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Successful Use of Directional Casing While Drilling

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Abstract

This paper provides technical feedback of a successful use of Directional Casing While Drilling (D-CwD), a technique allowing to simultaneously drill and case the hole while following the directional plan. It highlights how substantial gains were realized on Badamyar project in Myanmar, having benefited from the D-CwD technique to optimize the architecture.

The Badamyar development campaign involved the drilling of four horizontal gas wells in conventional offshore environment in Myanmar. Other regional wells had already experienced wellbore issues to get the 13 3/8″ casing vertically to 450m. On Badamyar, drilling directly with the casing allowed to minimize operational exposure to losses and wellbore instability, and to achieve the challenge to get the 13 3/8″ to 800m and 45deg inclination, avoiding the requirement for an additional surface casing.

All four 13 3/8" sections were successfully directionally casing-drilled and cemented in fourteen days within budget duration, which, despite the additional complexity, is comparable to the best performance in the block in the last twenty years. The average Rate of Penetration was 30 m/hr, same as fastest conventional case in the field, without mentioning the huge advantage that when reaching the required depth, the casing is already in the hole. Indeed, once the casing has reached the required depth, drill pipe is run inside the casing to unlatch and recover the directional BHA, and pull it back to surface, leaving the casing in place ready for the cement job. While conventionally, casing still needs to be run with associated time and risks (losses, wellbore stability, stuck casing, accidental side-track, etc…).

This Directional-CwD was a new concept to most of the teams involved: Operator, Rig contractor and Tubular Running Services. It required changing the "hundred and thirty years of conventional drill-pipe drilling" mindset. This paper describes the decision making process to switch from conventional to casing-drilling, the preparation phase where risks were identified and mitigated, as well as the excellent operational results.

This paper, by presenting a successful first implementation within a major O&G company, brings to the drilling industry an additional case that the system works, is technically fit-for purpose, cost effective, and has the tremendous potential to replace conventional drilling in several applications. It also highlights some potential limits and opportunities for optimization which should be considered for further development (trajectory constraints, fatigue life and well control).

Introduction

Badamyar Drilling Campaign (Nov. 2016 to Feb. 2017) involved drilling and completion of four horizontal wells on Badamyar gas field on M6 block, in Andaman Sea, Myanmar, from PVD-1 Jack-up rig and new WP4 platform, at 40m water depth.

The Badamyar well architecture was similar to offset Yadana wells (20″ CP Driven, 13 3/8″ casing, 9 5/8″ casing set inside targeted reservoir and 8 ½″ reservoir section) except that the 13 3/8″ had to be set much deeper and at much higher inclination instead of shallow and vertical. The primary objective of the 13 3/8" section was to set the 13 3/8" casing directly at 800mTVD (45deg inclination) without an additional section in the architecture (i.e. to avoid a contingent 16" Liner). The secondary objective of this section was to improve the drilling performance compared to previous drilling campaigns.

Directional Casing While Drilling was identified as a technical solution to meet the above objectives. This technique, which was introduced quite recently in the drilling industry as shown on below table [Table 1], adds directional control to the casing drilling concept, turning any deviated well into a potential candidate for this application and associated benefits.

Table 1—History of Drilling Techniques

1859	First oil well drilled (Cable-tool technique). First use of casing to protect the hole from collapse
1880s	Conventional “Rotary” drilling with Kelly
1980s	Horizontal drilling
1990s	Non-retrievable Casing While Drilling (Vertical)
2002	Directional Casing While Drilling (Retrievable BHA)

This paper highlights the main implementation steps of D-CwD on Badamyar Drilling campaign, by giving a glance of the technical concept, equipment and expected benefits, and detailing the operational results, concerns and performance.

Context & Concept

Looking for an alternative drilling solution

The exact same architecture of the offset wells of Yadana field (13 3/8" casing at 450m depth, vertical) was not suitable for Badamyar development campaign, where it was required to deepen the 13 3/8" casing for two reasons. First, the 13 3/8″ casing point had to be deep enough to allow at least 4m3 kick margin for drilling the next long 12 ¼″ section through Badamyar gas reservoir layers. It was also preferred to reduce the 12 ¼″ open hole length by covering more formation with the 13 3/8″ casing.

However, the deeper the 13 3/8" casing the higher the operational risk: as soon as the well deviates from vertical, mud weight should be raised for wellbore stability, which limits the possibility to use seawater, and can also induce severe losses as observed on offset wells just below 20" CP shoe, in very soft sandy shales formation. This dilemma could have been addressed by planning for an additional section in the architecture: a contingent 16″ Liner between the 20″ CP and the 13 3/8″ casing, in order to cover the losses zones below the CP shoe and to be able to raise mud weight to ensure 13 3/8″ section wellbore stability. However, such a contingent architecture would have heavily impacted the campaign budget.

Directional CwD was identified at an early stage of the campaign preparation as an alternative drilling solution to bring the 13 3/8" casing to 800mTVD depth and 45deg inclination, allowing to use seawater and reduce the risks induced by losses and wellbore instability. As presented in this paper, this technique allowed to plan and realize the well with no contingent section [Figure 1].

