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Abstract

Baker Hughes GE has conducted several hundred whipstock operations over the last years on the NCS with a high success rate. This work will go into detail on some of the operations that were less successful, particularly in terms of where and how the whipstock was set inside the wellbore. One whipstock operation was set with a KOP right in the area of oval casing issues. Hence, five cases with the potential of being analyzed with regards to setting depth of the operation were chosen. The main criterions that have been analyzed are:

- Casing ovality
- Dogleg severity of the wellbore
- Casing eccentricity
- Lithological formation around casing wellbore
- Favorable whipface angle

After analysis of the cases in question, it was found that a casing ovality of 10% at the KOP is detrimental for a whipstock operation, while one case showed 5% and were successful. This shows there to be a cut-off percentage somewhere 5 and 10% ovality when planning a whipstock setting depth. Several whipstock operations had also been set in areas of a DLS in excess of 3 °/30 m, where the chances of compromising the operation is greater.

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List of Abbreviations

WS -	Whipstock
WF -	Whipface
BHA -	Bottom Hole Assembly
USIT -	Ultrasonic Imaging Tool
CLB -	Cement Bond Log
TOC -	Top of Cement
mMD -	Meters Measured Depth
max -	Maximum
NCS -	Norwegian Continental Shelf
FIT -	Formation Integrity Test
WMM -	Watermelon Mill
POOH -	Pull Ouf Of Hole
RIH -	Run in Hole
LHS -	Left Hand Side
RHS -	Right Hand Side
MWD -	Measurement While Drilling

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1. Introduction

1.1. Background

What is a whipstock

A whipstock is a wedge-shaped steel casting with a tapered concave groove down one side to guide the bit into the wall of the hole to start a deflection. There are two basic types of whipstocks: permanent and retrievable. (Mitchell & Miska, 2011) A whipstock is mainly used as a tool to deflect the main wellbore into a different path. There are several reasons for this. One can be to hit a different part of the reservoir, a different altogether, no drilling progress and the need for a redirection before hitting the target due to troublesome formation.

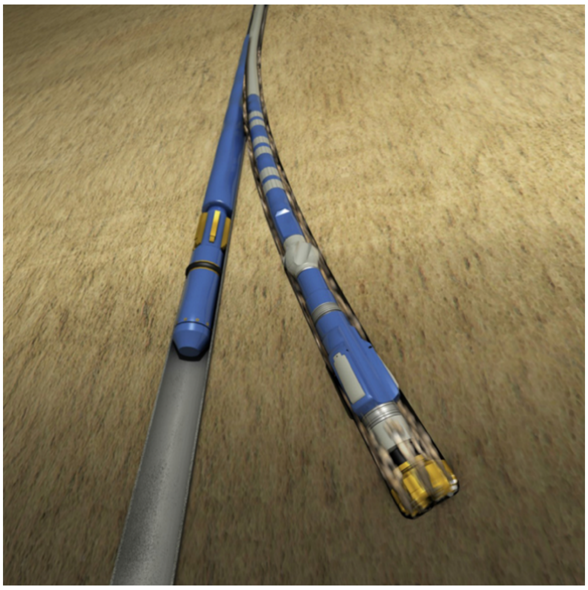


Figure 1: Whipstock Operation for Casing Exit Energy (2017)

Why is optimal setting depth important?

The setting depth of the whipstock is very important in many aspects. It first and foremost is the point of redirection of the wellbore onto a new path, which consequently then acts as the fundament for the new wellbore being drilled. If the whipstock is set in an area of unconsolidated formation it can create major problems when drilling out the rat hole, resulting in formation collapsing. If the casing is set in an area of oval casing, it may primarily experience difficulties setting down the anchor but also create issues when starting to mill the casing due to tension/compression forces in the casing walls. Another problem is that the cement job done in the area is poor and this can cause issues for the milling assembly when milling and drilling the rathole. The current criterion for setting depth of whipstock says as a rule of thumb that the

KOP needs to be sufficiently deep to allow for a contingency sidetrack in the same wellbore in case of primary window failure, but not so deep that the dogleg severity of the deflected borehole becomes an issue.

1.2. Problem Definition

Baker Hughes performs around 60 whipstock jobs per year for several different clients on the Norwegian Continental Shelf. Performing the jobs in one trip is of great focus for Baker Hughes but this has not been possible in some cases due to problems that have been overlooked or not paid enough importance to. One major issue has been mill selection. Due to limited information about the formation around the whipstock setting area, it has been very difficult to choose the mill that will be able to perform the run in one trip. The other problem Baker Hughes has noticed to be an issue is the setting depth and face orientation of the whipstock. In some cases, the whipstock has been set in areas of oval casing, areas of challenging DLS and poor face orientation.

1.3. Aim and Objectives

Optimum setting depth for a whipstock

The aim of the master thesis is to come up with a criterion for where in the wellbore to set the whipstock or where not to set the whipstock. This will be done by evaluating previous whipstock job done by Baker Hughes, look at potential failure mechanisms that may arise during the operation and give a recommendation for how to avoid these issues.

Angle orientation of whipstock with casing collapse/resistance in mind

Casing exit angle should be based on the planned wellpath of the sidetrack to be performed but different considerations must be taken into account depending on the exit angles selected. As a general rule of thumb, an exit is planned between 30 and 60 degrees left or right of highside. Due to the walking tendency of the mill, it is preferable to exit left of highside where gravity will work as a counterforce, creating a better directional behavior in the rathole area. If selecting exit angle outside the recommended, conditions outside the window area need to be considered carefully as it becomes more difficult to control the wellpath during milling and risk of falling back into the old wellbore increases.

Another aspect that is not paid much attention to is the shock loading that the casing will experience when initiating milling. As casing experience loads from the outside from different directions, this may deform casing depending on the severity of the loads that it experiences. Loading will, therefore, be least severe where the casing has the lowest internal radius, i.e. the blue area. Red line indicates this area is more than bit radius, while the blue line indicates less than bit radius. This will be explained further in section 3 - Case Study Analysis.

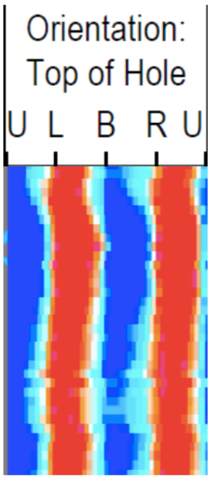


Figure 2: Min/Max internal radius of a casing

One-trip only objective of running whipstocks

The number one priority in all operations that Baker Hughes executes, is safety above all. After safety comes cost-effective and time-saving delivery of the operation. This is accomplished by focusing on the one-trip only principle of running whipstocks.

Anonymity of cases

Due to confidentiality from the service provider of the USIT/CBL log, the cases that will be examined and analyzed in section 3 will be anonymized and given a number instead of the actual wellbore name.

2. Literature Study

2.1. History of whipstocks

In the early days of oil and gas exploration wells were drilled in just one direction, straight down, due to lack in directional drilling technology and lack in understanding and knowledge about petroleum reservoirs. After the development of hole deviation measuring tools, engineers discovered that wells they previously thought to be vertical in fact were in some cases +/- 50° deviated. This was to dips in geological formations, faults, and bedding planes. These geological effects caused the drill bit to be pushed away from its vertical path and onto the direction of the formation.

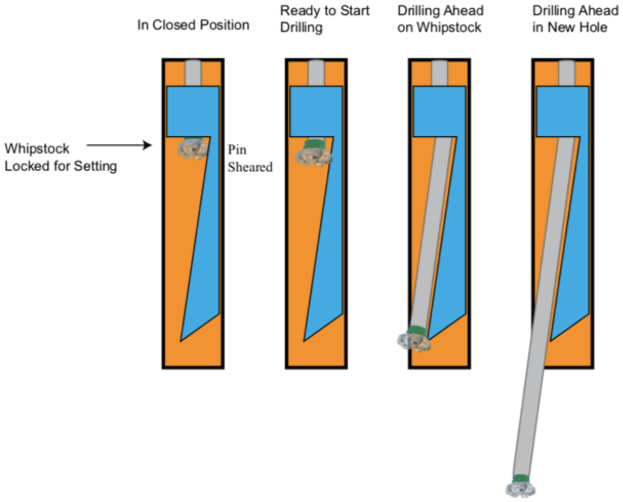


Figure 3: First type of whipstock operation. Devenish et al. (2015)

In the late 1920s, the first purposefully deviated wellbore was drilled using a hardwood wedge. The wedge was dropped downhole in order to push the bit to the side of the wall and change the wellbore direction. The earliest whipstocks used, as we know them today, has records back to the 1930s from wells drilled in Huntington Beach in California. Steel whipstocks were lowered downhole, oriented with the desired whipstock and mechanically anchored to the side of the wall. This technique was used as the main tool for directional drilling from the 1930s to the 1950s when BHA directional drilling tools were being developed. *(Devenish et al., 2015)*

2.2. Types of whipstocks

2.2.1. Pathmaster

The PathMaster whipstock is the shortest whipstock assembly with a face angle of 3 degrees. The systems incorporate a short target trajectory, normally set in hard formations where excess rathole is not desired or because of cost savings as a result of not utilizing as much equipment in the BHA and the time it takes to mill/drill. The short length of the Pathmaker assembly has the capability of passing through a dogleg as high as 15°/30 m and set in wellbores as high as 9 degree DLS sections.

2.2.2. Windowmaster G2

The WindowMaster G2 one-trip window cutting system with the SilverBack window mill or Pathmaker formation mill provides a means to effectively exit casing and create a window through which it is suitable to run a drilling BHA, liners and other completion equipment. This is the whipstock mostly commonly used by Baker Hughes on the NSC. The complete window is normally milled, and a pilot hole is drilled for the subsequent drilling BHA. When it is run with a whipstock packer, and whipstock face orientation is necessary, two additional electric line runs are normally required. The first, to set the packer and the second to ascertain the direction of the orientation key located inside the packer. When run with a bottom trip anchor, only one additional electric line trip is usually required. This is normally an electric line gyro tool run through the drill pipe and into a universal borehole orientation sub located above the milling BHA, with its internal key previously lined up with the whipstock face.

The desired whipstock face orientation, in this case, is obtained by drill pipe manipulation. Also, when using the BHA, if an MWH is available, and a hole angle of 5 ° or greater exists at the KOP, the use of an electric line can be eliminated altogether. This is done by running the MWD in place of the uniform borehole orientation sub, with its tool face previously lined up with the whipstock face. Flow pumped through the MWD will then give whipstock face direction at the surface. In this case, only one drill pipe trip is necessary to run in, orient, anchor in place, mill the window and drill the pilot hole, making it the most desirable method.

