



TESTING CENTER FOR OIL AND GAS LEMIGAS

SCIENTIFIC CONTRIBUTIONS OIL AND GAS (SCOG)

Vol. 49. No. 3, September: 441 – 460 - <https://journal.lemigas.esdm.go.id>

ISSN: 2089-3361, e-ISSN: 2541-0520

Published by:

LEMIGAS

Bottom Hole Assembly Performance Evaluation for Horizontal Well Drilling: Case Study of Well “AM-63” in Penang Field, Indonesia

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Received: 06 March 2026; Revised: in revised form 25 June 2026; Accepted: 13 August 2026

Available: online 30 September 2026.

ABSTRACT - Horizontal well drilling is highly complex, particularly in the landing section, due to the increased inclination angle, which can increase torque and drag. These conditions reduce the effectiveness of Weight-on-Bit (WOB) transfer, lower the Rate of Penetration (ROP), extend drilling time, and increase the risk of hanging problems, which could lead to a stuck-pipe case. This study aims to evaluate the performance of the Bottom Hole Assembly (BHA) design in Well AM-63 and to formulate recommendations for a more effective BHA design for future wells. The study employs a quantitative, evaluative case study approach. The data analyzed include the wellbore trajectory, BHA configuration, drilling parameters, torque and drag, ROP, and drilling time in the 12% section (2,310-4,195 ftMD). The analysis results show that a relatively heavy BHA configuration increases the contact force between the drillstring and the wellbore wall near the landing section (4,004-4,195 ft MD), resulting in increased torque and drag, decreased ROP, and increased drilling time. The actual drilling time for the 124" section was 160 hours, which was longer than the planned 65 hours, resulting in an additional 95 hours. This study provides a quantitative evaluation, based on field data, of the performance of the Bottom Hole Assembly (BHA) at the Penang Field by demonstrating the relationship between BHA configuration, wellbore trajectory, and increases in torque and drag due to friction. The findings of this study serve as a practical reference for optimizing BHA design while highlighting the trade-off between successful drilling direction control and efforts to minimize friction in horizontal well drilling operations. Based on the evaluation results, it is recommended to use a lighter BHA configuration to reduce torque and drag, improve WOB transfer efficiency, and minimize the risk of hanging while drilling subsequent horizontal wells. The results provide practical guidance for improving drilling efficiency and for optimizing BHAs in future horizontal well developments under similar field conditions.

Keywords: stuck pipe prevention, torque and drag, bottom hole assembly, horizontal well, *optimum* rate of penetration.

How to cite this article:

Herianto, Harry Budiharjo S., and Alip Meindar, 2026, Bottom Hole Assembly Performance Evaluation for Horizontal Well Drilling: Case Study of Well “AM-63” in Penang Field, Indonesia, Scientific Contributions Oil and Gas, 49 (3) pp. 441-460.



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<https://doi.org/10.29017/scog.v49i3.2142> | 441

1. Introduction

Horizontal well drilling has become a widely adopted technology in oil and gas field development because it increases reservoir contact, thereby boosting productivity and hydrocarbon recovery. As technology advances, the lateral length of wells continues to increase, and their use is becoming more widespread-both in offshore and onshore operations-because they enhance the efficiency of field development (Mitchell et al., 2011).

Despite its advantages, horizontal well drilling presents challenges for drilling mechanics, particularly in the landing section. In this interval, an increase in the inclination angle toward 90 deg increases the contact force between the drillstring and the borehole wall, thereby increasing drag forces and reducing the effectiveness of Weight on Bit (WOB) transfer. (Al-Saedi et al., 2020).

These conditions can lead to hanging and potentially to a stuck pipe, increasing drilling time and costs. One factor contributing to this situation is the design of the Bottom Hole Assembly (BHA), particularly the configuration and weight distribution of the drilling string.

The well is located in the southeastern area of the Pinang field, in the vicinity of wells Pinang #54, Pinang #43, Pinang #52, and Pinang #36. The target formation for well P_PINA23_HW01 is the BK3460 Sand, with an estimated Initial Production (IP) of 340 BOPD.

This problem occurred during drilling of Well AM-63, where a hang-up occurred upon entering the landing section due to increased drag forces, resulting in suboptimal WOB transfer to the bit. Therefore, this study aims to evaluate the BHA design and drilling mechanics conditions in Well AM-63 to identify the primary cause of the high drag. The evaluation results are then used as the basis for optimizing the BHA design in upcoming wells by adjusting the configuration and reducing the weight of BHA components (Elsayed et al., 2021). This optimization is expected to reduce drag forces, improve WOB transfer, and minimize the risk of hanging, thereby making drilling operations more efficient and economical.

2. Methodology

This study employs a quantitative analysis method using a case study approach focused on well AM-63, which experienced a hanging in the landing section (12-1/4"). The data used include the well trajectory, Bottom Hole Assembly (BHA) configuration, drilling parameters, torque and drag data, Weight on Bit (WOB), and Rate of Penetration (ROP). All operational data were verified for consistency and completeness before being used in the evaluation process.

The evaluation was conducted by analyzing the relationship between BHA design, torque and drag values, and drilling performance. The evaluation results were used to optimize the BHA design for subsequent wells by adjusting component configurations to reduce drag and torque, improve WOB transfer, and minimize the risk of hanging. The analytical procedure consisted of three main stages. First, the well trajectory and BHA configuration were evaluated to identify drilling conditions that could increase mechanical resistance in the landing section. Second, torque and drag simulations were performed using WellPlan software and compared with actual field measurements obtained from Rigsite records. Finally, the simulated and measured responses were interpreted by correlating changes in PickUp (P/U), Slack-Off (S/O), Torque Off Bottom, Torque On Bottom, Rate of Penetration (ROP), and drilling time to determine the influence of the existing BHA configuration on the occurrence of hanging. Torque and drag simulations were performed using open-hole friction factor values of 0.30, 0.40, and 0.50, representing low, moderate, and relatively high friction conditions commonly encountered during directional and horizontal drilling operations. These values were selected to evaluate the sensitivity of the simulated hookload and torque responses under different wellbore contact conditions. The friction factor that produced the closest agreement between simulation results and field measurements was considered to represent best the mechanical conditions encountered during drilling of the landing section.

2.1 Well plan dan well trajectory

A well plan is a drilling path designed to guide drilling operations so that the target reservoir can be reached safely and efficiently. The drilling path for Well AM-63 was designed using the "build and hold" profile method until an inclination angle approaching horizontal was reached in the reservoir interval. Figure 1 shows the wellbore design for Well AM-63, indicating that the landing section is the most complex part because the sharp change in inclination angle increases contact forces between the drilling string and the wellbore wall. According to drilling mechanics principles, the increase in inclination angle also increases the normal contact force acting between the drill string and the wellbore wall. This increased contact force leads to greater frictional resistance, resulting in higher torque and drag as the drilling operation approaches the horizontal section. These conditions can increase torque and drag, thereby contributing to hanging problems during drilling.

