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A simulation study of the drilling Jar placement in highly deviated wells

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Abstract

Drilling jar represents one of the key element during facing wellbore problems such as stuck pipe or tight hole. The first action to be done by a driller when noticing huge torque and drag is to make jarring motion upwards and downwards with fluid circulation. Furthermore, the importance of jar placement become inevitable especially in deviated wells so that the produced hole problems can be overcome. Therefore, this paper aims to simulate the drilling jar placement and select the optimum location in which it helps to solve stuck pipe or tight hole problem if it occurs. Moreover, the drilling parameters are optimized such as WOB, flow and rotation RPM. The effect of hammer length, overpull, and slackoff loads on jar forces during jarring up and down into an offshore well are analyzed for drilling three sections" 16", 12.25", and 8.5".

Keywords: *Drilling jars; Impact, Impulse; Weight on bit; location.*

1. Introduction

Jarring is a technique used to get the stuck equipment from the borehole by hitting the drillstring with a force impulse which is a transient wave. The jarring process is done through utilizing the drilling jars which they are designed in order to generate an impact force either upward or downward. Furthermore, they are run in inclined wells so as to release or free the drillstring in case of tight hole or string sticking. The three types of the drilling jars are mechanical, hydraulic or hydro-mechanical design. Hydraulic jars are moved by a straight pull and provide an upward hit or shot. Mechanical ones are positioned at surface to be operated when applying a compression load and giving a downward hit. However, hydro-mechanical ones use both techniques during freeing operations. The top of the drill collars (DCs) are usually selected for positioning jars. They are needed to retrieve the expensive equipment installed in bottom hole assembly (BHA) during drilling shale formation which are subjected to swelling and sloughing occurring due to bad mud properties [1-5].

Regarding drilling jars behavior and placement, there are complex and not fully described physics which are required in order to the generated forces amplitude and duration of jarring. Although, computer applications and resources are necessary for solving sets of equations related to the jarring forces, till a little period ago they have been limited for researchers. Currently, jarring analysis contains either the wave tracking (WTM) or the finite element method (FEM). Their independent variables are time and space. This means that a time domain is a root for both techniques. Although the time domain probably appears to be an easy approach, there another methods, ways, or techniques to investigate this problem [5]. Therefore, the need for reviewing the history of drilling jars' analysis and computation is important.

There are several researchers who have presented various studies regarding drilling jar dynamics and placement. However, advanced technologies and studies of jarring are presented by few authors. They have concentrated on two methods to do the jar analysis, called WTM and FEM. Firstly, an analytical approach was applied in order to compute the dynamic loads on drillstrings in 1979 under jarring operations based on building 1D, constant elastic medium model with big length to diameter ratios. Authors determined the best jar position in the drillstring in case of studying the stress history during sticking. Authors approach used stress WTM in its closed form under which conventional analytical techniques of the stress wave reflections, refractions and propagation [6]. Several year later, transient dynamic analysis of the drillstring was performed under jarring operations by the FEM. The numerical method allowed the authors to take complex strings and different damping forms into consideration. Further, the numerical model was developed by using FEM commercial software package, ANSYS™, in order to simulate a nonlinear transient dynamics of any typical drillstring. The drillstring parameters such as the force, velocity, displacement, and acceleration histories are available. Moreover, a comparison a uniform DC with DCs, heavy weight drillpipe (HWDP), drillpipe (DP), and accelerator was done. Authors have been reached so many interesting effects which are not seen in the preceded works [7]. Another study was done to show the impact of HWDP on jarring operations. A researcher has used the WTM in order to develop a simulation model capable of taking more complex drillstring in two cases: (a) DCs with jar, and (b) HWDP with jar. There was no attempt to simulate both DC and HWDP with jar. He points out that initially the velocity of jarring hammer is higher in HWDP than in DCs. Additionally, it was noticed that running jars in HWDP decreases peak force by 50%; but increases impulse by 40 % as compared to jars in DCs [8].

Drilling jar placement was programmed using a computerized FEM in order to determine the optimum jar performance at the stuck point. This means selecting the largest jarring force to release the stuck equipment. Furthermore, this study provides recommendations for jar placement, trip setting, and bottom hole assembly (BHA) design [9]. A practical approach has been presented to jarring analysis. In this work, they extended the Skeem *et al.*'s works [6] using the closed form of stress WTM in order to do jarring analysis. To integrate the HWDP and the drillstring stretch below jar (Anvil section), authors followed and took Skeem's work and they also pointed out that although the FEM is a good technique for simulation, it takes large computational resources and is a time-consuming iterative solution. However, the WTM is still a perfect method for field applications and persons on the rig [10]. Regarding determination of loads affecting on DP during jarring operations, Aarrestad and Kyllingstad [11] used stress WTM in its closed form in order to determine the drillstring loads in wells in case of the generated stresses from jarring operations may overtake the tensile strength of the DP and lead to a failure. The authors show that there is no significant effect from jarring operations on the drillstring stresses in the DP.

Therefore, the main aim of our paper is to do a simulation study for the drilling jar placement in highly deviated well. Therefore, it required to know the jar mathematics and components in order to perform the simulation study.

2. Drilling jars

Jars are designed in order to provide an impact either upwards or downwards (Figure 1).

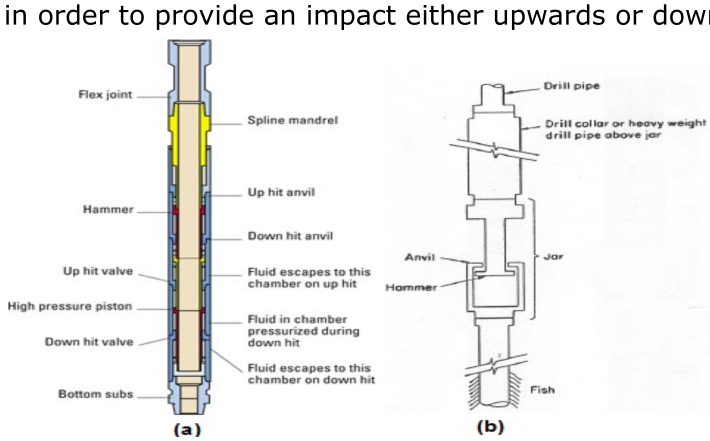

Figure 1. (a) Hydraulic jar [12], (b) Basic jar schematic [4]

They are run in inclined wells so as to jarring free the drillstring in case of tight hole or stuck pipe through several processes or stages shown in Figure 2. They are classified as mechanical, hydraulic or hydro-mechanical design (Figure 1). Details of the drilling jar mechanism and components have previously been presented and discussed in several scientific papers and textbooks [1-11].

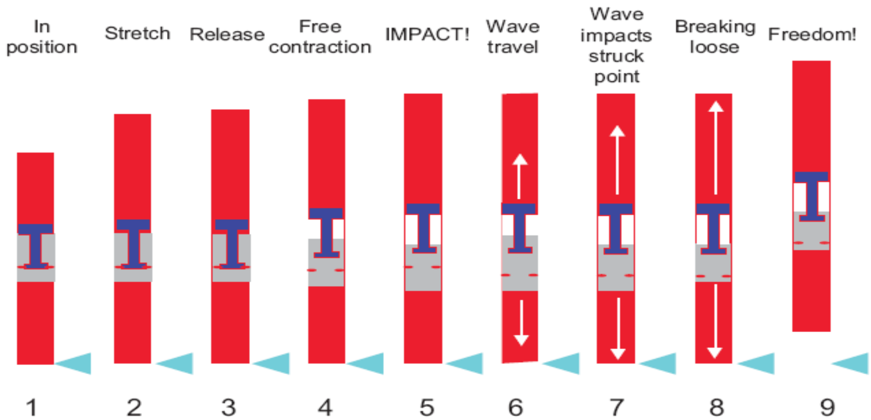

Figure 2. Jarring process [5]

3. Jar mathematics

Drilling jar mathematics have been introduced since several years ago. Several researchers have studied the behavior of the drilling jars and performance simulation analytically and numerically. Their studies are usually based on the WTM and the FEM. In 1979, Skeem *et al.* [6] analyzed drillstring dynamics during jarring operations. They presented a model to simulate the performance during pre-impact and post-impact jarring operation based on 1D and elastic medium with a significant length to diameter ratios. Further, Equations (1) through (8) are the mathematical relationship on which the simulated model depends.

