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Experience based Technical Sidetrack

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Summary

Drilling is more experience-based than any other field in oil and gas industry. It involves many industry standards and regulations in order to enhance technical integrity. In addition, the "best practices" provide a system-wide reference for the engineers to plan as well as execute drilling and completion operations. If it is possible to transfer the experiences globally, the best practices and procedures can be even further improved. This approach is a paradigm shift from the tradition and can achieve the enormous enhancements in the drilling industry.

In this thesis, sidetracking activity is introduced to show the applicability of the experiences, regulations and industry standards for drilling operations. The method to sidetrack a wellbore, the required BHA design and operational parameters are established mainly by the experiences extracted from NTNU-governing documents and NORSOK Standards. Sidetracking from cement plug with the rotary steerable system, some experience-based recommendations and adjustments are concluded for our well model.

Moreover, the original and sidetracked well models are simulated in Landmark engineering programs. The well trajectories are designed in Compass, hydraulic as well as torque and drag programs are simulated in WellPlan, the casing designs are built in WellCat in order to check the safety of the well models and find critical results, which can threaten the operations. Furthermore, the risks in sidetracking and drilling operations are revealed and assessed based on the field experiences, where the risk levels are also reduced to the acceptable degree.

The observations of this research study indicate that the experience transfer is usually running smoothly in the same field. However, it is difficult to share the "learned lessons" among the different fields. Therefore, drilling organizations should be eager to incorporate and establish a simulator/experience transfer system that stores all industry standards and experiences in one database. In addition, the experience transfer system should have the capability to integrate with currently available software package in the company, which will make the system more user-friendly to find relevant standards and experiences.

Obviously, there will be challenges to find appropriate information out of the huge database in the experience transfer system. Thus, the system should have the well-organized search mechanism, which is another research study of this topic.

Acknowledgement

This thesis is completed at the Department of Petroleum Engineering and Applied Geophysics, Norwegian University of Science and Technology (NTNU). The main objective of the project has been to write a scientific paper and specialize in drilling engineering. The report has been prepared in close cooperation with professors at NTNU.

Hence, I would like to express my gratitude to my supervisor, Professor Sigbjørn Sangesland for providing me with this opportunity. Working together with him on this topic, led me to improve my knowledge.

A deep gratitude goes to Bjørn Brechan, my co-supervisor. I would like to thank him for arranging meetings with the engineers at Statoil, all the input data he has supplied and all the knowledge he has shared, which kept me motivated through the semester. I could not have had a better supervisor.

Last but not the least, I am thankful to my fellow students for sharing their knowledge and interesting discussions made during the semester.

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1 Introduction

Drilling operations are established principally by field experiences. That is why, the collected experiences out of drilling operations are very valuable and can determine the required technical models, such as BHA design, casing program, cement design, mud program etc. The field experiences can also detect the potential risks and reveal their countermeasures. As the wells become more complicated to drill, many technical issues emerge and become solved in the drilling industry. The reports, which consist of drilling problems and their solutions, are the supportive experiences for the execution of the same well activities in the future and can avoid potential dangers in advance or solve the problems in a shorter period of time with a better quality.

1.1 Case Study

In this thesis, sidetracking activity is chosen to illustrate the applicability of the experience and industry standards for drilling operations. The data was provided by my co-supervisor, Bjorn Astor Brenchan, and it reflects one of the wells in the North Sea. In this well, the conductor, surface and intermediate casings were set and cemented in place. While drilling for the next hole section, the drilling was stopped at 2250 m MD due to a bad weather condition. Once drilling started after several days of wait on weather (WOW), the formation collapsed and it was not possible to follow the planned well trajectory because of wellbore instability issues. To avoid these problems, it was decided to perform technical sidetrack in openhole at 2200 m MD.

1.2 Methodology

Sidetracking and drilling operations for this well are designed based on the regulations and industry standards. The method to sidetrack a wellbore, the required BHA design and operational parameters are detected mainly by the experiences extracted from NTNU-governing documents and NORSOK Standards.

Moreover, all activities performed in both original and sidetracked wellbores have been simulated in Landmark products to evaluate the safety and integrity of the well models. The wellpaths are built in Compass, torque & drag as well as hydraulic programs are established in WellPlan and casing designs are modeled in WellCat. It is worth mentioning that the simulations based on predetermined operational parameters did not show any critical result for sidetracked well model.

Furthermore, the risks in sidetracking and drilling operations are uncovered as well as assessed based on the field practices. The relevant countermeasures are also found in order to mitigate the risk level as well as provide safe sidetracking and drilling operations.

2 Fundamental Theory

2.1 Experience and Work Process

Exploration and Production (E&P) projects, that are profitable to commence drilling operations, are considered as a subsequent series of separate tasks rather than as a whole workflow in the past years. It is now perceived that the field development has to be treated as a whole workflow to decrease the time and expenditure spent on the entire process. As a result, the generation of a smooth project workflow gets more crucial ever than before particularly due to today's low price of crude oil and hardly accessible reserves. Many of the new discoveries are either small or located in the harsh environment. In addition, the recovery of remaining reserves under the maturing fields also gets increasingly difficult, leading the companies to investigate the methods how to decrease the time spent on operations *(McCann et al., 1998)*.

E&P expenses can be reduced by involving the cost control and risk reduction for all phases of the workflow. Especially, a drilling workflow has more potential to affect E&P costs. In the E&P cycle, a drilling workflow begins with the planning of a well trajectory and ends at the well construction *(François Clouzeau, 1998)*. The research performed by a team in late 1997 revealed eight principles that commonly contribute to a successful project and have been observed almost in any thrived operation *(Thorogood, 2000).* These principles are:

- Accomplish early planning and effective design
- Execute risk assessment thoroughly and properly
- Set clear milestones, delegate the workload with the special focus on accountabilities of team members
- Evaluate performance of the project consistently against stretch targets
- Run the whole project seriously with total commitment to the goals
- Be eager to learn as a company
- Strive for a balanced position or interest between contracts and business goals
- Implicate all team members into the project

Some of these principles will be reviewed further in this chapter.

2.1.1 Drilling Workflow

The investigation of the operational process designates "gaps" in the procedures and provides consistently sound workflow in the drilling. A general structure for the workflow is shown in *Figure 1*. There are 3 phases of drilling operation:

- Planning and Design
- Execution
- Evaluation

The first phase of drilling workflow consists of two separate stages - "preliminary well planning" and "detailed well design". An operating company is responsible for implementing the entire planning and design of a well. The accountabilities of an operator are explained with more details in *Appendix A.1*. Execution phase is where both contractor and service companies are largely involved in the process. A contractor is in charge of drilling a well and service companies are responsible for providing mud, cement programs and other well constructions. The execution phase gets started as soon as the operator obtains the permits to run a field. When the execution phase is finalized, real-time data shall be gathered in the database in the appropriate format in order to enable easy access for analysis of the drilling performance and risks. The collection of the operational data will support the subsequent activities in the field.

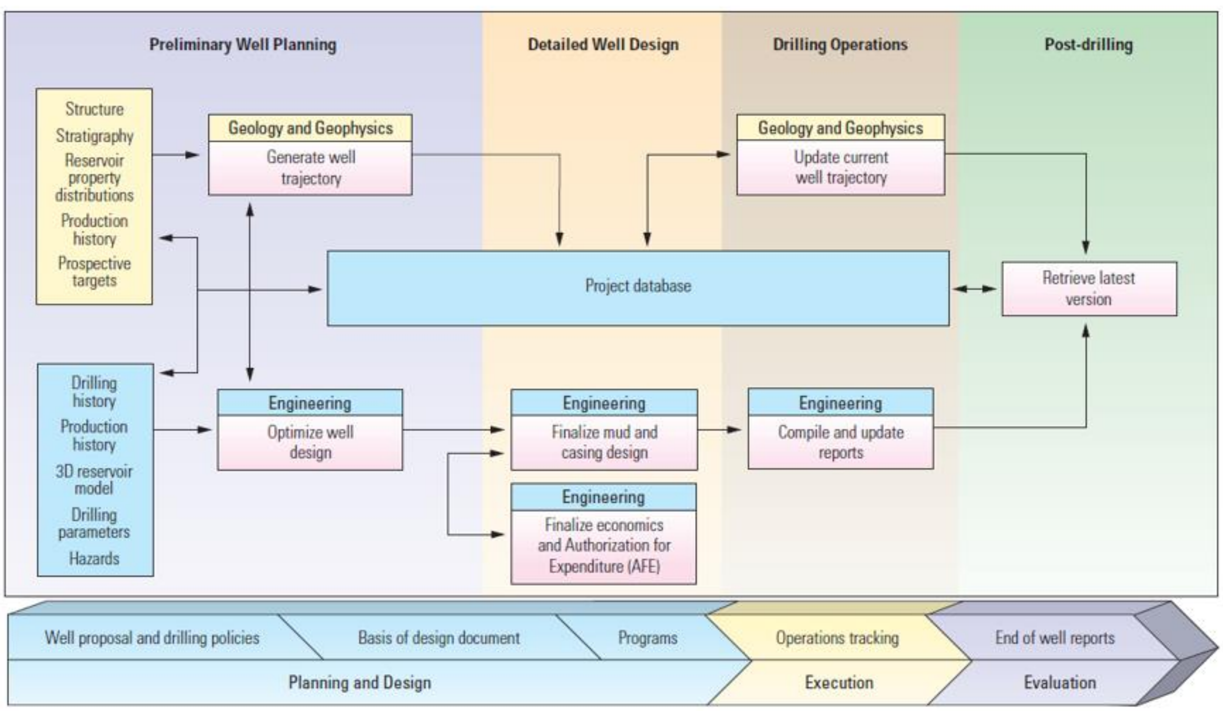


Figure 1. Drilling workflow (*François Clouzeau, 1998)*.

Drilling workflow is always followed by scheduling and reporting to keep the drilling time in the predetermined frame and document every single activity. Proper reporting enables easy information sharing among all members of a team, and scheduling empowers the generation of the smooth workflow. Both reporting and scheduling are important and supportive for the drilling activities. Major types of reports and schedules are introduced in *Appendix A.2* .

2.1.2 Drilling Performance Curve

There is no real economic model that reflects the evaluation of the drilling performance. The classic approach - depth versus days plot is the main technique to compare a success or failure of the drilling performance *(Brett and Millheim, 1986).* The drilling is apparently more experienced-based and performed for a series of wells in the field. This approach triggered the curiosity of the researchers to apply "learning curve theory" techniques into the process as an evaluation tool.

The application of the learning curve theory to drilling operations or so-called Drilling Performance Curve (DPC) model is a quantification of what has been observed qualitatively – The first well to drill in the area is expensive and the last one is cheap *(Emery, Sternberg, 1982).* The best mathematical algorithm that reflects the learning curve theory for drilling operations is *(Brett and Millheim, 1986, Shapero)*:

$$t = C_1 * e^{(1-\mathrm{n})*\mathrm{C}_2} + C_3 \tag{1}$$

Where,

t = the time required to drill nth well.

n = the well number in the area of uniform geology.

C_1 = the difference in time spent on drilling the first and the last well in the field.

C_2 = an adaptation rate of the drilling team to the new geological environment.

C_3 = an optimum average time to drill a well in the area.

The higher C_2 is, the faster the company adapts to the new drilling environment. The following factors increase C_2 value:

- The tight communication between the well planners and field engineers
- The proper documentation and successful analysis of the drilling problems
- The competent application of the plans

- A high level of preparedness

The C_3 value measures how much the drilling organization has learned from its previous experience. If C_3 stays constant during drilling for several wells in the same area, it means that a company has ceased learning from its previous experience.

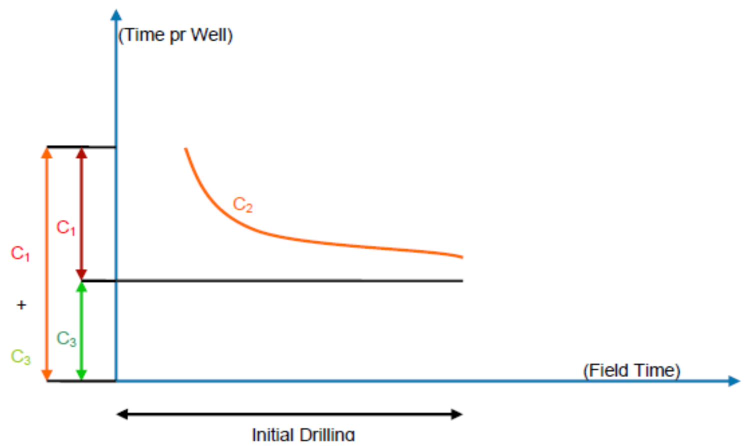


Figure 2. A typical learning curve for the drilling process *(Hellström, 2010).*

The analysis of DPC model can bring up a better idea how to build a stronger foundation or structure for the company. The general recommendations for the company structure, which is derived from the analysis of the drilling performance model, are summarized in *Appendix A.2* .

2.1.3 Positive and Negative Experiences

Both positive and negative experiences are very valuable information to capture and store for the future use. The "best practices or procedures" available in drilling companies are established by investigation of positive and negative experiences along the history and each of them produces a foundation for the company to run its business.

The experiences gained from the positive events are the irreplaceable inputs for the next planning, execution, evaluation phases of drilling projects and can improve "the best practices or procedures" currently available in the company. Positive experience means an activity or task completed at the higher quality or shorter period than expectations. It is worth examining the reasons of any achievement in order to transmit the learned skills to the same task in the future. That is what keeps high efficiency as well as continuous progress in drilling operations.

The negative experience causes non-productive time (NPT) for the drilling operations leading to the escalation of drilling costs. NPT can be defined as an unexpected event that ceases the drilling process and extends the operational schedule *(Reid et al., 2006).* Nevertheless, the negative experience also supports identifications of the risks in the operations and enables to apply "learned lessons" to the upcoming activities.

In addition to the waste of time and costs, delays in drilling process can develop the risk for drilling fluid to be over-exposed. The overexposure of drilling fluids can result in the damage of wellbore and increase a skin factor of the borehole that, in turn, reduces reservoir throughput. The interaction of drilling fluid with the rock formation can also cause the onset of irrecoverable instability and the well can become collapsed *(Wang et al., 2009).*

There are many root-causes of NPT. It is hard to identify the most time-consuming reasons due to a fact that the reasons can be changed by geographical regions of oil and gas resources *(Amadi-Echendu and Yakubu, 2015).* However, generally, the followings are the main sources of NPT *(Moazzeni et al., 2011)*:

- Lost circulation
- Mechanical or differential pipe sticking
- Killing the influx or kick
- Formation breakdown because of high equivalent circulating density (ECD) or pressure surges
- Wellbore instability problems
- Reduced ROP in hard formation
- Unplanned tripping to change a drill bit
- Fishing activities
- Remedial cementing operations

According to Dodson, approximately, 40% of NPT is produced by both wellbore instability and pore pressure issues such as kicks, gas flow, shallow water flow, lost circulation and stuck pipe *(Villatoro et al., 2009).*

2.1.4 Risk Assessment

Risk assessment is a key activity for the entire project that is extended from a conceptual planning phase to the day-to-day execution. It provides a better understanding of risks and their effects on the business delivery. Risk assessment is an integral part of the whole workflow, as well as strongly associated with the time-estimating process and contingency costs of the project *(Thorogood and Bardwell, 1998).* In the risk assessment, the goals to accomplish are:

- Detect the possible hazards
- Evaluate the risks
- Minimize the risk levels
- Record the results

Even though there are numerous risk assessment systems used by different companies, the fundamental of the system is common and its iterative process to achieve the goals are shown in *Figure 3 (Main, 2006).*

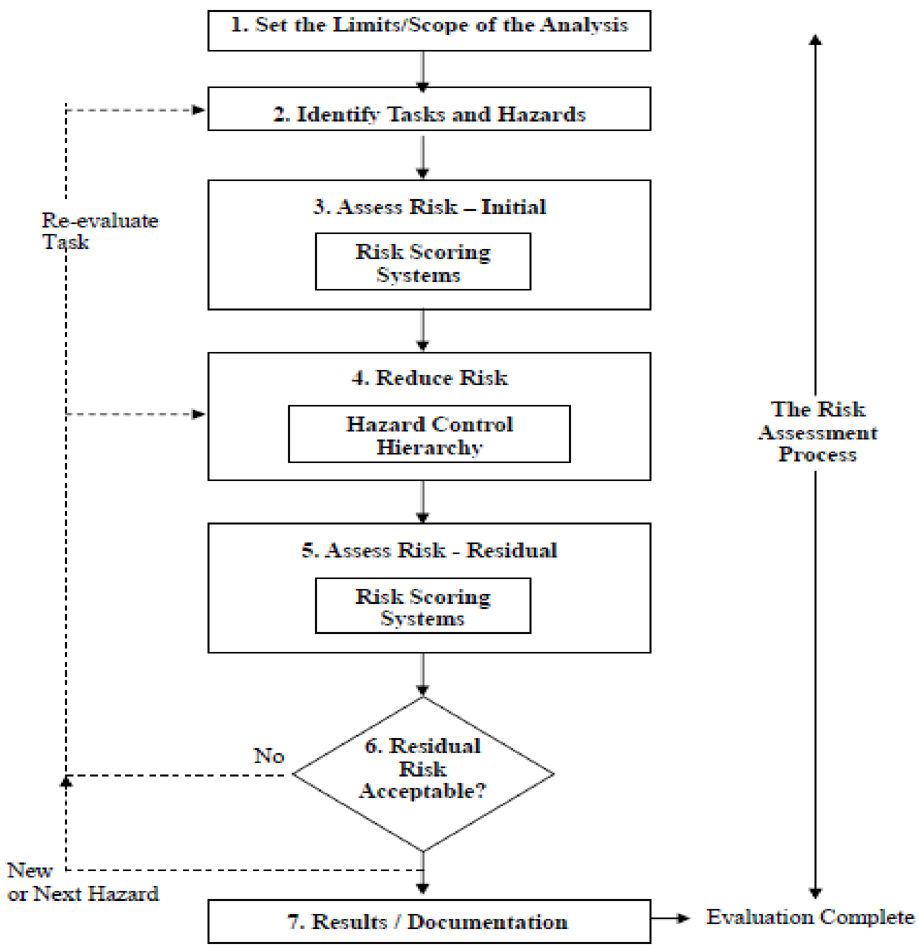


Figure 3. The Risk Assessment Process *(Main, 2004).*

2.1.4.1 *Types of Risk Assessment*

There are also several types of risk assessment to identify different risks and hazards for the drilling operations. Some of them will be introduced in this section.

