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Analysis of PDC Bit Selection with Rotary Steerable Assemblies in the Gulf of Mexico

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Abstract

Bit selection is a critical decision when running any bottomhole assembly. Bit type and corresponding operating parameters are often primary sources of downhole shock, vibration, and stick-slip, and strongly influence a BHA's directional tendency while maximizing penetration rate.

Bit manufacturers have adopted a variety of initiatives for rating and improving bit performance, including:

- Global bit record databases with dull grading system.
- Bit stability/dynamics simulation programs.
- New bit features to improve stability and reduce bit-induced shock, vibration, and stick-slip.
- Adoption of harder, more durable polycrystalline diamond cutters.

However, most bit selection continues to be based on local field knowledge, offset performance, and generic appearance. Offset bit records rarely identify detrimental operating conditions that result in shock, vibration, and stick-slip problems, which promote premature bit wear, tool/motor failure, poor borehole quality, and reduced ROP.

Accordingly, the need to improve bit selection based on cross field experience was identified, leading to the adoption of a bit tracking system for the North American Gulf Coast region based on "push the bit" rotary steerable runs to date. Bit performance metrics were established using the following criteria:

- General stability (recorded downhole shock, vibration, and stick-slip).
- Directional steering ability.
- Overall penetration rate expected.

Each bit was characterized according to number of blades on bit, size of cutters on bit, size of bit, specialized bit features, well profile, and reamer being used.

This paper presents the findings of the new tracking system and establishes a quick-look guide for selecting optimal bit characteristics for the hole sizes and depth ranges mapped within the Gulf of Mexico.

Introduction

This paper derives observations from a rotary steerable tracking system to evaluate how well profile, general PDC bit features, and BHA characteristics may or may not have an effect on the downhole shock and vibration and directional steerability of a BHA.

To improve bit selection in the Gulf of Mexico with "push the bit" rotary steerable assemblies, a bit tracking system has been adopted based on cross field performance metrics. There are many bit, well, and BHA characteristics contained in the tracking system. Some of these characteristics are: bit size, reamer size, number of blades on a PDC bit, size of cutters on a PDC bit, WOB applied to BHA, RPM applied to the BHA, measured depth of the bit run, formation drilled, well bore trajectory, and ROP as related to depositional environment. Each one of these will be analyzed herein to see if there are any significant effects on performance in regard to downhole shock and vibration and directional steerability which is defined as inability to steer the well in the desired direction and/or any ROP problems.

Bit/Reamer Characteristics

There are several features on a PDC bit and reamer that could affect the performance of a rotary steerable system. Many of these features can be difficult to classify (such as backrake angle and cutter arrangement). Accordingly, the bit size, the reamer size (if used in BHA), the blade count on a PDC bit, and the size of the cutters on the PDC bit have been selected to distinguish the effect of each on the behavior of a rotary steerable system. The bit size appears to be one of the most important considerations with respect to the occurrence of shock and vibration.

In Table 1, the effects of bit size on shock and vibration and steerability are listed. This analysis did not include reamer assemblies; reamers will be discussed in the next section. The data show that as the bits get smaller, the incidence of shock and vibration decreases. The bits sized from 12.25 in. and smaller showed shock and vibration in less than 20% of the bit runs. In addition, the occurrence of steerability problems with the 12.25-in. bits and with smaller bit sizes was typically lower than 15%. The only exception was the 6.75-in. PDC bit; this result can be attributed to the small sample size available for this bit size.

For the bit sizes greater than 12.25 in., the incidence of shock and vibration generally exceeded 20%. The 14.75-in. and 18-in. bits show the occurrence of shock and vibration in 38.6% and 50% of the runs, respectively. The higher rate for the 18-in. bits may be related to the small sample size, but the 14.75-in. category has sufficient samples to make this a notable effect. As for steerability, the 16-in. and 17.5-in. bits show a higher rate of steering issues with 28.6% and 25%, respectively. However, the small sample size for each of these bit sizes is likely the source of these higher-than-normal percentages.

Table 1. Percentage of bits showing shock and vibration and steerability issues.

Bit Size (in.)	S & V (%)	Steerability (%)
6	10.5	0
6.5	11.5	3.8
6.75	0	16.7
8.5	4.4	5.9
9.875	6.8	4.1
10.625	15	11.7
12.25	14.8	5.2
14.5	23.1	0
14.75	38.6	9.1
16	28.6	28.6
16.5	12.5	0
17.5	28.6	25
18	50	0
18.125	22.2	0
18.25	9.5	9.5

Figure1 shows the distribution of the total runs with respect to bit size and the number of runs with shock and vibration and steerability issues within each category.