$$V_C = \frac{F_o\, C_A}{A_{DC}\, E_{DC}} \quad (1)$$

$$t_{reflect} = 2\,\frac{L_{DC}}{C_A} \quad (2)$$

$$V_N = V_C\left(1 + 2\,\sum_{n=1}^{N} \lambda^n\right) \quad (3)$$

$$\lambda = \frac{A_{DC} - A_{DP}}{A_{DC} + A_{DP}} \quad (4)$$

$$F_1 = \frac{A_{DC}\, E_{DC}}{C_A}\,\frac{V_N}{2} = \frac{1}{2}\,\frac{V_N}{C_A}\,F_O \quad (5)$$

$$I(F,T) = \int F_T(t)\, dt \quad (6)$$

$$F_{AVG} = \frac{I(F,T)}{T} \quad (7)$$

$$V_S = \frac{(F - F_S)C_A}{A_{DC}\, E_{DC}} \quad (8)$$

In order to select the jar placement during tripping, a program based on Equations (9) and (10) was done for determining the trip setting load value (the overpull) required to trigger the jar. Moreover, the jar location within the drillstring indicates the obtainable triggering load. That means the higher the jar is in the drillstring, the higher the upward triggering load ($F_{UP-SETTTING}$). However, the hit load is reduced due to less weight of the BHA above the jar during downward motion [9].

$$F_{UP-SETTING} = F_{MAXIMUM} - F_{SAFETY} - F_{STRING_{ABOVE_{JAR}}} - F_{DRAG} \quad (9)$$

$$F_{DOWN-SET} = F_{BHA\_ABOVE\_JAR}(1 + f_{DRAG})\, f_{BOUYANCY}\, COS\,(\alpha) + F_{SAFETY\_DOWN} \quad (10)$$

Wang *et al.* [10] did a practical approach for do the jar analysis based on the closed form of the WTM. Equations (11) through (20) are their guide to simulate the impact and impulse forces on jars, their respective velocities and stresses in case pre-, during, and post-impact.

$$V_U = \frac{V_{HAMMER}\, A_{DC\_A} + V_{ANVIL}\, A_{DC\_B}}{A_{DC\_A} + A_{DC\_B}} \quad (11)$$

$$F_I = \frac{A_{DC\_A} E_{DC\_A}}{C_{A\_A}} \Delta V_{HAMMER} = \frac{A_{DC\_A} E_{DC\_A}}{C_{A\_A}} \Delta V_{ANVIL} \quad (12)$$
$$\Delta V_{HAMMER} = V_{HAMMER} - V_U \quad (13)$$
$$\Delta V_{ANVIL} = V_U - V_{ANVIL} \quad (14)$$
$$\sigma_R = \frac{A_O - A_I}{A_O + A_I} \sigma_I \quad (15)$$
$$\sigma_T = \frac{2A_I}{A_I + A_O} \sigma_I \quad (16)$$
$$I = (F - F_S)T \quad (17)$$
$$S = \frac{I\, C_A}{A_{DC} E_{DC}} \quad (18)$$
$$V'_N = V_N \left(1 - K_1 \frac{A_{DC\_A}}{A_{DC\_B}} L_{DC\_A} (J)^{0.5}\right) \quad (19)$$
$$V'_C = V_C (1 - K_2 (t')^{0.5}) \quad (20)$$

However, the jarring operations produce various loads on the drillstring which was found insignificant by Aarrestad and Kyllingstad [11]. They determined the loads during the five phases of the jarring process based on Equations (21) through (24), which are:

- Loading in which the storing of strain energy in the drillstring),
- Acceleration which happens after the jar triggers but before the hammer and anvil,
- Impact which is short and lasts for 10 to 50 milliseconds,
- Post-impact where the stress waves are propagating.
- Recocking in which the jarring cycle over can be able to be started.

$$\Phi = \eta \frac{1 + r_{CP} - 2r_{CP}^{n+1}}{1 - r_{CP}^{n}} \quad (21)$$
$$\eta = \frac{A_{DC\_B}}{A_{DC\_B} + A_{DC\_A}} \quad (22)$$
$$r_{CP} = \frac{A_{DC\_A} - A_{DP}}{A_{DC\_A} + A_{DP}} \quad (23)$$
$$\Phi \approx \eta \frac{4\, A_{HWDP}\, A_{DC\_A}}{\left(A_{DC_A} + A_{HWDP}\right)(A_{DP} + A_{HWDP})} \quad (24)$$

It known that the jar is an impact tool mounted as a part of the drillstring in order to free stuck pipe. It gathers kinetic energy at the point where the pipe is stuck. Therefore, Speight [13] presented simple jar formulas for making jarring calculations and analysis as shown in Equations (25) through (34) as follows:

$$F_{ES} = -(F_S + F_{POF}) \quad (25)$$
$$F_{ET} = (F_{TIS} - F_{POF}) \quad (26)$$
$$F_{EMW} = (F_{TI} - F_S - F_{POF}) \quad (27)$$
$$F_{TMW} = (F_{TO} + F_T - F_{POF}) \quad (28)$$
$$F_{ES} = (F_S - F_{POF}) \quad (29)$$
$$F_{ES} = (F_{TS} - F_{POF}) \quad (30)$$
$$F_{EMW} = (F_{TO} + F_S - F_{POF}) \quad (31)$$
$$F_{TMW} = (F_I + F_T - F_{POF}) \quad (32)$$
$$F_{SP} = F_{TD} - F_{SD} \quad (33)$$
$$WD = \frac{\Delta P_M\, A_P\, L\, N_B}{396000}, HP \quad (34)$$

Therefore, all the above equations are very essential to do jar placement simulations. Formation type, mud type, hole curvature, dogleg severity, BHA inclination, and stabilizer locations and numbers are influencing factors on the jar placement. They effect on a friction which is directly influencing the jar performance. This friction can be determined through the difference between WOB (weight on bit) of MWD downhole and WOB at the surface or using the friction decay measurement [14]

4. Well data description

An offshore well is drilled till 8935 ft (MD)/ 5600 ft (TVDss) with maximum inclination angle about 58° in order to explore expected oil reserve in the structure block of the field. After the success of drilling the first well, it is a keeper well, then followed by a sequence of appraisal and development wells. In case of failure, the well would be abundant and sidetracked to another known subsurface location with proved reserves. Furthermore, the well consists of drilled four sections: 36", 16", 12.25", and 8.5" hole section.

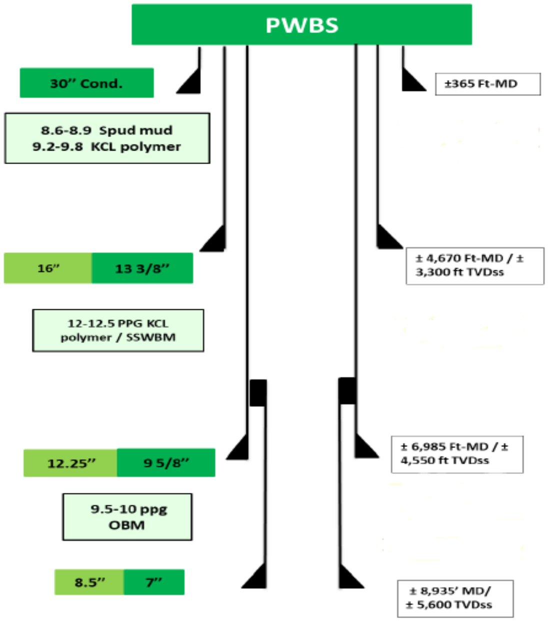

Figure 3. Well profile data

A driven 30" conductor pipe is set to ± 365 ft MD RKB to achieve ± 105 ft penetration below mud line to provide seal around conductor pipe shoe. After that, A 16" surface hole is drilled to ± 4,670 ft MD / ± 3,300 ft TVDss (As per 13 ⅜" Casing point criteria) to cover all sands and weak zones, and then set and cement 13 ⅜" casing. Then, a 12.25" intermediate hole is drilled to ± 6,985 MD / ± 4,550 ft TVDSS, so as to cover all expected high pressure zones. Setting and cementing of 9 ⅝" liner are done, then run 9 ⅝" tieback to surface. Lastly, a 8.5" intermediate hole is drilled to ± 8,935 ft MD / ± 5,600 ft TVDSS, Stop drilling after 50 ft TVDss below top of target formation, set & cement 7" liner. Perforation of the well using TCP or TT based on OHL is the final step of this well. Figure 3 shows the well sections and their respective mud type with its density. Tables 2 through 7 show the BHA and string description for drilling each section.

5. Simulation results

Drilling jars are considered one of the most important downhole tool because they help to reduce and solve the drilling problems resulting from tight wellbore and instable formations. These problems increase when drilling a well with high inclination angle such as our well (Figure 1). When the inclined angle ranges from 40-80, this leds to hole instability problems. Therefore, it is necessary to select the best position of the drilling jar in order to avoid all produced problems. In our case, an offshore well is drilled to 8935 ft (MD)/ 5600 ft (TVDss) with maximum inclination angle about 58° in order to explore expected oil reserve in the structure block of the field. A simulation study was done to analyze the jar placement during drilling the main three sections of this well: 16", 12.25", and 8.5". Tables 2 through 7 show the mounted BHA and drillstring equipment for drilling each section. First of all, the downhole parameters such as WOB, flowrate and rotation RPM need to be selected and optimized in order to avoid the problem of buckling (Table 1). Table 1 shows the simulation results of these parameters with the selected mud type. However, more details are discussed in the following sections.

