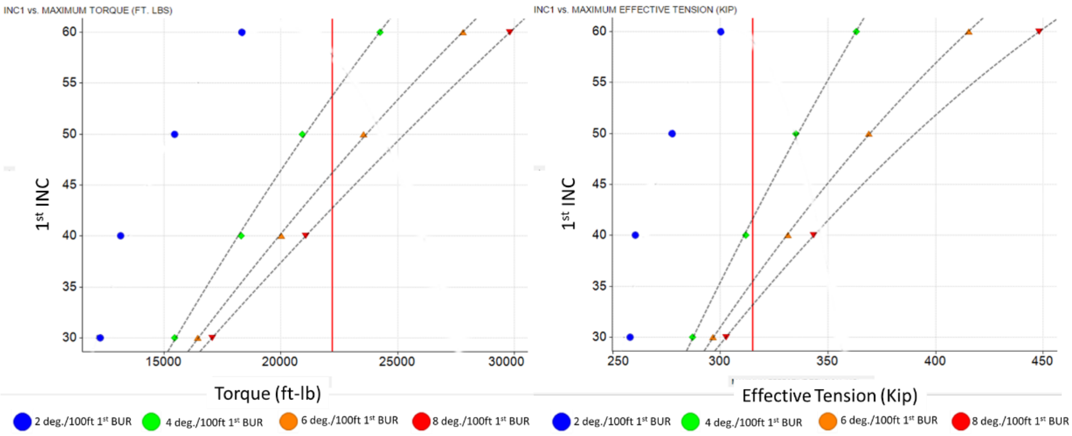


Figure 37: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 120 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 73: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-42.67+5.48*10^{-3}x-5.15*10^{-8}x^2$	$y=-27.81+4.02*10^{-3}x-3.08*10^{-8}x^2$	$y=-18.45+3.12*10^{-3}x-1.63*10^{-8}x^2$
Max 1st INC	60	53	45	42

Table 74: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-136.03+0.72x-4.99*10^{-4}x^2$	$y=-103.59+0.59x-4.74*10^{-4}x^2$	$y=-82.11+0.48x-3.67*10^{-4}x^2$
Max 1st INC	60	41	35	33

3.2.2.4) 8 deg/100ft TUR

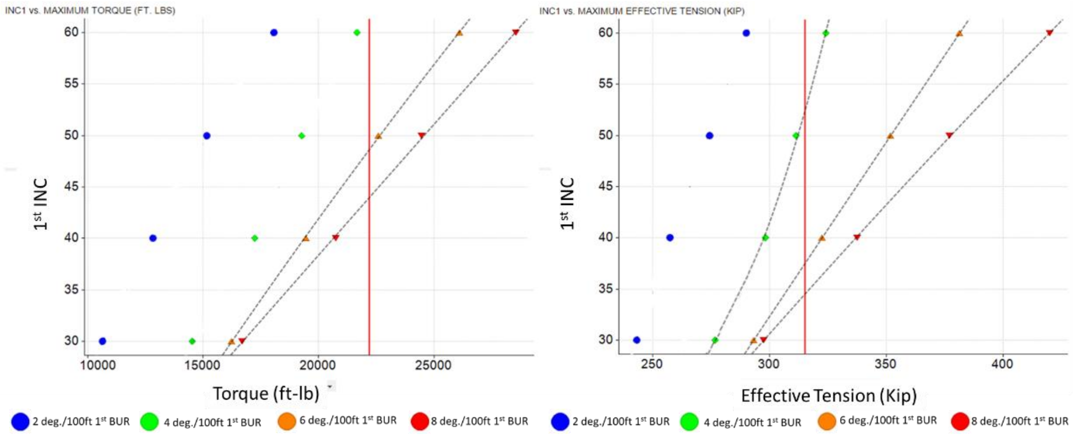


Figure 38: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 120 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 75: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.			$y=-28.28+3.92*10^{-3}x-2.06*10^{-8}x^2$	$y=-12.87+2.58*10^{-3}x-7.59*10^{-10}x^2$
Max 1st INC	60	60	48	43

Table 76: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.		$y=376.68-2.87x+5.83*10^{-3}x^2$	$y=-71.97+0.35x-1.97*10^{-5}x^2$	$y=-55.54+0.32x-1.00*10^{-4}x^2$
Max 1st INC	60	52	37	34

3.2.3) 150 deg. Turn degree

3.2.3.1) 2 deg/100ft TUR

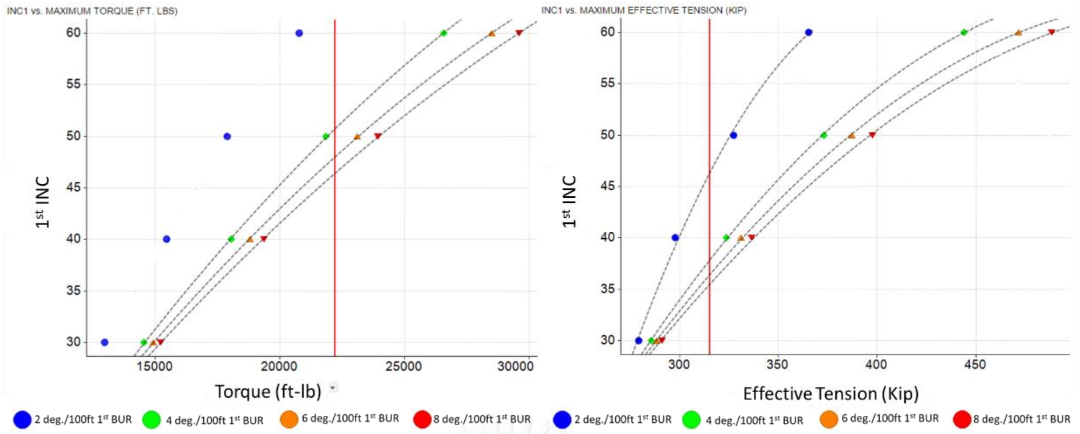


Figure 39: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 150 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 77: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.		$y=-25.24+4.49*10^{-3}x-4.83*10^{-8}x^2$	$y=-20.69+4.01*10^{-3}x-4.13*10^{-8}x^2$	$y=-17.90+3.68*10^{-3}x-3.53*10^{-8}x^2$
Max 1st INC	60	50	47	45

Table 78: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=271.26-1.64x+2.02*10^{-3}x^2$	$y=-96.51+0.61x-5.73*10^{-4}x^2$	$y=80.81-0.52x+4.69*10^{-4}x^2$	$y=71.47-0.47x+4.05*10^{-4}x^2$
Max 1st INC	46	37	36	35

3.2.3.2) 4 deg/100ft TUR

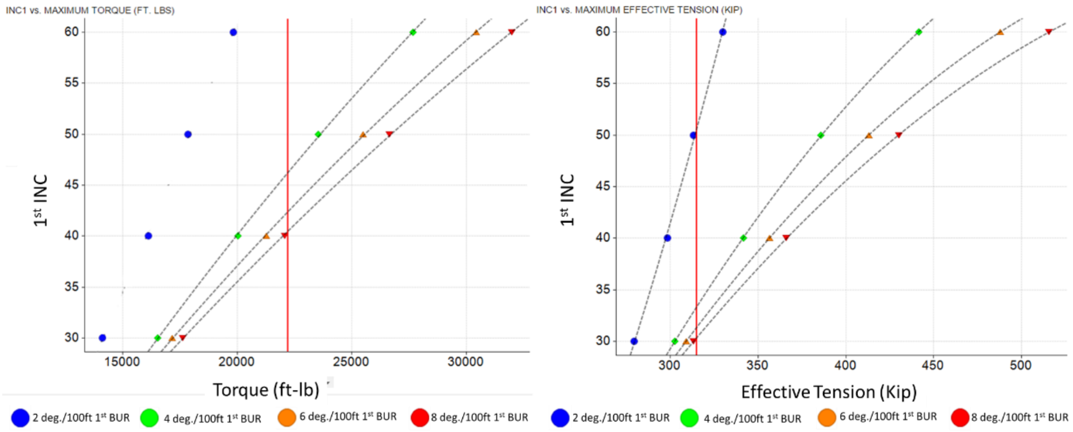


Figure 40: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 150 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 79: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.		y=-28.33+4.02* 10^{-3}x-2.98*10-8x2	y=-21.65+3.42* 10^{-3}x-2.41*10-8x2	y=-18.60+3.12* 10^{-3}x-2.06*10-8x2
Max 1st INC	60	45	41	40

Table 80: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	y=33.19 -0.09x+1.14*$10^{-3}x^2$	y=-91.70+0.53x -4.20*$10^{-4}x^2$	y=-71.65+0.43x -3.30*$10^{-4}x^2$	y=60.55 -0.37x+2.73*$10^{-4}x^2$
Max 1st INC	50	33	31	30

3.2.3.3) 6 deg/100ft TUR

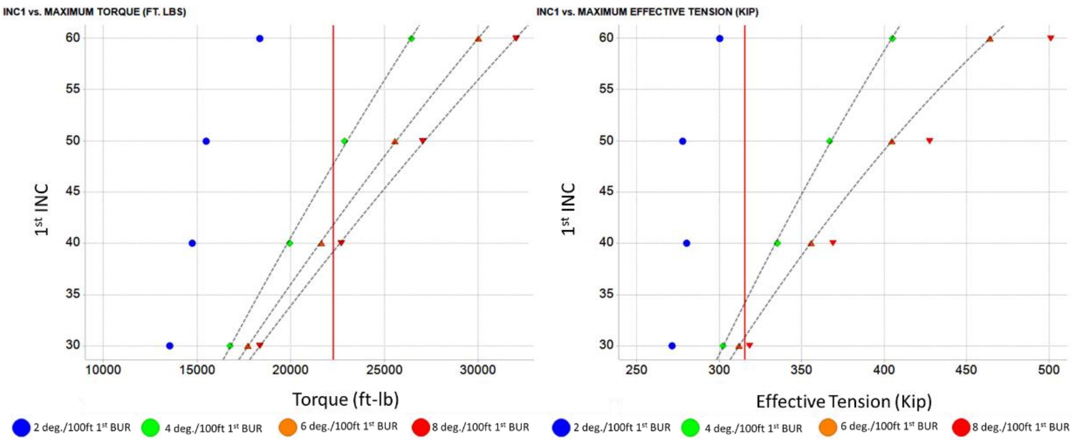


Figure 41: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 150 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 81: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-34.86+4.34*10^{-3}x-2.80*10^{-8}x^2$	$y=-24.05+3.41*10^{-3}x-2.02*10^{-8}x^2$	$y=-11.24+2.22*10^{-3}x-1.61*10^{-9}x^2$
Max 1st INC	60	46	41	38

Table 82: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-99.46+0.53x-3.31*10^{-4}x^2$	$y=-62.52+0.44x-3.09*10^{-4}x^2$	
Max 1st INC	60	34	30	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

3.2.3.4) 8 deg/100ft TUR

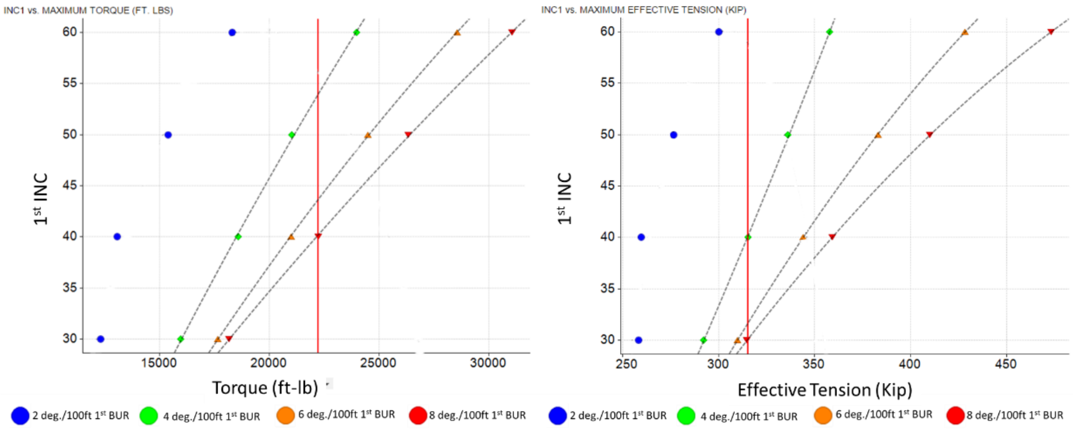


Figure 42: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 150 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 93: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.		$y=-46.51+5.44*10^{-3}x-4.16*10^{-8}x^2$	$y=-37.63+4.49*10^{-3}x-3.74*10^{-8}x^2$	$y=-24.21+3.36*10^{-3}x-2.08*10^{-8}x^2$
Max 1st INC	60	53	43	39

Table 94: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.		$y=-63.76+0.21x-3.87.*10^{-4}x^2$	$y=-110.24+0.60x-4.66*10^{-4}x^2$	$y=-77.44+0.44x-3.20*10^{-4}x^2$
Max 1st INC	60	39	31	30

3.2.4) 180 deg. Turn degree

3.2.4.1) 2 deg/100ft TUR

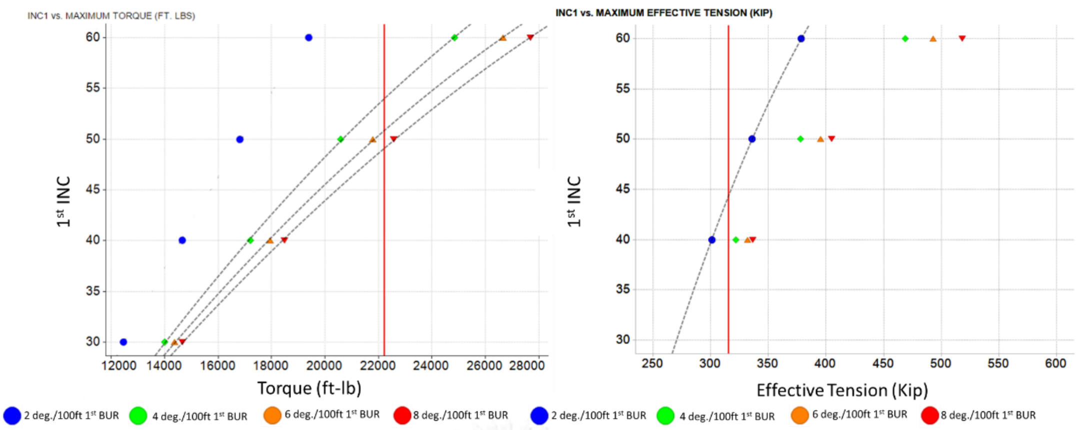


Figure 43: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 95: The maximum 1st INC, by torque criteria

Torque				
1st TUR	2			
1st BUR	2	4	6	8
Eq.		$y=-30.70+5.21*10^{-3}x-6.87*10^{-8}x^2$	$y=-22.29+4.23*10^{-3}x-4.74*10^{-8}x^2$	$y=-20.99+4.08*10^{-3}x-4.63*10^{-8}x^2$
Max 1st INC	60*	50*	47*	46*

Table 96: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	2			
1st BUR	2	4	6	8
Eq.	$y=-111.55+0.70x-6.52*10^{-4}x^2$			
Max 1st INC	44**	-	-	-

Remark

* cannot design with inclination lower than 30 deg.

** cannot design with inclination lower than 40 deg.

\- cannot design due to exceed torque and drag limit

3.2.4.2) 4 deg/100ft TUR

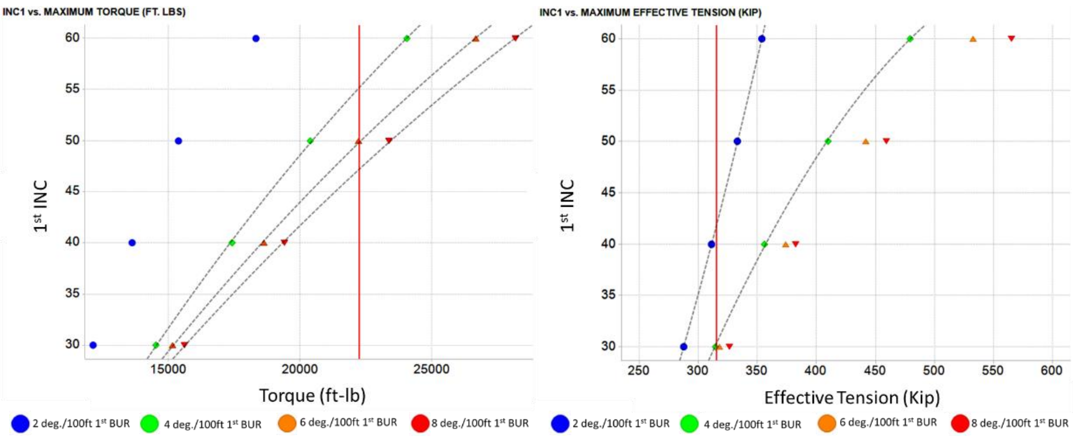


Figure 44: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 97: The maximum 1st INC, by torque criteria

Torque				
1st TUR	4			
1st BUR	2	4	6	8
Eq.		$y=-36.80+4.63*10^{-3}x-4.44*10^{-8}x^2$	$y=-18.95+3.11*10^{-3}x-1.97*10^{-8}x^2$	$y=-23.63+3.42*10^{-3}x-2.74*10^{-8}x^2$
Max 1st INC	60	43	39	38

Table 98: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	4			
1st BUR	2	4	6	8
Eq.	$y=-26.92-0.01x+7.21*10^{-4}x^2$	$y=-89.77+0.51x-4.18*10^{-4}x^2$		
Max 1st INC	41	30	-	-

Remark

- cannot design due to exceed torque and drag limit

3.2.4.3) 6 deg/100ft TUR

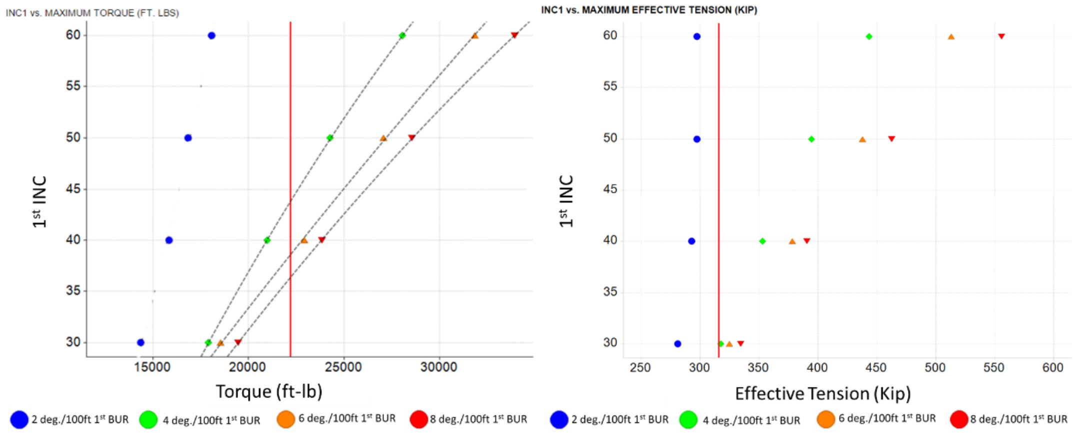


Figure 45: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 99: The maximum 1st INC, by torque criteria

Torque				
1st TUR	6			
1st BUR	2	4	6	8
Eq.		$y=-45.74+5.04*10^{-3}x-4.52*10^{-8}x^2$	$y=-19.26+2.87*10^{-3}x-1.18*10^{-8}x^2$	$y=-24.94+3.25*10^{-3}x-2.20*10^{-8}x^2$
Max 1st INC	60	43	38	35

Table 100: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	6			
1st BUR	2	4	6	8
Eq.				
Max 1st INC	60	-	-	-

Remark

- cannot design due to exceed torque and drag limit

3.2.4.4) 8 deg/100ft TUR

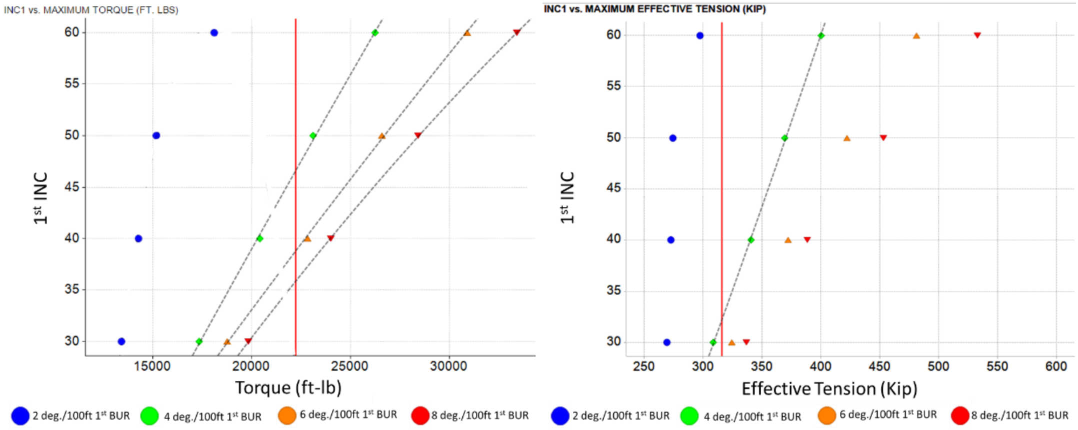


Figure 46: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build and hold profile.

Table 101: The maximum 1st INC, by torque criteria

Torque				
1st TUR	8			
1st BUR	2	4	6	8
Eq.		$y=-33.16+3.79*10^{-3}x-9.03*10^{-9}x^2$	$y=-22.27+2.96*10^{-3}x-9.50*10^{-9}x^2$	$y=-28.40+3.38*10^{-3}x-2.21*10^{-8}x^2$
Max 1st INC	60	45	38	35

Table 102: The maximum 1st INC, by effective tension criteria

Effective Tension				
1st TUR	8			
1st BUR	2	4	6	8
Eq.		$y=-63.04+0.35x-1.99*10^{-4}x^2$		
Max 1st INC	60	31	-	-

Remark

- cannot design due to exceed torque and drag limit

4.) 2D Build, Hold and Drop

4.1) 1000ft TVD 1st KOP with immediate 2nd KOP

4.1.1) 90 deg. Turn degree

4.1.1.1) 2 deg/100ft TUR

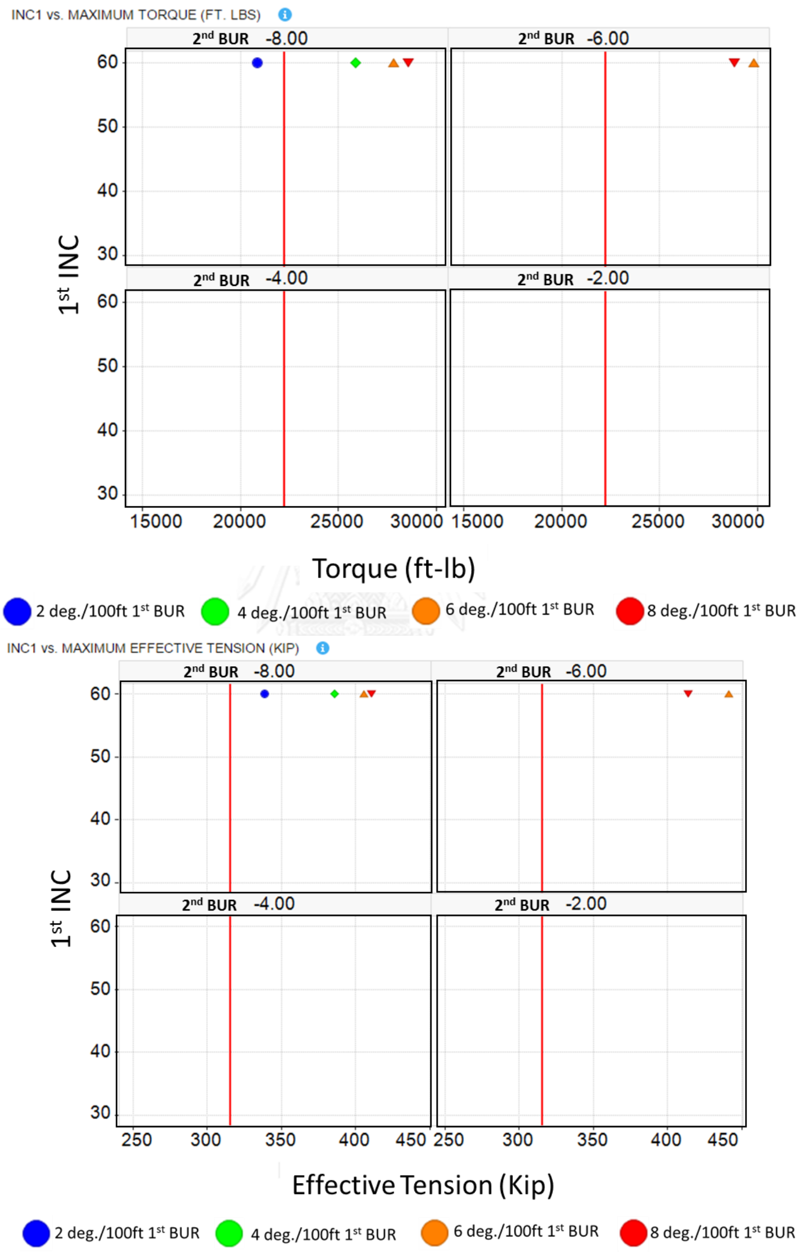


Figure 47: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 103: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	-	-
-8	Eq.				
	r^2				
	Max 1st INC	60*	-	-	-

Table 104: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	-	-
-8	Eq.				
	r^2				
	Max 1st INC	-	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.1.2) 4 deg/100ft TUR

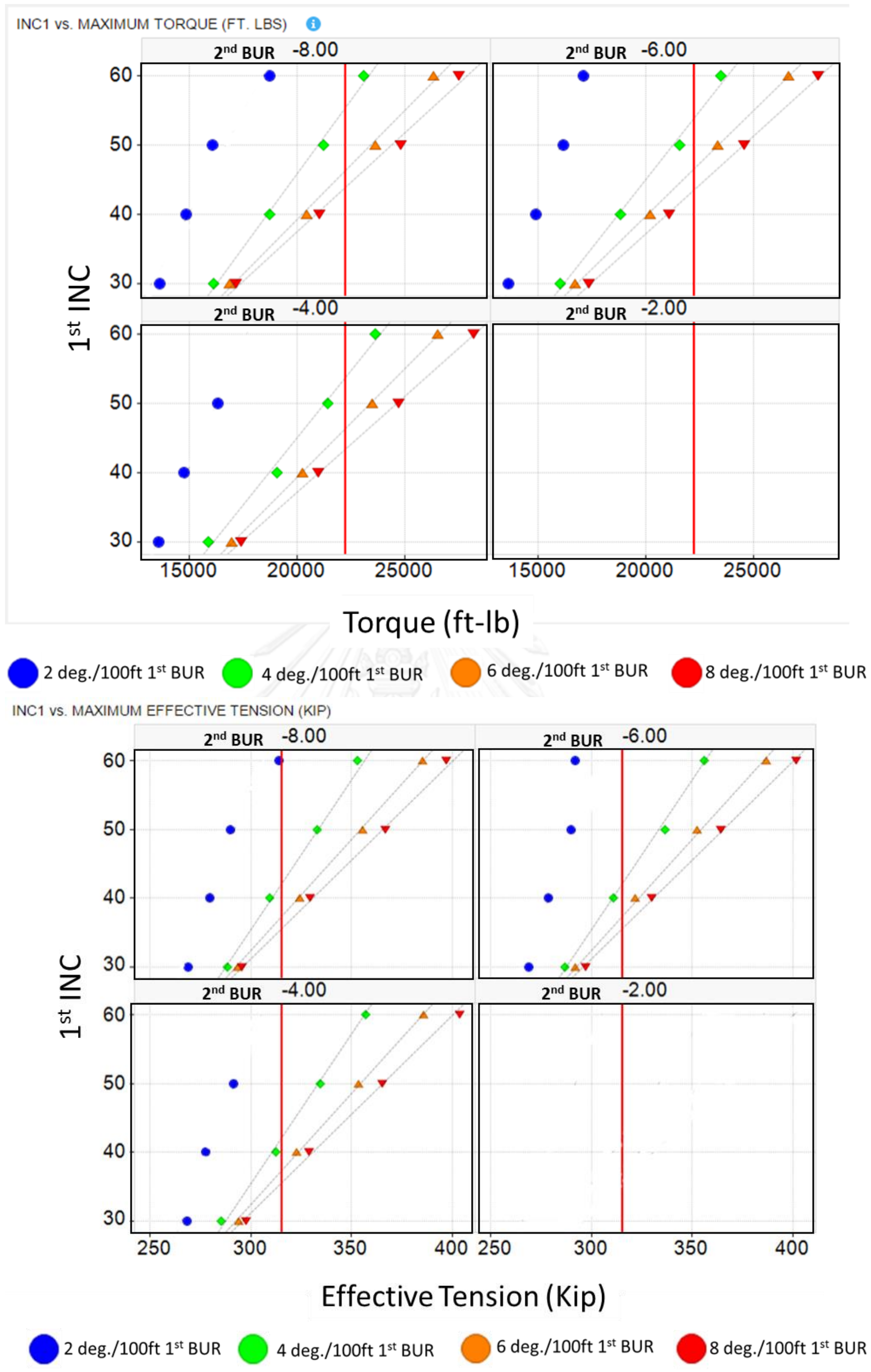


Figure 48: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 105: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	x	x	x
-4	Eq.		$y=-32.52+3.88*10^{-3}x$	$y=-23.39+3.1410^{-3}x$	$y=-18.28+2.77*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	50	53	46	43
-6	Eq.		$y=-34.12+3.96*10^{-3}x$	$y=-21.28+3.05*10^{-3}x$	$y=-19.27+2.83*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	53	46	43
-8	Eq.		$y=-39.24+4.26*10^{-3}x$	$y=-23.8+3.16*10^{-3}x$	$y=-19.63+2.86*10^{-3}x$
	r^2		1.00	1.00	0.99
	Max 1st INC	60	54	46	43

Table 106: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		$y=-90.83+421.28*10^{-3}x$	$y=-65.65+326.3*10^{-3}x$	$y=-53.16+281.29*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	50	42	37	35
-6	Eq.		$y=-93.44+429.1*10^{-3}x$	$y=-62.25+316.99*10^{-3}x$	$y=-55.22+287.67*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	38	35
-8	Eq.		$y=-102.12+458.29*10^{-3}x$	$y=-65.55+325.4*10^{-3}x$	$y=-56.42+292.02*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	37	36

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.1.3) 6 deg/100

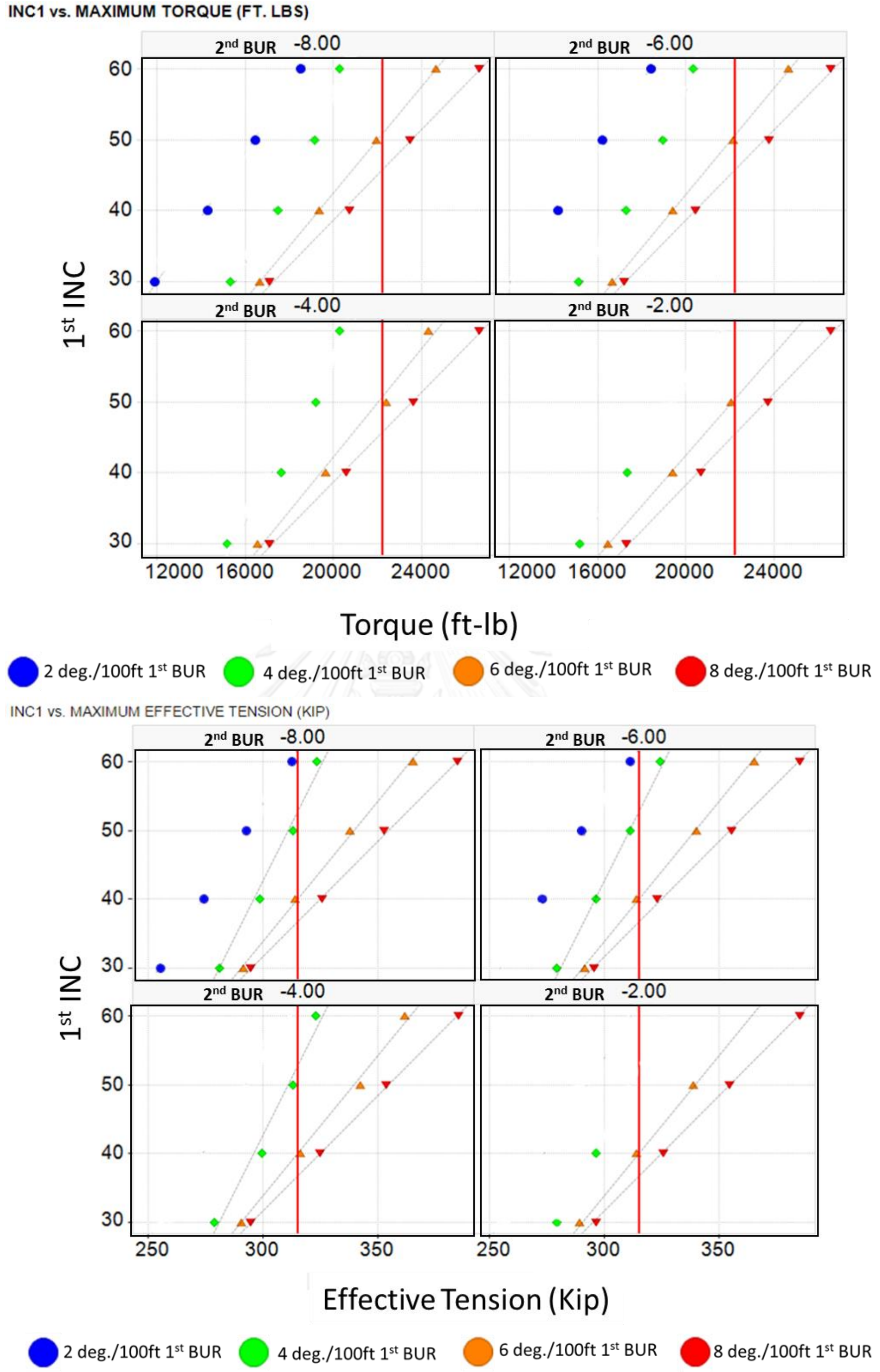


Figure 49: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 107: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-28.77+3.56*10^{-3}x$	$y=-26.19+3.22*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	x	40	50	45
-4	Eq.			$y=-34.11+3.82*10^{-3}x$	$y=-24.5+3.16*10^{-3}x$
	r^2			0.99	1.00
	Max 1st INC	x	60	50	45
-6	Eq.			$y=-32.68+3.75*10^{-3}x$	$y=-24.78+3.17*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60*	60	50	45
-8	Eq.			$y=-32.46+3.75*10^{-3}x$	$y=-25.13+3.19*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60	60	50	45