When studying the rotary steerable assemblies that have a reamer present (Fig 2, and Table 2), there were no significant effects indicated by the reamer addition. Data for all reamer sizes show that less than 16% of the runs had shock and vibration problems. However, there appears to be some steerability issues with various reamer sizes. For most reamers, steering issues were only present in less than 10% of the

Table 2. Percentage of reamer runs showing shock and vibration and steerability problems.

Reamer Size (in.)	S & V (%)	Steerability (%)
7.5	15.8	5.3
9.875	14.8	0
10.625	0	8.3
12.25	9.4	9.4
14	8.3	25
14.5	4.8	9.5
14.75	0	0
16	0	25
17	0	12.5
19	0	28.6
20	13.3	6.7

runs. The two exceptions are the 16-in. and 19-in. reamer sizes. The 16-in. reamers show that 25% of the runs had steering problems, and the 19-in. reamer had steering problems in 28.6% of the runs. Both reamer sizes have small samples, but the 16-in. size displayed steering issues in the bit size as well. The steerability issues in the 16-in. and the 19-in. reamer are likely related to the large hole size in a relatively shallow and soft marine depositional environment.

Tables 3 through 5 show the percentage of runs with problems with respect to the number of blades on a PDC bit and the size of the cutters. In addition, Figs. 3 through 5 show the distribution of the shock and vibration and the steering issues as related to number of bit blades and cutter size. One thing to note is the high percentage of shock and vibration and steerability problems in the 1016 bit (10-bladed with 16-mm cutters); only a low number of samples is available to evaluate this type of bit. Table 3 shows the percentages of shock and vibration and steerability problems in relation to the different combinations of number of blades and cutter size. Data for the 619 size combination (6-bladed with 19-mm cutter) shows that 21.9% of the bit runs with this bit have shock and vibration issues.

Table 3. Percentage of shock and vibration and steerability issues in combination with blades/cutter size.

All Bit Sizes	S & V (%)	Steerability (%)
319	20	0
411	0	10
516	7.4	7.4
519	10.4	3
613	10.4	3
616	9.4	2.9
619	21.9	5.5
711	10.7	3.6
716	27.3	3
719	6.1	3
811	16.1	12.9
813	14.9	7.5
816	7.9	11.1
916	4	6
1016	50	25

Also, the 716 size combination (7-bladed with 16-mm cutters) shows the highest incidence of shock and vibration. The higher percentage of incidents in the 716 is primarily in the greater than 12.25” bit size. All the other blade/cutter size combinations have less than a 20% incidence rate. Regarding steerability problems, the 811 and the 816 blade/cutter size combination exceed 10%, but none of the combinations appear to be excessive in regards to steerability issues.

The analysis of the effects of the number of blades is covered in Table 4. The ten-, three-, and seven-bladed bits show the highest incidence of shock and vibration with 50%, 20% and 20.3%, respectively. However, the high percentage associated with ten- and three-bladed bits could be related to the small sample size of the respective bit types. All the other combinations do not show any significant problems with shock and vibration. As for steerability issues, there does not appear to be any significant problems except with that of the ten-bladed bits in which the sample size was small.

Table 4. Percentage of shock and vibration and steerability issues in relation to number of blades on a PDC bit.

Number of Blades	S & V (%)	Steerability (%)
3	20	0
4	0	4.8
5	6.5	4.8
6	13.3	3.7
7	20.3	4.3
8	12.8	9.6
9	3.9	5.9
10	50	25

As for the cutter size analysis, Table 5 does not show any significant effects on the incidence of shock and vibration or steerability in relation to the size of the cutters on the PDC bit.

Table 5. Percentage of shock and vibration and steerability problems related to cutter size on the PDC Bit.

Cutter Size (mm)	S & V (%)	Steerability (%)
10	0	0
11	11.6	8.7
13	10.7	4.8
16	10.5	5.4
19	15	4.3

Environmental and Operational Characteristics

The environment and manner in which a PDC bit and rotary steerable system are operated are critical issues when trying to reduce shock and vibration and maintain directional control. Rock strength, abrasivity, mud program, reactivity, mineralogy, and depositional characteristics are just a few of the complexities that affect a bit's performance. Regrettably, much of this information is confidential and could not be included in the tracking system. However, rock strength can be roughly characterized by depth because compressive strength tends to increase with overburden. Additionally, the formation type provides a platform for assumptions on abrasivity and reactivity.

The corresponding WOB, RPM, and well profile control the ROP response in any location. It is important to note that any bit will suffer from diminished performance when operating parameters are poorly chosen.