2.2.2.1. Features/Benefits

- Unconventional design – It requires only one drill pipe prior to complete the casing exit
- A fixed lug retrieval tool – Allows for whipstock recovery in multiple zone applications

  - Field proven whipstock system – Offers reliability
  - Flexibility in operations – Allows MWD whipstock operation
  - Incorporation of Metal Muncher cutting technology – Ensures cleaner and faster cuts

2.2.2.2. Windowmaster G2 XL

The WindowMaster G2 XL whipstock is used to create ultra-low dogleg windows that produce less drag for accommodating stiffer drilling assemblies and complex completion equipment.

2.3. Whipstock anchoring system

2.3.1. Mechanical set whipstock

A mechanical set whipstock needs a foundation below to be set on. A foundation can consist of cement, a packer or smaller sized casing. The advantage of using a mechanical set whipstock is that the system is simpler than the alternatives and have a lower risk of failure (less than 2% according to Equinor). Mechanical whipstocks are normally less expensive than other whipstock alternatives. The disadvantage of using this type is often the need for an extra run to prepare for setting of the whipstock. Unless previous operations have established a foundation for the whipstock, extra tripping is needed to either set and dress of a cement plug or set a packer as a foundation.

2.3.2. Hydraulic set whipstock

The only difference between mechanical and hydraulic whipstock is the anchoring system. A hydraulic whipstock uses hydraulic pressure to activate the slips segments of the anchoring system. This means that the system can be set at a selected depth inside a casing without the need for a foundation. This functionally can save operational time as less preparation of the wellbore is needed. The main disadvantage of using a hydraulic set whipstock is a higher failure rate. Failure rates are vary depending on who's hydraulic whipstock system is being used but it

Figure 4: Hydraulic set anchor
Bruton et al. *(2014)*

is above 15% according to Equinor data (Based on whipstock operation performed in 2017 and 2018)

2.4. When is whipstock used?

Before steerable drill bit systems were invented, the whipstock was mainly used as a tool to deflect the drill bit onto a non-vertical path in an open hole. As the development of steerable systems progressed, the need for a whipstock to obtain a deviated path minimized and today is almost exclusively used in casing milling for multilateral drilling. Traditionally, sidetracking off of a cement plug has been the industry standard but since success is mainly reliant on the integrity of the cement plug has alternatives such as whipstock technology been applied for secure and successful deviation of the wellbore.

2.5. General procedure of setting whipstock

Procedure from Baker Hughes whipstock procedure programs

2.5.1. Mechanical Whipstock

- Run drift assembly to clean the casing below the KOP

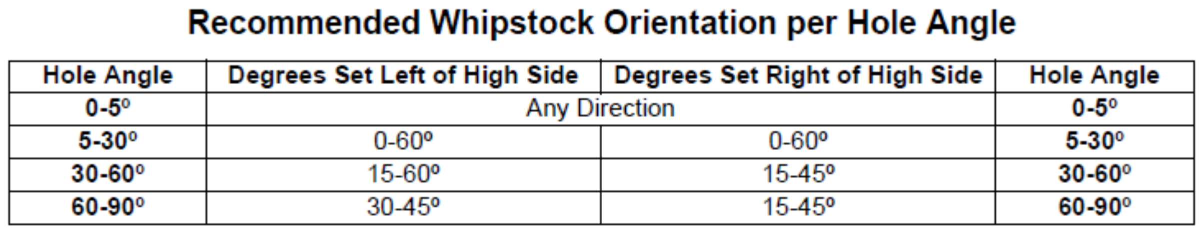
To prepare for a sidetrack, a drift run should be run to reach the setting depth of the whipstock. Drift run thru the casing will thus ensure that the whipstock is able to be run in the hole without encountering restrictions.

- RIH with hydraulic whipstock assembly

After drifting through the wellbore with the cleanout assembly and circulating the well clean, the whipstock may be run. Whipstock is made up and RIH according to Whipstock Running Procedure.

- Orient the whipstock to desired/planned angle

Orienting the whipstock to the correct angle will ensure that the whipstock is "pointed" in the correct direction when the plug/bottom is tagged to set the anchor. Orientation of the whipstock is accomplished by Mud Pulse telemetry from the MWD.



Recommended Whipstock Orientation per Hole Angle

Hole Angle	Degrees Set Left of High Side	Degrees Set Right of High Side	Hole Angle
0-5°	Any Direction		**0-5°**
5-30°	0-60°	0-60°	**5-30°**
30-60°	15-60°	15-45°	**30-60°**
60-90°	30-45°	15-45°	**60-90°**

Table 1: Recommended Whipstock Orientation per Hole Angle

- Set whipstock anchor at desired/planned depth

Depth of plug/tag is noted, and a predetermined weight is set down to Trip Anchor. Workstring is then raised to a predetermined weight above neutral weight. If the anchor does not move upwards, the anchor is set.

- Mill window

As the anchor is set, window mill needs to be released from the whipstock. Shear bolts are sheared using a predetermined force. When freed, milling assembly is P/U a few meters to confirm free rotation. The window is ready to be milled.

2.5.2. Hydraulic Whipstock

The procedure of running a hydraulic whipstock is the same as for a mechanical whipstock, except for how the anchor is set.

- Run drift assembly to clean the casing below the KOP
- RIH with hydraulic whipstock assembly
- Orient the whipstock to desired/planned angle
- Set whipstock anchor at desired/planned depth
- Mill window

2.5.3. Whipstock face orientation

If there has been no indication of preferred face orientation by the operator, and the wellbore at the KOP has more than 5° of inclination, it is recommended that the whipstock is oriented relative to the high side of the wellbore.

2.5.4. KOP position for whipstock

The operator will always have the mindset of whipstock operation being done as deep into the wellbore as possible after tubing and casing below having been cut and POOH. Build or drop sections add stress to BHA and can cause window problems. According to Baker Hughes manuals, KOP should be in sections with less than 3°/30 m.

2.6. Alternative to window milling: Section Milling

An alternative to milling a window using whipstock is milling section. This technique uses under-reamer mills to remove 360 degrees of the casing for a specified length. Sidetracks can, therefore, be kicked off in any direction, and a lower dogleg severity can be achieved. On the other hand, more casing is being milled therefore steel has to be handled so-called swarf. Another downside to section milling is the number of trips it takes to complete a kickoff compared to a one-trip only whipstock milling system.

2.7. Common problems facing whipstocks, NPT issues

The most common problems Baker Hughes has faced regarding whipstock operation, together with mill selection, is shown in the table below:

Table 2 - Whipstock Problems Faced by Baker Hughes GE (2012-2018)

Issue	**Number of cases**
Twist off	3
Faulty WMM	1
Drilling problem post WS operation	4
Stuck while milling	1
Restrictions above KOP	1
Mill selection issue	6
Procedure issue	1
Valve issue	1
WS valve issue	3
Several tight spots in wellbore	1
Oval casing	2
Obstruction at KOP after ended milling	1
EZSV set too high	1
Several WS runs	1
Drop WS issue	1
Faulty Whipstock	1
No progress while milling	2

2.8. Window Mills

As of today, whipstock operations conducted by Baker Hughes on the NCS is generally run with either the Pathmaker Formation mill or SilverBack Window Mill.

2.8.1. Pathmaker Formation Mill

The Pathmaker formation mill provides a one-trip casing exit and can drill extended rathole in tough and abrasive formations such as dolomite, anhydrite, limestone, and sandstone. In the past, some of these formations required two trips to mill the window. These windows can now be cut and extended ratholes drilled in one trip saving time and money. The Pathmaker formation mill is designed to fit both the Pathmaster and the WindowMaster G2 whipstocks.

Figure 5: Pathmaker Formation Mill Baker Hughes (2018)

2.8.1.1. Features/Benefits

- PDC's are capable of milling both steel and formation
- Cuts hard formation casing exits in one trip
- Mills window and capable of drilling an extended rathole in one trip
- Allows for directional drilling to begin immediately after casing exit
- Balanced spiral set cutter arrangement allows for a smoother and cleaner cut
- High set carbide cutters protect PDC's when starting the casing exit
- An aggressive all cutter center design allows for maximum penetration rates in the formation
- Watercourses guide and clean cutter elements

2.8.1.2. Type of formation

The Pathmaker is designed primarily for a medium to hard and/or abrasive formations such as limestone, sandstone, dolomite, and anhydrite. It is also suitable for deep sandy shale and salt, particularly for depths below 3,000 meters. The mill will tend to run more smoothly in harder formations because the rock is strong enough to stabilize it against the whipstock face while milling the window. Soft formations provide less support so much care must be taken while milling the window. Determining the formation properties (composition, compressive strength, etc.) at the proposed kick-off point is key in order to determine the correct application for the Pathmaker mill.

2.8.2. Silverback Window Mill

The SilverBack window mill is designed primarily to cut a window and drill a minimal (2-9 meters) amount of rathole in soft to medium formations. Soft formations provide less support so much care must be taken while milling the window. It is also vital to have knowledge of the formation properties at the proposed KOP in order to determine the correct application and operating parameters for the SilverBack mill.

Figure 6: Silverback Formation Mill BakerHughes (2013)

2.8.2.1. Type of formation

The Silverback Window Mill is primarily designed for milling soft to medium formations such as unconsolidated sands, soft shale and limestone, and clay.

2.8.3. Mill Twist off

Tool twist off is a type of equipment failure which can happen when high values of torque is experienced by a tool. This will lead to a very expensive fishing operation, so a twist off should be avoided by all costs. Another reason why a tool can experience a twist-off downhole is when the drill string is static at a location of high dogleg severity. The bit/mill will, therefore, fatigue on the equipment which eventually will lead to a twist-off.

2.9. Casing Collapse Resistance

Typically, four types of collapse failure:

- Elastic collapse
- Plastic collapse
- Transition/elastoplastic collapse
- Yield collapse

Casing collapse can be defined as the mechanical force capable of deforming a cylinder from the result of an external load. (Asadi *et al.*, 2011)

Conventional collapse design is based upon uniform loads and pressures outside of the casing wall, it only accounts for pore pressure and not the effects from cement, other formation pressures nor eccentric casings. Conventional design does neither take into account the pressure increase that arises from imperfect cement jobs and voids in the formation. Equations that are used to predict casing loads at downhole conditions, assume that pressures are equal in all directions around the casing wall. This is not what takes place in reality. Conventional casing depends on homogenous hydraulic pressure loading at the exterior of the casing. The aftermath of the formation stress and other mechanical properties are overlooked. This is done to simplify casing design, but engineers often experience that the diameter of drilled holes alters over time.