Table 108: The maximum 1^{st} INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-87.38+405.67*10^{-3}x$	$y=-70.19+338.48*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	x	40	40	36
-4	Eq.		$y=-158.07+668.77*10^{-3}x$	$y=-91.17+415.55*10^{-3}x$	$y=-67.83+332.35*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	x	53	40	37
-6	Eq.		$y=-154.97+660.31*10^{-3}x$	$y=-87.59+404.56*10^{-3}x$	$y=-67.53+331.26*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60*	53	40	37
-8	Eq.		$y=-166.27+694.73*10^{-3}x$	$y=-87.79+405.83*10^{-3}x$	$y=-69.28+336.65*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	53	40	37

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.1.4) 8 deg/100ft TUR

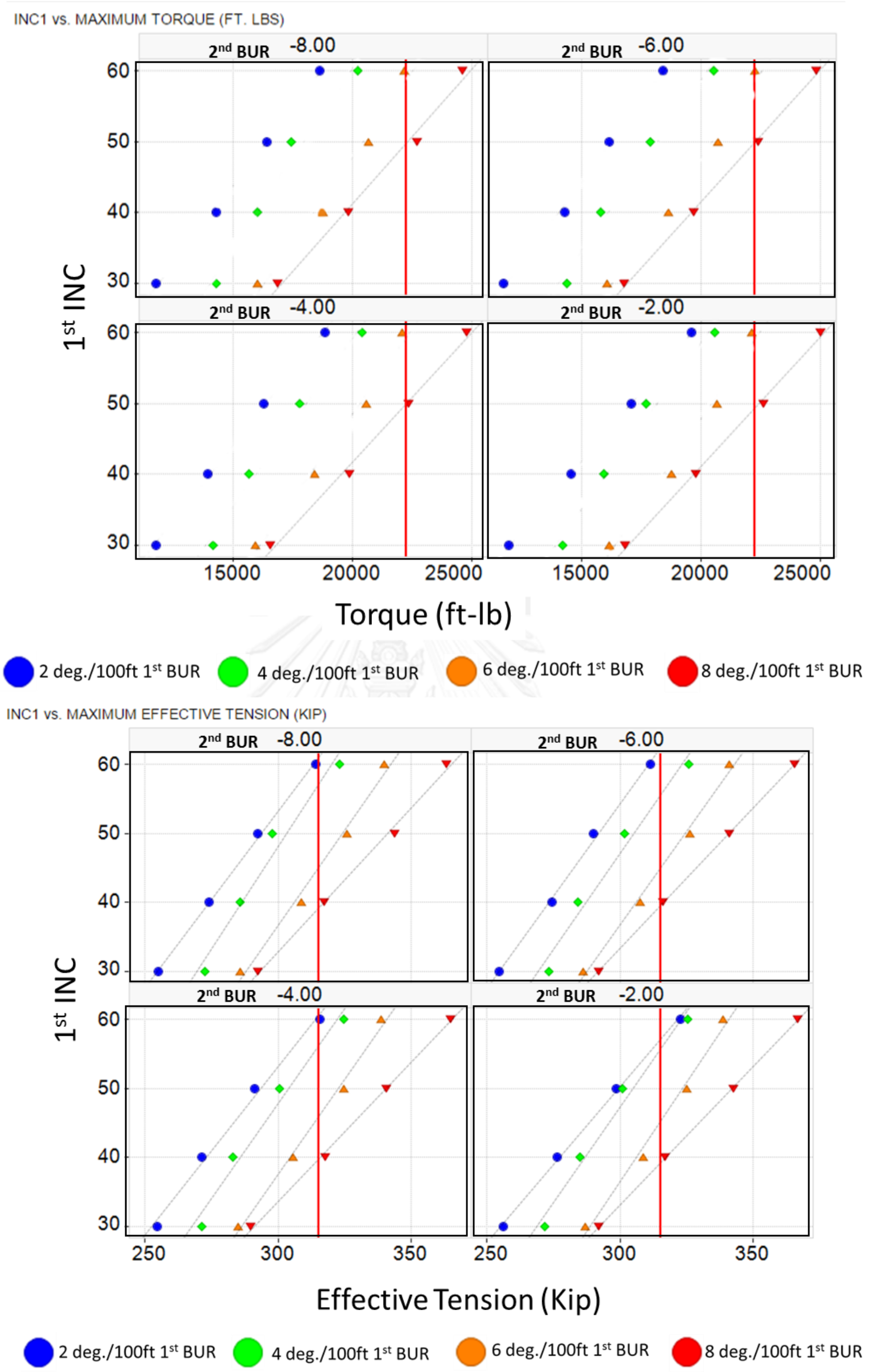


Figure 50: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 109: The maximum 1st INC, by torque criteria

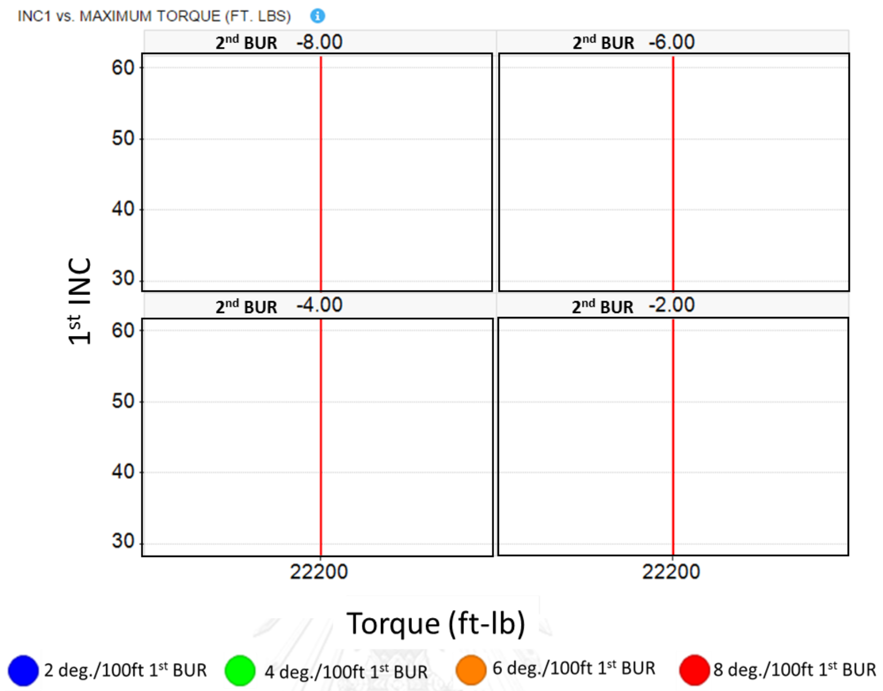
	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-51.26+4.96*10^{-3}x$	$y=-32.16+3.67*10^{-3}x$
	r^2			0.98	1.00
	Max 1st INC	60	60	58	48
-4	Eq.			$y=-47.1+4.78*10^{-3}x$	$y=-31.56+3.67*10^{-3}x$
	r^2			0.99	0.99
	Max 1st INC	60	60	58	49
-6	Eq.			$y=-48.01+4.79*10^{-3}x$	$y=-33.15+3.73*10^{-3}x$
	r^2			0.99	1.00
	Max 1st INC	60	60	57	49
-8	Eq.			$y=-48.85+4.84*10^{-3}x$	$y=-34.93+3.81*10^{-3}x$
	r^2			0.98	0.99
	Max 1st INC	60	60	58	49

Table 110: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-85.16+451.41*10^{-3}x$	$y=-118.54+552.83*10^{-3}x$	$y=-136.16+575.62*10^{-3}x$	$y=-87.22+401.22*10^{-3}x$
	r^2	1.00	0.98	0.99	1.00
	Max 1st INC	57	56	45	39
-4	Eq.	$y=-93.1+487.56*10^{-3}x$	$y=-117.07+549.66*10^{-3}x$	$y=-127.55+550.46*10^{-3}x$	$y=-87.54+403.94*10^{-3}x$
	r^2	0.99	0.98	0.99	1.00
	Max 1st INC	60	56	46	40
-6	Eq.		$y=-119.57+555.6*10^{-3}x$	$y=-125.62+541.35*10^{-3}x$	$y=-88.66+406.81*10^{-3}x$
	r^2		0.97	0.99	1.00
	Max 1st INC	60	55	45	39
-8	Eq.		$y=-129.68+592.64*10^{-3}x$	$y=-128.78+551.58*10^{-3}x$	$y=-92.27+417.14*10^{-3}x$
	r^2		0.97	0.99	1.00
	Max 1st INC	60	57	45	39

4.1.2) 120 deg. Turn degree

4.1.2.1) 2 deg/100ft TUR



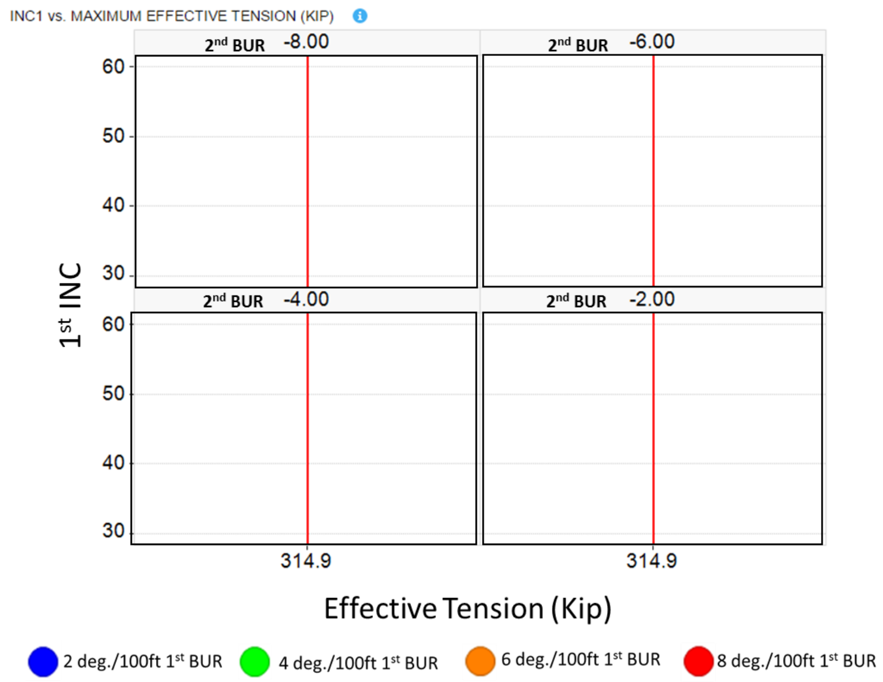


Figure 50: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 111: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 112: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.2.2) 4 deg/100ft TUR

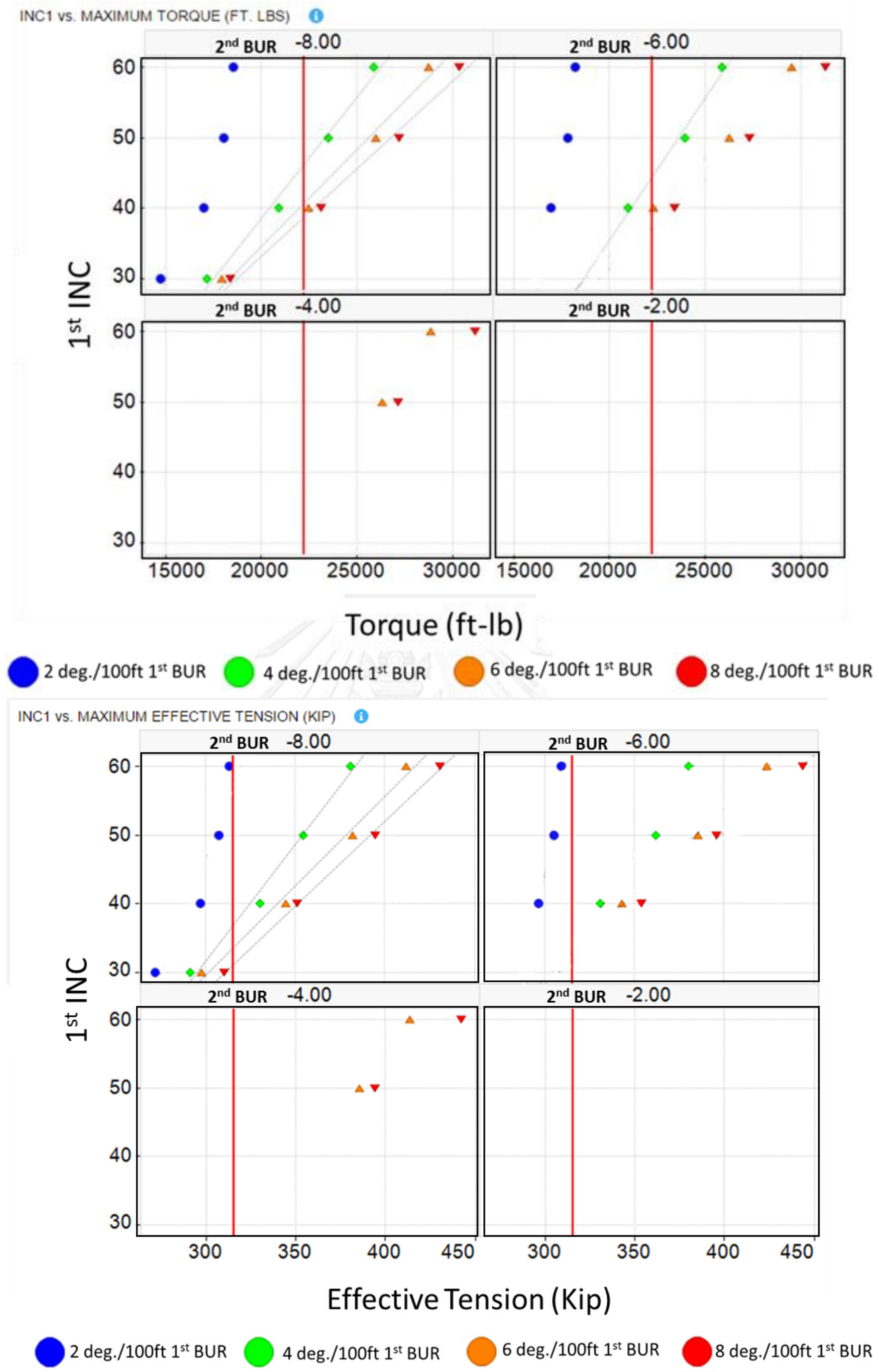


Figure 51: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 113: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-6	Eq.		$y=-45.01+4.02*10^{-3}x$	$y=-21.64+2.75*10^{-3}x$	$y=-19.27+2.53*10^{-3}x$
	r^2		0.98	1.00	1.00
	Max 1st INC	60	44	39	36
-8	Eq.		$y=-30.07+3.43*10^{-3}x$	$y=-20.42+2.75*10^{-3}x$	$y=-16.42+2.48*10^{-3}x$
	r^2		0.99	0.99	0.99
	Max 1st INC	60	45	40	38

Table 114: The maximum 1st INC, by effective tension criteria

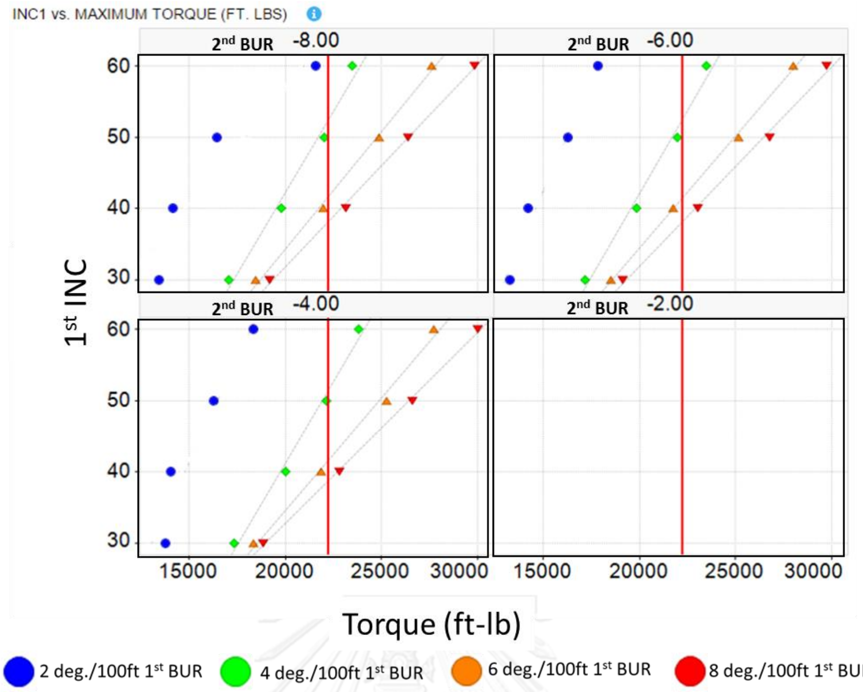
	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-6	Eq.		$y=-92.88+399.25*10^{-3}x$	$y=-45.7+249.15*10^{-3}x$	$y=-38.57+222.6*10^{-3}x$
	r^2		0.98	1.00	1.00
	Max 1st INC	60	33	33	32
-8	Eq.		$y=-70.55+340.43*10^{-3}x$	$y=-48.77+261.01*10^{-3}x$	$y=-47.01+247.57*10^{-3}x$
	r^2		0.99	0.99	1.00
	Max 1st INC	60	37	33	31

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.2.3) 6 deg/100ft TUR



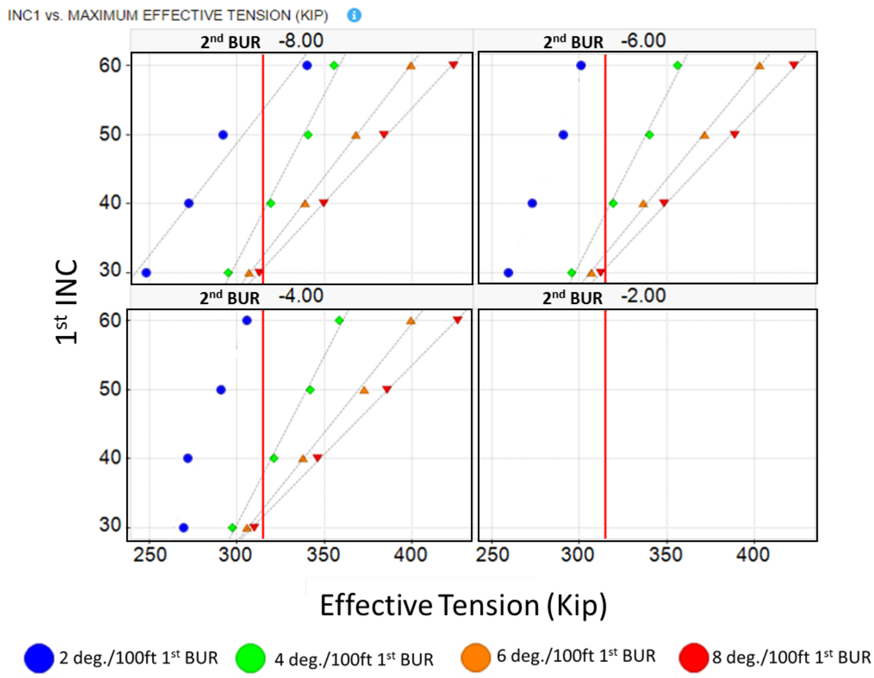


Figure 52: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 115: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		$y=-50.17+4.57*10^{-3}x$	$y=-28.35+3.15*10^{-3}x$	$y=-20.55+2.67*10^{-3}x$
	r^2		0.99	0.99	1.00
	Max 1st INC	60	50	41	38
-6	Eq.		$y=-50.88+4.65*10^{-3}x$	$y=-28.06+3.13*10^{-3}x$	$y=-23.89+2.79*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	52	41	38
-8	Eq.		$y=-48.57+4.55*10^{-3}x$	$y=-31.38+3.29*10^{-3}x$	$y=-24.75+2.83*10^{-3}x$
	r^2		0.98	1.00	1.00
	Max 1st INC	60	51	41	38

Table 116: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		$y=-115.74+487.48*10^{-3}x$	$y=-66.57+315.4*10^{-3}x$	$y=-49.4+257.32*10^{-3}x$
	r^2		0.99	1	1
	Max 1st INC	60	38	33	32
-6	Eq.		$y=-116.56+492.7*10^{-3}x$	$y=-64.46+308.69*10^{-3}x$	$y=-54.24+269.67*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	39	33	31
-8	Eq.	$y=-48.65+324.76*10^{-3}x$	$y=-114.11+485.65*10^{-3}x$	$y=-70.73+327.64*10^{-3}x$	$y=-55.23+272.73*10^{-3}x$
	r^2	0.96	0.99	1.00	1.00
	Max 1st INC	54	39	32	31

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.2.4) 8 deg/100ft TUR

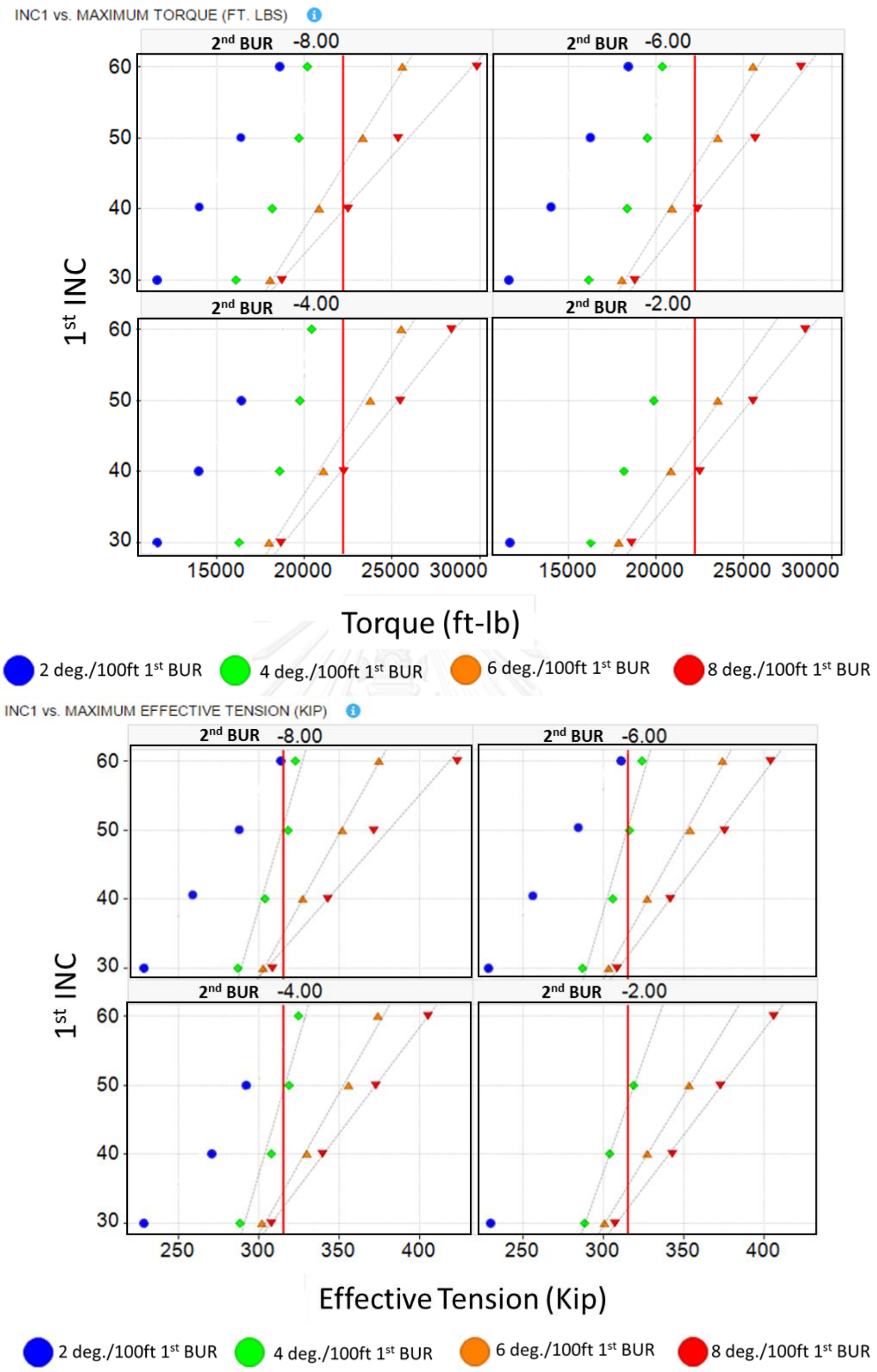


Figure 53: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 117: The maximum 1st INC, by torque criteria

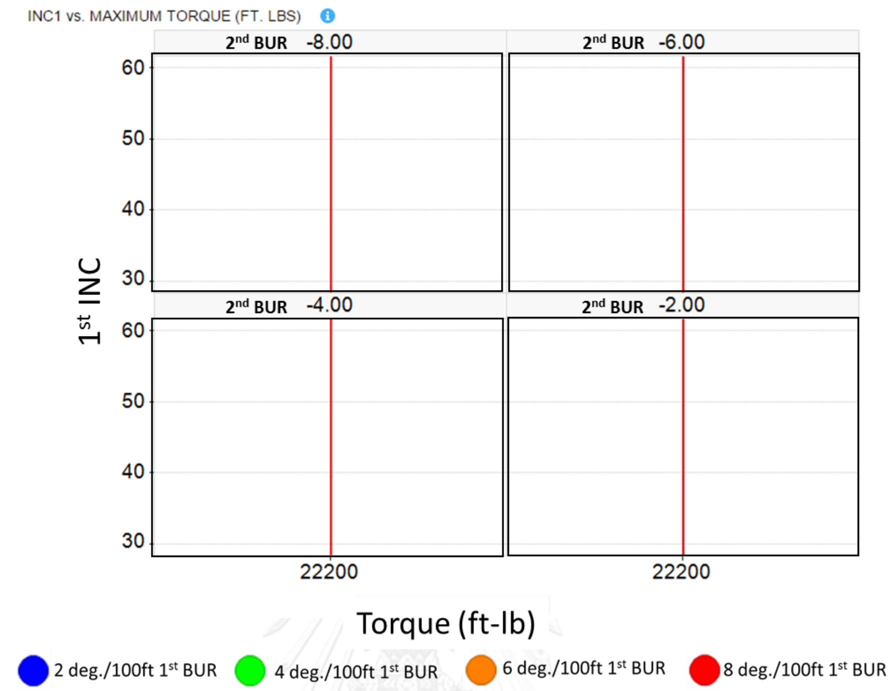
	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-41.25+3.91*10^{-3}x$	$y=-27.97+3.08*10^{-3}x$
	r^2			0.98	1.00
	Max 1st INC	30	50	45	40
-4	Eq.			$y=-41.25+3.91*10^{-3}x$	$y=-27.97+3.08*10^{-3}x$
	r^2			0.98	1.00
	Max 1st INC	50	60	45	40
-6	Eq.			$y=-42.42+3.97*10^{-3}x$	$y=-29.37+3.13*10^{-3}x$
	r^2			0.99	0.99
	Max 1st INC	60	60	45	39
-8	Eq.			$y=-42.18+3.97*10^{-3}x$	$y=-21.34+2.75*10^{-3}x$
	r^2			1.00	0.99
	Max 1st INC	60	60	45	39

Table 118: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-158.71+653.59*10^{-3}x$	$y=-84.02+378.76*10^{-3}x$	$y=-64+305.08*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	30	47	35	32
-4	Eq.		$y=-201.44+794.72*10^{-3}x$	$y=-94.15+408.51*10^{-3}x$	$y=-64.57+307.3*10^{-3}x$
	r^2		0.94	0.99	1.00
	Max 1st INC	50	49	34	32
-6	Eq.		$y=-199.65+792.91*10^{-3}x$	$y=-96.74+417.23*10^{-3}x$	$y=-66.76+312.64*10^{-3}x$
	r^2		0.96	1.00	1.00
	Max 1st INC	60	50	35	32
-8	Eq.		$y=-197.02+785.33*10^{-3}x$	$y=-96.35+416.59*10^{-3}x$	$y=-50.37+263.63*10^{-3}x$
	r^2		0.95	1.00	0.98
	Max 1st INC	60	50	35	33

4.1.3) 150 deg. Turn degree

4.1.3.1) 2 deg/100ft TUR



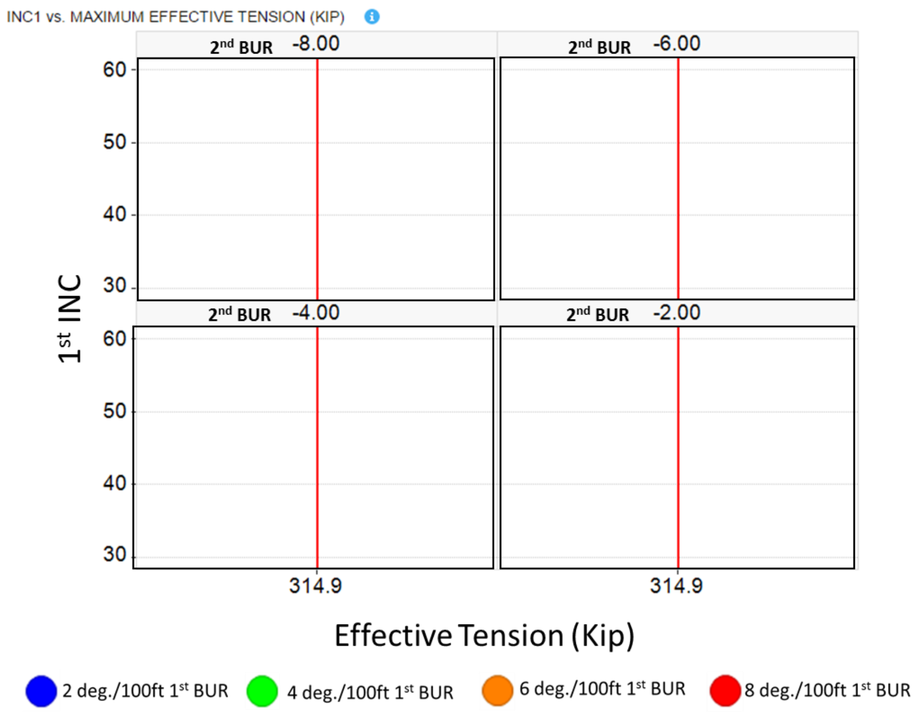


Figure 54: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 119: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 120: The maximum 1st INC, by effective tension criteria

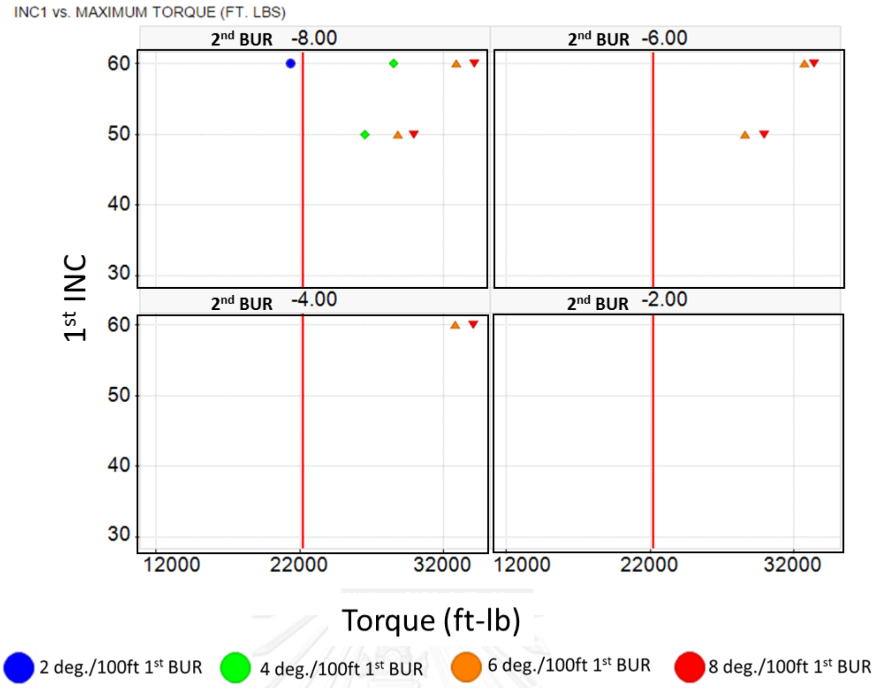
	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