The effects of WOB on the bit run are shown in Table 6, and the distribution of the shock and vibration and steering problems are documented in Fig. 6. All the WOB categories show a significant amount of shock and vibration. However, the 10- to 15-Klbf category shows the most stability with only 16.4% of the bit runs having problems with shock and vibration. As for steerability, the 5- to 10-Klbf range and the > 25-Klbf category show the most trouble with steering the well, with, respectively, 15.9% and 15% of the runs having steering issues

Table 6. Percentage of shock and vibration and steerability problems as related to the average applied WOB.

WOB (Klbf) Analysis	S & V (%)	Steerability (%)
0 to 5	26.3	5.3
5 to 10	39	15.9
10 to 15	16.4	2
15 to 20	37.5	3.1
20 - 25	23.5	11.8
> 25	30	15

The shock and vibration and steerability response to RPM are included in Table 7 and Fig. 7. The 125- to 150-RPM range with a percentage of 18.5% shows the best reduction in shock and vibration due to rotating speed. All the other ranges exceed 30%. However, the high percentages observed in the various RPM classes prove that RPM is a significant factor in the amount of shock and vibration a BHA will experience. As for steerability, the 100- to 125-RPM range has the highest incidence of problems—16.1% of the runs. The 50- to 75-RPM range is second with 12.5%.

Table 7. Percentage of runs that show shock, vibration, and steerability problems due to RPM.

RPM Analysis	S & V (%)	Steerability (%)
50 to 75	37.5	12.5
75 to 100	37.5	0
100 to 125	30.6	16.1
125 to 150	18.5	7.5
> 150	47.5	4.9

Tables 8 and 9 and Figures 8 and 9 show the distribution of shock and vibration and steerability problems as related to depth and formation type drilled by a PDC bit.

The shallow wells have the highest amount of shock and vibration, as expected, because the well tends to washout at a shallow depth and result in a bigger wellbore than programmed. Another issue is that directional work usually comes at a deeper depth, so in most cases the shallow well will be a vertical section. However, there does not seem to be many steering problems at this depth. The depth range from 10,000 to 15,000 ft has the highest incidence of steering problems—38.9%. The 15,000- to 20,000-ft interval has the second highest percentage of shock and vibration. This is probably related to the application of more WOB for steering purposes or as the formation transitions and becomes firmer.

Table 8. Percentage of runs with shock and vibration and steerability issues related to depth of the well.

Depth (ft)	S & V (%)	Steerability (%)
0 to 10,000	55.5	7.4
10,000 to 15,000	3.3	38.9
15,000 to 20,000	26.3	13.8
> 20,000	16.5	6.3

In reference to shock and vibration, each type of lithology investigated shows a definite reaction and a high incidence rate to shock and vibration. Salt and sandstone lithologies show the highest percentages; close to 50% of the runs have some sort of shock and vibration event. When shale is drilled, the percentage drops to 31%, which suggests that shale is able to dampen the amount of shock and vibration generated at the bit. This follows conventional wisdom in that PDC bits expend more energy drilling harder lithologic formations such as sandstone and salt. As for steerability, sandstone shows the highest percentage of steering problems; one-third of the bit runs through sandstone have directional concerns.

Table 9. Percent of shock and vibration and steerability problems as related to the formation drilled.

Formation Type	S & V (%)	Steerability (%)
Salt	47.5	9.5
Sandstone	50	33.3
Shale	31.6	8.9
Shale/Sandstone	31.6	10.5

As for the profile of the well, Table 10 shows the percentages of PDC bit runs in a building regime, a dropping regime, a tangent section, and a vertical section. Figure 10 shows the distribution of each shock and vibration and steering episode as related to the directional profile for the run. It comes as no surprise that vertical sections have the highest number of shock and vibration events. As for the other well profiles, there does not seem to be a big difference in the percentage of shock and vibration events. Regarding steerability concerns, there does not seem to be any significant deviation among the four profiles. This proves that the rotary steerable system was able to steer the well in the desired application the majority of the time.

Table 10. Percentage of runs with shock and vibration and steerability issues in relation to well profile.

Well Profile	S & V (%)	Steerability (%)
Build	23.8	10.7
Drop	16.7	11.9
Hold	21.7	12.2
Vertical	44.3	11.4

Finally, the overall average ROP as related to the area drilled is summarized in Table 11. For simplification purposes, the Gulf of Mexico (GOM) was divided into three different areas: land, shelf, and deepwater. Figure 11 illustrates the graphical representation of change in ROP for the different areas of the GOM as related to shock and vibration and steering events.

Table 11. Summary of ROP (ft/hr) versus area as related to a good run, the presence of shock and vibration, or steering problems.