Several factors can contribute to collapse of a casing: wear on casing, wear due to casing buckling, increased external pressure due to temperature, plastic formations, tectonic activity. (Clegg, 1971)

Wear on casing happens when spinning joints are sent downhole and scrape the inside of the casing wall. This is especially problematic in some instances:

- Sections that take a long time to drill, so the drill pipe stays stationary at one point wearing down the casing at that point.
- Points of high dogleg severity. The drill pipe will always touch one side of the casing, hence decreasing the thickness of the wall at that point. This will furthermore decrease the collapse pressure and the pipes mechanical properties.

Plastic formation is another problematic effect that can cause uncertainties for the collapse resistance of a casing. Formations such as salt deposits, shale, and clay, who dispose of some chemical-physical behavior which can be classified as plastic. These formations radially spread pressure on the wellbore, which in severe cases can cause casing to collapse or buckle.

Results from experiments done by Jammer *et al.* (2015) showed that casing that is perfectly cemented increased its collapse strength by 60% and up to 260% in the case of casing-cement-casing. A substantial increment of collapse pressure is only noticeable as long as cement voids are smaller than 90 degrees of the circumference of the outside of the casing. The larger the cement void is, the larger the loss of the enhancement of the collapse strength due to cement bonding.

2.9.1. Bending loads and wear

In high dogleg sections, the casing will experience bending forces depending on the severity. The localized stress on the outer diameter of the pipe can be expressed as:

$$\sigma_b = \frac{ED}{2R} \tag{1}$$

where :
E=Modulus of elasticity (psi), R=curvature radius (in.) and D=outside diameter (in.)

This bending stress can be expressed as an equivalent axial force:

$$F_{bending} = \frac{E\pi}{360} D\left(\frac{\alpha}{L}\right) A_s \tag{2}$$

where

$F_{bending}$ = axial load caused by bending (psi), α/L = dogleg severity (°/100 ft) and A_s= cross-sectional area of the casing (in^2)

The bending load is overlaid on the axial load spread as a local result.

In wells that exceed about 60 degrees of inclinations, casing experiences serious forces from both wear and bending. Casing that is subjected to wear and bending can decrease one of the main purposes of a casing, collapse. A study done by Kuriyama *et al.* (1992) looked at the effect wear and bending has on collapse strength of casing using steel tubes with some internal wear and that was put under bending loads. Experiments showed the relationship between wear ratio of the casing and decrease in collapse strength. This was proven to be almost proportional. The maximum bending loads a casing will be subjected to is at a build section of a well. The higher the dogleg, the higher the bending loads.

Casing ovality can often be experienced at points of high dogleg. Ovality caused by bending is derived from this evaluation:

$$u = \frac{12}{\left(5 + 24\left(\frac{\frac{t}{D}^{2}}{\frac{D}{2R}^{2}}\right)\right)} \tag{3}$$

where R is the bending radius.

Curvature

Curved wells add stress to casing and cause issues if not carefully considered when drilling or completing the wellbore (Byrom, 2015). Curvature can be defined as the change of angle over a certain length which is expressed mathematically as:

$$\kappa = \frac{d\theta}{ds} \tag{4}$$

Where:

κ is the curvature of the wellbore
θ is the angle of the section
S is the length of the curvature along the path

The radius, R, of the curvature can therefore be expressed as follows (subjected to terminology used in the oil-field):

$$R = \frac{1}{\kappa} \tag{5}$$

The bending force subjected to a casing wall from the surroundings is extremely hard to calculate and predict due loads being not only in a single plane but multiple.

Effect of couplings on Bending stress

The greatest stress experienced by a casing joint is near the couplings, unless eccentric pipe and it is touching the wellbore wall. This is only valid in cases of poor cement jobs and casing run without stabilizers.

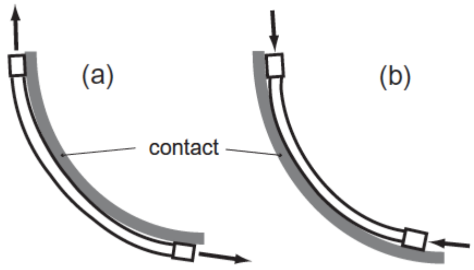


Figure 7: Effect of bending loads in tension and compression Byrom (2015)

2.9.2. Dogleg severity

Dogleg severity is defined as the rate at which a wellbore alters its inclination, both to a higher and lower value. Monitoring the dogleg severity is very important due to the problems that could arise as a result of this parameter being too extensive, most importantly being tool passage. High dogleg severity can also affect the collapse strength of the casing if it is subjected to non-uniform loads at the point of the dogleg being the most critical.

Micro-dogleg is also a downhole effect worth considering. These are natural occurrences in any well and it can explain why we experience high torque at some places where we do not expect to see an increment in torque. This can happen in both drilling through a new formation but also reentering an existing wellbore. As normal surveys measure once every stand (every 30 meters roughly), this only gives us an indication of how the well path looks (Mills *et al.*, 2016).

2.9.3. Poor Cementing

Most common reasons for voids behind the casing wall are due to poor cementation, specifically cement not reacting well with local formation, and possible cavings or craters. Simulations done by Berger *et al.* (2004), shows that the max Von Mises experienced by voids is at 60 degrees. After the critical angle of 60 degrees, the pipe will start to experience more uniform loads again leading to a decrease in Von Mises.

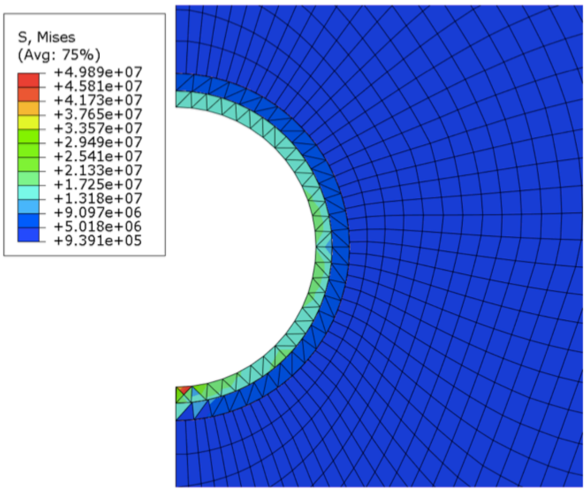


Figure 8: Model one showing a good cement job
Berger et al. *(2004)*

A study was done by (Hemmatian *et al.*, 2014) where two models were compared: one for bad and one for good cement and then looked at the effects it had on casing damage. A good cement sheet (Figure 8) was shown to protect the casing wall against extreme forces caused by the formation. The Von Mises stresses were evenly distributed across the casing wall and the cement sheet absorbed the excessive forces induced by the formation and preventing any damage done to the casing wall.

The second model (Figure 9) simulated the stress distribution across the casing wall in case of voids in the cement sheet. As a cause of poor cementation, non-uniform load could arise and damage and buckle the casing. The simulation revealed that due to the weakness in the cement bond, the Von Mises dramatically increased compared to the first model.

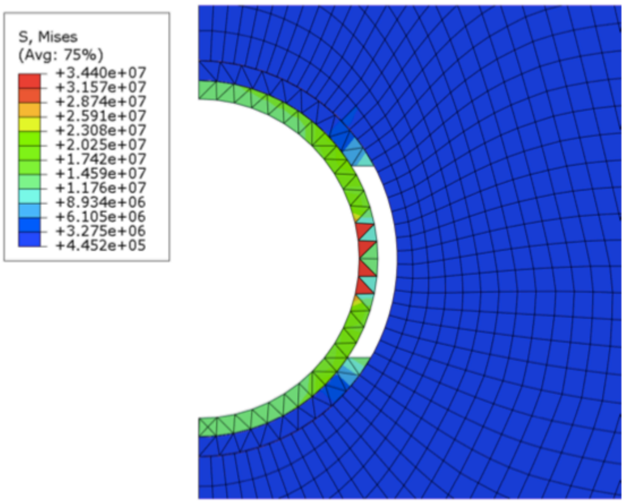


Figure 9: Model two showing a void in the cement sheet Berger et al. *(2004)*

Casing also undergoes substantial displacement in the location of the removed cement sheet. The displacement does not differ too much from the value in model one, but the difference is that good cement job in model one protects the casing against the force from the non-uniform loads while the poor cement job in model two does not sufficiently protect the casing against damage.

2.9.4. Effect of Eccentricity

Casing eccentricity is explained as the degree of which the pip is off-center in the wellbore. Eccentricity is normally expressed as a percentage, 0% being perfectly centered and 100% being completely off-center (Figure 10)

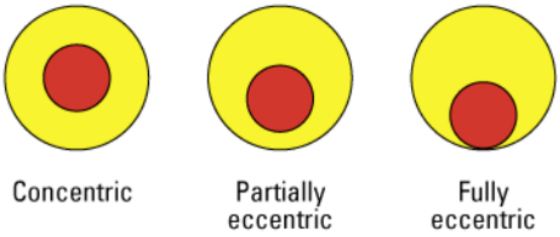


Figure 10: Concentric casing/Eccentric casing (Schlumberger Oilfield Glossary)

Basic engineering calculations are based on a concentric annulus, but this is not what we see in reality. This can lead to misguided or inaccurate conclusions about loads acting on the casing downhole (Akgun *et al.*, 2004). It is usually assumed that the casing eccentricity has a negligible effect on the casing collapse resistance. However, Berger *et al.* (2004) and Shen (2011) shows that the effect of eccentricity is sensitive to the cement mechanical properties and can be as high as 10%. Guohuaa W. *et al.* (2012) shows that in the case of non-uniform loading on the casing, the effect of eccentricity is intensified, and the risk of casing collapse is significantly increased. Formulas for eccentricity can be expressed as:

$$e = 2\,(r_w - r_c) \tag{6}$$

$$STO = 1 - e \tag{7}$$

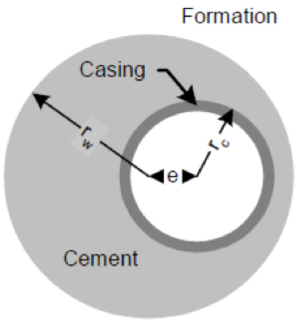


Figure 11: Stand-off - Casing Eccentricity Berger et al. *(2004)*

In case of a perfect cement job, decrease in casing collapse resistance is of very little concern considering casing eccentricity. Relative eccentric azimuth is the angle of horizontal projection in relation to north direction, turning clockwise (Figure 12)

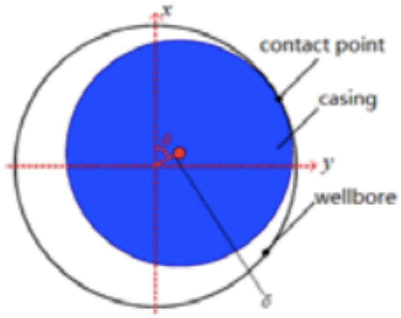


Figure 12: Eccentric Azimuth Guohuaa W. et al. *(2012)*

General relationship between the stratum principal stress and tectonic features says that the maximum horizontal stress direction is roughly 45° (Between 135 and 315 degrees with regards to north as the reference point).