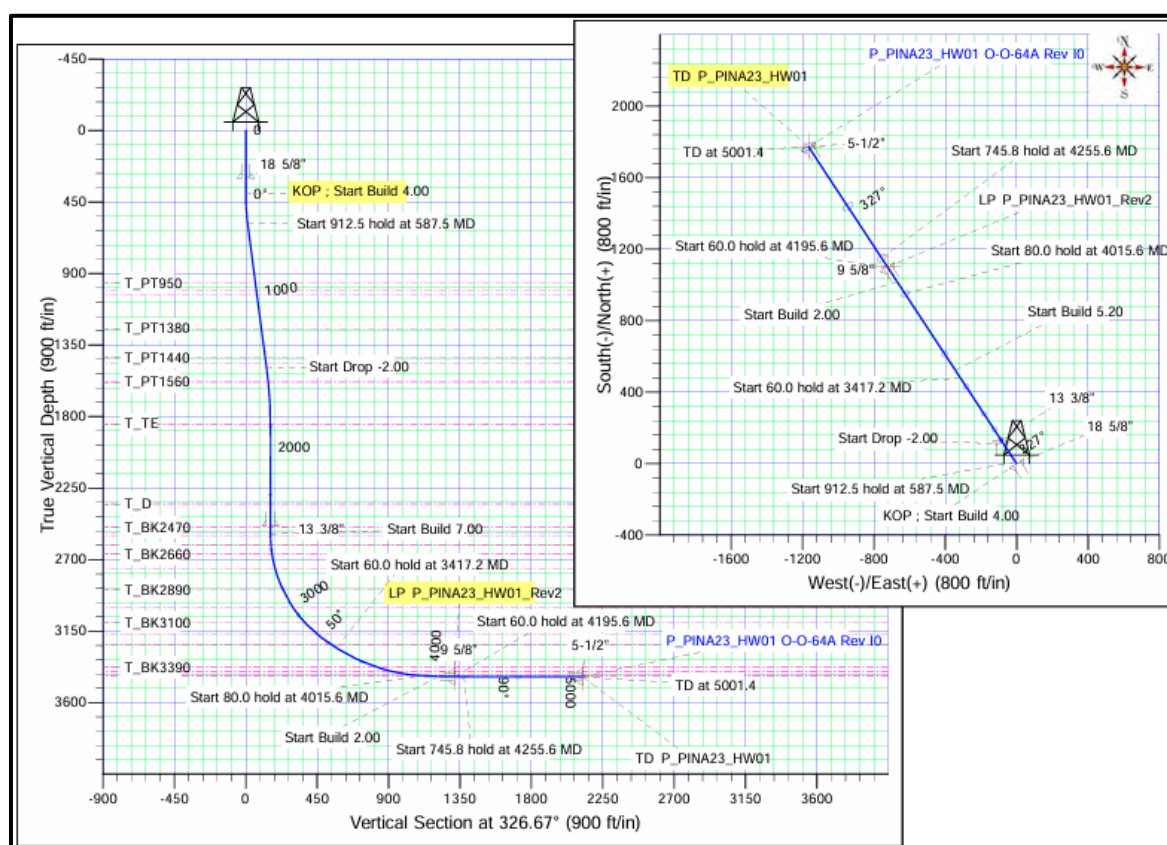


Figure 1.
Well design AM-63 (presented using software compass halliburton sperry drilling)

- **Comparison of the well plan and the actual well path**

A comparison between the planned trajectory (well plan) and the actual trajectory was conducted to determine the success rate of directional control during the operation. Based on the well plot in Figure 2, the actual trajectory of Well AM-63 generally follows the planned trajectory from the vertical phase through the build and landing sections. The results of the latest survey (Last Survey) show a Center-to-Center (CC) value of 6.9 ft at the end of the 12-1/4" section. These deviations are relatively small, indicating that the drilling process was able to keep the drill path within the target. These results indicate that the directional drilling operation successfully achieved the planned well trajectory; therefore, trajectory deviation was not considered the primary cause of the hanging condition observed in Well AM-63. Thus, the landing was successfully achieved as designed, and the deviation from the plan was not the cause of the hanging problem. This problem is more closely related to the mechanics of drilling, specifically to increases in torque and drag and decreases in the effectiveness of Weight on Bit (WOB) transfer as the inclination angle approaches the horizontal.

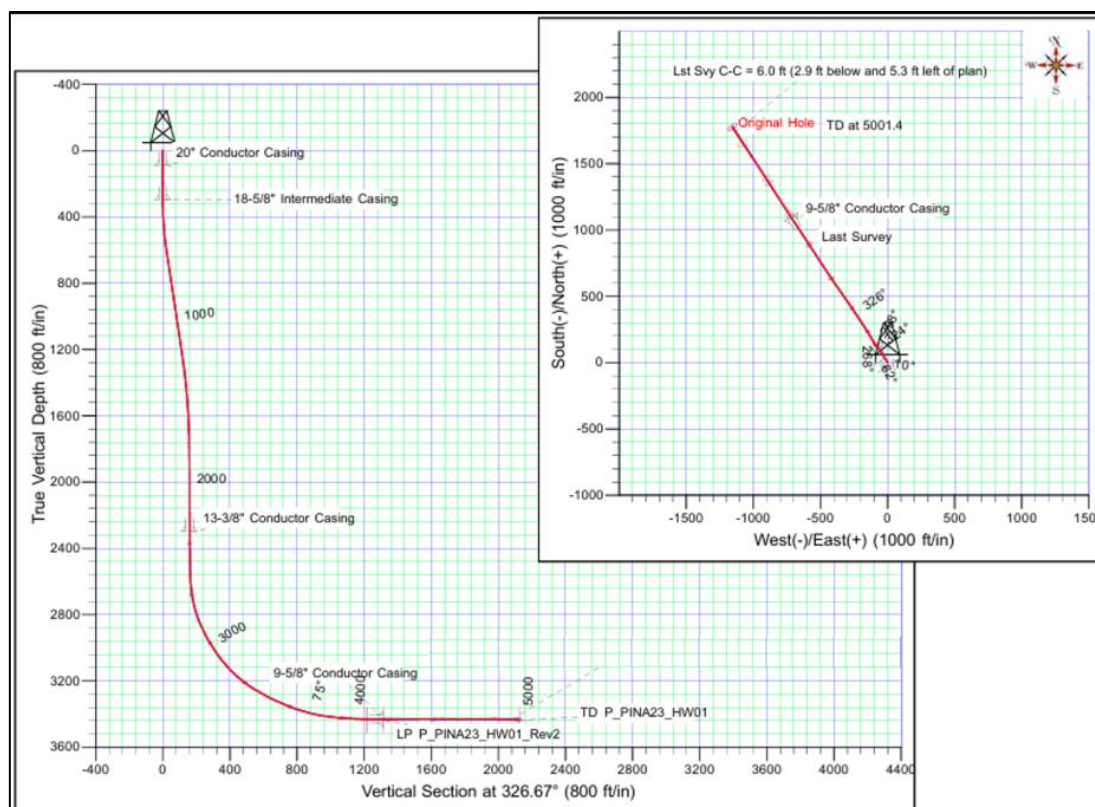


Figure 2.

