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## Design Optimization and Application of Hybrid Bit to Reduce a Well Cost in Geothermal Field

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### Abstract

Hybrid bit is one of the innovations developed for very hard and abrasive formations such as in geothermal field. This bit eliminates the risk of losing cones, reduces tripping time, and increases ROP to reduce the well cost. The stage of data processing by calculating the UCS formation using D-BOS software and design optimization based on 9-7/8" bits simulations in granodiorite formations. The 1st phase was to determine the 4 best out of 7 hybrid bit designs that were selected from the highest ROP obtained, the most stable cutter cutting force, and the lowest vibration by comparing the results of FEA modeling of 1 ft drilling simulation. The 2nd phase is to choose 1 of the best from the 4 selected by doing 50 ft of drilling dynamics simulation which is assessed by directional capability, the durability, and the lowest MSE. In this study to improve drilling optimization in geothermal field, it was found that the Z616 hybrid bit design was the most optimal one. Based on 1st phase simulation, this bit was able to produce ROP of 6.38 m/hr, a stable cutter cutting force, very low average lateral 2.109 g and axial vibration 0.329 g. Furthermore, for the 2nd phase simulation of 50 ft, seen from the comparison of directional capability, this bit has a 0.91 deg/100 ft DLS in rotating mode, and 6.5 deg/100ft DLS in sliding mode means quite stable when drilling in rotary mode and easy to make some angle in slide mode. By its durability, the average value of lateral acceleration is 10 g, and the lateral force is 6 klbf. By MSE side, this bit also produces the lowest average MSE value of 769 psi. From the economic view, this bit can save USD 198,625 - USD 564,712 of a well cost.

## INTRODUCTION

Bit usage in geothermal drilling have been dominated by TCI (Tri-Cone Insert) type due to formation hardness and abrasiveness. Even though this bit is suitable for geothermal type, but this bit has some issues of losing cone, bit lifetime and tripping time lead to high well cost geothermal drilling.

PDC (Polycrystalline Diamond Compact) type keeps improving their technology to provide better than TCI, thus one of the innovations is creating Hybrid Bit. This bit is a combination between PDC type and impregnated type that works with crushing altogether with plowing action (Noviasta et al., 2017). This bit can eliminate all those TCI weaknesses. By drilling faster, has no cone and high durability makes this bit usage is much longer and can reduce the geothermal well cost. Stinger conical diamond element is the key of this type of hybrid bit (Gunawan, Krisnanto, Mardiana, Noviasta, & Febriarto, 2018). When stinger element and PDC cutter were tested on 30.000 psi granite rocks compressive strength, stinger element can drill 30% longer in compare with PDC cutter without any broken element (Azar et al., 2015).

The process began by taking all field and historical well data related to geothermal rocks especially in granodiorite formations which is solid and abrasive, then a simulation was conducted by drilling dynamic software. The result then was compared to existing field data to get the well cost economic view.

## METHODS

Figure 1 shows the procedure of the research. D-BOS software was used for rock strength assessment through gamma ray and sonic log of the offset well. While IDEAS software was used for modeling and simulation of drilling dynamic of seven hybrid bit designs. The selection was conducted to find the best design. It consisted of two selection phases to simplify the primary objective of drill bit usage in hard formation, the first phase parameter are most related to drilling cost and the second phase is an additional but also important for bit selection (Azar et al., 2015). In the first phase, the best four designs were selected based on the highest ROP, the lowest vibration, and the stability of cutter cutting force by one ft drilling simulation. In the second phase, the best design of the four selected design was chosen based on directional capability, durability, and Mechanical Specific Energy (MSE) value from 50 ft drilling dynamic simulation. The bit optimization design is limited by blade counts (6, 7, and 8) altogether with primary cutter size 13 mm and 16 mm refer to bit manufacture standard for hard formation and abrasive (Finger & Blankenship, 2010). In addition, the economic view of the chosen hybrid bit application was determined and compared with TCI bits application.