A *project risk assessment* brings up the main business concerns, such as partner, political, financial and schedule issues. This evaluation is supported by *a well risk assessment* in order to define the technical issues by the analysis of offset wells or peer reviews. The risk assessment of a well commences from the conceptual planning phase of the drilling workflow and extends up to the execution phase. It identifies technical work programs and structures many planning activities. As the plan gets more detailed and the number of involved people increases, *an operational risk assessment* is required to develop. The operational risk assessment makes the engineers conscious of the potential problems in the area and empowers them to bring up their own experience to anticipate - what can go wrong? Thus, it equips the crew members to be prepared for the avoidance of the risks as a team *(Thorogood, 2000).*

2.1.5 Importance of Offset Well Data

A large volume of operational data from the drilled wells has been historically stored. These data usually consist of well trajectories, casing points, casing analysis, drilling risks, drilling events, BHA performance, operational window, costs, time etc. There are also huge data generated by engineering programs used in the planning phase of drilling. The engineering programs simulate different drilling scenarios and produce outputs, such as ROP, WOB, TOB, RPM, hook load, torque etc. If it is feasible to save useful data at high quality, those data can be enormously valuable in the well planning and execution of the operations. The historical data can support or achieve the following goals:

- Prediction of potential issues, failure events, challenges and risks
- Mitigations of operational problems
- Engineering analysis, modeling and optimization
- Multiple well correlations
- Time analysis for lost and trouble zones
- Real-time monitoring
- Performance measurement and benchmarking

- Evaluation of the service quality/costs

In the modern drilling system, static and historical well data are integrated with the real-time data to advance the operations and provide valuable information on a real-time basis. This structure is explained shortly in *Appendix A.4* .

2.2 Sidetracking Methods

The sidetracking operation can be executed in both open and cased wellbores. It can be classified as below:

1. Cased hole sidetracking with a whipstock *(Ketil Tørge et al., 2014).*
2. Openhole sidetracking with a whipstock *(Appendix B.1).*
3. Openhole sidetracking over the whipstock with a mud motor *(Appendix B.2).*
4. Openhole sidetracking over the cement plug with a mud motor.
5. Openhole sidetracking without deflection barrier *(Dang et al., 2013).*

The whipstocks for OH sidetrack (method 2) are almost never used today due to a fact that changing trajectory is very complicated and too much experience is demanded to run the tools accurately. Downhole motors are more advanced and relatively less costed tools *(Appendix C).* Therefore, they have replaced permanent/removable whipstocks in OH sidetracking operation. Currently, the most applied method to sidetrack a well in the openhole is to use a mud motor with a deflection barrier. A deflection barrier can be either openhole whipstock (method 3) or cement plug (method 4).

2.2.1 Sidetracking Procedure

The steering with a mud motor over the cement plug is one of the most employed techniques in openhole sidetracking and its operational procedure will be described in this section.

Firstly, the cement slurry is pumped to fill across the kickoff interval and then engineers must wait for the cement to be cured in the formation. Afterward, a conventional bit and straight-hole drilling assembly are run into the hole to time-drill the cement plug up to the planned KOP. Drilling with considerably low ROP, WOB, TOB as well as RPM are called “time-drilling” *(Chamat and Leavitt, 2011),* and time-drilling the cement plug up to KOP is named “dressing off” the cement plug *(Broussard et al., 2009)*. Usually, the time-drilling is employed to have more chance of success in sidetracking operation. If the DS takes the weight and the motor begins to stall during dressing off the cement plug, it means that the plug is strong enough to commence kicking off activity. ROP operated for dressing off the cement plug should be, at least, lower than 50% of ROP applied for penetrating the formation.

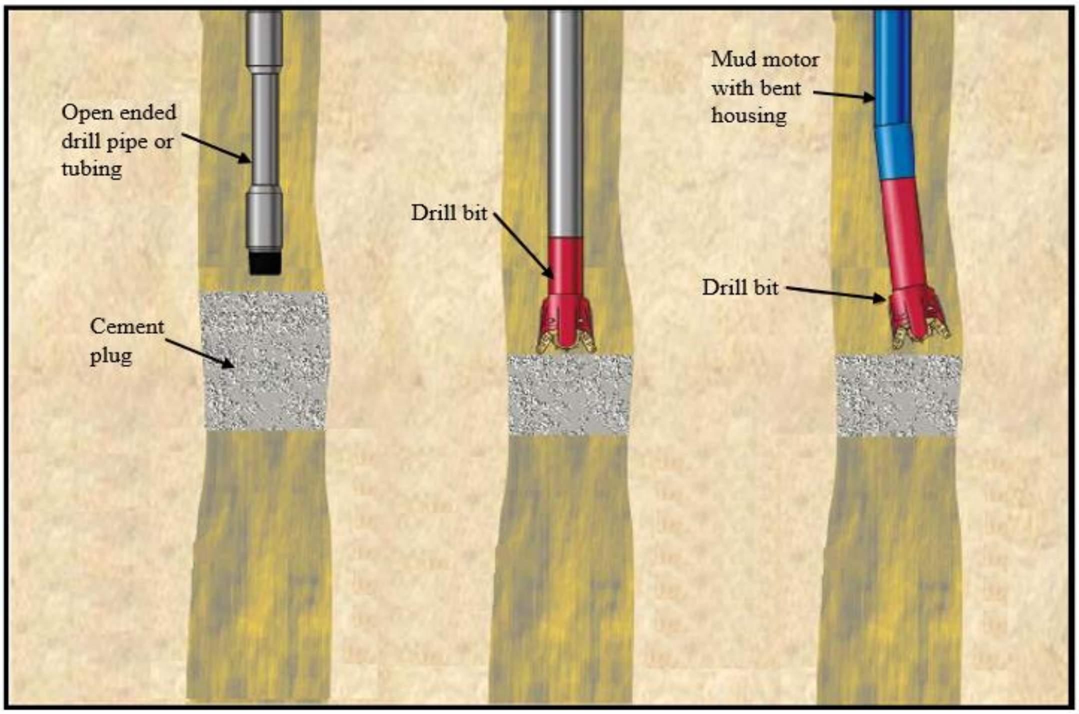


Figure 4. A sequence of operation to kick off the cement plug *(Broussard et al., 2009).*

If the cement plug is confirmed to be firm, a directional BHA should replace the conventional assembly and shall be run to the dressed top of the cement plug. The toolface of the downhole motor should be then orientated in the formation. Time-drilling is also employed for kicking off the wellbore. Afterward, drilling parameters can be increased for penetrating further to the planned target *(Ron Dirksen, 2015)*.

If the cement plug is not sufficiently firm to commence sidetracking, the cement will be washed away during dressing off and extra trips will become mandatory to set a new cement plug. The success of OH sidetrack from the cement plug with a mud motor are primarily dependent on the followings *(Dewey et al., 2012)*:

- Formation Compressive Strength
- Downhole temperature/ pressure
- Cement plug depth
- Wellbore deviation
- Quality of Cement
- Cure time of Cement
- BHA design and deflection tool *(Appendix C)*

2.2.2 Design Considerations

There are three main parameters to consider for the planning phase of sidetracking activity in order to accomplish the operation efficiently and successfully *(Ron Dirksen)*.

1. Strength of a formation

The sidetracking point in the openhole should be selected in the softest formation to increase the chance of success. Preferably, it should be softer than the cement plug or should place between harder formations. Since the bit always has a tendency to penetrate into the least resistance zone, trying to enter into a hard rock can be very problematic. The strength of the rock is measured by the parameter, called unconfined compressive strength (UCS). This parameter represents the maximum compressive load, which a rock can withstand before the failure. If the formation rock is very hard (UCS>25 000 psi), a whipstock is more likely to be used due to low possibility of the cement to be harder than the formation. For a medium formation, where UCS is between 15000 and 25000 psi, a motor with a good cement plug can be considered to execute sidetracking. For a soft formation (UCS<15 000 psi), sidetracking can be successful by operating a mud motor toward the high side of the hole with a good cement plug or to the low side of the hole without cement plug *(Dang et al., 2013)*.

2. Inclination angle of the wellbore

The inclination is necessary to consider during the planning of the sidetracking operation in order to obtain the gravity assistance. If the sidetrack point is in the vertical section of a well, inclination has nothing to support the activity and there is no preferable direction to orient the toolface to obtain the assistance of the gravity. Therefore, cutting efficiency of the stabilizer and BHA against borehole will be minimized leaving more challenging condition for the operation. But, if the point is located in an inclined wellbore, the orientation of the toolface to the low side of the hole will support technical sidetracking due to a gravity effect that will try to drag the BHA down *(Figure 5).* When a mud motor or RSS is applied, it is the best to sidetrack at the point where the wellpath has a high inclination or azimuth change.

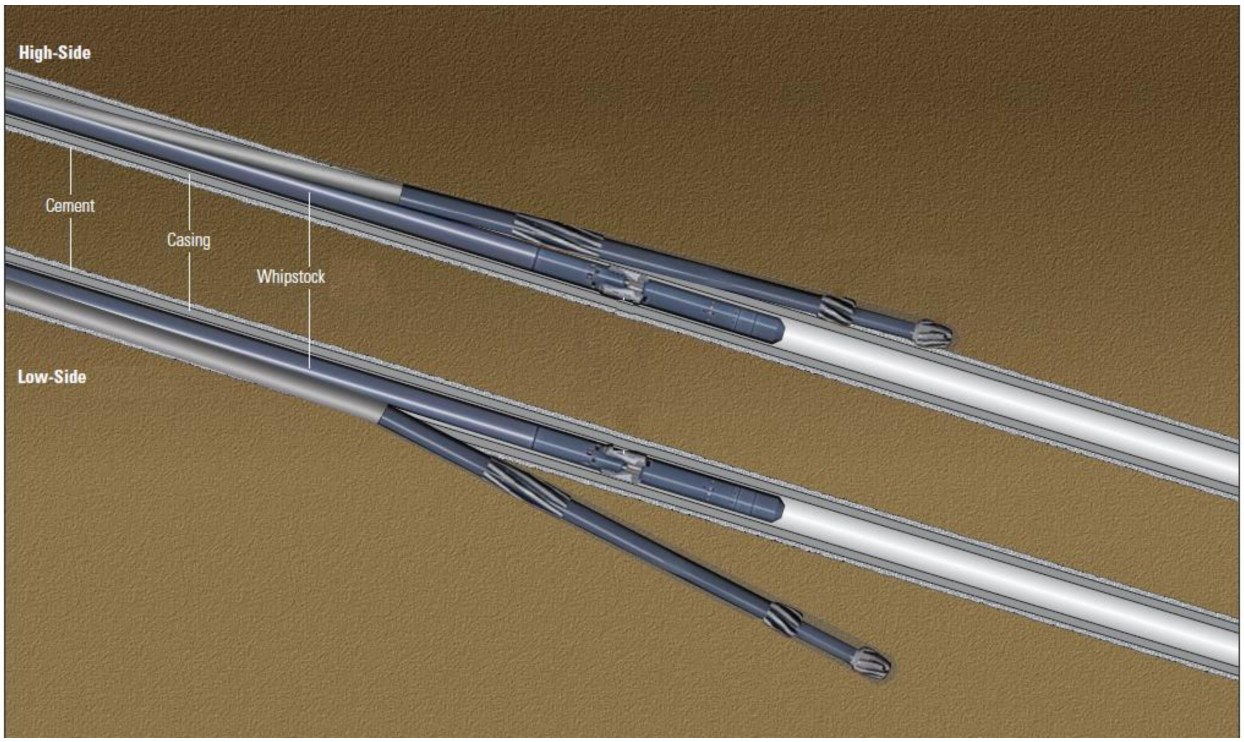


Figure 5. The gravity effects over a sidetracking operation. The gravity supports sidetracking if the toolface is oriented to the low-side *(Ketil Tørge et al., 2014).*

3. Depth of a sidetrack point

The depth of a sidetrack point determines the DLS required for reaching a target that, in turn, identifies the required BHA configuration and deflection tool *(Appendix C).* Sometimes, the sidetrack depth can also establish whether the activity will be performed in the cased or open hole. If the sidetracking can be executed in either location in the wellbore, it is often recommended to perform the operation in the openhole in order to avoid milling activity and generation of sharp dogleg angle.

2.2.3 Cement plug vs Openhole whipstock

The procedures hired to sidetrack from cement plug and openhole whipstock are introduced in the sub-chapter *above* and *Appendix B.2* respectively. Pros and cons of these two methods will be reviewed in this section.

Sidetracking from the cement plug is difficult in the following well conditions:

- Highly deviated wellbores
- Small diameter openhole sections
- High pressure and temperature intervals

A cement plug is operationally simple for execution, but the strength of the cement becomes occasionally stronger than the surrounding rock in the sidetrack point. In addition to that, the cement gets strung out if the DLS is high at KOP in the borehole. In some well applications, the numerous cement plugs must be set to achieve a successful sidetracking operation that results in the waste of time and money.

In the case of sidetracking from the openhole whipstock, all uncertainties and limitations related to the cement plug are eliminated and the following benefits are gained *(Danny Harrell, 2001)*:

- Possibility to sidetrack at high temperature and pressure
- Elimination of a separate trip for setting the cement plug
- No need to wait for the cement to be cured
- No loss of material to replace a failed cement plug

In any well configuration, sidetracking from whipstock takes much less time than the sidetracking from the cement plug unless any of unexpected events has been encountered during execution of the activity. There is no need to wait for cement to get hardened, and extra trips to set the cement plug are also eliminated during sidetracking from whipstock. The cement treatment takes approximately 24 hours and extra trips might take several hours based on the well depth. Thus, sidetracking from whipstock with a mud motor saves minimally a day price of the rig, giving a great economical profit. Traditionally, there was a risk of deployment of the whipstock in the wrong direction and it was one of the reasons to avoid the method. Now, that problem is completely removed by the flexibility of the system. The flexibility of the system enables the orientation of the whipstock face before its mechanisms are actuated *(Appendix B.2)*. However, the technique still carries two risks *(Al-Salmi et al., 2011)*:

1. The fall of a whipstock while running into the hole.
2. The spinning of a whipstock during drilling.

The first risk can be minimized by involving an experienced engineer to run a system and follow the best practice in order to deploy a whipstock safely in the hole. The second risk is reduced by the introduction of the hydraulically set expandable anchor and ability to cement the whipstock itself in the formation *(Appendix B.2)*. Nevertheless, if the formation is soft or medium in strength, the operation can fail while drilling over the whipstock regardless of its gripping mechanisms due to a fact that formation can break apart and whipstock can start to spin inside the broken rock. Consequently, the openhole sidetracking from whipstock with a mud motor is not recommended to be executed in the soft or medium strength formation.

3 Sidetracking Well Model - Industry Standards & Results

The problem in the given well was introduced shortly in the "*Introduction*" chapter above and will be reviewed at the details in this chapter.

During drilling 12 ¼" hole section at 2250 mMD, a bad weather condition imperiled the operation and it was decided to stop drilling for a while. Wait on Weather (WOW) took several days. When drilling commenced, wellbore instability issues emerged, and the hole was collapsed. As a result, technical sidetrack was planned for this section. The objectives of technical sidetrack are:

- Deviate the wellbore trajectory away from the dangerous zone/wellbore instability problems.
- Hit all geological targets after sidetracking wellbore.
- Generate as low DLS as possible along the borehole.

In addition to the mentioned objectives above, the purposes to drill a new 12 ¼" section are:

- Fix the TD of 12 ¼" hole section at 4313 mMD/3968 mTVD.
- Set 9 5/8" casing at 4313 mMD/3968 mTVD in the Intense sand formation *(Table 1)*.
- Achieve an acceptable cement job and acquire enough cement above 9 5/8" production casing shoe.

Since the thesis relates to sidetracking and experience transfer, the general objectives for drilling 12 ¼" section are out of the scope and some parts of these objectives, revealed only by field experiences, will be reviewed in this report.

The previous experience in the field, as well as industry standards and regulations, are documented in every drilling company. These documents are extensively referred to run the business safely and efficiently. The referred documents in this thesis, where necessary standards and experiences are gathered for the operations, will be the followings:

- NTNU-Casing Design *(Brechan, 2014a)*
- NTNU-Drilling and Completion Operations *(Brechan, 2014b)*
- NTNU-Drilling Experience *(Brechan, 2014d)*

- NTNU-Well Construction *(Brechan, 2014f)*
- NORSOK Standards D-010 *(2013)*
- Drilling Programs extracted from the same field *(Brechan, 2014c)*
- Recommendations to drill/ Statement of Requirements *(Brechan, 2014e)*

3.1 Wellbore Visualization

Wellbore instability issuers are developed at 2250 mMD/2216 mTVD in the 12 ¼" section of the borehole. The previous casing is 13 3/8" intermediate casing, which is set at 2120 mMD/2093 mTVD. It is decided to kick off the original trajectory at 2200 mMD/2169 mTVD, nearly 80 m below the previous casing shoe and 50 m above the collapsed area, in order to not to fall over the problematic zone again.

Compass software of Landmark products is used to develop the required trajectory for the new/sidetracked wellbore. A new wellbore trajectory is built as close to the original wellpath as possible to avoid an extreme difference in the sidetracked well model *(Figure 6)*.

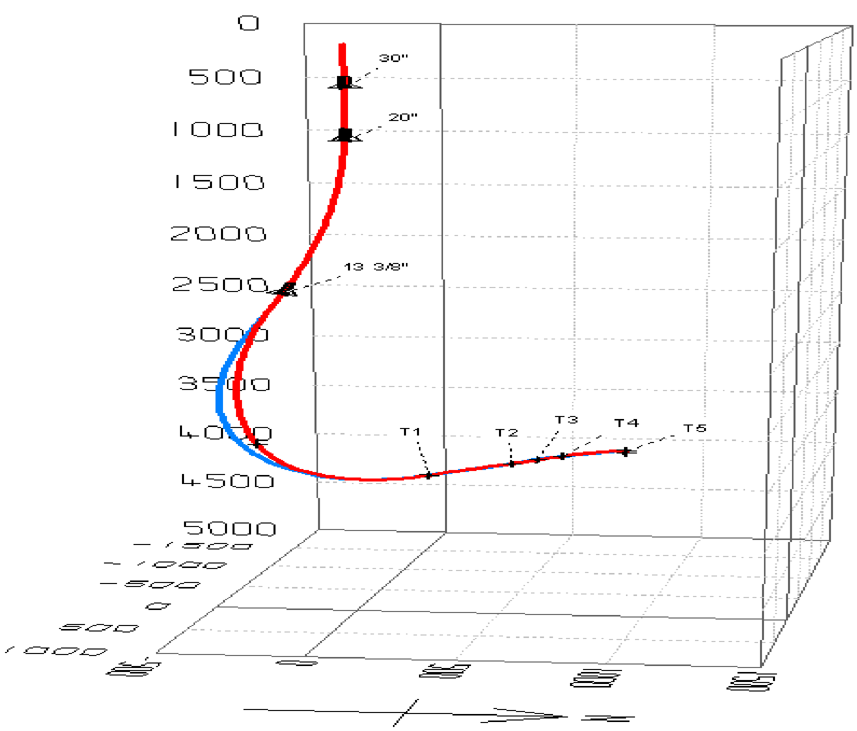


Figure 6. 3D Views of the original and sidetracked wellbore trajectories. A red line represents the sidetracked well trajectory, while a blue line is the original wellpath. T1-T5 are the geological targets.

The sidetracked wellpath is away from the original wellpath between 2200 mMD (KOP) and 3700 mMD, which is enough to be aside from the problematic zone. These trajectories overlap considerably in between 3700 mMD and 5500 mMD. At the end of the wellbore, the sidetracked wellpath deviate again from the original well trajectory while hitting the geological targets *(Figure 15).*

There are totally five geological targets and all of them are hit successfully in the sidetracked wellbore. The max. DLS along the borehole is increased from 2.99^0/30m to 3.41^0/30m after the wellbore is sidetracked. This change in DLS produces the slight difference and should not introduce the complex challenges for the new/sidetracked well design.