Well actual AM-63 (presented using software compass halliburton sperry drilling)

2.2 Design of bottom hole assembly (BHA) well AM-63

The Bottom Hole Assembly (BHA) used in the drilling of the AM-63 Landing Section (12-1/4") consists of a 12-1/4" bit, 8" Downhole Motor (DHM), 8" float sub, 8" M/LWD (Gamma Ray/Resistivity) sub, 8" crossover sub, 6-1/2" jar, and a combination of HWDP and DC designed to support horizontal drilling operations until the landing section is reached.

Based on Table 1, the BHA AM-63 uses several large-diameter components that are relatively heavy, including the 8" DHM, 8" Float Sub, 8" M/LWD, and 8" Cross Over Sub. These components provide sufficient stiffness and directional control during drilling, however, their relatively large diameter and weight also increase the normal contact force between the drillstring and the wellbore wall, particularly in the landing section. Consequently, this configuration contributes to higher torque and drag values, reducing Weight on Bit (WOB) transfer efficiency during drilling.

2.3 Analysis of drilling parameters

• Analysis of rate of penetration (ROP) & drilling time

The Rate of Penetration (ROP) evaluation focused on the 12%-inch borehole interval, particularly as drilling entered the landing section. The analysis uses data from the Daily Drilling Report (DDR), which includes drilling depth, Weight on Bit (WOB), RPM, flow rate, drilling torque, and drilling time. This data is used to evaluate changes in ROP values during drilling operations and their relationship to increases in operations and their relationship to increases in torque and drag. Based on Table 2, the ROP during sliding decreased in the interval around 3,640-4,170 ft MD compared to the previous interval, even though the WOB and flow rate remained relatively constant. This indicates that the decrease in ROP is influenced not only by drilling parameters but also by increased mechanical resistance in the form of torque and drag, which reduces the effectiveness of transferring the Weight on Bit (WOB) to the drill bit.

Table 1.
BHA AM-63 components (presented using halliburton sperry drilling insite software for BHA output preview)

Item #	Description	Serial number	OD (in)	ID (in)	Weight (lbpf)	Length (ft)	Cum. Length (ft)
1	12-1/4" Smith PDC	JP7810	8,500	4,000	150,56	1,08	1,08
2	8" TerraForce Lobe 6/7 - 4.0 stg 8m Sleeve Stabilizer	114245S5	8,000	5,250	123,16	28,87	29,95 29,95
3	8" Float Sub c/w float valve	DSS12-01653G	8,000	3,240	143,21	1,93	31,88
4	8" PM Collar (Survey)	13051567	8,000	3,250	152,10	8,75	40,63
5	8" DGR Collar (Gamma) DGR Insert DDS Insert	90702358	8,000	1,920	142,70	6,49	47,12 47,12 47,12
6	8" EWR Collar (Resistivity) EWR-P4 Insert	90702358	8,000	2,000	151,00	13,42	60,54 60,54
7	8" HCIM Collar HCIM Insert	90702358	8,000	1,920	149,90	3,61	64,15 64,15
8	8" PWD	90735606	8,000	1,920	143,40	7,73	71,88
9	8" HOC	13038086	8,150	3,250	151,20	9,84	81,72
10	8" Screen Sub	10705196	8,000	3,250	143,03	6,53	88,25
11	8" Cross Over Sub	12106171	8,000	3,060	146,24	4,40	92,65
12	2 Jts x 5" HWDP		5,000	3,000	49,30	62,00	154,65
13	10 Jts x 5" DP		5,000	4,276	22,60	300,00	454,65
14	3 Jts x 5" HWDP		5,000	3,000	49,30	90,00	544,65
15	6-1/2" Sledgehammer Jar	11373508	6,500	2,500	88,24	20,96	565,61
16	6 Jts x 5" HWDP		5,000	3,000	49,30	180,00	745,61
17	4 Jts x 5" HWDP		5,000	3,000	49,30	120,00	865,61
18	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	895,61
19	5" HWDP 1		5,000	3,000	49,30	31,50	927,11
20	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	957,11
21	5" HWDP 2		5,000	3,000	49,30	31,50	988,61
22	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.018,61
23	5" HWDP 3		5,000	3,000	49,30	31,50	1.050,11
24	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.080,11
25	5" HWDP 4		5,000	3,000	49,30	31,50	1.111,61
26	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.141,61
27	5" HWDP 5		5,000	3,000	49,30	31,50	1.173,11
28	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.203,11
29	5" HWDP 6		5,000	3,000	49,30	31,50	1.234,61
30	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.264,61
31	5" HWDP 7		5,000	3,000	49,30	31,50	1.296,11
32	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.326,11
33	5" HWDP 8		5,000	3,000	49,30	31,50	1.357,61
34	6 1/2" Drill Collar		6,500	2,813	91,70	30,00	1.387,61
35	5" HWDP 9		5,000	3,000	49,30	31,50	1.419,11

Table 2.
ROP data for the landing section of Well AM-63 (rigsite measurement)

Depth		Drilling Mode	Toolface	Slide Dist.	Rotate Drilled	ROP ft/hr	Drill Time (Hrs)
From	To						
3607	3625	Oriented	HS	18		13,8	1,30
3625	3640	Rotary			15	52,9	0,28
3640	3667	Oriented	20L	27		10,1	2,67
3667	3670	Rotary			3	30,0	0,10
3670	3700	Oriented	20L	30		7,2	4,18
3700	3702	Rotary			2	20,0	0,10
3702	3718	Oriented	10L	16		8,0	2,00
3718	3728	Oriented	5R	10		5,5	1,83
3728	3732	Rotary			4	30,0	0,13
3732	3735	Rotary			3	36,0	0,08
3735	3745	Oriented	5R	10		4,2	2,37
3745	3767	Rotary			22	37,7	0,58
3767	3774	Oriented	5L	7		6,9	1,02
3774	3784	Oriented	5L	10		5,3	1,90
3784	3789	Rotary			5	6,3	0,80
3789	3795	Rotary			6	72,0	0,08
3795	3810	Oriented	5L	15		4,2	3,53
3810	3812	Oriented	5L	2		3,4	0,58
3812	3818	Oriented		6		3,5	1,73
3818	3829	Rotary			11	73,3	0,15
3829	3833	Oriented	5L	4		10,9	0,37
3833	3836	Oriented	5L	3		2,2	1,37
3836	3840	Oriented	20L	4		2,6	1,52
3840	3857	Rotary			17	20,8	0,82
3857	3860	Rotary			3	45,0	0,07
3860	3874	Oriented	10L	14		2,7	5,25
3874	3891	Rotary			17	22,7	0,75
3891	3898	Oriented	20L	7		2,7	2,60
3898	3902	Oriented	20L	4		6,0	0,67
3902	3920	Rotary			18	27,7	0,65
3920	3940	Rotary			20	29,3	0,68
3940	3949	Oriented	20L	9		2,7	3,38
3949	3952	Oriented	20L	3		2,5	1,20
3952	3973	Rotary			21	33,2	0,63
3973	3983	Rotary			10	40,0	0,25
3983	3993	Rotary			10	42,9	0,23
3991	4004	Oriented	20L	13		2,1	6,18
4004	4017	Rotary			13	24,4	0,53
4017	4045	Rotary			28	28,0	1,00
4045	4084	Rotary			39	33,4	1,17
4084	4090	Oriented	20L	6		5,9	1,02
4090	4093	Oriented	10L	3		0,6	5,00
4093	4107	Rotary			14	46,7	0,30

Based on Table 3, the planned drilling time (target time) for the 12-1/4" section was 64.65 hours, rounded to 65 hours, while the actual time required was 160 hours. Thus, there was a 95-hour delay relative to the plan, resulting in a drilling delay. performance of approximately 246% of the set target time. These results indicate that drilling operations in this section proceeded more slowly than planned.