- cannot design due to exceed torque and drag limit

4.1.3.2) 4 deg/100ft TUR



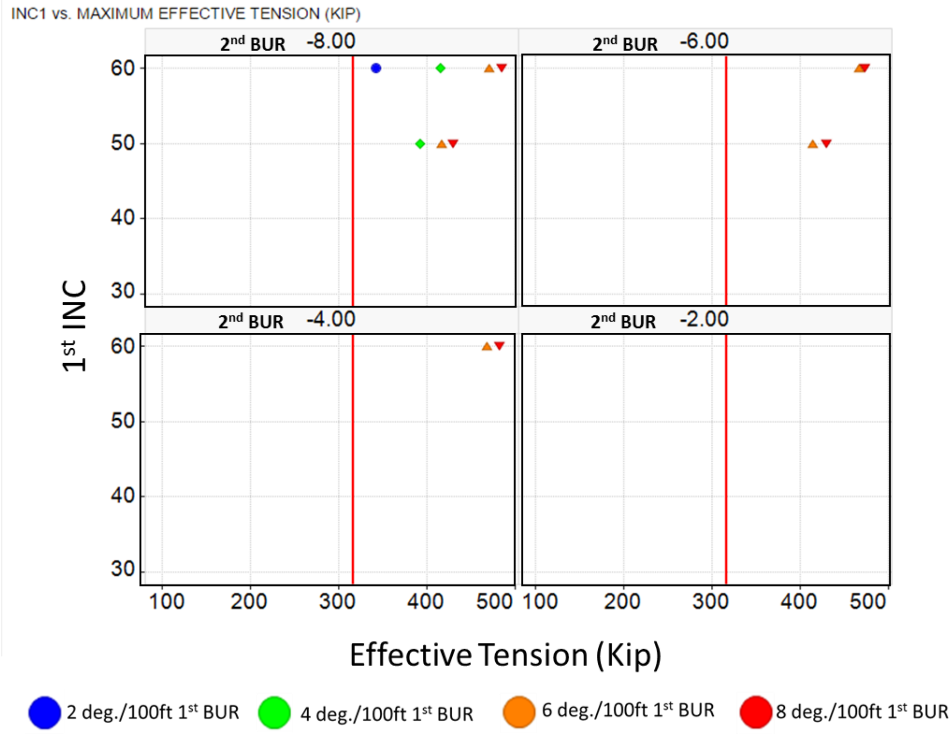


Figure 55: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 121: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-8	Eq.				
	r^2				
	Max 1st INC	60*	x-	x-	x-

Table 122: The maximum 1st INC, by effective tension criteria

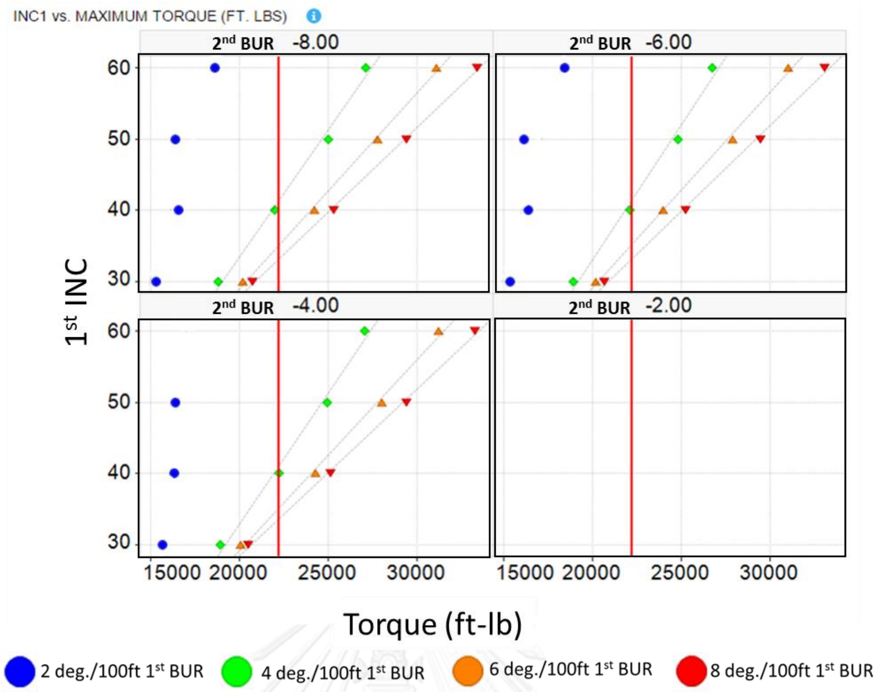
	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x-	x-
-8	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.3.3) 6 deg/100ft TUR



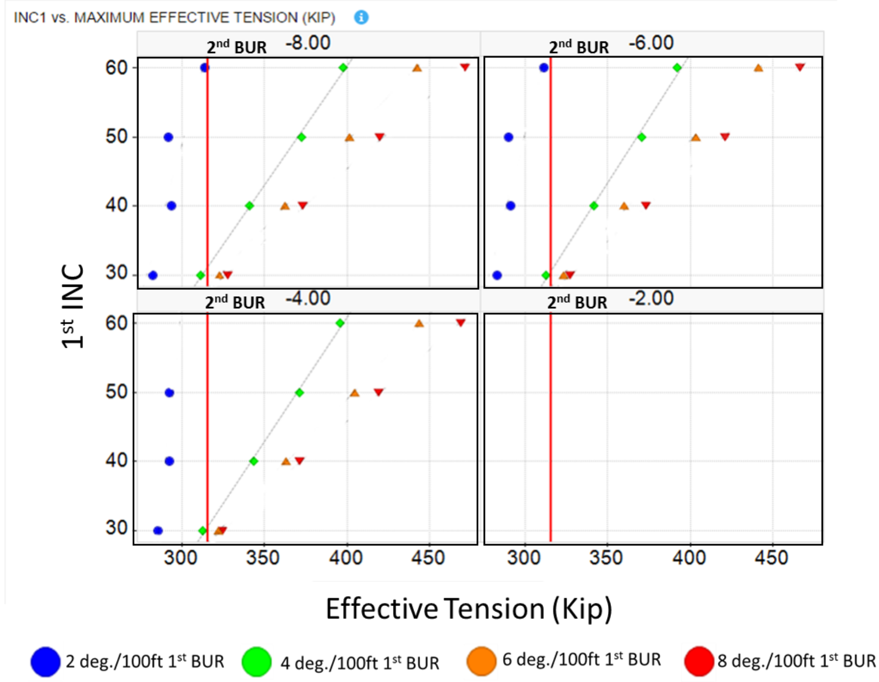


Figure 56: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile

Table 123: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		$y=-40.66+3.68*10^{-3}x$	$y=-24.34+2.68*10^{-3}x$	$y=-18.4+2.34*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	50	40	35	33
-6	Eq.		$y=-42.71+3.79*10^{-3}x$	$y=-25.74+2.74*10^{-3}x$	$y=-20.29+2.41*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	41	35	33
-8	Eq.		$y=-37.96+3.57*10^{-3}x$	$y=-25.98+2.75*10^{-3}x$	$y=-19.56+2.37*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	41	35	33

Table 124: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		$y=-82.28+357.74*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	50	30	-	-
-6	Eq.		$y=-86.54+371.28*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	60	30	-	-
-8	Eq.		$y=-77.17+343.5*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	60	31	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.3.4) 8 deg/100ft TU

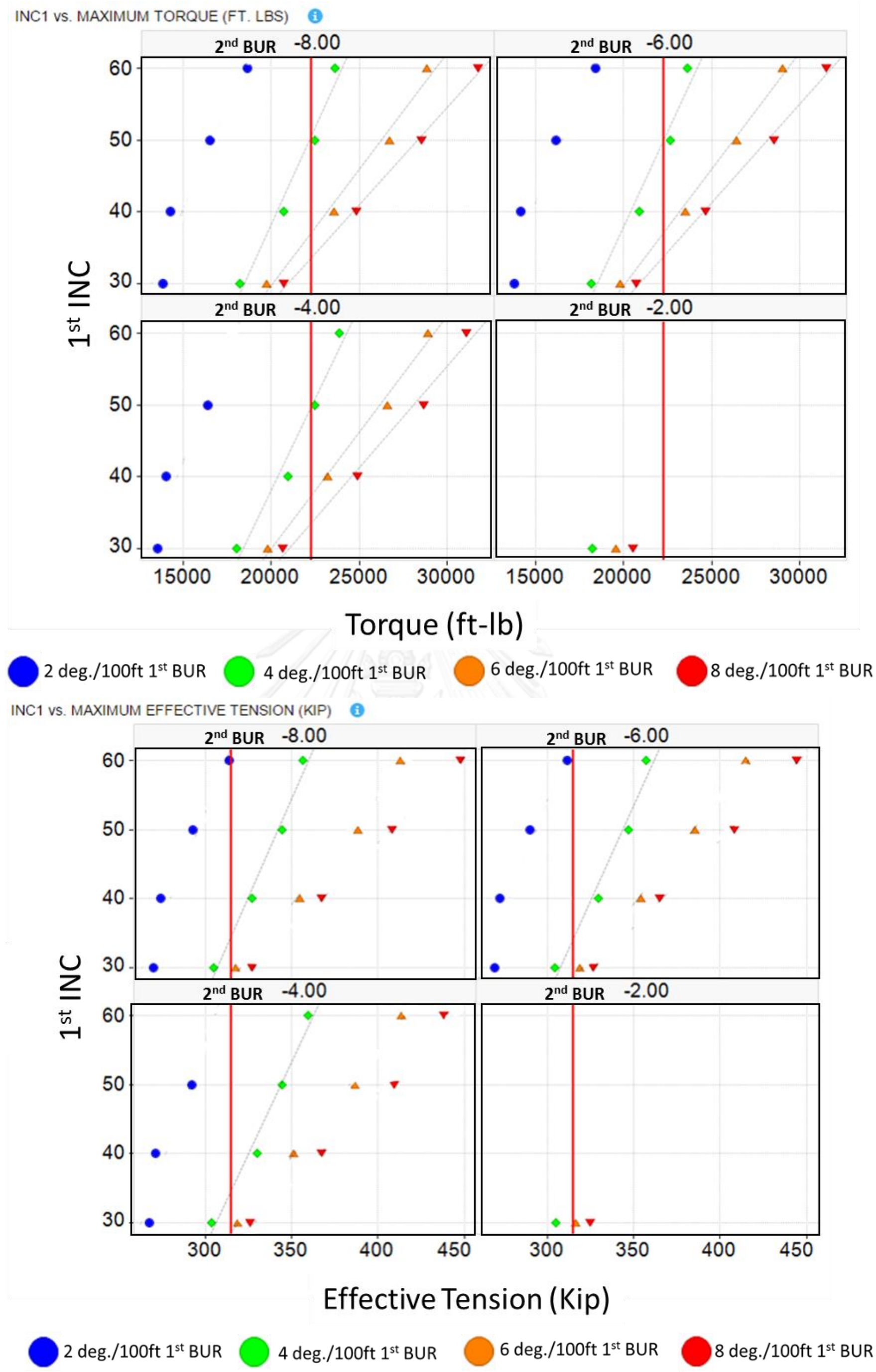


Figure 57: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 125: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	30*	30*	30*
-4	Eq.		$y=-63.8+5.1*10^{-3}x$	$y=-34.78+3.24*10^{-3}x$	$y=-29.28+2.82*10^{-3}x$
	r^2		0.97	0.99	0.99
	Max 1st INC	50	48	37	33
-6	Eq.		$y=-67.7+5.28*10^{-3}x$	$y=-35.1+3.24*10^{-3}x$	$y=-27.32+2.74*10^{-3}x$
	r^2		0.95	0.99	1.00
	Max 1st INC	60	49	36	33
-8	Eq.		$y=-69.68+5.4*10^{-3}x$	$y=-34.9+3.23*10^{-3}x$	$y=-26.71+2.71*10^{-3}x$
	r^2		0.97	0.98	1.00
	Max 1st INC	60	49	36	33

Table 126: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	30*	-	-
-4	Eq.		$y=-133.22+532.73*10^{-3}x$		
	r^2		0.98		
	Max 1st INC	50	35	-	-
-6	Eq.		$y=-139.8+552.14*10^{-3}x$		
	r^2		0.97		
	Max 1st INC	60	34	-	-
-8	Eq.		$y=-144.58+568.54*10^{-3}x$		
	r^2		0.98		
	Max 1st INC	60	34	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4) 180 deg. Turn degree

4.1.4.1) 2 deg/100ft TUR

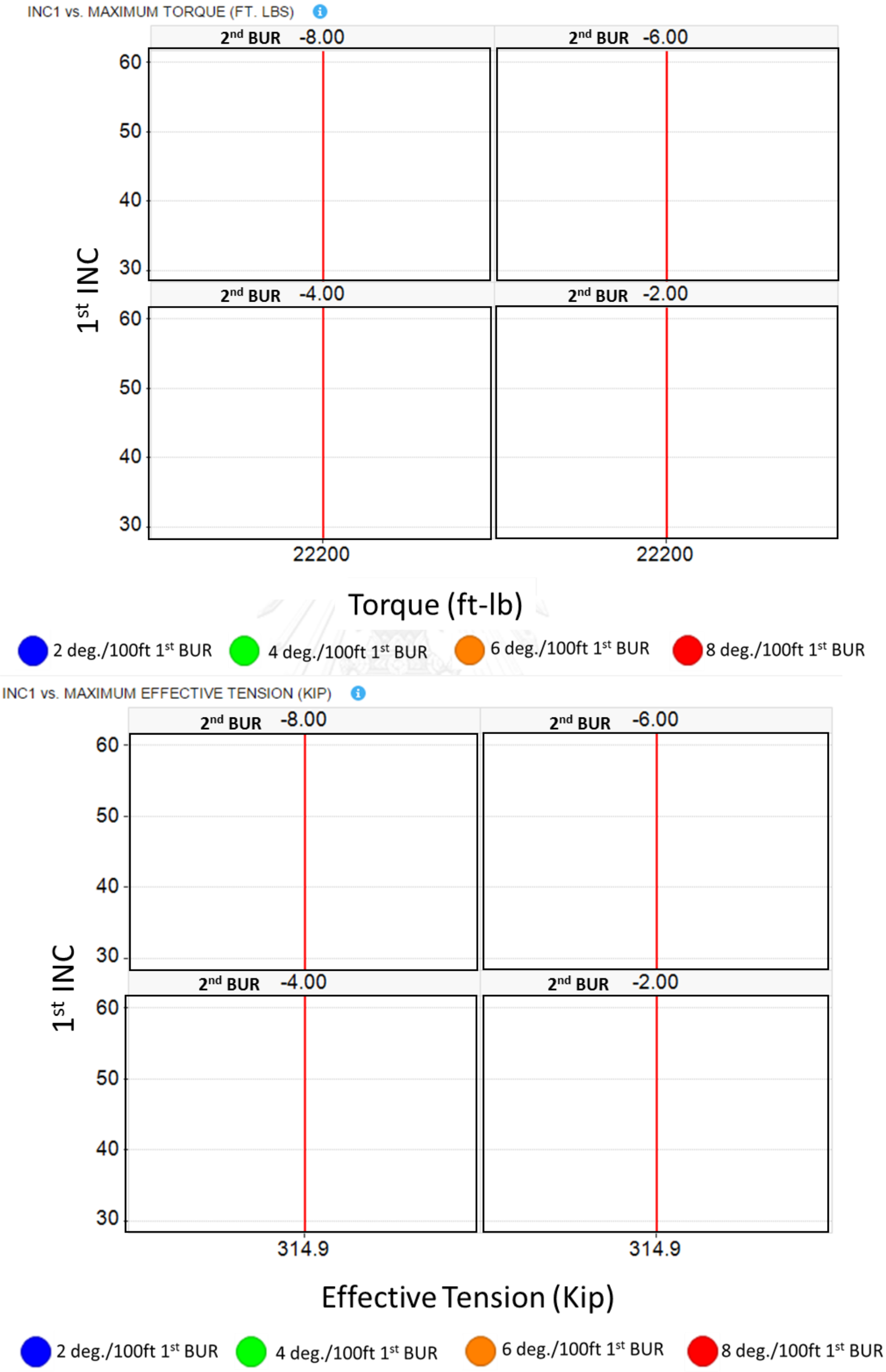


Figure 58: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 127: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 128: The maximum 1^{st} INC, by effective tension criteria

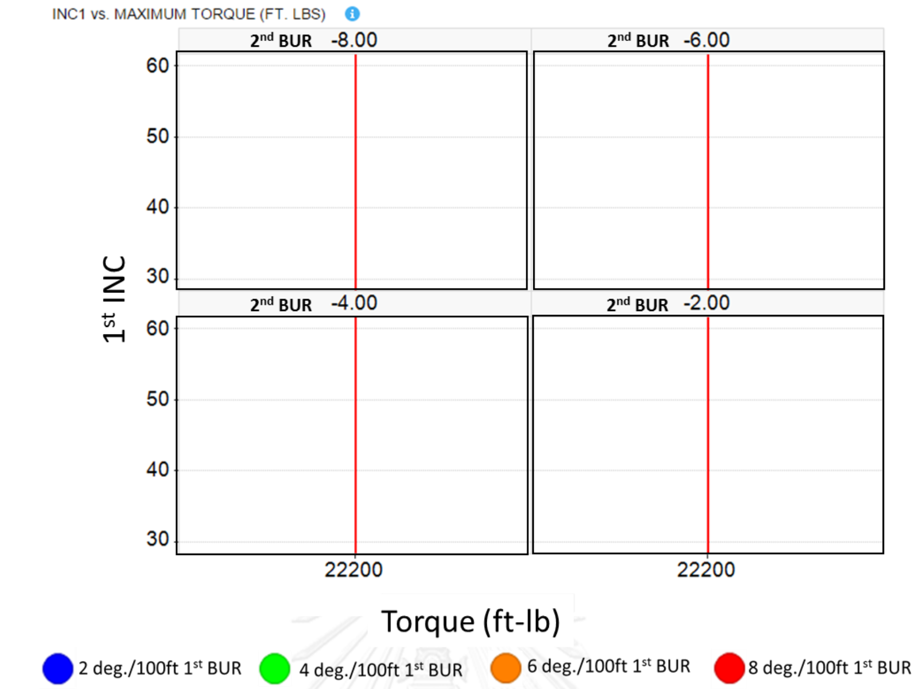
	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4.2) 4 deg/100ft TUR



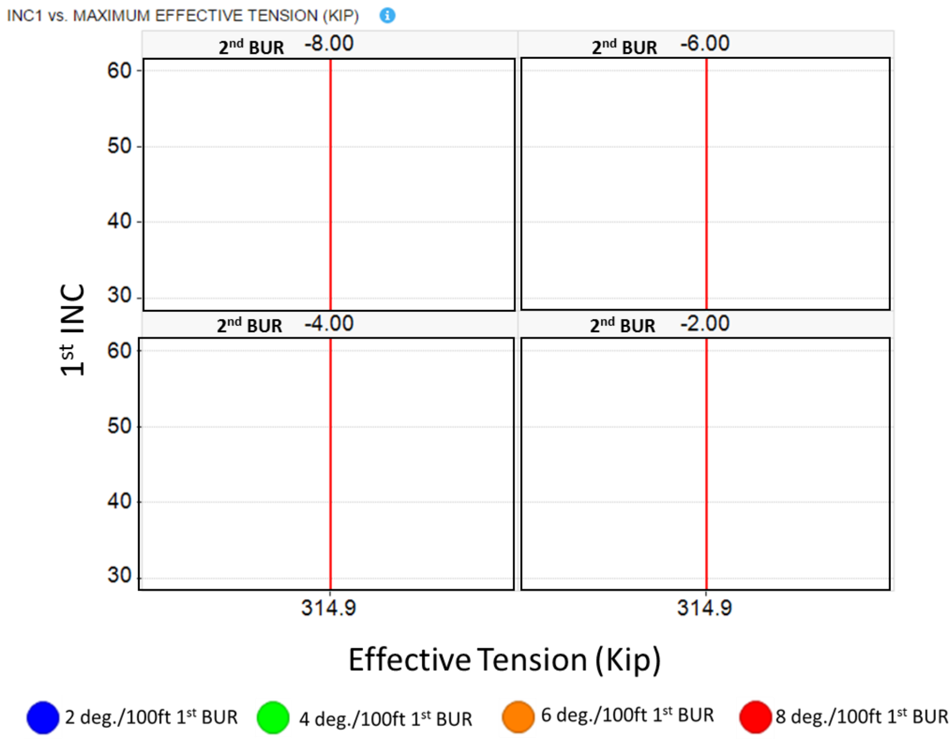


Figure 59: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 129: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 130: The maximum 1st INC, by effective tension criteria

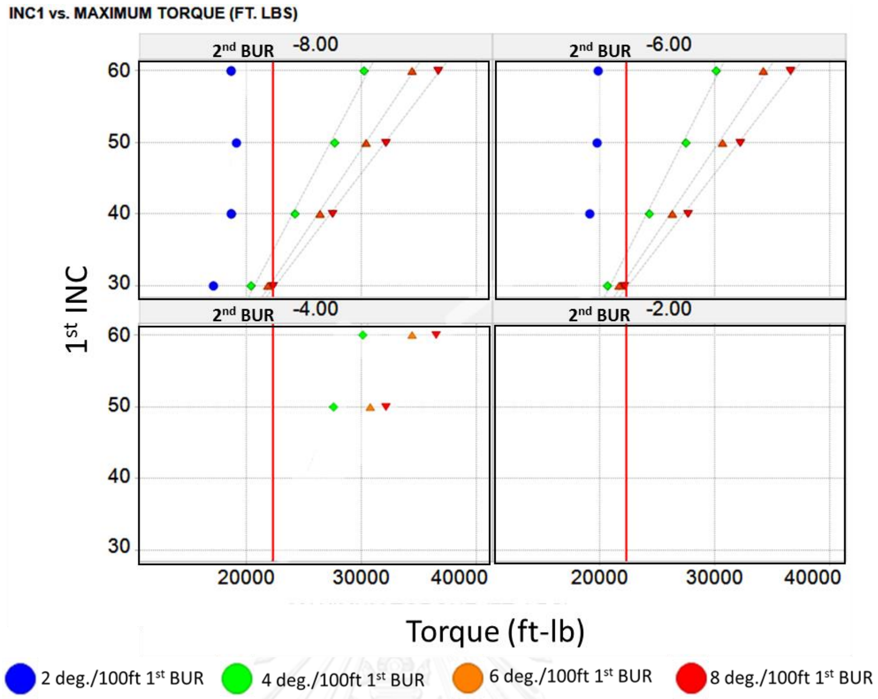
	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4.3) 6 deg/100ft TUR



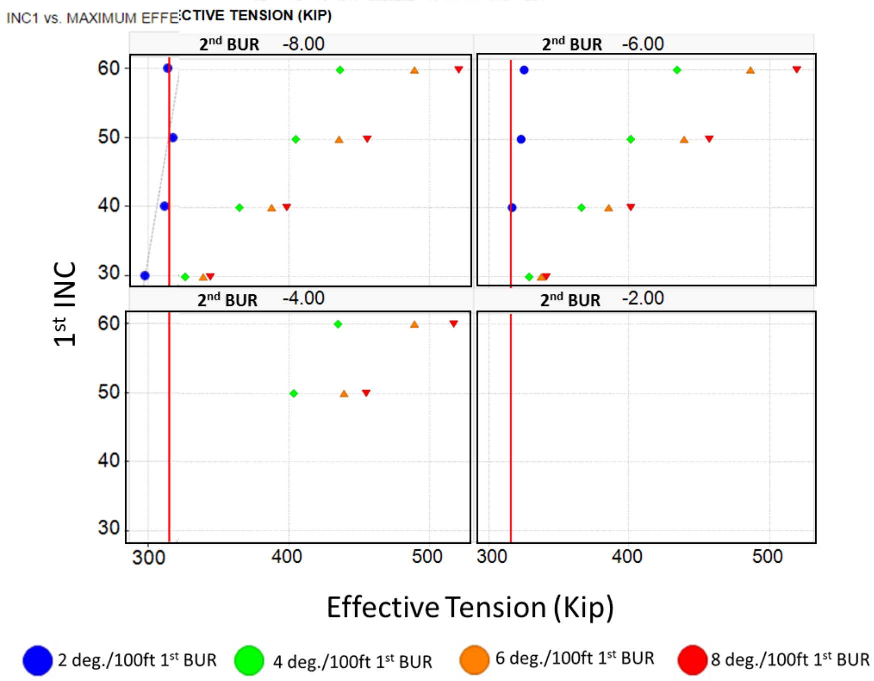


Figure 60: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 131: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x-	x-	x-
-6	Eq.		$y=-67.7+5.28*10^{-3}x$	$y=-35.1+3.24*10^{-3}x$	$y=-27.32+2.74*10^{-3}x$
	r^2		0.95	0.99	1.00
	Max 1st INC	60	49	36	33
-8	Eq.		$y=-69.68+5.4*10^{-3}x$	$y=-34.9+3.23*10^{-3}x$	$y=-26.71+2.71*10^{-3}x$
	r^2		0.97	0.98	1.00
	Max 1st INC	60	49	36	33

Table 132: The maximum 1^{st} INC, by effective tension criteria

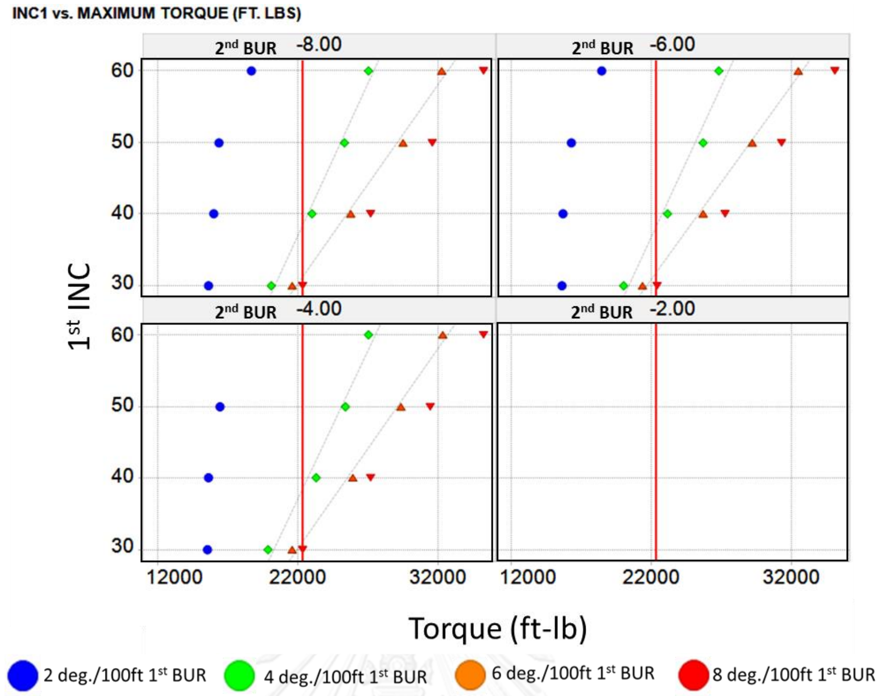
	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x-	x-	x-
-6	Eq.				
	r^2				
	Max 1st INC	-	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	50	x-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4.4) 8 deg/100ft TUR



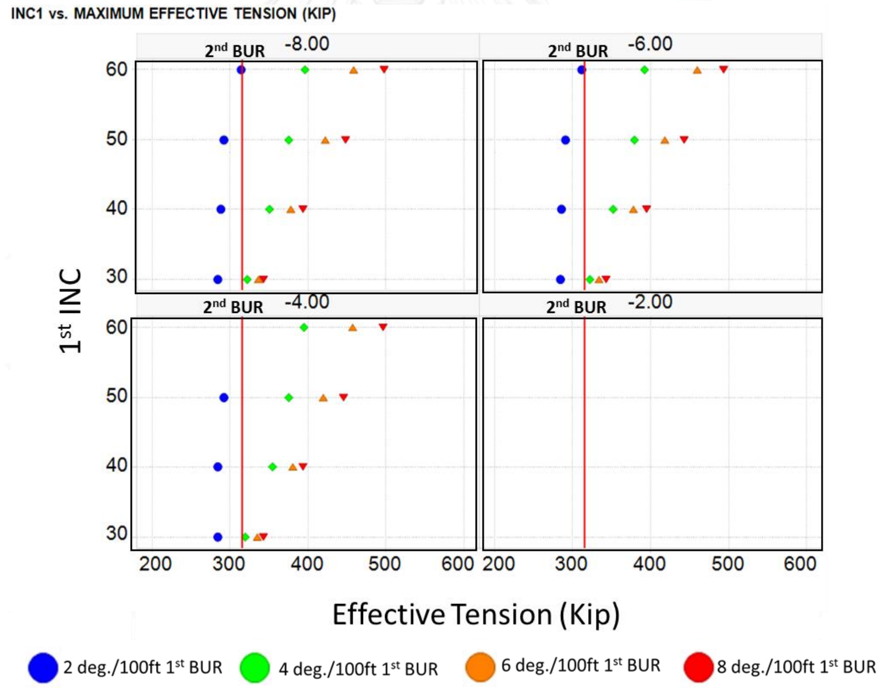


Figure 61: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 133: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.		y=-53.72+4.13*10-3x	y=-31.13+2.79*10-3x	
	r^2		0.97	0.99	
	Max 1st INC	50	37	31	-
-6	Eq.		y=-55.7+4.21*10-3x	y=-28.46+2.7*10-3x	
	r^2		0.96	1.00	
	Max 1st INC	60	37	31	-
-8	Eq.		y=-56.33+4.25*10-3x	y=-30.64+2.77*10-3x	
	r^2		0.99	0.99	
	Max 1st INC	60	37	31	-

Table 134: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	-	-	-	-
-6	Eq.				
	r^2				
	Max 1st INC	-	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	-	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.2) 1000ft TVD 1st KOP with 5300 ft TVD 2nd KOP

4.2.1) 90 deg. Turn degree

4.2.1.1) 2 deg/100ft TUR

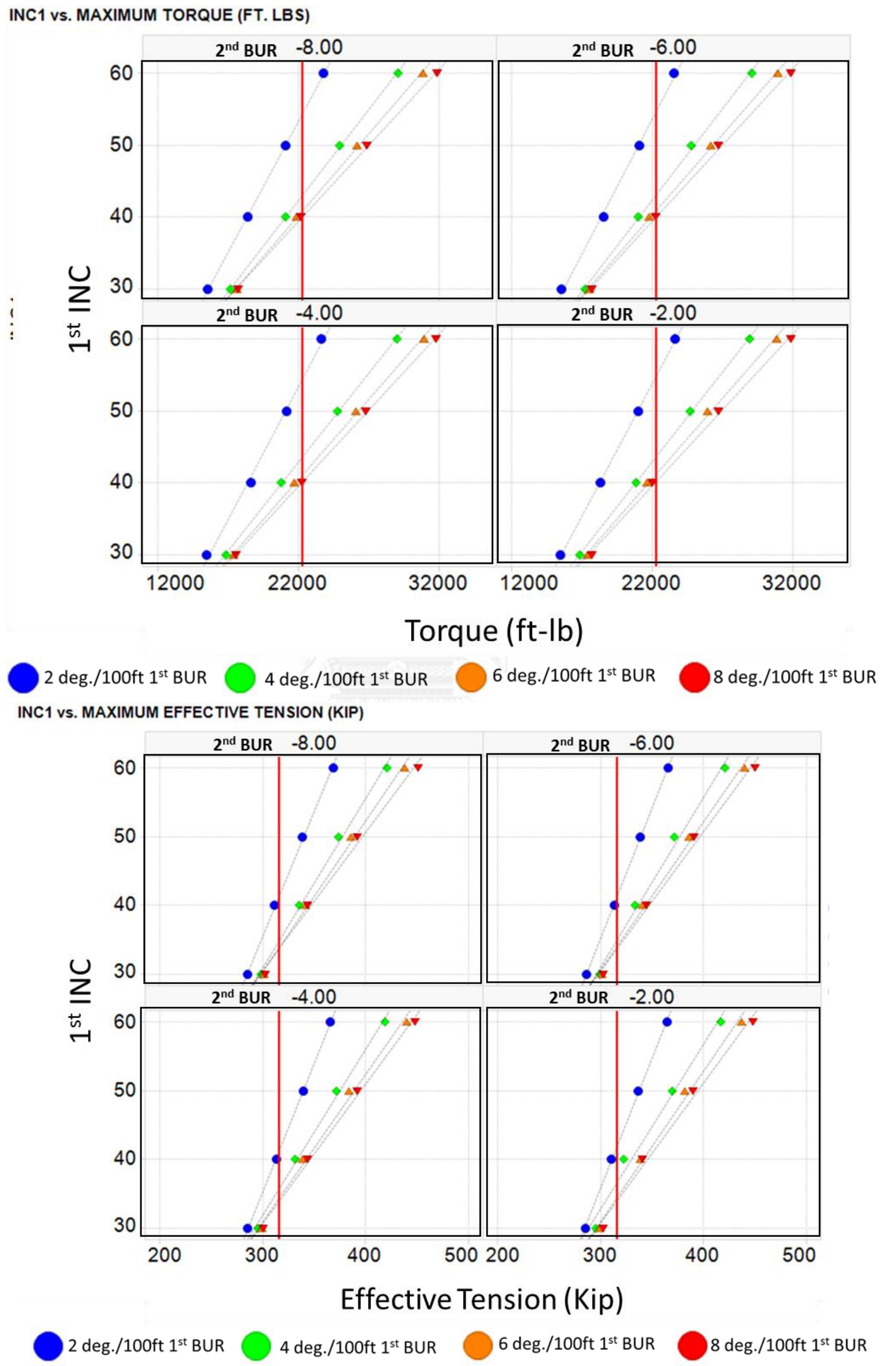


Figure 62: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 90 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 135: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-27.03+3.67*10^{-3}x$	$y=-11.87+2.49*10^{-3}x$	$y=-8.59+2.24*10^{-3}x$	$y=-6.88+2.11*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	54	43	41	40
-4	Eq.	$y=-27.76+3.69*10^{-3}x$	$y=-11.33+2.47*10^{-3}x$	$y=-8.46+2.23*10^{-3}x$	$y=-6.93+2.11*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	53	43	41	40
-6	Eq.	$y=-28.85+3.75*10^{-3}x$	$y=-13.54+2.54*10^{-3}x$	$y=-8.97+2.24*10^{-3}x$	$y=-7.24+2.12*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	54	42	40	39
-8	Eq.	$y=-26.65+3.64*10^{-3}x$	$y=-13.31+2.53*10^{-3}x$	$y=-9.79+2.27*10^{-3}x$	$y=-6.99+2.11*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	53	42	40	39

