INTEGRATED ENGINEERING ANALYSIS TO SUPPORT SUCCESSFUL UTILIZATION OF CASING DRILLING IN GEOTHERMAL WELLS

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ABSTRACT

Casing drilling has become a common operation for drilling a well nowadays. Instead of using a drill pipe to transfer the energy from the surface to the drill bit, this operation uses casing, so when the bit reaches the end of the section, the casing is already there to protect the well.

One of the problems in drilling a geothermal well in Indonesia is the difficulty of running in-hole the 13 3/8-in casing after drilling a 17 1/2-in section. The openhole exposure may trigger the wellbore to collapse, creating an obstruction to conveying the casing to the final depth. To solve this problem, a nondirectional casing drilling technology was proposed as the solution. The main component of this technology is the drillable alloy PDC casing bit, which is attached to a standard casing that is rotated at the surface. The casing can be fully rotated while applying weight to cut through the obstruction. A comprehensive engineering analysis was performed prior to the job to support the operation.

The casing drilling system successfully set the 13 3/8-in casing 314 m deeper than the initial point of the casing running obstruction. The drilling and reaming capability of the casing bit helped in cutting through all the formation filling the predrilled hole. The cementing process was executed well, with good integrity to the surface. Since then, this operation has become an effective standard practice for our team and has been performed in more than eight wells.

As a way forward, this paper also provides a feasibility study of a fully directional casing drilling technology to be applied in geothermal wells to improve the drilling efficiency. This study includes the readiness of the tools and main engineering aspects: hydraulics and mechanical (torque and drag, casing wear, fatigue, pipe stress, and vibration).

1. INTRODUCTION

1.1 Problematic Zone in Geothermal Drilling

During development drilling phase of Field K, located in the Sumatera Area, it was found that 17.5-in section was a problematic zone. This section experienced several problems during drilling: loss of circulation, high over-pull while pulling the drillstring out of hole, and a stuck pipe incident. Sidetracking from the main wellbore was also performed to get away from the loss of circulation zone and the bit reached TD at 952-m MD.

Running the casing afterwards was also difficult as the formation was not stable. The casing could not go to the designated depth as the formation had collapsed. There was no rotational capability of the casing, and so due to obstruction the casing setting depth was shallower than planned. To solve the problem encountered in the main pilot hole, a casing drilling operation was proposed with the objectives:

1. Set the casing to the designated bottom hole
2. Set the casing immediately so the hole is not exposed for a long time and the problematic zone is sealed

1.2 Casing Drilling Introduction

Casing drilling is a rotary drilling process where the hole is being cased from the moment the drilling is started. The casing replaces the drillstring to provide the hydraulic and mechanical energy to the bit to cut the rock.

In general, casing drilling can be divided into two categories: nondirectional and directional. Nondirectional casing drilling is usually used to drill a section that does not require any directional work, such as in a vertical or a tangent section. A specially designed casing drilling bit is connected directly to the casing and can be drilled out for the next section of drilling. In a directional section, the casing will be connected to the conventional drilling BHA with some driving system and M/LWD tools. The BHA then can be retrieved and recovered after the drilling operation.

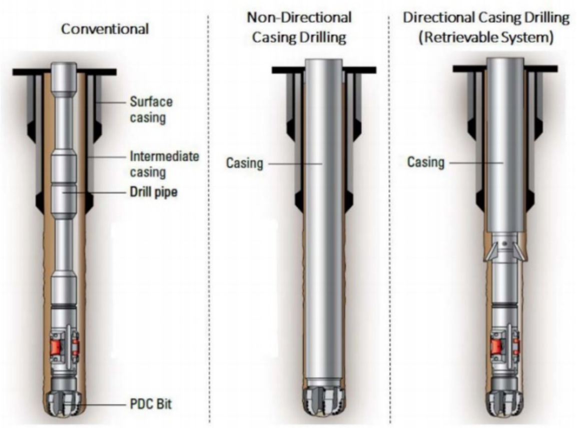


Figure 1. Conventional vs. casing drilling

Casing drilling is not a new technology. Rotary drilling in the past was initially introduced with the casing as the drillstring because the drill pipe had not yet been developed. The benefits of using casing during drilling was already understood in the early times, but the implementation was not practical. Nowadays, technologies for applying casing drilling are becoming more advanced: top drives are robust and commonly available; casing driving tools are more convenient; PDC cutters have been developed for more durable cutting action; more robust and versatile casing connections, materials, and accessories have been developed.