For 16" hole section, the WOB simulation is done and shown in Figure 4. It shows various WOBs that produce sinusoidal and helical buckling during rotating and sliding. Based on simulation results, it is recommend to

- Control Maximum WOB based on MTR differential pressure to avoid MTR stall.
- Select maximum surface RPM while drilling with 1.5° bent housing as 70 RPM.
- Control WOB in the first 150 ft below conductor shoe up to 30 KlB to avoid sinusoidal buckling in the vertical section.

Furthermore, the WOB limitations during drilling 16" section with various drilling bits are recommended as follows (Figure 5 and Table 1):

- Max. WOB for VMA-10 4.3.5 TCI bit is 72 KlB'S.
- Max. WOB for MX-C09 4.3.5 TCI bit is 72 KlB'S.
- Max. WOB for TH42CP 4.2.5 TCI bit is 80 KlB'S.
- Weight below Jar 15 KLB'S at 58° inclination for BHA#2 (Table 2 &3).

- While rotating: Maximum WOB to sinusoidal buckling is 78 Klbs, and maximum WOB to helical buckling is 86 Klbs.
- While sliding: Maximum WOB to sinusoidal buckling is 52 Klbs, and maximum WOB to helical buckling is 55 Klbs.

Regarding jar placement simulation, Figure 7 shows the simulation results of 16" hole section with jar placement appeared in Tables 2&3. It clear that the hammer length has a little effect on the jar impact forces but has a great effect on impulse forces during jarring up operations. With 300 Klbs overpull, the impact forces slightly change but the impulse forces increase sharply with increasing the hammer length until both forces meet at hammer length of 93 ft. Moreover, the same behavior repeats during jarring down into the wellbore with slackoff weight of 74 Klbs. However, the impact forces increase in case of jarring up more than those in case of running into the hole but the behavior of impulse forces is opposite with increasing the hammer length. For 62 ft hammer length and 93 ft anvil; the more overpull loads, the more impact forces and the constant impulse forces till 210 Klbs, and the increase until reaching nearly 1750 Lbs at 300 Klbs overpull. However, the more weight of the drillstring and BHA, the more impact and impulse forces until reaching to the maximum slackoff weight of 74 Klbs.

For 12.25" hole section, the WOB simulation is done and shown in Figure 5 with jar location shown in Table 4&5 during operations in order to select the optimum values of WOBs which avoid both sinusoidal and helical buckling during rotating and sliding operations. Additionally, it is recommended in this section to:

- Control Maximum WOB based on MTR differential pressure to avoid MTR stall.
- Maximum downhole RPM for GP is 250 RPM.
- MWD flow range (600 - 800) GPM.

Also, the WOB Limitations is selected in this section as follows(Figure 5 and Table 1):

- Max. WOB for TKC56 PDC Bit: 55 KlB’s.
- Max. WOB for TD506S PDC Bit: 48 KlB’s.
- Weight below jar is 15 KlB’S at 58° inclination.
- Max. WOB to sinusoidal buckling is 81 Klb’s.
- Max. WOB to helical buckling is 97 Klb’s.

Regarding jar placement shown in Tables 4&5 during drilling 12.25" hole section, the simulation results show the same behavior of jar forces as previously discussed in 16" drilled section. However, the values of the impulse force decrease with using the same overpull of 300 Klbs during jarring up, hammer length of 62 ft and anvil length of 93 ft. while running operations, the more slackoff weight (97 Klbs), the lower impulse forces and the more slightly impact forces on the drilling jar during jarring operations in this section (Figure 8).

For 8.5" hole section of jar placement shown in Tables 6 &7 and WOB simulations plotted in Figure 6, it recommended to select the maximum downhole RPM for GP as 250 RPM and useMWD flow range as (450 - 550) GPM. Otherwise, the WOB limitations are recommended as follow (Figure 6 and Table 1):

- Max. WOB of 55 KlB’s for 7600 Geo-Pilot.
- Max. WOB of 38 KlB’s for 8 ½’’ TKC66 PDC bit.
- Max. WOB of 36 KlB’s for 8 ½’’ TD506X PDC bit:
- Weight below jar is 7 KlB’S at 58° inclination.
- Max. WOB to sinusoidal buckling is 103 Klbs.
- Max. WOB to helical buckling is 132 Klbs.

Finally, the placement of jar and accelerator in 8.5" hole and drillstring is shown in Tables 6 through 8 during operations. The simulations results is also presented in Figure 9. With 175 Klbs overpull of jarring up and 121 Klbs slackoff weight of jarring down operations, the hammer length does not have a significant effect on jar impulse and impact forces. Furthermore, the impulse and impact forces increase with increasing both overpull and slackoff loads for 31 ft hammer length and 31 ft anvil length (Figure 9).

Table 1. Simulation results for drilling parameters

Depth, ft (from –to)		MUD Type	GPM	Surface RPM	WOB
Drilling 36" and 16" hole section (Driven conductor)					
365	520	Spud	450-550	60-70	Up to 30 K.LB
520	2800	Spud	550-850		Up to 45 K.LB
2800	4670	KCL POLYMER			
Drilling 12.25" hole section					
4670	6985	KCL POLYMER	600-800	80-120 (max. D.H RPM is 250	Up to 40 KLB's
Drilling 8.5" hole section					
6985	8935	OBM	450-550	100-140	Up to 35klb's

Table 2. BHA#2: MTR/MWD drilling BHA

No.	Tool	Co	OD Iin)	ID (in)	Length (ft)	Blade O.D. (in)	Connection Top		Connection Bottom		Distance from bit (ft)	Air weight (lb)	Bouyed weight (lb)	Cum. Bouyed weight (lb)	lb/ft
15	5 7/8" D/P	-	5.875	5.153	3472		VX 57	B	VX 57	P	4670.00	93971	79911	162794	27.06
14	30 X 5" HWDP	-	5.875	4.000	930.0		VX 57	B	VX 57	P	1197.30	51280	43608	82882	55.14
13	Sub- X/O	-	8.250	2.810	2.69		VX 57	B	6 5/8" REG	P	267.30	396	337	39274	147.22
12	2 X 8 1/4" Spiral DC	-	8.250	2.810	62.00		6 5/8" REG	B	6 5/8" REG	P	264.61	10605	9018	38938	171.05
11	8" Hydraulic Jar	-	8.000	3.000	33.00		6 5/8" REG	B	6 5/8" REG	P	202.61	3800	3231	29919	115.15
10	3 X 8 1/4" Spiral DC	-	8.250	2.810	93.00		6 5/8" REG	B	6 5/8" REG	P	169.61	15908	13528	26688	171.05
8	X-Over Sub	-	9.500	3.000	3.00		6 5/8" REG	B	7 5/8" REG	P	76.61	651	554	13160	217.00
6	9 1/2" UBHO	-	9.500	3.000	4.00		7 5/8" REG	B	7 5/8" REG	P	73.61	868	738	12607	217.00
5	9 1/2" MWD	-	9.500	4.000	30.00		7 5/8" REG	B	7 5/8" REG	P	69.61	6429	5467	11868	214.30
4	14 5/8" String Stabilizer	-	9.500	3.000	7.00	14.62	7 5/8" REG	B	7 5/8" REG	P	39.61	1522	1295	6401	217.48
3	9 1/2" Float Sub	-	9.500	3.000	3.00		7 5/8" REG	B	7 5/8" REG	P	32.61	652	555	5107	217.48
2	9 5/8" SperryDrill 6/7 Lobe - 5 stg	-	9.625	6.135	28.30	15.87	7 5/8" REG	B	7 5/8" REG	B	29.61	5068	4310	4552	179.08
1	4.4.5. TCI Bit	-	9.500	3.000	1.31	16.00	7 5/8" REG	P			1.31	285	242	242	217.48

Hole Section TD	4670	ft MD (approx)		
Mud Weight	9.8	ppg	BF	0,85038
Total Buoyed String Weight at TD	162,794	lbs		
Maximum Tensile Capacity of DP	560,763	lbs		
Margin of Overpull	285,817	lbs		
Weight Below Jars	26,688	lbs		
Weight Above Jars	52,963	lbs		

BHA Type	2nd BHA 16" TCI/MTR/GWD Assy. 9 5/8" performance MTR (0.13 RPG, 6/7 Lube, 600-1200 GPM, 350 max Op. Diff. Press, 1.5 AKO, 15 3/4" Sleeve) Maximum surface RPM = 60-70 MWD flow range (550-850) GPM WOB up to 45 klbs