Geological prognosis for formations is shown in *Table 1*. This table will be referred extensively while explaining the experiences in the given field. The wellbore will be kicked off and sidetracked approximately 40 m above Alone formation and the casing is planned to be set at 4313 mMD/3968 mTVD in Intense formation.

FORMATIONS and ZONES	PROGNOSIS	
	Depth [mTVD RKB]	Thickness [mTVD]
Alone	2207	62
Gaia	2269	55
Free	2324	110
Stellar	2434	355
Brute	2689	449
Tuvan	3138	31
Sail	3169	371
Sail sandstone (sst)	3540	115
Base Sail sst	3655	68
Garn	3723	24
Unknown*	3747	39
Unknown*	3786	106
Intense	3892	97
Mirage	3989	29
Imagine 3.3	4018	70
Shivers	4088	120
ASOT (6)	4208	146
Aisha	4354	19
TD	4373	-

Table 1. Geological Prognosis for Formations and Zones.

3.1.1 Section Overview

Technical sidetrack will be executed in 12 ¼" hole section which extends from 2120 mMD/2093 mTVD to 4313mMD/3968 mTVD *(Table 2)*, and this section will be on focus in the upcoming sub-chapters. Once drilling is finalized at the TD of 12 ¼" section, 9 5/8" production casing is designed to be run into the hole.

	mMD	mTVD
Section Start	2120	2093
Section TD	4313	3968
Section Length	2193	1875
Casing Shoe	4313	3968

Table 2. 12 ¼" Section Overview.

There are both inclination and azimuth changes along 12 ¼" section. The highest inclination and azimuth are 67^0 and 299^0 respectively *(Figure 16)*. The DLS along the section is not high and fluctuates between 0.4-1.66 ^{0}/30m. The inclination is dropped from 19^0 to 10^0 along 2120-2810 mMD interval and built up to 67^0 at TD. Unlike the inclination changes, azimuth angle keeps only increasing along the entire 12 ¼" section from 149.69^0 to 299^0.

3.2 Casing Design

Every single load generated by drilling operations are modeled in WellCat for the casing designs of the original and sidetracked wells. The only result of the "lost return with mud drop" load in the sidetracked well will be examined since there is not any other critical result that can endanger drilling operations for the sidetracking well model. In addition to the result of the "lost return with mud drop" load case, the industry standards and regulations of the casing design will be introduced and discussed in this section.

3.2.1 Casing Depth

A casing shall be set at the depth where a safety margin is enough between formation fracture pressure and well control limit. The well control limit is determined by kick tolerance, which is one of the most important parameters for building the casing design. The kick tolerance is the highest gas volume that can be circulated safely out of the hole without fracturing the formation in the openhole. Its volume should be enough to be recognized while drilling. The industry standards for the kick tolerance are extracted from NTNU governing documents and shown in *Table 3*.

Well Condition	Kick Tolerance
Drilling the hole sections where the hydrocarbon reservoirs cannot be exposed.	4 m^3
Drilling the hole sections larger than 8 ½” where hydrocarbon reservoirs can be exposed.	8 m^3 for 12 ¼” hole
Drilling the hole sections smaller than 8 ½” where hydrocarbon reservoirs can be exposed.	4 m^3

Table 3.Min kick tolerance or max gas kick volume.

Intense formation is hydrocarbon bearing zone and present at the end of 12 ¼” section in our well model *(Table 1).* Therefore, the kick tolerance for 12 ¼” section is determined 8 m^3 while building the casing design for the sidetracked well model.

3.2.2 TOC Depth

According to NTNU- Drilling Experience document, the TOC for 9 5/8” casing must be 400 mMD above the casing shoe. It is also mentioned in NORSOK Standards that the planned cement length shall be 200 mMD above the source of inflow. Tuvan is the hydrocarbon-bearing formation and its uppermost part is at 3138 mTVD *(Table 1).* In the sidetracked borehole, the uppermost part of Tuvan formation falls to 3206 mMD and 200 m MD above this depth is 3006 mMD where the TOC must be reached.

Moreover, 9 5/8” casing is production casing where the packer will be deployed. It is recommended to set a packer in the cemented area of the casing to enhance the operating envelope of the packer. Referring to NTNU governing documents, the TOC of the casing must be minimum 10 m above the planned setting depth of the packer. The packer is intended to be set at 3100 mMD in our well model. Consequently, when the TOC for 9 5/8” casing is reached at 3006 mMD in order to cover Tuvan formation, the packer will be naturally set at the cemented area of the casing.

To conclude with, TOC for 9 5/8” production casing must be set minimally at 3006 mMD in our well model.

3.2.3 Design Factors

A design factor is defined as the minimum allowable safety factor. By knowing this value, the maximum allowable load can be determined and compared with the anticipated loads. Industry standards for the design factors are extracted from NTNU-Casing Design document and illustrated in *Table 4*. These values are applied to both original and sidetracked well models while building the load cases for drilling operations.

DESIGN FACTORS	Burst	Tension	Compression	Collapse	Triaxial
Casing	1.1	1.4	1.4	1.1	1.25
Casing Connection	1.1	1.4	1.3	N/A	N/A

Table 4. Design Factors.

3.2.4 Lost Returns with mud drop

“Lost returns with mud drop” represents the load generated by evacuation of drilling fluids in the casing. When the hydrostatic pressure of mud is much higher than the pore pressure, the mud invades into the formation and its level falls down in the casing. This causes a sudden pressure decrease at the internal pressure profile of a casing. Since the external pressure profile remains the same, the case leads to collapse loading. This load case creates the most dangerous collapse loading, which can lead the casing to the failure during drilling.

The international standard is to assume the loss-circulation zone to be at TD. That is how WellCat also establishes the depth of loss zone. The “lost return with mud drop” load case threatens the drilling operations in our well model. This load is severe during drilling 12 ¼” hole section and collapses the connections of 13 3/8” intermediate casing as seen in a blue line in *Figure 7*.

The simulations indicate that the mud level drops 1300 m inside 13 3/8” intermediate casing while drilling 12 ¼” section. The casing should not get hollow of mud more than 250 m based on NTNU governing documents when the field is known. The field is drilled before and pressure prognosis is known from the offset wells in this project *(Figure 13)*. Hence, another load case scenario of the “lost returns with mud drop” is created to meet the regulation. In the triaxial plot *(Figure 7)*, a pink line represents a newly created load scenario and it does not exceed the safety envelope. Therefore, the case meets the design criteria and there is no risk of casing failure.

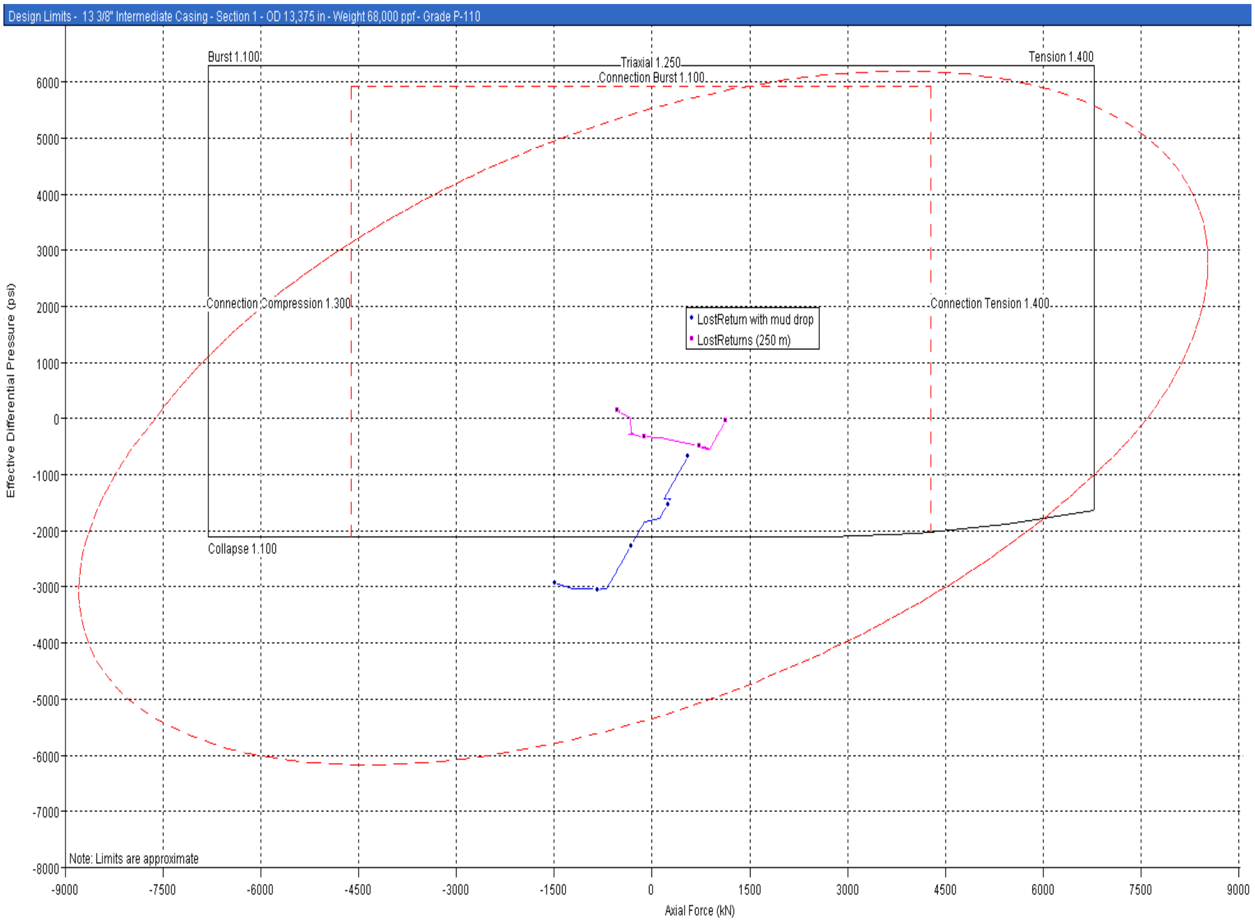


Figure 7. Design Limit Plot for 13 3/8” intermediate casing.

3.3 Operational Risks

There are some potential risks during sidetracking and drilling for 12 ¼” section that can damage operations and injure personnel. Those risks are split as below and will be evaluated accordingly in the *“Risk Assessment”* sub-chapter.

- Risks linked to sidetracking activity
- Risks linked to drilling for 12 ¼” hole section

3.3.1 Risks during Sidetracking Activity

There are five potential risks related to sidetracking activity in our well model. The consequences of these risks are dangerous and can result in the catastrophic incidents. These five risks and their possible outcomes will be introduced separately in the following sections.

3.3.1.1 *Bad weather condition*

A bad weather condition triggers unsafe environment for drilling operations that are hardly possible to deal with. This harsh environment can lead the drilling operations to be ceased until the weather condition becomes better and allows for safe drilling. In addition, delays in drilling process produce the danger for drilling fluids to be over-exposed. The interaction of drilling fluid with the rock formation can cause the onset of irrecoverable instability problems, which are difficult to cure. That is why the preferred solution is usually to sidetrack the wellbore away from the problematic zone. The same problem was encountered during drilling 12 ¼" section in the given well, which directed the operations to sidetracking activity.

3.3.1.2 *Poor cement plug*

A cement plug is a necessary barrier for technical sidetrack to assist the wellbore deviation. The poor cement plug means that sidetracking barrier is weak and kicking off the wellbore is more likely to fail. The failure to sidetrack the wellbore over the cement plus demands for setting a new cement plug and causes the loss of time, money as well as material.

3.3.1.3 *Insufficient hole cleaning*

If the hole cleaning is not sufficient, the cuttings will tend to accumulate on the low side of the hole. When the cuttings bed height is considerably high, DS can get stuck leading to delayed operations or fishing activities.

3.3.1.4 *Casing wear and corrosion*

Casing wear and corrosion are critical parameters and should be measured accurately to check the safety and integrity of a casing. Loss of casing wall thickness due to the wear and excessive corrosion are the reasons of the decreased well integrity and can result in the disastrous events, such as oil spills and blow-outs.

3.3.1.5 *Collision with other wells*

The collision can be a large risk for sidetracking operations. The outcome of collision is catastrophic and causes the destruction of nearby wells. In addition, it causes drilling a new section in order to proceed the operations.

3.3.1.6 *Summary of Sidetracking Risks*

Five risks and their consequences are described above and summarized in *Table 5* below. Each of them endangers sidetracking operations and carries the potential peril to increase NPT. Therefore, they will be evaluated in the *"Risk Assessment for Sidetracking Activity"* sub-chapter to decrease the risk levels for sidetracking activity.

Sidetracking Risks		
Risk Description		Consequence Description
1	Bad weather condition	Delayed operations and potential wellbore instability issues after WOW
2	Poor cement plug	Failure to sidetrack a well- loss of time/money and material
3	Insufficient hole cleaning due to additional inclination created by sidetracking	Stuck pipe
4	Casing wear and corrosion due to additional DLS produced by sidetracking	Loss of well integrity- potential catastrophic incidents, such as oil spills and blow outs
5	Collision with other wells	Destroyed offset wells and demand to drill a new section/wellbore

Table 5. Sidetracking risks and their possible outcomes.

3.3.2 Risks during Drilling 12 ¼" section

Five risks during drilling 12 ¼" section and their possible outcomes will be introduced in the upcoming sections. Each of them is defined by field experience and carries potential danger for the operations.

3.3.2.1 *ECD during cementing*

When the section is long and fracture pressure at the casing shoe is low, the cementing activity can be a problem in such a narrow window due to high ECD generated by the displacement of the cement slurry. The fractures around the casing shoe cause the loss of cement slurry to the formation, disable drilling for the next hole section, and leave the undesired conditions for the cementing of the casing.

In the sidetracked well model, fracture gradient at casing shoe is 1.97 S.G. and the shoe is set at 4313 mMD/3968 mTVD. The simulated values show that cementing activity produces 10600 psi pressure at the casing shoe, while the fracture pressure at the same depth is 11150 psi. The difference between these pressures is equal to 550 psi. The cement job, in this case, might be achieved without any adjustment in the activity, but it would carry a potential risk to fracture the formation. Consequently, the adjustments in the cementing activity are required to reduce the risk level.

3.3.2.2 Differential sticking across permeable sand intervals

Differential sticking is one of the most observed sources of NPT in drilling operations and occurs usually at permeable sand zones. Its outcomes are delayed operations and fishing activities, which result in the loss of time/costs. It can be more problematic if the sticking takes place while running the casing. The rig might be unable to overpull a heavy casing once it is lowered into the hole.

3.3.2.3 Swabbing

The swabbing is the temporary reduction in the bottom hole pressure, generated by pulling the DS out of the hole. If the hydrostatic pressure reduction is large enough to establish the underbalanced condition, the well will take a kick and subsequently blow out.

3.3.2.4 Wellbore instability

Wellbore instability is the undesirable condition of an openhole interval that does not preserve its gauge size and structural integrity, leading to the collapsed borehole.

3.3.2.5 Worn drill bit

The bit sometimes gets worn during penetrating through the different formations, which causes reduced ROP and increased NPT. If the bit is considerably worn, it can also be a reason for the extra trips during drilling operations.

In our well model, 12 ¼" section is intended to be kicked off and subsequently drilled in one trip. That is why the risk level of getting worn bit should be minimized as much as possible to eliminate the possibility of the unplanned bit trips.

3.3.2.6 Summary of Drilling Risks for 12 ¼" section

Five risks and their possible consequences are described above and summarized in *Table 6* below. Each of them involves the potential danger to cease the drilling operations and increase NPT. Thus, they will be examined in the *"Risk Assessment for Drilling 12 ¼" section"* sub-chapter to find the effective countermeasures for the reduction of the risk level.

Drilling Risks of 12 ¼" section		
Risk description		Consequence description
1	Formation fracture due to high ECD induced by cementing activity of 9 5/8" casing	Loss of cement slurry, poor cement job and unable to drill for the next hole section
2	Differential sticking across permeable sand intervals	Delayed operations and potential fishing activities- loss of time/costs
3	Swabbing during POOH	Potential well control problems- fluid influx, kick and blow out
4	Wellbore instability	Collapsed hole
5	Worn drill bit	Extra bit trips

Table 6. Drilling Risks for 12 ¼" section.

4 Evaluation of the Results and Discussion

A method selected to sidetrack a well, BHA design required to achieve successful sidetracking and drilling, as well as countermeasures applied to mitigate the operational risks, will be discussed in this chapter. Many of the recommendations for the elements of the sidetracking well model are made based on the field experiences and industry standards during evaluations.

4.1 Method Selection

There are several methods to sidetrack a well in openhole. The most applied method today is either sidetracking from cement plug or OH whipstock with a downhole motor. Advantages and disadvantages of these methods are already reviewed in the *"Cement plug vs Openhole whipstock"* sub-chapter. In this sub-chapter, application of both methods to the given task will be discussed in order to identify a better technique for the sidetracking well model.

Some parameters in the well configuration play an important role to reveal the chance of success for the method applied to the sidetracking operation. These parameters are the followings:

- Formation Strength
- Downhole Temperature
- Downhole Pressure

Formation strength, downhole temperature and pressure at the sidetracking interval are very important parameters to identify a better method for the operation. If the formation strength (UCS >25 000 psi) as well as downhole temperature and pressure are high ($T_{formation}$ >140 ^{0}C; P_{pore} >10 000 psi), sidetracking over OH whipstock must be considered to eliminate the uncertainties associated with the cement plug. It is not necessary to have all mentioned parameters at the high level to employ OH whipstock for the sidetracking activity. Even if one of them is high in the setting area of the cement plug, the operation is more likely to fail for several times during kicking off the wellbore. That is why OH whipstock is more reasonable to utilize in the sidetracking activity under the well condition where any of the mentioned parameters is high.

If the cement plug is planned in our well model, the length of the plug would cover the distance from 2150 mMD/2121 mTVD to 2250 mMD/2215 mTVD, where:

- 15 000 psi > UCS >25 000 psi
- 60 ^{0}C > $T_{formation}$ >80 ^{0}C
- 3 500 psi > P_{pore} >4 500 psi

It must be emphasized that sidetracking over OH whipstock with a downhole motor involves a significant risk when the formation is soft or medium in strength. Since the formation strength is medium in our well model, the operation can fail while drilling over the whipstock regardless of its gripping mechanisms due to a fact that formation can break apart and whipstock can start to spin inside the broken rock. This risk carries an enormous danger for the entire drilling operation. It can be a reason of being stuck with the whipstock and loss a well. Moreover, the downhole temperature and pressure in our well model are not high and allows the application of the cement plug. Thus, it is more rational to hire the cement plug under the existing well configuration.

However, the following factors should be also investigated before making a final decision whether to apply the cement plug or not:

- DLS along the cement plug
- DLS required to deviate the wellbore
- Inclination at KOP

High wellbore deviation along the cement plug creates the obstacles for the cement to be cured properly. The cement can get strung out if the DLS is high. The cement plug is set in the original wellbore and, therefore, DLS meant in this context belongs to the original wellpath. The max DLS along the cement plug is 0.4 ^{0}/30m in our well model, which is low and will not induce any problem for the setting of the cement.

In addition, the required DLS to build the curvature in the formation is also necessary. It determines the BHA configuration and deflection tool. In some formations, it can be challenging to build the required DLS to hit the expected area. In our well model, the required DLS for reaching a new target is low (1.66 ^{0}/30m) and it should be possible to build the needed deviation with a downhole mud motor.

