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OPTIMISING THE UNDER-REAMER STRING DESIGN FOR WELLS AT HAI THACH FIELD, NAM CON SON BASIN

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Summary

According to the drilling program approved for Hai Thach field, the drilling section below the 16" casing liner (14.85" internal diameter) will be carried out by two separate BHAs: first drilling the 12.25" section by PDC bit to the section target, then under-reaming the wellbore to 14.5" and 16.5" diameter in order to run 13.625" casing string. Using two separate BHAs for reaming the wellbore certainly leads to a time increase in the run in hole (RIH) and pull out of the hole (POOH) of the drill-string and hence the associated costs such as rig and other related third party services. Therefore, it is necessary to study and calculate the optimal drill-string design to ensure the wellbore under-reaming as well as to minimise the drill-string running time, thereby improving the Drillex and Capex. The application of the optimised reamer string design in the wells of Hai Thach field has brought a feasible concept that can be applied for other wells having similar profiles and geological stratigraphy in Vietnam in the future.

Key words: Under-reamer string optimisation, wellbore reaming, drill-string simulation, reamer string design, Hai Thach field.

1. General

Well HT-xx is designed with a well profile completed by a 30" conductor pipe and 22" surface casing × 16" casing liner × 13.625" intermediate casing × 10" intermediate casing and 5.5" production tubing (Table 1).

According to the well design, the 16.5" hole section is used for 13.625" casing running, the wellbore diameter must reach 16.5" to ensure sufficient annular for cementing to achieve the highest quality and efficiency.

But the fact is that the 16" casing liner has internal diameter of only 14.85". It is, therefore, merely possible to drill inside casing with a bit of 14.5" when going through cement below the 16" casing shoe and then reaming the hole up to 16.5"; however, the 14.5" PDC bit cannot bring up the borehole diameter up to 16.5" for 13.625" casing running and cementing. So, the under-reaming equipment is needed to achieve the required wellbore diameter of 16.5" for running the 13.625" intermediate casing (Figure 1).

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Because the 14.5" PDC bit was not available in the market at the time of drilling operation, it required more time as well as higher cost to order due to the customised design and manufacture. Therefore, the solution in this situation was to use a pilot drill-string with the 12.25" PDC bit for reaming the borehole below 16" casing shoe to the two diameters of 14.5" and 16.5" to reach the target mentioned above.

2. Optimal solution design

2.1. Primarily approved design

With the approved drilling programme as described above, for reaming the wellbore to 16.5" for the 13.625" casing section, it is necessary to have two BHAs with details as follows (Tables 2 and 3).

- 12.25" pilot BHA, and
- 12.25" × 14.5" × 16.5" under-reaming BHA.

With pilot under-reaming BHAs, the drilling operation needs to run the process at least twice. It includes making up 12.25" pilot BHA then drilling to section target and POOH for 12.25" × 14.5" × 16.5" under-reaming BHA and

Table 1. Casing specification for well HT-xx [1]

Description	Grade	Weight (lb/ft)	OD (in)	ID (in)	Inner pressure (psi)	Outer pressure (psi)	Yield strength (×1000 lbs)
30" Conductor	X56	456	30	27	4,900	4,090	7,521
22" Surface casing	X80	224	22	20	6,360	3,870	5,278
16" Intermediate casing	P110	96	16	14.85	6,920	2,340	3,065
13.625" Intermediate casing	Q125	88.2	13.625	12.375	10,030	4,800	3,191
10.75" × 10" Production casing	SM125S	73.2	10.75	9.394	13,670	10,810	2,660
	SM125S	68.7	10	8.672	15,050	13,370	2,516
7.625" Contingency liner	P110	39.0	7.625	6.625	12,620	11,080	1,231
5.5" Production liner	SM13CRS-110	29.7	5.5	4.376	19,670	20,180	959
5.5" Production tubing	SM13CRS-110	23.0	5.5	4.67	14,530	14,540	729