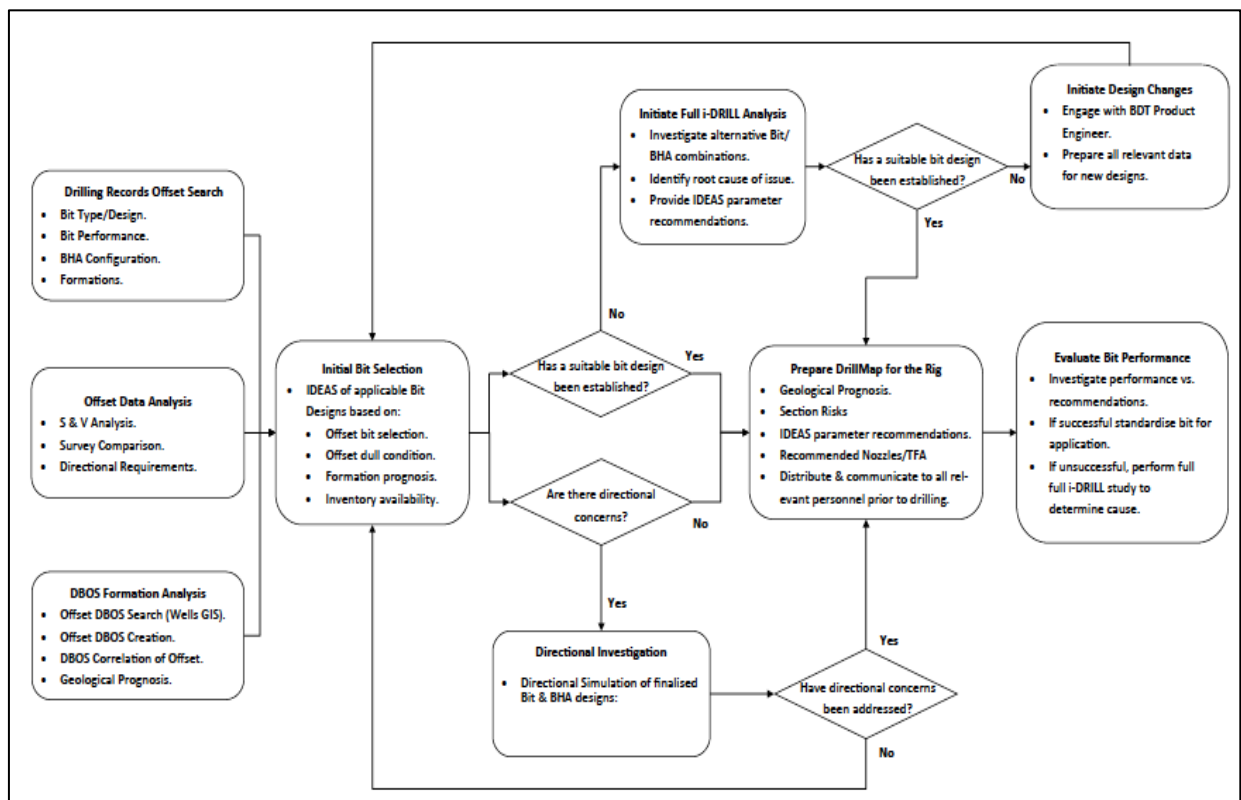


Figure 1. Flow Chart Hybrid Bit Design Optimization (Noviasta et al., 2017).

## RESULTS

i-Drill is the simulation service to analyze drilling dynamics in drilling operation using IDEAS platform software which is based on Finite Element Analysis (FEA). FEA is commonly used to solve engineering problems in where the exact/analytical solution could not solve them. The principle of FEA is dividing an object or system into several parts. These parts are called element that each element with the others is connected with a node. Then, mathematical equations that represent objects or systems are built to solve the problem. Drilling dynamics such as using this software, such as lateral, axial, and torsional vibration, lateral force, etc. are the output of the IDEAS simulation.

Granodiorite is one kind of volcanic rocks that seldom appears in geothermal field. This rock is challenging to drill as in some areas to drill this granodiorite might take times, bits and of course well cost. Granodiorite is one type of intrusive igneous rock which is deep below the surface with high pressure and high temperature, so that it has a high level of hardness and crystallinity. Based on the Bowen reaction series diagram, this rock arranged by 65%-90% Plagioclase and 20%-60% Quartz. Both minerals are resistant to the weathering process.

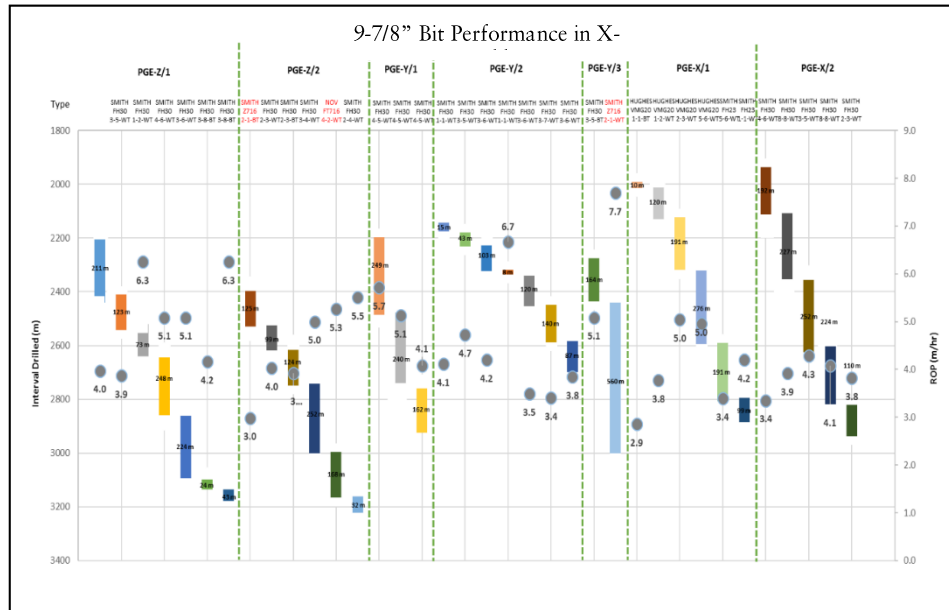


Figure 2. Run summary 9-7/8" bit performance in granodiorite formation.

Normally this granodiorite rock is found in 9-7/8" section of big hole geothermal wellbore type. Based on well history from several field to finish one section of 9-7/8" normally it takes 4-6 TCI bit to drill. The bit itself comes out to surface with critical condition and bad grade out with severe under gauge. The ROP (Rate of Penetration) itself to drill this rock was so poor averagely from 3 to 5 m/hr as shown in [Figure 2](#).

Based on the results of post-run review, hybrid bit Z716 in PGE-Z/2 well able to drill in depth intervals of 2400-2500 mMD (125 m) with bit time of 41.9 hrs, grading in New Bit and grading out 2-1-BT-N-X-I-WT-DTF, with ROP of 2.98 m/hr. Referring to RSA software calculation using gamma ray and sonic log as an input this well has granodiorite type with 23-28 kpsi UCS (Unconfined compressive Strength) and high abrasive type seen from the red colour in section “formation” and “formation abrasion” as shown in [Figure 3](#).