Table 3.
Comparison of planned vs actual drilling time in section 12-1/4"

Activity	Target time	Target time rounded	Plan Depth (ft MD)	Actual Depth (ft MD)	Actual Time (AT)	Actual & Outlook Time in Hour
	Hours	Hours			Hours	
Drill 12-1/4" hole	64.65	65	4195	4195	160	160

This condition is also seen in Figure 1: Relationship between ROP and Depth. The actual curve (blue) lies to the left of the target curve (red) for almost the entire drilling interval, where (ft) the planned rate (31.76 ft/hr) is higher than the trend of the actual curve (20 ft/hr). These results indicate that the rate of penetration (ROP) is not optimum.

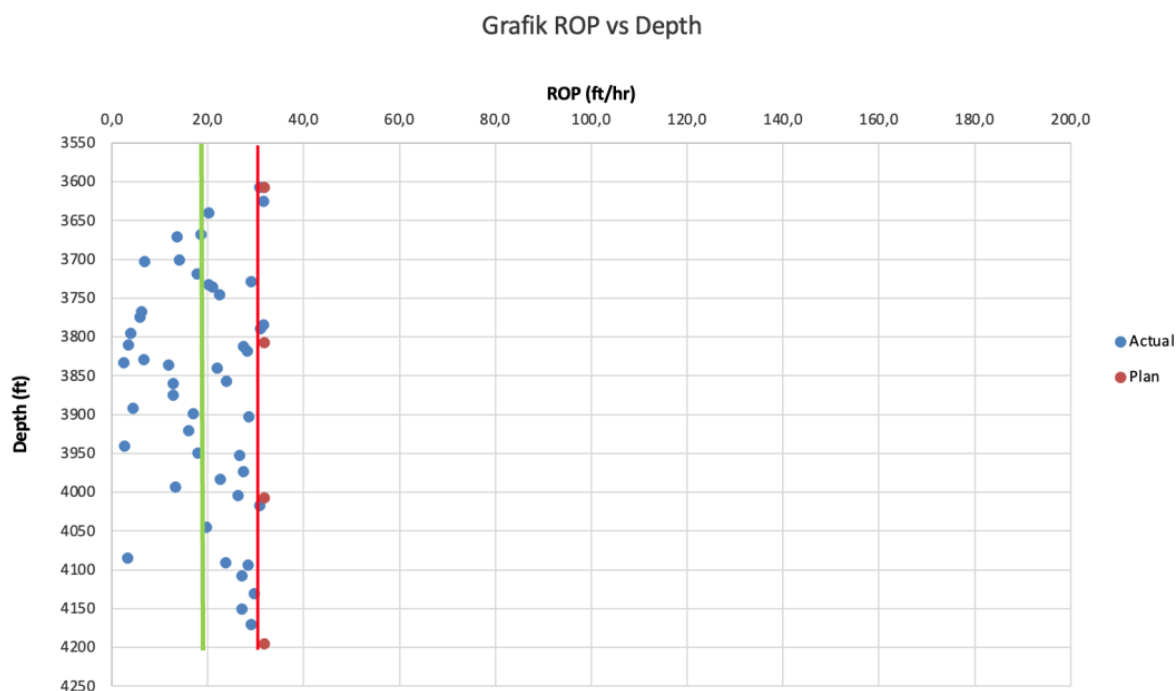


Figure 3.
Figure of ROP vs. Depth along the landing section (green line represent the trend of the actual ROP)

- **Torque and drag analysis**

Torque and drag analyses were conducted to evaluate the drilling mechanics in the 12¼- inch section of Well AM-63. These two parameters were used to determine the magnitude of the frictional force between the drillstring and the borehole wall. An increase in drag can hinder the transfer of Weight on Bit (WOB) to the drill bit, while an increase in torque indicates increased rotational resistance due to contact between the drill string and the formation. These conditions can reduce drilling efficiency and cause hanging problems in the landing section. The actual hookload and torque data in Table 4 were used as the basis for the analysis and then presented in the form of a roadmap Figure to facilitate interpretation of changes in each parameter along the drilling.

Table 4.
Actual hookload and torque data for well AM-63 in the 12-1/4” section

Depth		Drilling Mode	Tool face	Slide Dist.	Rotate Drilled	ROP ft/hr	Drill Time (Hrs)	RPM	WOB (Klbs)	Flow Rate	P/U Weight	S/O Weight	Rot. Weight	Drilling Torque Off/On (K ft-lbs)
From	To													
3607	3625	Slide	HS	18		13,8	1,30		15	780				
3625	3640	Rotary			15	52,9	0,28	30	15	780				
3640	3667	Slide	20L	27		10,1	2,67		15	780				
3667	3670	Rotary			3	30,0	0,10	30	15	780	163	138	156	3.9 - 5.9
3670	3700	Slide	20L	30		7,2	4,18		15	780				
3700	3702	Rotary			2	20,0	0,10	30	15	780				
3702	3718	Slide	10L	16		8,0	2,00		15	780				
3718	3728	Slide	5R	10		5,5	1,83		15	780				
3728	3732	Rotary			4	30,0	0,13	30	15	780	165	136	158	4.0 - 6.0
3732	3735	Rotary			3	36,0	0,08	30	15	780				
3735	3745	Slide	5R	10		4,2	2,37		20	780				
3745	3767	Rotary			22	37,7	0,58	30	15	780				
3767	3774	Slide	5L	7		6,9	1,02		20	780				
3774	3784	Slide	5L	10		5,3	1,90		15	780				
3784	3789	Rotary			5	6,3	0,80	30	15	780				
3789	3795	Rotary			6	72,0	0,08	30	15	780	165	136	156	4.1-6.1
3795	3810	Slide	5L	15		4,2	3,53		15	780				
3810	3812	Slide	5L	2		3,4	0,58		15	780				
3812	3818	Slide		6		3,5	1,73		15	780				
3818	3829	Rotary			11	73,3	0,15	30	15	780				
3829	3833	Slide	5L	4		10,9	0,37		20	780				
3833	3836	Slide	5L	3		2,2	1,37		20	780				
3836	3840	Slide	20L	4		2,6	1,52		25	780				
3840	3857	Rotary			17	20,8	0,82	30	15	780	164	135	150	4.2 - 6.2
3857	3860	Rotary			3	45,0	0,07	30	15	780				
3860	3874	Slide	10L	14		2,7	5,25		25	780				
3874	3891	Rotary			17	22,7	0,75	30	15	780				
3891	3898	Slide	20L	7		2,7	2,60		25	780				
3898	3902	Slide	20L	4		6,0	0,67		25	780				
3902	3920	Rotary			18	27,7	0,65	30	15	780	161	130	148	5-7
3920	3940	Rotary			20	29,3	0,68	30	15	780				
3940	3949	Slide	20L	9		2,7	3,38		20	780				
3949	3952	Slide	20L	3		2,5	1,20		20	780				
3952	3973	Rotary			21	33,2	0,63	30	15	780				
3973	3983	Rotary			10	40,0	0,25	30	15	780	166	131	145	5-7
3983	3993	Rotary			10	42,9	0,23	30	15	780				
3991	4004	Slide	20L	13		2,1	6,18		25	780				
4004	4017	Rotary			13	24,4	0,53	30	15	780				
4017	4045	Rotary			28	28,0	1,00	30	15	780	168	132	146	5.2-7.2
4045	4084	Rotary			39	33,4	1,17	30	15	780				
4084	4090	Slide	20L	6		5,9	1,02		20	780				
4090	4093	Slide	10L	3		0,6	5,00		20	780				
4093	4107	Rotary			14	46,7	0,30	30	10	780	170	138	140	5.2-7.7

- **Pick up (P/U) analysis**

Table 5.