Table 136: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-77.21+376.98*10^{-3}x$	$y=-38.96+239.33*10^{-3}x$	$y=-34.62+218.71*10^{-3}x$	$y=-30.44+203.94*10^{-3}x$
	r^2	1	0.99	0.99	0.99
	Max 1st INC	42	36	34	34
-4	Eq.	$y=-76.75+373.43*10^{-3}x$	$y=-40.47+241.28*10^{-3}x$	$y=-33.32+214.29*10^{-3}x$	$y=-30.24+203.04*10^{-3}x$
	r^2	1	1.00	0.99	1.00
	Max 1st INC	41	36	34	34
-6	Eq.	$y=-78.6+379.47*10^{-3}x$	$y=-42.93+246.66*10^{-3}x$	$y=-33.93+215.31*10^{-3}x$	$y=-30.42+202.97*10^{-3}x$
	r^2	1	0.99	0.99	0.99
	Max 1st INC	41	35	34	33
-8	Eq.	$y=-73.44+363.16*10^{-3}x$	$y=-42.96+246.36*10^{-3}x$	$y=-35.48+219.51*10^{-3}x$	$y=-29.71+200.91*10^{-3}x$
	r^2	1	1.00	1.00	0.99
	Max 1st INC	41	35	34	34

4.2.1.2) 4 deg/100ft TUR

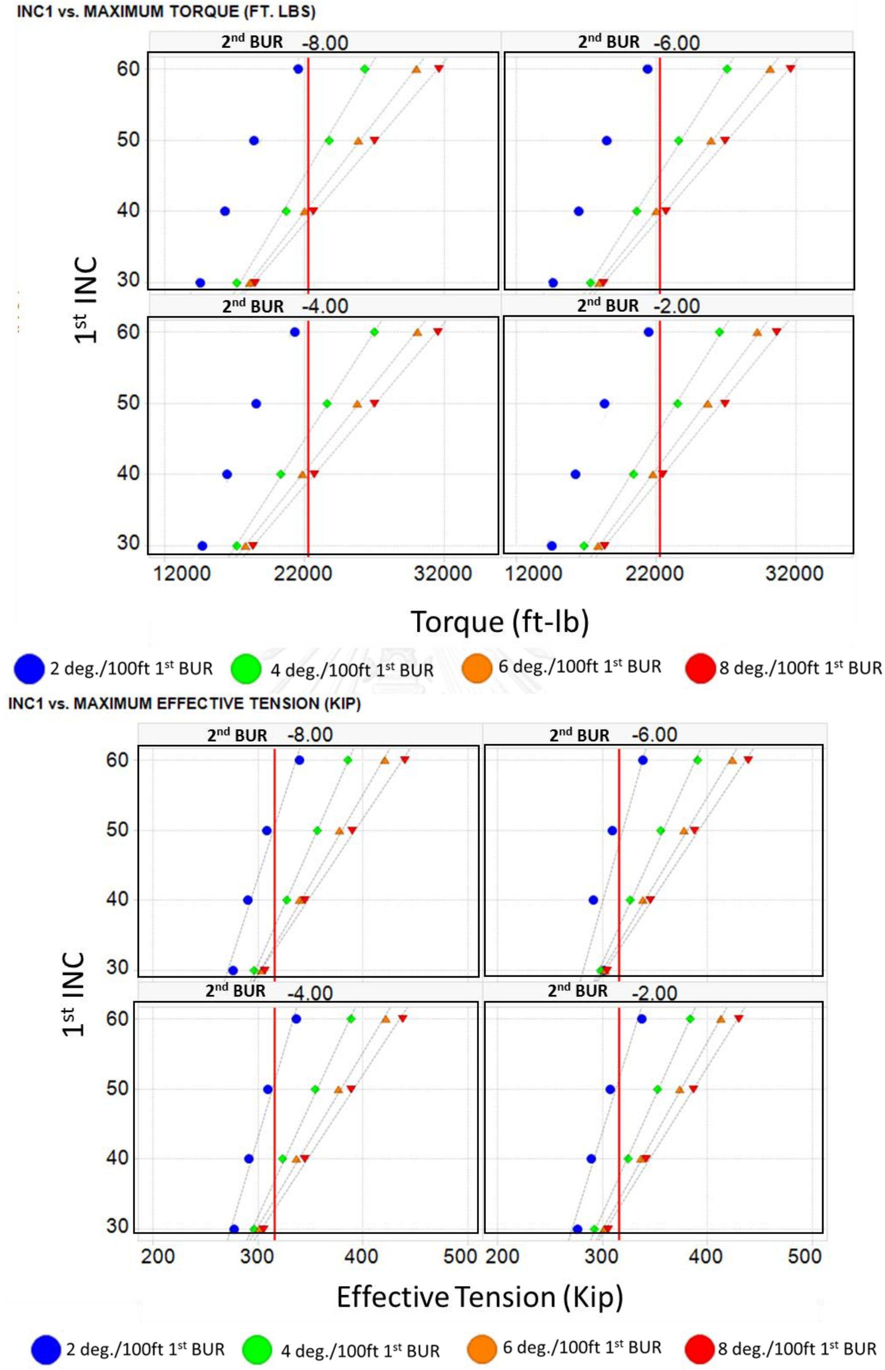


Figure 63: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 90 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 137: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-22.72+3.1*10^{-3}x$	$y=-16.82+2.62*10-3x$	$y=-14.09+2.4*10-3x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	46	41	39
-4	Eq.		$y=-21.79+3.03*10^{-3}x$	$y=-13.45+2.45*10^{-3}x$	$y=-11.84+2.28*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	45	40	38
-6	Eq.		$y=-23.58+3.09*10^{-3}x$	$y=-13.83+2.45*10^{-3}x$	$y=-11.22+2.26*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	44	40	39
-8	Eq.		$y=-26.73+3.26*10^{-3}x$	$y=-15.65+2.53*10^{-3}x$	$y=-11.84+2.28*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	45	40	38

Table 138: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-99.62+478.47*10^{-3}x$	$y=-67.5+332.53*10^{-3}x$	$y=-50.2+267.33*10^{-3}x$	$y=-42.35+238.84*10^{-3}x$
	r^2	0.97	1.00	1.00	1.00
	Max 1st INC	51	37	34	33
-4	Eq.	$y=-107.82+503.14*10^{-3}x$	$y=-64.66+321.73*10^{-3}x$	$y=-44.16+248.43*10^{-3}x$	$y=-38.96+227.53*10^{-3}x$
	r^2	0.98	1.00	1.00	1.00
	Max 1st INC	51	37	34	33
-6	Eq.	$y=-119.16+529.82*10^{-3}x$	$y=-66.77+326.28*10^{-3}x$	$y=-44.12+247.24*10^{-3}x$	$y=-37.66+223.84*10^{-3}x$
	r^2	0.68	1.00	1.00	1.00
	Max 1st INC	48	36	34	33
-8	Eq.	$y=-94.95+460.83*10^{-3}x$	$y=-70.6+338.32*10^{-3}x$	$y=-47.33+256.14*10^{-3}x$	$y=-37.28+222.43*10^{-3}x$
	r^2	0.96	1.00	1.00	1.00
	Max 1st INC	50	36	33	33

4.2.1.3) 6 deg/100ft TUR

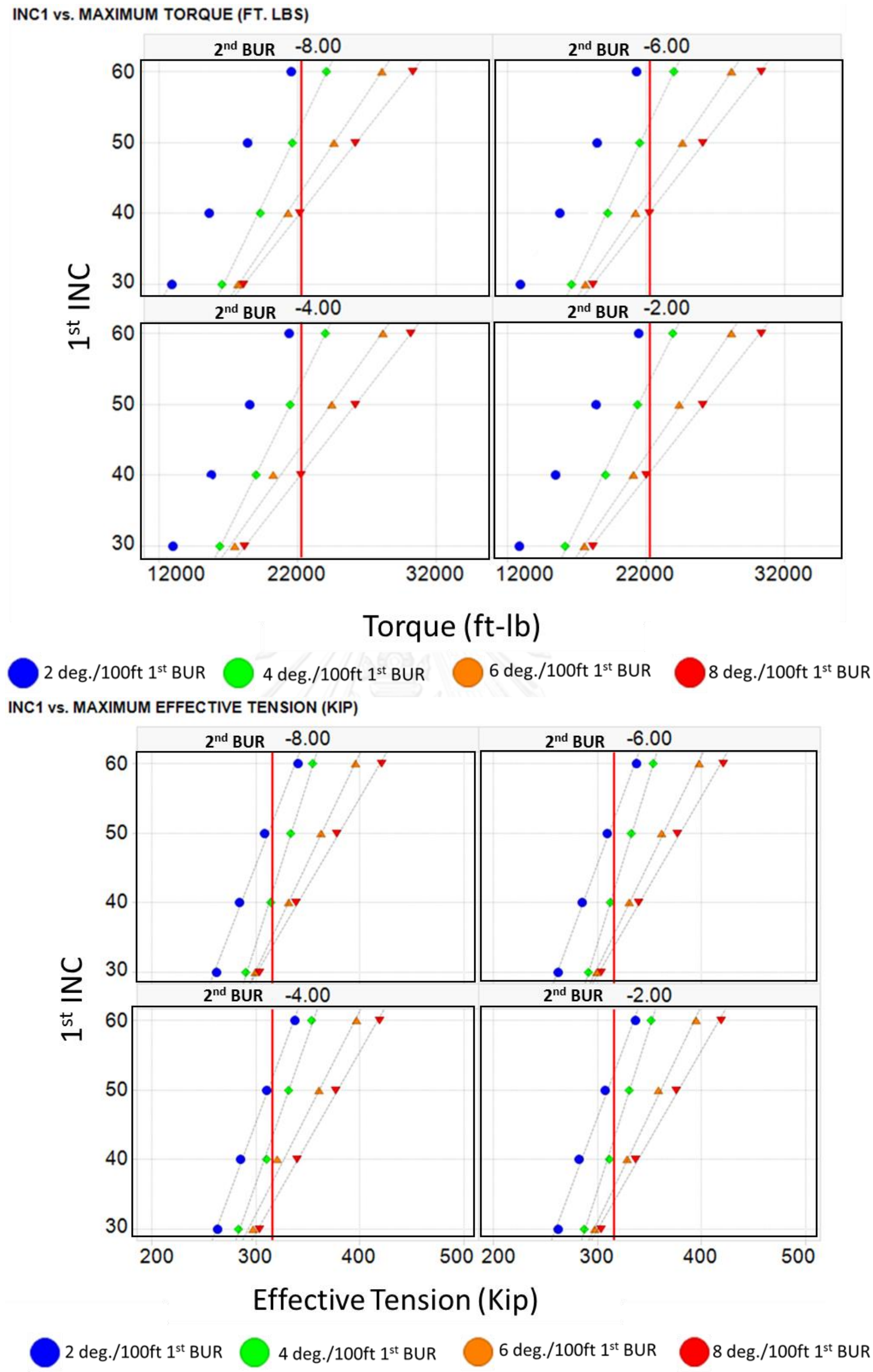


Figure 64: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 90 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

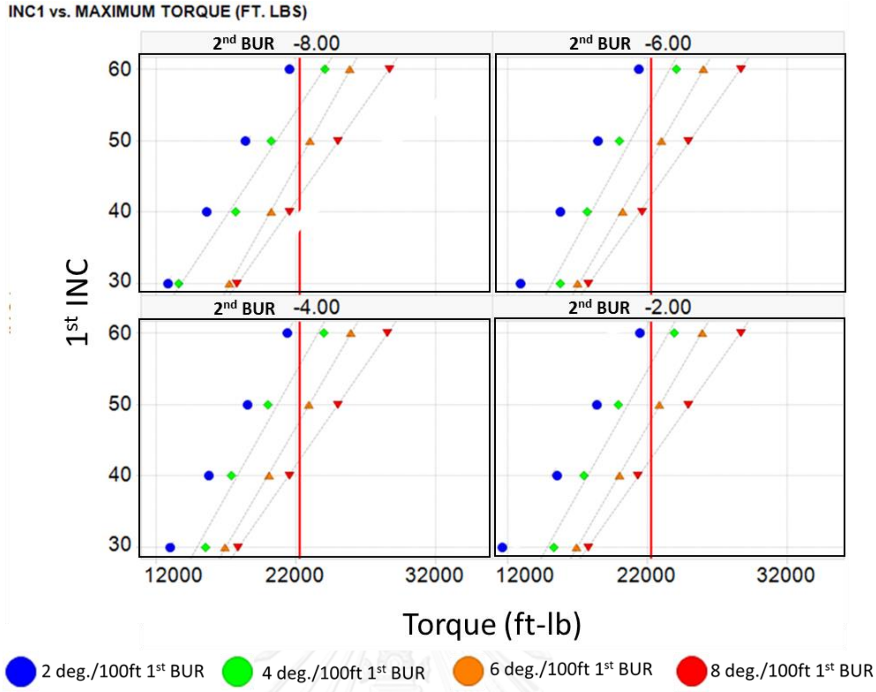
Table 139: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-33.77+3.91*10^{-3}x$	$y=-19.69+2.84*10^{-3}x$	$y=-14.56+2.47*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	52	43	40
-4	Eq.		$y=-35.01+3.96*10^{-3}x$	$y=-16.71+2.73*10^{-3}x$	$y=-15.58+2.51*10^{-3}x$
	r^2		1.00	0.99	1.00
	Max 1st INC	60	52	43	40
-6	Eq.		$y=-38.04+4.08*10^{-3}x$	$y=-20.23+2.85*10^{-3}x$	$y=-15.03+2.48*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	52	42	40
-8	Eq.		$y=-36.84+4.02*10^{-3}x$	$y=-21.41+2.9*10^{-3}x$	$y=-14.64+2.47*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	52	42	40

Table 140: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-73.84+399.85*10^{-3}x$	$y=-104.65+467.54*10^{-3}x$	$y=-62.24+311.05*10^{-3}x$	$y=-47.32+257.62*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	52	43	36	34
-4	Eq.	$y=-75.55+402.99*10^{-3}x$	$y=-90.69+424.33*10^{-3}x$	$y=-55.64+292.73*10^{-3}x$	$y=-48.7+260.69*10^{-3}x$
	r^2	1	1.00	0.99	1.00
	Max 1st INC	51	43	37	33
-6	Eq.	$y=-75.28+402.93*10^{-3}x$	$y=-110.46+481.98*10^{-3}x$	$y=-61.03+305.58*10^{-3}x$	$y=-47.35+256.66*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	52	41	35	33
-8	Eq.	$y=-70.23+385.62*10^{-3}x$	$y=-106.94+470.09*10^{-3}x$	$y=-63.57+312.8*10^{-3}x$	$y=-46.36+253.71*10^{-3}x$
	r^2	1	1.00	1.00	1.00
	Max 1st INC	51	41	35	34

4.2.1.4) 8 deg/100ft TUR



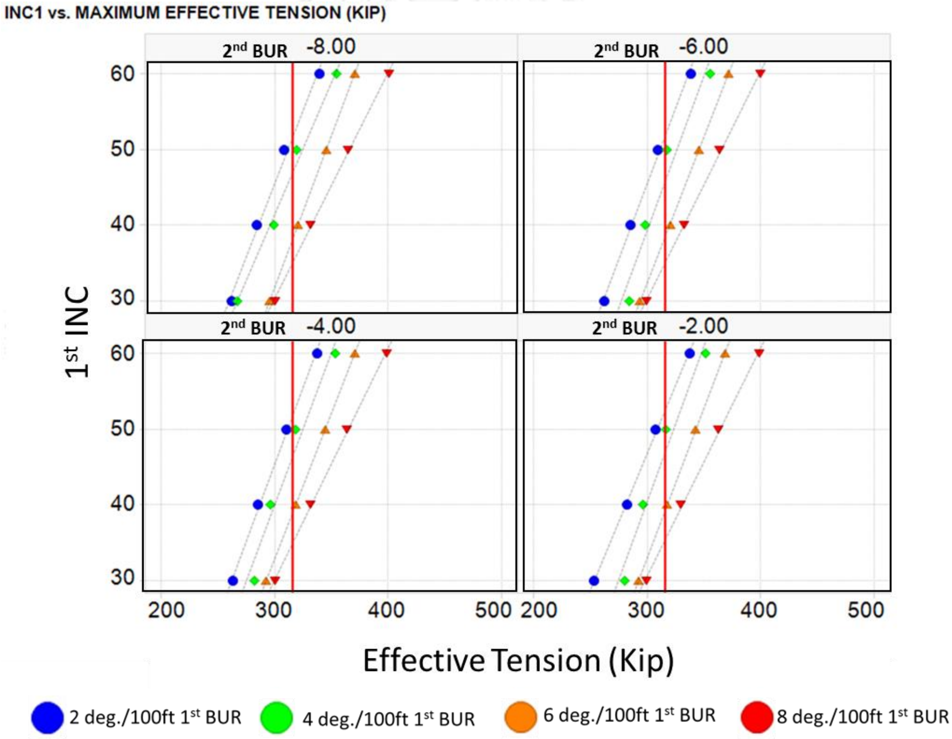


Figure 65: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 90 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 141: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-21.23+3.46*10^{-3}x$	$y=-27.18+3.37*10^{-3}x$	$y=-18.82+2.75*10^{-3}x$
	r^2		0.98	1.00	1.00
	Max 1st INC	60	55	47	42
-4	Eq.		$y=-21.61+3.46*10^{-3}x$	$y=-26.7+3.34*10^{-3}x$	$y=-20.26+2.81*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	55	47	42
-6	Eq.		$y=-23.86+3.55*10^{-3}x$	$y=-27.61+3.37*10^{-3}x$	$y=-19.37+2.77*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	54	46	42
-8	Eq.		$y=-10.47+2.94*10^{-3}x$	$y=-30.19+3.48*10^{-3}x$	$y=-19.33+2.77*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	54	46	42

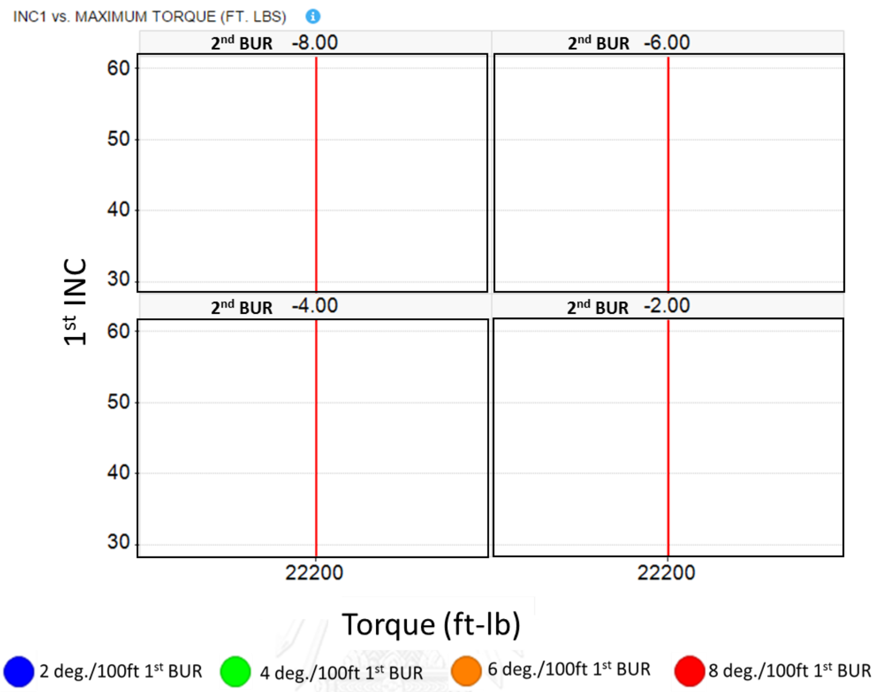
Table 142: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-61.34+360.44*10^{-3}x$	$y=-82.79+410.77*10^{-3}x$	$y=-85.62+395.39*10^{-3}x$	$y=-59.76+301.32*10^{-3}x$
	r^2	1	0.97	1.00	1.00
	Max 1st INC	52	47	39	35
-4	Eq.	$y=-76.32+405.58*10^{-3}x$	$y=-80.51+401.76*10^{-3}x$	$y=-82.49+384.57*10^{-3}x$	$y=-61.76+306.27*10^{-3}x$
	r^2	1	0.96	1.00	1.00
	Max 1st INC	51	46	39	35
-6	Eq.	$y=-74.09+398.64*10^{-3}x$	$y=-83.02+407.84*10^{-3}x$	$y=-83.37+385.87*10^{-3}x$	$y=-59.85+300.58*10^{-3}x$
	r^2	1	0.95	1.00	1.00
	Max 1st INC	51	47	38	35
-8	Eq.	$y=-70.4+386.32*10^{-3}x$	$y=-62.95+347.96*10^{-3}x$	$y=-88.31+400.43*10^{-3}x$	$y=-59.25+298.63*10^{-3}x$
	r^2	1	0.99	1.00	1.00
	Max 1st INC	51	47	38	35

4.2.2) 120 deg. Turn degree

4.2.2.1) 2 deg/100ft TUR

4.1.4.2) 4 deg/100ft TUR



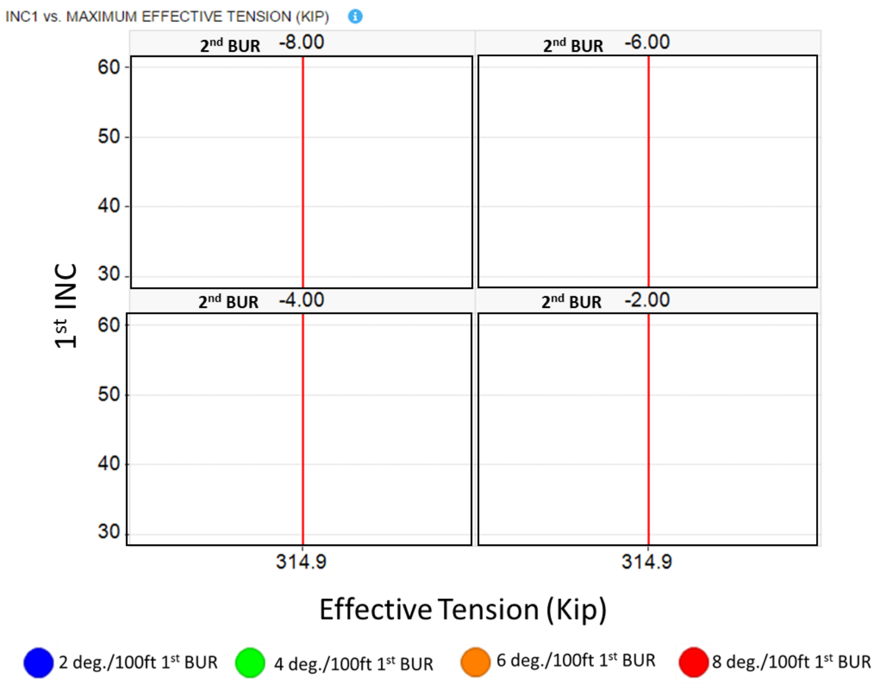


Figure 66: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 120 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile

Table 143: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-4	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-6	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-8	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-

Table 144: The maximum 1st INC, by effective tension criteria

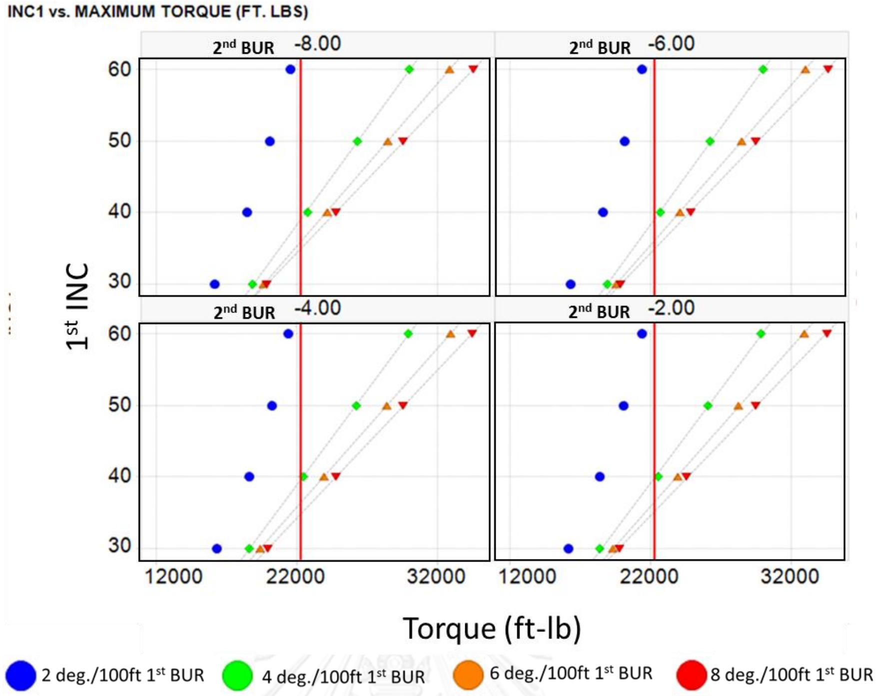
	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-4	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-6	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-
-8	Eq.				
	r^2				
	Max 1st INC	x-	x-	x-	x-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.2.2.2) 4 deg/100ft TUR



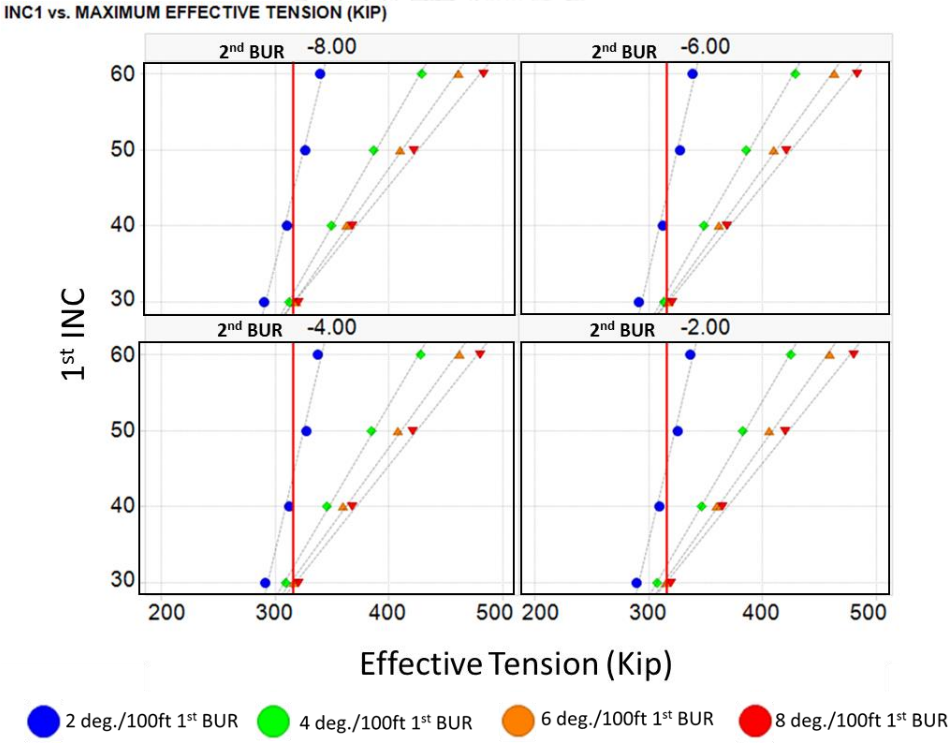


Figure 67: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 120 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 145: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-18.58+2.63*10^{-3}x$	$y=-12.93+2.22*10^{-3}x$	$y=-10.14+2.04*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	39	36	35
-4	Eq.		$y=-19.22+2.64*10^{-3}x$	$y=-12.94+2.22*10^{-3}x$	$y=-11.16+2.07*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	39	36	34
-6	Eq.		$y=-21.13+2.7*10^{-3}x$	$y=-13.62+2.23*10^{-3}x$	$y=-10.61+2.04*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	38	36	34
-8	Eq.		$y=-20.95+2.69*10^{-3}x$	$y=-14.6+2.27*10^{-3}x$	$y=-10.49+2.04*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	38	35	34

Table 146: The maximum 1st INC, by effective tension criteria

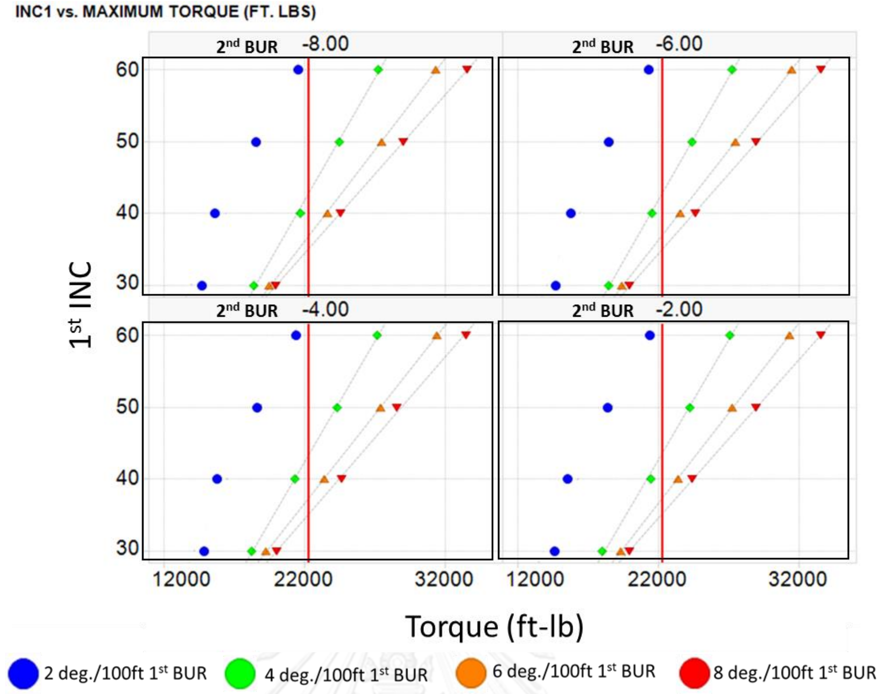
	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-152.27+626.04*10^{-3}x$	$y=-48.9+257.08*10^{-3}x$	$y=-35.29+208.73*10^{-3}x$	
	r^2	0.99	1.00	1.00	
	Max 1st INC	45	32	30	-
-4	Eq.	$y=-155.87+633.5*10^{-3}x$	$y=-48.19+254.03*10^{-3}x$	$y=-34.39+205.51*10^{-3}x$	
	r^2	0.97	1.00	1.00	
	Max 1st INC	44	32	30	-
-6	Eq.	$y=-157.92+639.66*10^{-3}x$	$y=-50.42+258.69*10^{-3}x$		
	r^2	0.98	1.00		
	Max 1st INC	44	31	-	-
-8	Eq.	$y=-144.65+598.92*10^{-3}x$	$y=-50.61+258.9*10^{-3}x$		
	r^2	0.99	1.00		
	Max 1st INC	44	31	-	-

