ADVANCED DYNAMICS FEA MODELLING AS A NEW APPROACH TO IMPROVE GEOTHERMAL DRILLING PERFORMANCE IN INDONESIA

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ABSTRACT

With the downturn of the oil and gas business, geothermal projects in Indonesia are picking up, corresponding with the government's commitment to increase geothermal utilization for generating electricity. In general, geothermal fields are located in the volcanic areas with hard formations like tuff and breccia. The unconfined compressive strength (UCS) vary from one field to another, in the range of 20 to more than 35 kpsi, with the volcanic rocks also having high abrasiveness and impact. Due to the limited drilling data available for geothermal areas, a "trial and error" approach usually becomes the method in selecting the bits and designing the BHA. However, this practice can lead to inefficient drilling, and generates higher costs in the end of the day as it doesn't include the effects of the dynamics of the drill string.

A comprehensive four dimensional, time-based Finite Element Analysis (FEA), run on a Unix platform, is applied for drilling optimization prior to the job. This simulation is much more accurate than static BHA modelling as all of the components are modelled in detail individually. The simulation modeled interaction between the cutting structure and formation drilled using rock mechanics derived in the lab. The result of the simulation are the drilling behavior of the all of the drill string components, including the vibrations, stress, torque, directional capability of the system, and even ROP prediction.

In Indonesia's geothermal drilling application, advanced FEA modelling has been used as a standard job planning method for bit/BHA optimization, directional capability prediction, and producing stable drilling parameter roadmap as an operation guideline. In one of the cases, only from bit optimization, this method can potentially save up to US$ 360,000 in drilling costs. With its capability, FEA modelling also has been utilized for post-job evaluation to review the drilling system and come up with better solution for the next campaign.

1. INTRODUCTION

Renewable and sustainable energy are becoming the main topics being talked about as conventional energy sources like fossil fuel have reached their peak and keep declining. As one of the sources of energy that can sustain production over longer periods, many people direct the spotlight to the utilization of geothermal energy. Becoming the part of Asia Pacific ring of fire gives a lot of opportunity to Indonesia to gain all of the positive things from geothermal. The mountains from Sumatera to the Maluku islands are really tempting to be explored and optimized as the main source of geothermal energy.

In oil and gas drilling operations, there are so many tools that can be used in the planning phase, especially when designing the bit and the Bottom Hole Assembly. If it is a development well, a wealth of data from previous wells can be used to optimize the process. Electronic logs, bit records, formation evaluation logs, and many other data can be utilized in order to get the best configuration to drill the well. An appropriate bit can be selected, or even designed for one certain application based on the rock strength analysis (RSA) of the offset wells. If the BHA seems to not getting the best result, a dynamic drilling simulation can be performed to make it better.

Even though geothermal drilling is not considered as a new thing in Indonesia, the process becomes really challenging most of the time. The information about a field to be drilled is usually limited, especially those related to the formation characteristics. Most of geothermal resources are located in mountainous areas, so that the volcanic, igneous, and metamorphic rocks become a real challenge to the drilling operation.

However, in general, the approach in selecting and designing a bit, and also optimizing the BHA that is usually performed in the oil and gas industry can be applied to geothermal drilling. The understanding of providing a good data set for drilling pre-job planning is gaining awareness among of geothermal operators. For example, sonic logs (Mason et al, 1986), which can be used to produce better formation compressive strength predictions, are now run in many fields now.

Conventionally, in designing or selecting drill bits and BHA, the bits were simulated separately from the BHA system. However in fact, the bits, driving system, stabilizers, MWD/LWD tools, and other drill string components work as an integrated unit when drilling a hole. The interaction between the formation and the bit will affect all of the components from the bottom part to the surface. An integrated BHA modeling is very critical to get the most proper and stable drilling system to drill a hole.

The Dynamic FEA Modeling can also be used to contrast the drilling dynamics of the bits and BHA options (Aslaksen et al., 2007). This time-based simulation is run on a Unix platform. The analysis is capable of simulating downhole drill string behavior with a detailed components model including bits, reamers, driving systems, and all of the BHA components up to the surface. It includes axial, lateral, and torsional vibrations check, directional capability and ROP prediction, and also provides safe drilling parameter roadmaps to be applied in the field (Figure 1). The simulation is based on the cutter-rock interaction data from lab tests and has a wide range of lithologies to make the result as accurate as possible.