According to a study done by Guohuaa W. *et al.* (2012), it was proved that it does not matter what the casing relative eccentric azimuth is, the direction of the maximum stress is constant. The larger the off-center distance for the casing, the more the stress fluctuates in the inner wall of the casing, hence larger maximum stress on the inner wall of the casing.

2.9.5. Non-uniform and combined external loads

A non-uniform load is defined as a load that is unevenly distributed across a given surface. A non-uniform load that acts on a casing wall can originate due to several different causes.

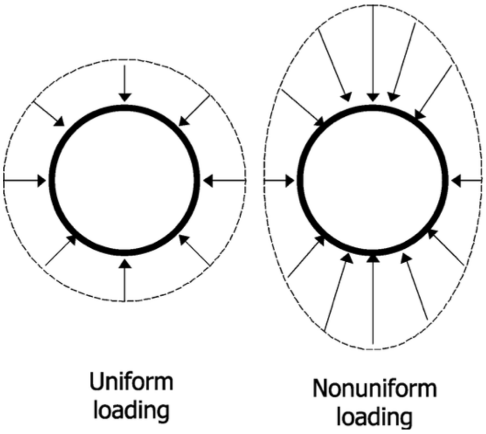


Figure 13: Uniform and nonuniform loading (Willson et al., 2002)

Radial deformation under uniform load is about one-tenth of that of the deformation caused by non-uniform loads. Studies found that combining non-uniform and uniform loads on a casing wall meant a loss in its collapse resistance, comparing it to only non-uniform loads exerted externally. On the contrary, radial deformation is shown to decrease when exposed to both non-uniform and uniform loads, reducing the chances of tools getting stuck inside. Enlarging the thickness of the casing wall was proven to counteract a non-uniform load better than to raise the steel grade of the casing (El-Sayed, 1995).

The collapse resistance of API casing exposed to non-uniform loads is lower than that for uniform pressure. The reduction ranges from 72.6% to 88.7% depending on the D/t ratio.

Moreover, the radial deformation could increase to the point where it causes a restriction in the casing *(El-Sayed, 1995)*

Non-uniform loads resulting from formation movement causing ovalization of the casing can result in major operational problems. On the other hand, deformation of a casing caused by formation is defined by the rate at which the load from the rock/formation acts on the walls of the casing. Given that this effect takes place over a long period of time, it can take years before it becomes an operational issue such as tool passage. This is true as long as there is no additional collapse mechanism acting on the casing wall as for example a fluid pressure differential. In this case, it does not lead to undesirable deformity of the casing cross-sectional, but it may decrease the collapse resistance of the cross-section to furthermore conventional loads (Pattillo *et al.*, 2004).

2.9.6. Effect of Voids and Cement channels

Presence of cement voids behind the casing wall can reduce the collapse resistance of the casing of up to 60%, depending on the circumferential spread of the void. Cement channels can decrease the casing collapse resistance with up to 60%, the same as the effect as voids have on casing collapse strength.

2.10. Cement Bond Log

When performing a wireline log run, several different types of downhole parameters are being gathered to create a clear picture of how the wellbore looks. One rather important parameter that is being logged during such a trip is the bonding of the cement between the outer casing wall and formation. This log is called a CBL, cement bond log (Figure 19). This log creates a clear picture of the success of a cement job. In a perfect world, the cement bonds well with the formation and casing wall all the way from the shoe until the TOC. This is not the case in most cement jobs due to several downhole effects. Eccentric pipe, drilling mud mixing with the cement, cement not reacting well with certain types of formation and small gas pockets in the formation can be a few reasons why CBL detects poor bonding between casing and formation.

2.11. Geomechanical Properties of Formation

Casing is affected differently depending on what type of geological environment it is set in. For instance, if a casing is run through a salt formation, we would expect to see large deformations effects on the casing wall which can end up being detrimental for operations to be conducted.

When rocks are under stress from the surroundings it reacts in three different ways:

(1) Deformation: depending on the elastic properties of the rock type
(2) Failure: depending on the strength properties of the rock type
(3) Changes in measurable physical properties

(1) and (2) can be categorized at the geomechanical response to stress while (3) goes under the geophysical response.

Stress can be defined as the combined effect of all naturally occurring stresses occurring over a given area (overburden stress, pore pressure, tectonic pressure, and if relevant, any artificially induced stresses such as fluid pressure, external loads, etc. (Schön, 2015)

2.11.1. Deformation Properties

The properties of deformation in Figure 15 has been derived from a static compression laboratory test. Young’s modulus is defined as the stiffness of a solid material, measuring the relationship between the stress and strain which can be represented on a Young’s modulus graph (Van der Pluijm, 2004). From this graph, we can pinpoint the materials plastic deformation strength, the ultimate tensile strength, and fracture point. Young’s modulus can be defined as:

$$E(\sigma) = \Delta\sigma/\Delta\varepsilon \qquad (8)$$

Figure 15 and Figure 14 (Johnson & DeGraff, 1988) represents the spread of values normally seen in different rock types for static Young’s modulus and Poisson’s ratio.

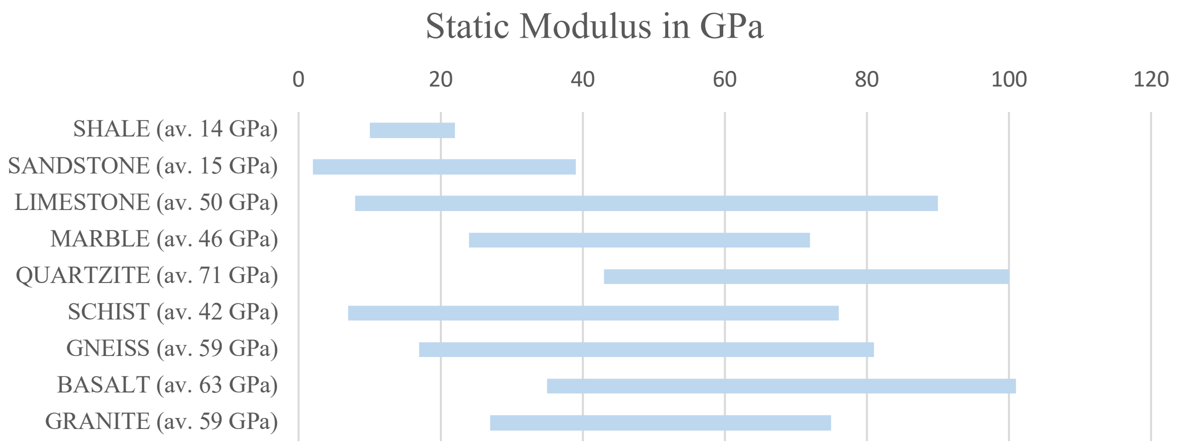


Figure 15: Static Modulus in GPa for a range of formation types

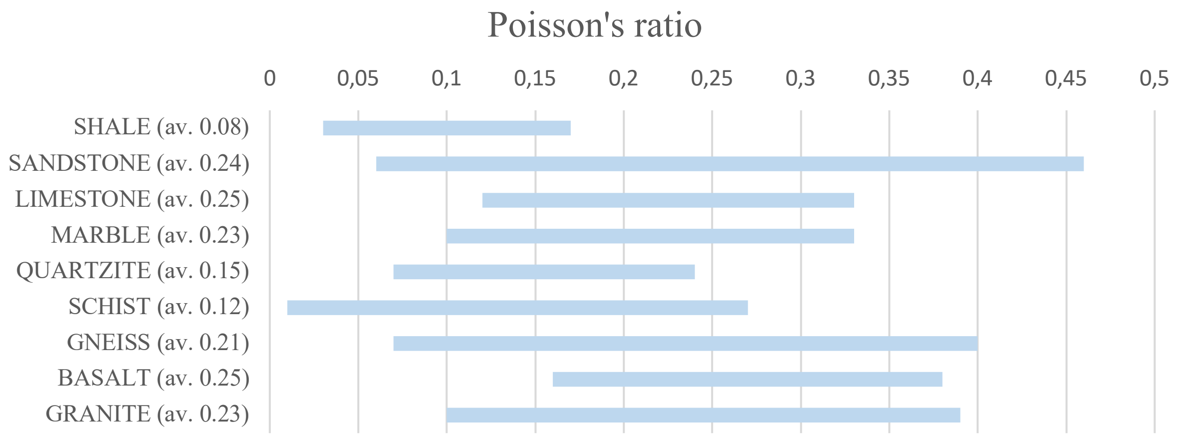


Figure 14: Poisson's ratio for a range of formation types

2.11.2. Failure and Strength Properties

The ultimate strength of a rock defines the amount of stress applied. The type of stress can be compressive, shear, or tensile (Schön, 2015). The failure criterion most frequently used is called the Mohrs Coulomb failure criterion and is defined by the given equation:

$$\tau = c + tan\varphi \cdot \sigma_n \tag{9}$$

τ: shear stress

c: cohesion of the material

φ: angle of internal friction

σ_n: normal stress

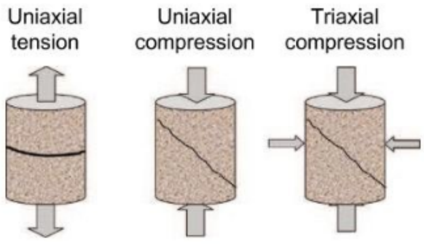


Figure 16: The three modes of a failure test (Schön, 2015)

Table 3 - Uniaxial Compression Strength for Rock types

Rock	**Uniaxial Compression Strength in MPa**
Granite	100-250
Quartzite	290-300
Sandstone	35-150
Shale	2-250
Limestone	90-120
Dolomite	40-350
Rock salt	40-350

(Fjaer *et al.*, 2008), (Rzhewski & Novik, 1978)

2.11.3. Mobile formation

One of the most problematic formations to encounter with respect to casing collapse resistance is a salt formation. This is due to its mobile tendencies. Predictions made by a model developed by SPR (Strategic Petroleum Reserve) and WIPP (Waste Isolation Pilot Program) suggested that the chances of a cemented borehole experiencing unequal deformation is very small. Very small and insignificant ovalization of the casing might occur. (Willson *et al.*, 2002)

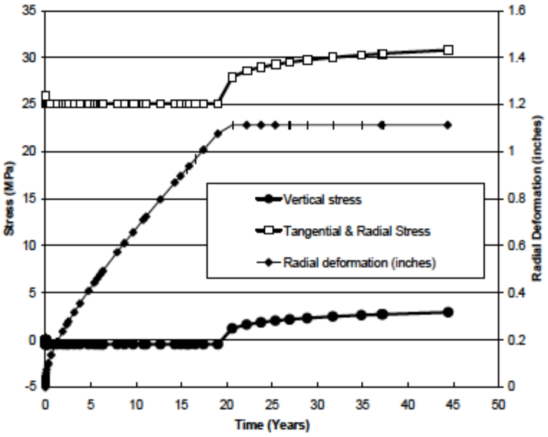


Figure 17: Radial Borehole closure & Stresses Induced in the Casing (Willson et al.*, 2002)*

A severe case of salt mobility will occur in case of a non-circular borehole (i.e. poor cementing, voids). Since the closure rate of the formation not being uniform, a non-uniform loading will impact the casing wall over a certain period of time. As can be seen from Figure 17, radial deformation increases at a steady rate deforming the casing wall.