Remark

x cannot design due to unfollow casing regulation

- cannot design due to exceed torque and drag limit

4.2.2.3) 6 deg/100ft TUR



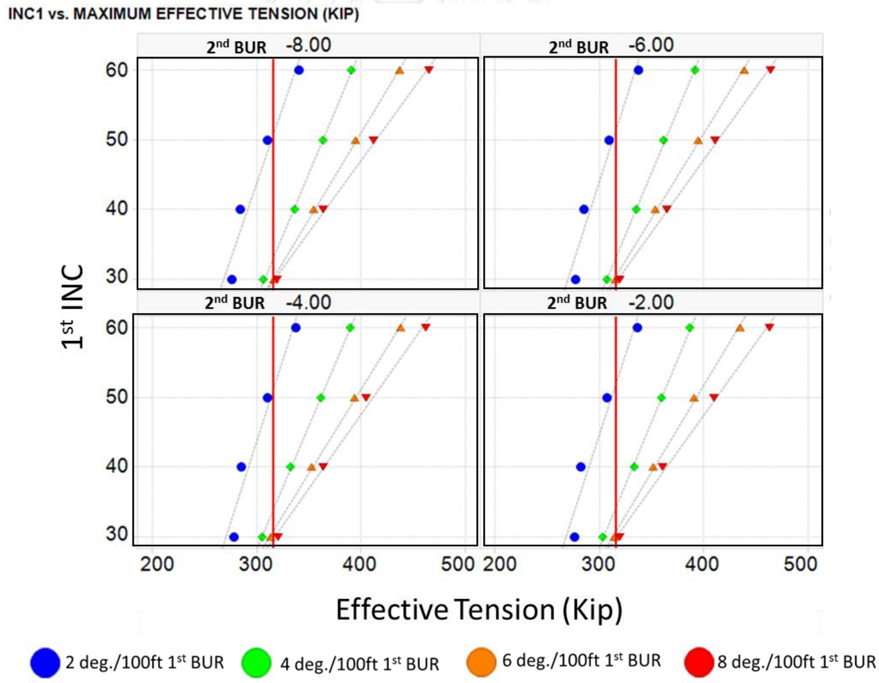


Figure 68: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 120 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 147: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-30.48+3.33*10^{-3}x$	$y=-18.48+2.51*10^{-3}x$	$y=-13.78+2.2*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	36	34
-4	Eq.		$y=-31.32+3.35*10^{-3}x$	$y=-17.73+2.47*10^{-3}x$	$y=-14.97+2.25*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	36	34
-6	Eq.		$y=-33.15+3.41*10^{-3}x$	$y=-18.64+2.5*10^{-3}x$	$y=-14.27+2.21*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	41	36	34
-8	Eq.		$y=-32.88+3.4*10^{-3}x$	$y=-19.72+2.54*10^{-3}x$	$y=-13.93+2.2*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	41	36	34

Table 148: The maximum 1st INC, by effective tension criteria

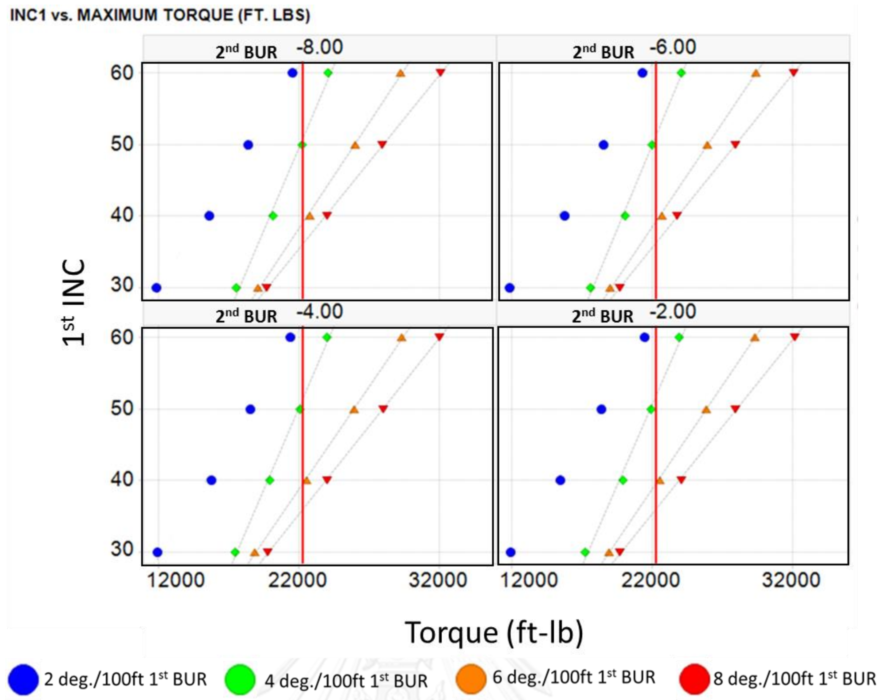
	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-92.88+458.47*10^{-3}x$	$y=-79.23+359.21*10^{-3}x$	$y=-47.79+248.83*10^{-3}x$	
	r^2	0.94	1.00	1.00	
	Max 1st INC	51	33	30	-
-4	Eq.	$y=-96.2+466.3*10^{-3}x$	$y=-77.59+352.96*10^{-3}x$	$y=-45.32+241.27*10^{-3}x$	
	r^2	0.95	1.00	1.00	
	Max 1st INC	50	33	30	-
-6	Eq.	$y=-95.19+464.01*10^{-3}x$	$y=-79.8+357.5*10^{-3}x$	$y=-46.26+242.98*10^{-3}x$	
	r^2	0.95	1.00	1.00	
	Max 1st INC	50	32	30	-
-8	Eq.	$y=-86.87+435.52*10^{-3}x$	$y=-79.82+357.22*10^{-3}x$		
	r^2	0.94	1.00		
	Max 1st INC	50	32	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.2.2.4) 8 deg/100ft TUR



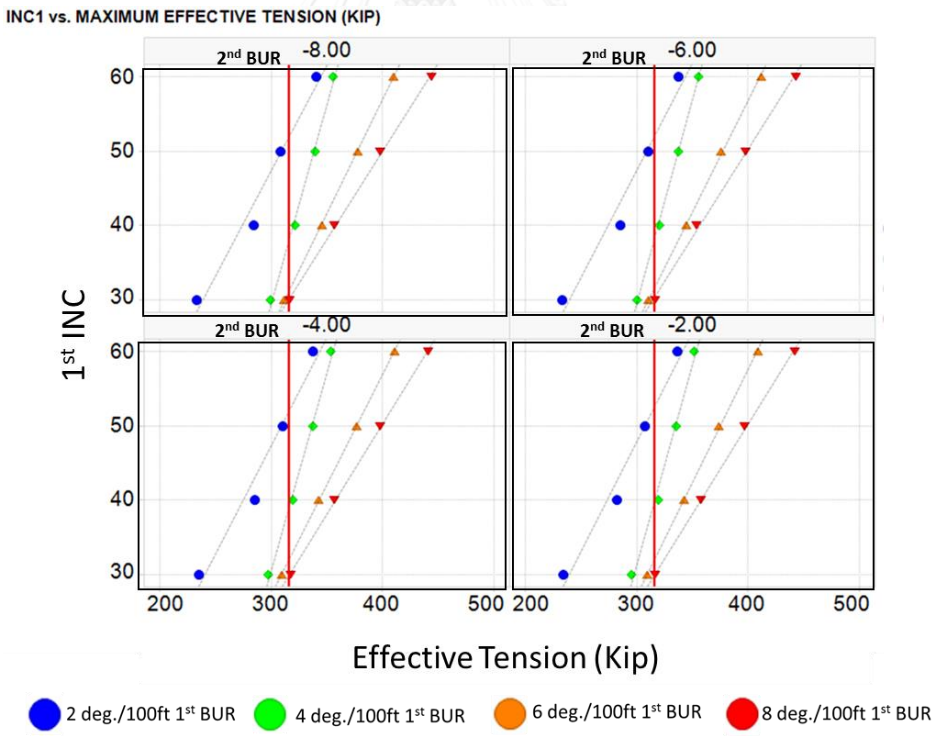


Figure 68: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 120 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 147: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-48.52+4.51*10^{-3}x$	$y=-24.77+2.89*10^{-3}x$	$y=-18.13+2.43*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	50	38	35
-4	Eq.		$y=-50.19+4.56*10^{-3}x$	$y=-24.16+2.86*10^{-3}x$	$y=-18.74+2.46*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	50	38	35
-6	Eq.		$y=-53.79+4.72*10^{-3}x$	$y=-25.42+2.91*10^{-3}x$	$y=-17.68+2.42*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	49	38	35
-8	Eq.		$y=-51.84+4.61*10^{-3}x$	$y=-26.66+2.95*10^{-3}x$	$y=-17.87+2.42*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	49	38	35

Table 148: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-40.49+294.53*10^{-3}x$	$y=-129.99+537.68*10^{-3}x$	y=-64.15+304.41*10-3x	
	r^2	0.98	0.99	1.00	
	Max 1st INC	52	39	31	-
-4	Eq.	$y=-39.91+290.84*10^{-3}x$	$y=-128.77+531.04*10^{-3}x$	$y=-61.54+296.19*10^{-3}x$	
	r^2	0.97	1.00	1.00	
	Max 1st INC	51	38	31	-
-6	Eq.	$y=-38.94+287.9*10^{-3}x$	$y=-134.82+547.89*10^{-3}x$	$y=-63.03+299.62*10^{-3}x$	
	r^2	0.97	1.00	1.00	
	Max 1st INC	51	37	31	-
-8	Eq.	$y=-37.54+283.11*10^{-3}x$	$y=-130.95+534.84*10^{-3}x$	$y=-65.62+306.52*10^{-3}x$	
	r^2	0.98	0.99	1.00	
	Max 1st INC	51	37	30	-

Remark

x   cannot design due to unfollow casing regulation

-    cannot design due to exceed torque and drag limit

4.2.3) 150 deg. Turn degree

4.1.3.1) 2 deg/100ft TUR

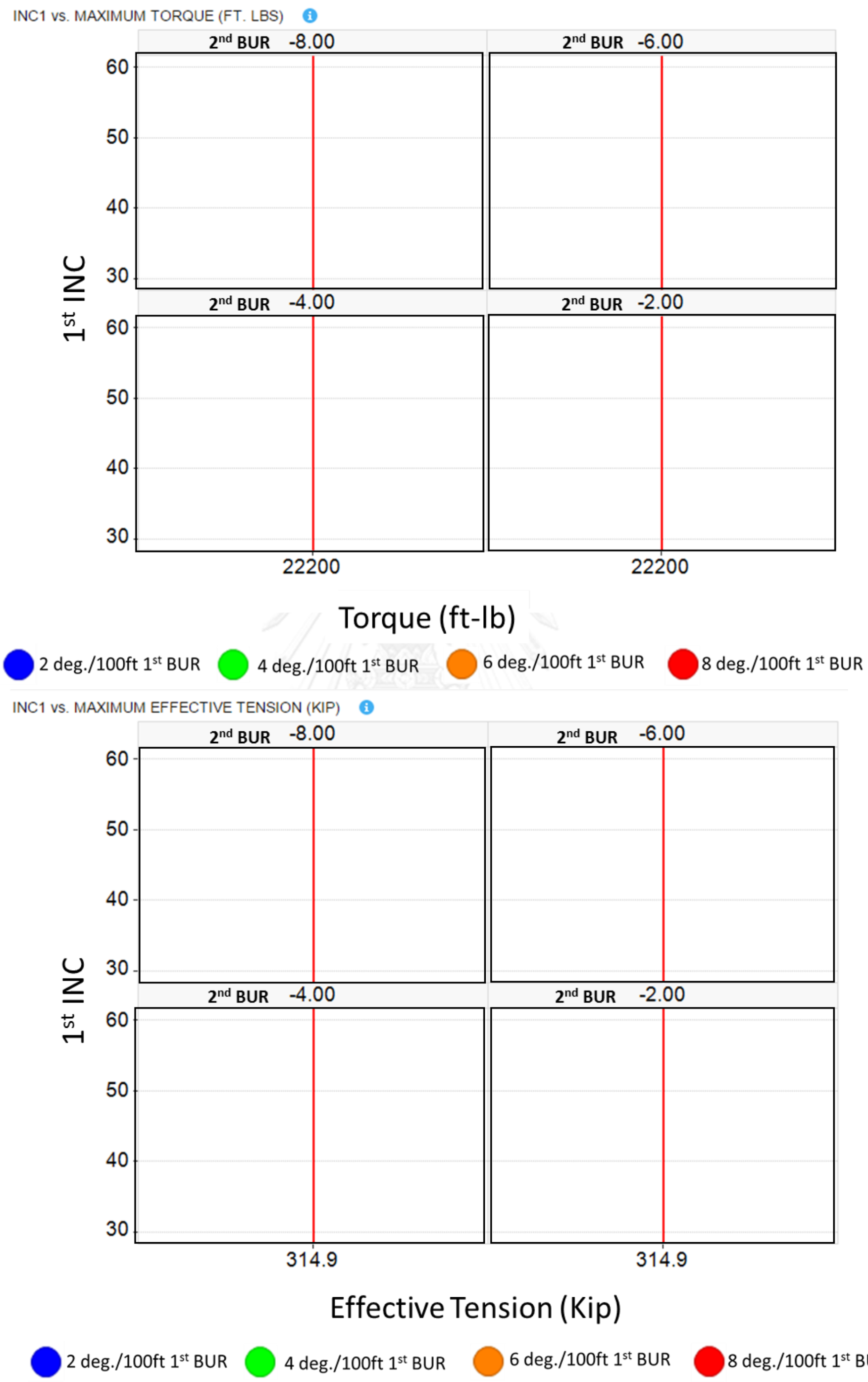


Figure 69: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 149: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 150: The maximum 1st INC, by effective tension criteria

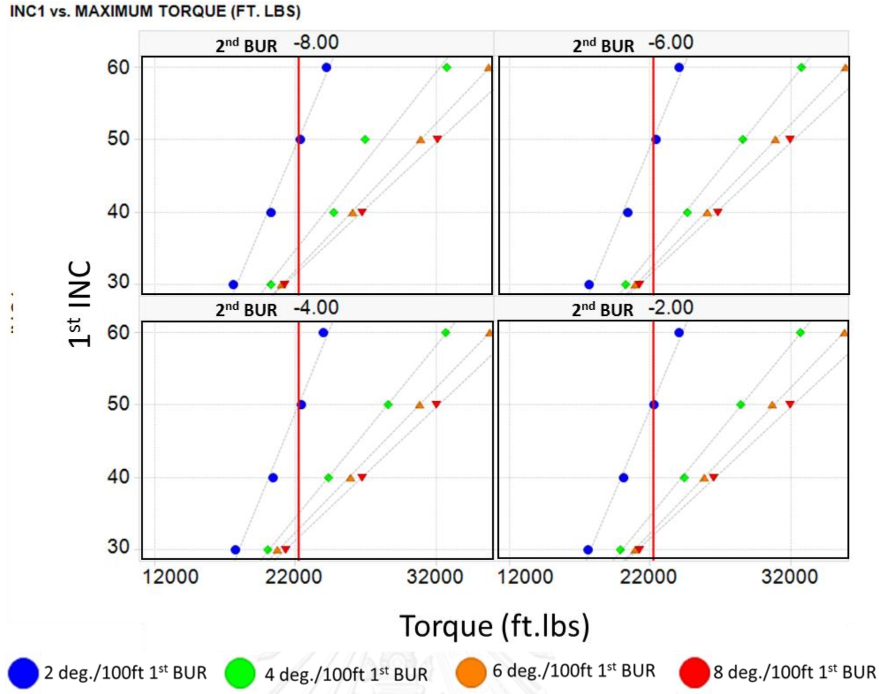
	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.3.2) 4 deg/100ft TUR



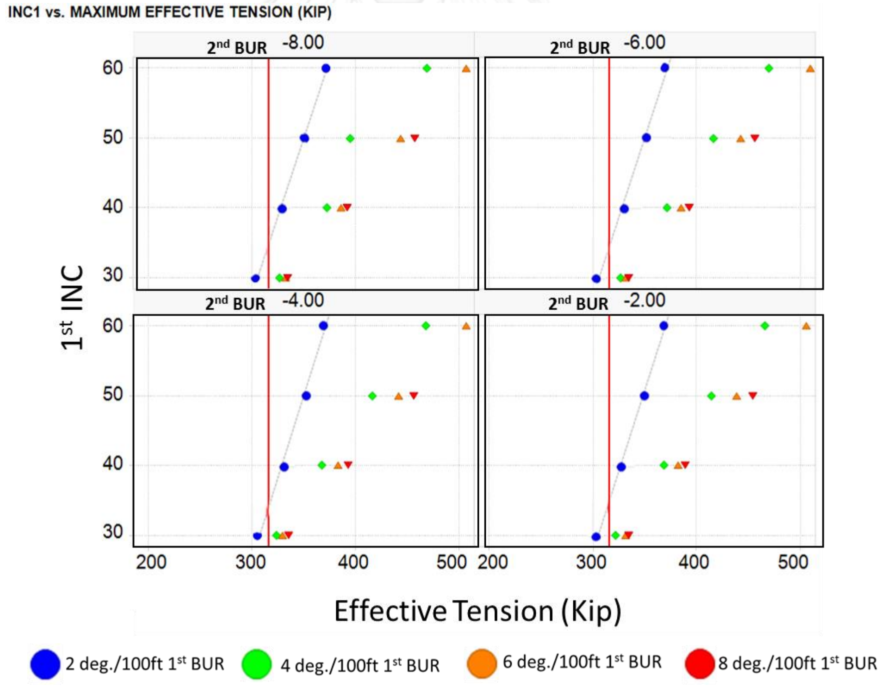


Figure 70: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 151: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-51.49+4.59*10^{-3}x$	$y=-17.15+2.36*10^{-3}x$	$y=-12.01+2.01*10^{-3}x$	$y=-8.15+1.81*10^{-3}x$
	r^2	0.99	1.00	1.00	1.00
	Max 1st INC	49	34	32	31
-4	Eq.	$y=-55.03+4.73*10^{-3}x$	$y=-17.75+2.37*10^{-3}x$	$y=-11.54+2*10^{-3}x$	$y=-9.03+1.83*10^{-3}x$
	r^2	0.99	1.00	1.00	1.00
	Max 1st INC	48	34	32	31
-6	Eq.	$y=-53.19+4.65*10^{-3}x$	$y=-19.06+2.41*10^{-3}x$	$y=-12.1+2.01*10^{-3}x$	$y=-8.64+1.82*10^{-3}x$
	r^2	0.99	1.00	1.00	1.00
	Max 1st INC	49	33	32	31
-8	Eq.	$y=-51.26+4.56*10^{-3}x$	$y=-19.2+2.45*10^{-3}x$	$y=-12.8+2.03*10^{-3}x$	$y=-8.35+1.81*10^{-3}x$
	r^2	0.99	0.97	1.00	1.00
	Max 1st INC	49	34	31	31

Table 152: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-109.77+459.18*10^{-3}x$			
	r^2	1.00			
	Max 1st INC	34	-	-	-
-4	Eq.	$y=-113.39+467.1*10^{-3}x$			
	r^2	0.99			
	Max 1st INC	33	-	-	-
-6	Eq.	$y=-107.77+451.19*10^{-3}x$			
	r^2	0.99			
	Max 1st INC	34	-	-	-
-8	Eq.	$y=-105.44+444.05*10^{-3}x$			
	r^2	1.00			
	Max 1st INC	34	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.3.3) 6 deg/100ft TUR

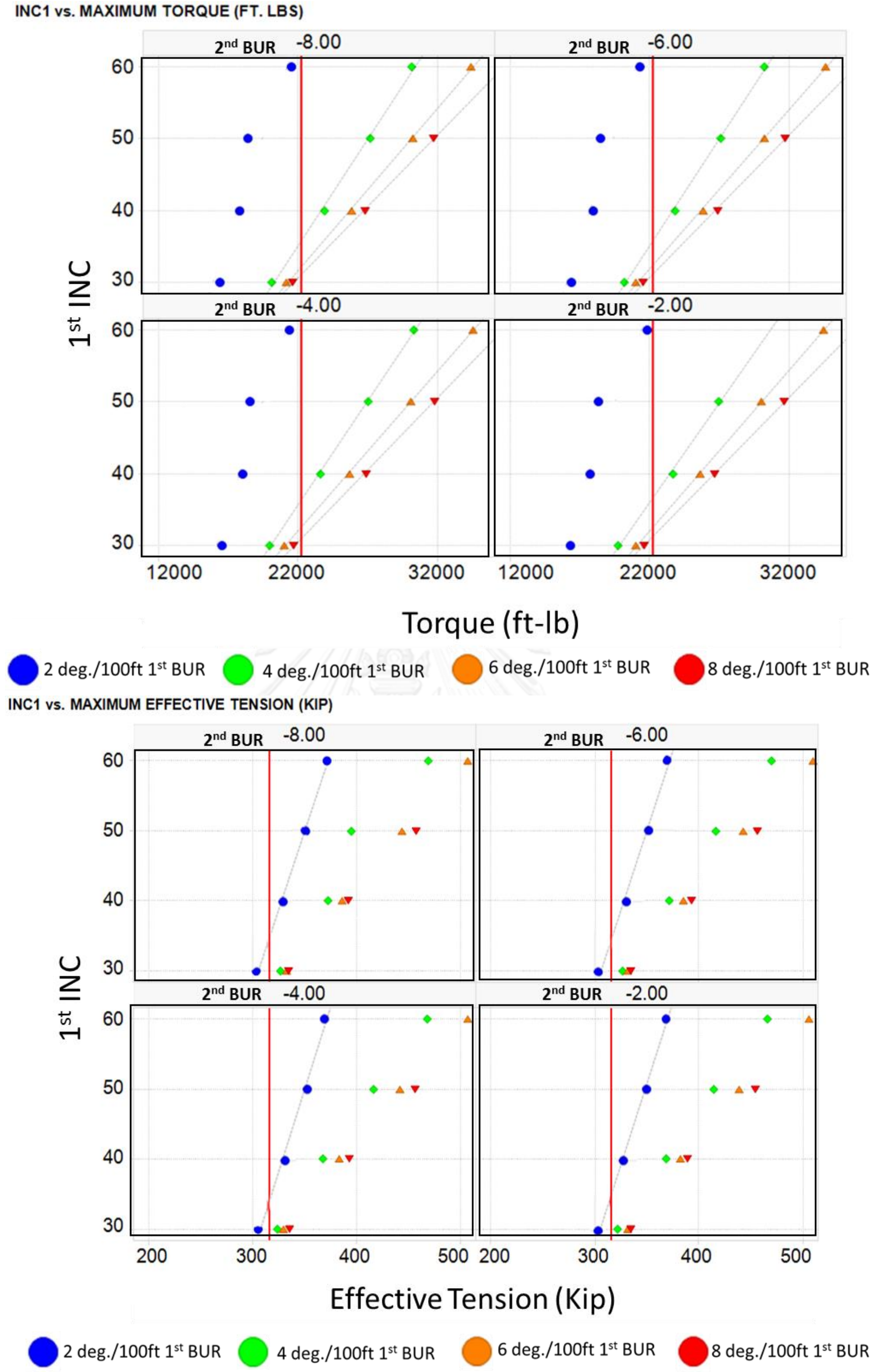


Figure 71: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 153: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-24.94+2.77*10^{-3}x$	$y=-17.15+2.24*10^{-3}x$	$y=-12.7+1.98*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	32	30
-4	Eq.		$y=-28.02+2.9*10^{-3}x$	$y=-16.76+2.22*10^{-3}x$	$y=-13.6+2.01*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	32	30
-6	Eq.		$y=-30.32+2.97*10^{-3}x$	$y=-16.82+2.21*10^{-3}x$	$y=-12.9+1.98*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	31	30
-8	Eq.		$y=-30.14+2.97*10^{-3}x$	$y=-18+2.26*10^{-3}x$	$y=-13.07+1.99*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	31	30

Table 154: The maximum 1st INC, by effective tension criteria

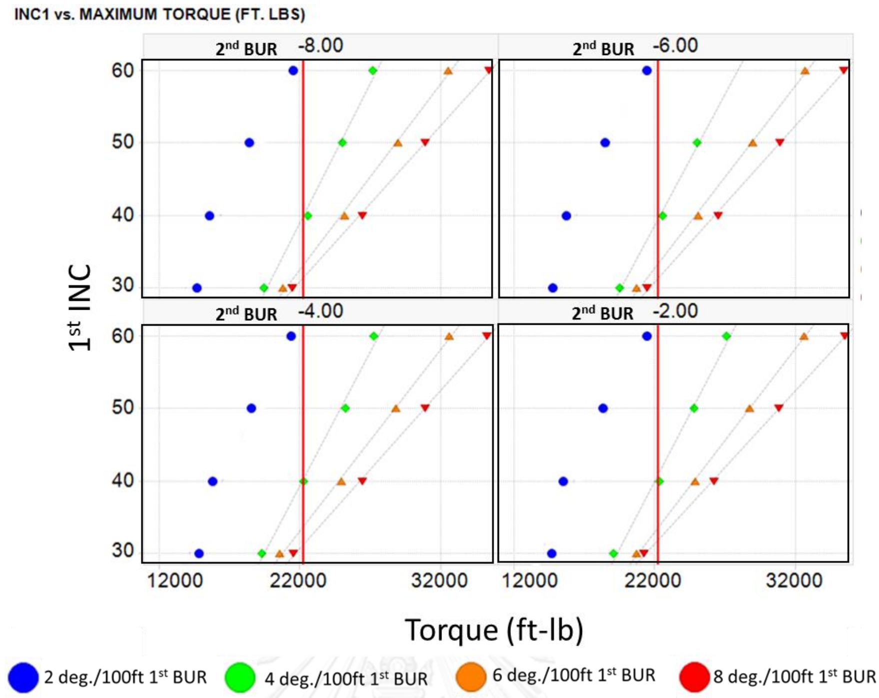
	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-136.01+584.03*10^{-3}x$			
	r^2	0.88			
	Max 1st INC	47	-	-	-
-4	Eq.	$y=-157.73+651.04*10^{-3}x$			
	r^2	0.90			
	Max 1st INC	47	-	-	-
-6	Eq.	$y=-153.42+638.57*10^{-3}x$			
	r^2	0.90			
	Max 1st INC	47	-	-	-
-8	Eq.	$y=-136.99+585.27*10^{-3}x$			
	r^2	0.88			
	Max 1st INC	47	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.3.4) 8 deg/100ft TUR



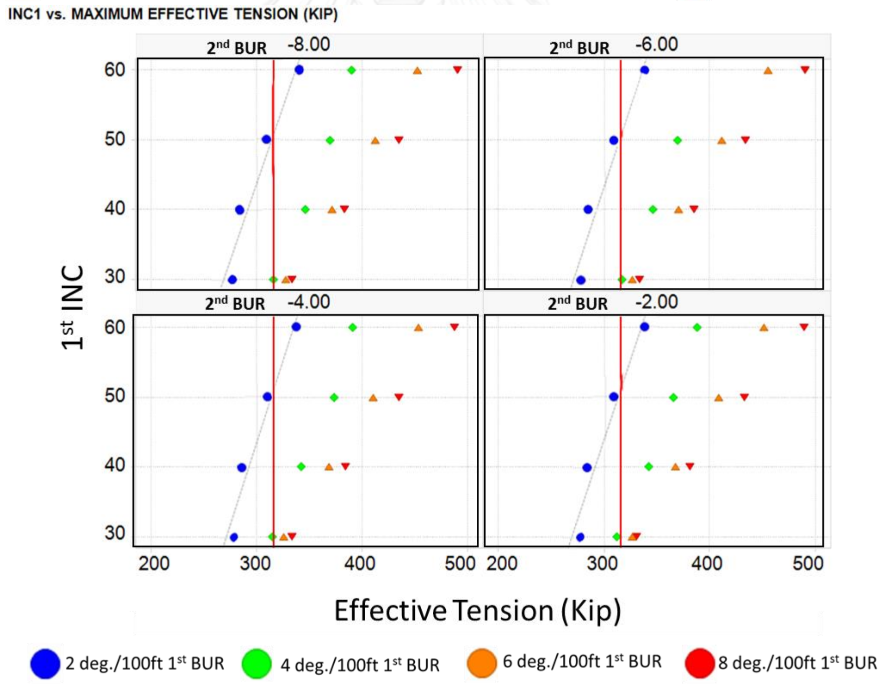


Figure 72: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 155: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-42.18+3.73*10^{-3}x$	$y=-22.68+2.53*10^{-3}x$	$y=-15.09+2.11*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	39	32	31
-4	Eq.		$y=-41.85+3.69*10^{-3}x$	$y=-21.91+2.5*10^{-3}x$	$y=-17.24+2.18*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	39	33	30
-6	Eq.		$y=-40.99+3.62*10^{-3}x$	$y=-22.66+2.52*10^{-3}x$	$y=-16.68+2.16*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	38	32	30
-8	Eq.		$y=-45.44+3.84*10^{-3}x$	$y=-23.8+2.56*10^{-3}x$	$y=-16.39+2.15*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	38	32	30

Table 156: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-91.65+454.09*10^{-3}x$	$y=-95.59+399.26*10^{-3}x$		
	r^2	0.93	0.99		
	Max 1st INC	51	30	-	-
-4	Eq.	$y=-96.98+469.1*10^{-3}x$			
	r^2	0.95			
	Max 1st INC	50	-	-	-
-6	Eq.	$y=-93.54+458.22*10^{-3}x$			
	r^2	0.95			
	Max 1st INC	50	-	-	-
-8	Eq.	$y=-87.65+438.72*10^{-3}x$			
	r^2	0.94			
	Max 1st INC	50	-	-	-

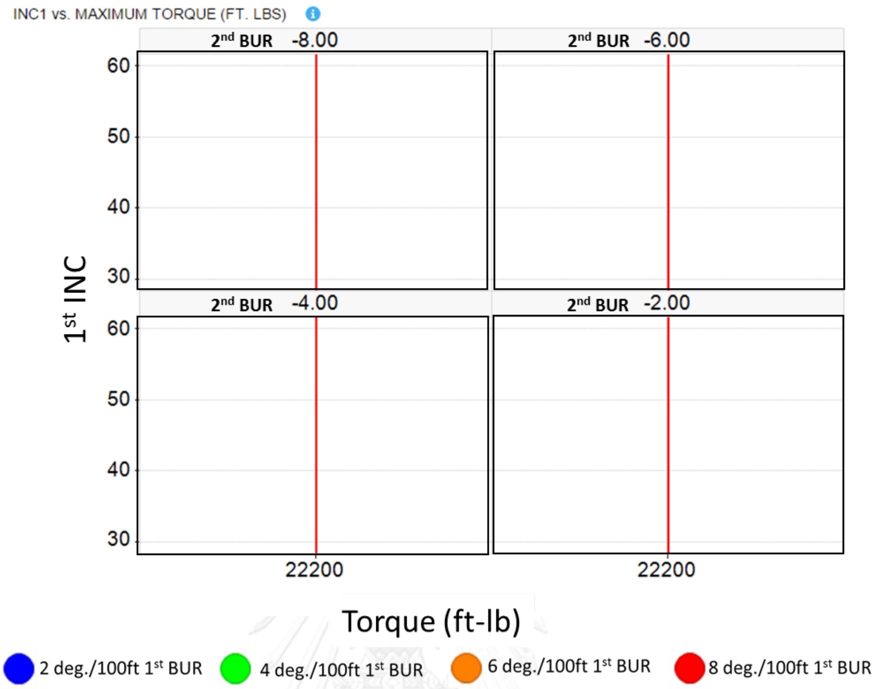
Remark

x cannot design due to unfollow casing regulation

- cannot design due to exceed torque and drag limit

4.2.4) 180 deg. Turn degree

4.1.4.1) 2 deg/100ft TUR



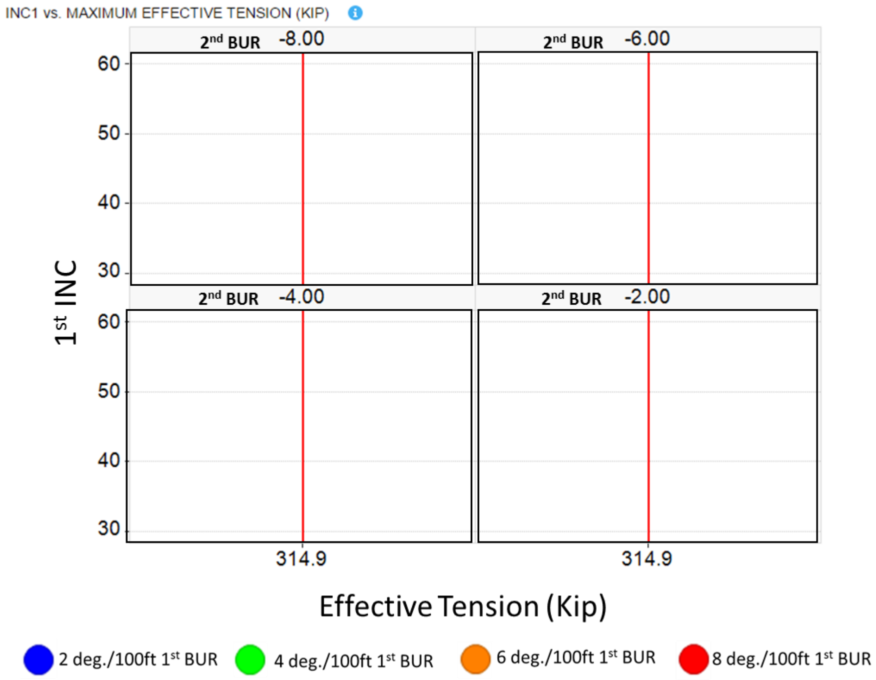


Figure 73: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 157: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Table 158: The maximum 1^{st} INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-6	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-8	Eq.				
	r^2				
	Max 1st INC	x	x	x	x