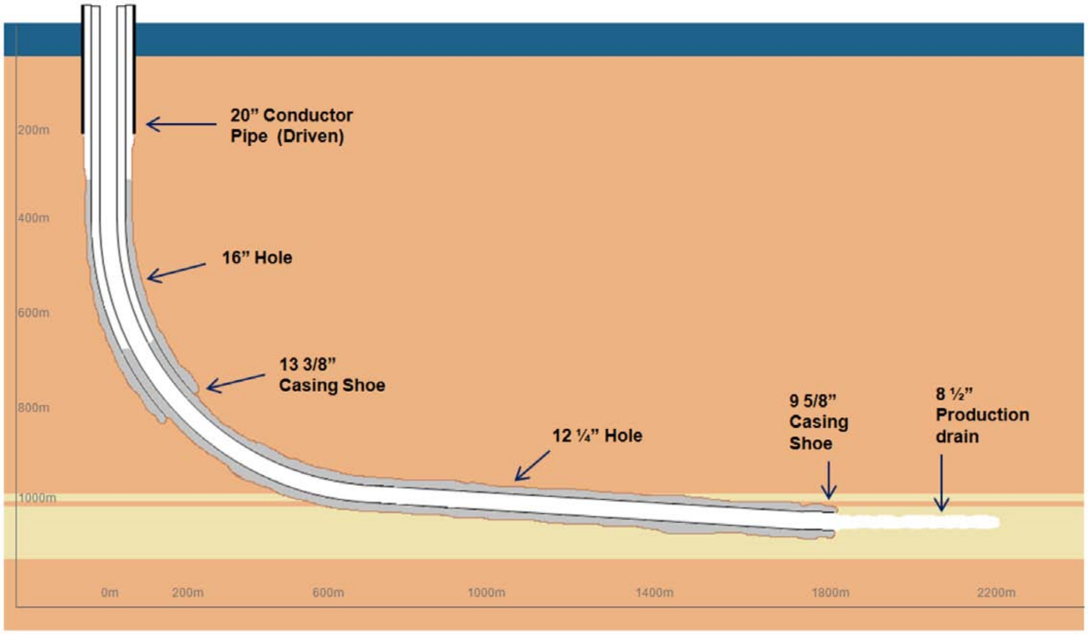


Figure 1—Badamyar well architecture

Principle of D-CwD

Directional Casing While Drilling allows simultaneous drilling and casing of the well, using directly the casing in place of drill pipes to run a directional BHA. Once the BHA run on casing joints has drilled to the required depth, drill pipe is run inside the casing to unlatch and recover the entire BHA back to surface, while leaving the casing in place ready for the cement job [Figure 2].

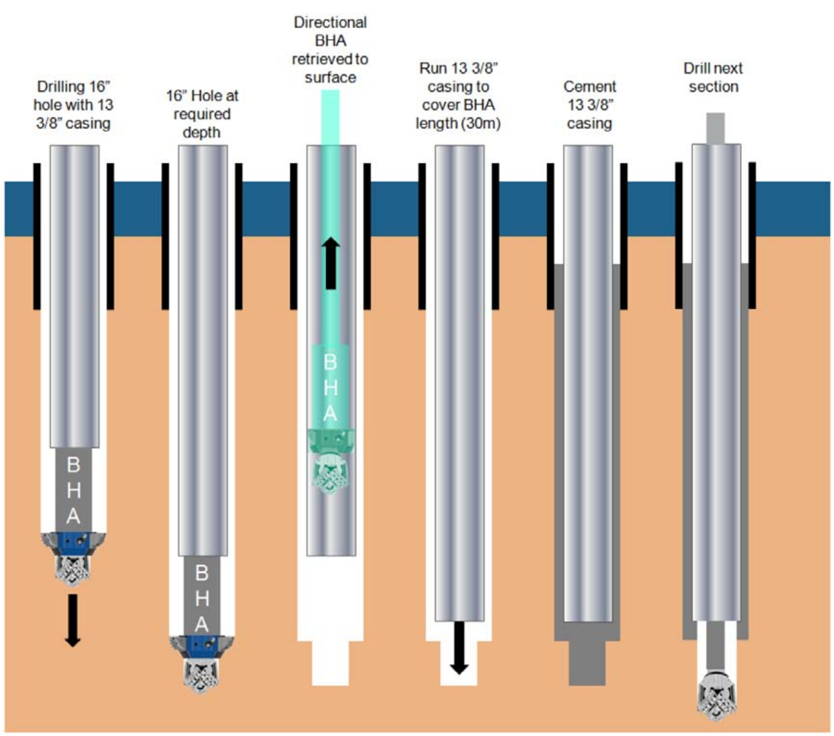


Figure 2—Directional Casing While Drilling – General sequence of operations

The retrievable BHA is made of the same components as in conventional drilling, allowing full directional control and logging data acquisition [Figure 3].

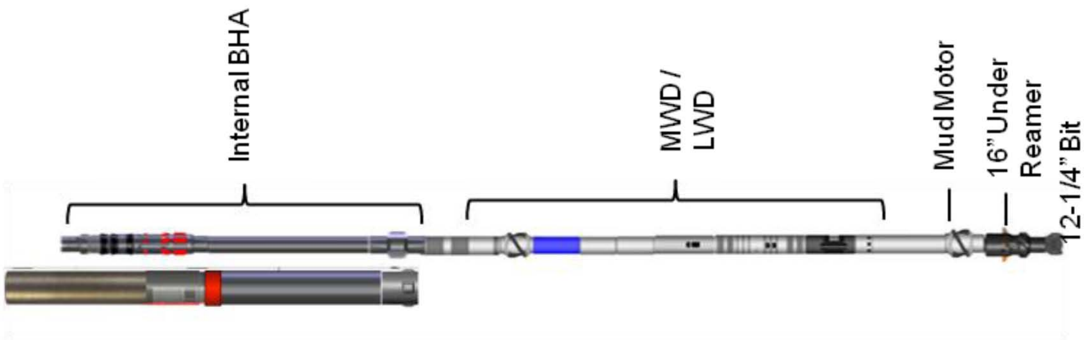


Figure 3—Directional Casing While Drilling – Internal and External BHA

Switching from Conventional to Directional Casing While Drilling

Part of the feasibility study was to conduct a detailed review of previous regional experience with Directional Casing Drilling. The most similar case in terms of architecture was the ANGSI field development (Petronas, Malaysia, 2012). In 2016, this D-CwD technology had records of more than a hundred Directional casing drilling jobs in Malaysia, with inclination up to 82deg and measured depth up to 1680mMD. These cases showed that despite being recent, this D-CwD technology was field proven.

The second driver in the decision making process to switch from conventional drilling to Directional Casing While Drilling was the expected benefits, as summarized below.

Hole Cleaning. Thanks to the bigger Outer Diameter of the casing versus conventional Drill Pipe in the same hole size, the annular velocity is much higher with CwD, leading to significant improvements in hole cleaning compared to conventional drilling. In shallow sections or top holes, typically drilled in 17 ½″ or 16″, the annular velocity in conventional drilling mode is commonly less than 40m/min (not sufficient to optimize hole cleaning), as a result of low flowrate usually restricted to avoid wash-out of soft formation at the bit and big annular volume.