Area	Good Run ROP (ft/hr)	S & V ROP (ft/hr)	Steerability ROP (ft/hr)
Deepwater	81	73	99
Shelf	70	57	53
Land	37.5	21	6

The deepwater area had the highest ROP for wells with steering issues. In essence, the BHA jetted through the softer formations encountered in the deepwater environment and the rotary steerable system was not able to get the pads to push against the soft formation. The presence of shock and vibration consistently caused a reduction in overall ROP. Shock and vibration events result in energy being lost in the drillstring and not spent on drilling the formation. Steering problems lead to slower drilling in firmer formations with the bit unable to provide penetration into the formation and, thus, directional control is more difficult.

Conclusions

Some key conclusions from the study are

1) The bit sizes > 12.25 in. have more of a tendency to have shock and vibration problems, especially the 14.75-in. bit.
2) The 17.5-in. and 16-in. bits are associated with the greatest number of steering problems. The other bit sizes did not show any abnormal amount of steering issues.
3) No real shock and vibration events where attributed to reamer size analysis. Only the 16-in. and 19-in. reamers showed any steering issues.
4) The 619 and 716 bits showed the most shock and vibration events. The 1016 bit has a high percentage of shock and vibration and steering issues, but this was related to the low sampling rate.
5) WOB analysis shows a high degree of shock and vibration for all WOB ranges except for the range from 10 to 15 Klbf, which is probably related to the formation character, it being firm enough to take weight and competent enough to steer the well.

6) RPM analysis also shows a high degree of shock and vibration associated with all RPM ranges except for the range from 125 to 150 RPM.
7) The depth range from 10,000 to 15,000 ft showed the lowest amount of shock and vibration problems, but this same depth range had the most steerablity problems.
8) Salt and sandstone formations had the highest number of incidents of shock and vibration. Sandstone lithologies yielded the highest amount of steering problems.
9) Vertical wells have the highest amount of shock and vibration events. There seems to be no real steering issues in relation to the lithology drilled.
10) The highest ROP in competent formations was achieved in wells that did not have shock and vibration and steerability problems.
11) The operator will have to experiment to find the best combination for the reduction of shock and vibration and enable the BHA to steer the well in the desired direction.
12) Bit companies are working to develop or have developed programs to model the expected shock and vibration from a bit and how well the bit will perform.

Rotary steerable systems help to reduce most of the problems associated with directional control of a well. The proper choice of PDC bit characteristics and features along with proper application of operating parameters reduces the problems associated with shock and vibration and, in turn, delivers a higher ROP regardless of area, depth, and trajectory.

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Nomenclature

BHA = Bottomhole assembly
GOM = Gulf of Mexico
Klbf = Kilopounds
PDC = Polycrystalline diamond compact
ROP = Rate of penetration, ft/hr
RPM = Revolutions per minute
S & V = Shock & Vibration
WOB = Weight on bit