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4.2) 4 deg/100ft TUR

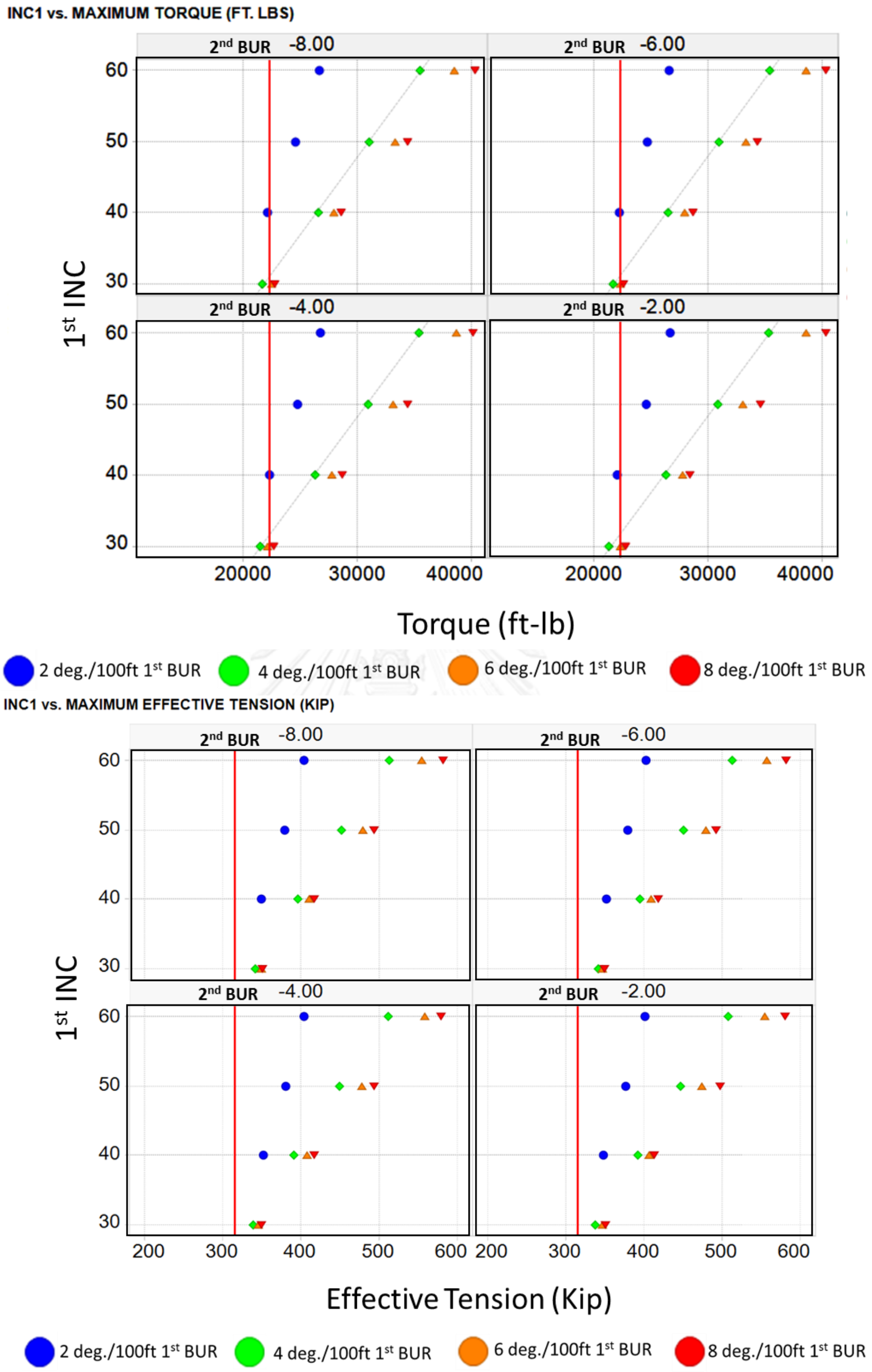


Figure 74: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 159: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-16.27+2.16*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	40	31	-	-
-4	Eq.		y=-16.35+2.15*10-3x		
	r^2		1.00		
	Max 1st INC	40	31	-	-
-6	Eq.		y=-17.37+2.18*10-3x		
	r^2		1.00		
	Max 1st INC	40	30	-	-
-8	Eq.		y=-12.25+1.88*10-3x		
	r^2		1.00		
	Max 1st INC	40	30	-	-

Table 160: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x-	-	-	-
-4	Eq.				
	r^2				
	Max 1st INC	x-	-	-	-
-6	Eq.				
	r^2				
	Max 1st INC	x-	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	x-	-	-	-

Remark

x cannot design due to unfollow casing regulation

- cannot design due to exceed torque and drag limit

4.1.4.3) 6 deg/100ft TUR

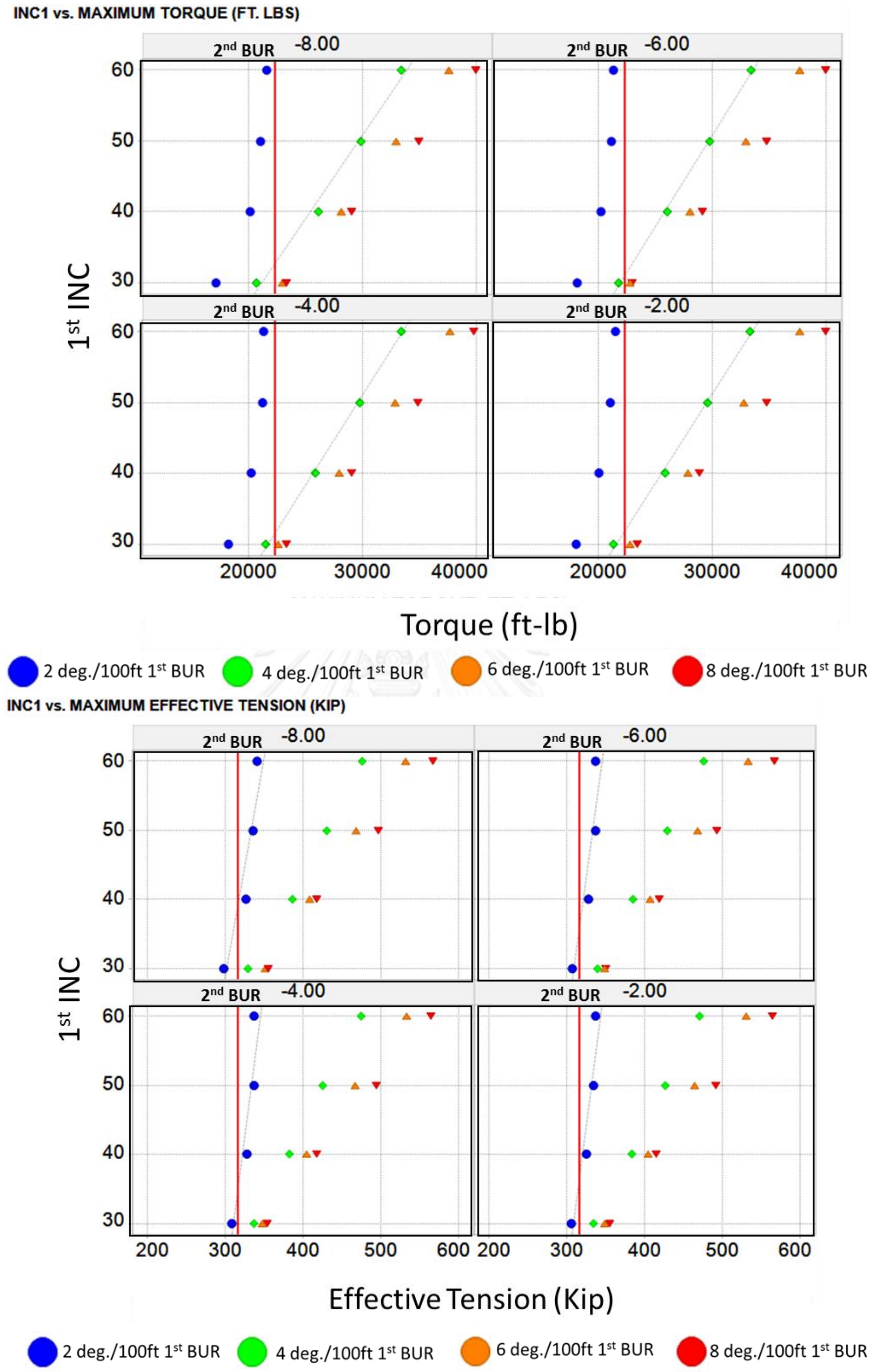


Figure 75: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP, 5deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 161: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		y=-24.13+2.51*10-3x		
	r^2		1.00		
	Max 1st INC	60	31	-	-
-4	Eq.		y=-24.93+2.54*10-3x		
	r^2		1.00		
	Max 1st INC	60	30	-	-
-6	Eq.		y=-26.28+2.57*10-3x		
	r^2		1.00		
	Max 1st INC	60	30	-	-
-8	Eq.		y=-19.74+2.36*10-3x		
	r^2		0.99		
	Max 1st INC	60	32	-	-

Table 162: The maximum 1st INC, by effective tension criteria

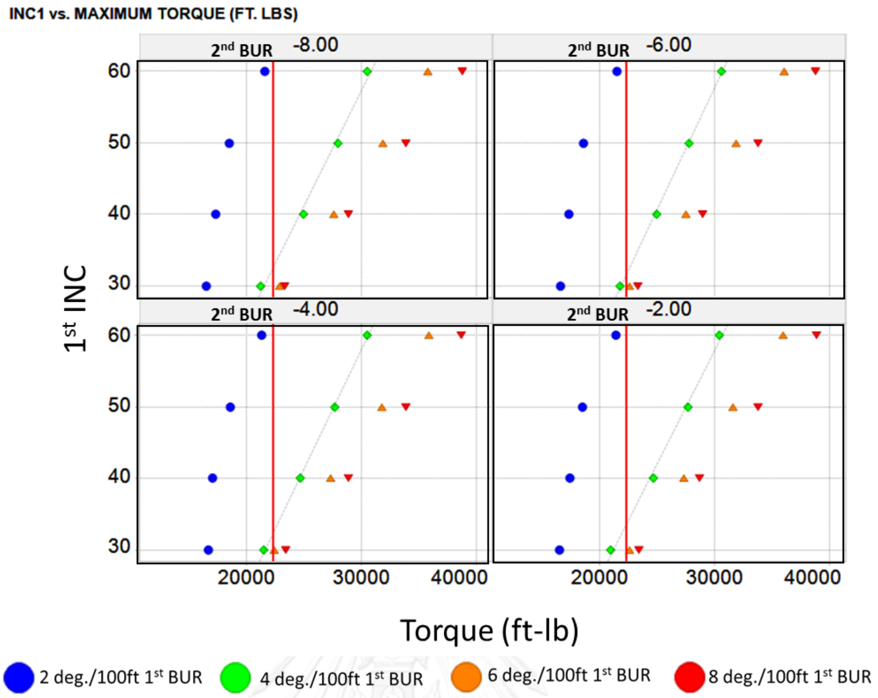
	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	y=-235.43+861.74*10-3x			
	r^2	0.89			
	Max 1st INC	35	-	-	-
-4	Eq.	y=-237.66+863.81*10-3x			
	r^2	0.82			
	Max 1st INC	34	-	-	-
-6	Eq.	y=-224.66+825.59*10-3x			
	r^2	0.81			
	Max 1st INC	35	-	-	-
-8	Eq.	y=-160.13+631.66*10-3x			
	r^2	0.86			
	Max 1st INC	38	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.1.4.4) 8 deg/100ft TUR



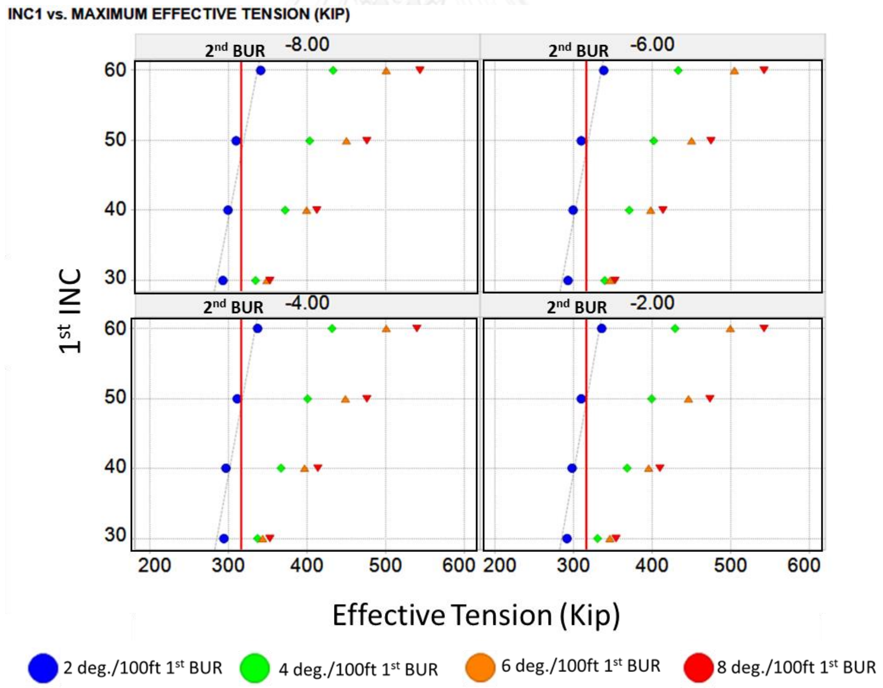


Figure 75: Maximum torque and effective tension versus 1st INC as a function of 1000ft. 1st KOP with 5300ft TVD 2nd KOP,180 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 163: The maximum 1st INC, by torque criteria

		Torque			
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		y=-36.91+3.16*10-3x		
	r^2		0.99		
	Max 1st INC	60	32	-	-
-4	Eq.		y=-42.01+3.34*10-3x		
	r^2		1.00		
	Max 1st INC	60	31	-	-
-6	Eq.		y=-44.07+3.4*10-3x		
	r^2		1.00		
	Max 1st INC	60	30	-	-
-8	Eq.		y=-39.13+3.22*10-3x		
	r^2		0.99		
	Max 1st INC	60	31	-	-

Table 164: The maximum 1st INC, by effective tension criteria

		Effective Tension			
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	y=-146.94+622.68*10-3x			
	r^2	0.90			
	Max 1st INC	49	-	-	-
-4	Eq.	y=-144.16+612.27*10-3x			
	r^2	0.88			
	Max 1st INC	48	-	-	-
-6	Eq.	y=-141.11+601.12*10-3x			
	r^2	0.89			
	Max 1st INC	48	-	-	-
-8	Eq.	y=-133.16+574.59*10-3x			
	r^2	0.89			
	Max 1st INC	47	-	-	-

Remark

x cannot design due to unfollow casing regulation

\- cannot design due to exceed torque and drag limit

4.3) 5300ft TVD 1st KOP with immediately 2nd KOP

4.3.1) 90 deg. Turn degree

4.3.1.1) 2 deg/100ft TUR

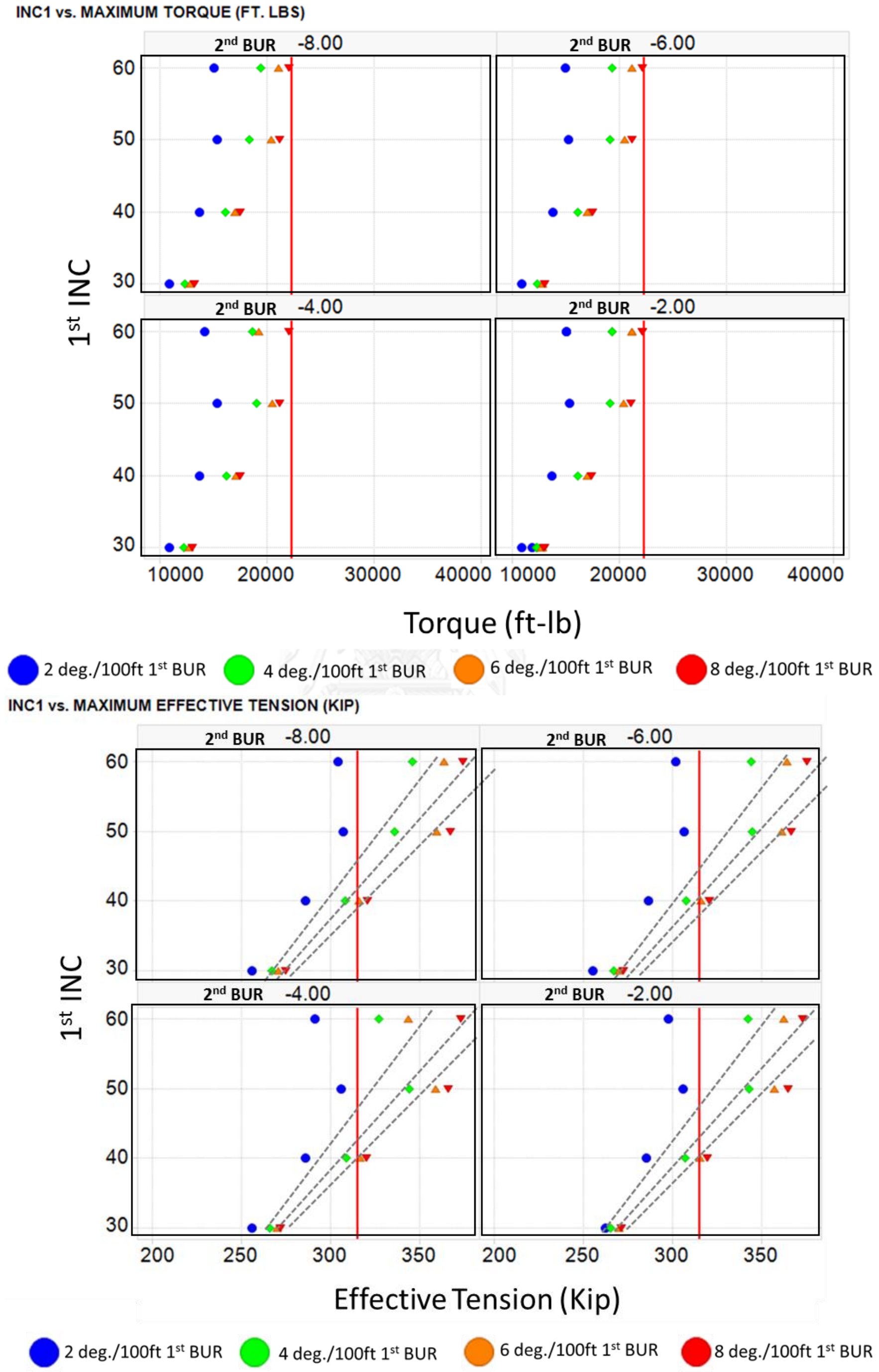


Figure 76: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 165: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	60	60	60
-4	Eq.				
	r^2				
	Max 1st INC	60	60	60	60
-6	Eq.				
	r^2				
	Max 1st INC	60	60	60	60
-8	Eq.				
	r^2				
	Max 1st INC	60	60	60	60

Table 166: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-38.24+256.34*10^{-3}x$	$y=-31.95+228.97*10^{-3}x$	$y=-28.17+214.07*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	40	39
-4	Eq.		$y=-38.27+255.47*10^{-3}x$	$y=-30.98+225.07*10^{-3}x$	$y=-27.58+211.59*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	42	39	39
-6	Eq.		$y=-38.83+257.14*10^{-3}x$	$y=-29.46+220.01*10^{-3}x$	$y=-28.11+212.97*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	43	39	38
-8	Eq.		$y=-47.39+287.78*10^{-3}x$	$y=-30.7+224.16*10^{-3}x$	$y=-29.5+216.45*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	43	39	38

4.3.1.2) 4 deg/100ft TUR

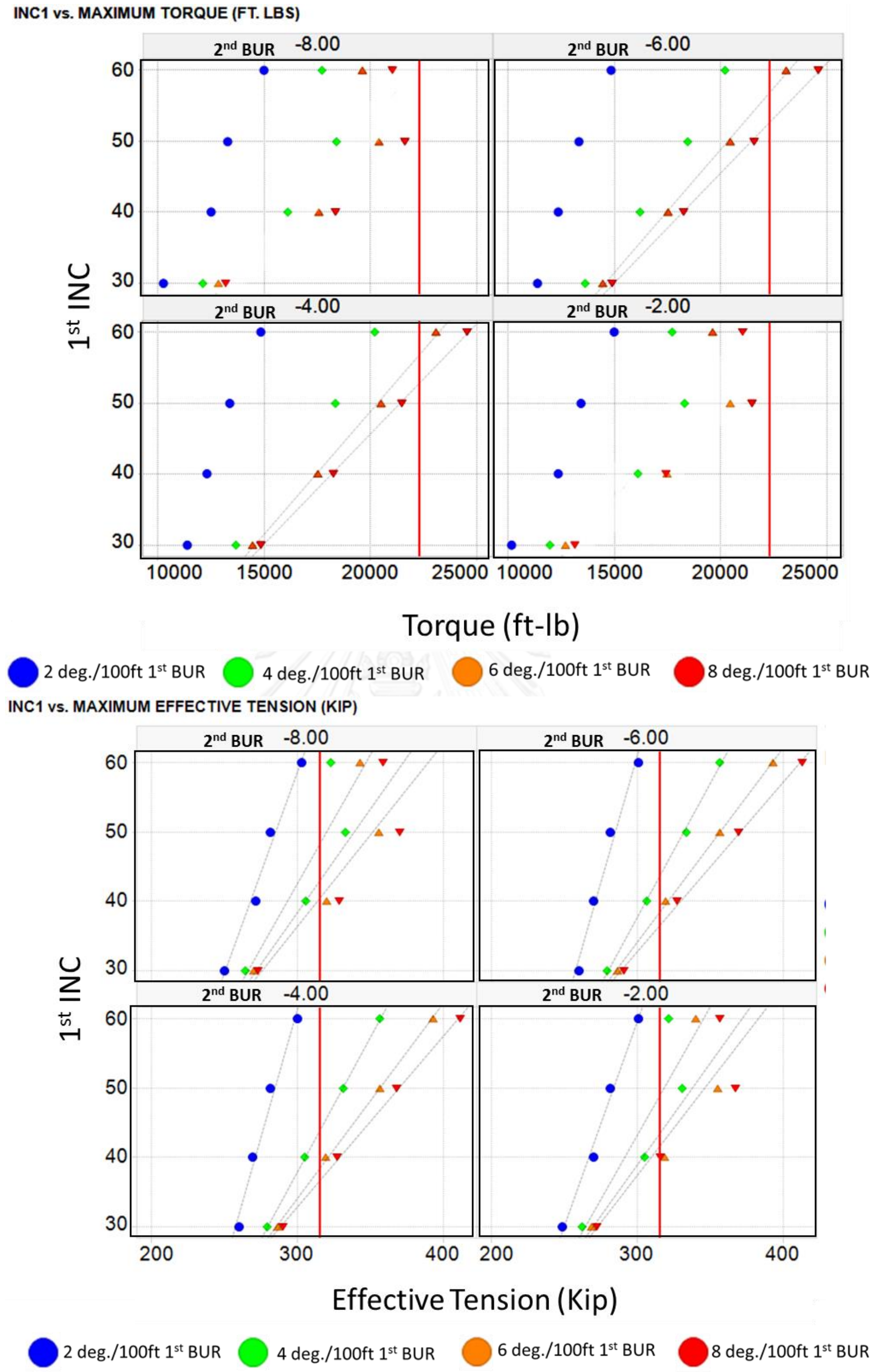


Figure 77: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 4deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

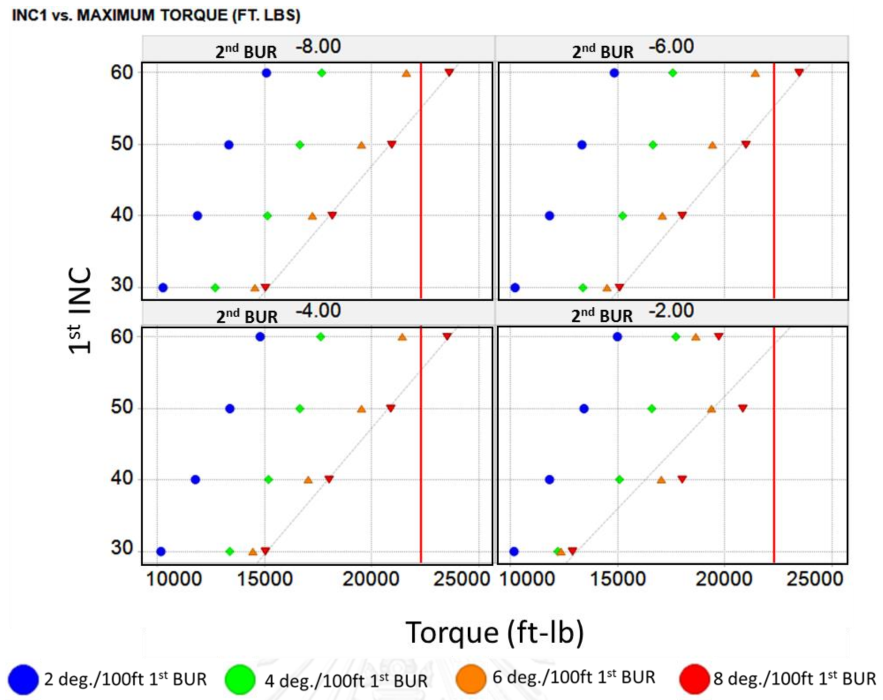
Table 167: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	60	60	60
-4	Eq.			$y=-20.34+3.46*10^{-3}x$	$y=-16.31+3.1*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60	60	55	51
-6	Eq.			$y=-20.43+3.47*10^{-3}x$	$y=-16.32+3.1*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60	60	55	51
-8	Eq.				
	r^2				
	Max 1st INC	60	60	60	60

Table 168: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-67.79+369.93*10^{-3}x$	$y=-49.12+293.42*10^{-3}x$	$y=-44.15+271.88*10^{-3}x$
	r^2		0.75	0.74	0.83
	Max 1st INC	60	48	43	41
-4	Eq.		$y=-78.43+387.68*10^{-3}x$	$y=-50.28+281.17*10^{-3}x$	$y=-40.9+245.86*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	43	38	36
-6	Eq.		$y=-78.07+385.87*10^{-3}x$	$y=-49.8+279.71*10^{-3}x$	$y=-40.49+244.12*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	48	38	36
-8	Eq.		$y=-68.82+371.21*10^{-3}x$	$y=-51.05+298.05*10^{-3}x$	$y=-42.63+263.38*10^{-3}x$
	r^2		0.75	0.75	0.79
	Max 1st INC	60	48	42	40

4.3.1.3) 6 deg/100ft TUR



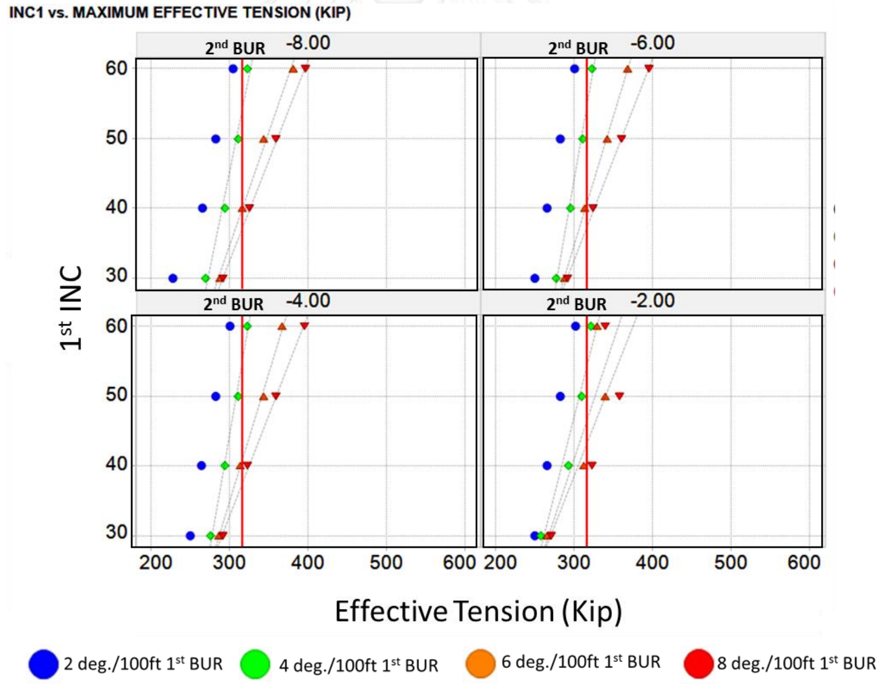


Figure 78: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 6deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

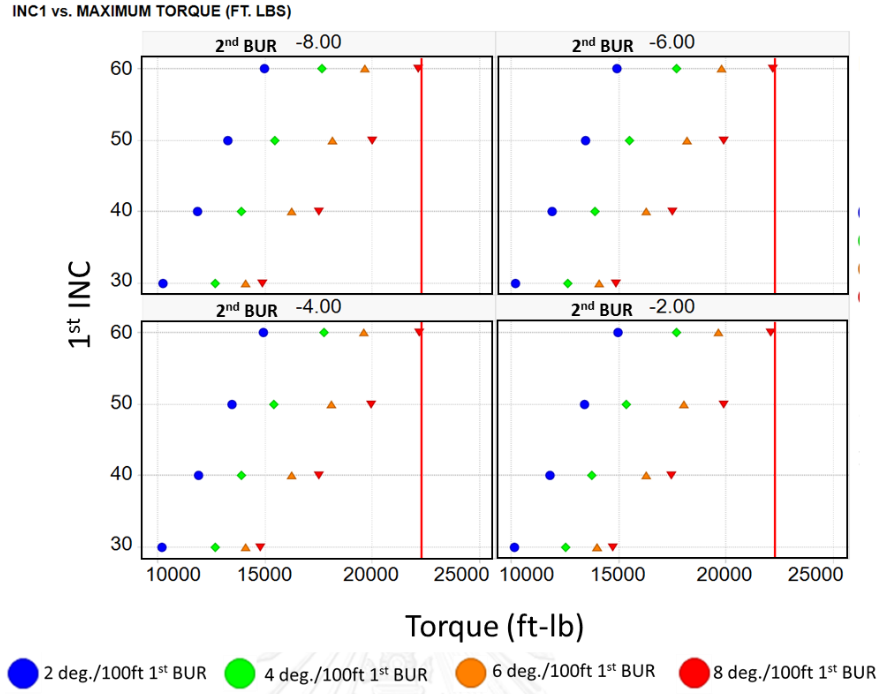
Table 169: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	60	60	60
-4	Eq.				$y=-23.17+3.53*10^{-3}x$
	r^2				1.00
	Max 1st INC	60	60	60	54
-6	Eq.				$y=-23.59+3.54*10^{-3}x$
	r^2				1.00
	Max 1st INC	60	60	60	54
-8	Eq.				$y=-23.34+3.52*10^{-3}x$
	r^2				1.00
	Max 1st INC	60	60	60	54

Table 170: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-85.91+444.07*10^{-3}x$	$y=-59.94+337.14*10^{-3}x$	$y=-47.11+286.11*10^{-3}x$
	r^2		0.94	0.73	0.69
	Max 1st INC	60	53	46	42
-4	Eq.		$y=-149.95+649.23*10^{-3}x$	$y=-75.12+367.45*10^{-3}x$	$y=-53.72+288.98*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	54	40	37
-6	Eq.		$y=-149.76+647.67*10^{-3}x$	$y=-75.79+369.21*10^{-3}x$	$y=-53.84+288.72*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	53	40	37
-8	Eq.		$y=-120.4+553.23*10^{-3}x$	$y=-62.55+324.77*10^{-3}x$	$y=-53.57+287.44*10^{-3}x$
	r^2		0.98	0.99	1.00
	Max 1st INC	60	53	39	36