When KOP is located in the vertical section of the borehole, where the inclination is zero, it can also be a problem to deviate the wellbore. The assistance of the gravity cannot be obtained in the vertical section, which causes the reduced cutting efficiency of the BHA and leaves the challenging conditions for the wellbore deviation. Since the inclination at KOP is 19^0 in the given well, it is possible to sidetrack to the low-side of the hole as seen in *Figure 6.* The deviation to the low-side of the hole enhances the cutting efficiency of the BHA and increases the chance of the success for the sidetracking activity.

None of the factors discussed above showed the critical problem for the application of the cement plug. As a result, the final decision is to employ the cement plug as a deflection barrier for the sidetracking activity.

4.2 BHA Design

A BHA design shall provide the required steering ability and effective survey measurements for the operations. It is intended in this thesis to build the BHA design that manages to sidetrack and drill the section in one trip. The components of this BHA are mainly selected by field experiences and industry regulations.

4.2.1 **RSS vs PDM**

A PDM is cheaper, but less powerful than the RSS. The ability to slide with a PDM at large depth is in question due to poor weight transfer to the bit. An RSS should be a preferred tool, at least, when any of the followings exists in the well condition:

- Abrasive wellbore tortuosity
- High DLS along the borehole
- High friction factor in cased or open hole
- Sidetracking/drilling area at high depth

In our well design, friction factor (FF) in cased hole is 0.25 and in openhole is 0.3. The highest DLS for the entire 12 ¼” section is 1.66 ^{0}/30m, and the sidetrack point is at 2200 mMD. None of the factors indicates that the use of a PDM with the bent-sub can be a problem in the given well conditions. However, the experience collected from the same field states the opposite. According to NTNU-Drilling Experience document, it is difficult to slide or orient in Tuvan zone when the mud motor with the bent-sub is used. Tuvan layer covers the interval from 3138 mTVD to 3169 mTVD in the formation *(Table 1)*, which falls over the 12 ¼" section in our well model. That is the main reason why RSS is recommended for this hole section.

The RSS can also dress off the cement plug till the KOP, deviate the trajectory and drill until the TD of the section – in one trip, which saves time/costs for the entire drilling operation. The following advantages and disadvantages have been noticed for the RSS based on NTNU-Drilling Experience document:

Advantages:

- The RSS drills a smoother well trajectory.
- It has a great steering ability and can create the DLS between 3.5-5 deg/30m.
- The RSS generates less wear on the bit and can save an extra bit trip.
- It achieves relatively higher ROP.

Disadvantages:

- High-pressure drop in mud system can make the RSS motor impossible to operate, leading to an extra bit trip.
- An extra bit trip can be required due to the tool failure – this risk is low based on the latest experiences with the tool.
- During planning the well path, consider that the assembly will have a slight rotary build throughout the section (0.2 deg/ 30 m) apart from Free formation *(Table 1)*, where the layer has a drop tendency.

According to the field experiences, steering above Sail formation *(Table 1)* with the RSS is not a problem, but it gets challenging in the Sail formation and further down. So, it is also recommended to include a dog-sub to the BHA design, which will provide enough steering ability for the drilling assembly.

Considering all facts mentioned above, the RSS and dog-sub are recommended to be used in the BHA design. This BHA design shall manage to complete the execution of the sidetracking and drilling for the 12 ¼" section in one trip.

4.2.2 Gyro vs MWD

An MWD tool is cheaper than the gyro but has magnetic interference with the metal objects. In our case, a metal object will be the last casing shoe that can affect negatively to the functions of the MWD tool. This casing shoe is set at 2120 mMD in the borehole.

In the given well, the top of cement plug reaches to 2150 mMD where the sidetracking operation will start up. It means that the bottom of the BHA will also be at 2150 mMD - 30m in front of the casing shoe prior to the operation begins. Under this condition, the position of the MWD tool in the BHA design becomes fundamental whether the last casing shoe will have a negative effect on the survey measurements or not.

The length of the MWD tool is 7 m and its bottom is positioned 12 m above the drill bit in the BHA design. Therefore, the top of the MWD tool is nearly 10m in front of the casing shoe in the openhole at the beginning of the sidetracking operation as seen in *Figure 8*. This distance should be enough for a successful operation of the MWD tool.

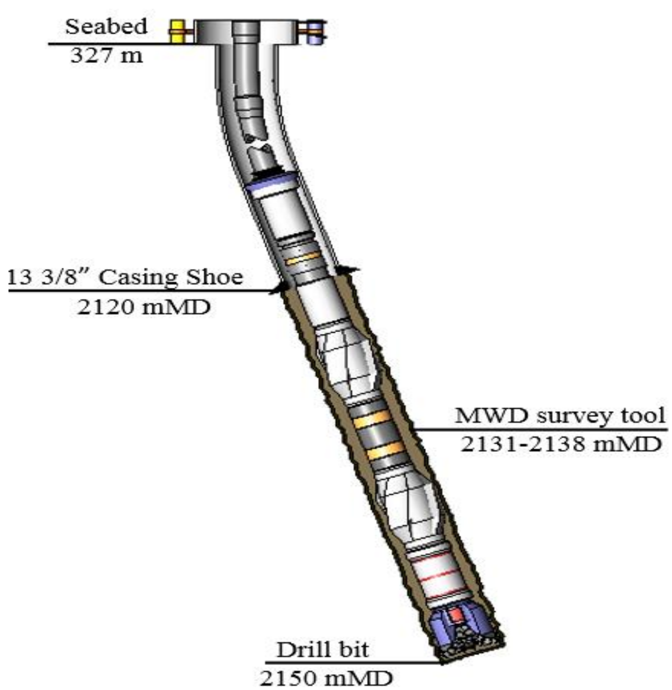


Figure 8. The position of the MWD tool in the openhole at the beginning of the sidetracking operation.

However, the TD of the 12 ¼” hole section is close to the top of Intense zone which is the reservoir formation and begins at 3892 mTVD/4143 mMD *(Table 1).* According to NTNU governing documents, a gyro tool must be run, at least, 500 mMD before entering the reservoir. Therefore, tripping activities have to be performed when drilling reaches at 3643 mMD in order to replace an MWD tool with the gyro. Drilling activities for 12 ¼” section are planned to be completed in one trip in our well model. Consequently, it is more reasonable to include a gyro tool into the BHA design in order to eliminate the extra trips in the middle of the operations and finalize drilling for the 12 ¼” section in one trip.

To conclude with, it is decided to apply the gyro tool for the complete 12 ¼” section. A gyro tool in the BHA design under the existing well conditions will enable sidetracking and drilling operations to be completed in one trip.

4.2.3 BHA Capacity

The selected BHA design has been used in several wells in the field and the collected experience recommends keeping the operational parameters in the following frame:

- Max drill string RPM while drilling: 220 rpm
- Max drill string RPM while backreaming: 135 rpm
- Max drill string RPM while off bottom: 135 rpm
- Max Bit RPM at all times: 250 rpm
- Flow Range: Min. 2750 lpm - Max. 3400 lpm
- Recommended WOB range: Min. 3 ton – Max. 15 ton

In our well model, none of these limits is exceeded and it is safe to proceed to drill with the pre-determined operational parameters. The drilling parameters determined for the sidetracked well model will be introduced in the “*Operational Parameters”* sub-chapter.

4.3 Operational Procedure

According to the selected technique and BHA design, the operational procedure will be in the following details:

1. Trip in hole with the open-ended drill pipe
    - Pump 100 m balanced cement plug
    - Trip out of the hole
    - Give time for the cement to set
2. Trip in hole with the RSS
    - Dress off the cement plug up to the KOP
    - Time-drill 50 m into the formation to build a curvature
    - Proceed to drill till the TD of the 12 ¼" section

The cement plug is set from 2150 mMD to 2250 mMD in the original borehole. Once the cement is cured properly, the RSS shall be run to dress off the cement plug and build a curvature. The time-drilling is employed for dressing off the cement plug and drilling the following 50 m into the formation. Thus, drilling till the KOP (2200 mMD) and the next 50 m into the formation will be executed by the lowest possible drilling parameters (WOB, TOB, RPM and ROP). Then, the operational parameters will be increased to the "normal level" to complete drilling activities for the 12 ¼" hole section.

4.4 Operational Parameters

Since there are no significant changes in the sidetracked well trajectory, there should not be considerable variations in the results of the casing, torque & drag, hydraulic, and other well programs. That is why the operational parameters for the sidetracked well model have been extracted from the Drilling Program of the original well.

However, the operational parameters applied for time-drilling from 2150 mMD to 2250 mMD should be much lower than the ones used for drilling from 2250 mMD to 4313 mMD, as described in the sub-chapter *above*. Therefore, TOB and WOB are decreased for twice, ROP is reduced for four times and RPM of DS is lowered from 140 to 60 during dressing off the cement plug and kicking off the wellbore in order to escalate the chance of the success for the sidetracking operation. Flow rate is kept the same for the entire 12 ¼” section. The values of the drilling parameters for both original and sidetracked well models are listed in *Table 7*.

<table>
<tr><th colspan="2">Operational Parameters</th><th>Flow Rate [lpm]</th><th>RPM [r/min]</th><th>ROP [m/h]</th><th>WOB [kN]</th><th>TOB [kN*m]</th></tr>
<tr><td>Original Well</td><td></td><td>3200</td><td>140</td><td>20</td><td>60</td><td>5</td></tr>
<tr><td rowspan="2">Sidetracked Well</td><td>from 2150 mMD to 2250 mMD (time-drilling)</td><td>3200</td><td>60</td><td>5</td><td>30</td><td>2.5</td></tr>
<tr><td>from 2250 mMD to 4313 mMD</td><td>3200</td><td>140</td><td>20</td><td>60</td><td>5</td></tr>
</table>

Table 7. Operational parameters for the original and sidetracked well designs.

According to the field experience extracted from one of the Drilling Programs, it is recommended to slow down on RPM and WOB through Tuvan and Sail sandstones to improve the bit life. Recommended RPM is 60-80 and WOB is 100-150 kN in these zones. In the sidetracked wellbore, Tuvan formation extends from 3196 mMD to 3228 mMD and Sail sandstone covers the distance from 3639 mMD to 3781 mMD. RPM and WOB through these formations in our well model are planned to be 140 and 60 kN accordingly. Thus, these parameters must be adjusted based on the indications of the field experience while penetrating through Tuvan and Sail formations in order to extend the bit life and avoid the undesired bit trips.

4.5 Risk Assessment

The risks, related to sidetracking and drilling for the 12 ¼” section, are already described in the *“Operational Risks”* sub-chapter. These risks have to be evaluated in order to mitigate the potential problems and provide safe drilling operations.

4.5.1 Risk Assessment for Sidetracking Activity

Five risks during sidetracking activity are mentioned in the *“Risks during Sidetracking Activity”* section and each of them will be assessed in this sub-chapter. The main point during the evaluation is to involve the field experiences in order to identify the risk mitigating methods as well as clarify the risk level after the countermeasures are applied to the operation.

4.5.1.1 Bad weather condition

A reason for sidetracking the given well was a bad weather condition that caused WOW and resulted in the wellbore instability issues. To prevent this problem from happening again, the weather forecast must be checked beforehand and drilling operations must be planned accordingly.

It would be the worst case if the harsh weather condition is encountered during casing running activity. According to NTNU-Drilling Experience document, the single trip tool made up to the hanger should be utilized as an emergency hang off tool while running the 13 3/8" and 9 5/8" casings. 9 5/8” production casing will be run into the hole once the drilling for 12 ¼” section is finalized. So, the technique written in NTNU governing document should be also applied to the casing running activity in our well model.

To conclude with, the bad weather can still be a problem for the given well even though the operations are planned accordingly. It is a fact that the weather forecast can be inaccurate/wrong.

4.5.1.2 Poor cement plug

There are some factors that influence the quality of the cement plug. The major ones are listed below:

- Formation Compressive Strength
- Temperature/Pressure
- Wellbore Tortuosity

All of these factors are already analyzed in the *“Method Selection”* sub-chapter and concluded that there is not any critical issue in the application of the cement plug under the existing well configurations.

However, a few more factors may also play a necessary role in the quality of the cement plug. One of them is setting time of the cement. Earlier begun drilling can cause the bit to rotate on the green cement and fall over the original wellbore instead of being deflected. A typical cure time of the cement is 24 h. Even though the cement is cured thoroughly, drilling over the cement plug must be performed carefully and slowly in order to keep it safe. Hence, time-drilling is employed in the sidetracked well model for dressing off the cement plug. In addition, the cured cement strength has to be stronger or equal to the formation strength.

The risk level for getting poor cement plug is low and sidetracking should be accomplished without any serious problem if all mentioned factors have been taken seriously into account.

4.5.1.3 Insufficient hole cleaning

The results simulated in WellPlan showed zero value of the cuttings bed height, which can be seen in *Figure 23.* Thus, the determined drilling parameters are sufficient to achieve the proper hole cleaning. That is why the probability of this risk for happening is low.

Nevertheless, there is a rule cited in NTNU governing documents that should be obeyed to avoid poor hole cleaning. This rule expresses that if the pumps are turned off (i.e. at connections), the build-up of the cuttings on the low side of the hole is feasible in the wellbores where the inclination is higher than 35^0. In our well model, the inclination reaches 67^0 towards the end of the 12 ¼" section. Therefore, it is recommended keep high RPM (150+) on the drill string to support the hole cleaning if the indications of the poor hole cleaning (e.g. increased torque) are present.

4.5.1.4 Casing wear and corrosion

According to NTNU governing documents, if re-entry operation or sidetracking activity has been performed the current well condition must be simulated for the casing wear prediction via CWear™ (also called DrillNet) software. Only simulations to measure the wall thickness loss is not enough. It is also required to quantify the casing wear through either acoustic measurements/'USIT' or multi finger caliper.

In the given well, the casing wear was simulated for the original wellbore and confirmed to be safe for the well integrity. Sidetracking caused the slight increase in DLS - from 2.99 ^{0}/30m to 3.41^0/30m. Since the casing wear is directly proportional to the DLS existing in the wellbore, the results should not introduce the excessive wear that can threaten the well integrity. Thus, the possibility of this risk to befall is low.

4.5.1.5 Collision with other wells

An anti-collision program is run in Compass software for the sidetracked well model and the best plan with enough safety margins is selected *(Appendix D.2)*. In addition, a gyro tool is run for the drilling of the entire 12 ¼" section that will provide more accurate survey measurements. Thus, the feasibility to collide with other wells is low.

4.5.1.6 *Risk Assessment Summary for Sidetracking*

Five risks for the sidetracking activity are assessed above and summarized in *Table 8* below. The possibilities of these risks to take place during sidetracking activity will be minimized considerably if the recommended countermeasures are applied. However, there is still a risk that endangers the operation. It is the bad weather condition where the risk level is moderate even the countermeasures are applied.

Analysis of Sidetracking Risks				
	Risk Description	Risk Level Previously	Applied Countermeasures	Risk Level Currently
1	Bad weather condition	High	Plan ahead; check the weather forecast; make up the single trip tool to the hanger for casing running activity	Moderate
2	Poor cement plug	Moderate	Employ time-drilling; achieve good quality of the cement; provide enough time for the cement to set	Low
3	Insufficient hole cleaning due to additional inclination created by sidetracking	Moderate	Build efficient hydraulics program; ensure good hole cleaning	Low
4	Casing wear and corrosion due to additional dog-leg angle generated by sidetracking	Moderate	Maintain the DLS within acceptable level; simulate a new well condition for the casing wear; perform acoustic measurements /'USIT' or multi finger caliper	Low
5	Collision with other wells	Moderate	Build an efficient anti-collision program; run a gyro tool	Low

Table 8. Analysis for Sidetracking Risks.

4.5.2 Risk Assessment for Drilling 12 ¼" section

Five risks during drilling 12 ¼" section are explained in the *"Risks during Drilling 12 ¼" section"* sub-chapter. Each of them will be assessed in this section to mitigate the risk level and achieve as low NPT as possible.

4.5.2.1 *ECD during cementing*

According to NTNU-Drilling Experience document, the value of ECD can be minimized by thinning the mud to low end of the drilling specifications before pulling the DS out of the hole for casing running. This process should commence during drilling the last 100 m of the section. If the mud thinning is not accomplished successfully while drilling, it can be also done after the casing is landed and prior to cementing. In that case, consider spending some time to thin the mud to the acceptable level. Another recommendation gained from the field experience is to use the foam cement to balance a narrow window. It secures successful cementing activity and avoids formation fracturing as well as prevents the loss of the cement to the formation.

Once the mentioned countermeasures are applied to the cementing activity of 9 5/8” production casing, the risk of the formation fracturing at the casing shoe is not a problem and its possibility of occurrence is low.

4.5.2.2 Differential sticking across permeable sand intervals

It is written in one of the Drilling Programs that differential sticking was noticed in Sail and Garn formations while running 9 5/8” casing into the hole where 1.70 S.G. OBM was present. Since the same scenario exists in our well model, the detected experience should be transferred.

Sail and Garn zones are formed back-to-back and they extend from 3540 mTVD to 3723 mTVD *(Table 1).* The DS must be rotated at high RPM to achieve sufficient hole cleaning before pulling the string out of the hole in order to avoid the possibility of the sticking while running the casing. The differential sticking can be also minimized by rotating the casing itself as continuously as possible while running it into the hole. In our well model, the casing rotation is required, at least, when the casing is reached to Sail formation - 3540mTVD/3639 mMD in order to evade the sticking issues.

If the mentioned countermeasures are fulfilled, the differential sticking during running of the 9 5/8” casing is not a problem and its feasibility to happen is low.

4.5.2.3 Swabbing

According to one of the Drilling Programs, there is the risk of swabbing in Tuvan formation while pulling the DS out of the hole. Tuvan is the hydrocarbon-bearing formation and extends from 3138 mTVD/3196 mMD to 3169 mTVD/3228 mMD *(Table 1).* Therefore, the geoservices shall supply the swab simulations for the POOH activity. Since the swabbing risk is known in advance, the problem can be eliminated by adjusting the pulling velocity of the DS. That is why the risk level of having problematic swabbing effects is low.

4.5.2.4 Wellbore instability

The experience gained from the same field indicates that the instability problems exist in Gaia zone, and inclination above 40 degrees should be avoided through this layer. Gaia zone occupies the interval from 2269 mTVD to 2324 mTVD in the formation *(Table 1)*. This interval in the sidetracked wellbore covers the distance between 2305 mMD and 2362 mMD where the highest inclination is 16^0, meaning that the wellbore instability problems should not be present in Gaia layer.

4.5.2.5 Worn drill bit

As mentioned before in the *"Operational Parameters"* sub-chapter, it is recommended to decrease the rotation of the DS to 60-80 RPM and apply 100-150 kN WOB while drilling through Tuvan and Sail formations in order to extend the bit life *(Table 1)*. Therefore, the drilling parameters must be adjusted accordingly in the planning phase of the drilling in order to eliminate the possibility of the extra bit trips.

The risk level to trip for the worn bit is low in our well model if the adjustments in the drilling parameters are fulfilled.

4.5.2.6 Risk Assessment Summary for Drilling 12 ¼" section

Five risks during drilling 12 ¼" section have been evaluated above and summarized in *Table 9* below. All of these risks and their countermeasures have been identified by field experiences written in NTNU governing documents and Drilling Programs. The possibilities of these risks to happen in our well model are reduced by applying the relevant countermeasures. These risks do not imperil the operations if the countermeasures are implemented fully.