Losses. While in conventional drilling it is a good practice to cure the losses in preparation for casing run, the casing drilling technique is less impacted by losses as the casing is already on bottom ready for cement job.

Drilling Fluid. For CwD, the simplest drilling fluid (sea water and high-vis sweeps, with dumped returns) was selected for two main reasons. With clays naturally dispersing in sea-water, the fluid circulated out of the well is in fact comparable to bentonitic mud, with a measured density of 1.08sg-1.12sg. This contributes to wellbore stability in similar conditions as a closed-loop mud system would do. In addition, the use of sea-water allows to dump the returns immediately after shakers, which is perfectly adapted to the high on-bottom ROP of casing drilling technique.

Time Gain. With Casing While Drilling, there is no wiper trip and no casing run, as the casing is already on bottom when reaching TD. However in D-CwD one trip with drill pipe must be counted to recover the BHA. The operational results presented in this paper will highlight the actual benefit compared to conventional drilling.

Well architecture. A contingent section is usually planned in case of expected wellbore instability or losses. Directional CwD can mitigates risks of wellbore instability and losses, and can eliminate the need to have a contingency section. In this case, the contingency section was indeed cancelled at project preparation phase.

The architecture was relying on using the Directional Casing While Drilling as base case. As contingency, a possibility to shorten the wells had been agreed with Geoscience department.

On Badamyar, the decision to use Directional Casing While Drilling was taken considering also there was no major risk involved: no well control issue which could have been more difficult to face compared to conventional drilling. A shallow hazard study confirmed there was no presence of hydrocarbon reservoir along the 13 3/8" section trajectories.

Teams, roles, interfaces

On this project Directional Casing While Drilling was a first for most of the teams involved in the operations. Prior to operation, several meetings and reviews were lead by the operator to ensure all equipment and procedures would interface properly between all concerned parties. The main roles and interfaces specific to this technology are summarized hereunder.

The Directional CwD company provides the downhole tools specific to this technique: a mechanism that locks the directional BHA to the casing shoe, a running tool able to unlock the BHA and retrieve it to surface with drill pipe once TD is reached, and a pump down plug which seats and locks inside the shoe track after pumping cement in order to prevent backflow, acting as a substitute to conventional float at the end of the cement job. The Directional CwD engineer and field specialists provides all technical expertise relevant for D-CwD design and operations: fatigue and torque simulations, operational program and risk assessment, recommended casing drilling parameters, and Dog Leg Severity limitation.

The Rig Contractor's equipment directly involved in this D-CwD is the Top Drive System (TDS), providing rotation, reciprocation and circulation to the casing string. The Saver Sub placed between the TDS and the Casing Running Tool (CRT) needed to be changed out to re-set it to run drill pipe to recover BHA, impacting the timing by 2.5hours. This was highlighted as an opportunity for optimization for future casing drilling projects. Regarding personnel, the Driller remains in charge of applying the drilling parameters requested by the Directional Driller.

The Bottom Hole Assembly (BHA) is supplied by the DD/MWD company. Although the DD/MWD and D-CwD are not necessary from the same company, the interface between both is key. The Directional Driller is specifically in charge of the directional control and adapts the parameters and sliding ratio to follow the trajectory, while the Casing Driller follows in real-time the actual fatigue and torque values against simulations.

In order to transmit rotation, circulation and reciprocation to the casing string, a Casing Running Tool links the TDS to the casing string. This CRT (model FA-1-14 used on Badamyar), supplied by the Tubular Running Services company, was selected to ensure it was fit for purpose for this application in terms of RPM, continuous torque, hoisting capacity, flowrate and pressure.

The Casing Drilling company and Cementing Services company worked in close relation to design the cement job. The initial recommendation from the Casing Drilling company was to use rigid rotating centralizers (Hydroform 15.25" OD – "crimped" on the 13 3/8" casing) and to limit their number to seven, as it was the maximum number of centralizers ever used for 13 3/8" directional casing while drilling. But this set-up was not giving satisfactory stand-off, with risk of having annulus not fully cemented as shown on the simulation from the Cementing company. Therefore it was decided to increase the number of centralizers to twenty and their OD to 15.75" [Figure 4].

On Badamyar (16" casing drilling), the actual hole size was estimated to be overgauged to 18.5" – 21". Cement job analysis showed the cement placement is acceptable and Cement Bond Log (CBL) done on the most overgaged well showed good cement barrier.