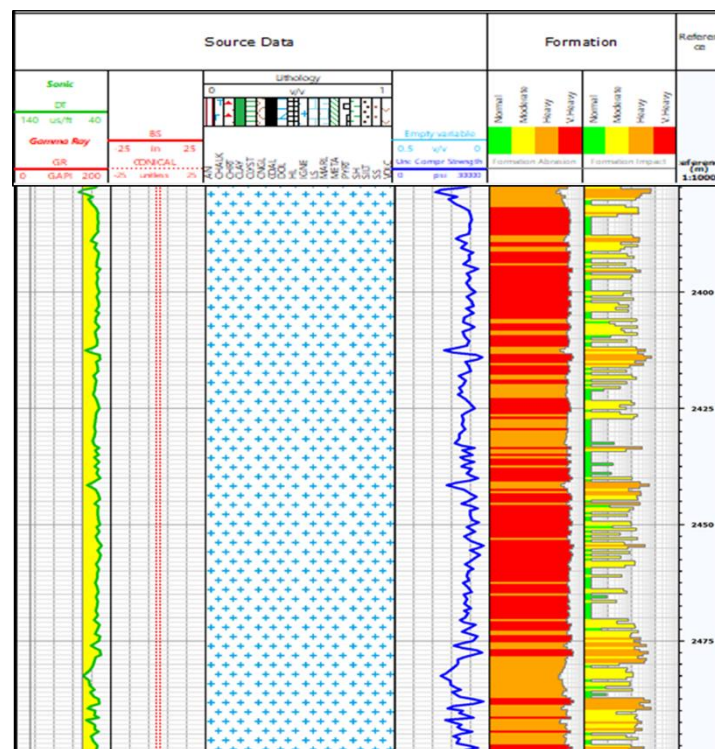


Figure 3. Rock strength analysis (RSA) results of PGE-Z/2 well.

The initial selection of bit type candidates adapts to the character of rock hardness and formation abrasion level, so that it is only carried out on seven-bit types with variations of 6, 7, and 8 blades and 13 mm and 16 mm primary cutter sizes. The difference in number of blades, size of primary cutter, position of stinger, length of gauge pad length (GPL), number of cutter and number of stingers will affect the characteristics and performance of bits. Table 1 explains the differences in detail from the seven-bit type candidates. The BHA (bottom hole assembly) is common geothermal directional BHA for J-Type well 40 deg inclination. The drilling parameters inputted for the purposes of static and dynamic bit selection simulations are as follows: WOB (weight on bit): 25 klbs; SRPM: 50 RPM; RPG motor: 0.29 rev / gal; Flow Rate: 500 GPM; Total RPM: 195 RPM; Depth of 2430 mMD; Revs: 300 revs (1 ft) for static bit selection and 50 ft for dynamic bit selection.

Table 1. Bit design detail from seven candidate bit.

No	Bit Types	Blades	Primary Cutter Size (mm)	Stinger Position	GPL (in)	Cutter Counts	Stinger Counts
Bit-1	Z616	6	16	Central, Secondary	3	41	31
Bit-2	Z613	6	13	Primary, Secondary	3	23	34
Bit-3	Z716-A	7	16	Primary, Secondary, Central	3	28	52
Bit-4	Z716-B	7	16	Secondary	3	38	22
Bit-5	Z713	7	13	Central, Secondary	3	50	27
Bit-6	Z816	8	16	Secondary	3	51	34
Bit-7	Z813	8	13	Secondary	3	64	21

The main objective of the first phase simulation is to determine the four best designs out of seven hybrid bits that are selected from the lowest vibration, the most stable cutter cutting force, and the highest ROP obtained by comparing the simulation results of FEA drilling dynamics modeling from 1 ft simulation.

From ROP comparison, Bit-1 (Z616), Bit-2 (Z613), Bit-3 (Z716-A), Bit-4 (Z716-B), Bit-5 (Z713), Bit-6 (Z816), and Bit-7 (Z813) reached 6.38 m/hr, 4.06 m/hr, 4.71 m/hr, 5.88 m/hr, 6.42 m/hr, 4.45 m/hr, and 4.65 m/hr. This means that Bit-1, Bit-3, Bit-4 and Bit-5 are the best four from seven designs by ROP achievement shown in Figure 4. Combination of blade count, primary cutter size, cutter counts, and stinger counts affected this result. Basic concept of ROP by more blade counts create less aggressive but durable in bit level of acceleration, is not always right anymore because there are several influences from other factors.

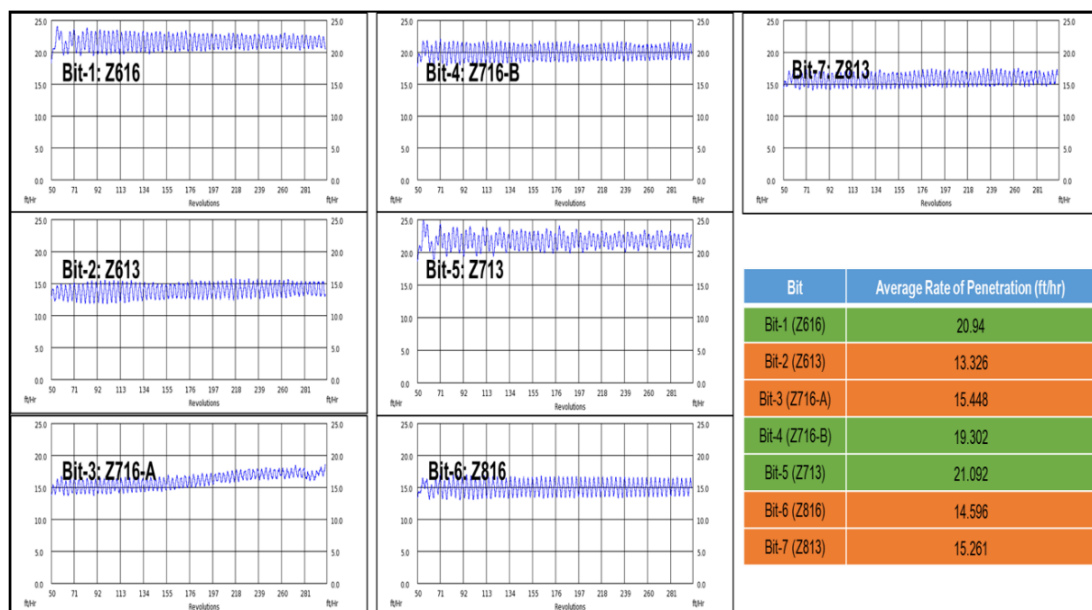


Figure 4. Simulated ROP Result.