Table 3. BHA#3: MTR/MWD/Sonic+GR drilling BHA

No.	Tool	Co	O.D. Iin)	I.D. (in)	Length (ft)	Blade O.D. (in)	Connection				Dis-tance from bit (ft)	Air weight (lb)	Bouyed weight (lb)	Cum. Bouyed weight (lb)	lb/ft
							Top		Bottom						
17	5 7/8" D/P	-	5.875	5.153	3538.5		VX 57	B	VX 57	P	4670.00	95751	81425	164073	27.06
16	27 X 5 7/8" HWDP	-	5.875	4.000	837.00		VX 57	B	VX 57	P	1131.53	46152	39247	82649	55.14
15	Sub- X/O	-	8.250	2.810	3.00		VX 57	B	6 5/8" REG	P	294.53	442	376	43402	147.22
14	2 X 8 1/4" Spiral DC	-	8.250	2.810	62.00		6 5/8" REG	B	6 5/8" REG	P	291.53	10605	9018	43026	171.05
13	8" Hydraulic Jar	-	8.000	3.000	33.00		6 5/8" REG	B	6 5/8" REG	P	229.53	3800	3231	34008	115.15
12	3 X 8 1/4" Spiral DC	-	8.250	2.810	93.00		6 5/8" REG	B	6 5/8" REG	P	196.53	15908	13528	30778	171.05
11	8 1/4" PBL Sub	-	8.250	3.000	3.00		6 5/8" REG	B	6 5/8" REG	P	103.53	1264	1075	17249	158.00
10	X-Over Sub	-	9.500	3.000	3.00		6 5/8" REG	B	7 5/8" REG	P	95.53	651	554	16174	217.00
9	14 5/8" String Stabilizer	-	9.500	3.000	5.00	14.625	7 5/8" REG	B	7 5/8" REG	P	92.53	962	818	15620	192.45
8	9 1/2" HOC	-	9.500	4.000	17.00		7 5/8" REG	B	7 5/8" REG	P	87.53	3643	3098	14802	214.30
7	9 1/2" BAT Collar	-	9.500	2.375	20.54		7 5/8" REG	B	7 5/8" REG	P	70.53	4083	3472	11704	198.80
6	9 1/2" HCIM Collar	-	9.500	2.375	5.31		7 5/8" REG	B	7 5/8" REG	P	49.99	1129	960	8231	121.70
5	9 1/2" DGR Collar	-	9.500	2.375	5.07		7 5/8" REG	B	7 5/8" REG	P	44.68	1023	870	7271	201.70
4	14 5/8" String Stabilizer	-	9.500	3.000	7.00	14.625	7 5/8" REG	B	7 5/8" REG	P	39.61	1522	1295	6401	217.48
3	9 1/2" Float Sub	-	9.500	3.000	3.00		7 5/8" REG	B	7 5/8" REG	P	32.61	652	555	5107	217.48
2	9 5/8" SperryDrill 6/7 Lobe - 5 stg	-	9.625	6.135	28.30	15.875	7 5/8" REG	B	7 5/8" REG	B	29.61	5068	4310	4552	179.08
1	Used PDC or New TCI Bit	-	9.500		1.31	16.000	7 5/8" REG	P			1.31	285	242	242	217.48
	Hole Section TD						4670		ft MD (approx)						
	Mud Weight						9.8		ppg						
	Total Bouyed String Weight atTD						164,073		lbs						
	Maximum Tensile Capacity of DP						560,763		lbs						
	Margin of Overpull						284,537		lbs						
	Weight Below Jars						30,776		lbs						
	Weight Above Jars						48,641		lbs						

BHA Type	3rd BHA 16" MTR/MWD/ Sonic+ GR Assy. 9 5/8" performance MTR (0.13 RPG, 6/7 Lube, 600-1200 GPM, 350 max Op. Diff. Press, 1.5 AKO, 15 3/4" Sleeve) Maximum surface RPM = 60-70 MWD flow range (600-900) GPM WoB up to 45 klbs

Table 4. BHA # 4 (PDC + MARSS +MWD Ass)- 12.25

No.	Tool	Com-pany	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection				Dis-tance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb / ft
							Top		Bottom						
19	5 7/8" D/P	-	5.875	5.153	5752.01		VX 57	B	VX 57	P	6985.00	155649	125945	207296	27.06
18	30 x 5 7/8" HWDP	-	5.875	4.000	930.00		VX 57	B	VX 57	P	1232.99	51280	41494	81351	55.14
17	Sub- X/O	-	8.000	2.813	3.00		VX 57	B	6 5/8'' REG	P	302.99	513	415	39857	171.00
16	2 X 8 1/4" Drill Collar	-	8.250	2.812	62.00		6 5/8'' REG	B	6 5/8'' REG	P	299.99	10605	8581	39442	171.05
15	8" Hydraulic Jar	-	8.000	3.000	33.00		6 5/8'' REG	B	6 5/8'' REG	P	237.99	3800	3075	30860	115.15
14	3 X 8 1/4'' Dril Collar	-	8.250	2.812	93.00		6 5/8'' REG	B	6 5/8'' REG	P	204.99	15908	12872	27786	171.05
13	8 1/4" PBL Sub	-	8.250	3.000	8.00		6 5/8'' REG	B	6 5/8'' REG	P	111.99	1264	1023	14914	158.00
12	8" Float Sub	-	8.000	2.813	3.00		6 5/8'' REG	B	6 5/8'' REG	P	103.99	513	415	13891	171.00
11	10 5/8'' S. Stabilizer	-	8.000	2.813	7.87	10.625	6 5/8'' REG	B	6 5/8'' REG	P	100.99	1157	936	13476	147.01
10	9 5/8" SperryDrill Lobe 6/7 – 3 stg	-	9.625	6.537	28.19	12.125	6 5/8'' REG	B	6 5/8'' REG	B	93.12	5457	4415	12540	193.57
9	8'' Double Pin X-over	-	7.920	2.760	3.00		6 5/8'' REG	P	6 5/8'' REG	P	64.93	450	364	8124	149.90
8	8'' Downhole Screen	-	7.920	2.760	3.00		6 5/8'' REG	B	6 5/8'' REG	P	61.93	450	364	7760	149.90
7	8" HOC Collar	-	8.000	4.000	11.00		6 5/8'' REG	B	6 5/8'' REG	P	58.93	1597	1292	7397	145.20
6	8" HCIM Collar	-	8.000	1.920	4.97		6 5/8'' REG	B	6 5/8'' REG	P	47.93	745	603	6104	149.90
5	8" PWD	-	8.000	1.920	4.44		6 5/8'' REG	B	6 5/8'' REG	P	42.96	637	515	5501	143.40
4	12 1/8" Inline Stabilizer	-	8.000	2.000	6.56	12.125	6 5/8'' REG	B	6 5/8'' REG	P	38.52	1252	1013	4986	190.84
3	8" DM Collar	-	8.000	3.500	9.20		6 5/8'' REG	B	6 5/8'' REG	P	31.96	1356	1097	3973	147.40
2	9600 EDL Geo-Pilot	-	9.625	2.375	21.71	12.125	6 5/8'' REG	B	6 5/8'' REG	B	22.76	3397	2748	2876	156.45
1	PDC Bit	-	8.000		1.05	12.250	6 5/8'' REG	P			1.05	158	128	128	150.12

Hole Section TD : Mud Weight Total Bouyed String Weight at TD Maximum Tensile Capacity of DP Margin of Overpull for 5 7/8" Weight Below Jars Weight Above Jars	6985 12.5 207,296 560,763 241,314 27,786 50,490	ft MD (approx) ppg lbs lbs (Premium) lbs lbs lbs
BHA type	4th BHA: 12.25'' PDC / MARSS / MWD Assy MWD flow range (600 - 800) GPM Surface RPM (80 - 120) WOB up to 40 KLB	