Calculation of a 12¼" hookload pickup section (calculated using wellplan software to get prediction of Pick Up Weight)

Run Measured Depth using:	Pick Up using:	Pick Up using:	Pick Up using:
	Open hole friction factor: 0.30	Open hole friction factor: 0.40	Open hole friction factor: 0.50
(ft)	(kip)	(kip)	(kip)
2.000,00	131,5	131,5	131,5
2.400,00	139,2	139,2	139,2
2.800,00	146,9	147,2	147,6
3.400,00	154,3	155,9	157,6
3.817,00	155,5	157,6	160,1
4170	163	164	168

Table 6.

Actual data picking up hookload section 12¼" (rigsite measurement)

Depth	P/U
(ft)	(kip)
2293	138
2355	138
2480	142
2605	142
2670	144
2793	147
2882	150
2981	151
3043	152
3106	153
3169	154
3232	156
3295	158
3358	160
3420	162
3481	162
3544	162
3607	163
3670	163
3732	165
3795	165
3857	164
3920	164
3983	166
4045	168
4107	170

- **Analysis slack off (S/O)**

Table 7.

Slack calculation for the 12¼" hookload section (Calculated using wellplan software to get prediction of Slack off weight)

Run Measured Depth using:	Slack Off using:	Slack Off using:	Slack Off using:
	open hole friction factor: 0.30	open hole friction factor: 0.40	open hole friction factor: 0.50
(ft)	(kip)	(kip)	(kip)
2.000,00	121,1	121,1	121,1
2.400,00	126,5	126,5	126,5
2.800,00	131,6	131,4	131,2
3.400,00	132,9	132,1	131,2
3.817,00	131,5	130	128,4
4170	135	129,3	127,8

Tabel 8.

Actual data slack off hookload section 12¼" (rigsite measurement)

Depth	S/O
(ft)	(kip)
2293	122
2355	123
2480	123
2605	125
2670	125
2793	127
2882	130
2981	131
3043	130
3106	130
3169	131
3232	132
3295	132
3358	133
3420	133
3481	136
3544	136
3607	137
3670	138
3732	136
3795	136
3857	135
3920	134
3983	135
4045	136
4107	137

- **Analysis torque off bottom**

Table 9.
Torque off bottom calculation for the 12¼" bottom section
(calculated using wellplan software to get prediction of Torque off bottom values)

Run Measured Depth using:	Torque Off Bottom using:	Torque Off Bottom using:	Torque Off Bottom using:
	open hole friction factor: 0.30	open hole friction factor: 0.40	open hole friction factor: 0.50
(ft)	(ft-lbf)	(ft-lbf)	(ft-lbf)
2.000,00	1.408,80	1.408,80	1.408,80
2.400,00	1.731,10	1.731,10	1.731,10
2.800,00	2.121,20	2.209,00	2.296,70
3.400,00	3.036,40	3.399,90	3.763,50
3.817,00	3.391,90	3.870,30	4.348,70
4170	3.900,00	4.700,00	5.500,00

Table 10.
Actual data torque off bottom section 12¼" (rigsite measurement)

Depth	Torque off bottom
(ft)	Ft-lbf
2293	1500
2355	1600
2480	1800
2605	1900
2670	2100
2793	2200
2882	2400
2981	2500
3043	2600
3106	2800
3169	2900
3232	3000
3295	3100
3358	3200
3420	3300
3481	3500
3544	3600
3607	3800
3670	3900
3732	4000
3795	4100
3857	4200
3920	5000
3983	5000
4045	5200
4107	5200

- **Torque on bottom analysis**

Table 11.
Torque On Bottom Calculation for the 12¼" Bottom Section (wellplan Software)

Run Measured Depth using:	Torque On Bottom using: open hole friction factor: 0.30	Torque On Bottom using: open hole friction factor: 0.40	Torque On Bottom using: open hole friction factor: 0.50
(ft)	(ft-lbf)	(ft-lbf)	(ft-lbf)
2.000,00	2.698,70	2.698,70	2.698,70
2.400,00	3.010,20	3.010,20	3.010,20
2.800,00	3.528,50	3.659,40	3.790,30
3.400,00	4.504,30	4.931,70	5.359,10
3.817,00	5.210,40	5.870,00	6.529,50
4170	5.800,00	6.800,00	8.000,00

Table 12.
Actual data torque on bottom section 12¼" (rigsite measurement)

Depth	Torque ON Bottom
(Ft)	Ft-lbf
2293	2500
2355	2600
2480	2800
2605	3000
2670	3200
2793	3500
2882	3800
2981	4000
3043	4200
3106	4600
3169	4800
3232	4900
3295	5000
3358	5200
3420	5300
3481	5500
3544	5600
3607	5800
3670	5900
3732	6000
3795	6100
3857	6200
3920	7000
3983	7000
4045	7200
4107	7700

3. Result and discussion

3.1 Evaluation of the BHA design on the drilling performance of well AM-63

Based on the data analysis, it was found that during the drilling of the 12% section of Well AM-63, there was an increase in torque and drag values, followed by a decrease in the Rate of Penetration (ROP) and an increase in drilling time during the landing section interval. This phenomenon indicates that drilling mechanics performance was not optimal.

The operational data consistently show that the onset of the hanging condition coincided with the transition from the build section to the landing section, where the well inclination increased significantly. Therefore, the discussion focuses on the relationship between the BHA configuration, torque and drag behavior, and drilling performance, as these parameters represent the principal findings of this study.

3.2 Evaluation of the bottom hole assembly (BHA) configuration

The AM-63 BHA uses several large-diameter components that are relatively heavy, such as an 8" DHM, an 8" Float Sub, an 8" M/LWD, and an 8" CrossOver Sub. This configuration results in a high total BHA weight, which increases the normal force between the drillstring and the borehole wall in the landing section. As the inclination angle increases, part of the BHA's weight is converted into contact force against the borehole wall, thereby increasing drag and reducing the effectiveness of Weight on Bit (WOB) transfer. As a result, the Rate of Penetration (ROP) decreases, and a higher WOB is required to maintain the ROP. This condition was one of the factors contributing to the hanging problem in Well AM63.