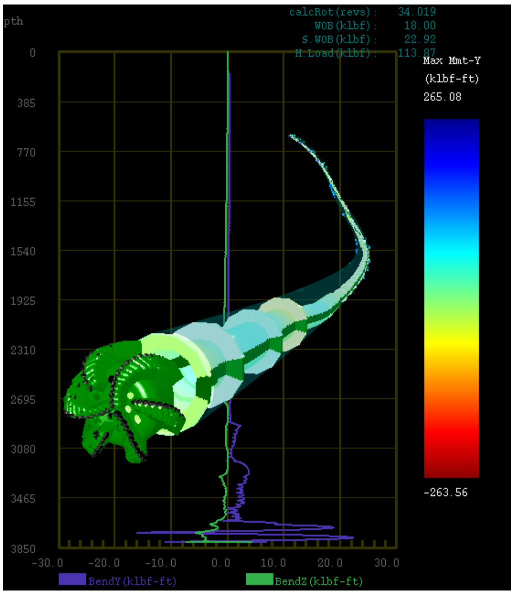

Figure 1: FEA modeling provides more accurate result in predicting drill string dynamics

With its capability to do 4D time-based simulation, this FEA modeling can be utilized on a pre-job work, like designing a bit and BHA configuration based on the stability, durability, and directional capability. A safe drilling parameter guideline can also be generated to be applied in the field. Furthermore, this simulation can also be utilized to find a root cause of an under-performing drilling system as a part of a post-job evaluation. The result of the analysis can be used to produce a recommendation for future drilling.

In Indonesia geothermal drilling, the dynamic FEA modeling has been performed in many segments of drilling operations, such as BHA optimization, bit optimization, and providing a safe drilling parameter roadmap for casing and drilling operations. There is also a case where this approach has been utilized for replicating a drilling dynamic issue to come up with a better recommendation for the next drilling campaign.

2. CASE STUDY-1: FEA MODELING OPTIMIZED BHA OPTIONS FOR 4 DIFFERENT SECTIONS

2.1 Simulation

Having a good foot print in geothermal drilling service is challenging. In order to meet the operator drilling objectives, an outstanding pre-job planning involving all of the contributors is necessary. In designing a BHA, instead of using a real trial and error method in the drilling campaign, an FEA modeling was performed to get the optimum BHA design based.

Four different hole sections, 26-in, 17.5-in, 12.25-in, and 8.5-in, were simulated with several bit and BHA options for each section in many cases of parameters, trajectory, and lithology. The objectives of the simulation were to:

- Select the best bit and BHA configuration for this application for each section.
- Optimize the best stabilizer OD size to reduce the vibration.
- Predict the directional capability of each BHA in every section.
- Generate a stable drilling parameter roadmap to be used as a guideline in the field.

The BHA selection was based on:

- Stability. The BHA with the lowest lateral, axial, and torsional vibration generated by the system (bit, driving system, etc.) will be selected.
- The directional capability. The DLS generated by the selected BHA needs to meet the requirements of the operator. The BHA will be selected also based on the directional tendency.

In FEA modeling, the nodes in the finite element mesh that represent the cutting structure of bit are governed by rock mechanics and behave in a highly nonlinear manner. Rock mechanics data are empirically derived in a laboratory test program and implemented within the model to establish an accurate rock/bit dynamic output (Aslaksen et al. 2007). Figure 2 shows how the bit modeled on the simulation.

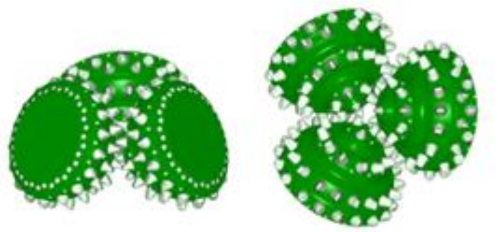

Figure 2: Model of 17.5-in TCI bit for the simulation

Taking an example of 17.5-in section BHA optimization, there are four main BHA configurations that have been simulated in this process as shown in Figure 3. The main differences between these BHAs are the stabilization and the placement of shock absorbers. From these configurations, more stabilizer OD sensitivities were performed, both for the motor stabilizer and string stabilizers. In all, 48 different BHA configurations were simulated.

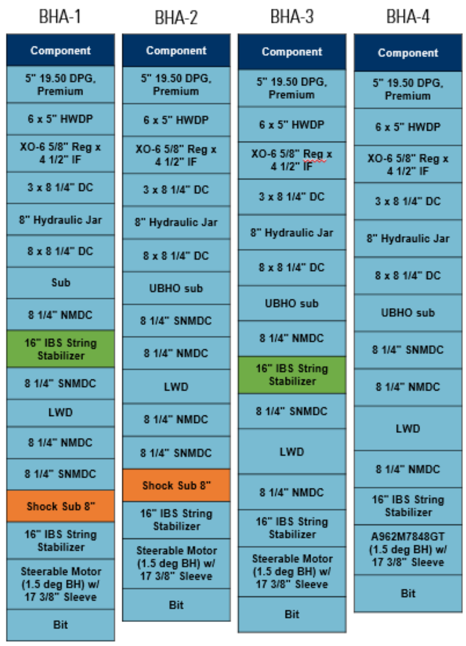

Figure 3: Four main simulated BHAs for 17.5-in section

The bit and BHA configurations were then simulated using distinct parameter WOB and RPM sets, for two different depths, representing the building section and the tangent section.