There are four main benefits of using casing drilling in a drilling operation. The first and simplest reason is reducing the flat time that occurs when running the casing after drilling a section. One unnecessary trip can be eliminated. Tessari et al., 2006, explain the other three benefits:

1. Reducing the downhole trouble time, such as lost circulation and well control
2. Casing drilling could improve the optimization of drilling economics
3. Casing drilling reduces the risk of losing excess fluid to a low-pressure section and damaging the production zone

One of the benefits of casing drilling is the tight annulus between the pipe and the wellbore, enabling the casing to smear or plaster the generated cuttings to the wellbore wall, even in a highly sensitive formation. The ground cuttings fill up the pores, resulting in a stronger and smoother wellbore. By this plastering effect, the loss of circulation rate can also be reduced. Furthermore, this well condition can lead to a better cementing operation.

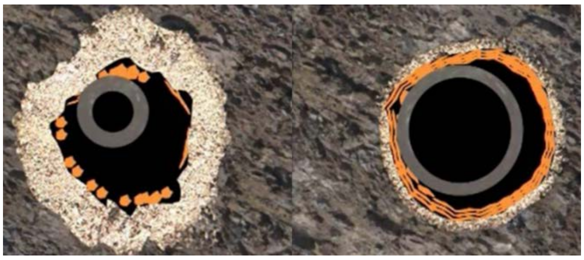


Figure 2. The plastering effect with casing drilling.

2. NONDIRECTIONAL CASING DRILLING IMPLEMENTATION FOR GEOTHERMAL WELL

The obstruction due to a collapsing wellbore meant that the 13.375-in casing could not landed at the designated depth in Well-A. To enhance the ability of the casing to bypass the obstruction, the nondirectional casing drilling system was proposed as the solution.

A specially designed casing drilling bit made from a copper-based alloy is connected to the bottom of the casing connection. The PDC cutter on the bit cuts the rock in the presence of a collapsed formation, thus enabling the casing to continue running in-hole. Once the casing is set in place, the cementing operation can be started. The unique alloy of the casing drilling bit can be drilled out with any standard bit after the cementing process, so that drilling can be continued.

To prevent any issue during the casing drilling operation, several operational and engineering feasibility studies were performed prior to the job, including hardware analysis, hydraulic studies, and mechanical aspects. The main objective of this operation was to convey the 13.375-in casing to seal the problematic zone so the next drilling section (12.25-in) could be drilled more safely.

Figure 3. Casing drilling bit drill-out process.

2.1 Casing Drilling Static Modeling

The point of weakness of the casing is the connection. Casing is not designed to fully rotate as it can damage the connection. One of the main objectives of the feasibility study was to check all engineering aspects during drilling that could damage the casing connection.

There are six main engineering aspects that need to be considered during the planning phase: torque, well tortuosity, casing wear, casing fatigue, pipe stress, and vibration.

Torque analysis is very important in the planning phase of casing drilling. Most of the equipment in the casing drilling operation is limited by its own torque rating. Torque is the main driver for well candidate selection, casing and connection selection, selection of the rig top drive, and monitoring downhole conditions. Usually, a casing drilling operation requires higher torque compared to conventional drilling. The torque value while drilling will be affected by the friction between the pipe and the wellbore.

A static simulation was performed to check the expected torque generated by the system during the drilling process. Based on this simulation, at TD, the surface torque is expected to reach around 24 klbf-ft. The simulation was also used to check the condition of the casing, i.e., whether it experienced buckling or not.

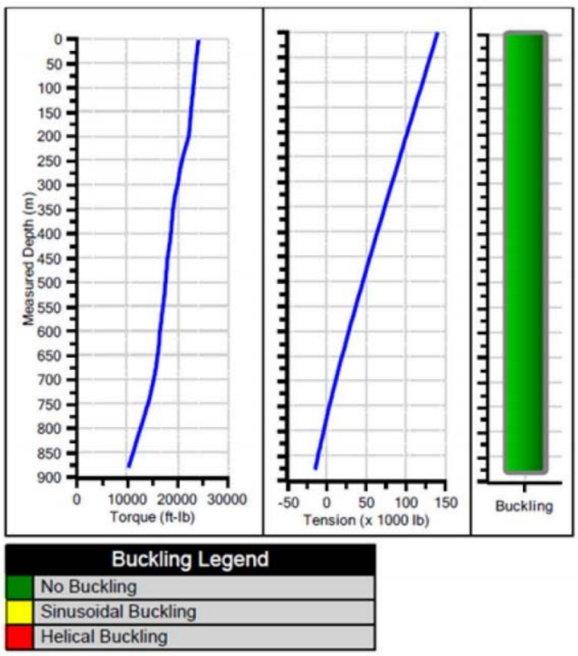


Figure 4. Torque and buckling simulation result.

Other important mechanical aspects that need to be checked during the planning phase are casing stress and fatigue. This kind of damage occurs when the material is subjected to a cyclic load with a certain amount of stress amplitude and a certain number of cycles. Stress analysis gives the casing revolution limit, i.e., the casing fatigue life threshold. For the casing drilling operation, it is highly recommended to set the maximum consumed fatigue life at 20%, as after that value, the stress in the casing increases rapidly.