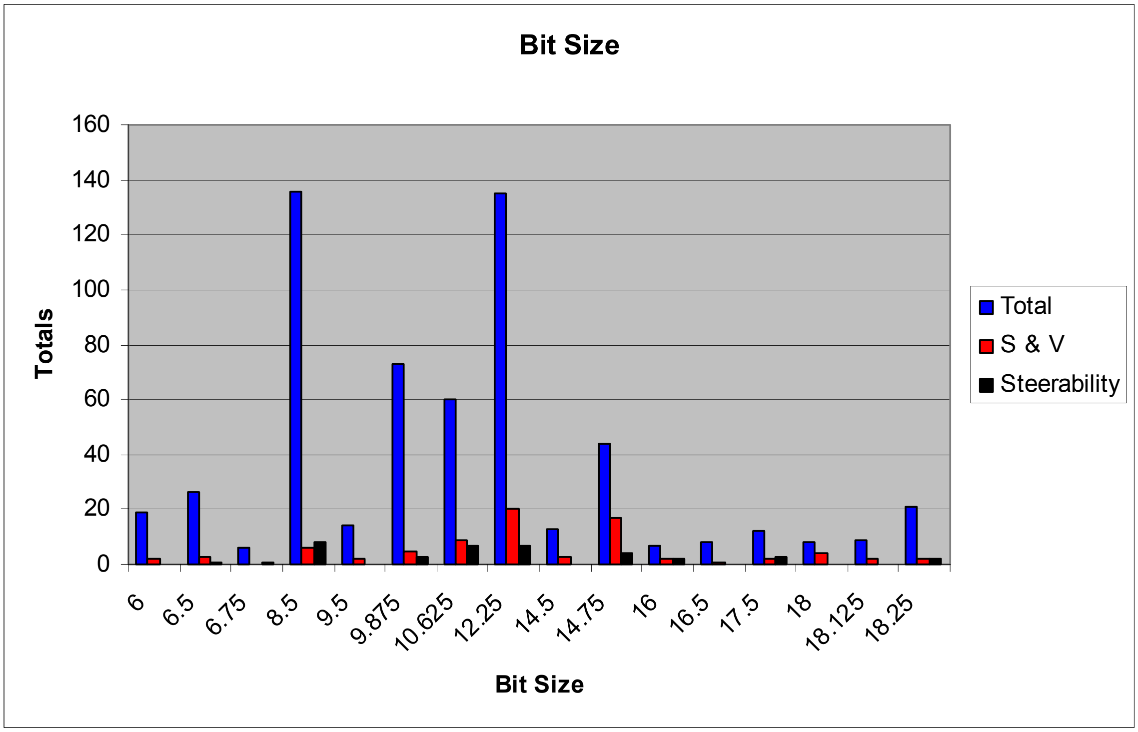

Figure 1. Distribution of total bit runs and those that had problems with shock and vibration (S & V)and steerability issues related to bit size (in.).

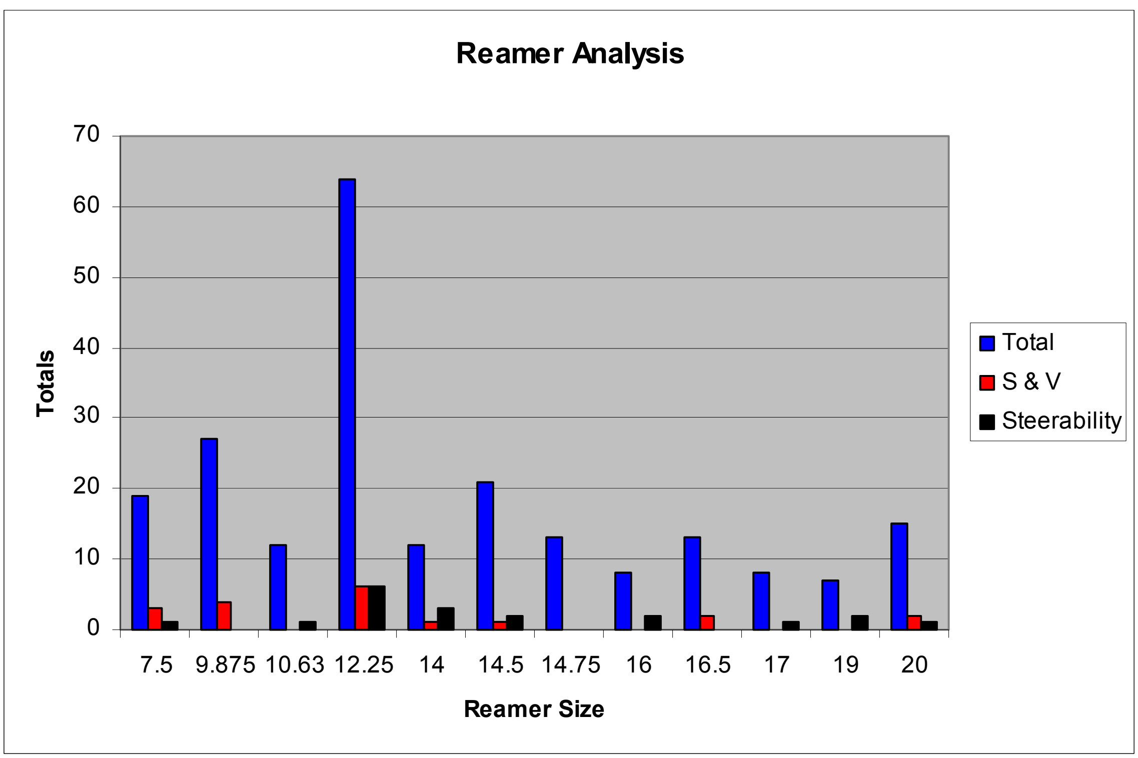

Figure 2. Distribution of total reamer runs and those with S & V and steerability issues related to reamer size (in.).