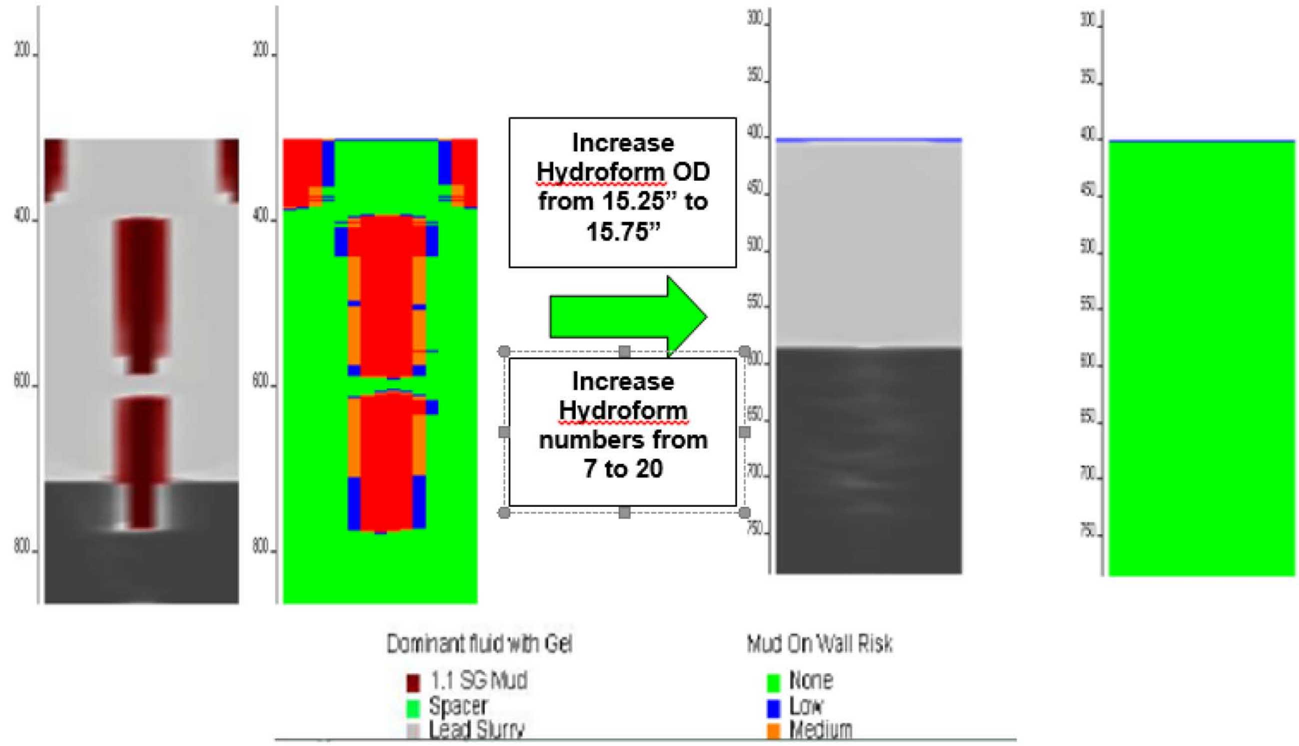


Figure 4—Optimization of 13 3/8″ casing centralization design with Hydroform centralizers. The simulated cement placement and quality is much improved by increasing the centralizer OD to 15.75″ and the number of centralizers to twenty.

The Casing Supplier and casing connection were selected to ensure the fatigue damage incurred by rotating the casing string would not reach the fatigue life. In practice, it means that the Casing Supplier was requested and able to provide consistent fatigue life figures, based on real fatigue tests.

Last but not least, the WellHead (WH) manufacturer was involved in the preparation, as the current WH design does not allow to install wear bushing for CwD (this could be engineered for future projects). A risk assessment was made to evaluate the risk of WH damage due to casing rotation. This risk was estimated low, as contact point would be with the Min ID of the WH (17.750", located below the landing shoulder) and not with the sealing bowl (ID = 18.595"). Also, centralizer placement on each joint was optimized to allow the estimated 60% sliding per joint before switching to rotary, to avoid having centralizer rotating in front of the WH. The centralizers are made of 1010 grade material, mild steel (softer than WH material) and had a smooth profile, with no aggressive edge. Finally the estimated side force was reasonably low, under 250lbs at WH level. On Badamyar, all pack-offs (elastomeric seals) were successfully installed and tested without issue.

Operations

Sequence of operations

In preparation for drilling the section, a well control stand and BHA retrieval stand were racked back in the derrick.

The external BHA was made up with 12 ¼" mill tooth bit and 16″ Under Reamer (UR), under a standard mud motor with 1.5deg Adjustable Kick Off (AKO) bend, followed by a MWD tool. With the external BHA in slips, the 13 3/8″ casing shoe joint, already pre-assembled with the internal BHA, was picked up and made-up to the external BHA. The BHA was then run in hole on 13 3/8″ Casing joints as per tally, until UR was at 20" Conductor shoe.

The 13 3/8" × 16" section was then drilled to TD as per Directional plan, with Sea Water (1.03 sg) & hi-vis sweeps, with flowrate ranging from 2,300 lpm to 3,400 lpm, and rotation from 40 to 60 RPM. Considerations of WOB, Torque and Drag are detailed later.

At TD, the hole was circulated clean with sea water, and then displaced to 1.10sg PAD or PAC? mud in order to improve the wellbore stability while recovering the BHA and preparing for cement job.

The CRT was rigged down and C-Plate and false rotary installed in order to run the BHA retrieval tool on 5″ Drill Pipe inside the 13 3/8″ casing.

Once reaching the shoe track, a gyro was dropped in order to get improve the survey accuracy compared to MWD for anti-collision purpose. The retrieval tool was then engaged to release the BHA, which was pulled out of hole and racked-back.

The CRT was rigged up again to break circulation, reciprocate and run 13 3/8″ casing inside 16″ hole to cover the BHA length and land the casing hanger inside WH bowl. The cement job was then performed, with Pump Down Displacement Plug pumped right after cement, and casing pressure tested at bump (value limited to 1,500psi due to PDDP pressure rating). After recovering the casing hanger landing string, the WH pack-off was installed and pressure tested.

The whole sequence was repeated four times in batch mode, resulting in four 13 3/8″ casing drilled and cemented as per plan.

Directional Drilling

In order to reach the shallow Badamyar target it was required to build the trajectory almost continuously at around 3deg/30m. This trajectory requirement was deemed achievable with Directional Casing While Drilling, based on previous D-CwD record, where 2.5deg/30m of continuous build had been achieved, with up to 5deg/30m instantaneous Dog Leg Severity (DLS), in similar; very shallow formation (300m) with 1.5deg AKO bent motor. The records obtained from offset wells drilled conventionnaly were also bringing confidence as 3 to 5 deg/30m had been achieved with 60%-80% sliding with 1.2deg AKO. In order to be conservative, the selected AKO for Directional Casing While Drilling on Badamyar was 1.5deg AKO. However, difficulties were experienced on one of the four wells to follow the planned trajectory at 3deg/30m.

On BDM-4G, the build-up rate was 1deg/30m below the plan, resulting in calling TD earlier than planned to leave room for trajectory correction in next 12 ¼″ section.

The lesson learnt was to avoid entering into a vicious circle: with more drag compared to conventional drilling, the actual WOB is not precisely known. With fear to stall motor and/or damage underreamer, it was tempting to restrict the weight and not push the WOB as much as it would be required to build. Consequently, it was also tempting to increase the sliding ratio- to 100% to catch up with trajectory. But avoiding casing rotation eventually creates more drag, which affects the WOB, downgrading the ability to build.

The correction successfully applied on the next well BDM-4I was to reduce the drag by applying rotation consistently at each joint: sliding ratio was limited to maximum 90%.