By cutter cutting force shown in Figure 5 Bit-1 (Z616), Bit-4 (Z716-B), Bit-5 (Z713), and Bit-6 (Z816) shown that these types of bit design are four bits with the most stable cutter cutting force compared to



the other bits. Number of cutter and stinger are significantly important to this cutter cutting force distribution.

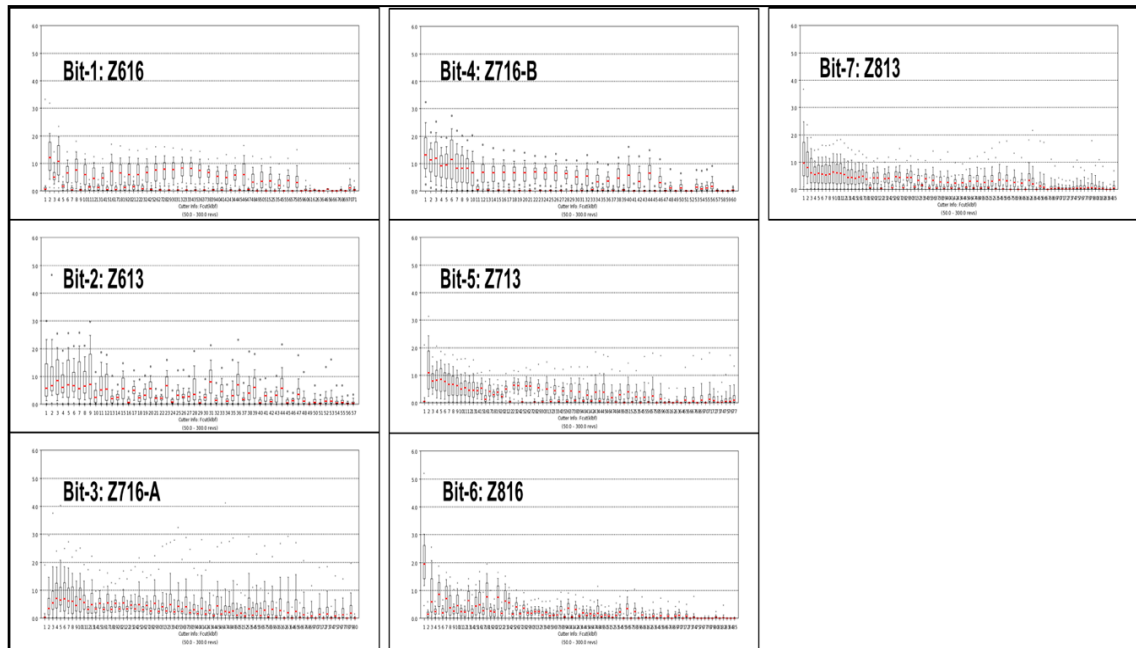


Figure 5. Cutter cutting force distribution comparison.

Third variable in the first phase selection is vibration. Stability is one of the parameters that must be seen in the process of selecting bits. If a bit experiences high vibration during drilling, then the ROP produced by these bits will not be optimal. Collisions which are experienced by bits in the wellbore due to the vibrations can also cause the cutting structure to break faster so that the bit efficiency over time decreases (Maitre, 1989). From the simulation of lateral vibration and axial vibration shown in Figure 6 and Figure 7, Bit-1 (Z616), Bit-2 (Z613), Bit-4 (Z716B), and Bit-6 (Z816) are the most stable bit rather than others with very low average lateral of 2.109 g and axial vibration of 0.329 g.

Based on a comparison of drilling dynamics FEA modeling from seven different types of hybrid bits using ROP, cutter cutting force, and vibration comparison, four of the best designs will be simulated in the second phase. The four bits are Bit-1 (Z616), Bit-4 (Z716-B), Bit-5 (Z713), and Bit-6 (Z816).

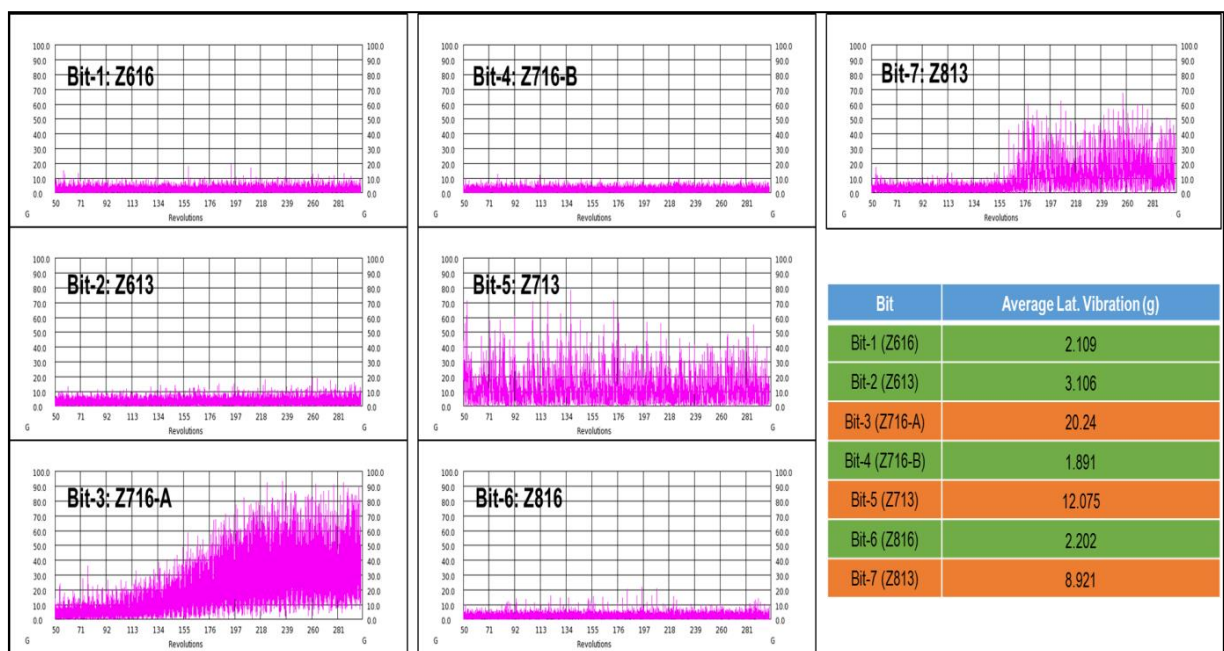


Figure 6. Lateral Vibration Comparison.