The weight of the string increases the normal force on the wellbore wall, which in turn increases the friction force, resulting in higher torque and drag, especially on the landing section. Therefore, the BHA configuration of Well AM-63 is believed to be one of the factors contributing to the increase in friction force during the drilling of the landing section.

According to the principles of drilling mechanics, the normal contact force between the drillstring and the wellbore wall increases as the inclination angle approaches the horizontal section. A heavier, stiffer BHA further increases this contact force, resulting in greater frictional resistance, torque, and drag. Consequently, a smaller portion of the applied surface weight is transferred to the drill bit, reducing drilling efficiency. These findings are consistent with previous studies reported by Mitchell et al. (2011), which explain that drillstring weight, well trajectory, and friction coefficient are the dominant factors controlling torque and drag behavior in highly deviated and horizontal wells.

3.3 The relationship between BHA design and increases in torque and drag

- **Pick up (P/U) analysis**

Based on Figure 2, at depths of approximately 3,300-3900 ft MD, the actual hookload curve begins to deviate from the calculated curve, particularly as it enters the build section through the landing section. The greatest deviation occurs toward the end of drilling, when the actual hookload lies to the right of the predicted curve. This condition indicates an increase in drag force due to increased friction between the drillstring and the borehole wall as the inclination angle reaches horizontal. This increase in drag reduced the effectiveness of force transfer along the drilling string and caused the drillstring to hang in Well AM-63.

Figure 2 clearly shows that the deviation between the predicted and actual Pick-Up hookload increases progressively after approximately 3,300 ft MD. This deviation indicates that frictional resistance increased with increasing well inclination, confirming that drag accumulation was concentrated in the landing section.

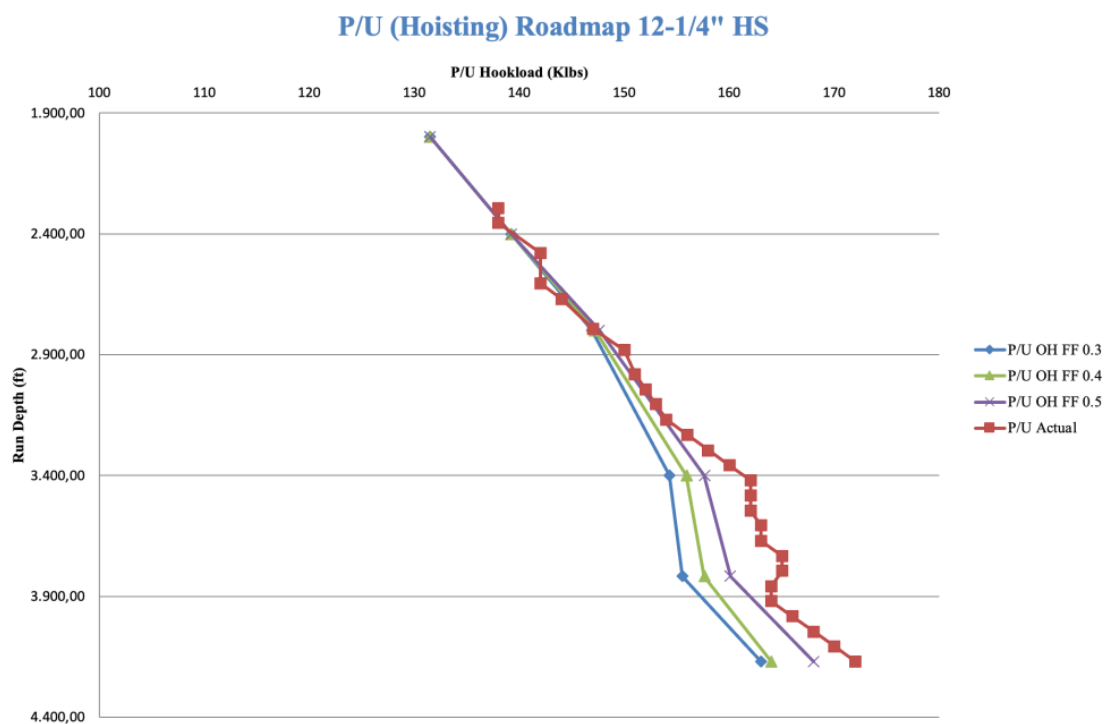


Figure 4.
Pick up (p/u) hookload section 12-1/4". Seen shifting from calculated (Prediction)

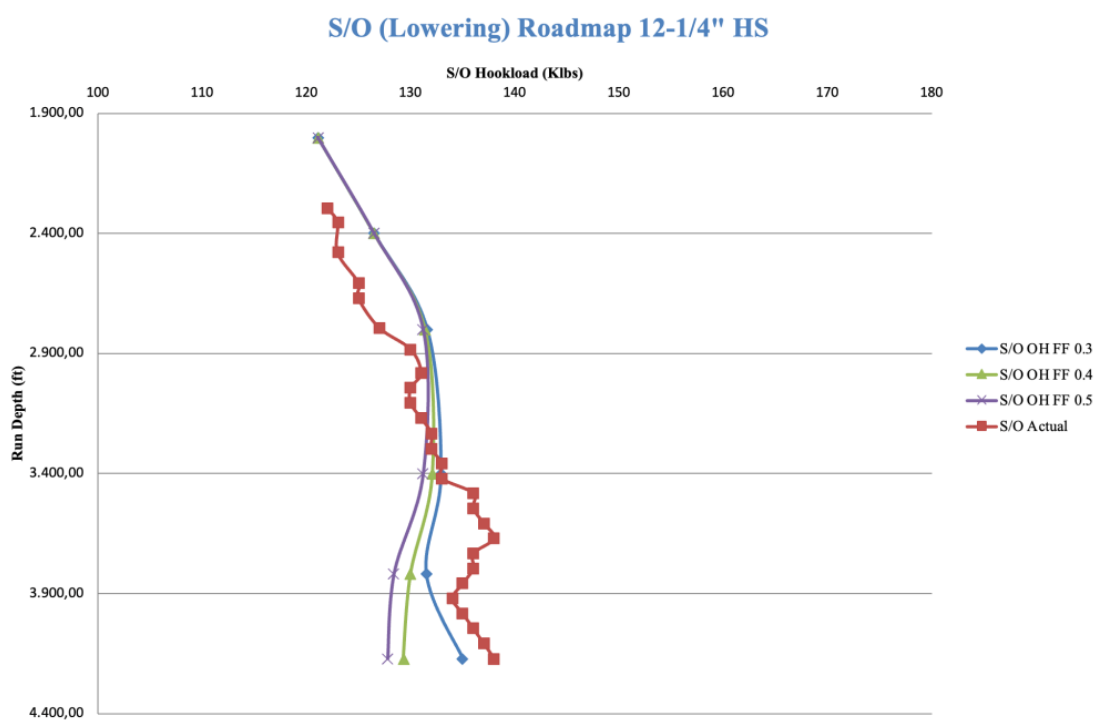


Figure 5.
Slack off (S/O) hookload section 12-1/4". Seen shifting from calculated (Prediction)

- **Slack off (S/O) analysis**

Based on Figure 3, the actual curve deviates from the theoretical curve in the interval from the build section to the landing section, starting at a depth of 3,400-3,900 ft MD. This difference indicates that as the drill string is lowered, drag increases, reducing the load transmitted to the lower part of the string. Although the drill string can still be lowered to reach the target depth, the increased drag results in less optimal Weight on Bit (WOB) transfer, thereby reducing drilling efficiency. This phenomenon is an early indication that high friction forces are developing, which will eventually lead to a hanging problem in the landing section.