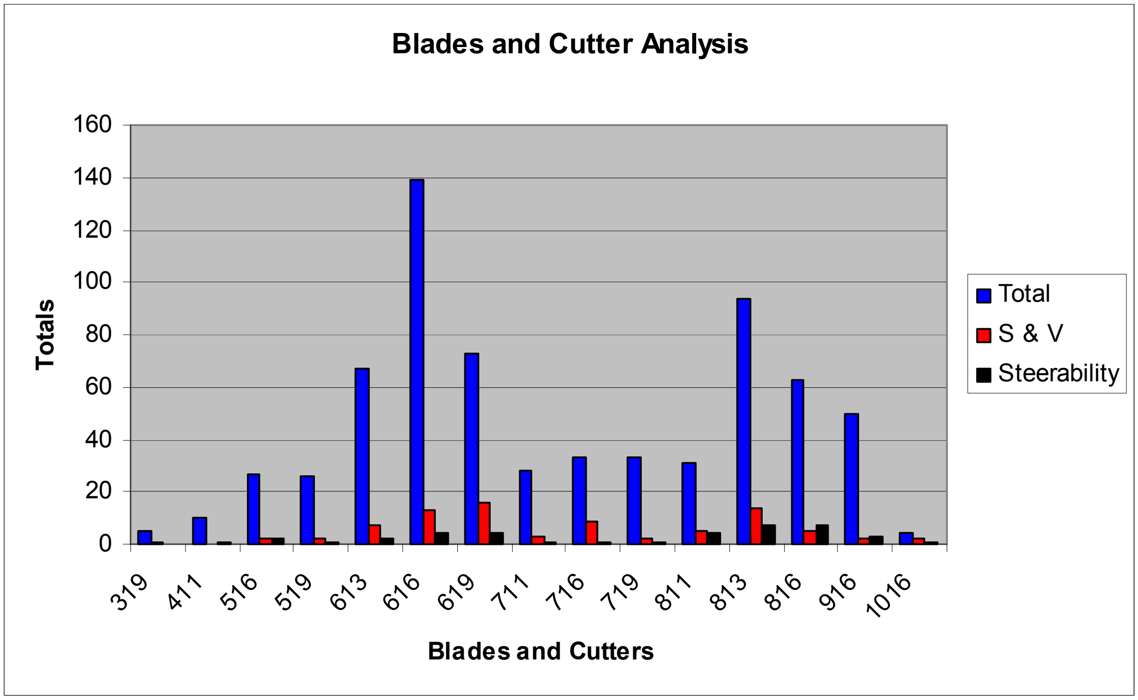

Figure 3. Distribution of total runs and those with S & V and steerability issues related to bit blade count and cutter size (mm).

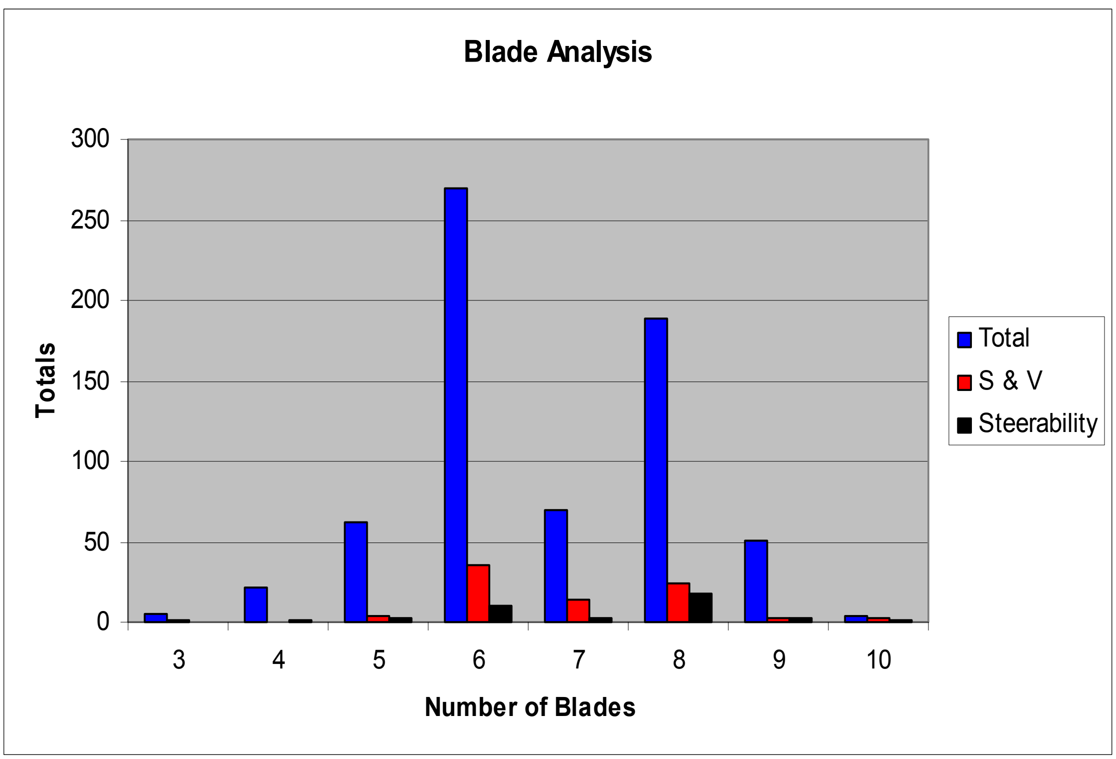

Figure 4. Distribution of total runs and those with S & V and steerability issues related to bit blade count.