Table 5. Contingent Logging BHA (PDC + RSS +Sonic/Density Assy):12.25

No.	Tool	Company	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection Top		Connection Bottom		Distance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb/ft
18	5 7/8" D/P	-	5.875	5.153	5749.52		VX 57	B	VX 57	P	6985.00	155582	125891	206674	27.06
17	30 x 5 7/8" HWDP	-	5.875	4.000	930.00		VX 57	B	VX 57	P	1235.48	51280	41494	80783	55.14
16	Sub- X/O	-	8.000	2.813	3.00		VX 57	B	6 5/8" REG	P	305.48	442	357	39289	147.22
15	2 X 8 1/4" Drill Collar	-	8.250	2.812	62.00		6 5/8" REG	B	6 5/8" REG	P	302.48	10605	8581	38932	171.05
14	8" Hydraulic Jar	-	8.000	3.000	33.00		6 5/8" REG	B	6 5/8" REG	P	240.48	3800	3075	30351	115.15
13	3 X 8 1/4" Drill Collar	-	8.250	2.812	93.00		6 5/8" REG	B	6 5/8" REG	P	207.48	15908	12872	27276	171.05
12	8 1/4" PBL Sub	-	8.250	3.000	8.00		6 5/8" REG	B	6 5/8" REG	P	114.48	1264	1023	14404	158.00
11	8" Float Sub	-	8.000	2.813	3.00		6 5/8" REG	B	6 5/8" REG	P	106.48	513	415	13381	171.00
10	10 5/8" S. Stabilizer	-	8.000	2.813	7.87	10.625	6 5/8" REG	B	6 5/8" REG	P	103.48	1157	936	12966	147.01
9	8" HOC Collar	-	8.000	4.000	11.00		6 5/8" REG	B	6 5/8" REG	P	95.61	1597	1292	12030	145.20
8	8" BAT Collar	-	8.000	1.905	20.38		6 5/8" REG	B	6 5/8" REG	P	84.61	2753	2228	10738	135.10
7	8" ALD Collar	-	8.000	2.375	16.30	12.000	6 5/8" REG	B	6 5/8" REG	P	64.23	2973	2406	8510	182.40
6	8" HCIM Collar	-	8.000	1.920	4.97		6 5/8" REG	B	6 5/8" REG	P	47.93	745	603	6104	149.90
5	8" PWD	-	8.000	1.920	4.44		6 5/8" REG	B	6 5/8" REG	P	42.96	637	515	5501	143.40
4	12 1/8" Inline Stabilizer	-	8.000	2.000	6.56	12.125	6 5/8" REG	B	6 5/8" REG	P	38.52	1252	1013	4986	190.84
3	8" DM Collar	-	8.000	3.500	9.20		6 5/8" REG	B	6 5/8" REG	P	31.96	1356	1097	3973	147.40
2	9600 EDL Geo-Pilot	-	9.625	2.375	21.71	12.125	6 5/8" REG	B	6 5/8" REG	B	22.76	3397	2748	2876	156.45
1	PDC Bit	-	8.000		1.05	12.250	6 5/8" REG	P			1.05	158	128	128	150.12
	Hole Section TD :						6985		ft MD (approx)						
	Mud Weight						12.5		ppg						
	Total Bouyed String Weight at TD						206,674		lbs						
	Maximum Tensile Capacity of DP						560,763		lbs (Premium)						
	Margin of Overpull for 5 7/8"						241,936		lbs						
	Weight Below Jars						27,276		lbs						
	Weight Above Jars						50,433		lbs						
	BHA type	Contingent Logging BHA: 12.25" PDC / RSS / Sonic+Density Assy MWD flow range (600 - 800) GPM Surface RPM (80 - 120) WOB up to 40 KLB													

Table 6. BHA # 5 (PDC + RSS + M/LWD Assy)- 8.5"

No.	Tool	Com-pany	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection Top	Connection Bottom	Distance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb/ft
20	5 7/8" D/P	-	5.875	5.153	7679.081		VX 57 B	VX 57 P	8932.00	207796	176071	243109	27.06
19	33 x 5 7/8" HWDP	-	5.875	4.000	1023.00		VX 57 B	VX 57 P	1252.92	56408	47796	67037	55.14
18	Sub- X/O	-	6.875	2.750	3.00		VX 57 B	4 1/2" IF P	232.92	292	247	19488	97.25
17	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	229.92	3100	2627	19241	100.00
16	6 1/2" Accelerator	-	6.500	2.520	12.00		4 1/2" IF B	4 1/2" IF P	198.92	1000	847	16614	83.33
15	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	186.92	3100	2627	15767	100.00
14	6 1/2" Jar	-	6.500	2.750	33.00		4 1/2" IF B	4 1/2" IF P	155.92	2400	2034	13140	72.73
13	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	122.92	3100	2627	11107	100.00
12	6 3/4" PBL sub	-	6.750	2.875	8.20		4 1/2" IF B	4 1/2" IF P	91.92	819	694	8480	99.83
11	6 3/4" Float Sub	-	6.750	2.760	3.00		4 1/2" IF B	4 1/2" IF P	83.72	302	256	7786	100.63
10	7 3/4" String Stabilizer	-	6.750	2.813	5.00	7.750	4 1/2" IF B	4 1/2" IF P	80.72	299	253	7530	59.71
9	6-3/4" HOC Collar	-	6.750	3.250	11.00		4 1/2" IF B	4 1/2" IF P	75.72	1140	966	7277	103.60
8	6 3/4" HCIM Collar	-	6.750	1.920	6.56		4 1/2" IF B	4 1/2" IF P	64.72	667	565	6312	101.70
7	6 3/4" PWD	-	6.750	1.905	4.44		4 1/2" IF B	4 1/2" IF P	58.16	428	362	5747	96.30
6	6 3/4" DGR Collar	-	6.750	1.920	4.55		4 1/2" IF B	4 1/2" IF P	53.72	445	377	5384	97.80
5	6 3/4" EWR-P4 Collar	-	6.750	2.000	12.10		4 1/2" IF B	4 1/2" IF P	49.17	1262	1069	5007	104.30
4	8 3/8" Inline Stabilizer (ILS)	-	6.750	2.000	6.560	8.375	4 1/2" IF B	4 1/2" IF P	37.07	1252	1061	3938	190.84
3	6 3/4" DM Collar	-	6.750	3.125	9.20		4 1/2" IF B	4 1/2" IF P	30.51	951	806	2877	103.40
2	7600 EDL Geo-Pilot	-	7.625	1.490	20.16	8.375	4 1/2 Reg B	4 1/2" IF B	21.31	2306	1954	2071	114.40
1	8.5" PDC	-	8.500		1.15	8.500	B	4 1/2" Reg P	1.15	138	117	117	120.00
	Hole Section TD :						8935	FT MD (ap-prox)					
	Mud Weight						10.0	ppg					
	Total Buoyed String Weight at TD						243,356	lbs					
	Maximum Tensile Capacity of DP						560,763	lbs					
	Margin of Overpull						205,255	lbs					
	Weight Below Jars						11,107	lbs					
	Weight Above Jars						54,144	lbs					
	BHA type	5th BHA: 8.5" PDC / RSS M/LWD Assy. MWD Flow range (450 - 550) GPM Surface RPM (100 - 140) WOB up to 35 KLB											

Table 7. BHA # 6 Quad Combo Assy. (PDC + RSS + GR/Den/Neutron/Sonic)- 8.5"

No.	Tool	Com-pany	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection Top	Connection Bottom	Distance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb / ft
23	5 7/8" D/P	-	5.875	5.153	7632.401		VX 57 B	VX 57 P	8932.00	206533	175001	246030	27.06
22	33 x 5 7/8" HWDP	-	5.875	4.000	1023.00		VX 57 B	VX 57 P	1299.60	56408	47796	71029	55.14
21	Sub- X/O	-	6.875	2.750	3.00		VX 57 B	4 1/2" IF P	279.60	292	247	23480	97.25
20	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	276.60	3100	2627	23233	100.00
19	6 1/2" Accelerator	-	6.500	2.520	12.00		4 1/2" IF B	4 1/2" IF P	245.60	1000	847	20606	83.33
18	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	233.60	3100	2627	19759	100.00
17	6 1/2" Jar	-	6.500	2.750	33.00		4 1/2" IF B	4 1/2" IF P	202.60	2400	2034	17132	72.73
16	1 x 6 1/2" DC	-	6.500	2.813	31.00		4 1/2" IF B	4 1/2" IF P	169.60	3100	2627	15098	100.00
15	6 3/4" PBL sub	-	6.750	2.875	8.20		4 1/2" IF B	4 1/2" IF P	138.60	819	694	12472	99.83
14	6 3/4" Float Sub	-	6.750	2.760	3.00		4 1/2" IF B	4 1/2" IF P	130.40	302	256	11778	100.63
13	7 3/4" String Stabilizer	-	6.750	2.813	5.00	7.750	4 1/2" IF B	4 1/2" IF P	127.40	299	253	11522	59.71
12	6-3/4" HOC Collar	-	6.750	3.250	11.00		4 1/2" IF B	4 1/2" IF P	122.40	1140	966	11269	103.60
11	6 3/4" BAT Collar	-	6.750	1.905	20.30		4 1/2" IF B	4 1/2" IF P	111.40	1983	1681	10304	97.70
10	6 3/4" ALD Collar	-	6.750	1.920	14.54	8.250	4 1/2" IF B	4 1/2" IF P	91.10	1517	1285	8623	104.30
9	6 3/4" CTN Collar	-	6.750	1.905	11.84		4 1/2" IF B	4 1/2" IF P	76.56	1211	1026	7338	102.30
8	6 3/4" HCIM Collar	-	6.750	1.920	6.56		4 1/2" IF B	4 1/2" IF P	64.72	667	565	6312	101.70
7	6 3/4" PWD	-	6.750	1.905	4.44		4 1/2" IF B	4 1/2" IF P	58.16	428	362	5747	96.30
6	6 3/4" DGR Collar	-	6.750	1.920	4.55		4 1/2" IF B	4 1/2" IF P	53.72	445	377	5384	97.80
5	6 3/4" EWR-P4 Collar	-	6.750	2.000	12.10		4 1/2" IF B	4 1/2" IF P	49.17	1262	1069	5007	104.30