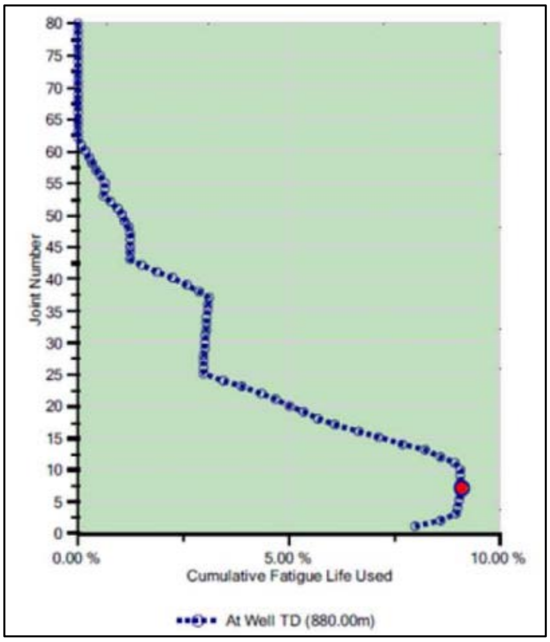


Figure 5. Cumulative fatigue

2.2 Casing Drilling Dynamic Simulation

Bit selection is very important for nondirectional casing drilling. Geothermal rock is usually very hard and abrasive. Rock strength analysis (RSA) has been performed prior to the operation. The RSA software calculates the rock unconfined compressive strength (UCMPS) based on the sonic log from the offset wells (Mason, 1985). The UCMPS is also used to predict the formation abrasion and impact index that can affect PDC cutter durability. Figure 6 shows the result of a compressive strength calculation; 5–15 kpsi with high abrasiveness and formation impact.

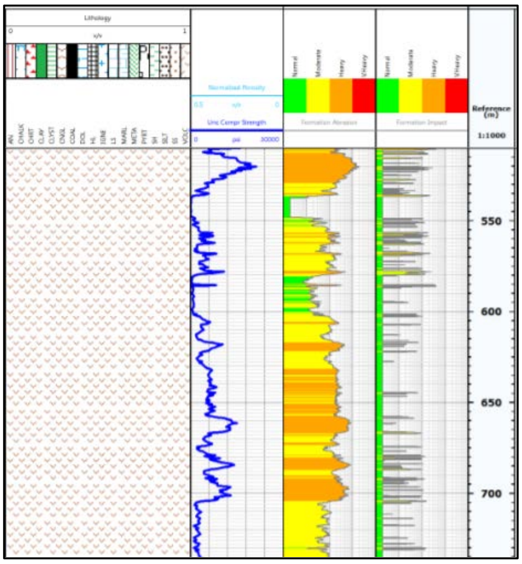


Figure 6. Rock strength analysis result

In this specific application, the section had previously been drilled by conventional BHA. The casing drilling bit would only be required to drill out some obstruction caused by a formation collapse. This part of the rock was expected to have low UCMPS, and therefore, an aggressive casing drilling bit could be used in this operation. The 17.5-in bit has 4 blades with 19-mm cutters on the body to cut the formation. However, a comprehensive study to provide recommended drilling parameters is needed to extend the lifetime of the bit.

Figure 7. Casing drilling bit.

An FEA-based modeling simulation was performed to check the dynamics of the drilling system using this bit (Aslaksen et al., 2007). This time-based simulation was run on a Unix platform. This simulation is much more accurate than static BHA modelling as all drillstring components are individually modelled in detail. The simulation modelling the interaction between the cutting structure and formation drilled was based on rock mechanics derived in the lab. The simulation shows the impact of drilling on all the drillstring components, including the vibrations, stress, torque, and even ROP prediction (Mardiana et al., 2017). In this application, the simulation was expected to provide a roadmap of the safe and stable drilling parameters to be applied in the field.

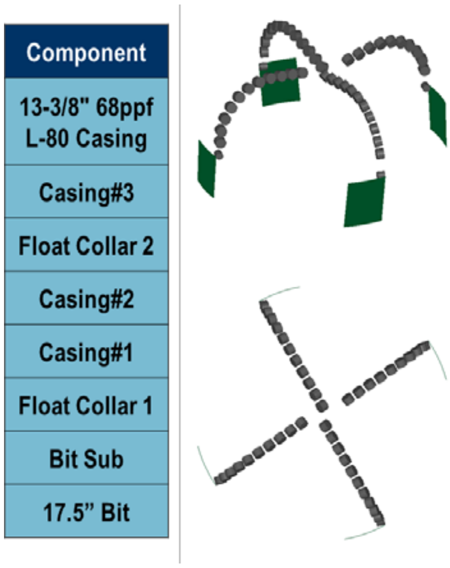


Figure 8. BHA components and casing drilling bit model.