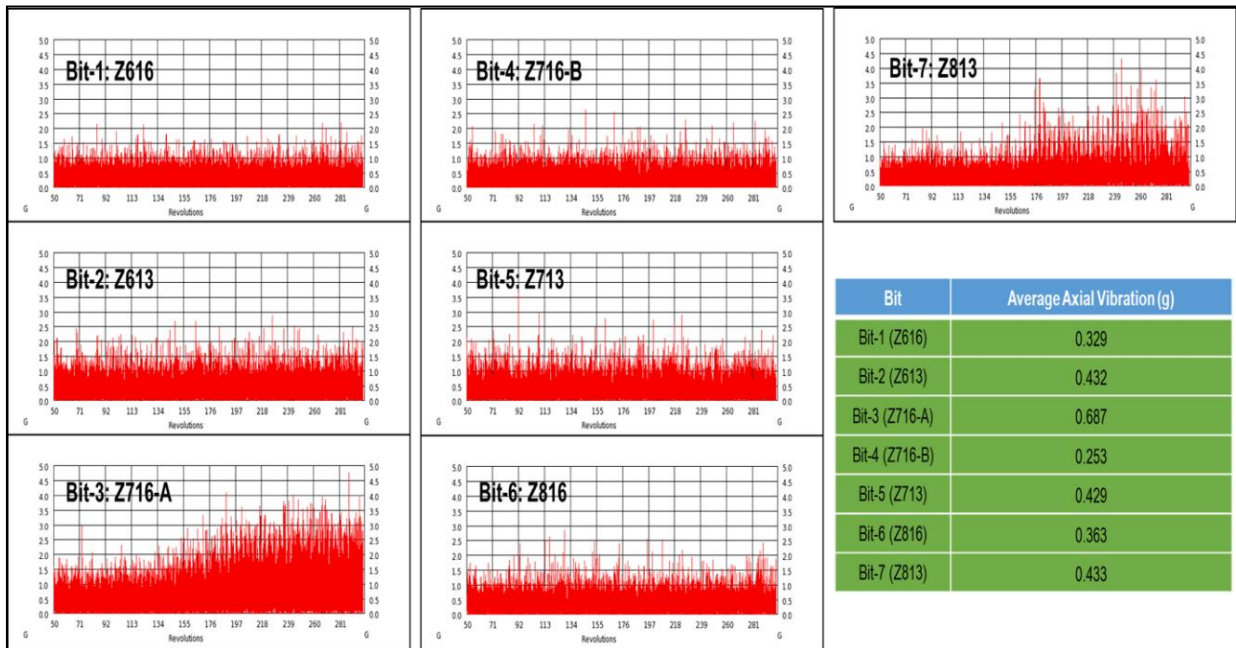


Figure 7. Axial vibration comparison.

The second phase is to choose the best design of the four selected designs by carrying out simulation of 50 ft drilling dynamics assessed from directional capability, durability, and the lowest MSE. As an approach to rock hardness, lithology input is carried out with hardness values that are similar to the hardness values of granodiorite formations such as RSA simulation results which range from 20-30 kpsi UCS.

Good bits are the most stable and easily controlled, especially for directional holes. Figure 8 shows a plot of the bit center path, and the geometric shape of the hole along the wellbore. The colors in the center path line bit show 1 color for 1 ft simulation. Gap is an enlargement of the hole in inch due to the drill bit and the hole are not centered. The greater the gap value, the higher the bit center path deviation. Meanwhile max disp is the maximum displacement which means the farthest distance of the bit movement in the wellbore cross section, which is measured from the center bit. From Figure 8, it also can be seen that the Bit-1 design is quite stable with a gap of only 0.0287 inches from 9-7/8" bits and with a pattern that is evenly distributed throughout the diameter of the hole (no empty area in the middle of the pattern) shows that this bit is really concentrated to be able to penetrate the rock indicated with the maximum displacement value of only 0.0832 inch. From Dogleg Severity (DLS) capability in rotary mode shown in Figure 9 the four bits mostly have same tendency, Bit-1, Bit-4, Bit-5, and Bit-6 create build up rate of 0.91 deg/100ft, 1 deg/100ft, 0.95 deg/100ft, and 0.83 deg/100ft. Meanwhile in sliding mode in Figure 10 the all bits also mostly have same tendencies, Bit-1, Bit-4, Bit-5, and Bit-6 create build up rate of 6.5 deg/100ft, 7.1 deg/100ft, 7 deg/100ft, and 6.5 deg/100ft, respectively.

Figure 11 and Figure 12 show that Bit-1 and Bit-4 have low lateral acceleration and low lateral force that produce higher acceleration and lower lateral force against formation. The profiles are similar to the simulation results in Figures 6 and 7, but with a longer simulation time range of 50 ft. with 17,000-20,000 revolutions. By its durability, Bit-1 and Bit-4 created mostly same average lateral acceleration value 10 g, and a lateral force of six kip. This reinforces the assumption that these two bits are the most durable bits compared to the other bits.