The trend observed in Figure 3 complements the Pick-Up analysis by demonstrating that the increased drag affected both pulling and lowering operations. The consistent deviation between the actual and theoretical curves confirms that friction was no longer localized but influenced the overall movement of the drillstring. The increasing separation between the calculated and measured Slack-Off curves confirms that additional drag developed during downward movement of the drillstring. This behavior indicates that a significant portion of the applied load was dissipated through friction before reaching the drill bit, thereby reducing the efficiency of Weight-on-Bit (WOB) transfer.

- **Torque off bottom analysis**

Figure 4 shows that the actual curve remains between the predicted curves up to approximately 3,900 ft MD. After entering the landing section, the actual torque value increases and approaches or even exceeds the calculations based on a high friction factor. This indicates an increase in rotational resistance resulting from increased contact area between the drillstring and the wellbore. The higher the required torque, the more rotational energy is being used to overcome friction rather than being transferred to the bit.

This condition is one of the causes of decreased drilling efficiency in the landing section. Figure 4 indicates that rotational resistance remained relatively stable in the build section but increased considerably after entering the landing section. This trend demonstrates that additional rotational energy was required to overcome friction rather than being transmitted efficiently through the drillstring.

- **Torque on bottom analysis**

Figure 5 shows that, during the landing section, the actual torque curve exhibits a fairly significant increase compared to the calculated results. This increase indicates that, in addition to high friction along the drill string, the bit also requires more energy to maintain the drilling speed. Due to the simultaneous increase in torque and drag, the transfer of Weight on Bit (WOB) became less effective. This condition is consistent with the operational report, which documented a weight transfer issue during the landing section interval. Thus, it can be concluded that the increase in torque and drag was the primary factor causing the hanging problem in Well AM-63; therefore, an evaluation of the Bottom Hole Assembly (BHA) design is necessary as the basis for improvements to be implemented in subsequent wells.

Among all torque and drag parameters, Figure 5 provides the clearest evidence of drilling inefficiency because it represents the drilling condition while the bit was actively cutting the formation. The significant increase in actual torque relative to predicted values indicates that mechanical energy was increasingly consumed by friction, thereby reducing the effective transfer of Weight on Bit (WOB) to the bit.

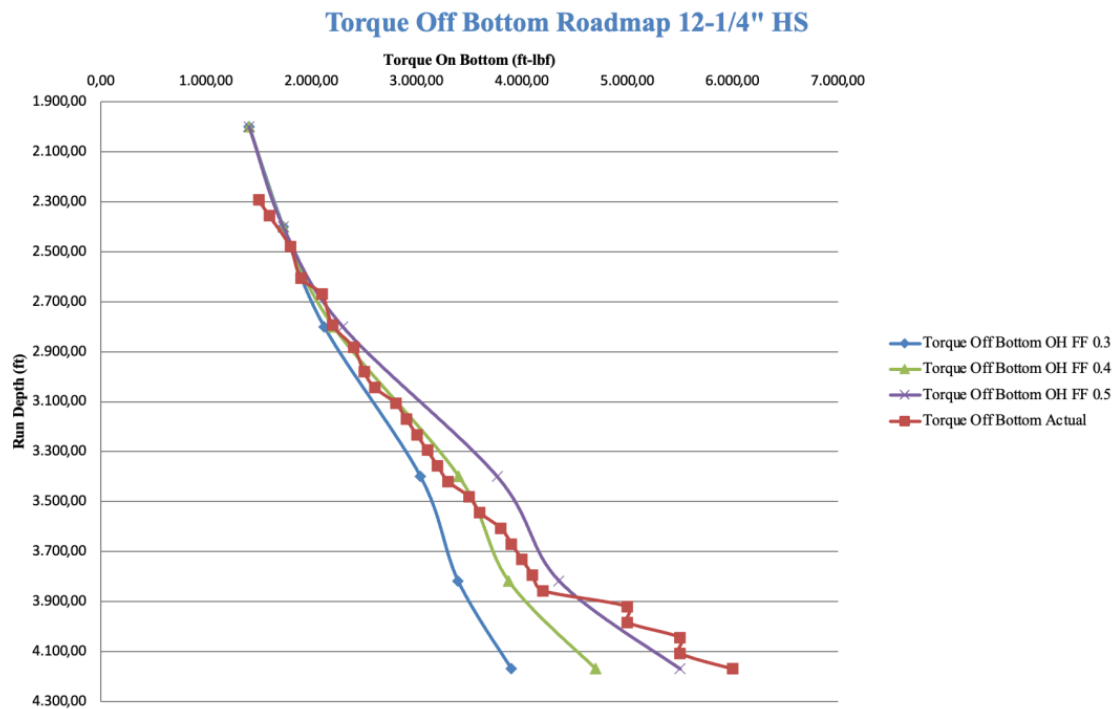


Figure 6.
Torque off bottom section 12¼" Seen shifting from calculated (Prediction)

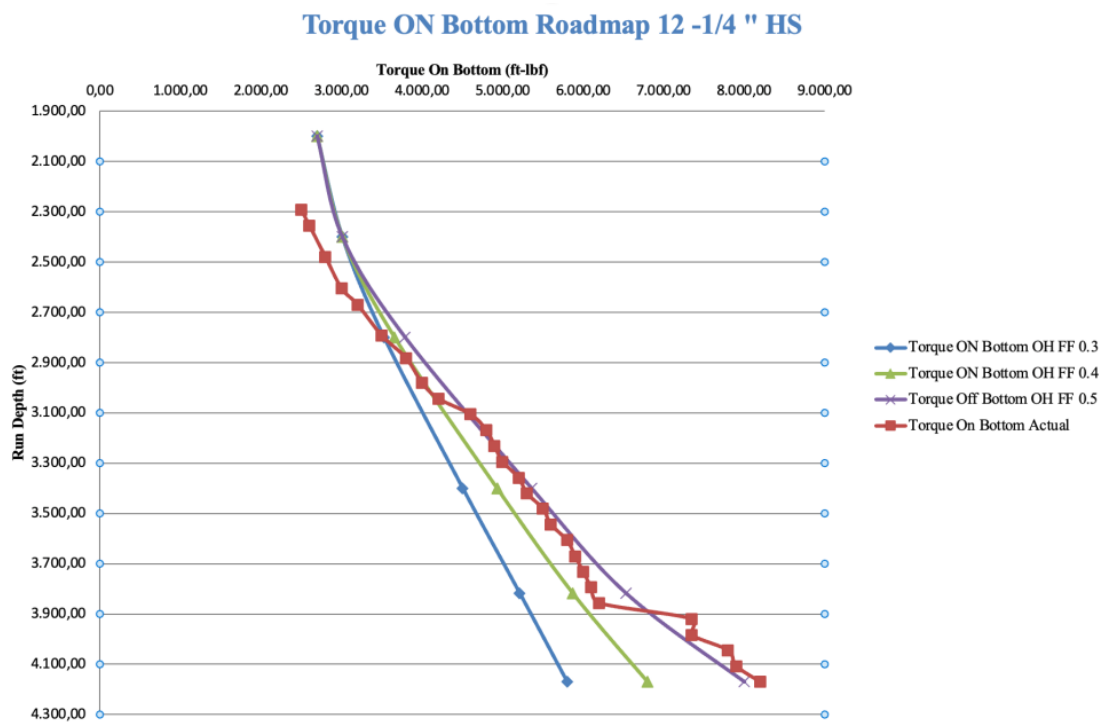


Figure 7.
Torque on bottom section 12¼" . Seen shifting from calculated (Prediction)