The bit and casing string were simulated to drill volcanic rock with 15–20 kpsi of compressive strength with different sets of parameters: 40–70 surface RPM and 5–25 klbs of WOB. Lateral, axial, and torsional vibration of the drilling system were calculated. The average value of results for each parameter set was then plotted in a traffic light plot to differentiate stable parameters from unstable parameters. The lateral vibration threshold was set to 5 G; axial vibration threshold was set to 1 G and torsional vibration or stick/slip was set to 40%. Vibrations beyond those values can lead to damage to PDC cutters that will affect the drilling efficiency.

WOB(klbf)				
25	0.63	0.99	1.00	1.26
20	0.46	0.67	0.83	0.96
17	0.38	0.57	0.64	0.78
15	0.33	0.46	0.63	0.65
13	0.32	0.36	0.46	0.54
11	0.27	0.31	0.43	0.44
9	0.21	0.25	0.30	0.35
7	0.15	0.19	0.25	0.26
5	0.10	0.11	0.16	0.19
RPM	40	50	60	70

Average AXIAL Vibration Level: > 1 G
Average LATERAL Vibration Level: > 3 G
Stick/Slip: > 40 %
All, Lat-Sti, Axi-Sti, Axi-Lat, Sti(40), Lat(3.0), Axi(1.0), Stable

Figure 9. Stable drilling parameter roadmap.

In Figure 9, the green color indicates stable parameters to be applied, while others indicate vibration. Based on this plot, it is recommended to avoid using 50 and 70 SRPM with WOB > 13 klb as it could lead to high lateral vibration.

2.3 Nondirectional Casing Drilling Job Implementation

The 20-in casing had been set in Well-A, and it was deepened by drilling a 17.5-in hole section with conventional BHA until 900-m MD. The 17.5-in XCD bit was connected to the casing string with two float collars during job execution. The bit was then run in-hole without any restriction inside the 20-in casing until the casing shoe. The first obstruction was found at 530-m MD. Light reaming with 1–2 klb of WOB was performed to pass the formation. During the casing running operation, several restrictions were found and successfully passed by various drilling techniques. The maximum applied WOB in this operation was 20–25 klb with 20–30 surface RPM. No vibration was observed on the drilling rig. At around 849-m MD, the surface torque increased up to 24 klbf-ft, almost 80% of the maximum allowable top drive torque. Other than that, calculation showed that real-time fatigue at the rig site had almost reached 20%.

The cementing operation was successfully performed afterwards with 15.8 ppg cement slurry pumped into the hole. To check the cement condition, a cement bond log (CBL) was run and showed an average value of 5mV, significantly better than the threshold of 20 mV. The casing drilling operation proved its ability to improve the well integrity by enabling the cement to be placed up to the surface. The well condition after casing drilling was much better as a result of having the smaller cuttings from the PDC cutters smeared on the wellbore. This action not only reduced the loss of circulation to the formation, but also smoothed the wellbore.

A 12.25-in milled tooth bit with IADC 215 was picked up to drill out the shoe track, float collar equipment, and casing drilling bit. The drill-out process took around 3.5 h and drilled 6 m into the volcanic formation. The objective of this operation was to ensure that the next 12.25-in BHA safely passed the casing shoe and continuously drilled the section until the designated TD. The milled tooth was pulled out of the hole with 3-4-CT-A-F-1-NO-TD dull grade.

Figure 10. 12.25-in milled tooth bit condition after drill-out process.

2.4 Continuous Utilization of Casing Drilling Technology

Since the first run in 2017, casing drilling operations have been performed in more than eight wells in various geothermal fields in Indonesia. This technology has proved to be a useful method for optimizing drilling operation by:

1. Setting the casing deeper and sealing the problematic zones
2. Eliminating an unnecessary dedicated clean-out trip prior to running the casing
3. Reducing the risk of having a stuck pipe due to formation instability
4. Improving the cement operation by the plastering effect

In the next section of this paper, a feasibility study of directional casing drilling will be discussed.

3. DIRECTIONAL CASING DRILLING QUICK FEASIBILITY STUDY

To ascertain the benefit of casing drilling in a directional section, a quick feasibility study has been performed. Similar to the planning phase of the previous nondirectional casing drilling, this feasibility study consists of: bit records and rock strength analysis in a 17.5-in hole section, static modeling to check torque and fatigue, and dynamic simulations to optimize the BHA, check the drilling dynamics of the drilling system, and provide the stable parameter roadmap.