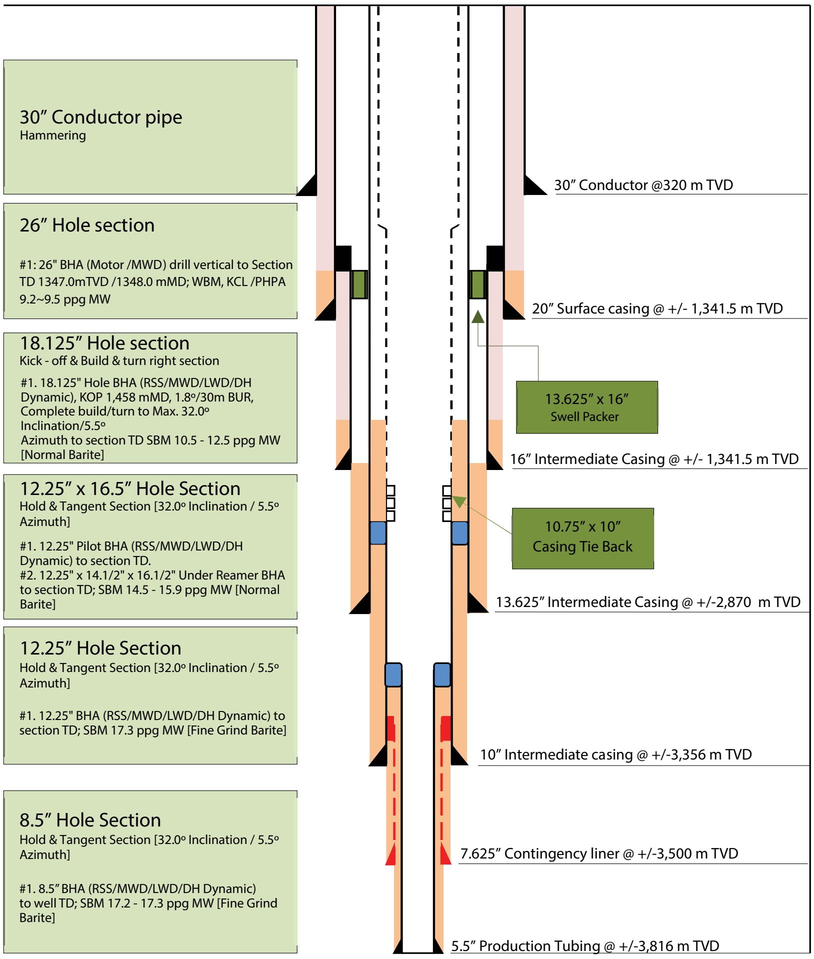

Figure 1. Well HT-xx profile.

reaming the borehole up to 16.5" as required for 13.625" casing running and cementing. Undoubtedly, this process takes more time for POOH and RIH, which obviously pumps up the costs related to rig waiting and third parties services. Therefore, having an integrated solution to reduce the cost but ensure the quality and efficiency of well construction is crucial.

2.2. Optimal solution proposal

To propose an optimal solution for BHA drilling and reaming, it is requisite to consider the following:

- Calculate, run the simulation to ensure that the drilling-string tools work stable for the formation to be drilled,

- Review hole cleaning efficiency and hydraulic model, simulate drilling parameters to select the BHA design for the highest ROP,

- Review the influence of directional drilling equipment in the process with the proposed BHA,

- Check the change of well trajectory during drilling and reaming operation.

It is a must to consider all key elements and factors of well design, drilling equipment, drill bit, geological features, well trajectory, drilling fluids, drilling hydraulics, drilling parameters as well as other related factors. The results of the engineering study shown that during drilling and reaming, the proposal for BHA drilling and reaming from 12.25" to 14.5" diameter by SHO - Staged Smiths Hole Opener (Figure 2) and 16.5" Rhino Reamer with an integrated BHA (with 3 different cutting inserts including drill, ream the borehole by Rhino Reamer up to 16.5"). "The Rhino Reamer XC gets around the limitations of the existing reaming equipment from another manufacturer and offers some outstanding features such as full activation with hydraulic mechanism or acceptance of multiple open/close times during operation (Figure 3).

Rhino reamer XC has been put into operation worldwide since September 2012

Table 2. 12.25" pilot BHA configuration [2]

No.	Description	Outer diameter (in)	OD (in)	ID (in)	Lower connection	Upper connection	Length (m)	Accu. length (m)
1	Bit - PDC - fixed cutter	12.25	Nozzle 5x20			6.625 Reg	0.400	0.40
2	AutoTrak steering unit		11.860	2.480	6.625 Reg	9.5 T2	2.530	2.93
3	Lower flex stabiliser	12.125	9.500	2.813	9.5 T2	9.5 T2	3.630	6.56
4	OnTrak II - MWD sensor sub	11.75	9.500	2.875	9.5 T2	9.5 T2	7.010	13.57
5	BCPM - MWD power and pulser sub		9.500	2.880	9.5 T2	9.5 T2	3.600	17.17
6	CoPilot		9.500	2.813	9.5 T2	9.5 T2	2.300	19.47
7	Top stop sub NM		9.500	2.813	9.5 T2	7.625 Reg	1.100	20.57
8	Sub - filter		9.500	2.813	7.625 Reg	7.625 Reg	1.700	22.27
9	Float sub (non-ported plunger)		9.500	2.813	7.625 Reg	7.625 Reg	1.700	23.97
10	String Stabiliser	11.375	9.500	2.813	7.625 Reg	7.625 Reg	1.700	25.67
11	Sub - X/O		8.000	2.813	7.625 Reg	6.625 Reg	1.000	26.67
12	Drill collar x 6		8.125	2.813	6.625 Reg	6.625 Reg	56.40	83.07
13	Jar		8.000	2.813	6.625 Reg	6.625 Reg	9.500	92.57
14	Drill collar x 3		8.250	2.813	6.625 Reg	6.625 Reg	28.20	120.77
15	Accelerator		8.000	2.813	6.625 Reg	6.625 Reg	9.500	130.27
16	Drill collar x 1		8.250	2.813	6.625 Reg	6.625 Reg	9.400	139.67
17	Sub - X/O		8.000	2.813	6.625 Reg	VX54	1.000	140.67
18	5.5" HWDP ×16		5.500	4.000	VX54	VX54	152.00	292.67
19	5.5" DP		5.500	4.778	VX54	VX54	2774.03	3066.7

Table 3. 12.25"x14.5"x16.5" under-reaming BHA [2]