No.	Tool	Com-pany	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection Top		Connection Bottom		Distance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb / ft
4	8 3/8" Inline Stabilizer (ILS)	-	6.750	2.000	6.560	8.375	4 1/2" IF	B	4 1/2" IF	P	37.07	1252	1061	3938	190.84
3	6 3/4" DM Collar	-	6.750	3.125	9.20		4 1/2" IF	B	4 1/2" IF	P	30.51	951	806	2877	103.40
2	7600 EDL Geo-Pilot	-	7.625	1.490	20.16	8.375	4 1/2 Reg	B	4 1/2" IF	B	21.31	2306	1954	2071	114.40
1	8.5" PDC	-	8.500		1.15	8.500		B	4 1/2" Reg	P	1.15	138	117	117	120.00
	Hole Section TD :						8935		FT MD						
	Mud Weight						10.0		ppg						
	Total Bouyed String Weight at TD						246,277		lbs						
	Maximum Tensile Capacity of DP						560,763		lbs						
	Margin of Overpull						202,333		lbs						
	Weight Below Jars						15,098		lbs						
	Weight Above Jars						54,144		lbs						
	BHA type	6th BHA: 8.5" PDC / RSS / Quad Combo Assy. MWD Flow range (450-550) GPM Surface RPM (100 -140) WOB up to 35 KLB													

Table 8. BHA # 7 Press Points Ass (PDC + RSS + GeoTap),8.5"

No.	Tool	Com-pany	O.D. (in)	I.D. (in)	Length (ft)	Blade OD (in)	Connection Top		Connection Bottom		Distance From Bit (ft)	Air Weight (lb)	Bouyed Weight (lb)	Cum. Bouyed Weight (lb)	lb / ft
21	5 7/8" D/P	RIG	5.875	4.276	7651.161		VX 57	B	VX 57	P	8932.00	207040	175431	244978	27.06
20	33 x 5 7/8" HWDP	RIG	5.875	3.000	1023.00		VX 57	B	VX 57	P	1280.84	56408	47796	69547	55.14
19	Sub- X/O	RIG	6.875	2.750	3.00		VX 57	B	4 1/2" IF	P	260.84	292	247	21998	97.25
18	1 x 6 1/2" DC	RIG	6.500	2.813	31.00		4 1/2" IF	B	4 1/2" IF	P	257.84	3100	2627	21751	100.00
17	6 1/2" Accelerator	WFD	6.500	2.520	12.00		4 1/2" IF	B	4 1/2" IF	P	226.84	1000	847	19124	83.33
16	1 x 6 1/2" DC	RIG	6.500	2.813	31.00		4 1/2" IF	B	4 1/2" IF	P	214.84	3100	2627	18277	100.00
15	6 1/2" Jar	W.F	6.500	2.750	33.00		4 1/2" IF	B	4 1/2" IF	P	183.84	2400	2034	15650	72.73
14	1 x 6 1/2" DC	RIG	6.500	2.813	31.00		4 1/2" IF	B	4 1/2" IF	P	150.84	3100	2627	13617	100.00
13	6 3/4" PBL sub	W.F	6.750	2.875	8.20		4 1/2" IF	B	4 1/2" IF	P	119.84	819	694	10990	99.83
12	6 3/4" Float Sub	Hall	6.750	2.760	3.00		4 1/2" IF	B	4 1/2" IF	P	111.64	302	256	10296	100.63
11	7 3/4" String Stabilizer	Hall	6.750	2.813	5.00	7.750	4 1/2" IF	B	4 1/2" IF	P	108.64	299	253	10040	59.71
10	6-3/4" HOC Collar	Hall	6.750	3.250	11.00		4 1/2" IF	B	4 1/2" IF	P	103.64	1140	966	9788	103.60
9	6 3/4" Geo-Tap	Hall	6.750	1.905	27.92	8.250	4 1/2" IF	B	4 1/2" IF	P	92.64	2962	2510	8822	106.10
8	6 3/4" HCIM Collar	Hall	6.750	1.920	6.56		4 1/2" IF	B	4 1/2" IF	P	64.72	667	565	6312	101.70
7	6 3/4" PWD	Hall	6.750	1.905	4.44		4 1/2" IF	B	4 1/2" IF	P	58.16	428	362	5747	96.30
6	6 3/4" DGR Collar	Hall	6.750	1.920	4.55		4 1/2" IF	B	4 1/2" IF	P	53.72	445	377	5384	97.80
5	6 3/4" EWR-P4 Collar	Hall	6.750	2.000	12.10		4 1/2" IF	B	4 1/2" IF	P	49.17	1262	1069	5007	104.30
4	8 3/8" Inline Stabilizer (ILS)	Hall	6.750	2.000	6.560	8.375	4 1/2" IF	B	4 1/2" IF	P	37.07	1252	1061	3938	190.84
3	6 3/4" DM Collar	Hall	6.750	3.125	9.20		4 1/2" IF	B	4 1/2" IF	P	30.51	951	806	2877	103.40
2	7600 EDL Geo-Pilot	Hall	7.625	1.490	20.16	8.375	4 1/2 Reg	B	4 1/2" IF	B	21.31	2306	1954	2071	114.40
1	8.5" PDC	Used	8.500		1.15	8.500		B	4 1/2" Reg	P	1.15	138	117	117	120.00
	Hole Section TD :						8935		FT MD (ap-prox)						
	Mud Weight						10.0		ppg						
	Total Bouyed String Weight at TD						245,226		lbs						
	Maximum Tensile Capacity of DP						560,763		lbs (Premium)						
	Margin of Overpull						203,385		lbs						
	Weight Below Jars						13,617		lbs						
	Weight Above Jars						54,144		lbs						
5	BHA type	7th BHA: 8.5" PDC / RSS / Geo-Tap Assy. MWD Flow range (450 - 550) GPM Surface RPM (100 - 140) WOB up to 35 KLB													