Unlike nondirectional casing drilling that only uses the casing drilling bit under the casing, directional casing drilling uses a conventional directional BHA that is connected to the casing strings using a drill-lock assembly (DLA). For setting the 13.375-in casing, the typical drill string consists of the 12.25-in bit, an under-reamer that opens the hole from 12.25-in to 17.5-in, a mud motor, stabilizers, MWD, drill collar, and the DLA that will lock this BHA to the casing. After reaching TD or at any point where it is necessary to pull the BHA out of the hole, the DLA enables the BHA to be retrieved and then to be set back to the casing to continue the drilling operation.

The feasibility study uses the new well trajectory and geometry from Well-B. The 13.375-in casing will be set in a 17.5-in hole at around 1,500-m MD from the 20-in casing shoe at 500-m MD. Based on the bit records from offset wells, this section is usually drilled by 2–3 17.5-in tungsten carbide insert (TCI) bit due to KREVS limitation. The TCI bit has bearings inside the cones that limit the number of revolutions the bit can achieve before the bearings fail. In directional casing drilling a 12.25-in bit will be used. To reduce the trips required for bit changes and improve the ROP, a 12.25-in conical diamond element (CDE) bit will be used (Mardiana et al., 2017).

Figure 11. Conical Diamond Element (CDE) for PDC bit.

The accumulated casing fatigue is affected by the casing revolution during drilling. Being conservative to minimize the casing fatigue, directional casing drilling is proposed for drilling half of the section. Conventional BHA will be used to drill the 17.5-in section from 500-m MD to 1,500-m MD, then directional casing drilling will be used until the section TD. Below is the BHA and well trajectory to be used in this feasibility study.

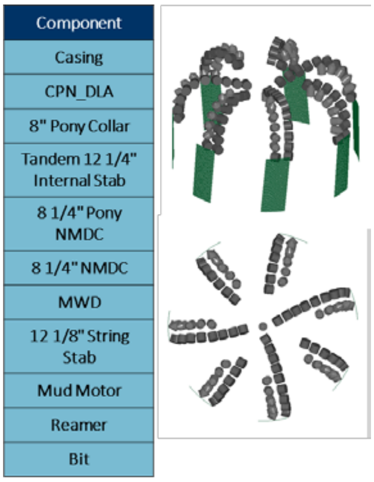


Figure 12. Directional casing drilling BHA and 12.25-in PDC bit.

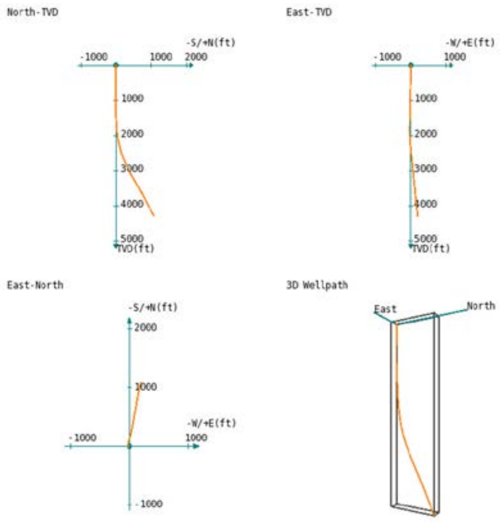


Figure 13. Well trajectory of Well-B.

There are two types of under-reamer that are usually used for directional casing drilling operations: the four-arm reamer and three-block reamer. The reamer selection is also important, especially for drilling hard volcanic rocks in a geothermal application. The dynamic simulation will show the different responses for the two reamers.

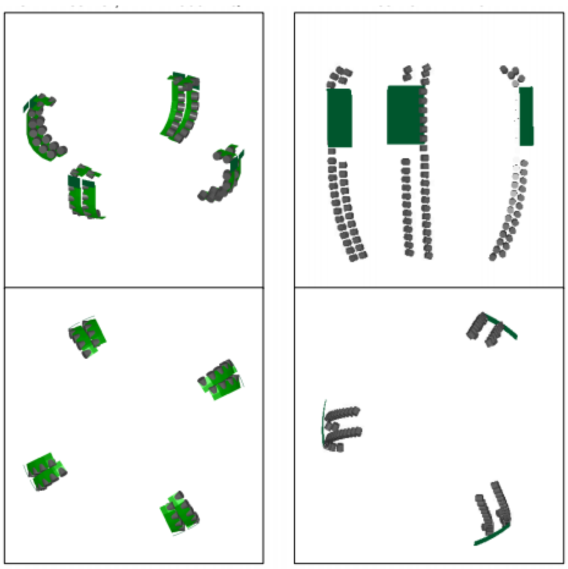


Figure 14. Four arms (left) and three blocks (right) reamer.

3.1 Directional Casing Drilling Static Simulation

Using the same method as nondirectional casing drilling, the static simulation generated 38.3 klbf-ft torque at the end of the section. Weight on bit was 20 klb with 40 SRPM and 64 motor RPM. For the simulation, a conservative 0.3 friction factor for cased and open hole was used. This torque result is still far below the torque rating of the 13.35-in casing that will be used for this operation. No buckling at the casing was observed from the simulation.