2.12. Atlas of log responses

The Atlas of Log Responses chart is a formation evaluation chart that has been developed by Baker Hughes to be able to identify the formation that is being drilled using MWD tools located at the BHA. In some cases, it will also be used to identify formation outside a cased hole. In this situation, the gamma-ray chart will be used to identify the type of lithology around the whipstock KOP.

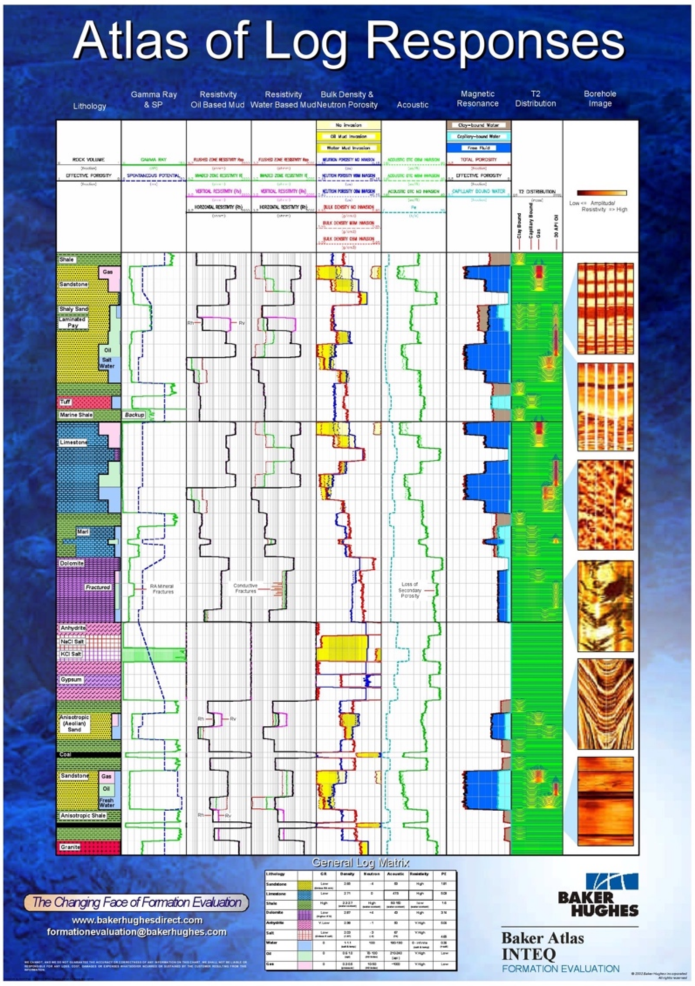


*Figure 18: Atlas of Log Responses by Baker Hughes (*INTEQ, 2002)

3. Case Study Analysis

In this section, a selection of whipstock job that had problems relating to the setting of whipstock anchor and the jobs that had issues with milling through the casing will be analyzed. Since Baker Hughes performs around 60 whipstock jobs each year, I have chosen to focus on 5 cases that have the most potential for a thorough analysis. Not all the wellbores that will be analyzed had previously conducted a USIT CBL log, which can create some difficulties interpreting root causes.

Due to confidentiality, none of the USIT/CBL logs will be included in the case study analysis and all the wellbores will be given a number from 1 to 5.

3.1. Example of a USIT/CBL

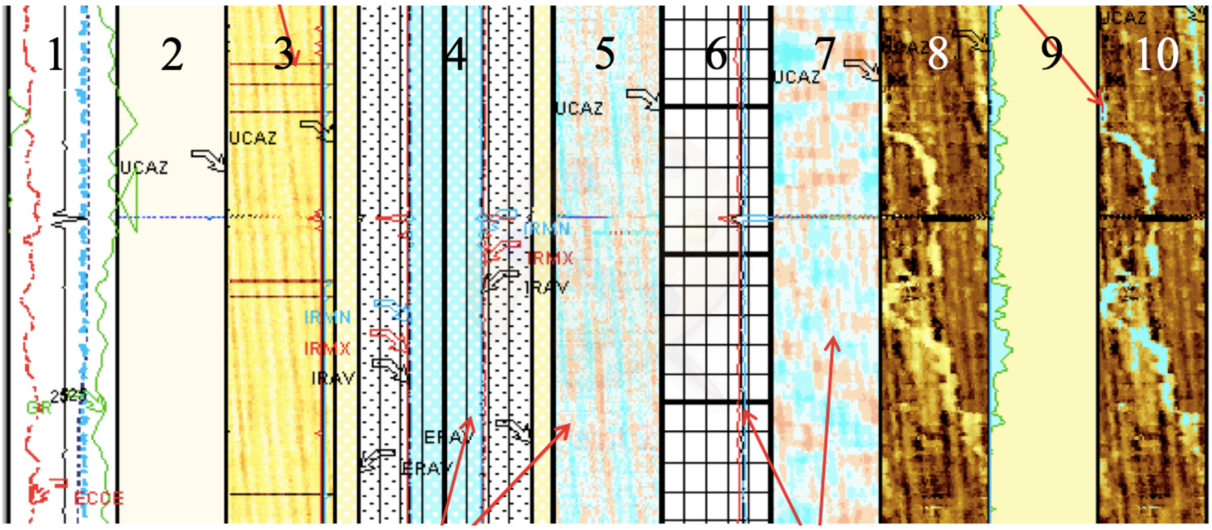


Figure 19: Example of a USIT CBL by Schlumberger (Abouganem, 2014)

1. Eccentricity, CCL, and gamma ray
2. Processing flags
3. Amplitude
4. Casing cross section
5. Internal radius image
6. Thickness image
7. Cement raw
8. Bond index
9. Cement interpreted

As well as the internal radius image log, the specific logs that have been looked at included a log of internal radius, minimum and maximum values. The logs of most importance and interest are 1, 5, 8 and 9.

Log 1 is used to determine where the casing collars are located, the eccentricity of the wellbore and determine the gamma-ray value of the formation outside the wellbore casing. Log 5 says something about the ovality of the casing with determining the minimum internal radius and maximum internal radius. Log 8 determines the extent of the bond between the formation and the casing wall, and the state of the cement job that has been done. Log 9 interprets the information from log 7 and 8 and creates an image to show where the potential voids are in the cement sheet. (*Kyi & Wang, 2015)*

3.2. Case 1

A G2 XL hydraulic whipstock was planned to be set at 1,515.3 meters, but during the first run experienced issues when setting down the anchor. Several runs were performed to successfully be able to mill the desired casing window. High levels of torque were experienced 2 meters above the initial setting depth which could indicate deformation or ovalization of the casing. In total 4 runs were done before the whipstock was successfully set.

3.2.1. Log interpretation

3.2.1.1. Cement quality

Both cement bond and casing condition reports state that the annular status for the depth interval in question, 1,470-1,500 mMD, is “Well bonded, heterogeneous, cement around the entire annulus.”

3.2.1.2. Casing deformation

Despite condition report stating a good cement job, the USIT cement bond log showed increased casing ovalization for the depth interval of 1,490-1,497 mMD. Due to different elastic properties of cement and casing, the cement bonding and quality is reduced with increasing casing deformation (max reduction where the casing radius is reduced).

Areas of debatable cement bond quality might be small and negligible for well integrity evaluation, but significant for casing collapse resistance evaluation. A worst-case interpretation at the depth of 1,492 and 1,498 mMD gives angular widths of 150 degrees for possible voids without cement bonding. Internal radius measurements from the USIT log show an ovalization of around 2-4.5% for the depth interval of 1,490-1,500 MMD (+ some uncertainties).

Max ovalization for a 13 3/8” 72#

$$\%\ ovalization = \left(\frac{311.15mm + 13.06mm}{311.15mm} - 1\right) * 100 = 4.2\%$$

Considering the max ovalization for a 12.25” drift diameter is 4% within API Spec for a 13 3/8”, at the point of max casing ovalization there is roughly a 15% reduction in collapse resistance. If we apply the estimated horizontal geomechanical stresses, Aadnøy and Kårstad (2010) show that the maximum expected ovalization can be up to 8-10%.

3.2.1.3. Shock loading

Whipstock face was oriented 48 degrees left of high side, and milling started at around 1,495.8 mMD. USIT CBL log shows that at this depth the maximum stress is concentrated between 30 and 120 degrees on left side.

The USIT log showed that whipstock orientation was unfavorable for milling. As milling progress and the casing wall is reduced, casing collapse resistance is being significantly reduced. When the casing is penetrated, the pressure overbalance is lost if there are voids where the mud hydraulic pressure can invade. A worst-case interpretation can assume that there is a hydraulic connection over the depth interval of 1,490-1,500 mMD. Transient deformation is also significantly more likely when milling through a point of maximum stress concentration compared to when milling at minimum stress concentration.

3.2.2. Geological formation

Interpretations from the gamma-ray log Figure 20 indicates that the formation outside the casing wall at the KOP 1,500 mMD is shaly sands.

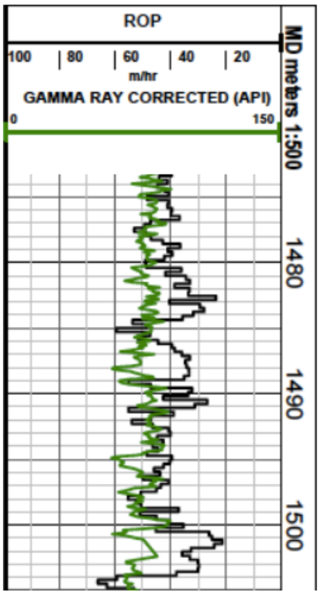


Figure 20: Gamma-ray log - Case 1

3.3. Case 2

A G2 XL Hydraulic whipstock was planned to set at 1,364.1 mMD. The anchor was set without problem and started milling. During milling, erratic torque was experienced and after reaching the formation no progress was made. Several polish runs were made and changed the mill from Pathmaker to Silverback, but still no progress. After POOH and RIH, it was not possible to reenter the milled window.