No.	Description	Outer diameter (in)	OD (in)	ID (in)	Lower connection	Upper connection	Length (m)	Accu. length (m)
1	Bullnose	8.000				6.625 Reg	0.40	0.40
2	String stabiliser	12.250	8.000	2.813	6.625 Reg	6.625 Reg	1.70	2.10
3	Float sub (non-ported plunger type)		8.000	2.813	6.625 Reg	6.625 Reg	1.70	3.80
4	Bit-hole opener (SHO)	14.500	8.000	3.000	6.625 Reg	7.625 Reg	4.00	7.80
5	Under reamer	16.500	9.500	2.700	7.625 Reg	7.625 Reg	4.50	12.30
6	Drill collar		9.500	2.813	7.625 Reg	7.625 Reg	9.40	21.70
7	Float sub (non-ported plunger type)		9.500	2.813	7.625 Reg	7.625 Reg	1.70	23.40
8	String stabiliser	12.250	9.500	2.813	7.625 Reg	7.625 Reg	2.00	25.40
9	Sub - X/O		8.000	2.813	7.625 Reg	6.625 Reg	1.00	26.40
10	Drill collar x 6		8.125	2.813	6.625 Reg	6.625 Reg	56.40	82.80
11	Jar		8.000	2.813	6.625 Reg	6.625 Reg	9.50	92.30
12	Drill collar x 3		8.250	2.813	6.625 Reg	6.625 Reg	28.20	120.50
13	Accelerator		8.000	2.813	6.625 Reg	6.625 Reg	9.50	130.00
14	Drill collar x 1		8.250	2.813	6.625 Reg	6.625 Reg	9.40	139.40
15	Sub - X/O		8.000	2.813	6.625 Reg	VX54	1.00	140.40
16	5.5" HWDP x16		5.500	4.000	VX54	VX54	152.00	292.40
17	5.5" DP		5.500	4.778	VX54	VX54	2772.60	3065.00

and some oil operators have successfully combined well drilling and reaming but no one has applied the method with 3 integrated cutting stages. Especially, this BHA proposal has never been applied for HPHT wells not only in Vietnam but also all over the world so far. Some limitations of the optimised design are the equipment capability to ream up borehole and hole cleaning, and monitor the well trajectory, namely:

Figure 2. *Staged hole opener - SHO of Smiths Bit [3].*

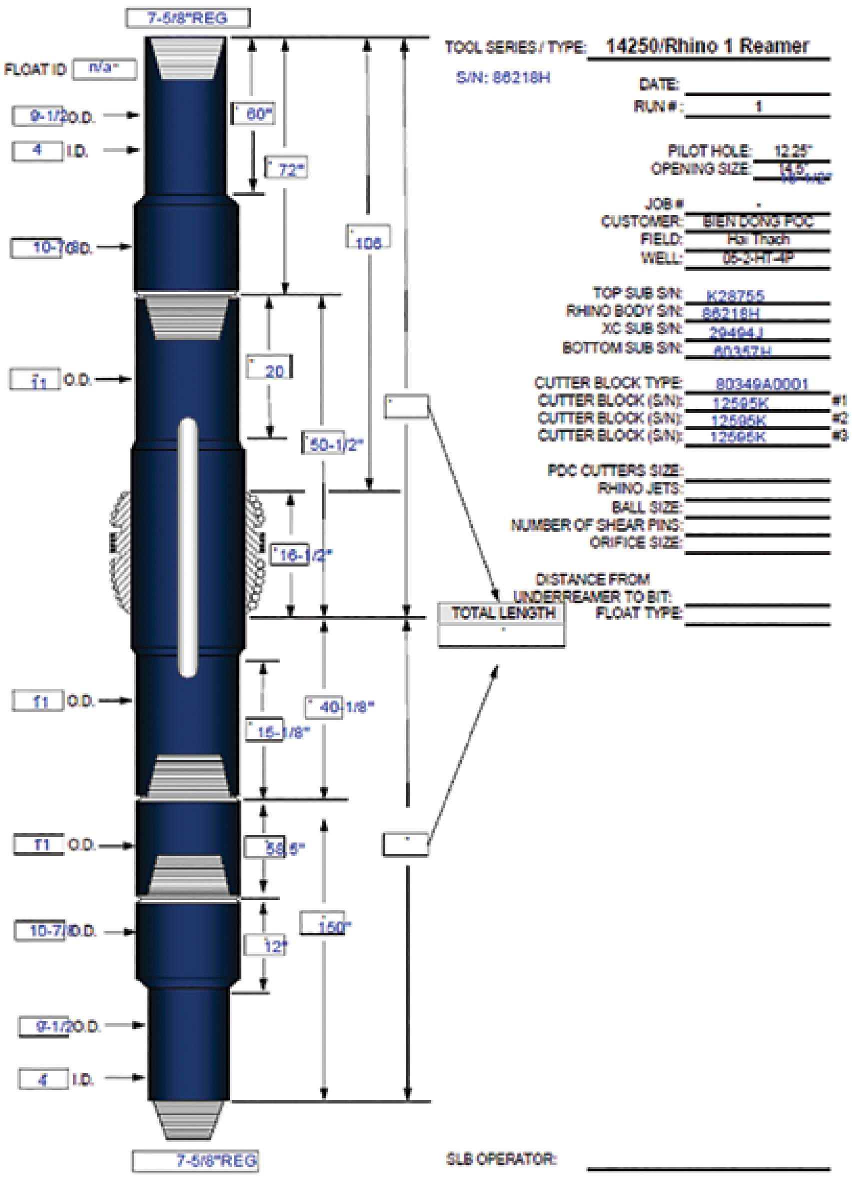

Figure 3. *Rhino reamer XC [4].*

- Existing wellbore diameter expansion equipment uses a combination of mechanical mechanisms (ball-drop) to activate the cutter block and retains only one hydraulic mechanism during operation. Since this combination can be used only for a single opening and closing cycle of cutting blades, it reduces the equipment flexibility during the reaming. This also makes it difficult to drill a well through complex geologic formations and the design will greatly lower the hole cleaning efficiency during and after drilling.