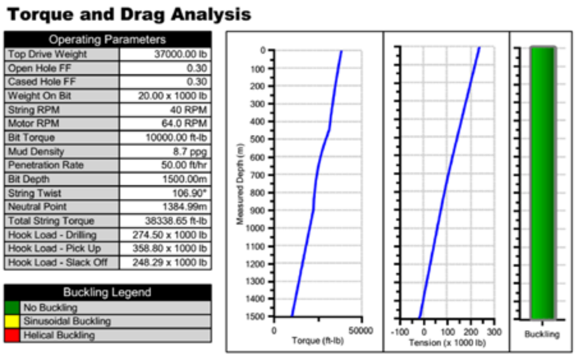
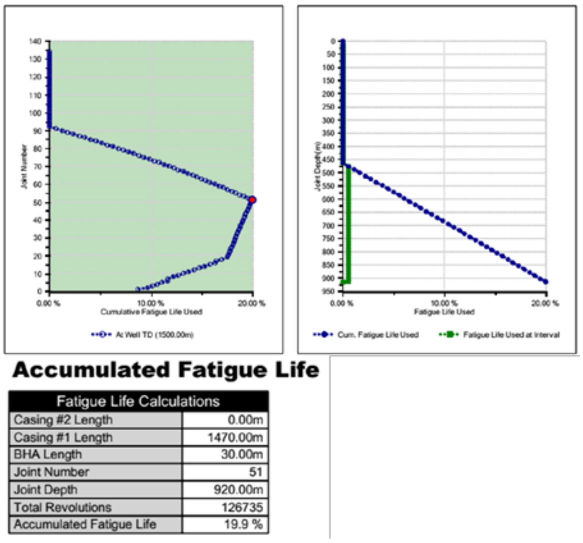


Figure 15. Torque and drag simulation result.

For the accumulative fatigue calculation, a conservative scenario was applied. The casing was simulated to be always rotated from the beginning of the 17.5-in hole section at 500-m MD to the TD with 40 SRPM and 50 ft/h of ROP. In the real scenario, the number of revolutions will be less as the motor will also be in sliding mode during the setting up of the trajectory. The fatigue consumption from the simulation was 19.9%, still below the recommended fatigue consumption of 20% and maximum allowable consumption of 40%.



Fatigue Life Calculations	
Casing #2 Length	0.00m
Casing #1 Length	1470.00m
BHA Length	30.00m
Joint Number	51
Joint Depth	920.00m
Total Revolutions	126735
Accumulated Fatigue Life	19.9 %

Figure 16. Accumulated fatigue life consumption.

3.2 Directional Casing Drilling Dynamic Simulation

The objective of this simulation was to compare the two reamers BHA: 4-arm reamer and 3-block reamer. Lateral and torsional vibration of these two BHA are shown below. Based on this simulation, both reamers experienced a low level of lateral vibration. The 3-block reamer has a slightly higher vibration. In terms of torsional vibration or stick/slip, the 3-block reamer has a slightly lower average value as it has higher count of PDC cutters.

Figure 17. Vibration results from the dynamic simulation.

The CDE bit is known to have very good durability when drilling in high compressive strength volcanic rocks. To deliver good performance and minimize the risk of BHA failure downhole, the selected reamer needs to have the same level of durability as the bit. The result from the dynamic simulation shows the depth of cuts of all PDC cutters on both reamers.

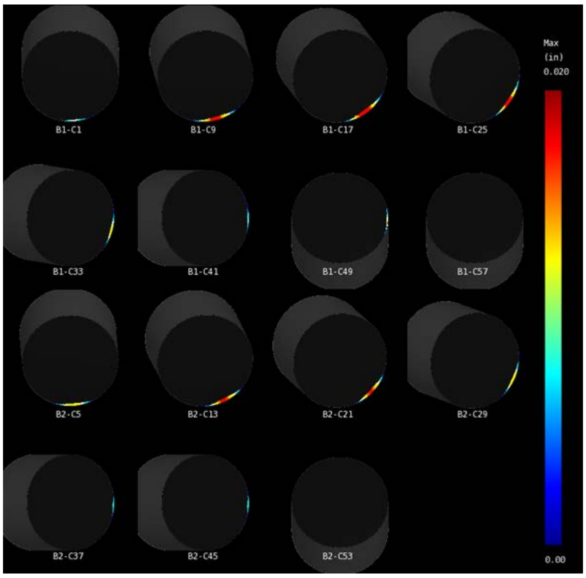


Figure 18. Depth of cut of PDC cutters on 4-arm reamer.