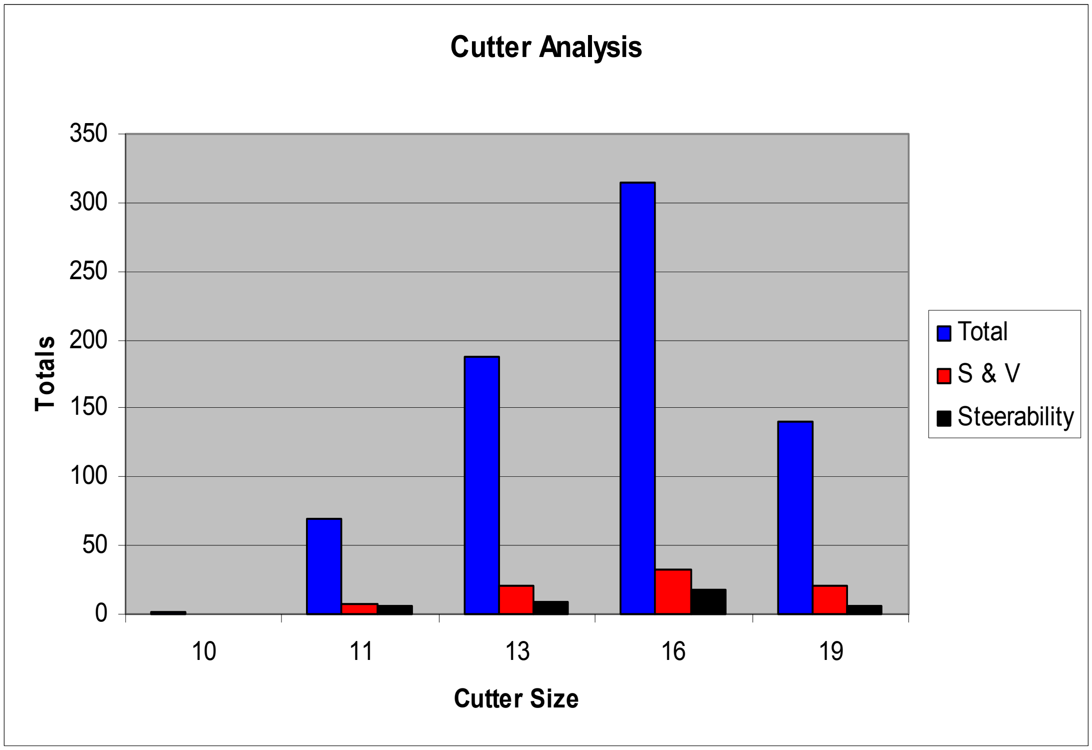

Figure 5. Distribution of total bit runs and those with S & V and steerability issues related to bit cutter size (mm).