3.3.1. Log interpretation

3.3.1.1. Cement quality

As we can tell from the USIT CBL log provided, there is no bonding between the cement and casing. Cement bond log report states that the formation bond is low and no barrier quality. Due to the inclination of the wellbore, the formation has some bonding on the low side of the annulus.

3.3.1.2. Casing deformation

The USIT CBL log shows no indications of any casing deformation happening in the area where the whipstock has been set. The casing experiences uniform loads as the critical angle for cement voids are measured to be more than 60°. The casing is very concentric throughout the whipstock setting area and it can be assumed to not cause any issues.

3.3.1.3. Shock loading

The whipstock face was oriented 51° left of highside. This angle shows to be at the most favorable angle in the casing at that point. Even if it had been milled at the most unfavorable position it would have been considered as a negligible issue due to the minimal ovality of the casing.

3.3.2. Geological formation

At the KOP of the whipstock, the formation can be interpreted to be shale/clay. As we move down, we notice that the gamma-ray encounters spikes at 1,381, 1,391 and 1,398 mMD which can indicate flickers of shaly sands.

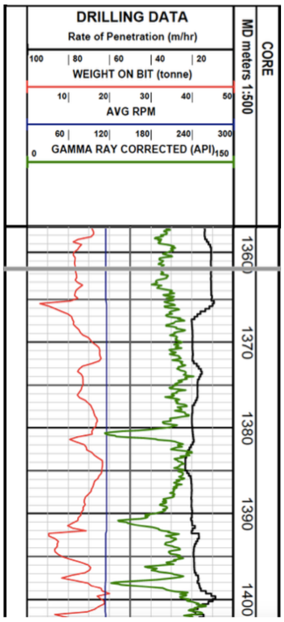


Figure 21: Gamma-ray log - Case 2

3.4. Case 3

Case 3 was set with a G2 XL Hydraulic whipstock. The planned depth of KOP was set at 1,429.4 mMD. The whipstock was successfully set at the desired depth and milled 1.8 meters when the operation experienced problems. When POOH it was noticed that the window mill had been twisted off. A second hydraulic whipstock was decided to be set.

3.4.1. Log interpretation

3.4.1.1. Cement quality

The wellbore in question does not include a report about the quality of the cement job but it can clearly be seen from the USIT log that the cement outside the casing at the point of where the whipstock has been set is poor due to the intrusion of a large pocket of fluid.

3.4.1.2. Casing deformation

The CBL USIT log shows indications of ovalization of the casing of the interval of 1,430-1,440 mMD. As stated earlier, when cement voids outside the casing exceed 60° of the outside wall the pipe will lose its initial collapse resistance. When going beyond 60° it will experience normal uniform loads again. This is consistent with what we see from the USIT CBL log. The most amount of ovalization is seen at depths where the voids are less than the critical angle. Internal radius measurements from the USIT log can prove an ovalization of 1-2.5% for the depth interval of 1,430-1,440m MD. Going back to 3.2.1.2, it was shown that the maximum ovalization for a 13 3/8” with drift diameter 12 ¼” was about 4%. If we then apply the horizontal geomechanical stresses, maximum expected ovalization can be up to 4-5%.

3.4.1.3. Shock loading

The whipstock was oriented with an angle of 31° to the right of high side and started milling at around 1,430 m. 1.8 meters was milled before having to end the milling process. USIT log shows milling was stared in a favorable position that should not lead to any serious issues regarding whipface angle.

3.4.2. Directional Drilling survey

As we can see from the directional data provided in Figure 22, the whipstock was set in an area of noticeable dogleg severity. This issue is hard to solve for this particular wellbore, because of high values of dogleg severity throughout the whole wellpath (Figure 23). The window mill was eventually twisted off, which can be contributed to high dogleg.

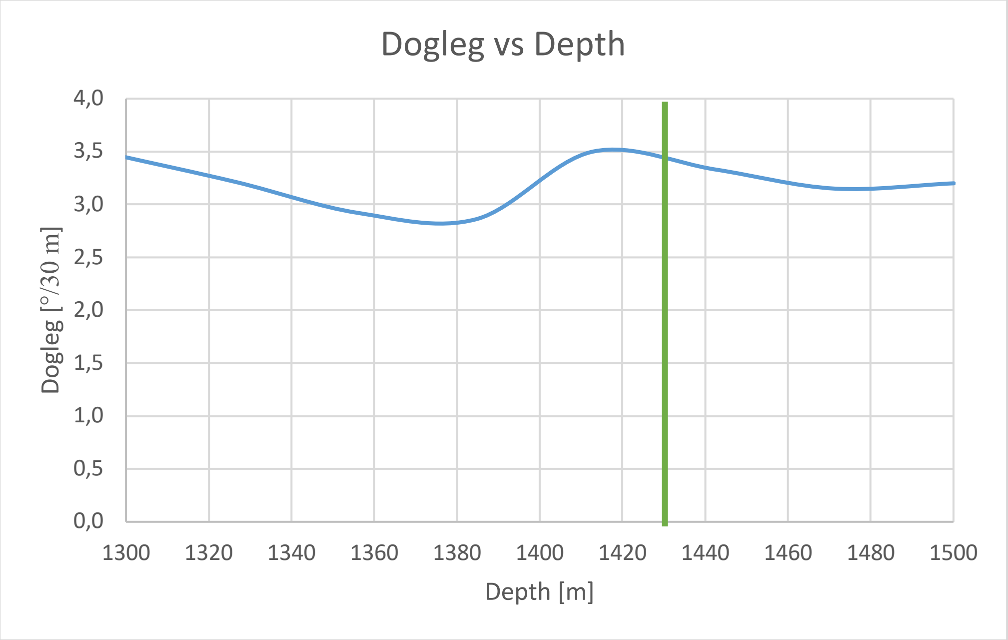


Figure 22: Directional data 1300-1500mMD - Case 3

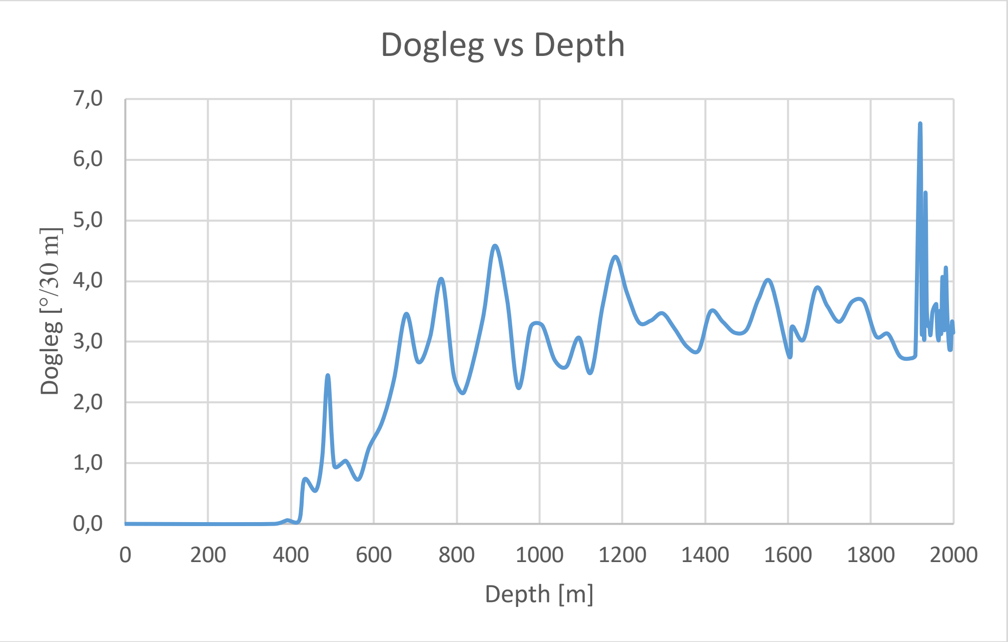


Figure 23: Directional data for entire wellbore - Case 3

3.4.3. Geological formation

Interpretations from the gamma-ray log indicate that the formation outside the casing wall is a sandstone formation with potential shales.

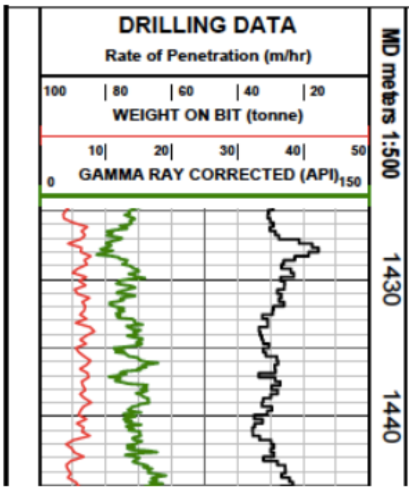


Figure 24: Gamma ray log - Case 3

3.5. Case 4

Whipstock anchor was activated and set at 1,035 mMD and milling commenced at 1,023 mMD. Reached a depth of 1,034 mMD when it was decided to POOH due to extremely slow progress. RIH to polish the milling window and experienced erratic torque at 1,033 mMD. After hours of minimal progress, Silverback mill was changed to a rock bit. Reached TD at 1,045 mMD after several tight spots. When trying to polish window it was not possible to reenter the milled window, took approximately 20 tons at 1,033 mMD. After several attempts, total depth was eventually reached, and FIT was performed.

3.5.1. Log Interpretation

Due to there not existing a CBL/USIT log for case 4, it makes it hard to interpret any casing deformation that might have occurred and the quality of the cement outside the casing.

3.5.1.1. Cement quality

No report about the quality of the cement outside the casing is available or ever been performed.

3.5.2. Directional Drilling Survey

As can be noticed from the directional data provided in Figure 25, the whipstock setting depth was chosen to be at the exact point of highest DLS of the entire wellbore (Figure 26). This is at a very unfavorable position as the KOP could have been changed ever so slightly to a lower DLS to avoid incidents that are more likely to occur above a 3°/30 m dogleg.