Analysis of Drilling Risks for 12 ¼" section				
	Risk Description	Risk Level Previously	Applied Countermeasures	Risk Level Currently
1	Formation fractures due to high ECD induced by cementing activity of 9 5/8" casing	Moderate	Perform mud thinning prior to POOH for casing running; use the foam cement	Low
2	Differential sticking across permeable sand intervals	Moderate	Circulate the hole for the cleaning prior to POOH for casing running; Rotate the casing while RIH	Low
3	Swabbing during POOH	Moderate	Pulling velocity of the DS should be controlled if swabbing simulations indicate the danger	Low
4	Wellbore instability	Moderate	Obtain inclination less than 40^0 through Gaia formation	Low
5	Worn drill bit	Moderate	Reduce WOB and ROP to the recommended level while penetrating Tuvan and Sail formations	Low

Table 9. Analysis of the Drilling Risks for the 12 ¼" section.

5 Conclusion

Based on the simulations as well as involved field experiences, the following conclusions and recommendations are made for sidetracking and drilling activities in our well model:

- The experience indicates that it is risky to set a whipstock in the formation interval where UCS< 25 000 psi. Thus, the cement plug as a deflection barrier must be employed for sidetracking activity.
- RSS is recommended due to a fact that the field experience shows Tuvan formation is difficult to be penetrated by PDM.
- "Lost returns with mud drop" load case shows 1300 m mud loss inside the casing, which collapses the connections of the casing in our well model. The experience indicates that the mud loss in the casing cannot occur more than 250 m when the field in known. Consequently, there is no need to spend extra money to make the casing stronger since 250 m mud loss does not damage the selected casing.
- Tuvan and Sail formations must be penetrated by recommended drilling parameters (60-80 RPM and 100-150 kN WOB) in order to avoid the extra bit trips.
- Sail and Garn formations generate the differential sticking issues during casing running process. Consider to rotate the casing while running into the hole.
- Industry standards indicate that the safe depth of the TOC is 200 mMD above the source of the inflow and the field experience shows that Tuvan is hydrocarbon-bearing formation. Hence, the TOC must be minimally reached to 3006 mMD for 9 5/8" casing.
- Tuvan formation produces the swabbing effects. Consider to decrease the pulling velocity of the DS.

The industry is good at transferring the experiences to the upcoming well operations in the same field. However, it is a challenge to transmit the "learned lessons" from the one field to another one. This challenge can be eliminated by involving drilling companies to corporate and establish a simulator linked to the common database where important experiences are gathered.

The author recommends that the simulator for the experience transfer should be built, and the system should integrate with Landmark products or any other software package that is in use in the company in order to make it more user-friendly. When the well configurations are set, the experience transfer system should show the industry standards and experiences employed for the well design. For instance, when an engineer is intended to design the sidetracking activity the experience transfer system should reveal the closest well condition where the sidetracking was executed before. Then, an engineer can extract the appropriate experiences and industry standards, which are necessary for the analysis of his/her well model.

If the experience transfer is achieved globally, the best practices and procedures can be even further enhanced. The difficulty is confidentiality of the data in each company and a lack of the desire to build the simulator/system that collects all valuable experiences in one database for the future use.

6 Further Work

The followings shall be implemented as the further work of this research study:

- A harsh weather condition is still the potential danger. The additional investigations can be performed in order to find the way to continue drilling under the bad weather condition.
- A gyro tool is decided to be run for the entire 12 ¼” section. However, it is more accurate to make an economical analysis. An MWD tool can be used from the beginning of the operation till 3643 mMD, then tripping is required to replace the MWD tool with the gyro and the gyro must be operated from 3643 mMD up to the end of the 12 ¼” section. The costs of these actions shall be compared with the costs of the action where the only gyro tool is run for the entire 12 ¼” section. Afterward, the costs analysis will identify precisely, whether the gyro tool for the use of the entire section is beneficial or not.
- Due to time restrictions, the simulations for the casing wear in DrillNet is neglected. This simulation is required for the operations even though sidetracking activity did not create the high DLS.
- Time evaluation and operational barriers are necessary to analyze in any drilling activity. Both of them are ignored due to time restrictions.
- The field related documents can be investigated more to find relevant experiences in order to apply those experiences to the model. However, more information about the field is required, which is difficult to discover because of the data confidentiality.
- The main principles and data search mechanisms can be investigated and established for the experience transfer system.

Appendices

Appendix A, Drilling Work Process

A.1 Work Process in Operating Company

Once geologists and geophysicists determined a drilling target, they can update interpretations and visualize the intended wellpath in the software *(Figure 1).* Drilling engineers can use geological data while building a well trajectory, which enables to design an optimal wellpath. Iterations to determine a target and surface location of the well between geologists, geophysicists and engineers are minimized due to data sharing among all involved members of a team, which makes a process smoother and faster than before. After selection of the tentative surface location and target, the well prognosis for lithology column, pore and fracture pressure gradients should be defined where iterations can be necessary again to adjust the previously determined surface location and trajectory in order to eradicate drilling hazards such as shallow gas and over-pressured zones *(François Clouzeau, 1998)*. An engineer is then able to model a casing design according to geological interpretations and offset data. Service companies get involved into workflow at this point to support the process by supplying mud, cement programs and other well constructions for the operating company. At the end of the planning phase, operating company applies for permits and prepares logistic arrangements to start execution phase of the project.

A.2 Recommendations for Company Structure

The general recommendations for the drilling company, identified by drilling performance model, are summarized below *(Brett and Millheim, 1986)*:

- Drilling programs should be planned for the long-term goals, not well by well, to create a positive impact on economics.
- A sufficient number of experts should be present in the company who have drilled many exploitation and exploration wells.
- The first wells in the field should be drilled by the best personnel, applying the highest technology and communication method.
- It is important to gather as much drilling data as possible from the first drilled wells.

- The high-quality drilling dates should be achieved as many as possible during drilling for the first wells. Because it takes more time to drill the first wells rather than the later-coming wells in the field.
- When the experienced team reaches a point where drilling curve flattened out, substitute the team with less experienced personnel and transfer them to the newly developing areas to focus again on the drilling of the first wells. Since the geology of the drilled field is fully recovered and experience is captured, as well as saved in the database, the less experienced team will not need the support to execute the operations.
- The advanced analytical tools are essential to investigate the process of planning, execution and evaluation prior to starting to drill a series of wells in the field.
- A high level of communication is necessary during drilling for the first wells, and when the team is exchanged in the platform.
- An organizational structure, which allows optimation of the strategies and the rapid implementation of a new technology, should be obtained in the company.

A significant amount of money can be wasted if the mentioned points are not applied and recognized in the company policy.

The application of analytical tools/ software simulators for the examination of DPC model enables to test a variety of operational strategies and analyze the impacts of these strategies on C_1, C_2, C_3 *(Brett and Summers, Millheim, 1983)*. Software simulators can also identify as the ideal C_3 value as possible and support the rate of learning. It is necessary to use an analytical tool for the analysis of the strategies, particularly in the development of the small fields prior to the actual application of the new strategy.

A.3 Scheduling & Reporting

Scheduling and reporting are imperative to keep the drilling time in the predetermined frame and document drilling activities to use for different purposes in the future. Several schedules and reports are required to have in any drilling organizations.

A.3.1 Detailed time curve and Drilling schedule

A "drilling schedule" lists all the predicted operations during drilling, and a "detailed time curve" shows anticipated time for executions of those operations. The drilling schedule makes a drilling crew aware of the upcoming activities and enables a smooth transition between tasks *(Pittman, 1985)*. Drilling crew must be prepared in advance for the next step and its implication. Maintenance personnel must know what machinery and equipment will be needed for repair in order to schedule preventive tasks accordingly. Service companies have to test and make their equipment ready before an activity begins in the rig-site. All of these basic steps demand the discipline of a formal program to ensure a smooth process *(McGhee, 1985).*

A.3.2 Historical Rig Time Curve

"Historical rig time curves" are largely used by operating companies to calculate expenditures and measure drilling efficiency. They consist of performance times for the drilling operations *(Remson, 1985)*. The average time that it takes a rig to perform an activity is termed "performance time". Usually, every rig owns a list of activities and their performance times, which are annually updated. Thereby, it founds the basis to determine drilling efficiency *(Remson, 1989)*.

A.3.3. 48-hour schedule

In addition to the detailed work schedule, the rig supervisors formulate a schedule for the next 48 hours. Many organizations are involved in drilling operations at the cross-purposes. This schedule creates a focal point for the coordination of those organizations and ensures the information flow among involved companies.

Another advantage of 48-hour schedule is that the safety of the personnel can be managed in advance. It provides extra time to think of possible hardships and be prepared. It is also useful for the people who appear rarely at the rig-site and follow the progress from a management or logistic point of view.

A.3.4 Morning Reports

A computerized "morning report" is a tool that delivers data collection of the rig performance and well progress. If the collection of the morning reports is correctly used as an estimation tool in the well-planning review and communication process, it can enhance the workflow considerably as well as assist management and customer service organizations. The morning report is the input value into the database of the drilling organization and provides simplified access for evaluation of technical and structural systems of the company. The morning report in the database can be edited, printed, sent, retrieved and used for any required analysis if the software package is user-friendly. The information collection, established by morning reports, can also be utilized to generate a number of regular reports *(Remson, 1989)*. Some of them are:

- End-of-the well report
- Annular rig performance analysis report
- Annular performance time charts for each rig
- Monthly safety and regulatory body compliance report
- Rig location history report
- Rig downtime summary report

Apart from the standard reports, databases are often accessed to produce many non-standard reports to strengthen the quality of maintenance, sales, drilling workflow and activities.

A.3.5 End of Well Report

The "End of Well Report" is retrieved from morning report database to compare actually achieved performance with the previously planned one. The report introduces downtime, safety statistics, unexpected events and challenges. If the results in "End of Well Report" do not meet the expectations of either operator or contractor, the reasons caused unsatisfactory outcomes must be discussed in order to reveal "gaps" existed in the operations and subsequently transfer "learned lessons" to the upcoming well operations *(Remson, 1989)*.

A.4 Drilling Integrated Workflow Environment

Many engineering programs have limited integration capabilities due to a fact that they are provided by different vendors. The efficiency of engineering programs (e.g. well-planning, geo-steering and real-time operation center) is increased when offset well data are integrated with real-time data. This is what makes Drilling Integrated Workflow Environment (DIWE) essential to apply to drilling operations. It achieves the seamless integration with a multi-vendor environment

(Figure 9) and enables drilling workflow updated on a real time basis which is a paradigm shift from the tradition *(Mohan et al., 2014).*

DIWE integrates historical, static and real-time data as well as stores all available offset well information, engineering designs, lessons learnt, best practices and root causes of failures in a manageable format. It advances planning, execution and evaluation phases of the drilling operation which, in turn, increases performance and safety in drilling activities *(Deeks et al., 2012)*. DIWE also contributes to building the engineering and earth models. Generally, it brings the following benefits in business ability:

- Increased Drilling Performance
- Enhanced Drilling HSE
- Improved Planning and Field Development
- Less Drilling Time
- Decreased NPT and Invisible Loss Time (ILT)
- Reduced Operational Costs

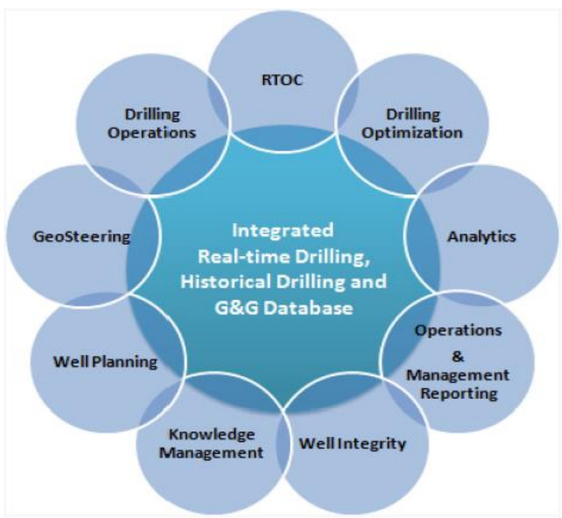


Figure 9. Integrated workflows enabled through DIWE *(Mohan et al., 2014).*

Appendix B, Technical Sidetrack

The sidetracking is the deviation of the wellbore from the present, original trajectory *(Figure 10).* There are many applications that sidetracking is required or profitable. In fact, it is often difficult to control the bit direction to penetrate into the desired zone. The corrections or adjustment along the wellpath might be necessary to maintain the course of the wellbore.

During drilling, DS can fail and a part of it can fall into the hole. The metal fatigue/break of DS is one of the reasons to sidetrack a well and pass alongside a fish. Technical sidetracking might be also performed to re-drill or re-complete for new ledges or laterals of a multilateral well. If a kick off point is in the cased borehole, the sidetracking provides a solution for this challenge too by involving the techniques that enable milling a window in the casing. *(Bourgoyne et al., 1986).*

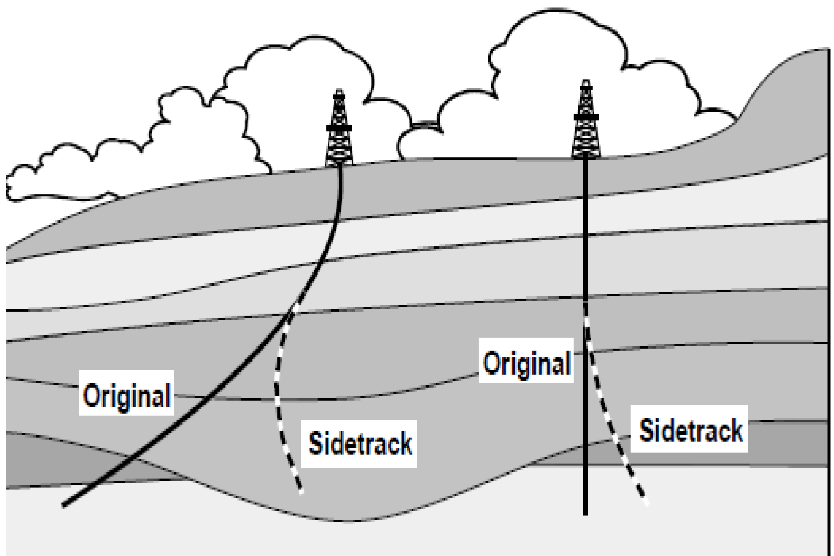


Figure 10. Technical Sidetrack *(Baker_Hughes, 1995).*

B.1 Sidetracking Procedure with a whipstock

The first of all, a whipstock assembly is run into the openhole and oriented in place to drill a "rat hole" below the toe of a whipstock. Then, the weight is applied to set the tool and shear the pin to start up the operation. Once the pin is sheared, drilling carries on until the top of the whipstock assembly reaches the "stop", meaning that it is time to pull the whipstock out of the hole *(a-d, Figure 11).* To enlarge the rat hole further to full gauge, a hole opener is run to ream the hole and tripped out afterward. Finally, a rapid angle build assembly is lowered to smoothen and maintain the trajectory *(e and f, Figure 11).* This whole procedure might be repeated for several times in the kickoff.

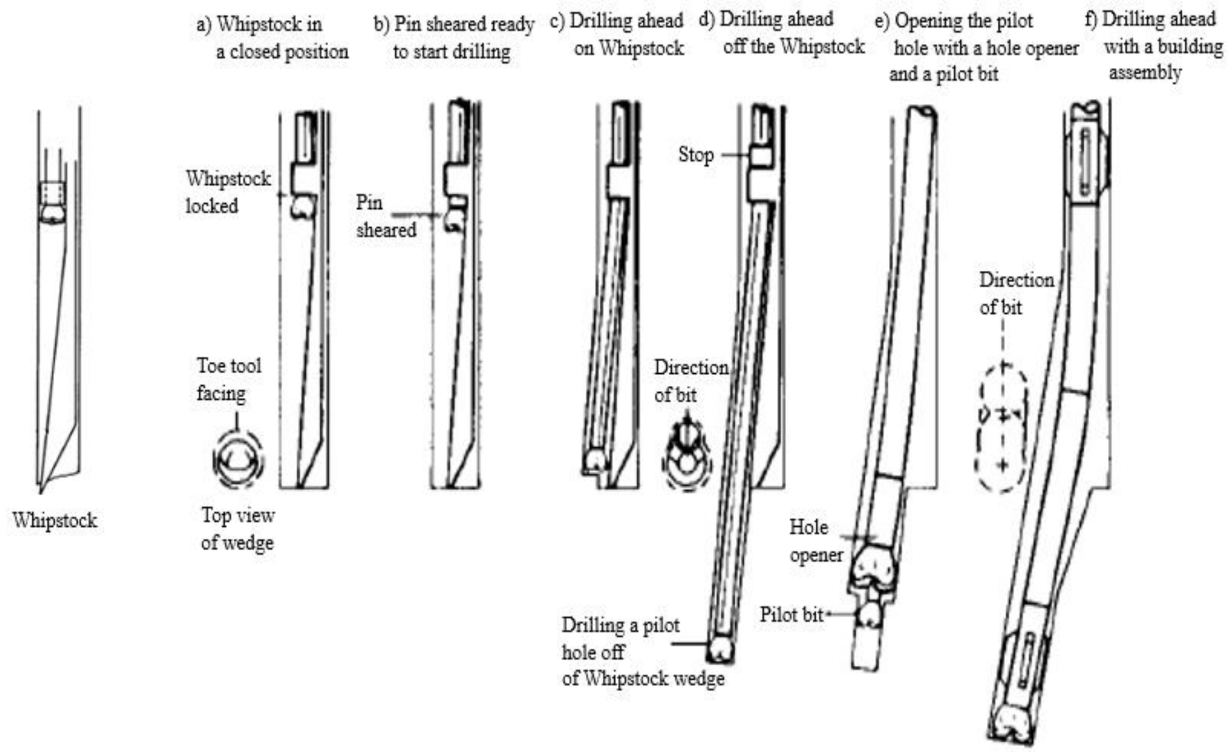


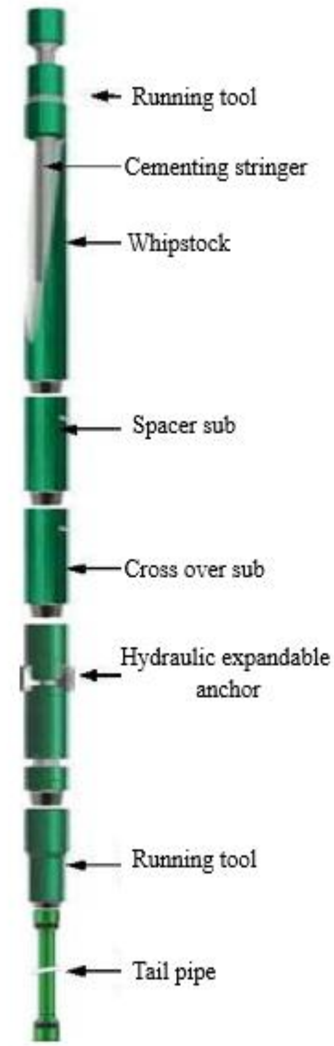
Figure 11. Whipstock and operational sequences for drilling *(Bourgoyne et al., 1986).*

Obviously, the main disadvantage of a whipstock tool is the number of trips required to complete the operation that is time-consuming, causing drilling costs to increase. Another disadvantage is that the traditional whipstock generates a sudden and sharp angle change and results in difficulties for subsequent activities. The advantage is that it is a fairly simple piece of equipment that requires relatively less maintenance and has no temperature or pressure restrictions *(Inglis, 1988).*

B.2 Advanced Whipstock System

An advanced whipstock system is illustrated in the next page. The system consists of a typical assembly with the individual components to sidetrack over the whipstock by operating the mud motor. The mechanism of the system enables cementing below the string in the case of need and provides three gripping points against borehole to secure operation. In addition, there is no need to wait for the cement to get hardened, which saves time/costs. It includes the following components and abilities *(Dewey et al., 2012)*:

- A whipstock builds the path over its ramp for a directional BHA and provides a smooth deviation.
- An expandable anchor, which is hydraulically set, provides three-point firm grip with the hole wall to restrict the turning motion of the system during drilling.
- It is possible to orient the whipstock ramp to the desired azimuth.
- A cementing stinger provides the path for pumping the cement below the system to isolate zones.
- A long tail pipe is to reach the cement to the bottom of the hole.
- A capability to complete running, orienting, anchor setting, cementing and stringer retrieving operations - all in one trip.