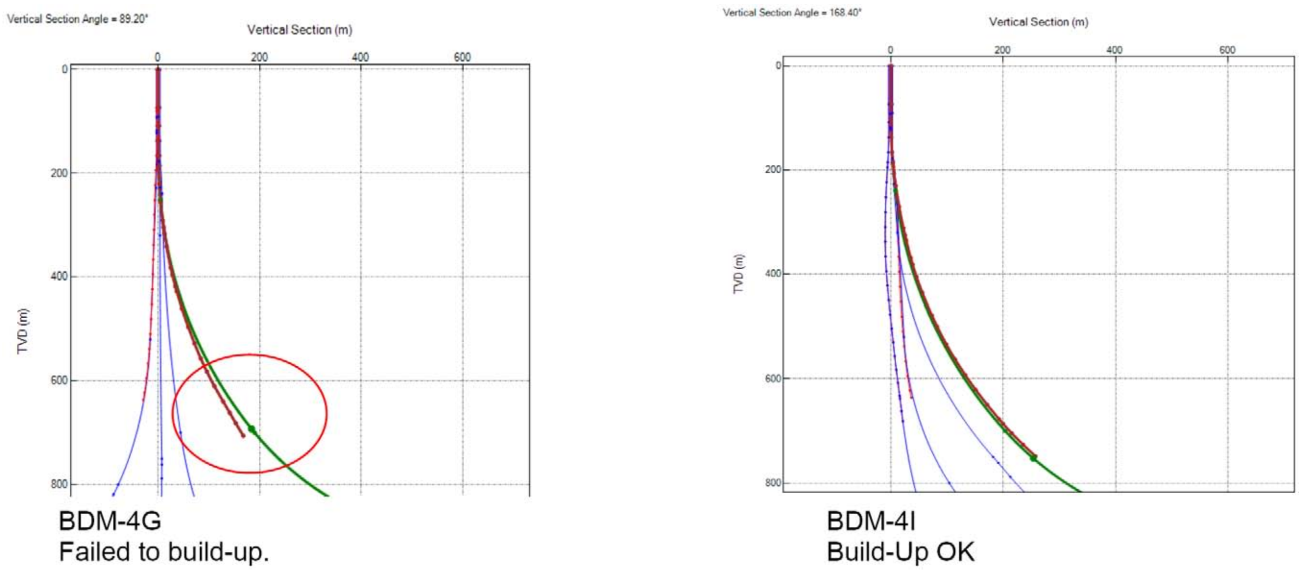


Figure 5—BDM-4G realized well trajectory failed to follow the planned trajectory (Left). Directional Drilling strategy was improved and BDM-4I planned trajectory was then perfectly followed (Right).

For next D-CwD projects, the use of Rotary Steerable System (RSS) in combination with Motor can be a promising solution. The Mud motor placed above the RSS would provide rotation in order to keep low surface rotation speed (limit casing fatigue damage), while the RSS would help to reduce tortuosity.

Fatigue

In a deviated section, the casing string is subject to cyclic bending stress when it rotates. The fatigue life of a casing connection is defined by the combination of a maximum acceptable number of cycles for a given bend angle. The Casing Drilling company recommends not to exceed 20% of the fatigue life given by the supplier (safety factor equivalent to five). The fatigue life given by Casing manufacturer was based on real test done with 13 3/8" 72# P110 and extrapolated (using DNV-B1 standard) to obtain the fatigue life over the whole Bending VS Cycles range. For example, a Dog Leg Severity of 5deg/30m DLS at each drilled joint corresponds to a maximum number of cycle acceptable for a connection of around 11,000 cycles, considering a safety factor of five [Figure 6].