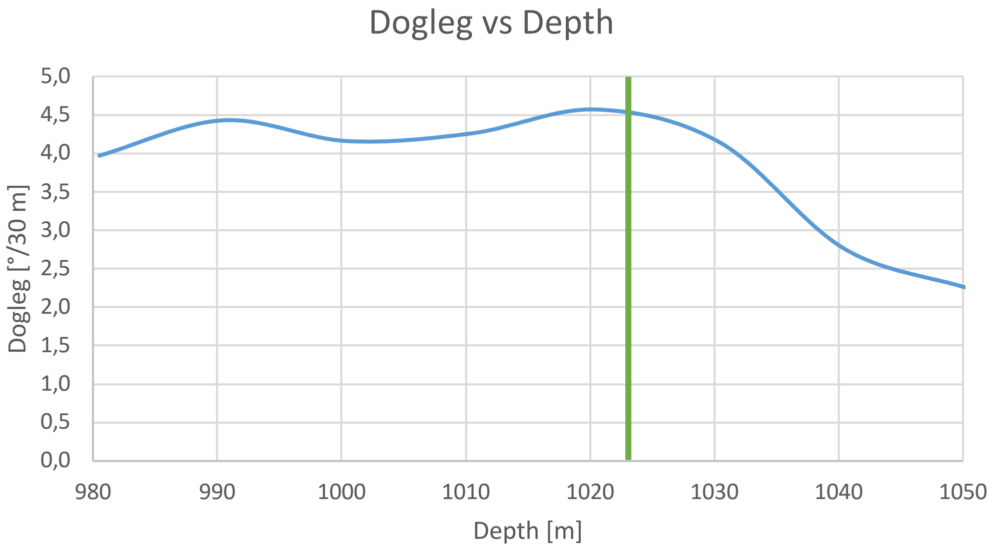


Figure 25: Directional data 980-1050mMD - Case 4

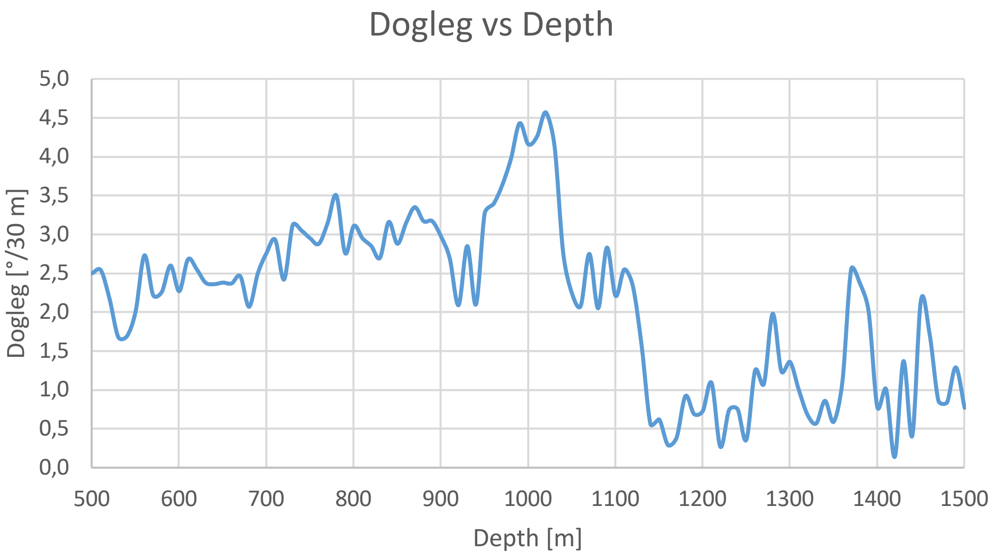


Figure 26: Directional data 500-1500mMD - Case 4

3.5.3. Geological formation

The only information available on what type of formation around the setting area comes from the activity program provided by the operator. The KOP was set in Top Hordaland and correlating this information to nearby wellbores, it can be estimated that it was set in an area of shaly sands.

3.6. Case 5

Was not able to engage anchor initial KOP at 2,338 mMD, the whipstock did not hold weight and kept sliding down. Due to some restrictions in the wellbore, whipstock was sheared off and left in the hole. Second whipstock run was set at 2,327 mMD and the string got stuck. After several attempts, the string was freed and estimated top of the new whipstock to be set at 2,303 mMD. A third mechanical whipstock was decided to be run and set on an EZSV at 2,300 mMD. The anchor was confirmed and set. Whipface at 39 degrees LHS. Continued milled without any issues.

3.6.1. Log Interpretation

3.6.1.1. Cement quality

According to the CBL status report, the annular status of the KOP is settled mud solids and patchy bonded.

3.6.1.2. Casing deformation

From the USIT CBL we can tell that the casing is slightly oval in the whole section 2,325-2,350 mMD. Having inspected the entire USIT CBL report, it is clear that case 5 generally has deformation issues throughout the whole wellbore, which together with the oval sections of the KOP could have led to the reasons of stuck pipe in the second whipstock run. The ovalization of Case 5 shows much of the same as in Case 3, with the USIT log showing about 1-2.5% ovalization in the depth of 2,325-2,340 mMD. Applying the horizontal geometrical stress, maximum expected ovalization can potentially be up to 4%

3.6.2. Directional Drilling Survey

The whipstock setting area of Case 5 is almost identical to the setting area of Case 4. Having been set in the exact area of maximum DLS (excess of 4°/30 m), this is the point at which the whipstock BHA and casing will experience the maximum amount of bending forces and potential wear issues relating to the inside of the casing wall.

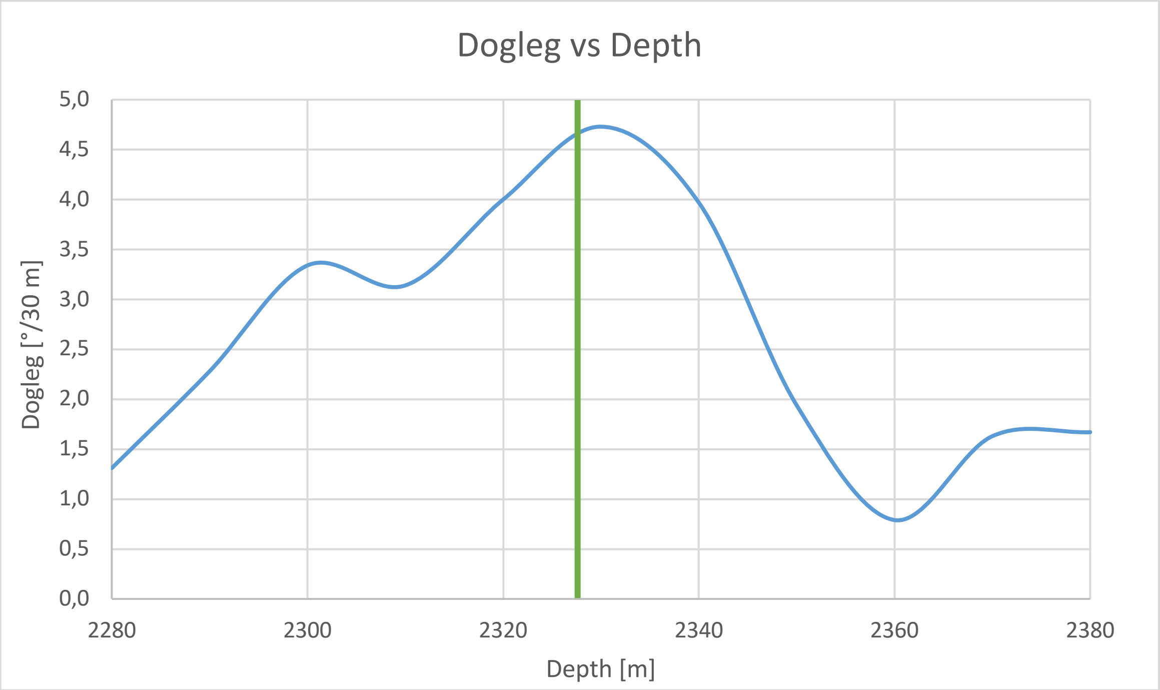


Figure 28:Directional data 2280-2380mMD - Case 5

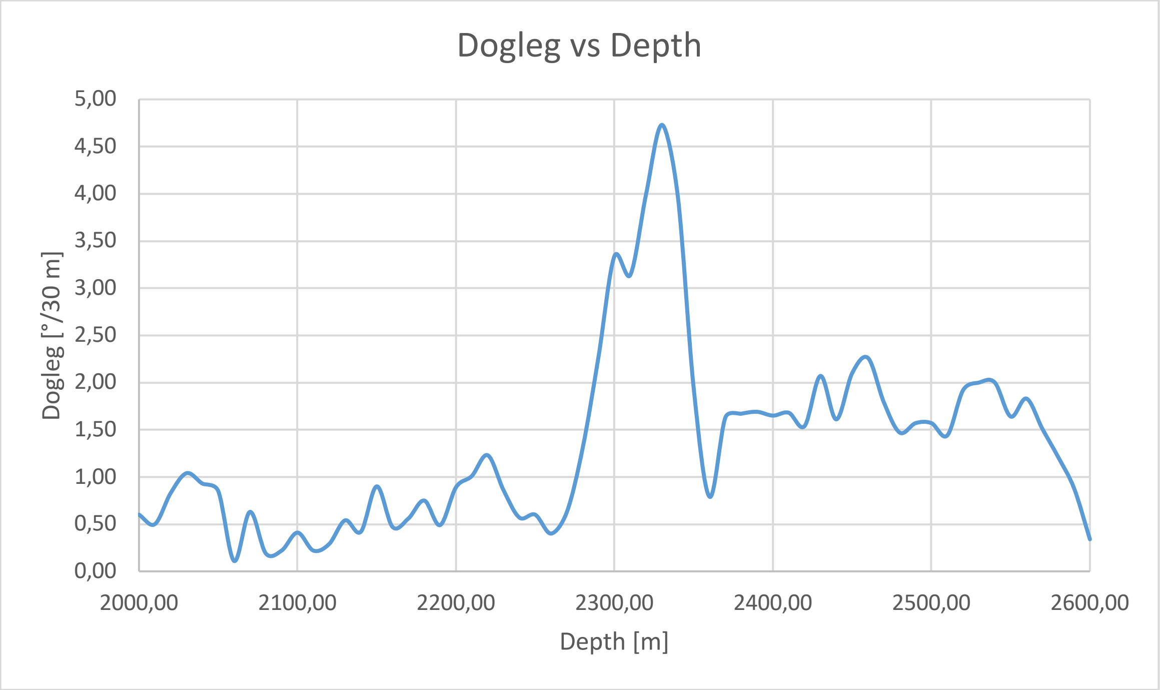


Figure 27: Directional data 2000-2600mMD - Case 5

3.6.3. Geological formation

No MWD documents from drilling the initial wellbore were found so the gamma ray tool used on the USTI CBL log run had to be used to gather information about the formation outside the casing wall. Comparing with the Atlas of Log Responses, this can be said to be a shaly sand.

4. Discussion

Having gone into detail on several of the whipstock jobs of interest done by Baker Hughes that had the potential of the initial plan of analysis, it was shown that very few jobs had issues similar to Case 1 where the ovalization was prominent. Table 2 in 2.7 shows all the potential cases that were under consideration for analysis.