Based on simulation results for drilling in rotating mode, the main BHA-4 (BHA without string stabilizer above the LWD tools and shock sub) generated lower vibration levels compared to other main BHA options. The shock sub on the BHA-1 and BHA 2 increased the bit and LWD tool axial and lateral vibration. All of BHA options generated low levels of stick/slip with similar trends.

Axial, lateral, and torsional vibration comparison for all of simulated BHA are shown in the pictures below (Figures 4-6). Also in sliding mode, BHA-3 and BHA-4 with all of the sensitivity generated lower vibration levels than the BHA with the shock sub. Increasing the WOB can also increase the vibration level of the BHA.

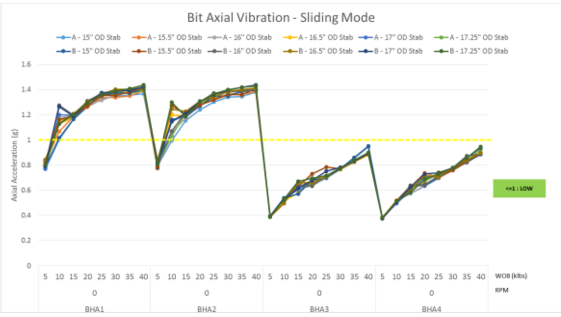

Figure 4: Axial Vibration result of 17.5-in section

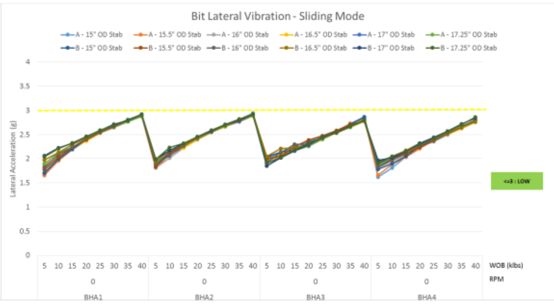

Figure 5: Lateral vibration for 17.5-in section

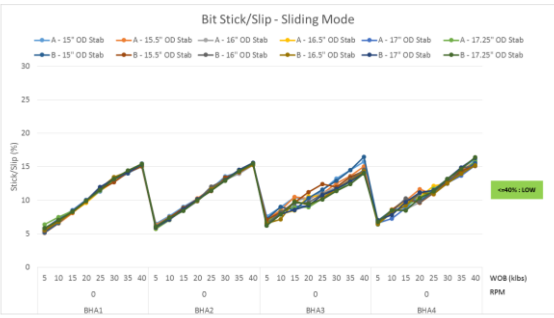

Figure 6: Stick/slip for all simulated BHA are in low level

Based on all vibration comparisons, there are four possible BHAs that are more stable compared to other options both at shallower (out of shoe) and deeper (at TD) depth.

- BHA 4 : Without String Stabilizer, Without Shock Sub; Motor with 1/8" Under gauged (17.375") sleeve stabilizer OD (A); String stabilizer with 15" OD
- BHA 4 : Without String Stabilizer, Without Shock Sub; Motor with 1/4" Under gauged (17.25") sleeve stabilizer OD (B); String stabilizer with 15" OD
- BHA 4 : Without String Stabilizer, Without Shock Sub; Motor with 1/8" Under gauged (17.375") sleeve stabilizer OD (A); String stabilizer with 17.25" OD
- BHA 4 : Without String Stabilizer, Without Shock Sub; Motor with 1/4" Under gauged (17.25") sleeve stabilizer OD (B); String stabilizer with 17.25" OD

Those 4 recommended BHAs then can be compared to contrast the vibration levels and bending stress experienced at the drill string. Finally, BHA 4 with 1/8-in under gauged stabilizer at the motor (17.375-in) and 15-in string stabilizer was chosen as the most recommended BHA. This BHA generated low levels of axial and lateral vibration, however it produced medium to high levels of stick/slip at the LWD tools. To reduce the risk of having tool failure, a stable parameter roadmap (Figure 8) based on thresholds listed in Figure 7 was provided to the operator as a drilling guideline.

Average LATERAL Vibration Level	Bit & Reamer (g)	MWD
Low	< 3	< 1
Medium	≥3 <5	≥1 <3
High	≥5 <12	≥3
Very High (cutter breakage)	≥12	N/A

Average AXIAL Vibration Level	Bit & Reamer (g)
Low	≤1
Medium	1 ≤ 2
High	2 ≤ 4
Very High	>4

Bit/Reamer Stick-Slip Level	STICK SLIP INDEX (%)
Low	0-40
Medium	40-80
High	80-100
Severe	>100

Figure 7: Vibration threshold for parameter roadmap

Top – closed to previous casing shoe

WOB & RPM Sensitivity Plot for Axial Acc.(g), Lateral Acc.(g), Stick_Slip(%)