- Normally being activated by a ball-drop mechanism, reamer is only located above the MWD tools and cannot be placed close to the drill bit. This fact leads to the bare hole increase below the borehole reaming section. The length of borehole to be expanded leads to an extreme risk for the casing seat point in the abnormal or high pressure as we need to place the casing seat on the strongest and most stable foundation possible to guarantee the drilling to the next well section.

- The incompatibility between the cutting mechanisms of the equipment leads to decrease ROP and extend the drilling time.

2.3. Engineering study result

Simulation is run for proposed optimal BHA options and engineering/design study as specified in Table 4.

The proposed drilling tool specifications are brought into calculation/simulation and check for stability through different types of formation. The output is indicated in Table 4.

The bending stress for BHA is checked with drilling parameter input relevant to the types of drilled formation (Figure 5).

__Table 4.__ The proposed BHA options

Option # 1

BHA 2	Max. OD (in)	Accum. Length (ft)
5,5" DP	6.7500	9050.00
5,5" HWDP x16	7.0000	974.714
Sub - X/O	8.2500	476.026
Drill collar x 1	8.2500	472.746
Accelerator	8.0000	441.746
Drill collar x 3	8.2500	410.578
Jar	8.0625	318.058
Drill collar x 6	8.1250	284.571
Sub - X/O	9.5000	99.531
Float sub (non ported plunger type)	9.5000	96.251
Sub filter	9.5000	90.674
String stabilizer	12.250	85.097
Top stop sub NM	9.5000	79.003
Co-pilot	9.5000	75.395
BCPM-MWD power and pulse sub	9.5000	67.850
Ontrack II – MWD sensor sub	11.750	56.039
Rhino reamer	16.500	33.039
SHO	14.500	13.529
Bit	12.250	0.8990

Option # 2

BHA 2a	Max. OD (in)	Accum. Length (ft)
5,5" DP	6.7500	9050.00
5,5" HW DP x16	7.0000	979.927
Sub - X/O	8.2500	481.239
Drill collar x 1	8.2500	477.959
Accelerator	8.0000	446.959
Drill collar x 3	8.2500	415.791
Jar	8.0625	323.271
Drill collar x 6	8.1250	289.784
Sub - X/O	9.5000	104.744
Float sub (non ported plunger type)	9.5000	101.464
Sub filter	9.5000	95.887
String stabilizer	12.250	90.310
Top stop sub NM	9.5000	87.030
Co-pilot	9.5000	83.422
BCPM-MWD power and pulse sub	9.5000	75.877
Ontrack II – MWD sensor sub	11.750	64.394
Sub X/O	9.500	41.404
Rhino reamer	16.500	38.124
SHO	14.500	18.614
Bit sub	8.0000	5.4910
Bit	12.250	0.8990

Option # 3

BHA 2b	Max. OD (in)	Accum. Length (ft)
5,5" DP	6.7500	9050.00
5,5" HWDP x16	7.0000	986.487
Sub - X/O	8.2500	487.799
Drill collar x 1	8.2500	484.519
Accelerator	8.0000	453.519
Drill collar x 3	8.2500	422.351
Jar	8.0625	329.831
Drill collar x 6	8.1250	296.344
Sub - X/O	9.5000	111.304
Float sub (non ported plunger type)	9.5000	108.024
Sub Filter	9.5000	102.447
String stabilizer	12.250	96.870
Top stop sub NM	9.5000	93.590
Co-pilot	9.5000	89.982
BCPM-MWD power and pulse sub	9.5000	82.437
Ontrack II – MWD sensor sub	11.750	70.954
Sub X/O	9.500	47.964
Rhino reamer	16.500	44.684
String stabilizer	14.250	25.174
Sub X/O	8.0000	21.894
SHO	14.500	18.614
Bit sub	8.0000	5.4910
Bit	12.250	0.8990

Option # 4

BHA 2c	Max. OD (in)	Accum. Length (ft)
5 1/2" DP	6.7500	9050.00
5 1/2" HWDP x16	7.0000	989.767
Sub - X/O	8.2500	491.079
Drill collar x 1	8.2500	487.799
Accelerator	8.0000	456.799
Drill collar x 3	8.2500	425.631
Jar	8.0625	333.111
Drill collar x 6	8.1250	299.624
Sub - X/O	9.5000	114.584
Float sub (non ported plunger type)	9.5000	111.304
Sub filter	9.5000	105.727
String stabilizer	12.250	100.150
Top stop sub NM	9.5000	96.870
Co-pilot	9.5000	93.262
BCPM-MWD power and pulse sub	9.5000	85.717
Ontrack II – MWD sensor sub	11.750	74.234
Sub X/O	9.500	51.244
Rhino reamer	16.500	47.694
Sub X/O	9.5000	28.454
String stabilizer	14.250	25.174
Sub X/O	8.0000	21.894
SHO	14.500	18.614
Bit sub	8.0000	5.4910
Bit	12.250	0.8990