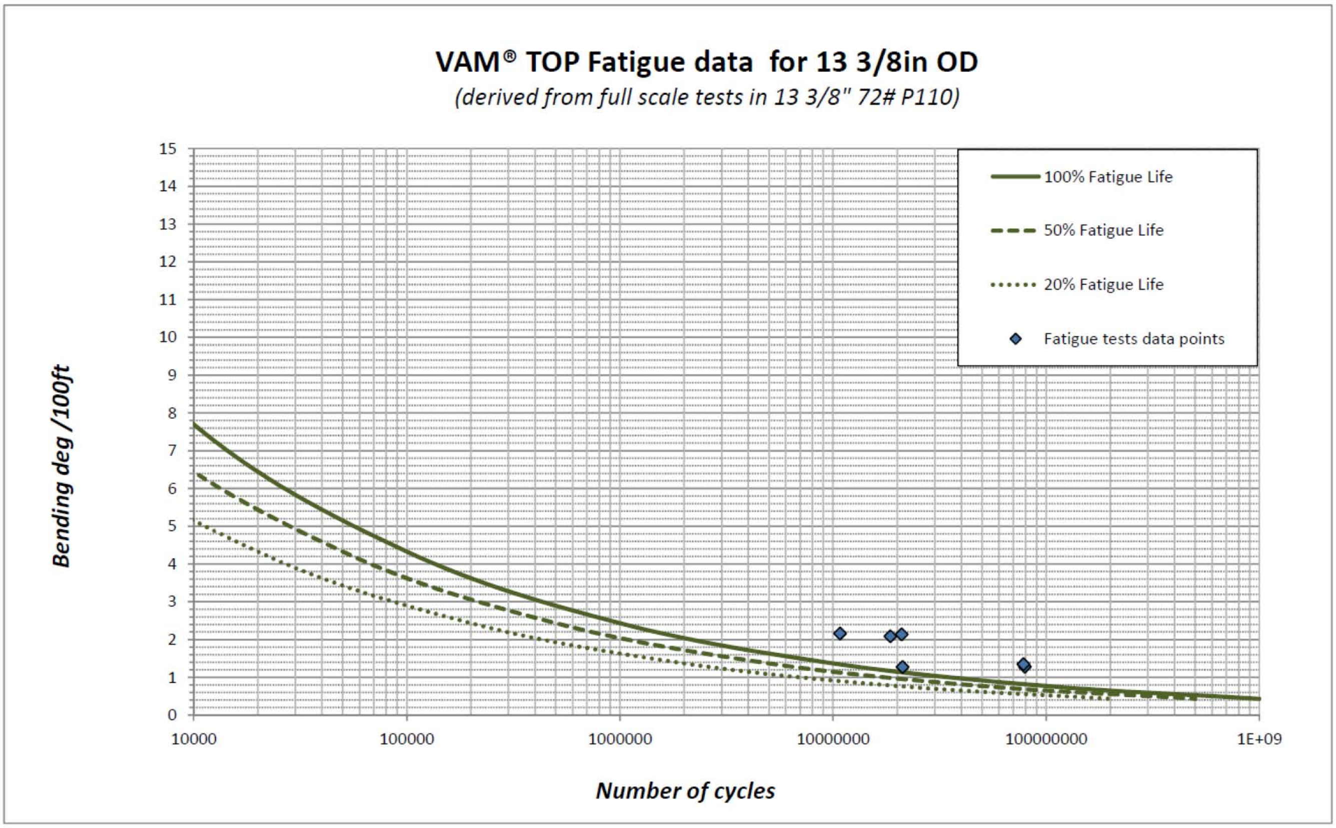


Figure 6—13 3/8″ Casing fatigue data, derived from real tests. If consider 20% of fatigue life as a limit for cumulated fatigue damage, a connection is allowed to rotate approximately 11 000 times in front of a 5deg/30m dog leg.

In practice, the estimated fatigue damage is calculated for each joint, at both engineering and operation stages, using the Casing Driller software, taking into account the number of rotations seen by the connection in front of each dogleg.

At the engineering stage, assumptions were taken for the entry data: Rotation Per Minute (RPM), rate of penetration (ROP) and sliding ratio (to estimate the number of cycles), and Well trajectory (to estimate the bending stress). The program calculated the fatigue life consumed for all joints in the drill string and highlighted the most fatigue-damaged joint. The bottom joint of casing is not necessarily the most fatigued joint; certain sections of the hole are more tortuous than others; and depending on the formation the ROP might be lower in some parts of the well. On Badamyar wells, the planned fatigue damage was between 6% and 21% depending on the well.

Then, considering real DLS and actual number of rotations in front of each dogleg, it was noticed that most of actual values were under the planned fatigue damage, due to sliding ratio higher than expected (and therefore less rotation). However; on one joint the fatigue life reached 30% of the fatigue life on BDM-4I, without issue [Figure 7].

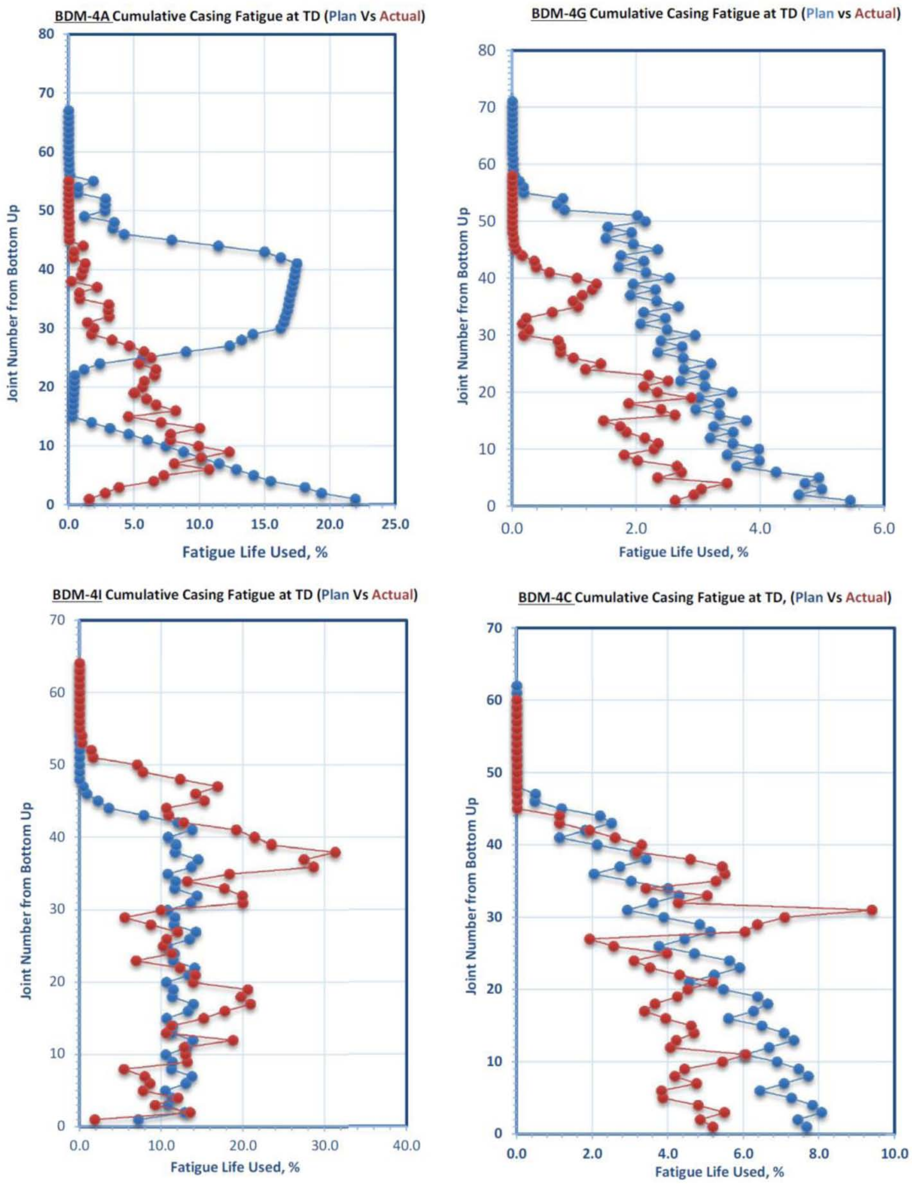


Figure 7—Cumulative 13 3/8″ casing fatigue for each well, planned versus actual.

For future projects, work could be done with casing supplier to raise the safety factor to more than only 20% of the fatigue life, and to lift the current constraints on Directional CwD on reachable TD and well trajectory.

Torque

In addition to fatigue life, the torque is also a constraint on the section length, as torque rating of casing is much less than conventional drill pipes for a given section to be drilled.