WOB(klbf)						
40	1.00	0.86	0.86	0.86	0.94	1.00
35	0.81	0.70	0.74	0.74	0.85	0.87
30	0.63	0.59	0.61	0.68	0.69	0.76
25	0.49	0.49	0.56	0.55	0.55	0.64
20	0.39	0.40	0.42	0.41	0.45	0.51
15	0.28	0.29	0.30	0.31	0.33	0.35
10	0.18	0.19	0.20	0.20	0.21	0.22
5	0.09	0.09	0.10	0.10	0.10	0.11
RPM	30	40	50	60	70	80
FlowRate	900	900	900	900	900	900
S.R.	0	0	0	0	0	0
TFA	0	0	0	0	0	0

All, Lat-Sti, Axi-Sti, Axi-Lat, Sti(60), Lat(5), Axi(2), Stable

RPM (rev/min)	WOB (klbs)
30	5-40
40	15-30
	40
50	5-40
60	5-40
70	5-40
80	5-40

Bottom – closed to section TD

WOB & RPM Sensitivity Plot for Axial Acc.(g), Lateral Acc.(g), Stick_Slip(%)

WOB(klbf)						
40	0.84	0.90	1.00	1.65	1.73	1.82
35	0.71	0.78	0.85	1.41	1.48	1.57
30	0.60	0.65	0.71	1.17	1.23	1.31
25	0.50	0.53	0.58	0.96	1.00	1.08
20	0.40	0.43	0.45	0.77	0.80	0.92
15	0.30	0.32	0.34	0.58	0.61	0.69
10	0.21	0.23	0.24	0.41	0.44	0.45
5	0.12	0.12	0.13	0.22	0.23	0.24
RPM	30	40	50	60	70	80
FlowRate	900	900	900	900	900	900
S.R.	0	0	0	0	0	0
TFA	0	0	0	0	0	0

All, Lat-Sti, Axi-Sti, Axi-Lat, Sti(60), Lat(5), Axi(2), Stable

RPM (rev/min)	WOB (klbs)
50	5-40
60	10-40
70	5-40
80	5-40

Stick/slip at motor/MWD will be at high level (80 – 100%)

Figure 8: Drilling parameter roadmap for 17.5-in section

Directional analysis also has been performed for all of the wellbore sections. The pictures below (Figure 9) shows the directional capability simulation results for the 8.5" section. The simulated rotary BHA has building and walking to the right tendency with the ability to generate up to 1.8 deg/100 ft DLS with 120 SRPM and 15 klbs of WOB.

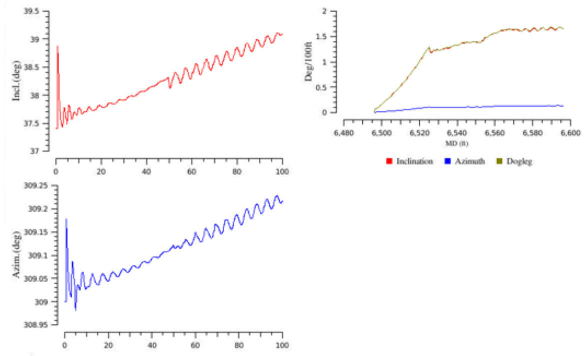

Figure 9: Example of directional capability simulation result for 8.5-in section

2.2 Field Results

All of optimized BHA recommendations for each segment were applied in the field. There was no issue with the drill string dynamic behavior. The BHA was stable and generated satisfying ROP. Most of the bit used in this drilling operation were pulled out of hole with no indication of experiencing severe vibration and came out in excellent condition. The directional objective was achieved. The drilling parameter roadmap for every section was followed and proven to be effective during the execution.

3. CASE STUDY-2: IMPLEMENTING FEA MODELING FOR GEOTHERMAL BIT UTILIZATION BREAKTHROUGH

3.1 Roller Cone Bit Limitation

The nature of geothermal field rock formation is high compressive strength, very abrasive formation, and high impact that can damage a PDC bit cutter easily. It is more efficient to chip and crush the hard formation with a roller cone bit (Figure 10), especially with a tungsten carbide insert (TCI) than shear it with a PDC.

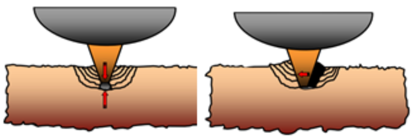

Figure 10: An insert of roller cone bit fracturing the formation, then removing it as the bit drills

It is already well-known that the three cone bit rotates with the bearing inside the cone (Figure 11). As the number of the rotations of the bearing accumulates, the reliability of the seal and the bearing to keep the rotation is reduced. This limitation makes it necessary for the roller cone bit to be pulled out if the number of revolutions has almost reached its limit.