Sidetracking system

Once the KOP is determined, operators decide whether to isolate the main bore (so-called mother bore) below the lateral. Usually, the main bore is required to be plugged for safety reasons. Then, the cement will be pumped from the cementing stringer to the bottom of the hole. Once the cementing activity is completed, a cementing stringer can be then pulled out of the hole, leaving the whipstock and anchor in place for the subsequent procedure, which is to receive the directional BHA and sidetrack a well. To increase stability, the cement can be pumped to the top of the whipstock.

The system has been applied to more than 65 fields and run for 135 times successfully. The deepest hole, where the technique applied successfully, has been 4 400 m. The system demands a gyro tool to orient the direction *(Dewey et al., 2012).*

Appendix C, Deflection Tools and Techniques

There are several deflection tools that can succeed to deviate the wellbore. To find an optimal one for a given application, pros and cons of these tools should be analyzed. The tools applied to deviate the wellbore are:

- Whipstocks
- Turbines or Turbodrills
- Mud motors with a bent-sub (or PDM)
- Non-rotating Steerable Drilling Systems
- Rotary Steerable Drilling Systems

Turbines, PDMs and non-rotating steerable drilling systems are established by two simple principles. The first principle is a bit tilt angle introduced to the BHA axis just above the bit and the second one is a generation of a sideforce on the bit *(Figure 12).* The introduction of a tilt angle and sideforce lead the bit to drill at an angle with respect to the present trajectory and cause wellpath deviation.

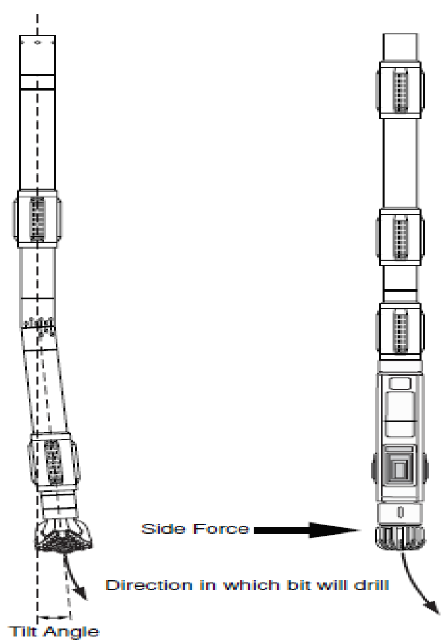


Figure 12. A bit tilt angle and sideforce *(Heriot-Watt_University, 2010).*

The most applied downhole motors, today, are PDMs and RSSs. Since the deviation tools are not in the scope of this thesis, only, PDM and RSS are compared in *Appendix C.1* in order to comprehend their effects over sidetracking operations.

C.1 PDM vs RSS

A PDM provides drilling in the sliding mode, which causes several inefficiencies. The sliding mode enables only the rotation of mud motor while steering the borehole. The motor has to be oriented to the desired direction to deviate the wellbore and the orientation of the motor can be challenging in the hole. Since the DS absorbs the torque over such a long distance, it can be required to turn the DS for 10-15 times at surface just to achieve one revolution of the toolface in the hole. Once the tool is positioned in the hole, it is also a problem to keep the BHA on the course due to the reverse torque generated by the motor as the bit drills. Surface torque is applied to hold the motor in proper orientation against revise torque. Since the DS rotation is absent, the removal of cuttings in the borehole also becomes difficult. In addition, high drag forces can restrict the running of DS into the hole and weight transfer to the bit can also become problematic due to the lack of DS rotation.

An RSS produces rotary drilling which makes DS rotation possible while steering the wellbore *(Warren, 2006)*. The benefits achieved by the RSS are:

- Effective weight transfer
- Improved hole clearing
- Reduced pipe sticking
- Smoother well trajectory
- No dependence on friction factor

With the RSS, the toolface is stationary in the hole and the bit shaft can stay constant to the desired direction.

Appendix D, Outputs of Engineering Programs

D.1 Pressure Prognosis

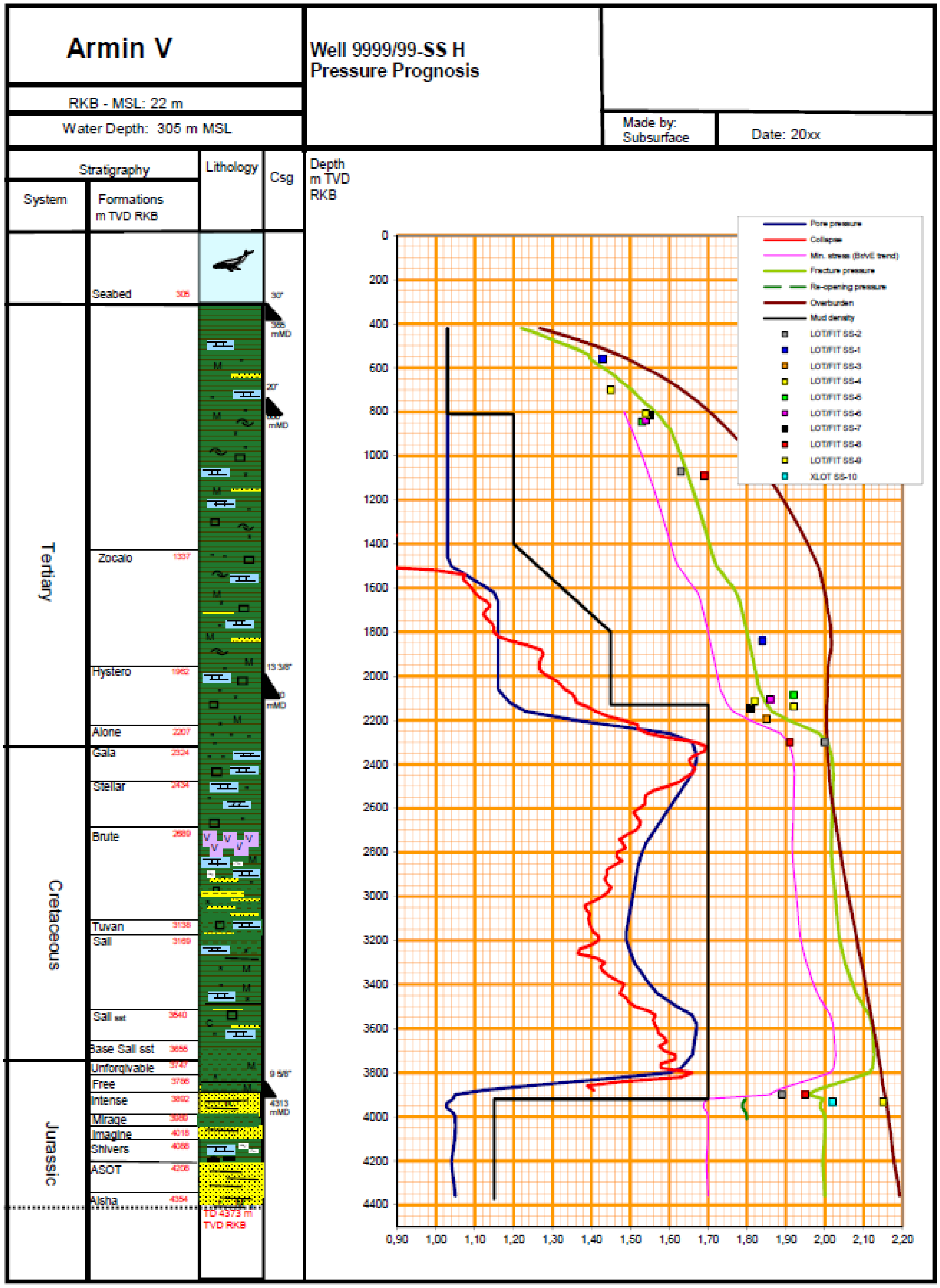


Figure 13. Pressure Prognosis.

D.2 Well Profile

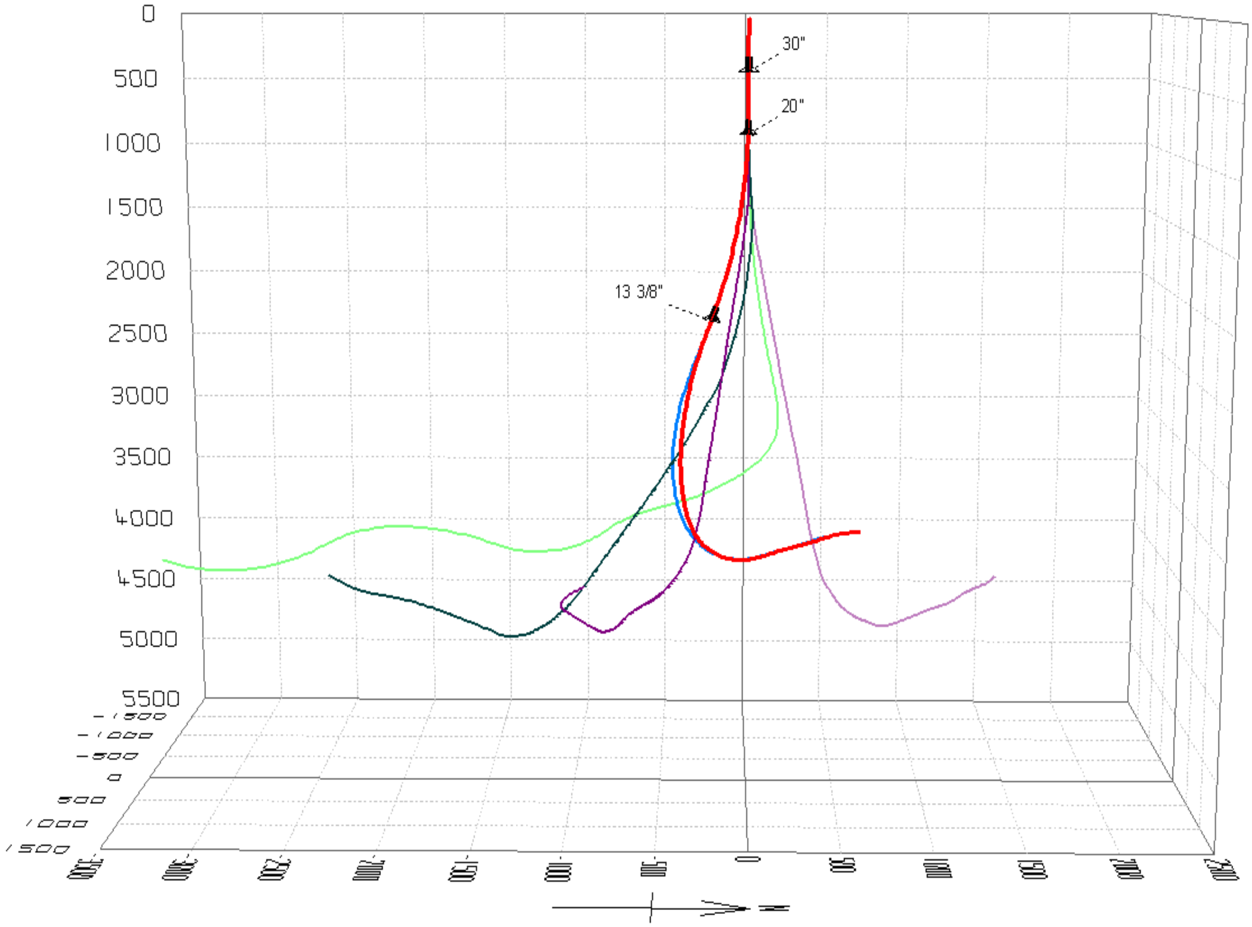


Figure 14. 3D Views of All Present Wells in the Template. A red line is sidetracked wellbore, while the blue one is the original wellbore.

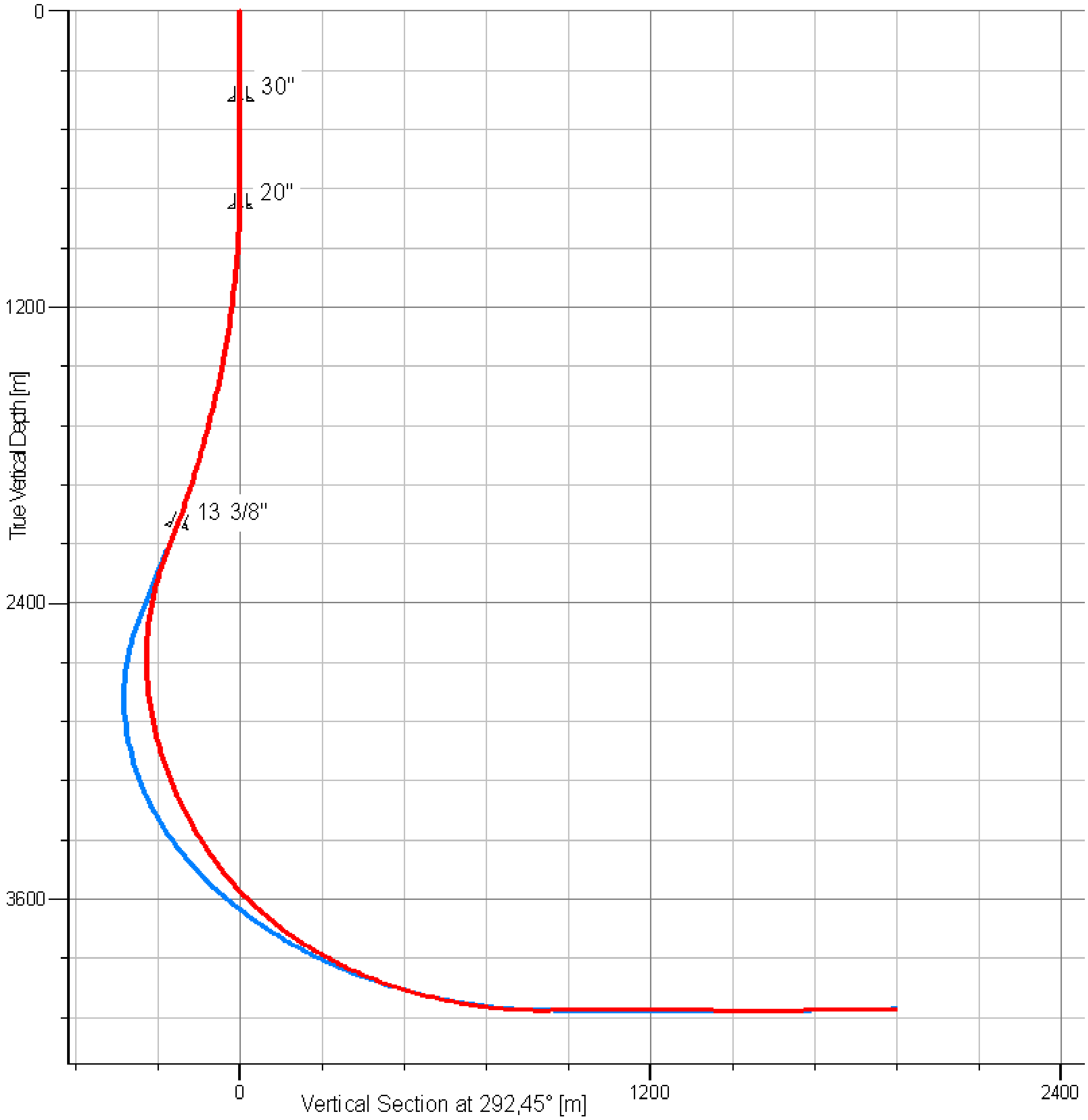


Figure 15. Vertical Planes of Original and Sidetracked Wellbores. A red line is sidetracked well, while the blue one is the original well.

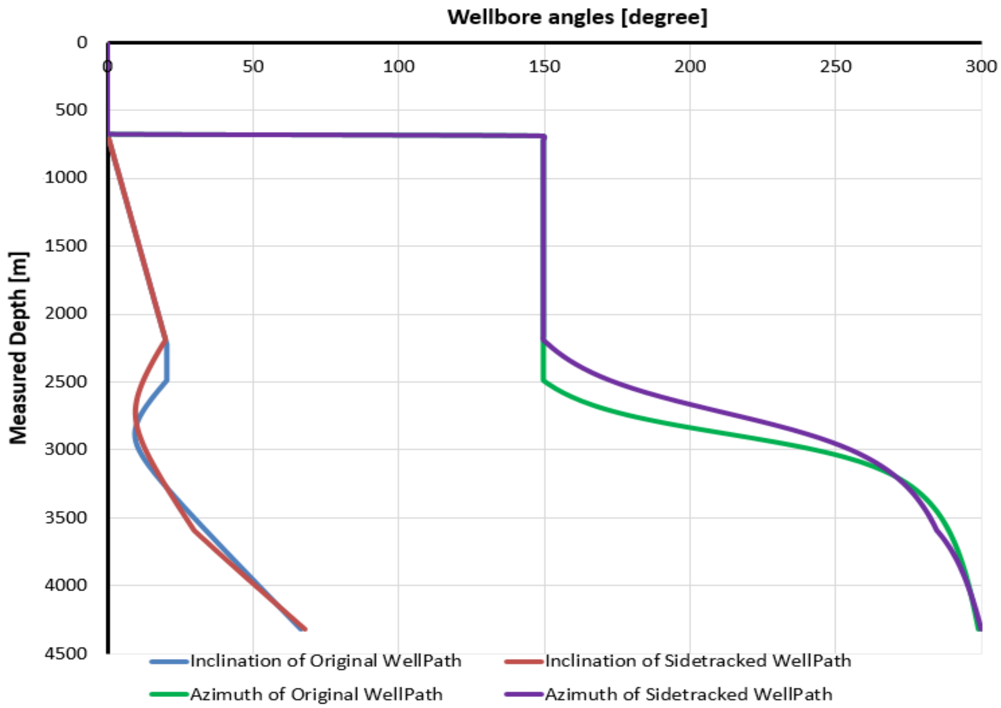


Figure 16. Inclination and Azimuth changes along Original and Sidetracked Wellbores.