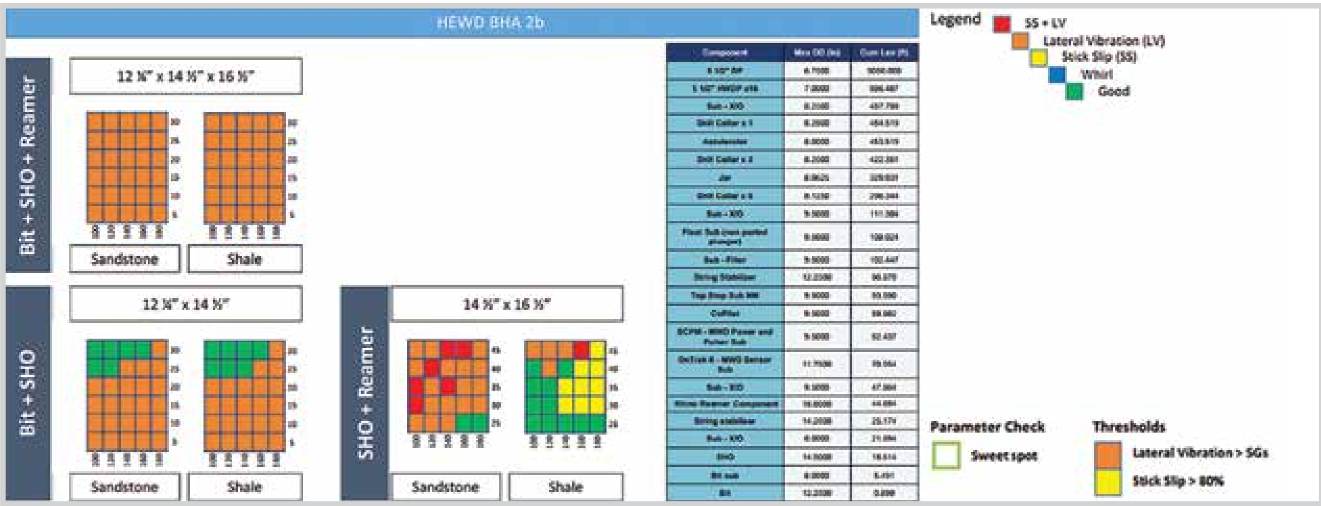

__Figure 4.__ Results of stability calculation of the integrated BHA when drilling and reaming through sandstone and shale formations.

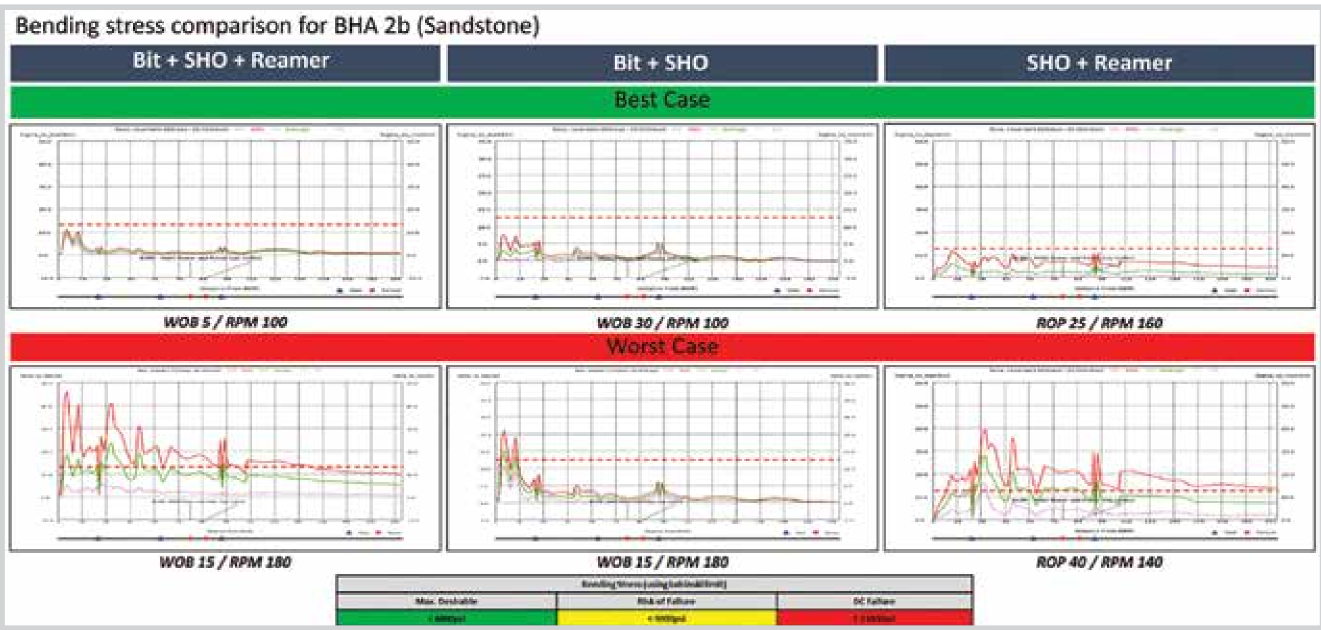

__Figure 5.__ Simulation results with parameter input corresponding to the integrated drilling and reaming BHA through sandstone.