The last factors to be considered in bit selection is Mechanical Specific Energy (MSE). MSE is the energy required to move 1 cm<sup>3</sup> rock. It is approximately the same as the ratio of energy input to ROP output. In this case, Teale defines this relationship as a function of the drilling parameters with (Teale, 1965):

$$MSE = \left( \frac{4 \times WOB}{\pi D^2 \times 1000} \right) + \left( \frac{480 \times RPM \times T}{D^2 \times ROP \times 1000} \right) \quad (1)$$

D: Bit diameter, (inches)

T: Torque, (ft-lb)

MSE: Mechanical Specific Energy, (Kpsi)

WOB: Weight on Bit, (lbs)

RPM: Rotational Speed, (rpm)

ROP: Rate of Penetration, (ft/hr)

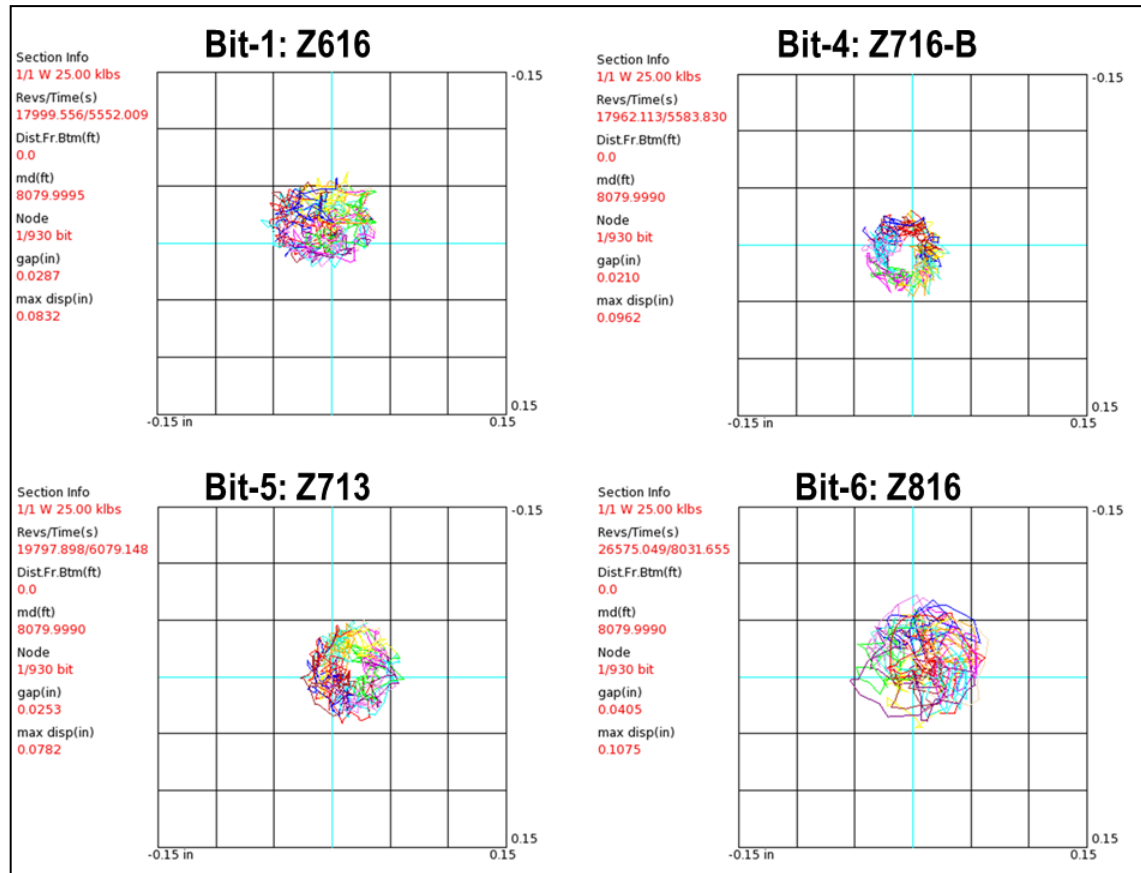


Figure 8. Bit center path.