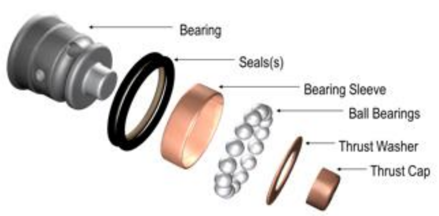

Figure 11: Bearings inside a roller cone bit

3.2 Innovative Conical Diamond Element Bit

In geothermal applications that have a hard-to-drill formation, it usually takes more than 1 bit to drill one section. Increasing the number of trips to pull out and run in back a bit inside a hole will increase the drilling cost. A highly durable PDC bit can help to reduce this drilling inefficiency (Iskandar et al., 2016). However, a conventional PDC bit might not be suitable for certain geothermal applications, especially those with extremely hard and abrasive characteristics. Damaged PDC cutters can potentially trigger bit change out trips.

A special cutter called a conical diamond element (CDE) was implemented on the PDC bit body to improve the impact and wear resistance. The unique 3D-shaped of this cutter make the diamond table is thicker than a normal PDC cutter. The thickness of the cutter is proven in the lab to improve the wear resistance up to 22% and doubled the impact resistance (Durrand et al., 2010).

The plowing mechanism of a CDE bit is more efficient and durable than shearing action of a PDC bit. The sharp conical geometry helps to concentrate the point loading and causes to rock to fail more efficiently. The cutter-rock contact point experiences very high stress that increases the fracture generation rate, and this can be achieved by applying less force compared to normal PDC cutters. This also reduces the reactive torque produced by the bit and will give better tool face control in order to increase the directional capability of the drill string.

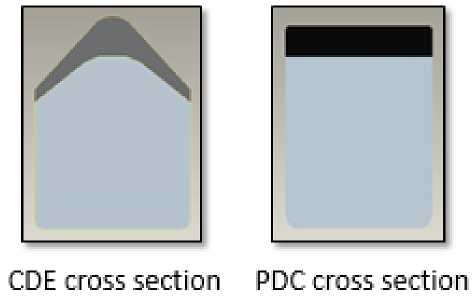

Figure 12: Comparison of PDC and CDE cutter cross section

A CDE can be customized based on the application (Figure 13). It can be act as a back-up cutters for a conventional PDC cutters to maintain the aggressiveness, combined with the conventional in the primary row, or replaced the PDC all over the blades to improve the durability significantly.

Figure 13: Variety of a CDE bit

The very first CDE bits were run in an Indonesia geothermal field with 20 – 35 ksi of formation compressive strength in 12.25-in and 9.875-in hole section with the objective of improving ROP and reducing the bit trips. A proper pre-job planning was set up to achieve the drilling objective, included performing drilling dynamics FEA modeling to check vibration trends of the bit and develop a drilling parameter roadmap. A seven bladed PDC bit with implemented conical diamond element on the secondary row (Figure 14) is considered as the best option to drill the 12.25-in and 9.875-in sections. The CDE element on the back-up cutter will protect the conventional cutter in the front from impact risk, but the ROP will not be sacrificed.

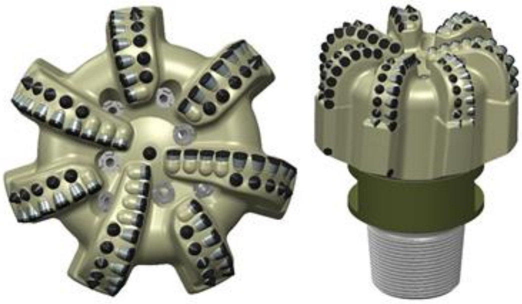

Figure 14: 12.25" section CDE bit to be run

3.3 FEA Modeling of CDE bit

Based on a previous FEA modeling simulation study for a different well in Indonesia, a CDE bit can generate much lower vibration levels compared to a TCI bit that usually been used for this application (Figure 15). It also can produce much higher ROP then a TCI bit (Figure 16).

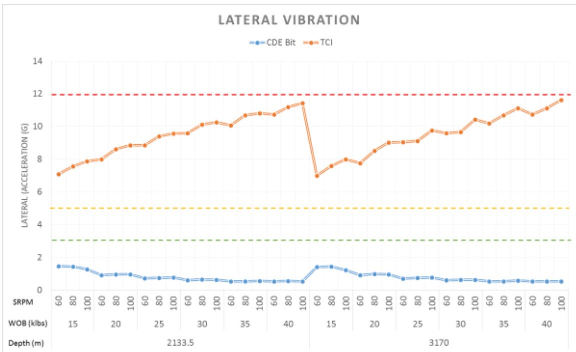

Figure 15: CDE bit generated lower lateral vibration than TCI

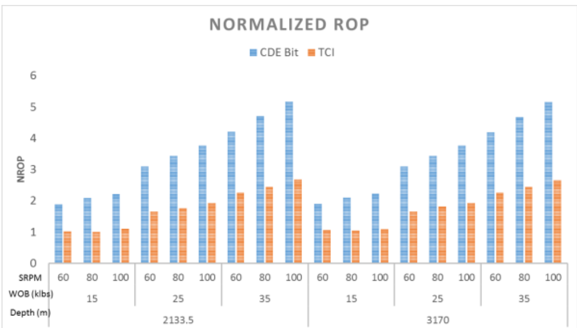

Figure 16: Based on FEA modeling simulation, CDE bit can double the ROP of TCI bit.