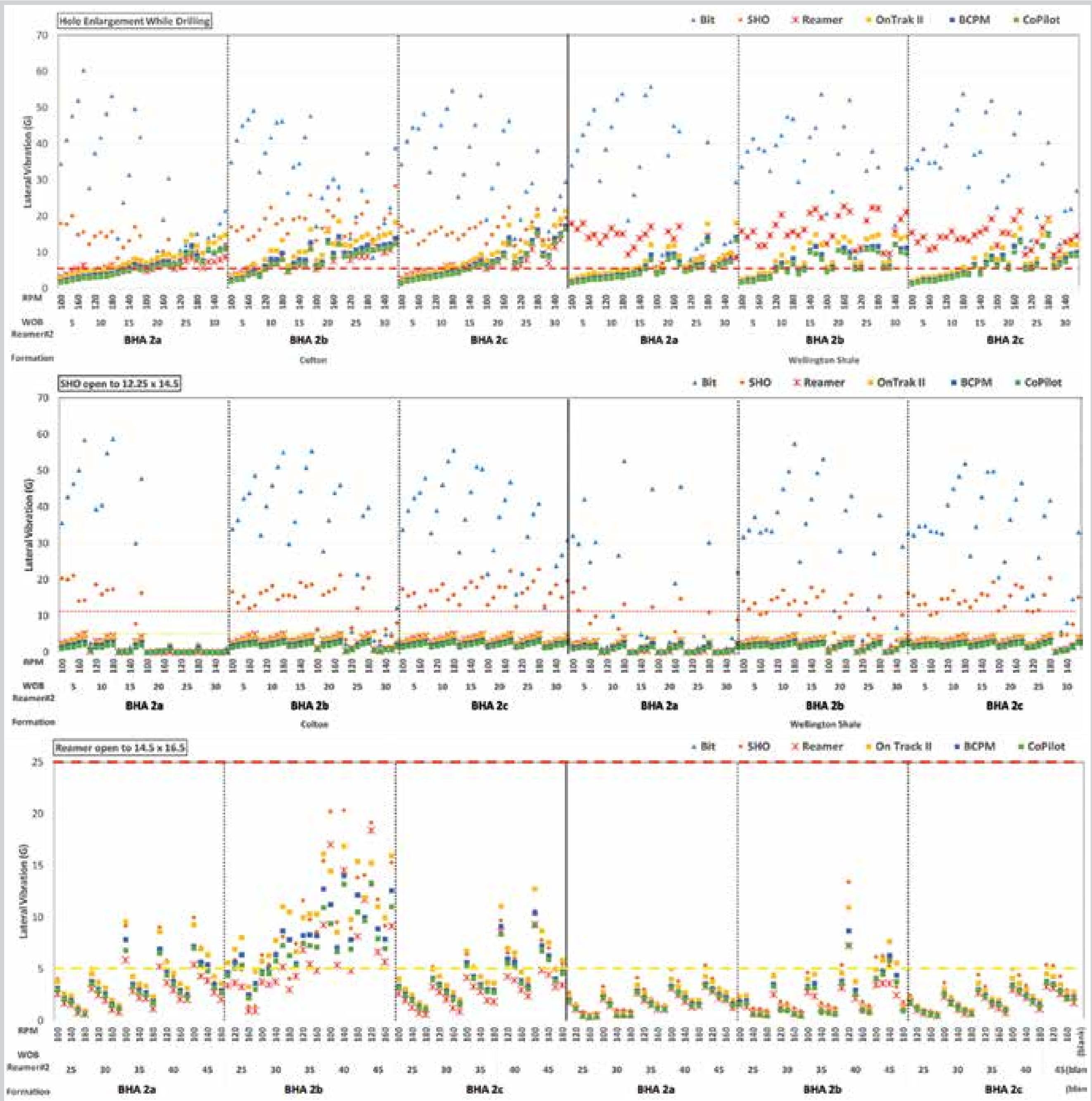

Figure 6. The simulation results show the influence of directional drilling equipment to the proposed integrated BHA.

The simulation shows the influence of directional drilling equipment to the proposed integrated BHA.

Simulation of well geometry/trajectory changes and hydraulic model per integrated BHA option and selection of cutting blades shape for 3 cutting stage mechanisms is shown in Figure 7.

The results of the well trajectory change simulation during drilling and reaming are shown in Figure 8.

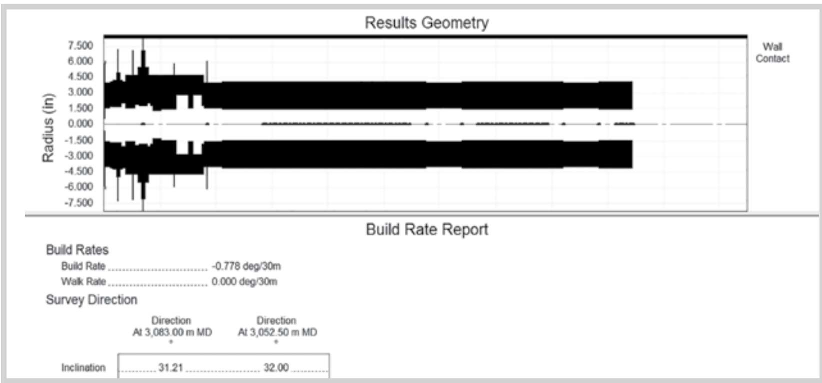

Figure 7. Simulation of the well geometry change during drilling and reaming.