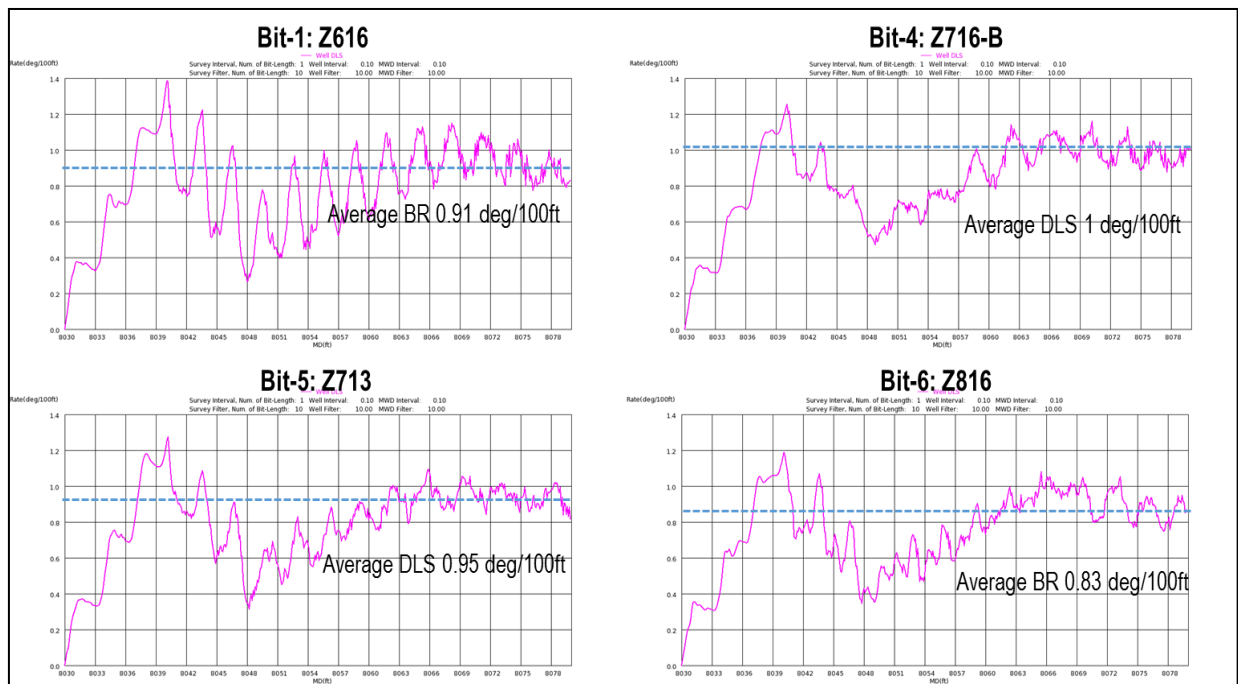


Figure 9. DLS capability in rotary mode

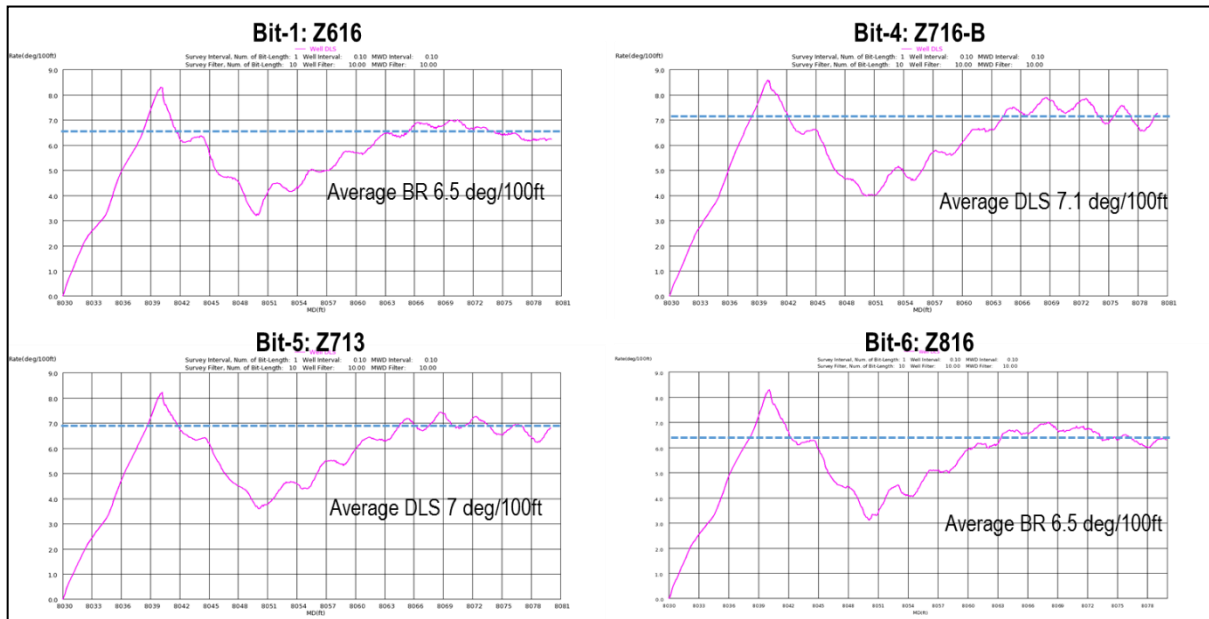


Figure 10. DLS capability in sliding mode.

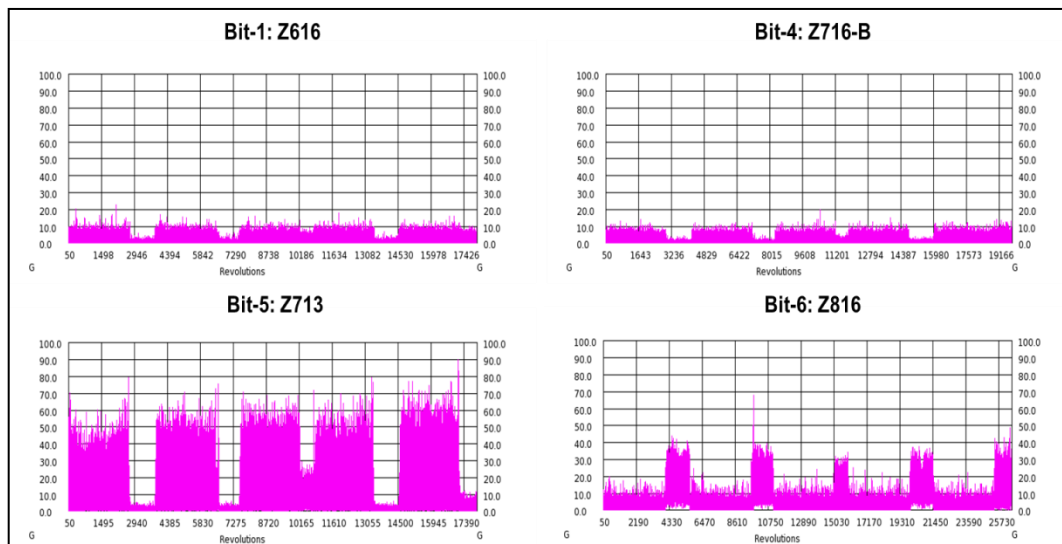


Figure 11. Lateral acceleration.