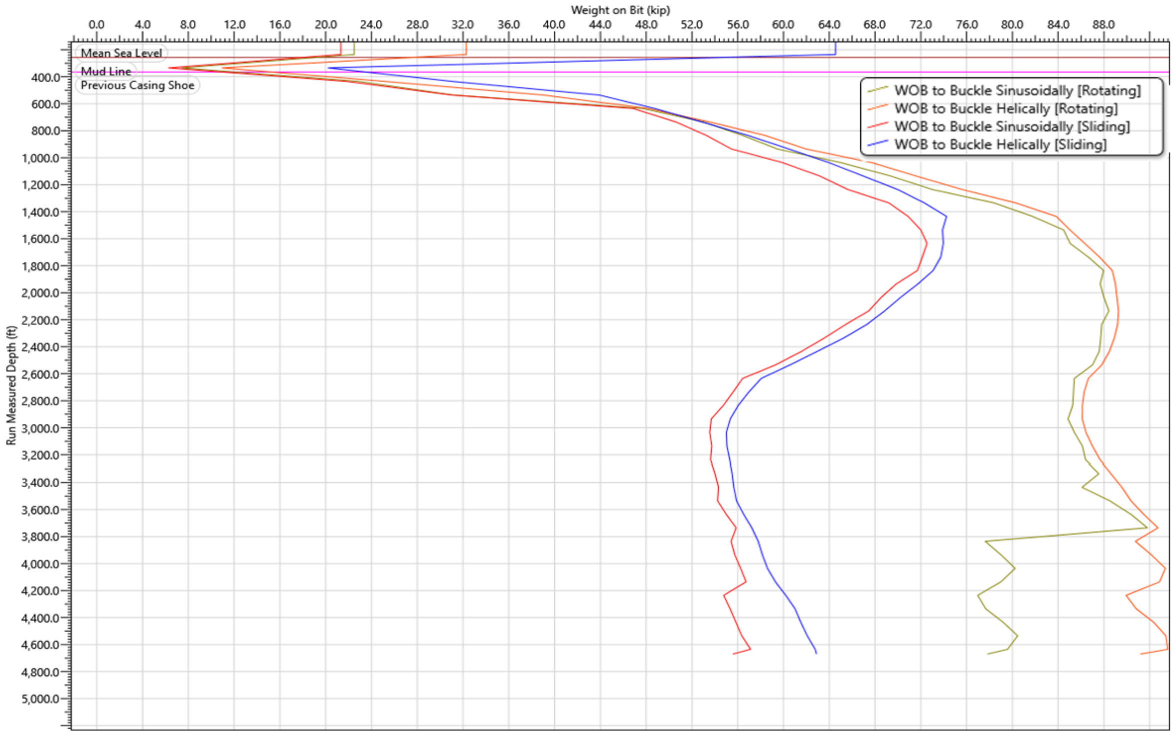

Figure 4. Selecting WOB for drilling 16" hole

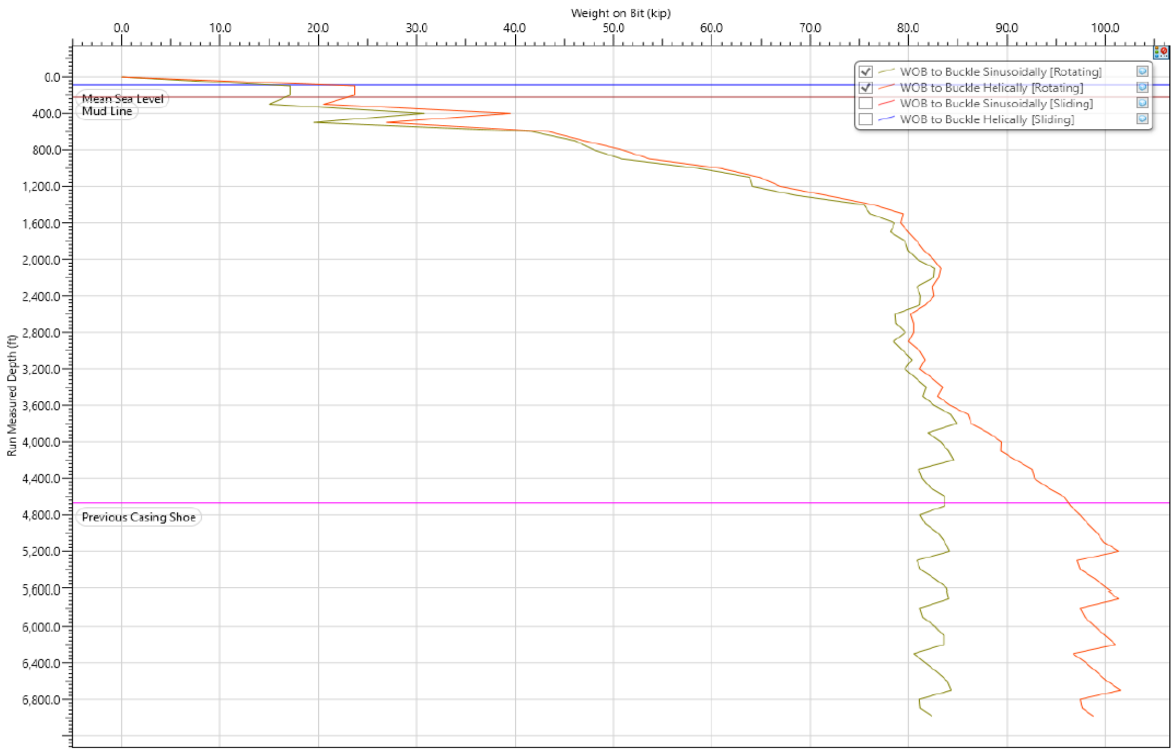

Figure 5. Selecting WOB for 12.25" hole section

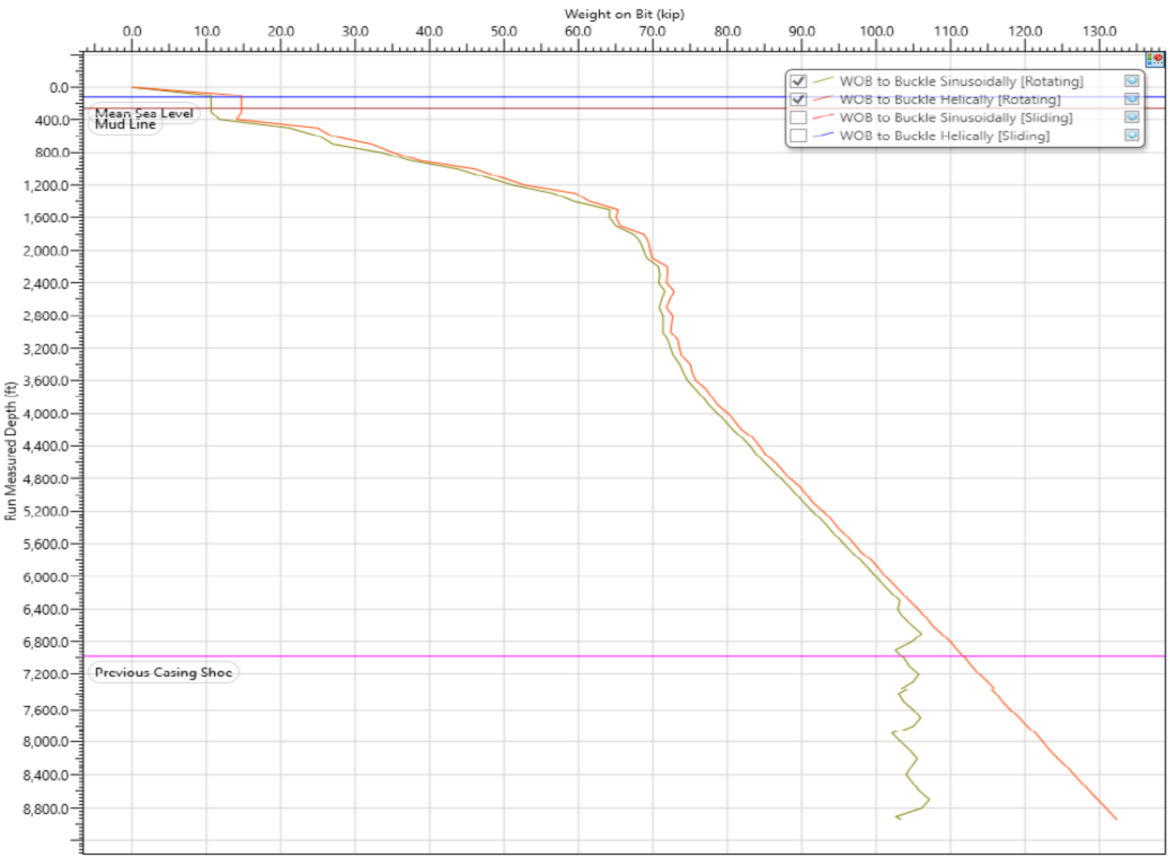

Figure 6. Selecting WOB for 8.5" hole section.