However, unlike conventional drill pipe, the casing torque limitation to be considered for drilling can be raised above the maximum make-up torque. For this casing connection (VAMTOP 61# L80), the casing manufacturer had confirmed that the maximum acceptable torque to be considered for casing drilling application was the Maximum Torque to Seability (MTS) (26 kft.lbs), more than 7kft.lbs above the maximum make-up torque (18.25 kft.lbs) taken to make-up connection.

For connection design, three torque parameters were taken into account. The planned off-bottom torque computed by the Casing Driller software (12 kft.lbs at TD), an estimate of the break-over torque after connection and an estimate of the bit torque.

On Badamyar, to resume rotation after some connections it was required to raise the TDS torque limiter to 25 kft.lbs, still slightly below MTS but above the maximum make-up torque, the connection torque design was just-good-enough to reach the planned TD. This 13 3/8″ casing was the lightest ever used for directional casing while drilling.

Well control

In Directional Casing While Drilling, there is a step in the sequence when the well cannot be closed with BOP only: when the BHA is being recovered with drill-pipes, the annular area between the casing and drill pipe is open and in direct communication with bottom-hole formation.

In case of well control situation, one must close the BOP (annular preventer) and the area between the casing and drill pipe. A "Threaded Casing Drive" (TCD) tool is provided to perform this function [Figure 8].

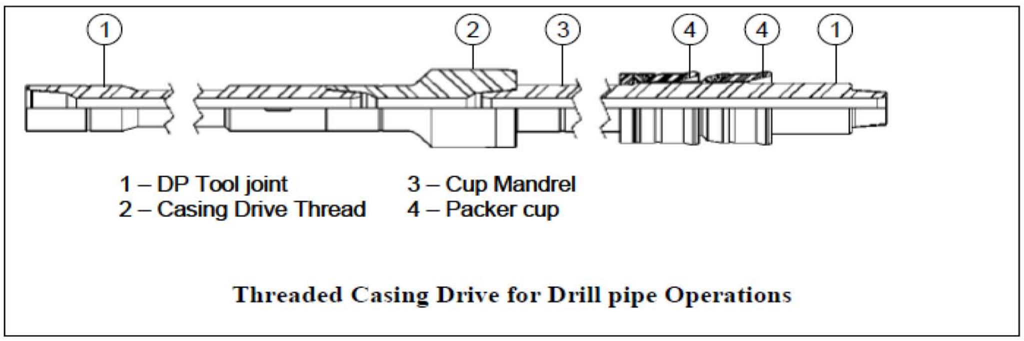


Figure 8—Threaded Casing Drive for sealing the annulus Drill Pipe / 13 3/8″ Casing in case of well control situation while recovering the BHA.

With very low risk of losing well control on Badamyar, only one drill was done to test the efficiency and functionality of the TCD, should a kick occur while pulling out of hole the BHA although the risk of swabbing is all the more reduced thanks to the casing already on bottom. This drill was done while running the BHA retrieval tool on drill pipe before unlatching the BHA. The Drill Pipe was set on slips, the Well Control Stand with TCD was picked up and made-up to the 5″ DP on slips. The false rotary table was removed and the well control stand was stabbed in the 13 3/8″ casing. The sealability of the TCD was checked by pumping 1min at 100gpm, with returns observed at flowline.

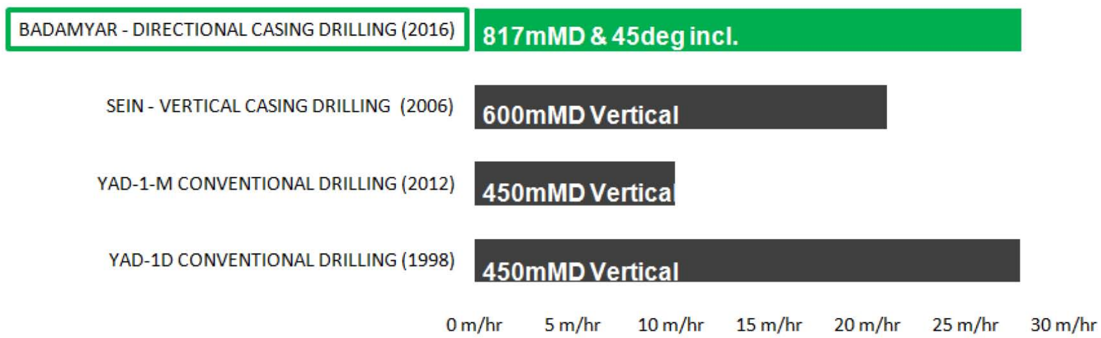
The above sequence lasted thirty minutes, which is too much if the well has to be shut-in due to an influx, especially in case of shallow-gas. This duration can be improved by practicing the drill a few times. An alternative design (Casing Circulating Tool) is now available and used instead of TCD.

Performance

In view of the expected benefits of the D-CwD applied on Badamyar, the performance of the technique is particularly visible on three criteria: the average ROP, the on-bottom instantaneous ROP and the overall time gain compared to conventional drilling.

The average Rate Of Penetration (ROP) was compared to offset wells, where 13 3/8″ casing had been set shallower and vertically. The average ROP on Badamyar is the same as a fast case of conventional drilling ROP (Yad-1D drilled in 1997).

Table 2—Comparison between different drilling techniques. Average Rate Of Penetration (ROP) in meters per hour, including connections.



Without need for close loop mud system and solid control, the Directional Casing While Drilling allowed to lift any limitation on instantaneous ROP. The on-bottom ROP of the longest 13 3/8″ section of Badamyar (BDM-4I) went up to more than 200 m/hr on some joints, with an average of 75m/hr in sliding mode and 82 m/hr in rotary mode.