The pre-job simulation with an actual BHA and trajectory was then performed for the 12.25-in and 9.875-in sections. Different sets of parameters and depths were simulated to find a stable parameter roadmap. Based on the rock strength analysis, high compressive strength volcanic rock (20 – 30 kpsi) was used as a formation to be drilled. An example of bit and model for the simulation is shown in Figure 17. The BHA used for the simulation (Figure 19) is shown in Figure 18.

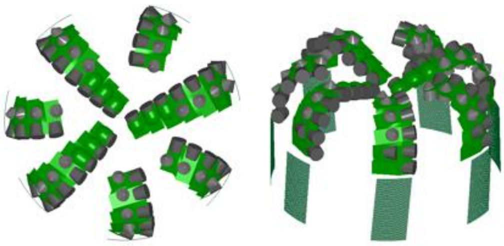

Figure 17: CDE bit model in the simulation

12.25" BHA

Component
5" 19.50 DPG, Premium To Surface
6 x 5" HWDP
3 x 6 ¾" DC
8" Accelerator
3 x 8" DC
Hydraulic Jar
7 x 8" DC
1 x 8" Pony NMDC
MWD/LWD
8" Pony NMDC
Steerable Motor (11 1/2" Sleeve. 1.5 ABH, Flapper NP)
12.25-in CDE Bit

9.875" BHA

Component
5" 19.50 DPG, Premium To Surface
12 x 5" HWDP
6.5" Accelerator
3 x 6 1/2" DC
Hydraulic Jar
1 x 6 1/2" DC
6 13/16" NMDC
MWD/LWD
6 3/4" Pony NMDC
Steerable Motor (9 3/8" Sleeve. 1.15 ABH, Flapper NP)
9.875-in CDE Bit

Figure 18: Simulated BHA for 12.25-in and 9.875-in sections

Depth MD (ft)	5050	7874
BHA Index	BHA1	
WOB (klbs)	15,20,25,30,35,40,45	
Surface RPM	60,80,100	
Flow Rate (gpm)	600	
Steering Mode	No	
Tool Face Angle (deg)	0	
Mud Wt. (ppg)	8.800	
Formation Compressive Strength (kpsi)	20 - 30	

Figure 19: Simulation setting for 9.875-in section

For both sections, CDE bits generally produced low levels of lateral, axial, and torsional vibration, even when drilling in a very hard formation (Figure 20). This stability can save the life of the bit and make the bit drill to TD in one run.

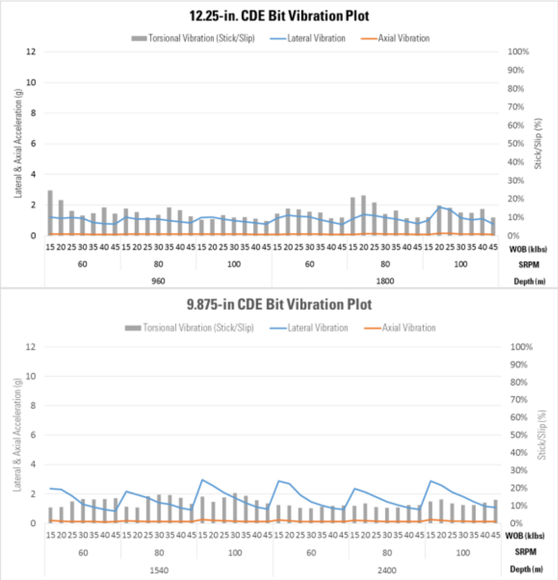

Figure 20: Bit vibration of 12.25-in and 9.875-in

Using the similar threshold as BHA optimization simulation, below is the drilling parameter roadmap for the CDE bit in this application (Figure 21).