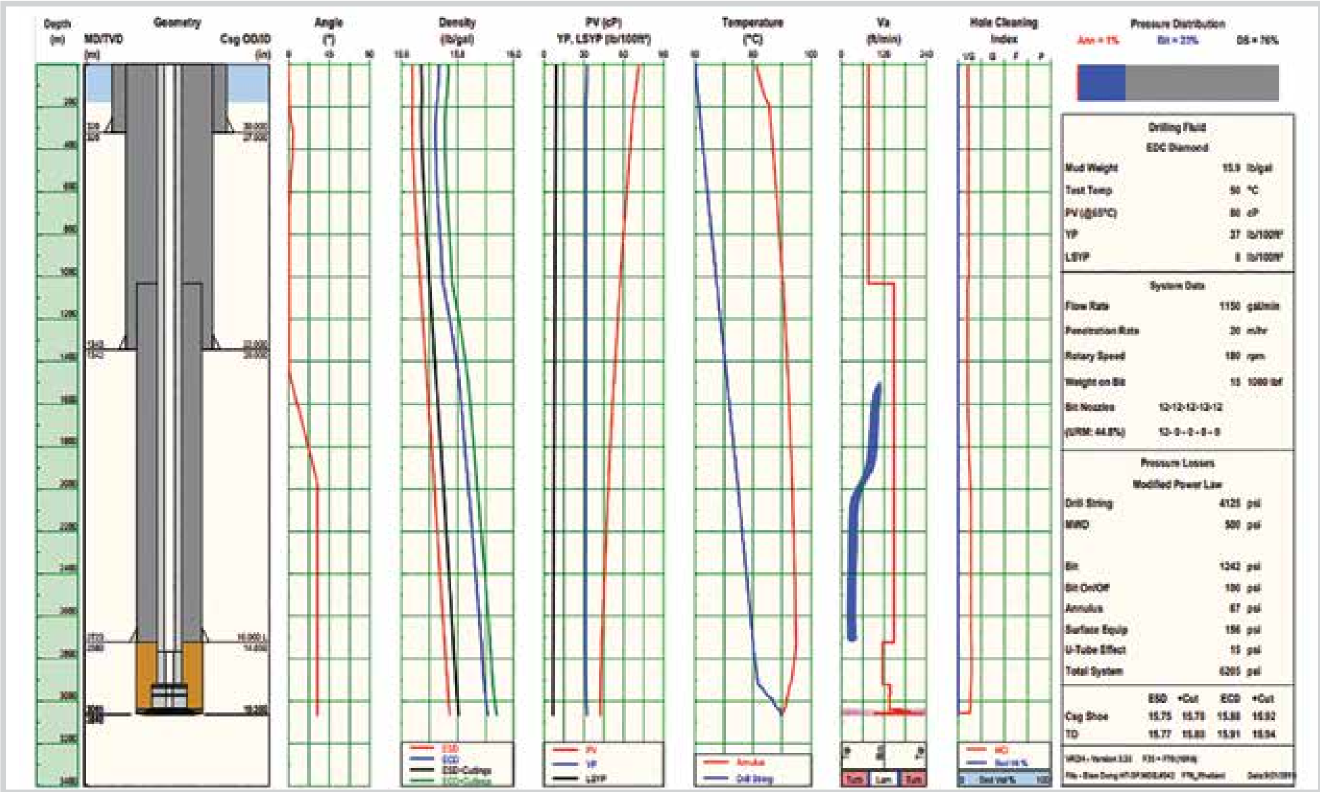

Figure 8. *Simulation of the well trajectory change during drilling and reaming.*