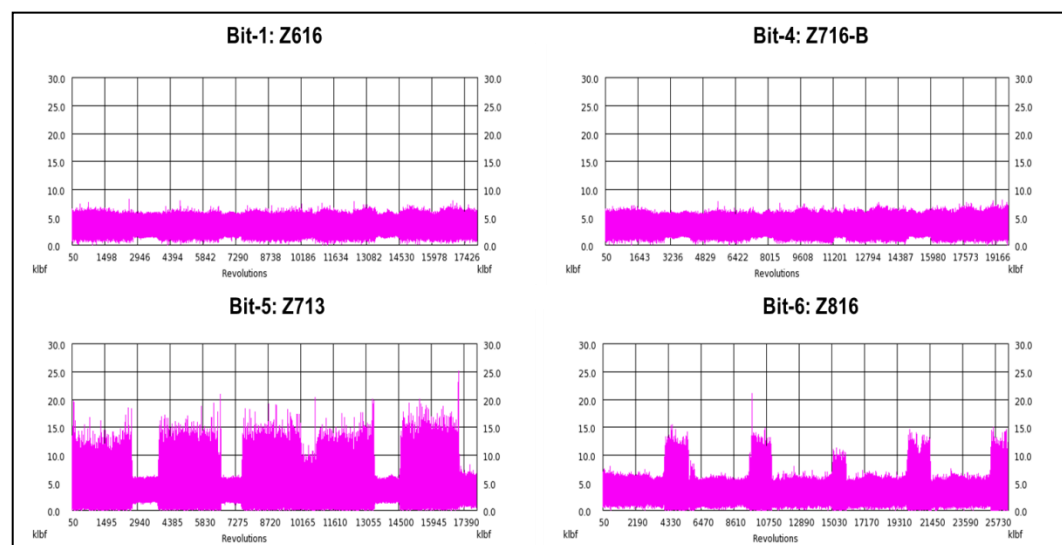


Figure 12. Lateral force.



Based on 50 ft drilling simulation database Bit-1 (Z616), is able to produce the lowest MSE value compared to other bits. The average MSE value of this bit is the lowest when drilling in hard formations of 769 psi. Bit-4 (Z716B) and Bit-5 (Z713) produce slightly higher and slightly erratic MSE values resulting from high vibrations. Bit-4 (Z716B) produces an MSE value of 833 Psi, while Bit-5 (Z713) produces an MSE value of 777 Psi, while Bit-6 (Z816) produces the highest MSE value with an average value of around 1079 psi.

Based on the static and dynamic drilling performance using simulation, overall refer to both phase simulation, Bit-1 (Z616) is the most ideal design for use in hard and abrasive formations, these bits are capable of producing good ROP, low vibration, good directional capability, and low MSE values with bit description of six blades, 16 mm cutter size with central stinger and has a secondary row of stingblade, three inch of gauge pad length (GPL), total cutter 41 pcs and total stinger counts 31 pcs (Table 1) (Bourgoyne Jr, Millheim, Chenevert, & Young Jr, 1991).

In accordance with drilling geothermal well costs in general and granodiorite formations in particular, the use of hybrid bits also passes the economic calculation stage where hybrid bit use can replace the use of several TCI bits thereby reducing overall tripping time and rig costs.

Based on references from offset wells, 9-7/8" Hole section spend four TCI bits with average ROP of 4.6 m/hr. The application of Z616 hybrid bits can increase ROP by an average of 35% from 4.6 m/hr (actual) to around 6.25 m/hr (simulation). The Table 2 describes the economic calculation of hybrid bit usage, where the drilling data were the drilling interval of 1000m; average TCI footage was 250 m; 9-7/8" TCI Price was USD 5,625/Bit; 9-7/8" Hybrid Bit Price was USD 37,000/Bit; Time for one tripping time was 25 hours; and Rig cost based on daily basis was USD 105,000/day. Based on several cases of hybrid bit application, well costs of USD 198,625 - up to USD 564,712 can be saved.

Table 2. Economic calculations using hybrid bits.

Case#1, ROP Improvement 35%, Full Hybrid									
Bit Type	Bit Cost	Drilling Time	Tripping Time	Drilling Cost	Tripping Cost	Operation Cost	Total Cost	Cost/m	Saving
	USD	hours	hours	USD	USD	USD	USD	USD/m	USD
4 TCI	22,500	217.39	75	951,086.96	328,125.00	1,279,211.96	1,301,711.96	1,301.71	
1 Hybrid	37,000	160.00	0	700,000.00	-	700,000.00	737,000.00	737.00	564,712
Case#2, ROP Improvement 0%, Full Hybrid									
Bit Type	Bit Cost	Drilling Time	Tripping Time	Drilling Cost	Tripping Cost	Operation Cost	Total Cost	Cost/m	Saving
	USD	hours	hours	USD	USD	USD	USD	USD/m	USD
4 TCI	22,500	217.39	75	951,086.96	328,125.00	1,279,211.96	1,301,711.96	1,301.71	
1 Hybrid	37,000	217.39	0	951,086.96	-	951,086.96	988,086.96	988.09	313,625
Case#3, ROP Improvement 35%, 1 Hybrid + 1 TCI									
Bit Type	Bit Cost	Drilling Time	Tripping Time	Drilling Cost	Tripping Cost	Operation Cost	Total Cost	Cost/m	Saving
	USD	hours	hours	USD	USD	USD	USD	USD/m	USD
4 TCI	22,500	217.39	75	951,086.96	328,125.00	1,279,211.96	1,301,711.96	1,301.71	
1 Hybrid + 1 TCI	42,625	174.35	25	762,771.74	109,375.00	872,146.74	914,771.74	914.77	386,94
Case#4, ROP Improvement 0%, 1 Hybrid + 1 TCI									

Bit Type	Bit Cost	Drilling Time	Tripping Time	Drilling Cost	Tripping Cost	Operation Cost	Total Cost	Cost/m	Saving
	USD	hours	hours	USD	USD	USD	USD	USD/m	USD
4 TCI	22,500	217.39	75	951,086.96	328,125.00	1,279,211.96	1,301,711.96	1,301.71	
1 Hybrid + 1 TCI	42,625	217.39	25	951,086.96	109,375.00	1,060,461.96	1,103,086.96	1,103.96	198,625

## CONCLUSIONS

Based on the first phase simulation of the bit selection from 1 ft drilling, the best ROP, cutter cutting force and vibration value were obtained by Bit-1 (Z616), Bit-4 (Z716B), Bit-5 (Z713), and Bit-6 (Z816). Based on the second phase simulation of the bit selection from 50 ft drilling, the best directional capability, durability and MSE value were created by Bit-1 (Z616). This bit is the most ideal bit for geothermal drilling with hard and abrasive formation. The application of Z616 Hybrid bit may save well costs of USD 198,625 up to USD 564,712.

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