D.3 Torque and Drag Analysis

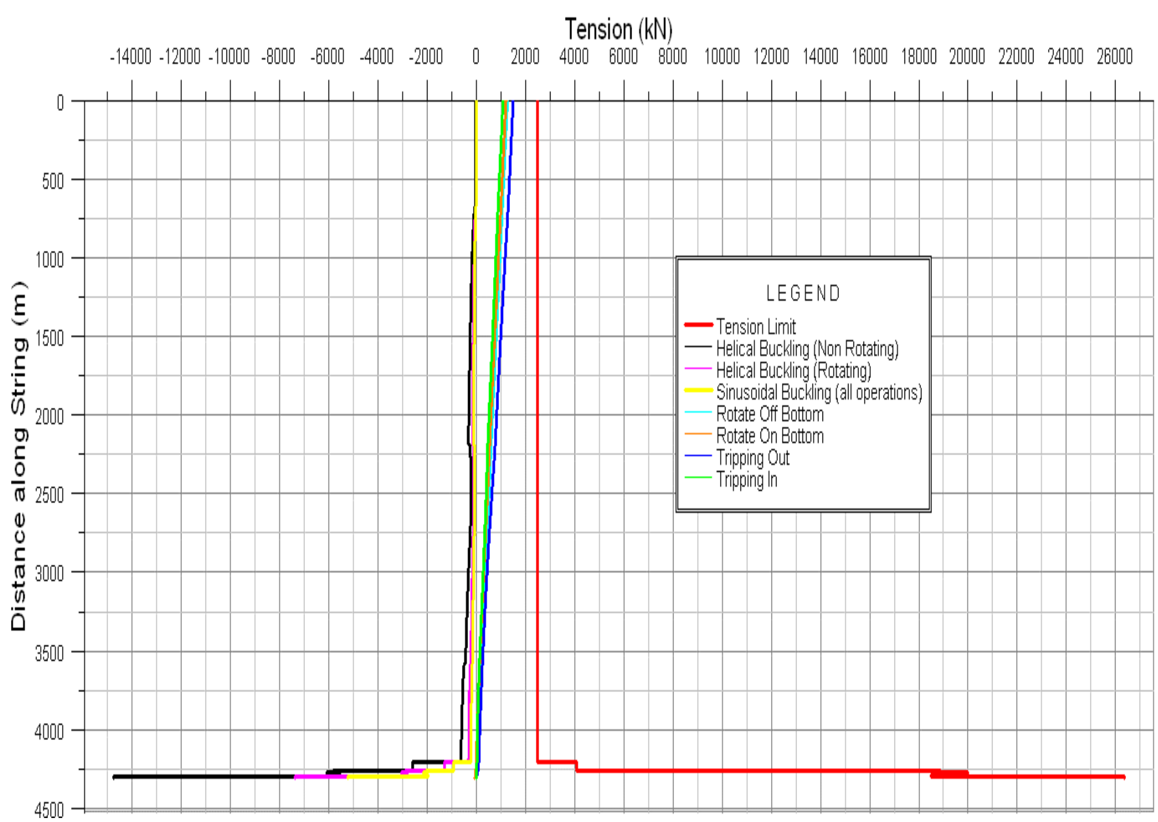


Figure 17. Effective Tension vs Depth for the Sidetracked Well.

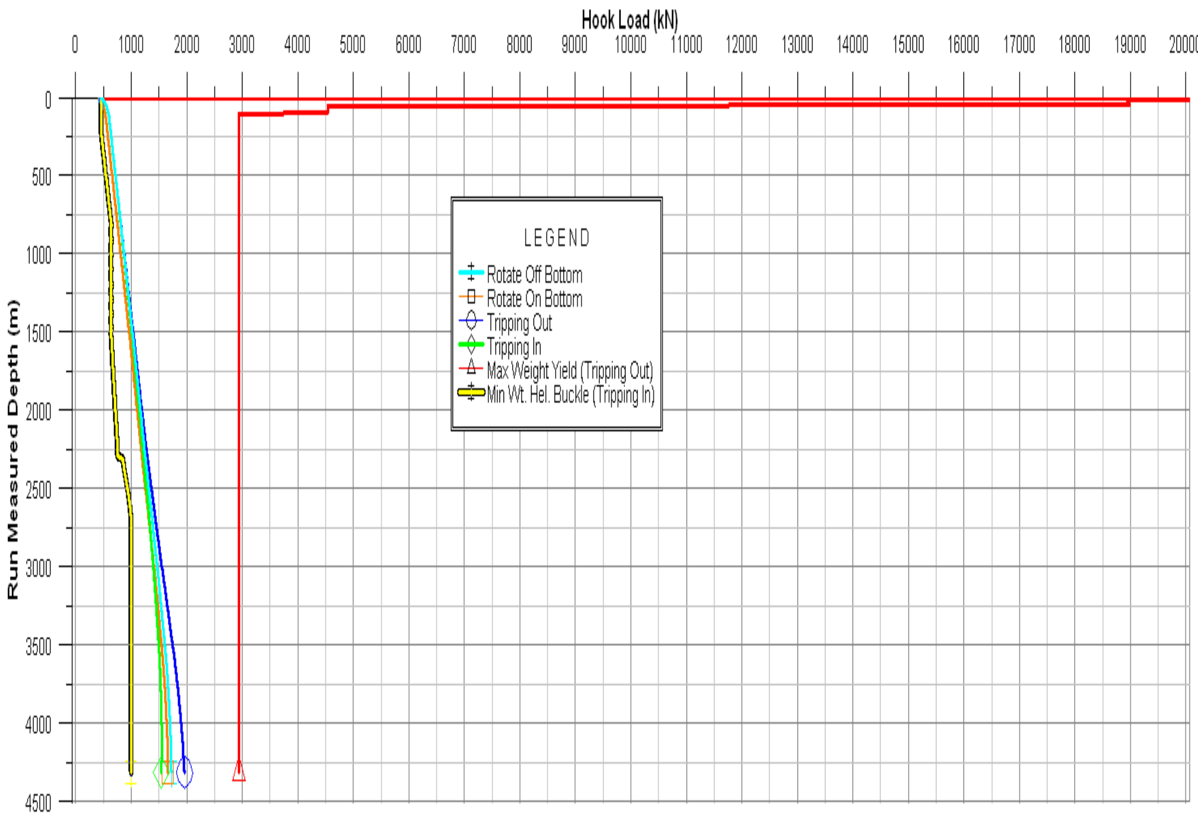


Figure 18. Hook Load vs Depth for the Sidetracked Well.

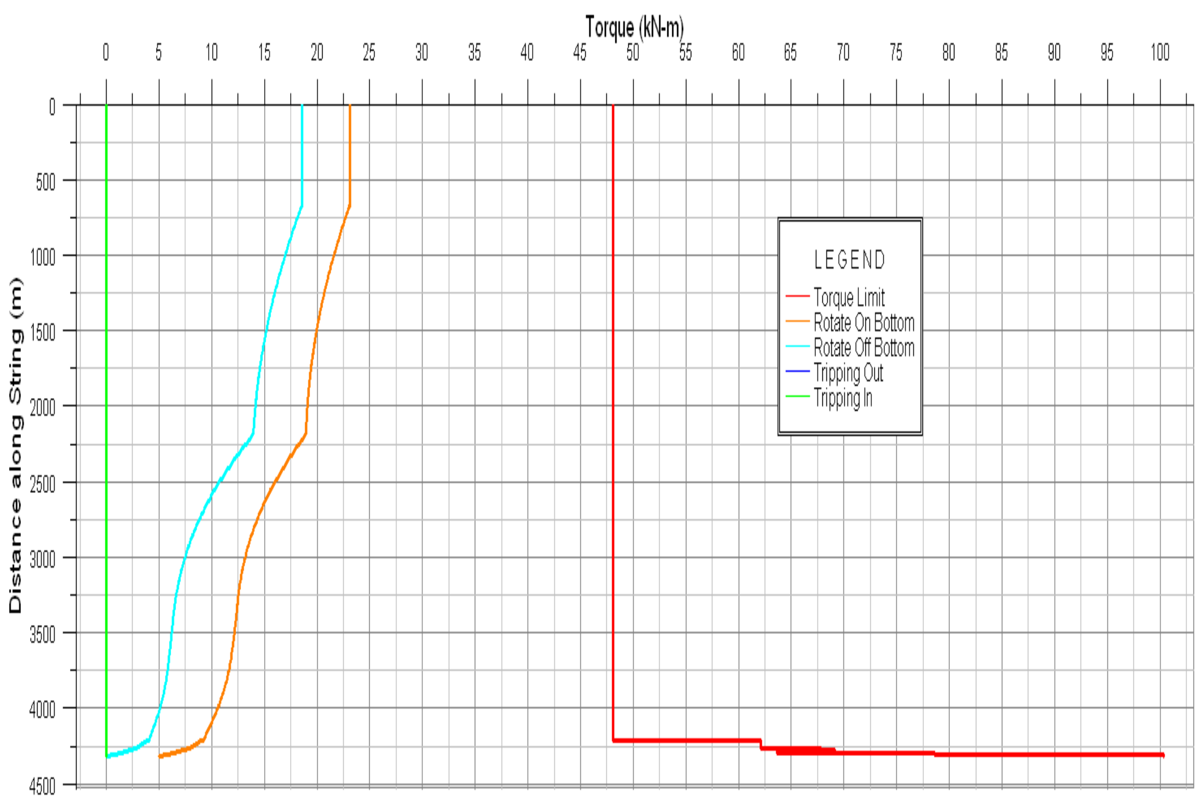


Figure 19. Torque vs Depth for the Sidetracked Well.

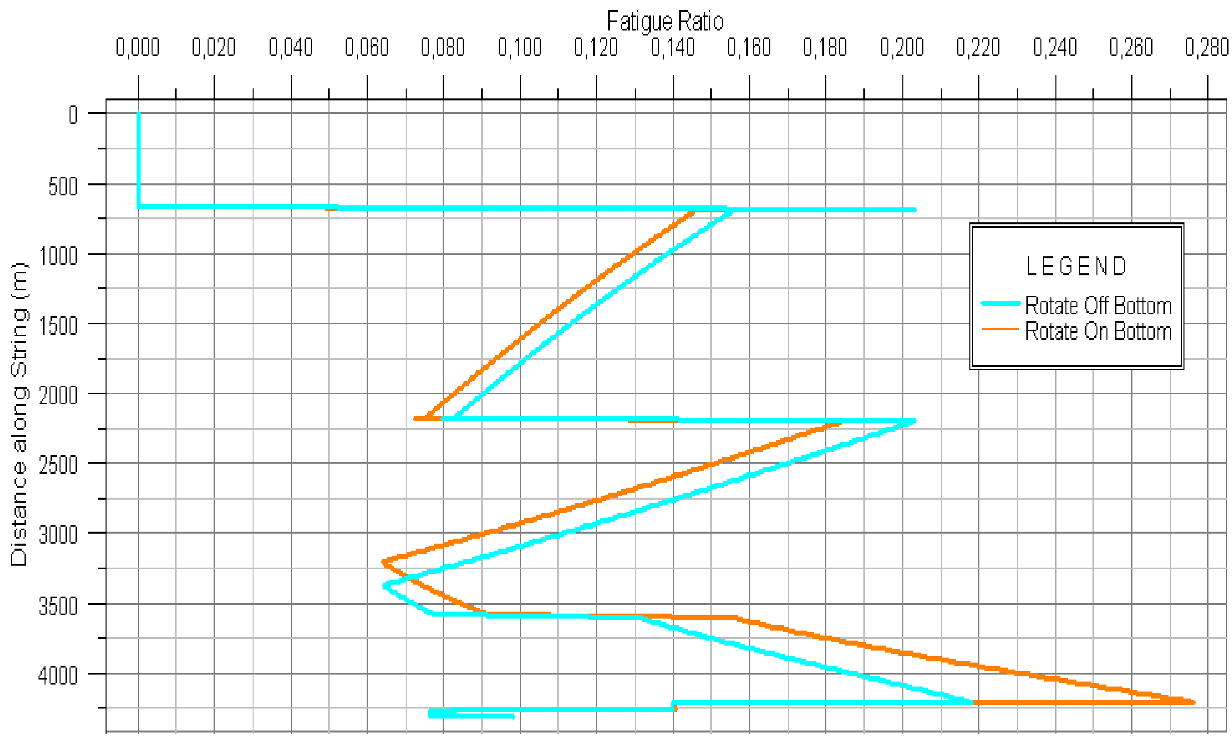


Figure 20. Fatigue Ratio vs Depth for the Sidetracked Well.

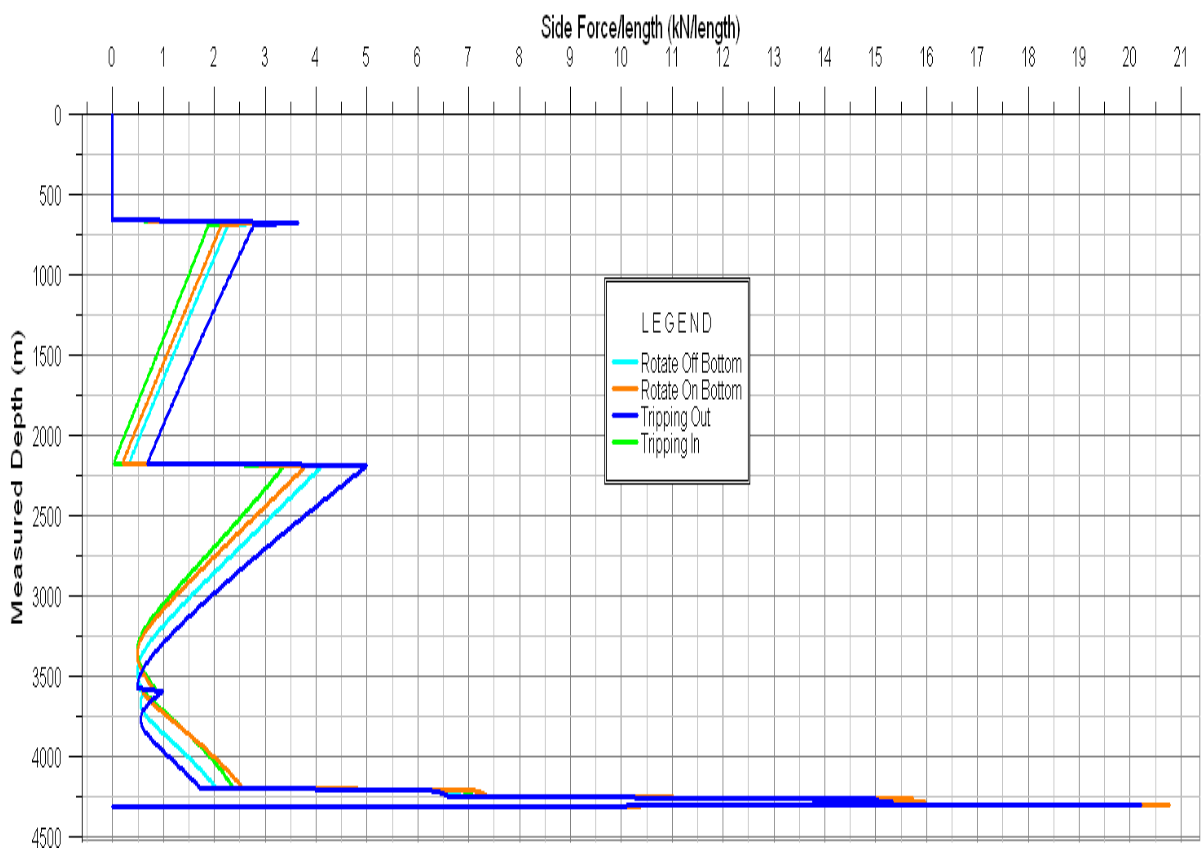


Figure 21. Side Force vs Depth for the Sidetracked Well.

D.4 Hydraulic Evaluations

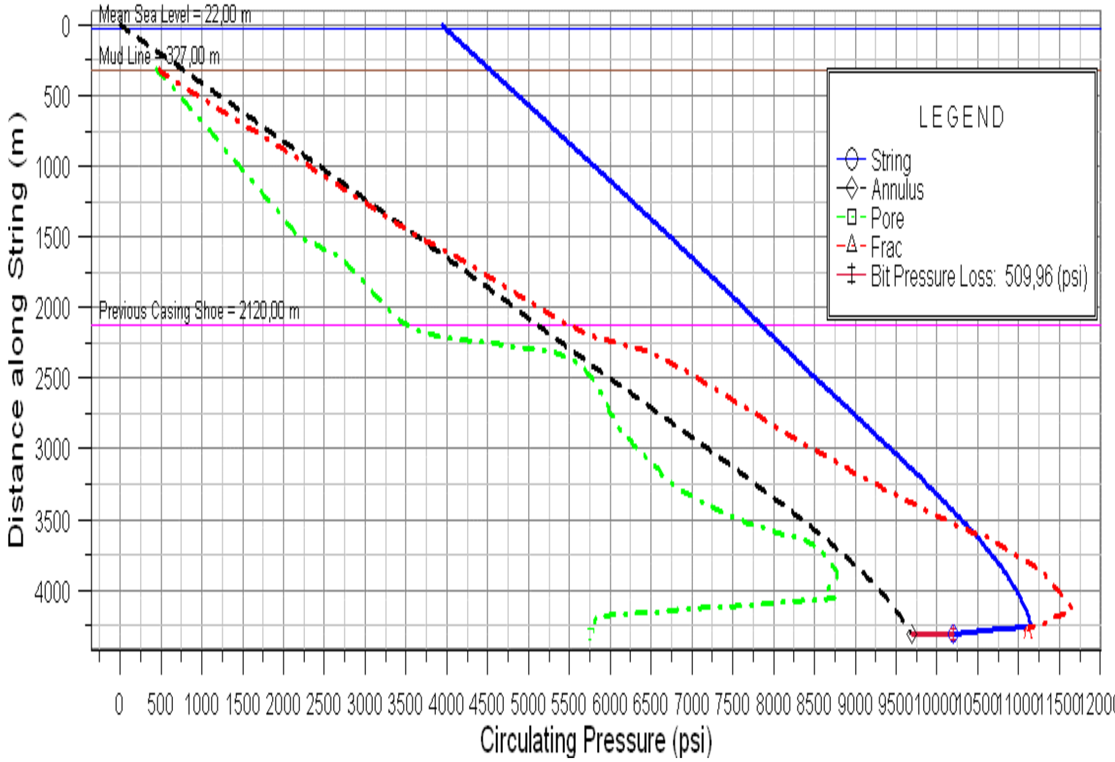


Figure 22. Circulating Pressure vs Depth for the Sidetracked Well.