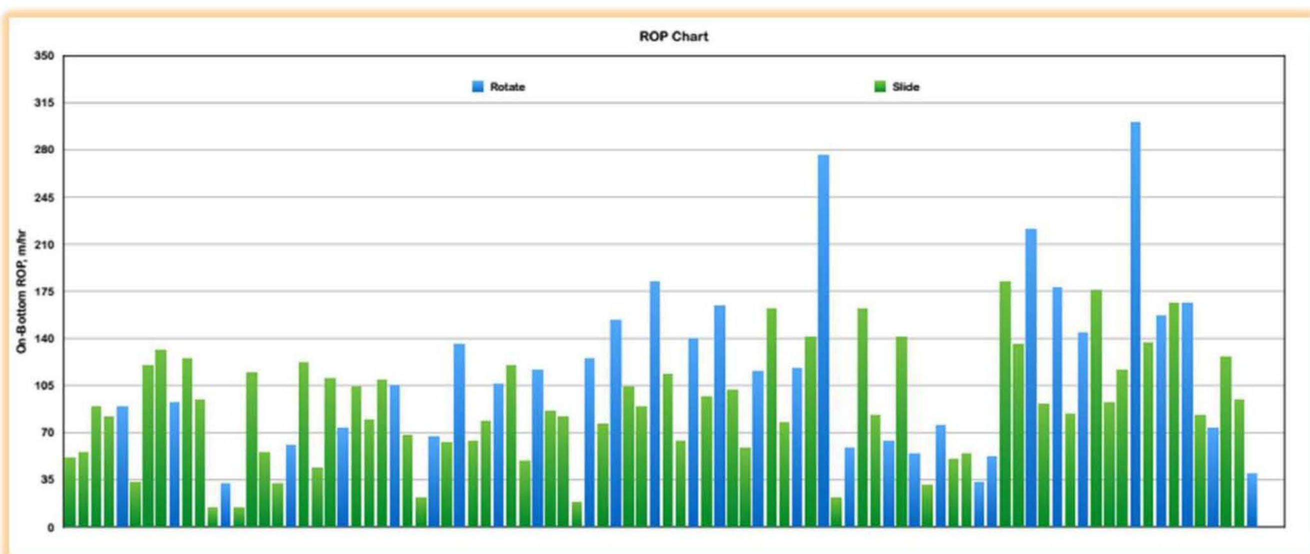


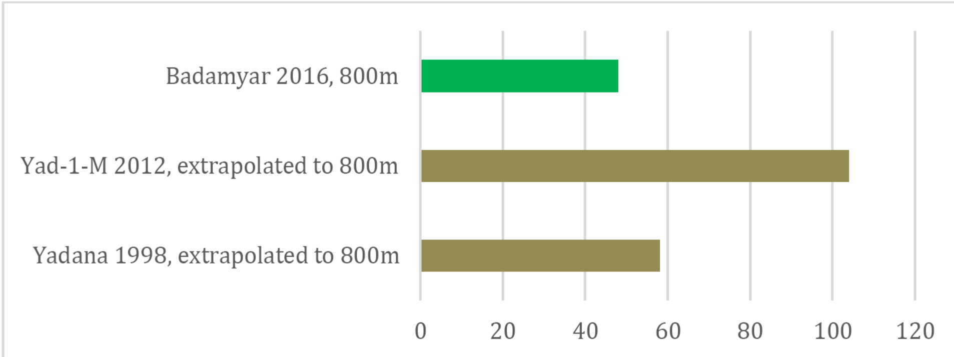
Figure 9—On-bottom instantaneous ROP per joint on BDM-4I (the longest casing drilled section of Badamyar).

If we consider the detailed timing analysis over the whole sequence, the time gain on Badamyar is 20% compared to conventional drilling. The Gain can be up to 100% if we consider the extra time required by conventional drilling to treat the issues (mainly losses) observed on some of the offset wells.

This comparison is based on actual timings realized on Badamyar and normalized timings from 1998 (fast case) and 2012 (slow case), obtained by extrapolating the realized ROP to the Badamyar section length (576m of open hole).

The duration to drill and case the hole (ready for cement job) was 47 hours on Badamyar, 20% less compared to a "losses-free" conventional case which would have taken 58 hours based on 1998 experience, and 50% less compared to a conventional case with losses which would have taken 104 hours based on 2012 experience, as shown on Table 3.

Table 3—Normalized durations (extrapolated to 800) of Conventional Drilling versus D-CwD



The comparison can also be made without normalizing the offset wells performance: on Yad-1m in 2012 it took 82 hours to drill, treat losses, and run the casing at 450m vertically, compared to only 47 hours on Badamyar to reach 800m at 45deg. This may lead to conclude that Badamyar performance would probably not have been possible with conventional drilling.

Conclusion

The Directional Casing While Drilling technique allowed to meet Badamyar objectives above expectations, realizing the planned well architecture without need for contingent section, and improving performance to exceed offset well records, safely. This application enabled to drill, set and cement four 13 3/8″ casings in fourteen days, 20% to 100% faster, deeper and at higher inclination compared to any other offset wells. Up to 45deg inclination was achieved, as per directional plan, at 3deg/30m. No time was lost due to losses or wellbore instability issues.

This technique required to use specific equipment, and to adapt procedures and operations. But the difficulty was probably more related to the decision making process of switching from conventional drilling to D-CwD, as any new approach always requires a change of mindset. In this aspect, Directional Casing While Drilling was a first for most of the teams involved, in particular a first trial within TOTAL operator, but long preparation, detailed engineering, review of expected benefits versus risk assessment brought confidence the technique was fit-for-purpose to deliver the targeted architecture in the safest and most efficient manner.

Whereas Badamyar provides an additional successful case showing the Directional CwD is field proven, it also highlights some potential ways of improvement on limitations such as casing fatigue, torque and well control. Optimizations and development of these aspects should eventually broaden the possible applications of D-CwD and pushing these boundaries will benefit to the whole drilling industry.

Aknowledgement

The authors wish to express their gratitude to management at Schlumberger, and Total E&P Myanmar for permission to release the field performance data and results contained in this paper.

Nomenclature

BHA – Bottom Hole Assembly
BOP – Blow Out Preventer
BUR – Build Up Rate
CRT – Casing Running Tool
D-CwD – Directional Casing While Drilling

DLS – Dog Leg Severity
ECD – Equivalent Circulating Density
ERD – Extended Reach Drilling
LWD – Logging While Drilling
MWD – Measurement While Drilling
RSS – Rotary Steerable System
ROP – Rate Of Penetration
RPM – Rotation Per Minute
SG – Specific Gravity
TCD – Threaded Casing Drive
TD – Total Depth
TVD – True Vertical Depth
UR – Under-reamer
WBM – Water Base Mud

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