Out of the 30 potential whipstock operations that could have been analyzed, the five cases where chosen based these predetermined criteria's:

- Ovality of casing
- Dogleg severity
- Eccentricity of casing
- Type of formation around the casing
- Favorable WF angle

Case	**Ovality**	**Eccentricity**	**High DLS**	**Favorable WF angle**
1	Yes	Minimal	No	No
2	No	No	No	Yes
3	Yes	No	Yes	Yes
4	NO INFO	NO INFO	Yes	NO INFO
5	Yes	Minimal	Yes	Yes

Table 4: Case Summary

Directional data seems to be paid little importance to when planning for a whipstock operation. Baker Hughes operational procedures state that whipstock operations should be conducted in areas of a DLS of less than 3°/30 m unless otherwise stated. Analysis done on case 3, 4 and 5 shows that all experience problems when set in an area of DLS being 3.5, 4.5 and 4.5 respectively. Twist off becomes a problem in one while the two others experience problems when reentering the milled window. Due to the troubles of stuck while milling, in some of the cases where the whipstock has been set in an unfavorable dogleg, there is a risk of being stuck for a long period of time and trying to get loose. This will wear down the casing at other points in the wellbore of high DLS as well as the BHA and mill experiencing high values of fatigue.

Casing ovalization

Case	Maximum Ovality
1	8-10%
3	4-5%
5	4%

Table 5: Casing ovalization - Case Summary

The ovalization in Case 1 can partially be contributed to the voids in the cement sheet that is shown on the USIT log, while Case 3 and Case 5 are both set in an area of a high DLS. The whipstock in Case 3 is also set in an area of poor cement outside the casing wall thus non-uniform loads being more prominent than the other cases.

Geological formation

Case	Lithology
1	Shaly sand
2	Shale/clay
3	Sandstone
4	Shaly sand
5	Shaly sand

Table 6: Geological formation - Case Summary

None of the cases seems to be set in any challenging lithologies, such as the likes of mobile formations. The NCS does consist of some areas of potentially movable formations but not in any of the cases analyzed.

5. Conclusion and Recommendations

→ Case 1 shows that is was milled in the least favorable direction and hence failed to perform a successful whipstock operation. This was not the situation in the other cases.

→ While Case 1 can have an ovalization of up to 10% and the operation ending up being unsuccessful, Case 3 and 5 had less ovalization (up to 4-5%). It is hard to conclude the cut-off percentage where the whipstock operation is in jeopardy of being unsuccessful, but 10% shows to be detrimental while 5% being challenging.

→ USIT log analysis for ovality of casing and eccentricity of well bore.

→ Directional data survey has to be considered.

→ More extensive work needs to be done regarding the geological formation around the wellbore casing with respect how much damage it does to the outside of the casing.

While conducting the case analysis at the Baker Hughes GE offices, it was discovered that it was extremely time-consuming digging up and looking for old wellbore documents through the internal document system. This is an aspect that should be looked at as this is particularly time-consuming for engineers planning future operations, which consequently costs the company money.

Recommendations

It has been difficult to reach any solid recommendations for Baker Hughes GE for future operations on the NCS, but the following should be considered:

→ Maximum ovality should be less than 10% for a successful whipstock operation.

→ Chances of ovality increases as DLS increases, so areas of more than 3°/30 m should be carefully considered and analyzed before given the go-ahead.

→ Lithological interference on casing resistance has to be considered on a case-by-case basis. It is recommended to make a note of the petrophysical properties and behaviors of the formation outside the casing wall.

6. References

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7. Appendix

A. API Specification 5CT - Specification for casing and tubing

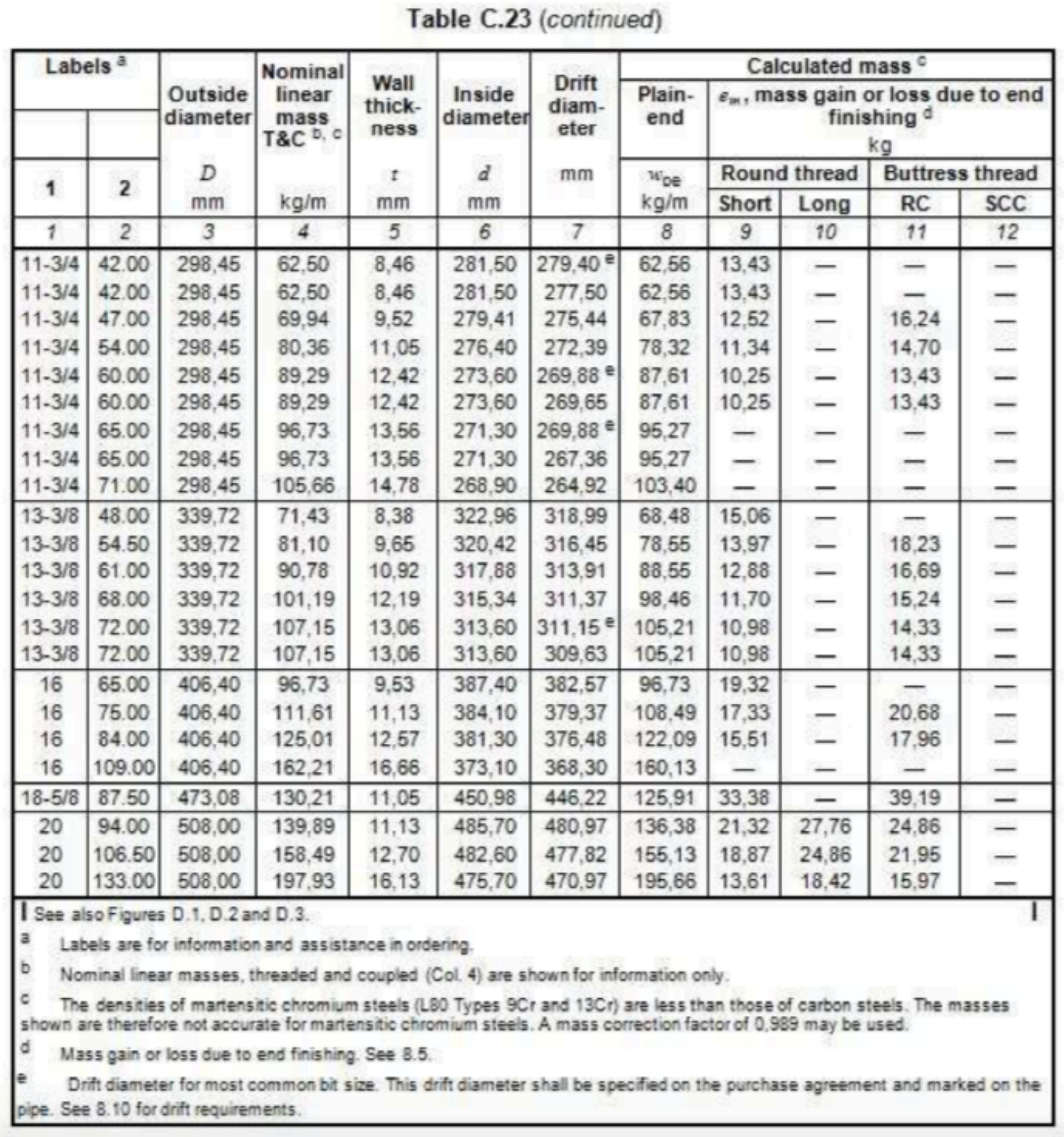

Table C.23 (*continued*)

Labels [a]		Outside diameter	Nominal linear mass T&C [b, c]	Wall thickness	Inside diameter	Drift diameter	Calculated mass [c]				
							Plain-end	e_m, mass gain or loss due to end finishing [d] kg			
1	2	D mm	kg/m	t mm	d mm	mm	w_{pe} kg/m	Round thread		Buttress thread	
								Short	Long	RC	SCC
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
11-3/4	42.00	298,45	62,50	8,46	281,50	279,40 [e]	62,56	13,43	—	—	—
11-3/4	42.00	298,45	62,50	8,46	281,50	277,50	62,56	13,43	—	—	—
11-3/4	47.00	298,45	69,94	9,52	279,41	275,44	67,83	12,52	—	16,24	—
11-3/4	54.00	298,45	80,36	11,05	276,40	272,39	78,32	11,34	—	14,70	—
11-3/4	60.00	298,45	89,29	12,42	273,60	269,88 [e]	87,61	10,25	—	13,43	—
11-3/4	60.00	298,45	89,29	12,42	273,60	269,65	87,61	10,25	—	13,43	—
11-3/4	65.00	298,45	96,73	13,56	271,30	269,88 [e]	95,27	—	—	—	—
11-3/4	65.00	298,45	96,73	13,56	271,30	267,36	95,27	—	—	—	—
11-3/4	71.00	298,45	105,66	14,78	268,90	264,92	103,40	—	—	—	—
13-3/8	48.00	339,72	71,43	8,38	322,96	318,99	68,48	15,06	—	—	—
13-3/8	54.50	339,72	81,10	9,65	320,42	316,45	78,55	13,97	—	18,23	—
13-3/8	61.00	339,72	90,78	10,92	317,88	313,91	88,55	12,88	—	16,69	—
13-3/8	68.00	339,72	101,19	12,19	315,34	311,37	98,46	11,70	—	15,24	—
13-3/8	72.00	339,72	107,15	13,06	313,60	311,15 [e]	105,21	10,98	—	14,33	—
13-3/8	72.00	339,72	107,15	13,06	313,60	309,63	105,21	10,98	—	14,33	—
16	65.00	406,40	96,73	9,53	387,40	382,57	96,73	19,32	—	—	—
16	75.00	406,40	111,61	11,13	384,10	379,37	108,49	17,33	—	20,68	—
16	84.00	406,40	125,01	12,57	381,30	376,48	122,09	15,51	—	17,96	—
16	109.00	406,40	162,21	16,66	373,10	368,30	160,13	—	—	—	—
18-5/8	87.50	473,08	130,21	11,05	450,98	446,22	125,91	33,38	—	39,19	—
20	94.00	508,00	139,89	11,13	485,70	480,97	136,38	21,32	27,76	24,86	—
20	106.50	508,00	158,49	12,70	482,60	477,82	155,13	18,87	24,86	21,95	—
20	133.00	508,00	197,93	16,13	475,70	470,97	195,66	13,61	18,42	15,97	—

See also Figures D.1, D.2 and D.3.

[a] Labels are for information and assistance in ordering.

[b] Nominal linear masses, threaded and coupled (Col. 4) are shown for information only.

[c] The densities of martensitic chromium steels (L80 Types 9Cr and 13Cr) are less than those of carbon steels. The masses shown are therefore not accurate for martensitic chromium steels. A mass correction factor of 0,989 may be used.

[d] Mass gain or loss due to end finishing. See 8.5.

[e] Drift diameter for most common bit size. This drift diameter shall be specified on the purchase agreement and marked on the pipe. See 8.10 for drift requirements.