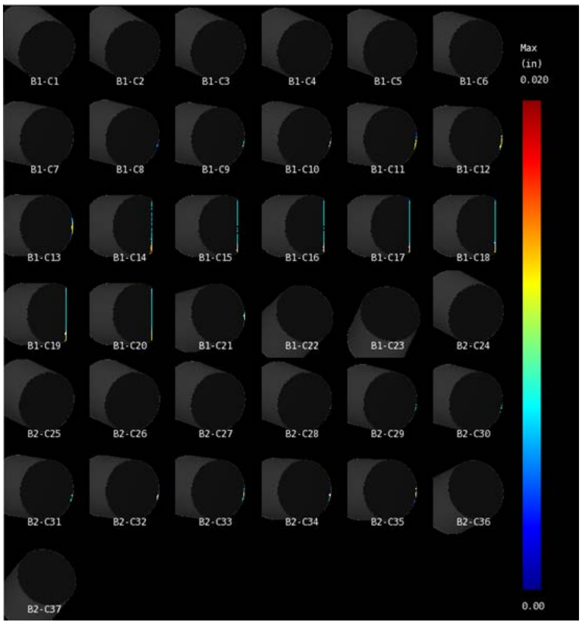


Figure 19. Depth of cut of PDC reamers on 3-block reamer.

The 4-arm reamer has only around 15 PDC cutters on each arm, 60 in total. The 3-block reamer has around 40–50 PDC cutters, 120–150 cutters in total. The lower count of cutters on the 4-arm reamer increases the depth of cut of each cutter, indicated by the red color on the above figures. This high depth of cut is very useful in soft formations, but in harder formations, this could lead to higher wear acceleration, thus reducing the bit durability. In this application, it is recommended to use the second 3-block reamer.

Whirling condition, where the casing moves in the wellbore cross-sectional area, could accelerate the casing stress and accumulate the fatigue faster. The casing displacement can also be checked to prevent casing whirling in the real operation.

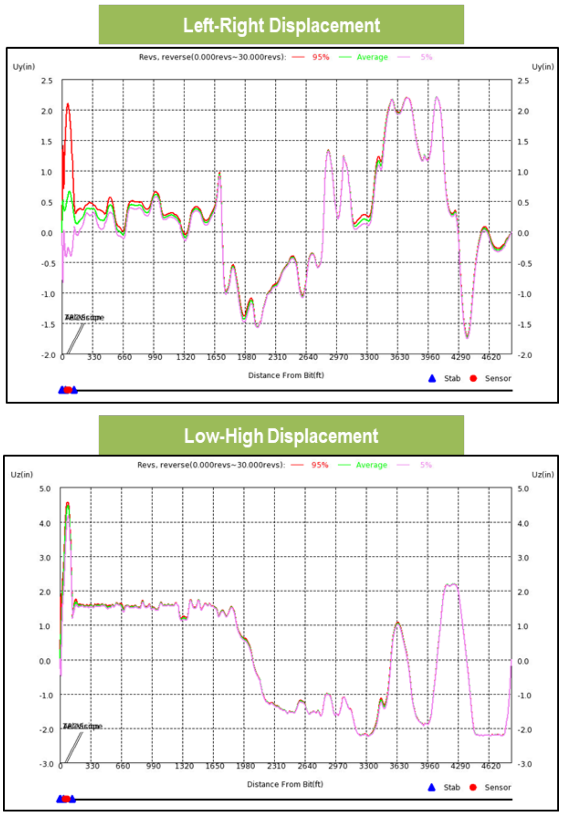


Figure 20. Casing left-right and low-high displacement.

The red line in Figure 20 shows the 95th percentile of the casing displacement, while the pink color shows the 5th percentile of the casing displacement, both on the left-right and low-high cross-sectional wellbore area. The gap between the two lines indicates casing whirling. Based on the two plots above, there was no casing whirling in this simulation.

To calculate the accumulative fatigue consumption using a dynamic drilling simulation, the 17.5-in section is divided into 80 segments of 40 ft. Fatigue consumption is calculated at each segment and then summed to yield the total stress throughout the run. The fatigue calculation is performed on the casing string only, from the casing shoe up to surface. K55 BTC connection is used in fatigue calculation.

One case will be simulated: 30 SRPM, 15 klb WOB, 0.2 CH – 0.25 OH friction factor and assuming no parameter changes throughout the run. Standpipe pressure used in the calculation is 1,500 psi.

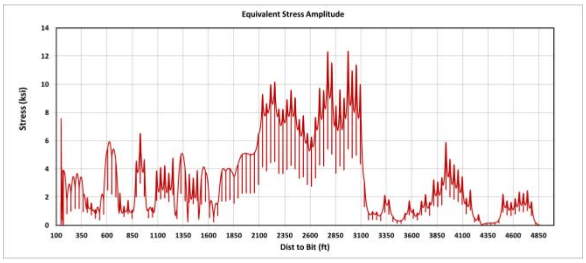


Figure 21. Simulated equivalent stress.