4.3.1.4) 8 deg/100ft TUR



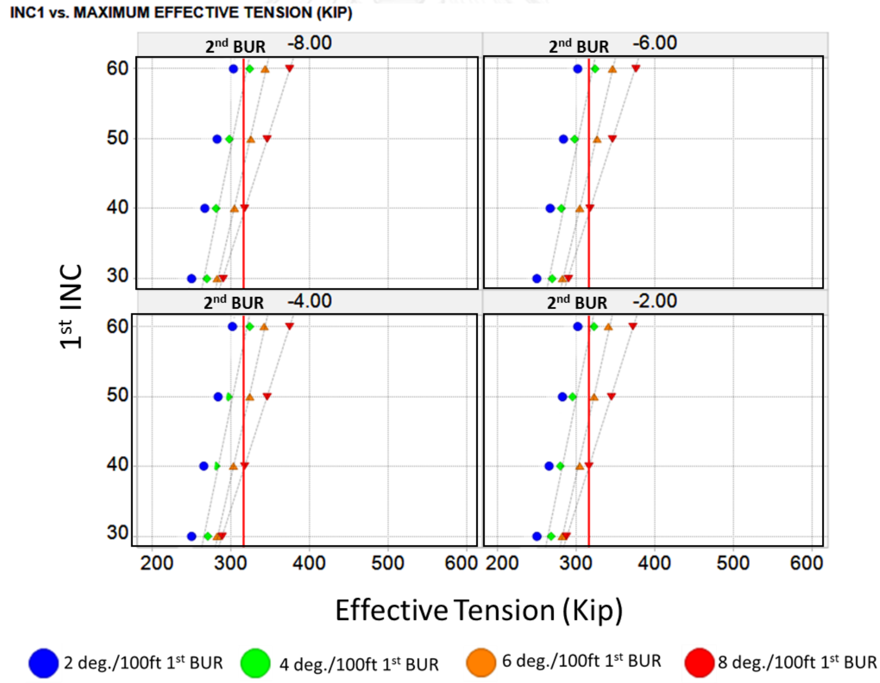


Figure 79: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 90 deg. Turn, 8deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 171: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				y=-30.33+4.06*10^{-3}x
	r^2				1.00
	Max 1st INC	60	60	60	59
-4	Eq.				y=-30.17+4.04*10^{-3}x
	r^2				1.00
	Max 1st INC	60	60	60	58
-6	Eq.				y=-31.48+4.11*10^{-3}x
	r^2				1.00
	Max 1st INC	60	60	60	58
-8	Eq.				y=-31.72+4.12*10^{-3}x
	r^2				1.00
	Max 1st INC	60	60	60	58

Table 172: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		y=-113.45+544.69*10^{-3}x	y=-110.64+498.96*10^{-3}x	y=-72.26+355.62*10^{-3}x
	r^2		0.96	1.00	1.00
	Max 1st INC	60	58	46	39
-4	Eq.		y=-114.99+546.93*10^{-3}x	y=-110.97+498.82*10^{-3}x	y=-70.57+349.03*10^{-3}x
	r^2		0.96	1.00	1.00
	Max 1st INC	60	57	46	39
-6	Eq.		y=-113.22+540.66*10^{-3}x	y=-104.05+474.28*10^{-3}x	y=-71.17+350.5*10^{-3}x
	r^2		0.97	1.00	1.00
	Max 1st INC	60	57	45	39
-8	Eq.		y=-114.98+547.09*10^{-3}x	y=-108.44+489.31*10^{-3}x	y=-71.48+351.24*10^{-3}x
	r^2		0.97	1.00	1.00
	Max 1st INC	60	57	45	39

4.3.2) 120 deg. Turn degree

4.3.2.1) 2 deg/100ft TUR

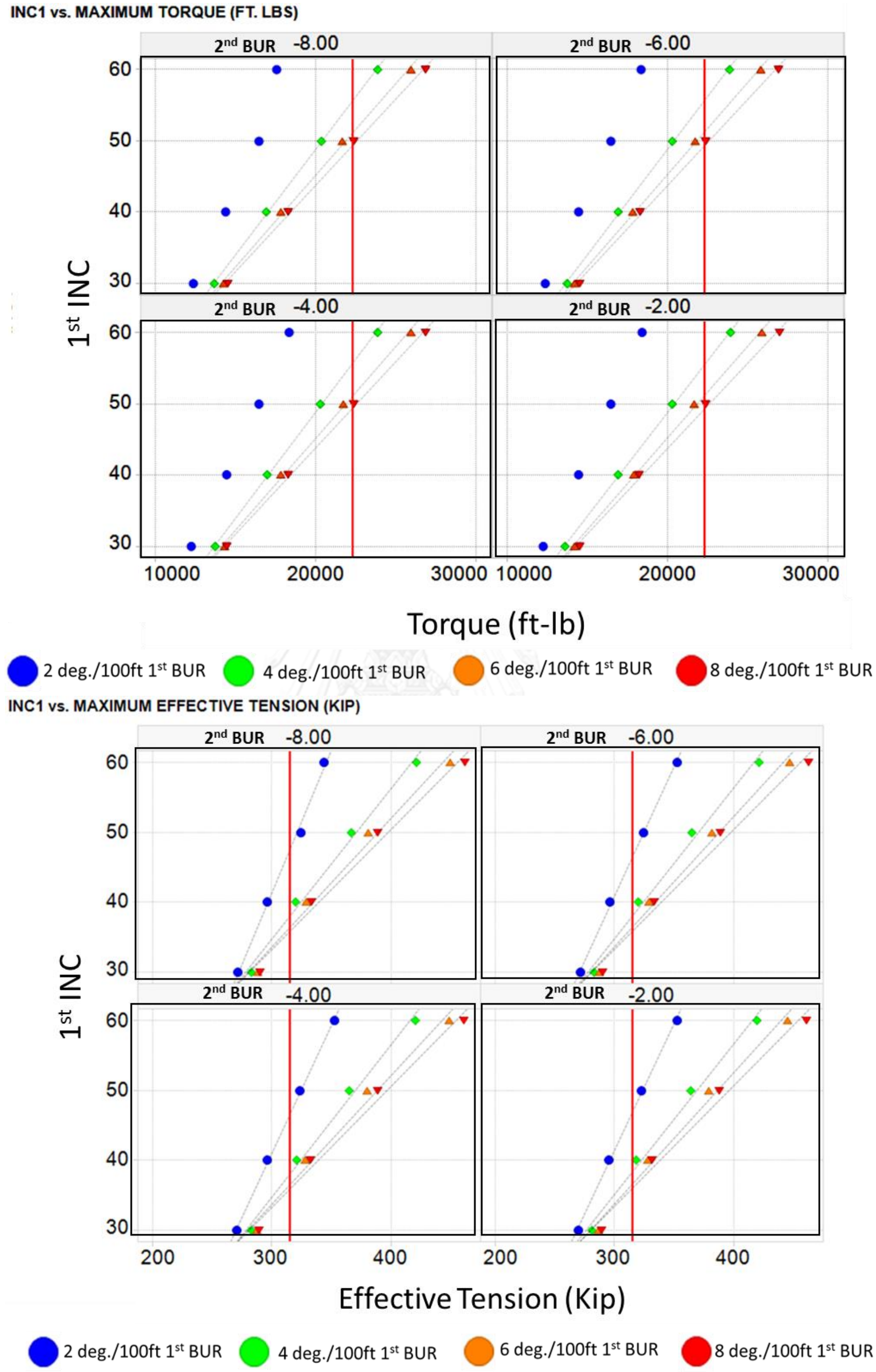


Figure 80: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 173: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-9.22+2.9*10^{-3}x$	$y=-6.09+2.57*10^{-3}x$	$y=-4.01+2.39*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	54	50	48
-4	Eq.		$y=-10.56+2.97*10^{-3}x$	$y=-6.3+2.58*10^{-3}x$	$y=-4.46+2.42*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	54	50	48
-6	Eq.		$y=-10.26+2.96*10^{-3}x$	$y=-6.24+2.58*10^{-3}x$	$y=-4.47+2.41*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	54	50	48
-8	Eq.		$y=-10.19+2.96*10^{-3}x$	$y=-6.14+2.57*10^{-3}x$	$y=-4.53+2.42*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	54	50	48

Table 174: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-67.34+362.71*10^{-3}x$	$y=-29.41+215.19*10^{-3}x$	$y=-22.5+187.64*10^{-3}x$	$y=-18.32+172.52*10^{-3}x$
	r^2	1.00	0.99	0.99	0.99
	Max 1st INC	47	39	37	37
-4	Eq.	$y=-68.79+366.13*10^{-3}x$	$y=-30.66+218.07*10^{-3}x$	$y=-21.48+184.07*10^{-3}x$	$y=-18.63+173.08*10^{-3}x$
	r^2	1.00	0.99	0.99	0.99
	Max 1st INC	47	39	37	36
-6	Eq.	$y=-70.26+370.61*10^{-3}x$	$y=-29.93+215.8*10^{-3}x$	$y=-22.19+186.21*10^{-3}x$	$y=-18.13+171.4*10^{-3}x$
	r^2	1.00	0.99	0.99	0.99
	Max 1st INC	47	38	37	36
-8	Eq.	$y=-81.31+408.96*10^{-3}x$	$y=-29.79+215.19*10^{-3}x$	$y=-21.59+184.08*10^{-3}x$	$y=-18.34+171.96*10^{-3}x$
	r^2	1.00	0.99	0.99	0.99
	Max 1st INC	48	38	37	36

4.3.2.2) 4 deg/100ft TUR

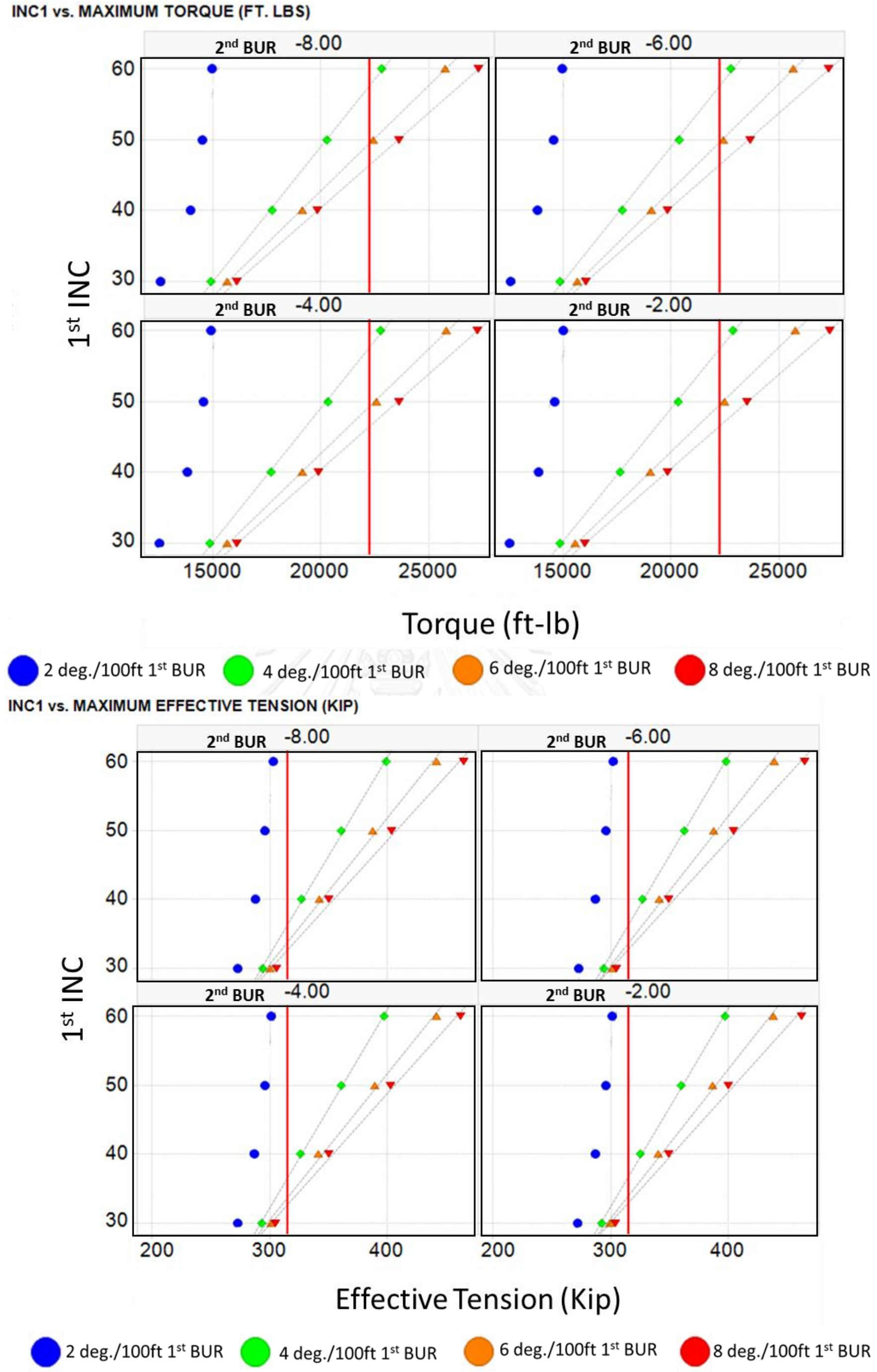


Figure 81: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

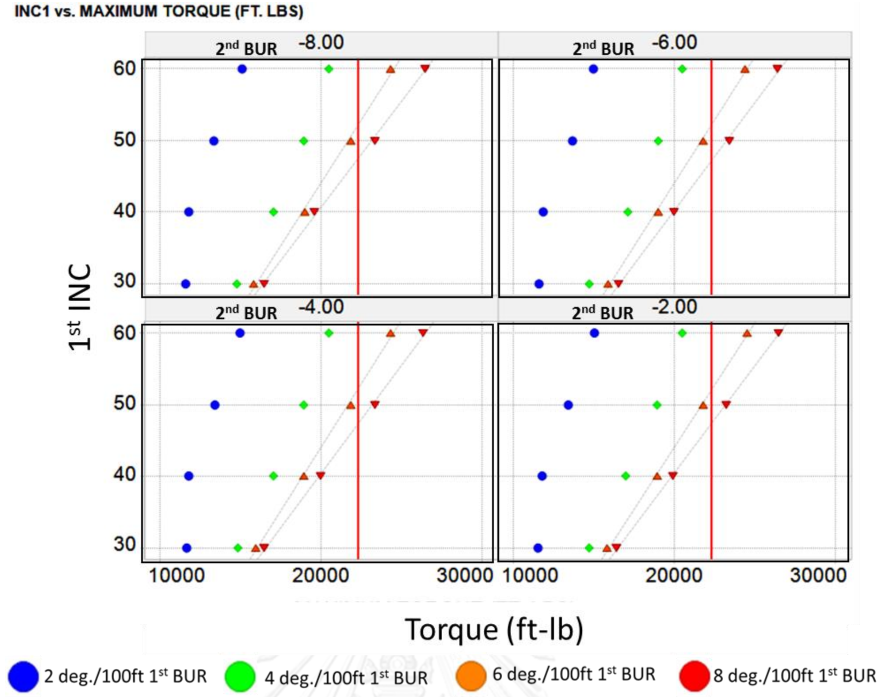
Table 175: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-25.73+3.75*10^{-3}x$	$y=-16.11+2.96*10^{-3}x$	$y=-12.52+2.65*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	56	49	45
-4	Eq.		$y=-26.55+3.8*10^{-3}x$	$y=-16.37+2.96*10^{-3}x$	$y=-13.56+2.7*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	57	48	45
-6	Eq.		$y=-26.9+3.82*10^{-3}x$	$y=-17.31+3.02*10^{-3}x$	$y=-12.93+2.67*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	57	49	45
-8	Eq.		$y=-26.71+3.8*10^{-3}x$	$y=-16.55+2.97*10^{-3}x$	$y=-13.23+2.68*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	56	48	45

Table 176: The maximum 1^{st} INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-54.22+287.63*10^{-3}x$	$y=-35.04+217.08*10^{-3}x$	$y=-27.65+189.75*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	36	33	32
-4	Eq.		$y=-54.52+288.18*10^{-3}x$	$y=-34.11+213.07*10^{-3}x$	$y=-28.21+190.84*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	36	32	31
-6	Eq.		$y=-54.89+288.74*10^{-3}x$	$y=-35.46+217.39*10^{-3}x$	$y=-27.08+187.38*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	33	31
-8	Eq.		$y=-53.87+285.17*10^{-3}x$	$y=-33.76+212.46*10^{-3}x$	$y=-27.42+188.09*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	35	33	31

4.3.2.3) 6 deg/100ft TUR



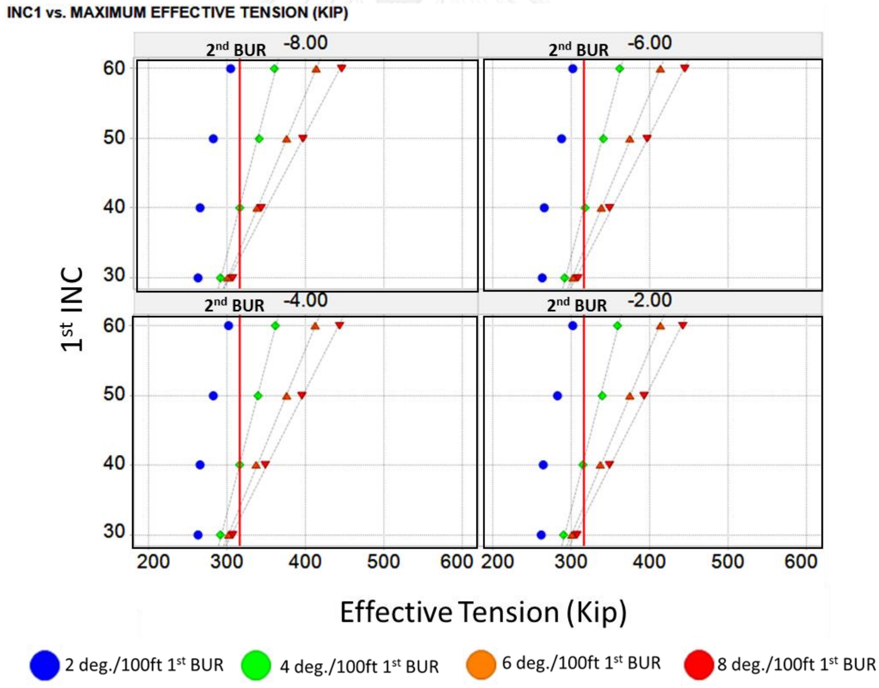


Figure 82: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 177: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-25.12+3.47*10^{-3}x$	$y=-19.17+2.99*10^{-3}x$
	r^2			1.00E+00	1.00
	Max 1st INC	60	60	52	47
-4	Eq.			$y=-26.73+3.55*10^{-3}x$	$y=-19.94+3.02*10^{-3}x$
	r^2			1.00E+00	1.00
	Max 1st INC	60	60	52	47
-6	Eq.			$y=-26.29+3.53*10^{-3}x$	$y=-19.8+3.01*10^{-3}x$
	r^2			1.00E+00	1.00
	Max 1st INC	60	60	52	47
-8	Eq.			$y=-25.94+3.51*10^{-3}x$	$y=-18.43+2.96*10^{-3}x$
	r^2			1.00E+00	1.00
	Max 1st INC	60	60	52	47

Table 178: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-97.19+437.22*10^{-3}x$	$y=-50.02+267.08*10^{-3}x$	$y=-37.22+220.99*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	41	35	33
-4	Eq.		$y=-96.1+431.78*10^{-3}x$	$y=-51.24+270.04*10^{-3}x$	$y=-36.94+219.52*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	40	34	33
-6	Eq.		$y=-94.55+426.58*10^{-3}x$	$y=-50.24+267.08*10^{-3}x$	$y=-36.42+217.56*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	41	34	33
-8	Eq.		$y=-94.42+426.93*10^{-3}x$	$y=-50.04+266.38*10^{-3}x$	$y=-34.23+212.53*10^{-3}x$
	r^2		1.00	1.00	0.99
	Max 1st INC	60	41	34	33

4.3.2.4) 8 deg/100ft TUR

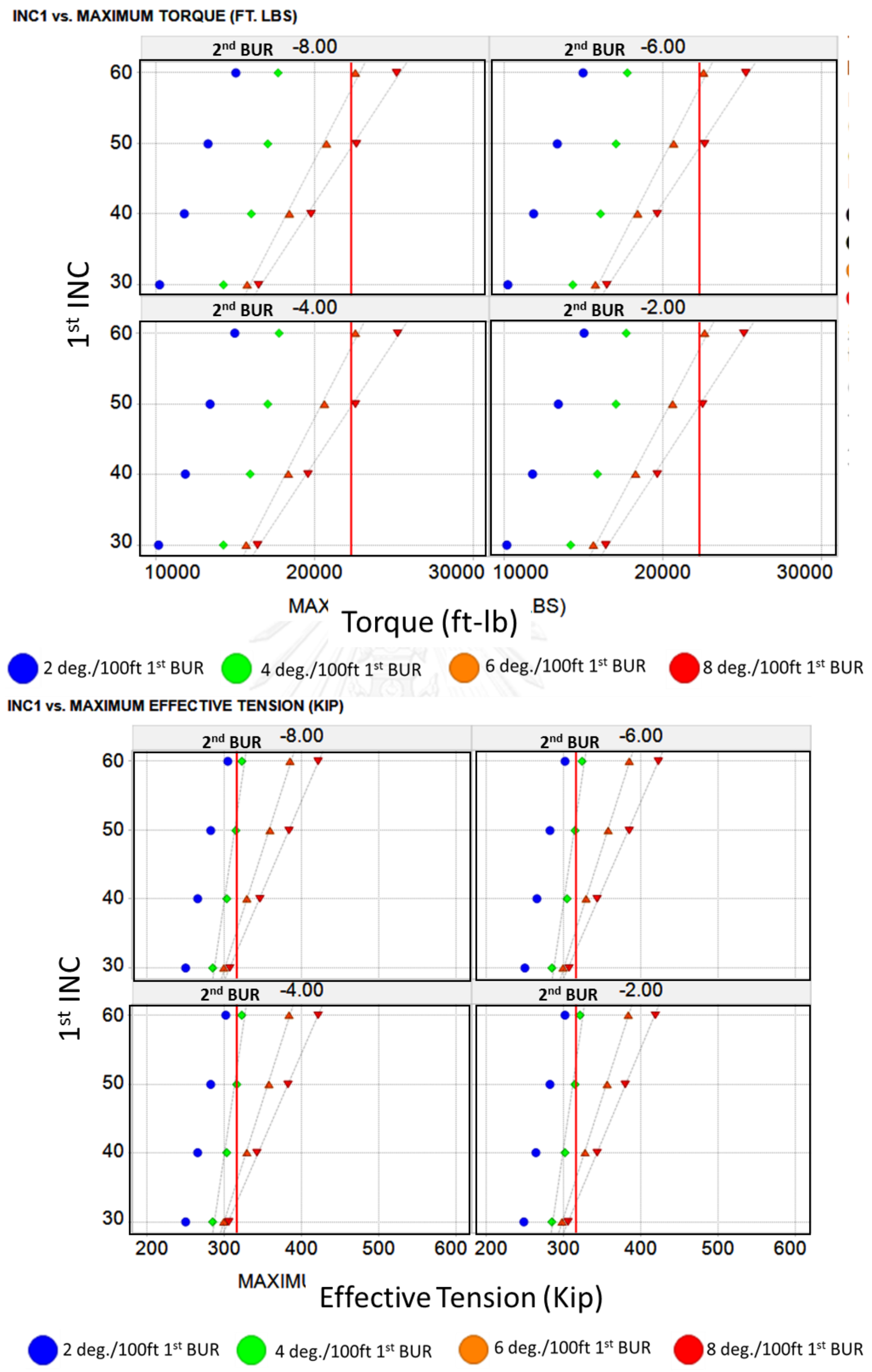


Figure 83: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 120 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 179: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.			$y=-36.64+4.24*10^{-3}x$	$y=-26.72+3.44*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60	60	56	48
-4	Eq.			$y=-38.74+4.34*10^{-3}x$	$y=-26.01+3.4*10^{-3}x$
	r^2			0.99	1.00
	Max 1st INC	60	60	56	48
-6	Eq.			$y=-39.44+4.37*10^{-3}x$	$y=-26.28+3.4*10^{-3}x$
	r^2			0.99	1.00
	Max 1st INC	60	60	56	48
-8	Eq.			$y=-38.97+4.34*10^{-3}x$	$y=-26.92+3.43*10^{-3}x$
	r^2			0.99	1.00
	Max 1st INC	60	60	56	48

Table 180: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-190.18+771.16*10^{-3}x$	$y=-73.98+349.34*10^{-3}x$	$y=-51.7+267.65*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	52	36	32
-4	Eq.		$y=-188.52+762.7*10^{-3}x$	$y=-75.14+351.67*10^{-3}x$	$y=-48.45+257.75*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	51	35	32
-6	Eq.		$y=-187.14+756.96*10^{-3}x$	$y=-75.51+351.96*10^{-3}x$	$y=-48.35+256.66*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	51	35	32
-8	Eq.		$y=-189.68+766.54*10^{-3}x$	$y=-75+349.97*10^{-3}x$	$y=-49.83+260.67*10^{-3}x$
	r^2		0.96	1.00	1.00
	Max 1st INC	60	51	35	32

4.3.3) 150 deg. Turn degree

4.3.3.1) 2 deg/100ft TUR

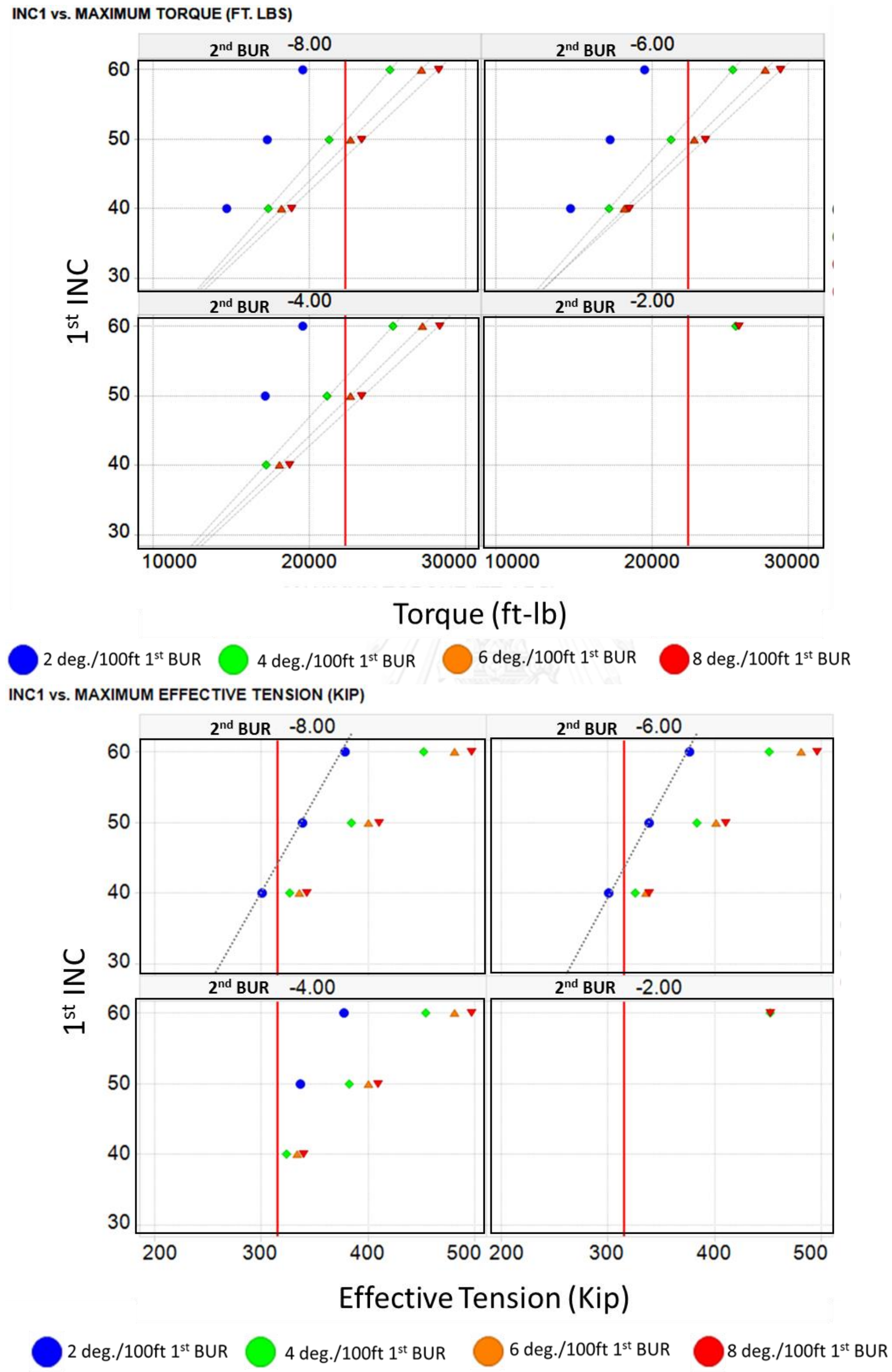


Figure 84: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 181: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	*	-	-	-
-4	Eq.		$y=-1.95+2.45*10^{-3}x$	$y=0.5+2.19*10^{-3}x$	$y=1.28+2.08*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60**	51	48	47
-6	Eq.		$y=-3.41+2.52*10^{-3}x$	$y=-0.41+2.22*10^{-3}x$	$y=1.77+2.06*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60*	51	48	47
-8	Eq.		$y=-4.26+2.56*10^{-3}x$	$y=-0.59+2.23*10^{-3}x$	$y=0.28+2.12*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60*	51	48	46

Table 182: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	*	-	-	-
-4	Eq.				
	r^2				
	Max 1st INC	**	-	-	-
-6	Eq.	$y=-39.3+263.85*10^{-3}x$			
	r^2	1			
	Max 1st INC	43	-	-	-
-8	Eq.	$y=-37.73+258.72*10^{-3}x$			
	r^2	1			
	Max 1st INC	43*	-	-	-

Remark

* cannot design with inclination lower than 30 deg.

* * cannot design with inclination lower than 40 deg.

*** cannot design with inclination lower than 50 deg.

\- cannot design due to exceed torque and drag limit.

4.3.3.2) 4 deg/100ft TUR

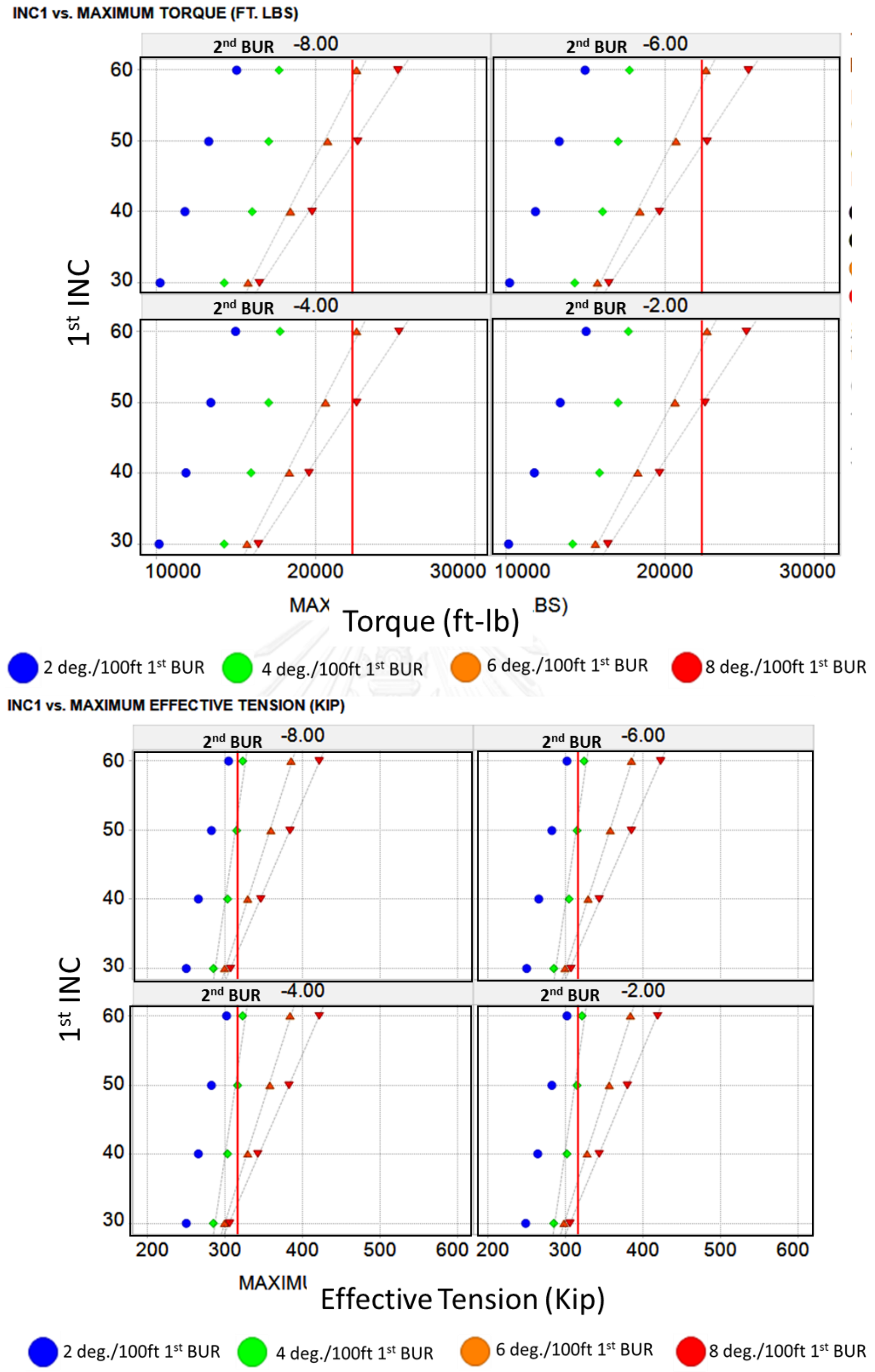


Figure 85: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 183: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-20.71+3.2*10^{-3}x$	$y=-13.83+2.63*10^{-3}x$	$y=-10.72+2.39*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	49	43	41
-4	Eq.		$y=-22.15+3.27*10^{-3}x$	$y=-13.82+2.62*10^{-3}x$	$y=-10.39+2.38*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	49	43	41
-6	Eq.		$y=-22.26+3.27*10^{-3}x$	$y=-14.66+2.67*10^{-3}x$	$y=-11.28+2.42*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	49	44	41
-8	Eq.		$y=-22.4+3.28*10^{-3}x$	$y=-14.34+2.65*10^{-3}x$	$y=-11.09+2.4*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	49	44	41

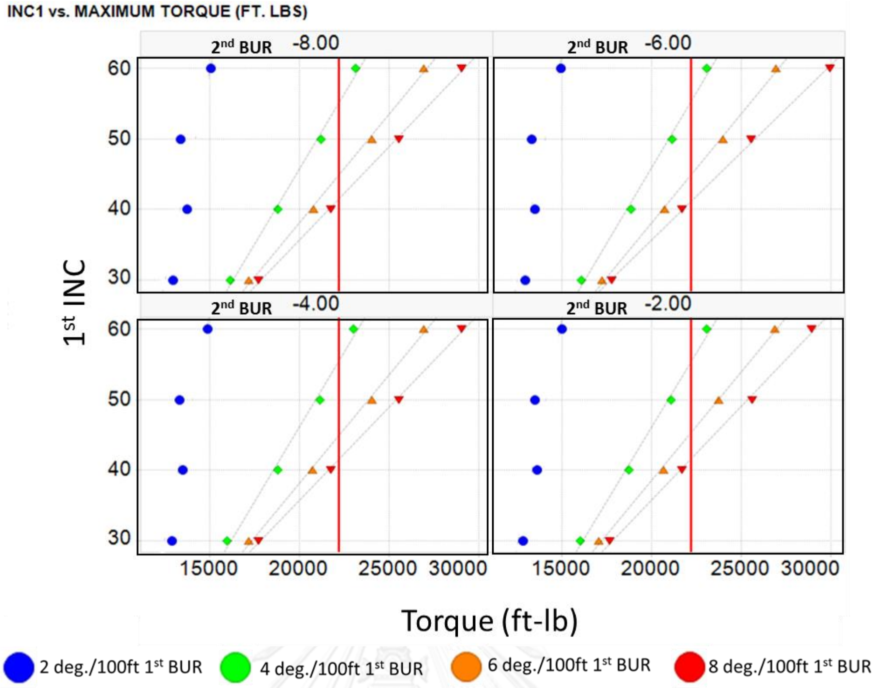
Table 184: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-73.35+391.15*10^{-3}x$	$y=-36.57+220.29*10^{-3}x$	$y=-23.17+172.01*10^{-3}x$	
	r^2	0.90	1.00	1.00	
	Max 1st INC	49	32	30	-
-4	Eq.	$y=-146+615.97*10^{-3}x$	$y=-37.19+221.15*10^{-3}x$	$y=-22.45+169.77*10^{-3}x$	
	r^2	0.99	1.00	1.00	
	Max 1st INC	47	32	31	-
-6	Eq.	$y=-144.4+610.29*10^{-3}x$	$y=-37.13+221.02*10^{-3}x$	$y=-23.4+172.27*10^{-3}x$	
	r^2	0.98	1.00	1.00	
	Max 1st INC	47	32	30	-
-8	Eq.	$y=-150.87+631.94*10^{-3}x$	$y=-37.29+221.08*10^{-3}x$	$y=-22.72+170.41*10^{-3}x$	
	r^2	0.98	1.00	0.99	
	Max 1st INC	48	32	30	-

Remark

- cannot design due to exceed torque and drag limit.