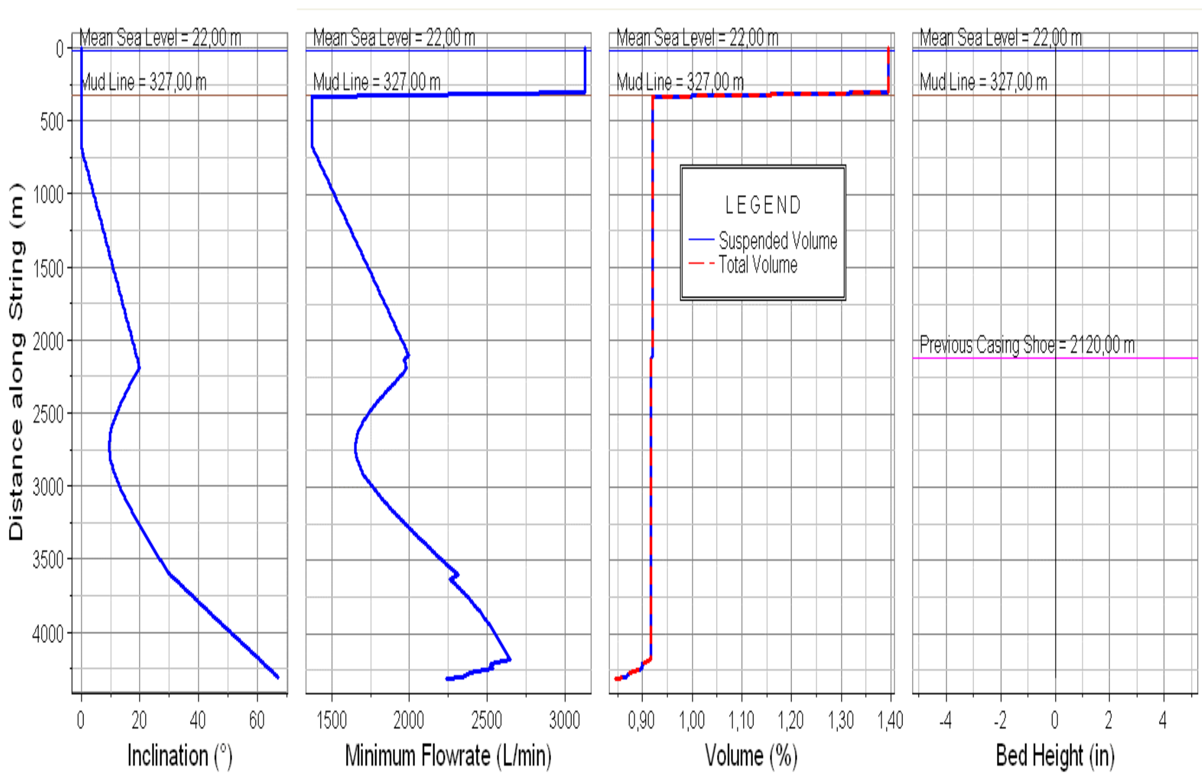


Figure 23. Cuttings transport for the Sidetracked Well.

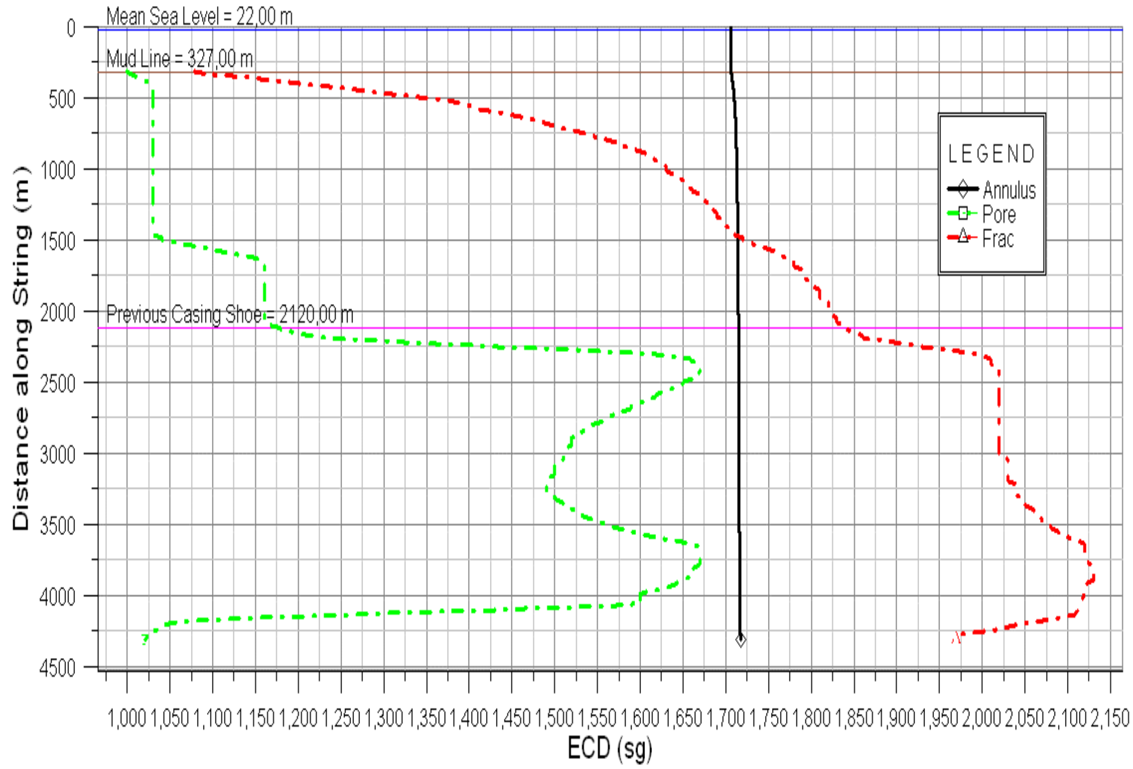


Figure 24. ECD vs Depth for the Sidetracked Well.

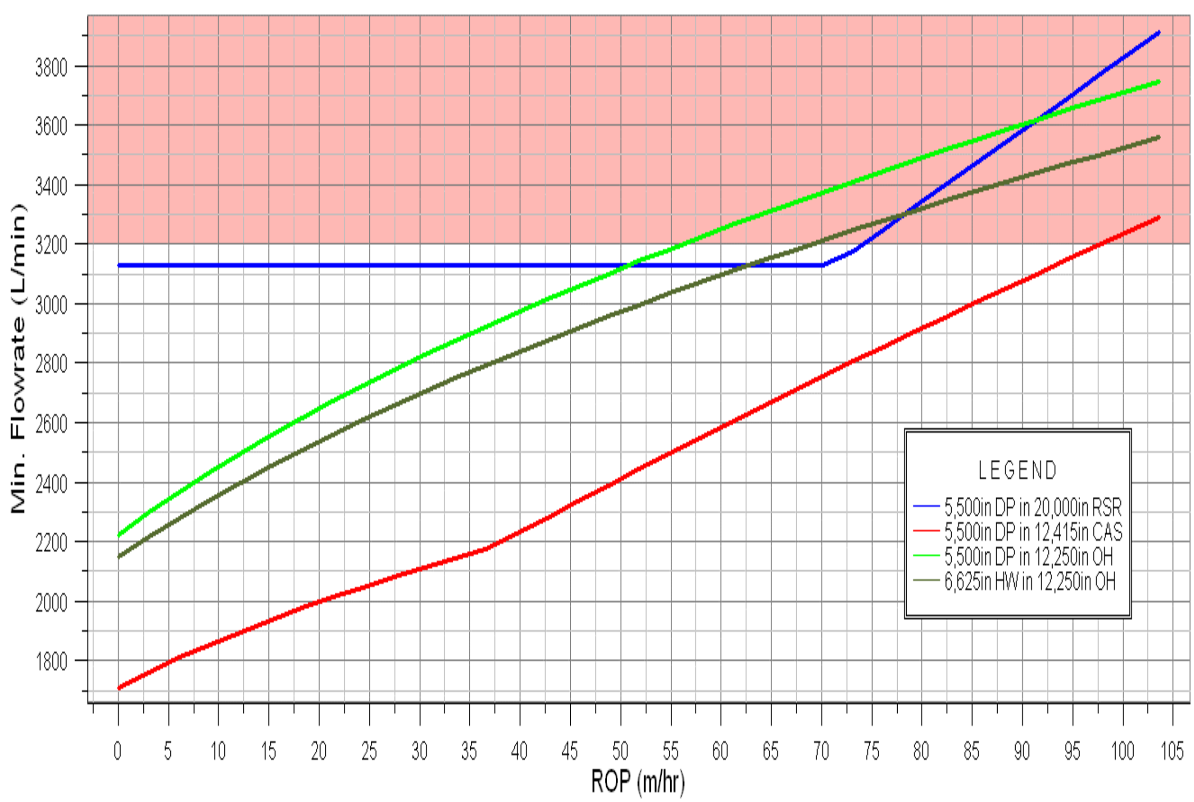


Figure 25. Min. Flow rate vs ROP for the Sidetracked Well.

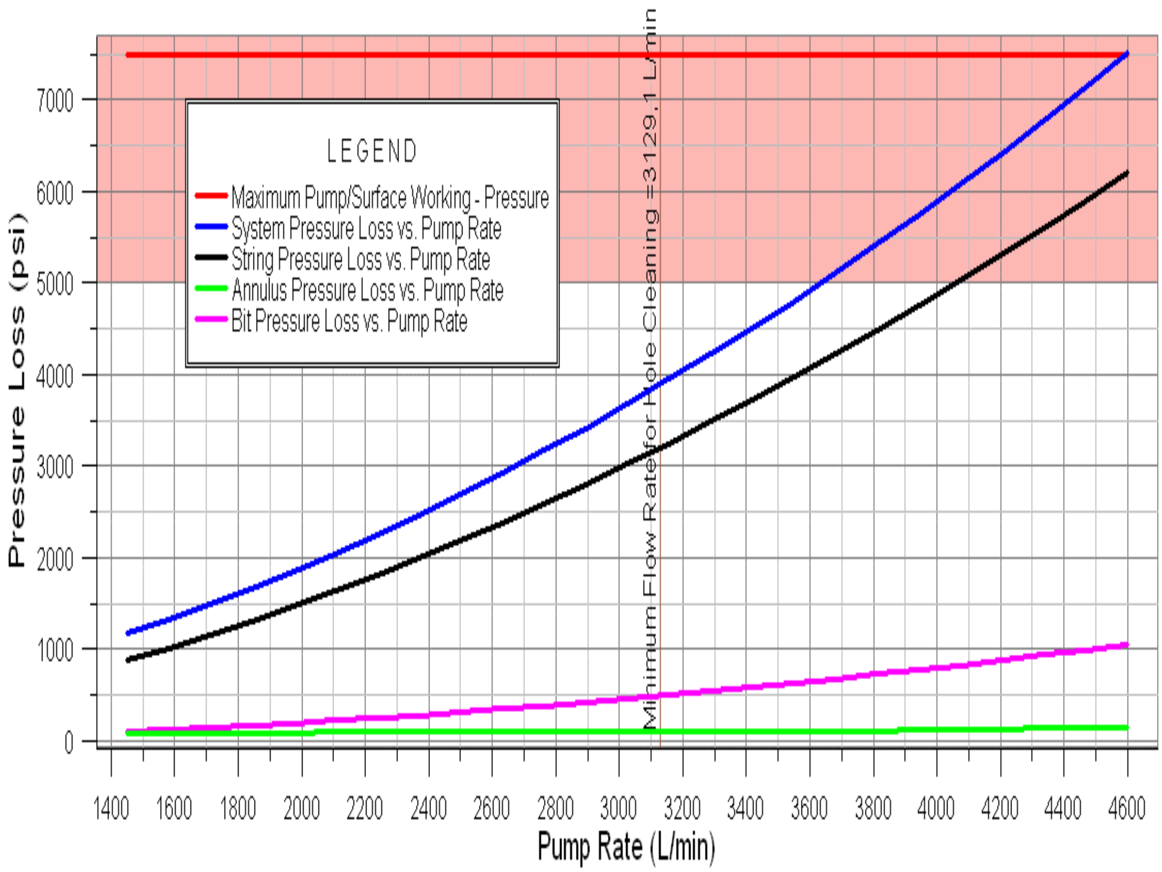


Figure 26. Pump Pressure vs Pump Rate for the Sidetracked Well.

D.5 Casing Program

WELL SCHEMATIC

Well: **SS 1 H**
Field: **Anonym**
Rig: **Anonym**

All depths measured from RKB

HOLE SIZE	HOLE TVD MD	CASING SIZE	TYPE / RAD. MARKERS	CENTRALIZERS/SHOE	TEST PRESS [psi]	LOT FIT	Estimated TOC TVD	Estimated TOC MD	CSG. SHOE TVD	CSG. SHOE MD	RKB	WL/TLC LOGS	LWD LOGS	SURV CSG/ OH
SB	327						m	m	m	m				
36"	365 365	30"	157,500 lb/ft , X-52 Nominal ID: 29.000" ,Drift ID: 28.813" Burst(Psi): 1516,67 Collapse(Psi): 224,86 Axial(kN): 10718,442		4000				365	365				MWD
26"	799.98 800	20"	133,000 lb/ft , K-55 Nominal ID: 18,730" ,Drift ID: 18,543" Burst(Psi): 3055,94 Collapse(Psi): 1496,27 Axial(kN): 9451,271		4000				800	800				MWD
17 1/2"	2093.62 2120	13 3/8"	68,000 lb/ft , P-110 Nominal ID: 12,415" ,Drift ID: 12,259" Burst(Psi): 6908,41 Collapse(Psi): 2335,39 Axial(kN): 9514,622		4000	Expect. LOT	327	327	2093	2120				MWD
12 1/4"	3968.77 4313	9 5/8"	47,000 lb/ft , Q-125 Nominal ID: 8,681" , Drift ID: 8,625" Burst(Psi): 10727,27 Collapse(Psi): 5635,98 Axial(kN): 7546,607		4000	FIT	1710	1720	3926 3968	4213 4313				Gyro and MWD
8 1/2"	4044 5811.13	7"	32,000 lb/ft , N-80 Nominal ID: 6,094" ,Drift ID: 6,000" Burst(Psi): 9060,00 Collapse(Psi): 8604,84 Axial(kN): 3315,636		4000		Btm cmt: #REF!	Btm cmt: #REF!	4044	5811	Liner			MWD OH: Gyro

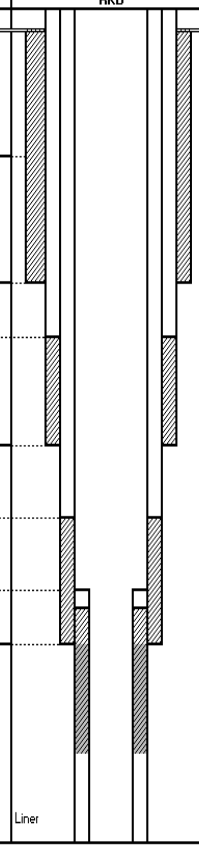


Figure 27. Well Schematic – Casing program for the Sidetracked Well.

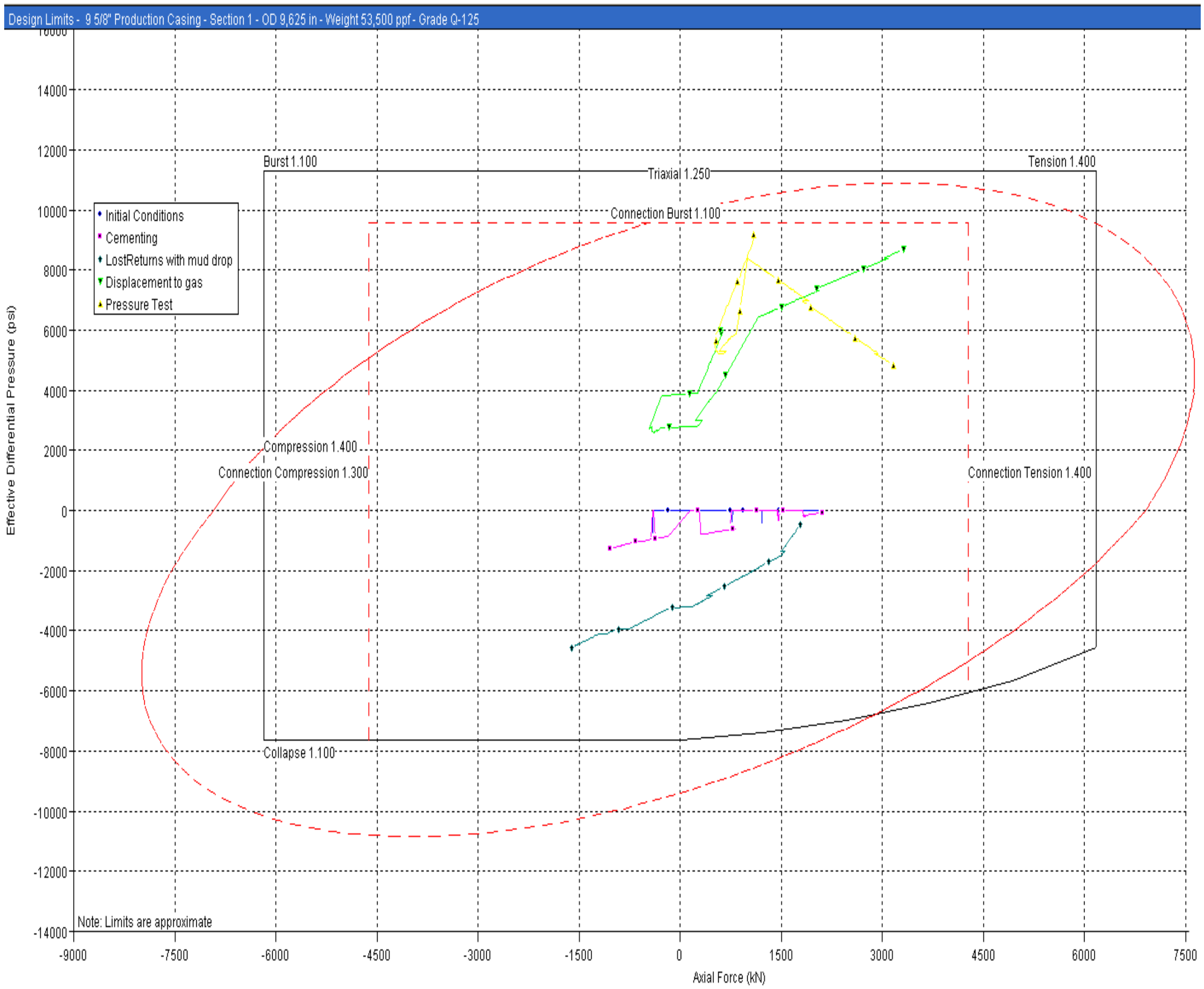


Figure 28. Design limits of 9 5/8” production casing for the Sidetracked Well.

Abbreviations

E&P- Exploration and Production

DIWE- Drilling Integrated Workflow Environment

BHA- Bottom hole assembly

ROP- Rate of penetration

WOB- Weight on bit

NPT- Non-productive time

ECD- Equivalent circulating density

DPC- Drilling performance curve

G&G data – Geological and geophysical data

DS - Drill string

TVD- True vertical depth

TC - Technical sidetrack

DLS - Dogleg severity

PDC bit – Polycrystalline-diamond compact bits

MWD - Measurement while drilling

PDM - Positive Displacement Motor

DC - Drill Collar

RSS - Rotary Steerable System

WOB - Weight on Bit

LCM - Loss Circulation Material

OH- Openhole

UCS - Unconfined Compressive Strength

TOC- Top of Cement

RPM – Revolutions per Minute

KOP- Kick-off point

RIH- Running into the hole

MD- Measured Depth

TVD- True Vertical Depth

WOW-Wait on weather

T&D - Torque and Drag

HSE – Health Safety Environment

ILT - Invisible Loss Time

TOB – Torque on Bit

POOH – Pull out of the hole

DP – Drill Pipe

MWD- Measurement While Drilling

FF – Friction Factor

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