12.25" Section

WOB(klbf)				All
45	0.79	0.89	1.00	Lat-Sti
40	0.70	0.79	0.86	Axi-Sti
35	0.61	0.69	0.76	Axi-Lat
30	0.52	0.58	0.64	Sti(40)
25	0.43	0.48	0.52	Lat(3.0)
20	0.34	0.37	0.40	Axi(1.0)
15	0.25	0.27	0.28	Stable
RPM	60	80	100	

9.875" Section

WOB(klbf)				All
45	0.84	0.92	1.00	Lat-Sti
40	0.75	0.82	0.89	Axi-Sti
35	0.65	0.72	0.79	Axi-Lat
30	0.56	0.62	0.68	Sti(40)
25	0.47	0.52	0.57	Lat(3.0)
20	0.38	0.42	0.46	Axi(1.0)
15	0.29	0.31	0.34	Stable
RPM	60	80	100	

Figure 21: Drilling parameter roadmap as a guideline

3.4 Field Results

As expected based on the simulation, the drilling execution with using these CDE bits was successful (Noviasta et al., 2017). No significant shock and vibration was observed that could damage the bit and the tools on the drill string. The bit maintained the exact inclination requirement from the operator, which was 30°. In line with the FEA modeling results that the bit could double the ROP generated by a TCI bit, a CDE bit could achieve a very high instantaneous ROP compared to TCI run on the offset well. As an outstanding result, even with a control drilling, both sections can improve the ROP up to 20% compared to the offset. Moreover, after drilling in very harsh condition, the bits were pulled out of the hole in very good condition (Figure 22) with the dull grading of 0-0-NO, which made this bit re-runnable for future drilling.

Figure 22: 9.875-in CDE bit post run condition

4. CASE STUDY-3: PROVIDING A SAFE PARAMETER ROADMAP FOR CASING DRILLING OPERATION

4.1 Casing Drilling in Geothermal

Instead of using drill pipe to connect the BHA and the surface, casing drilling operations utilizes the casing. The simplest reason casing drilling technology is utilized is that it eliminates at least one trip for running the casing. It also gives more assurance to be able to run the casing if there is an obstruction during the casing running process.

A geothermal operation had an issue with collapsing formation that generated some obstacles during 13.375-in casing running operation. To solve the situation, the non-directional casing drilling system was proposed to enable full casing rotation while applying weight from the surface. The obstruction can be drilled out while driving the casing down to bottom. The non-directional casing drilling system consists of drillable alloy casing bit that attached to the casing. Similar to the PDC bit, this casing bit has PDC cutters placed across the blades, ranging from 13 to 19 mm and available in standard or premium grades (Figure 23). The bit body is made of a special alloy that allows it to be drilled out by any standard PDC bit or roller cone milled tooth bit after the casing bit has drilled to TD, and the casing has been cemented in place.

Figure 23: The casing bit can be drilled out after the casing has been cemented at the TD

4.2 Simulation

The bit and BHA model for the simulation can be seen on the below pictures (Figure 24). A four-blade casing bit with 19 mm cutters is used to simulate the drilling behavior of the BHA.

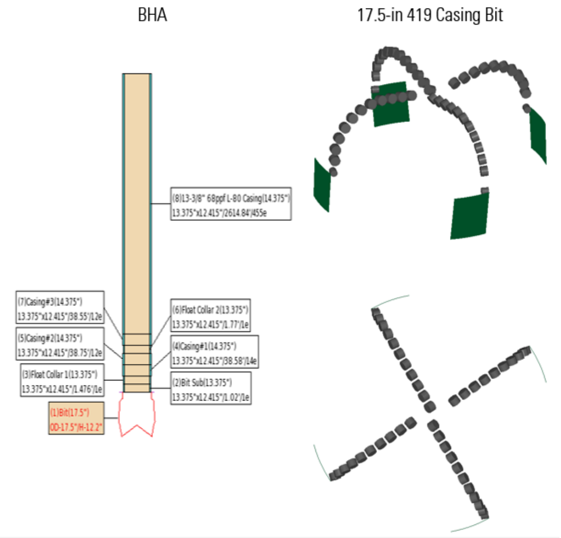

Figure 24: BHA and bit model in the simulation

Based on the vibration analysis, the BHA generated low axial vibration levels, low to medium lateral vibration, and generally low levels of torsional vibration. The vibration plot for all simulated parameters is shown in Figure 25. a drilling parameter roadmap was generated as a guideline to be applied in the field and is shown in Figure 26. It is highly recommended to maintain the parameters on the green area of the roadmap.

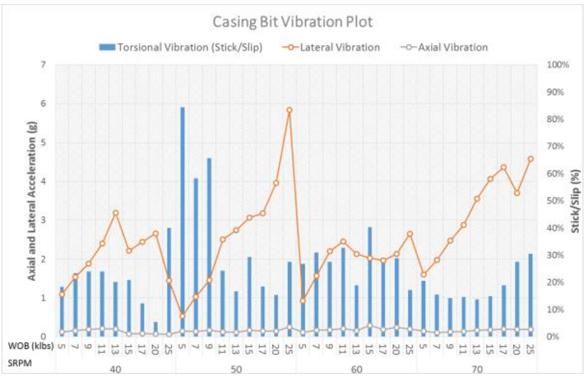

Figure 25: Vibration plots for 13.375-in casing drilling operation

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

Figure 26: Casing drilling parameter roadmap

4.3 Field Results

The casing drilling operation in this geothermal field was successful (Setiawan et al., 2017). The operator can set the casing 320 m deeper than the point of casing taking significant weight. The casing drilling/reaming capability helped cutting the obstruction with low vibration levels. The biggest value to the customer is its capability to save a well by enabling casing to be set as deep as possible with good stabilization.