4.3.3.3) 6 deg/100ft TUR



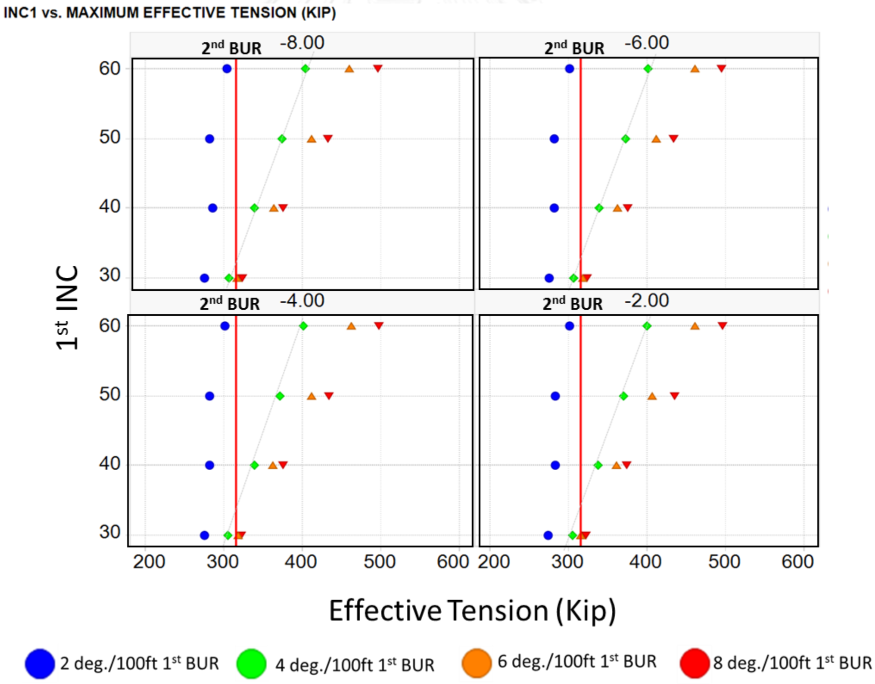


Figure 86: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 185: The maximum 1^{st} INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-37.96+4.2*10^{-3}x$	$y=-22.91+3.07*10^{-3}x$	$y=-17.36+2.66*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	54	44	41
-4	Eq.		$y=-38.61+4.24*10^{-3}x$	$y=-23.28+3.07*10^{-3}x$	$y=-17.04+2.64*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	54	44	41
-6	Eq.		$y=-39.58+4.27*10^{-3}x$	$y=-23.71+3.09*10^{-3}x$	$y=-13.93+2.48*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	54	44	40
-8	Eq.		$y=-39.36+4.26*10^{-3}x$	$y=-23.36+3.08*10^{-3}x$	$y=-17.22+2.65*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	54	44	40

Table 186: The maximum 1^{st} INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-65.52+312.74*10^{-3}x$	$y=-35.06+207.39*10^{-3}x$	
	r^2		1.00	1.00	
	Max 1st INC	60	32	30	-
-4	Eq.		$y=-65.48+311.96*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	60	32	-	-
-6	Eq.		$y=-66.22+313.34*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	60	32	-	-
-8	Eq.		$y=-63.99+306.16*10^{-3}x$		
	r^2		1.00		
	Max 1st INC	60	32	-	-

Remark

- cannot design due to exceed torque and drag limit

4.3.3.4) 8 deg/100ft TUR

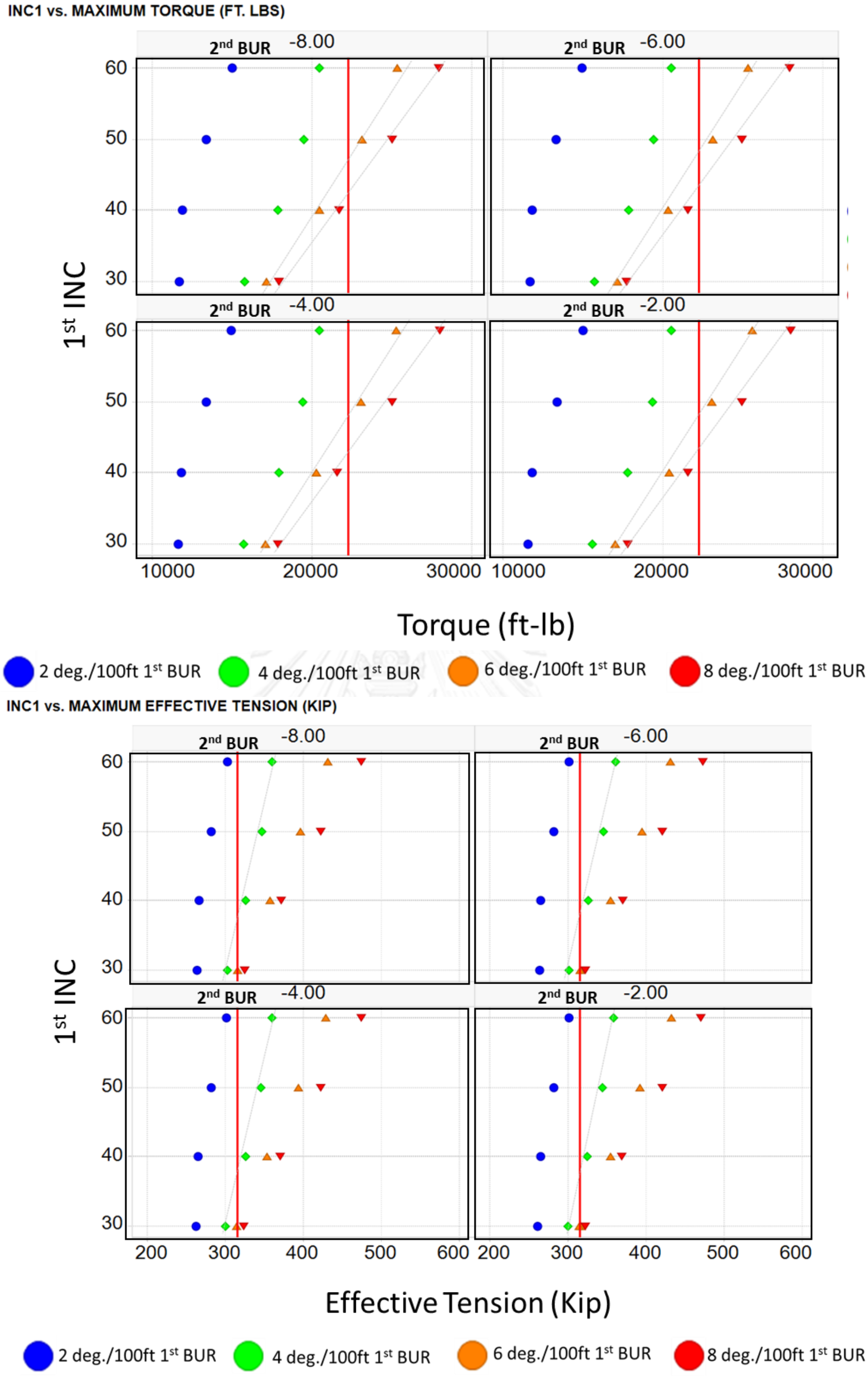


Figure 87: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 150 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 187: The maximum 1st INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-42.18+3.73*10^{-3}x$	$y=-22.68+2.53*10^{-3}x$	$y=-15.09+2.11*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	39	32	31
-4	Eq.		$y=-41.85+3.69*10^{-3}x$	$y=-21.91+2.5*10^{-3}x$	$y=-17.24+2.18*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	39	33	30
-6	Eq.		$y=-40.99+3.62*10^{-3}x$	$y=-22.66+2.52*10^{-3}x$	$y=-16.68+2.16*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	38	32	30
-8	Eq.		$y=-45.44+3.84*10^{-3}x$	$y=-23.8+2.56*10^{-3}x$	$y=-16.39+2.15*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	38	32	30

Table 188: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-91.65+454.09*10^{-3}x$	$y=-95.59+399.26*10^{-3}x$		
	r^2	0.93	0.99		
	Max 1st INC	51	30	-	-
-4	Eq.	$y=-96.98+469.1*10^{-3}x$			
	r^2	0.95			
	Max 1st INC	50	-	-	-
-6	Eq.	$y=-93.54+458.22*10^{-3}x$			
	r^2	0.95			
	Max 1st INC	50	-	-	-
-8	Eq.	$y=-87.65+438.72*10^{-3}x$			
	r^2	0.94			
	Max 1st INC	50	-	-	-

Remark

- cannot design due to exceed torque and drag limit

4.3.4) 180 deg. Turn degree

4.3.4.1) 2 deg/100ft TUR

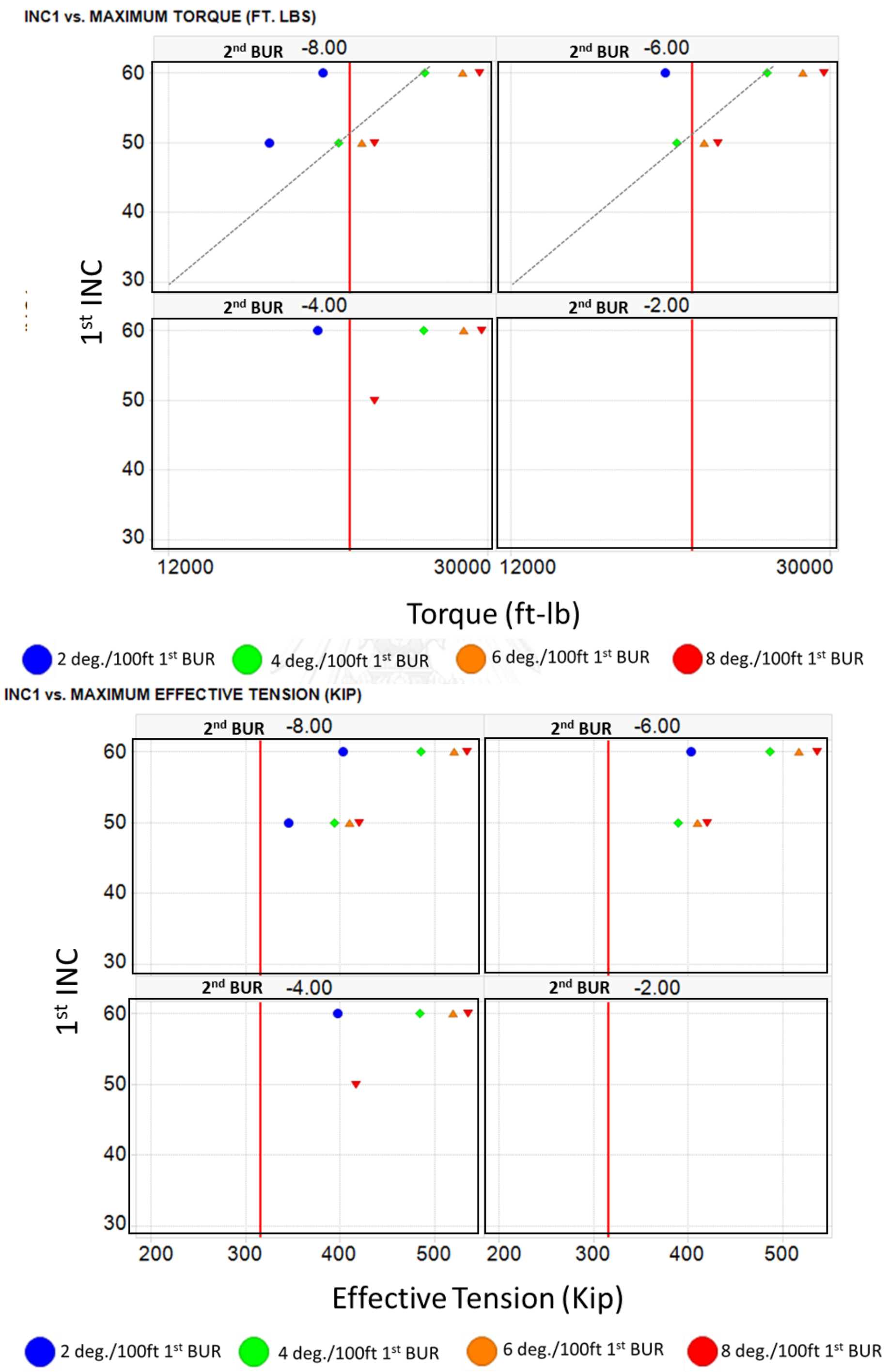


Figure 88: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 2 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 189: The maximum 1st INC, by torque criteria

	Torque				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.			$y=0.5+2.19*10^{-3}x$	$y=1.28+2.08*10^{-3}x$
	r^2			1.00	1.00
	Max 1st INC	60***	-	48	47
-6	Eq.		$y=-3.41+2.52*10^{-3}x$	$y=-0.41+2.22*10^{-3}x$	$y=1.77+2.06*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60***	51	48	47
-8	Eq.		$y=-4.26+2.56*10^{-3}x$	$y=-0.59+2.23*10^{-3}x$	$y=0.28+2.12*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60**	51	48	46

Table 190: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	2			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	x	x	x	x
-4	Eq.				
	r^2				
	Max 1st INC	-	-	-	-
-6	Eq.				
	r^2				
	Max 1st INC	-	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	-	-	-	-

Remark

x cannot design due to not follow casing regulation.

* * cannot design with inclination lower than 40 deg.

*** cannot design with inclination lower than 50 deg.

- cannot design due to exceed torque and drag limit.

4.3.4.2) 4 deg/100ft TUR

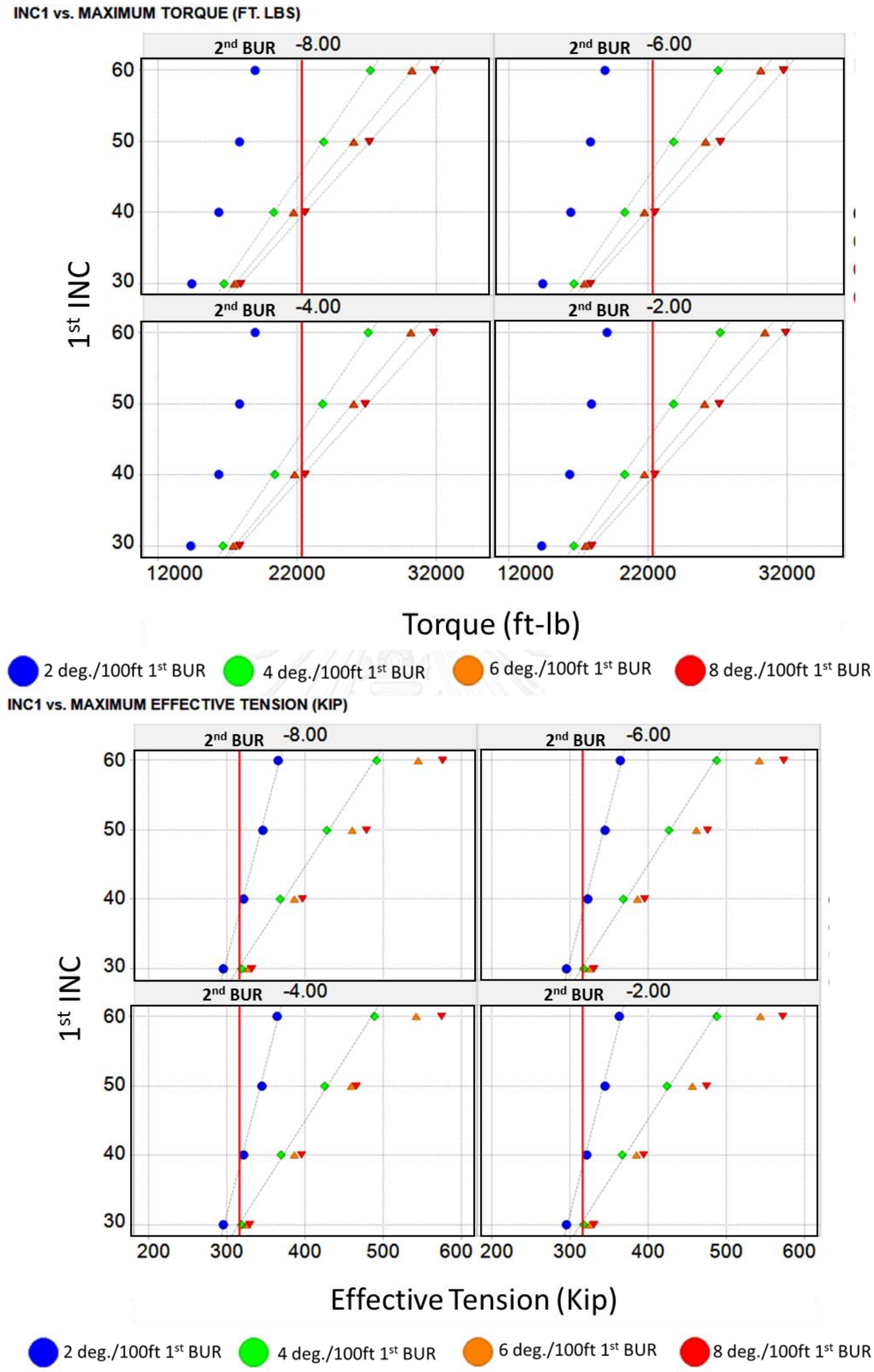


Figure 89: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 4 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 191: The maximum 1st INC, by torque criteria

	Torque				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-17.22+2.83*10^{-3}x$	$y=-10.53+2.33*10^{-3}x$	$y=-8.21+2.14*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	45	40	38
-4	Eq.		$y=-18.32+2.88*10^{-3}x$	$y=-11.2+2.36*10^{-3}x$	$y=-8.37+2.16*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	45	40	39
-6	Eq.		$y=-18.52+2.89*10^{-3}x$	$y=-11.1+2.35*10^{-3}x$	$y=-8.47+2.16*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	45	40	38
-8	Eq.		$y=-17.64+2.84*10^{-3}x$	$y=-11.16+2.35*10^{-3}x$	$y=-8.52+2.15*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	44	40	38

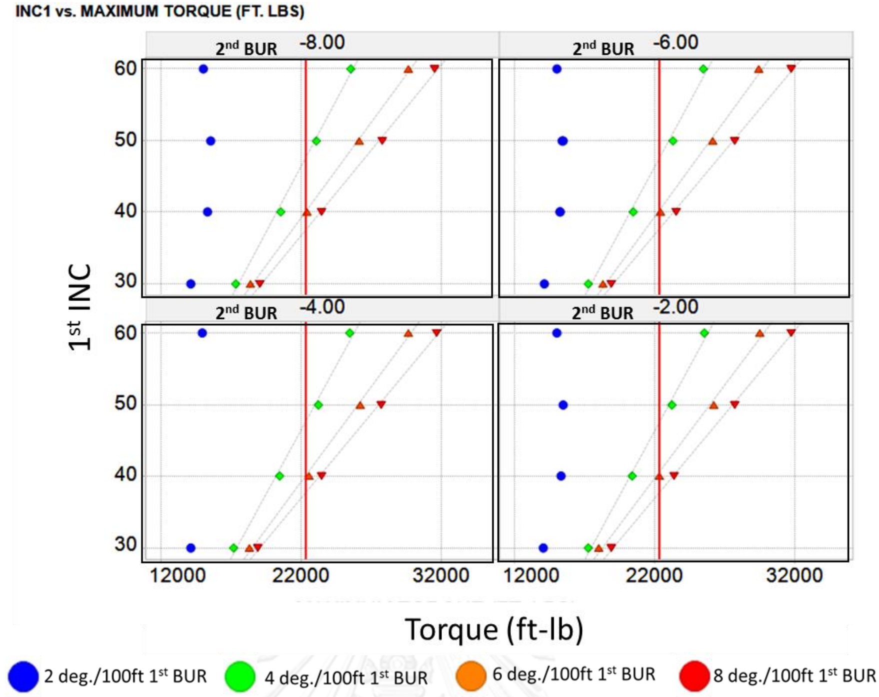
Table 192: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	4			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.	$y=-98.46+434.25*10^{-3}x$	$y=-24.81+175.27*10^{-3}x$		
	r^2	1.00	1.00		
	Max 1st INC	38	30	-	-
-4	Eq.	$y=-97.5+430.93*10^{-3}x$	$y=-25.45+176.28*10^{-3}x$		
	r^2	1.00	1.00		
	Max 1st INC	38	30	-	-
-6	Eq.	$y=-98.95+434.81*10^{-3}x$	$y=-25.23+175.94*10^{-3}x$		
	r^2	0.99	1.00		
	Max 1st INC	37	30	-	-
-8	Eq.	$y=-95.44+423.76*10^{-3}x$	$y=-23.99+172.1*10^{-3}x$		
	r^2	1.00	1.00		
	Max 1st INC	37	30	-	-

Remark

- cannot design due to exceed torque and drag limit.

4.3.4.3) 6 deg/100ft TUR



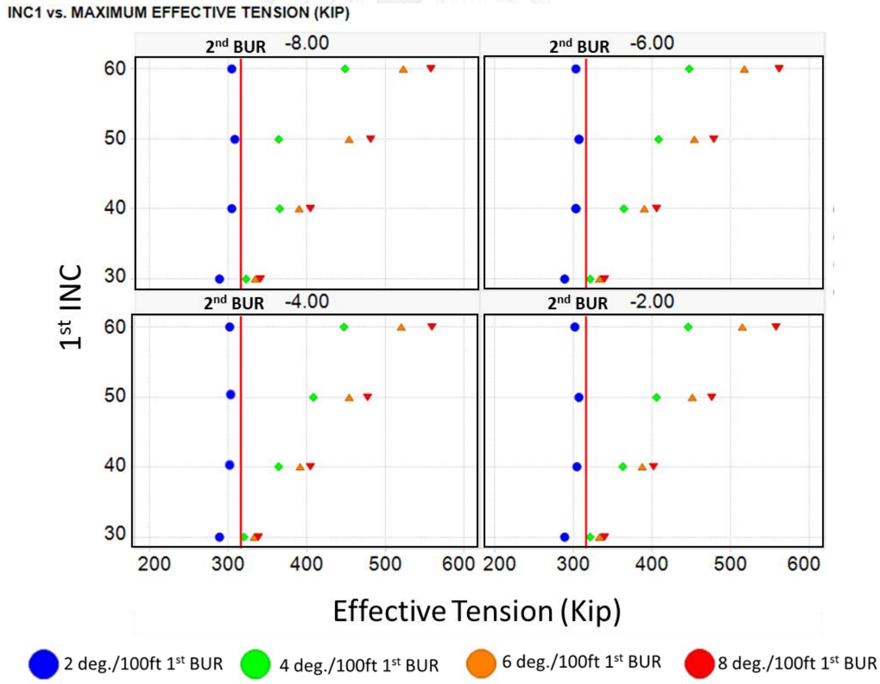


Figure 90: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 6 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 193: The maximum 1st INC, by torque criteria

	Torque				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-32.69+3.6*10^{-3}x$	$y=-17.42+2.6*10^{-3}x$	$y=-14.48+2.34*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	46	39	37
-4	Eq.		$y=-32.14+3.58*10^{-3}x$	$y=-18.9+2.65*10^{-3}x$	$y=-14.63+2.35*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	46	39	37
-6	Eq.		$y=-32.98+3.61*10^{-3}x$	$y=-19.48+2.68*10^{-3}x$	$y=-14.4+2.34*10^{-3}x$
	r^2		0.99	1.00	1.00
	Max 1st INC	60	46	39	36
-8	Eq.		$y=-34.15+3.67*10^{-3}x$	$y=-19.19+2.66*10^{-3}x$	$y=-15.55+2.38*10^{-3}x$
	r^2		1.00	1.00	1.00
	Max 1st INC	60	46	39	36

Table 194: The maximum 1st INC, by effective tension criteria

	Effective Tension				
	TUR	6			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-4	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-6	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	60	-	-	-

Remark

- cannot design due to exceed torque and drag limit.

4.3.4.4) 8 deg/100ft TUR

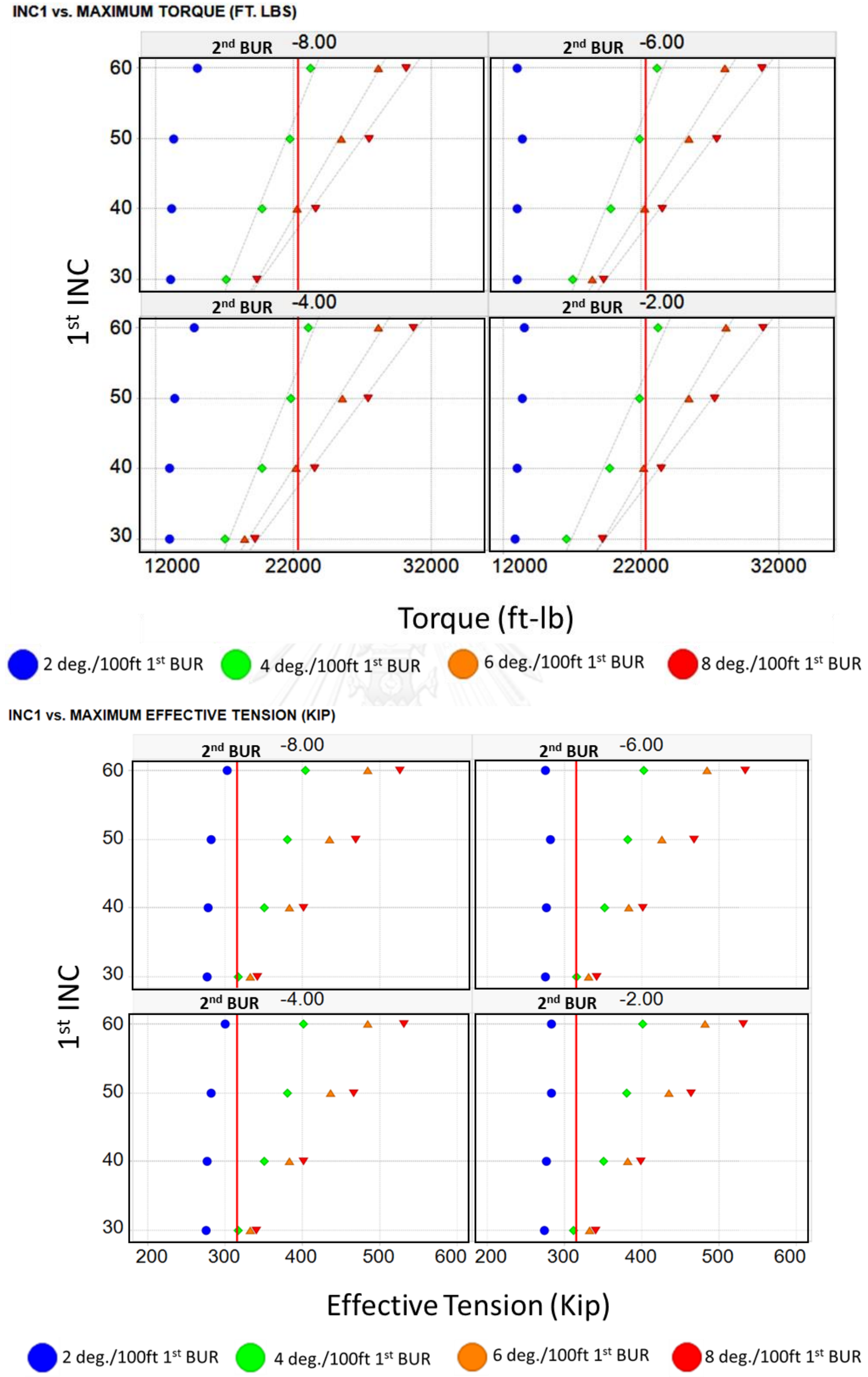


Figure 91: Maximum torque and effective tension versus 1st INC as a function of 5300ft. 1st KOP with immediately 2nd KOP, 180 deg. Turn, 8 deg/100ft TUR and varied well plan parameters for 3D build hold and drop profile.

Table 195: The maximum 1[st] INC, by torque criteria

	Torque				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.		$y=-43.97+4.37*10^{-3}x$	$y=-34.07+3.33*10^{-3}x$	$y=-19.95+2.58*10^{-3}x$
	r^2		0.97	1.00	1.00
	Max 1st INC	60	52	39	36
-4	Eq.		$y=-53.48+4.83*10^{-3}x$	$y=-27.28+3.07*10^{-3}x$	$y=-20.46+2.6*10^{-3}x$
	r^2		0.98	0.99	1.00
	Max 1st INC	60	52	40	36
-6	Eq.		$y=-52.58+4.78*10^{-3}x$	$y=-27.73+3.09*10^{-3}x$	$y=-20.22+2.59*10^{-3}x$
	r^2		0.97	0.99	1.00
	Max 1st INC	60	52	40	36
-8	Eq.		$y=-53.81+4.84*10^{-3}x$	$y=-35.23+3.37*10^{-3}x$	$y=-23.28+2.72*10^{-3}x$
	r^2		0.98	1.00	0.99
	Max 1st INC	60	52	38	36

Table 196: The maximum 1[st] INC, by effective tension criteria

	Effective Tension				
	TUR	8			
2nd BUR	1st BUR	2	4	6	8
-2	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-4	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-6	Eq.				
	r^2				
	Max 1st INC	60	-	-	-
-8	Eq.				
	r^2				
	Max 1st INC	60	-	-	-

Remark

- cannot design due to exceed torque and drag limit.

VITA

Anusara Hentoog was born at Phitsanulok, Thailand in July, 9th 1989. She graduated with a bachelor degree of science, geology from Chulalongkorn University, Bangkok, Thailand in 2012. After she was entranced to a Master degree's program in petroleum engineering, Chulalongkorn University, Bangkok, Thailand in 2014.

She joined Smith bits a Schlumberger company for 4 years working as a DBOS ENGINEER, service for Chevron Thailand locate in Bangkok, Thailand. Currently, she is a full-time student of degree's program in petroleum engineering, Chulalongkorn University, Bangkok, Thailand.

She has her passion in improving the drilling performance include pre-drilled analysis to eliminate risk and uncertainty. Her open and contextual evaluation methodology based on responsive constructivists creates new pathways for improving well planning process and decrease work load.