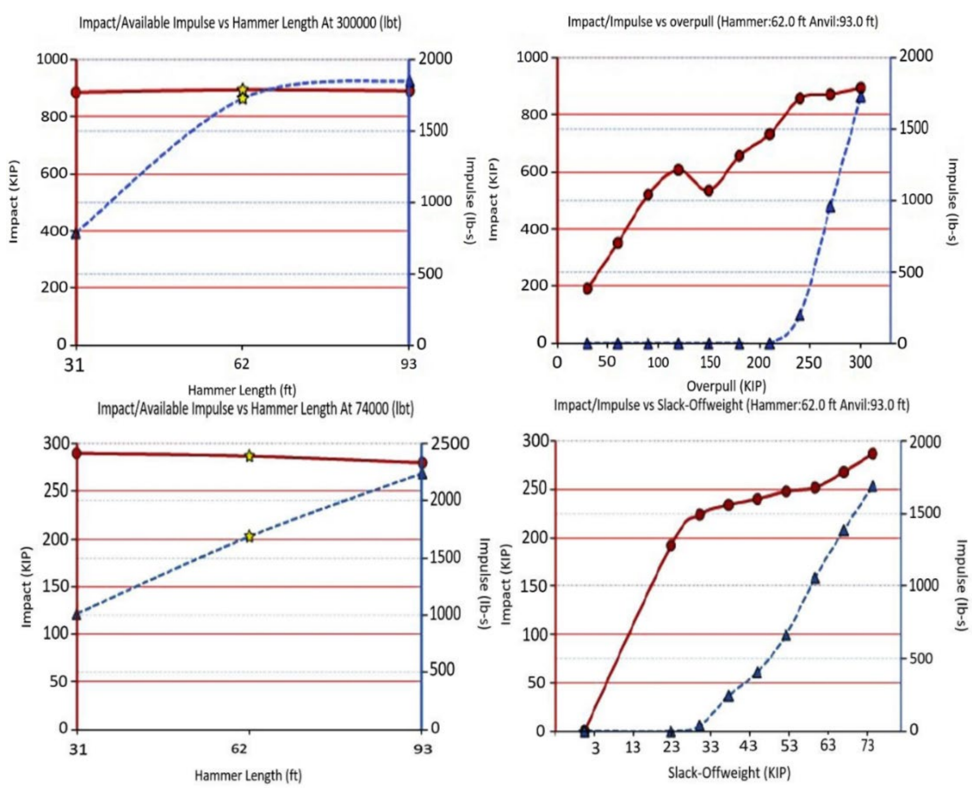

Figure 7. Jar placement simulation results for drilling 16" hole

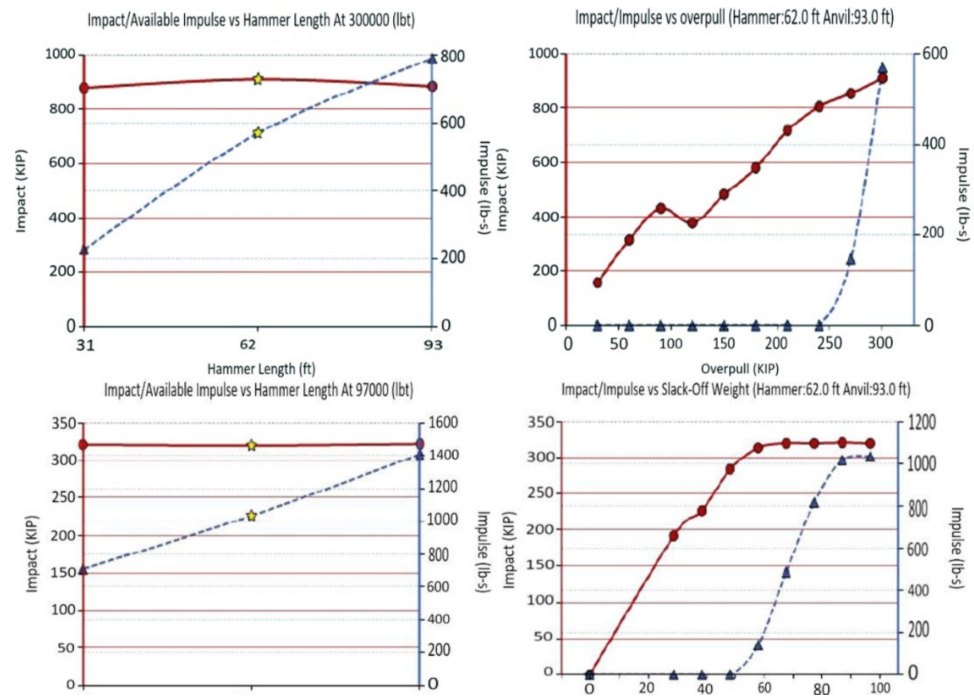

Figure 8. Jar placement simulation results for drilling 12.25" hole

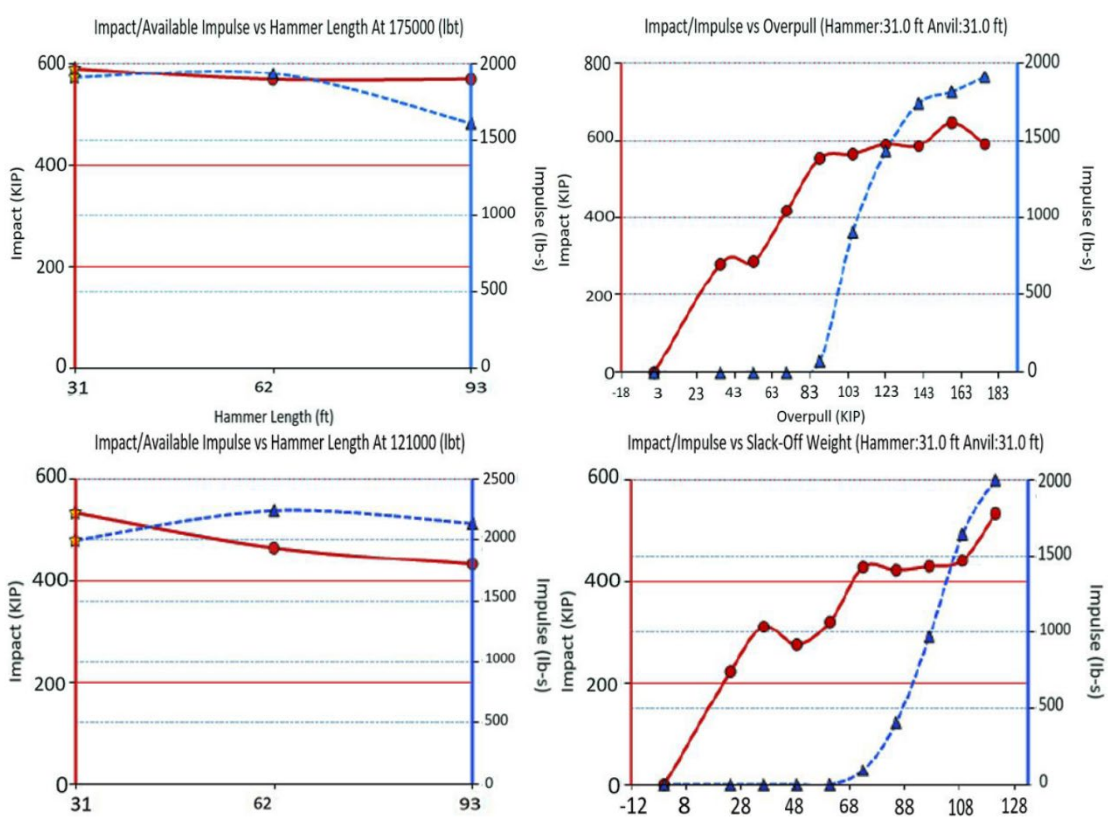

Figure 9. Jar placement simulation results for drilling 8.5" hole.

6. Conclusions and recommendations

From jar placement results, it is extracted the following:

1. Jar placement recommendation is not to put neutral point across jar.
2. The BHA was selected to keep the jar under compression while applying WOB up to 45 Klb's for drilling 16" hole section. Neutral point is simulated to be located in drill pipe while applying 40 - 45 KLB's WOB (First 400 ft above 5 ⅞'' HWDP), this issue was experienced in most of offset wells without any problem in such deviated holes.
3. The BHA is selected to keep the jar under compression while applying WOB up to 40 Klb's for 12.25" hole section. Neutral point is also simulated to be located in HWDP while applying maximum 40 KLB's WOB.
4. The BHA was selected to keep the jar & accelerator under compression while applying WOB up to 35 KLB's. Neutral point is simulated to be located in drill pipe while applying 30 - 35 KLB's WOB (First 200 ft above 5 ⅞ '' HWDP), this issue was experienced in most of offset wells without any problem in such deviated holes.

To conclude the simulation study of jar placement in a highly deviated well, the following conclusions are extracted:

1. The simulation study is important for selecting the best jar location so as to achieve the maximum forces without failure.
2. Jar placement needs to optimize and select the best drilling parameters affecting on the BHA and drillstring such as WOB, RPM, and flowrate.
3. The optimum WOB selection avoid sinusoidal and helical buckling problems.
4. Downhole directional equipment can be included in the simulation study.
5. Jar dimensions are key-elements for selecting its location.

Nomenclatures

ADC = cross-sectional area of drill collars
ADC_A= drill collar area above jars
ADC_B = drill collar area below jars
ADP = cross-sectional area of drill pipe
AHWDP = cross-sectional area of heavy weight drill pipe
AI = cross-sectional area with incident wave
AO = cross-sectional area with transmitted wave
Ap = the cross-sectional area of the piston in square inches,
CA = longitudinal wave propagation velocity
CA_A= longitudinal wave velocity above jars
CA_B = longitudinal wave velocity below jars
EDC = modulus of elasticity of drill collars
EDC_A = modulus of elasticity in drill collars above jars
EDC_B = modulus of elasticity in drill collars below jars
F = impact force
F(t) = impact force function with respect to time
FAVG= average force over impulse duration
FBHA_ABOVE_JAR = bottom hole assembly weight above the jar
fBOUYANCY = bouyancy factor
FDOWN_SETTING= recommended down hit setting
fDRAG = drag factor (fraction of string weight)
FDRAG = drag force
Femw = the set measured weight when an Induced force is required to set the jar at the center of the jar in compression/or tension, and this requires over pulling the measured weight (hoisting/trip out).
F_{ES} *= the effective jar set (cock) force*
Fet = the effective jar trip force
FI= impact force
FMAXIMUM = maximum overpull force (includes string weight)
FO = overpull force
Fpof = the pump open force
Fs = the set force

Fs = the up jar set force
FS = force needed to overcome sticking
FSAFETY_DOWN =a safety factor force
FSAFETY_UP = a safety factor force
Fsd = the axial force down to stuck depth
Fsp = the force at stuck point depth
FSTRING_ABOVE_JAR = bouyed string weight above the jar
Ft = the up-jar trip force
Ftd = the axial force down to well depth
Ftis = the trip in axial force
Ftmw = the trip measured weight when an induced force is also required to trip the jar at the center of the jar in tension, and this requires slacking off the measured weight (lowering/trip in),
Fto = the trip out axial force
Fts = the trip force
FUP_SETTING = recommended up hit setting
I = available impulse
I(F,T) = impulse function
J = jar stroke length
K1= experimentally derived drag constant
K2 = experimentally derived drag constant
L = the stroke length in inches,
LDC = drill collar length
LDC_A = length of drill collars above jar
N = number of reflections possible prior to the hammer impacting the anvil.
nb = the number of blows of the piston per minute.
pm = the pressure drop across the piston chamber in psi,
S = displacement of stuck point
T = duration of impact
treflect = time for reflection to return
t'= time from trigger to impact
VANVIL= anvil velocity
VC = free contraction speed
VHAMMER = hammer velocity
VN = hammer velocity
VS = slip velocity
VU = post impact velocity
V'C = drag modified anvil velocity
V'N = drag modified hammer velocity
WD = the work done by hammer, hp
Φ= *ratio of impact force to overpull force*
α = *inclination angle*
λ = *ratio of the drill collar and pipe cross sectional areas*
σ_I = *incident stress*
σ_R = *reflected stress*
σ_T =*transmitted stress*
****All quantities used in this work are measured in imperial system*

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