The actual curve shows increasing deviation from the theoretical curve, particularly from approximately 3,300 ft MD to the landing point. This condition indicates an increase in pull and thrust forces due to increased friction between the drillstring and the borehole wall. This increase is influenced by the BHA configuration, which has relatively large weight and dimensions, resulting in a higher normal force. As the wellbore inclination approaches the horizontal, the contact force against the wellbore wall increases, thereby increasing friction, drag, torque. These results are consistent with the torque and drag theory, which states that an increase in inclination, as well as the weight and size of the drillstring, is the primary factor increasing mechanical drilling resistance in horizontal wells. Thus, the BHA configuration of Well AM-63 contributed to increased torque and drag in the landing section.

Overall, Figures 2 through 5 consistently show that the actual hookload and torque responses deviate increasingly from the theoretical predictions as the drilling process enters the landing section. The similarity in trends across these four parameters indicates that the increase in mechanical resistance occurs systematically, rather than incidentally. This mechanical behavior is consistent with the decrease in the Rate of Penetration (ROP) shown in Figure 1 and the increase in drilling time shown in Table 3, thereby confirming that the hanging condition is primarily caused by increased torque and drag associated with the BHA configuration used.

The progressive deviation between the theoretical and actual curves observed from approximately 3,300 ft MD to the landing point indicates a continuous increase in mechanical resistance as the inclination angle approached horizontal. According to torque and drag theory, the normal contact force increases with well inclination, causing frictional resistance to increase proportionally. Under these conditions, heavier and stiffer BHA components produce greater wall contact, resulting in increased hookload, torque, and drag.

These observations agree with previous studies by Mitchell et al. (2011), which reported that drillstring weight, friction coefficient, and well trajectory are the dominant parameters controlling torque and drag in directional and horizontal wells. The consistency between the present results and previous research strengthens the interpretation that the BHA configuration contributed significantly to the hanging condition encountered in Well AM 63.

3.4 The effects of torque and drag on the decrease in ROP

The combined interpretation of Table 3 and Figures 1 through 5 indicates that the reduction in drilling performance resulted from the interaction between BHA configuration, increased torque and drag, reduced Weight on Bit (WOB) transfer, and lower Rate of Penetration (ROP), rather than from a single operational factor. The relatively heavy configuration of the Bottom Hole Assembly causes the normal force between the drillstring and the wellbore wall to increase upon entering the landing section. This increase in normal force results in higher torque and drag, preventing optimal transfer of Weight on Bit (WOB) to the drill bit. As a result of the reduced WOB received by the bit, the Rate of Penetration decreases, causing the drilling process to proceed more slowly. This situation is reflected in the increase in drilling time compared to the operational target. In addition, increased drag increases the pulling and thrust forces required to move the drill string, so the drill string tends to experience resistance to movement (hanging) in the landing section.

Overall, the results indicate that the reduction in drilling performance was not due to insufficient drilling parameters but to inefficient mechanical energy transfer caused by excessive friction. Consequently, improving BHA design is expected to provide greater benefits than merely increasing Weight on Bit or rotary speed under similar drilling conditions.

3.5 Recommendations for design improvements to the BHA for the next well

Based on the results of the evaluation of Well AM-63, the Bottom Hole Assembly configuration needs to be modified to mitigate the hanging problem in the next well. The improvements focused on reducing the weight, size, and stiffness of the drilling string while maintaining the ability to steer along the planned trajectory. Reducing the weight, size, and stiffness of the BHA is expected to lower the normal force acting on the wellbore wall, thereby reducing torque and drag. As friction decreases, the transfer of weight on bit to the drill bit becomes more effective, thereby increasing the rate of penetration and reducing drilling time.

In addition, the use of a Rotary Steerable System (RSS) can be considered to reduce torque and drag; it allows the drilling string to remain in a rotating state during both the angle-building and angle-maintaining sections. The use of an agitator can also be considered to enhance weight-transfer efficiency, thereby improving weight-on-bit (WOB) effectiveness.

These recommendations are directly derived from the findings presented in Table 1, Table 3, and Figures 1 through 5, which collectively demonstrate that. Reducing BHA weight and stiffness is expected to decrease frictional resistance, improve Weight-on-Bit transfer efficiency, increase Rate of Penetration, and minimize the likelihood of hanging in future horizontal wells.

4. Conclusion

The impact of increased torque and drag is reflected in a longer drilling time, from the target of 64.65 hours to 160 hours, an increase of approximately 95 hours. This indicates that the effectiveness of Weight on Bit (WOB) transfer is not yet optimum in the landing section. The Bottom Hole Assembly (BHA) design for Well AM-63 has not delivered optimal performance in the landing section. Although the actual trajectory successfully followed the well plan with a final deviation of only 6.9 ft center-to-center (C-C), there was a decrease in ROP in the 3833-4195 ft MD interval, followed by an increase in torque and drag, which triggered a hanging problem that ultimately led to a decrease in ROP. Based on the evaluation results, improvements to the Bottom Hole Assembly (BHA) design by adjusting the BHA size from 8" to 6-3/4" were implemented as a mitigation measure for subsequent wells to reduce torque and drag and minimize the potential for hanging issues.

5. Acknowledgement

The author would like to express his deepest gratitude to Pertamina Hulu Rokan Zone 3 and Halliburton Sperry Drilling Indonesia for all their assistance during the preparation of this journal article.

6. Declarations

6.1 Author contributions

Herianto: Initiated and developed the research concept, designed the research methodology, conducted an economic evaluation of chemical and mechanical well intervention alternatives, analyzed the research results, and drafted the manuscript; Harry B.S. and Alip M.: Contributed to field data collection, processing of production and intervention data, data validation, and technical analysis. They also assisted in reviewing the research results and refining the manuscript. All authors participated in interpreting the research results, critically reviewing the manuscript, and approving the final version for publication.

6.2 Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not for profit sectors.

6.3 Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6.4 The Use of AI or AI assisted Technologies

None.

7. Glossary of terms and symbols

Terms & symbols	Definition	Unit
BHA	Bottom hole assembly	
WOB	Weight on Bit	
KOP	Kick off point	
MD	Measured depth	
TVD	True vertical depth	
RPM	Revolutions per minute	
MWD	Measurement while drilling	
PDC	Polycrystalline diamond compact	
LWD	Logging while drilling	
DC	Drill collar	
DP	Drill pipe	
HWDP	Heavy weight drill pipe	
ROP	Rate of Penetration	
DDR	Daily drilling report	
Fdrag	Drag force	
Fi	Gaya axial BHA	

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