From the simulation, the highest stress value experienced by the casing is on the highest DLS part of the section (800–1,000-m MD).

The plot below shows the accumulated casing fatigue consumption using the dynamic simulation. The result is similar to the static calculation: 17.9%, even though a conservative scenario of full rotation was also used in this calculation.

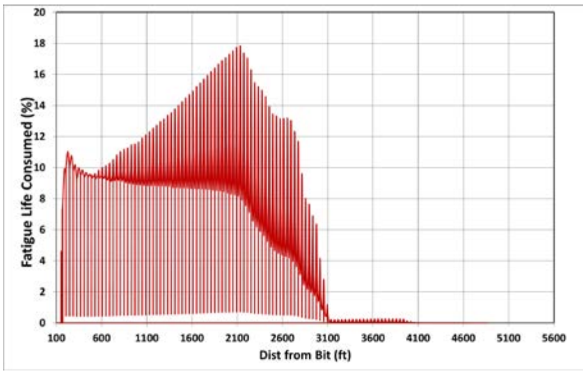
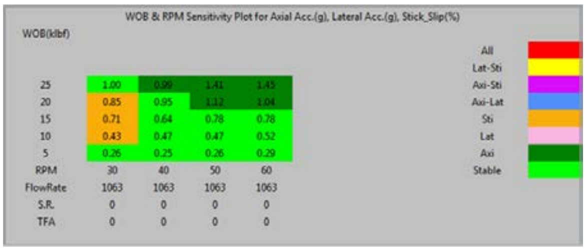


Figure 22. Cumulative fatigue life consumption.

As a summary of this analysis, from the vibration and stick/slip plots, the 4-arm and 3-block reamers generated similar trends of vibration. The 3-block reamer has slightly higher vibration than the 4-arm reamer. Bit lateral vibration is at a medium level, while reamer lateral vibration is at a low level. The 3-block reamer generated lower stick/slip on low RPM (<40 SRPM) compared to the 4-arm reamer. No casing whirling is indicated in this simulation based on the casing displacement plot. The casing fatigue life consumption is below 17.9% in all simulated cases.

Based on the analysis, it is recommended to use the 3-block reamer for this application. Below is the drilling parameter roadmap for this BHA option. This table considers all casing drilling BHA components. The threshold is set to low to medium level.



Vibration Level	Axial Vibration	Lateral Vibration	Stick/Slip
Low - Medium	≤ 2G (Bit & Reamer)	≤ 5G (Bit & Reamer)	≤ 60% (Bit & Reamer)
	≤ 2G (M/LWD Tools)	≤ 3G (M/LWD Tools)	≤ 80% (M/LWD Tools)
High - Severe	> 2G (Bit & Reamer)	> 5G (Bit & Reamer)	> 60% (Bit & Reamer)
	> 2G (M/LWD Tools)	> 3G (M/LWD Tools)	> 80% (M/LWD Tools)

Figure 23. Drilling parameter roadmap for directional casing drilling.

4. SUMMARY

Casing drilling operations could become a significant optimized drilling method for geothermal drilling in Indonesia. The ability to set the casing deeper if there is a restriction during casing running can reduce the operation time and optimize the casing placement.

For more advanced methods, directional casing drilling can give the following benefits:

1. Time required to drill the section and run the casing is reduced as the well is already cased during drilling.
2. The problematic zones are sealed, reducing losses, unstable formation.
3. The wellbore integrity is improved, thus the cement quality is better.

Based on the study discussed in this article, it is feasible to apply directional casing drilling in geothermal applications, with the recommendation below for the tools and future study:

1. Using a CDE bit can improve the bit durability without sacrificing aggressiveness.
2. The 3-block reamer is expected to give higher durability.
3. It is recommended to review the well trajectory prior to the operation to reduce the casing stress and minimize casing fatigue during the operation.
4. A future study of motor selection is required; high powered motors are necessary to deliver good torque to the cutting structures (bit and reamer).

NOMENCLATURE

BHA	: Bottom Hole Assembly
CDE	: Conical Diamond Element
PDC	: Polycrystalline Diamond Compact
FEA	: Finite Element Analysis
MD	: Measured Depth
TD	: Total Depth
ROP	: Rate of Penetration
RPM	: Rotation per Minute
WOB	: Weight on Bit
TCI	: Tungsten Carbide Insert
UCMPS	: Unconfined Compressive Strength
M/LWD	: Measurement/Logging While Drilling
IADC	: International Association of Drilling Contractors
SRPM	: Surface RPM
CH	: Cased Hole
OH	: Open Hole
DLS	: Dog Leg Severity

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