5. CASE STUDY-4: POST-RUN EVALUATION USING FEA MODELING

5.1 Simulation

One of the most satisfying things of drilling dynamics FEA modeling is the capability to figure out the root cause of dynamic drilling problems, for example if there is a tool failure. The simulation is capable in duplicating the condition of the field by matching some parameters, like ROP, torque, and even vibration trends. Calibrating the model is very essential to the post-job evaluation process and might take some time.

After a calibrated model is found and considered as the best replication of the field condition, several cases that might be contributing to the cause of the failure are then simulated by the software. Based on the simulation result, a recommendation is made to be applied in the next drilling program (Figure 27). The cycle should never stop seeking to find improvements in the drilling operation.

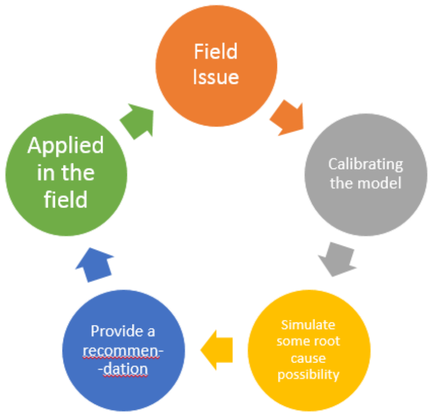

Figure 27: Simulation cycle of improvement

In one of the post-drilling evaluations, the operator found out that the bit bouncing was becoming an issue in the operation. The bit axial movement led the bit to have more insert damage and reducing the ROP in general. At one of the wells, the 24" bit came out of the hole with 2-3-BT dull grading. Figure 28 below shows the bit condition at the surface.

Figure 28: 24-in bit dull grading (2-3-BT-A-E-1-WT-TD) after pulled out of hole with based BHA

FEA modeling was performed to check the dynamics of the BHA and found out that the bit axial vibration and the bit axial displacement was affecting the drilling operation. Several new BHA options were simulated and it was discovered that placing one joint of 9 ½-in drill collar between the string stabilizer and the shock absorber reduced the BHA vibration by 38%. The comparison of the lateral and axial vibration history plot with actual BHA setup and the optimized BHA are shown in the picture below (Figure 29).

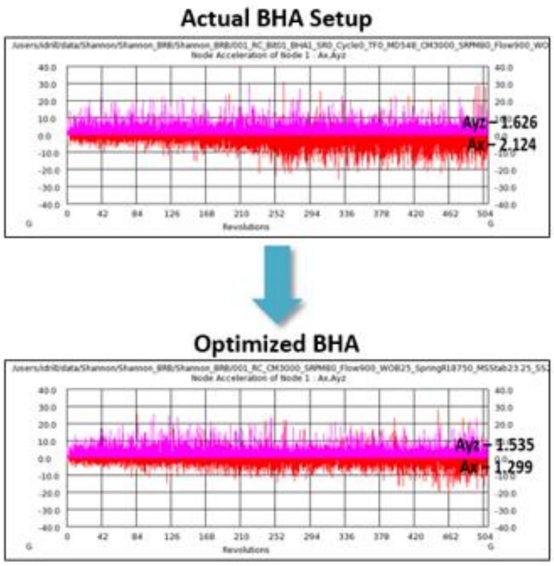

Figure 29: Placing 1 joint 9 ½-in DC between the shock absorber and string stabilizer can reduce the bit axial vibration.

5.2 Field Results

The recommendation from FEA modeling was implemented in the next drilling operation. The bit bouncing issue was reduced as the bit was pulled out of the hole in better condition than in the previous well. The dull grading of the 26-in bit run with the optimized BHA was 1-1-WT with around 30% of ROP improvement.

6. CONCLUSION

The drilling dynamics FEA modeling has proven to accurately predict, plan, and evaluate drilling performance in geothermal drilling in Indonesia. Instead of using the trial and error method, the simulation can save more time in designing the bit and BHA configuration. With the capability of calculating the stress distribution at the BHA and predict the fatigue accumulation on it, FEA modeling also will be very helpful if there is an under-performed drilling system to be evaluated and improved.

NOMENCLATURE

BHA	: Bottom Hole Assembly
FEA	: Finite Element Analysis
MD	: Measured Depth
OD	: Outer Diameter
PDC	: Polycrystalline Diamond Compact
POOH	: Pulled Out of Hole
ROP	: Rate of Penetration
RPM	: Revolutions per Minute
SRPM	: Surface Revolutions per Minute
TCI	: Tungsten Carbide Inserts
TD	: Total Depth
UCS	: Unconfined Compressive Strength
CDE	: Conical Diamond Element

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