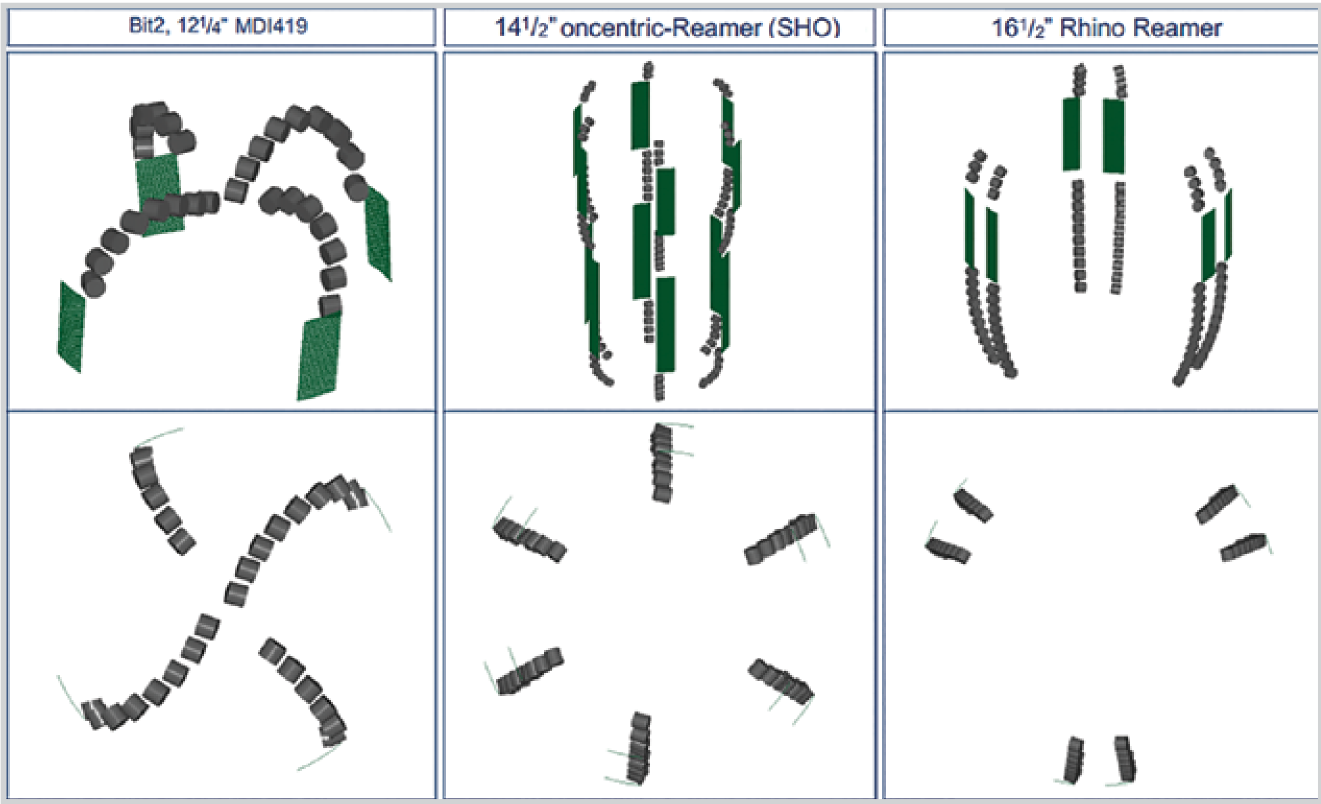

Figure 9. *Cutting shape/blades of drill bit, Stage Hole Opener and Rhino Reamer.*

After engineering study in turn with the BHA proposed options (Figure 10), the selection of suitable integrated BHA for the drilling and reaming and with the optimum cutter shapes of the reaming and drilling equipment to the all-purpose 13.625" casing running and cementing as well as the requirements for the sta-

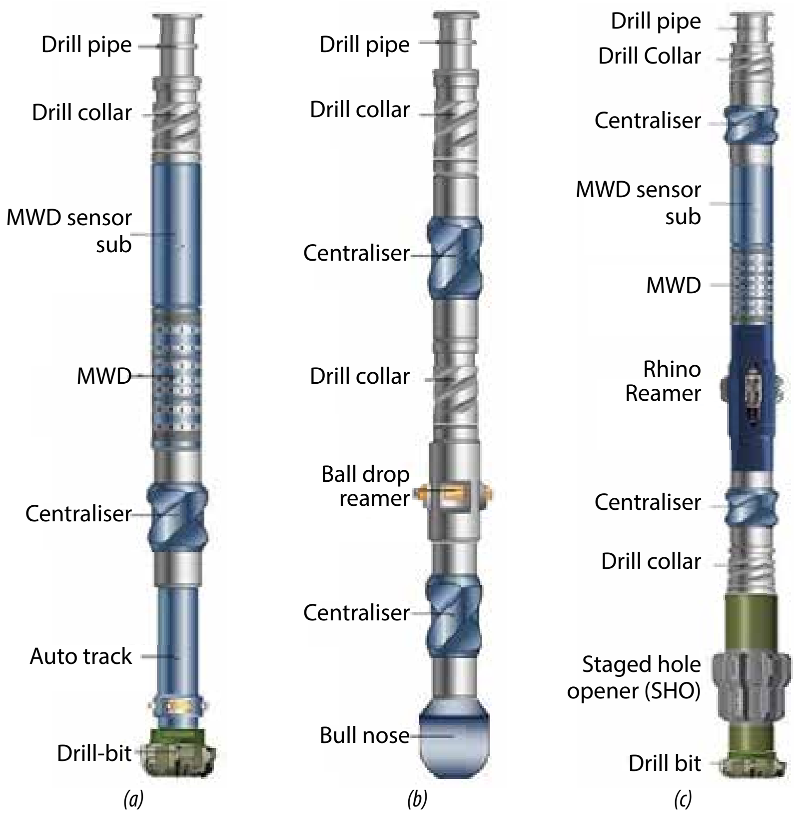

Figure 10. *Pilot BHA (a); Under-reaming BHA (b); Proposed integrated BHA with 3 cutting mechanisms (c).*

bility of the BHA proposed, the hole cleaning efficiency, the compatibility of different cutting mechanisms of per equipment, the ability to control the well trajectory.

Thus, in addition to serial advantages such as increasing the wellbore stability by reducing the back-reaming time, mitigating the duration of the drilling fluids impacting the formation, lessening the risk of differential sticking mechanisms due to the difference between pore and hydrostatic pressures, the application of integrated BHA combined with the borehole reaming has saved the drilling time thereby saving rig cost and contributing to improving the economic efficiency for Capex/Drillex.

3. Conclusion

To select the appropriate design of drilling BHA combined with reamers, the following points need to be assessed: the stability of the proposed BHA for the formation to be drilled; hole cleaning efficiency and hydraulic model according to drilling parameters input for the highest ROP; the influence of drilling equipment on well trajectory.

The goal of borehole reaming is achieved by a single BHA instead of two as originally designed.

The borehole reaming equipment is completely controlled by hydraulics instead of both mechanically activated (ball-drop) and hydraulic operation.

The proposed BHA can be used for multiple opening/closing cycles.

It is important to note that the bare hole (pilot hole) distance under the casing seat should be the shortest to ensure a good foundation for the casing seat. The proposed BHA minimises bare hole below the reaming section, thereby reducing the risk for casing seat.

The proposed integrated BHA with three cutting mechanisms for HPHT wells was carried out in well HT-xx at Hai Thach field by PV Drilling V Rig with very high economic efficiency. It has been proven to save more than USD 1 million for the Bien Dong 1 field development project.

Reference

[1] Bien Dong POC, "05-02-HT-4P drilling program", 19/8/2015.

[2] Baker Hughes, *BHA design*.

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[5] Bien Dong POC, "Internal technical report of 12.1/4" bit run; 12.1/4"x14.1/2" hole opener run; 14.1/2"x16.1/2" under reamer run".

[6] PV Drilling, "IADC equipment list of PV Drilling V (TAD) rig".