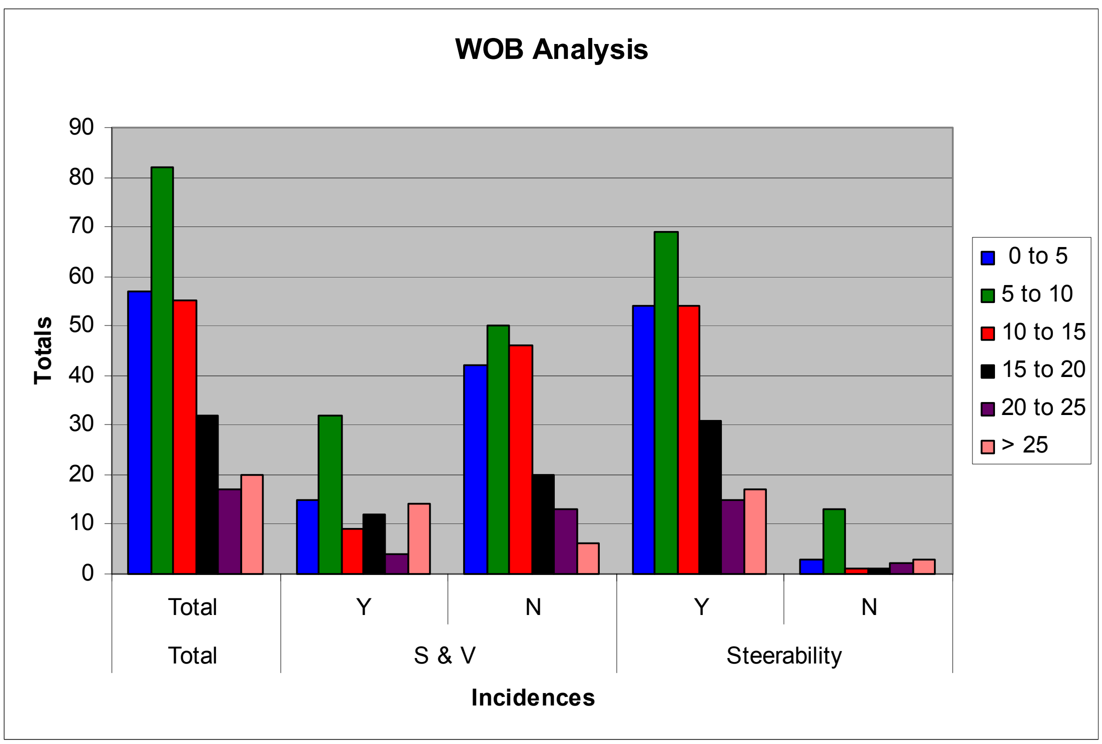

Figure 6. Distribution of total bit runs and those with S & V and steerability issues related to WOB (measured in kilopounds force). Y for S & V means that an S & V event occurred, and N for steerability means that a steering problem occurred.

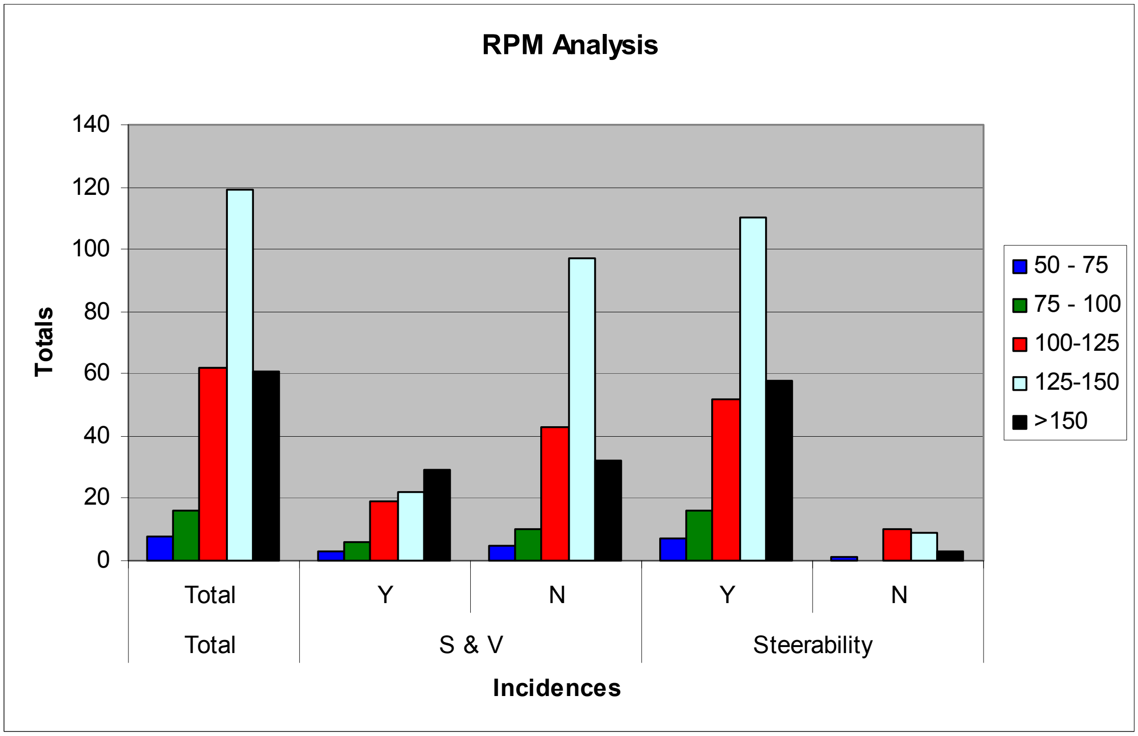

Figure 7. Distribution of total bit runs and those with S & V and steerability issues related to RPM. Y for S & V means that an S & V event occurred, and N for steerability means that a steering problem occurred.

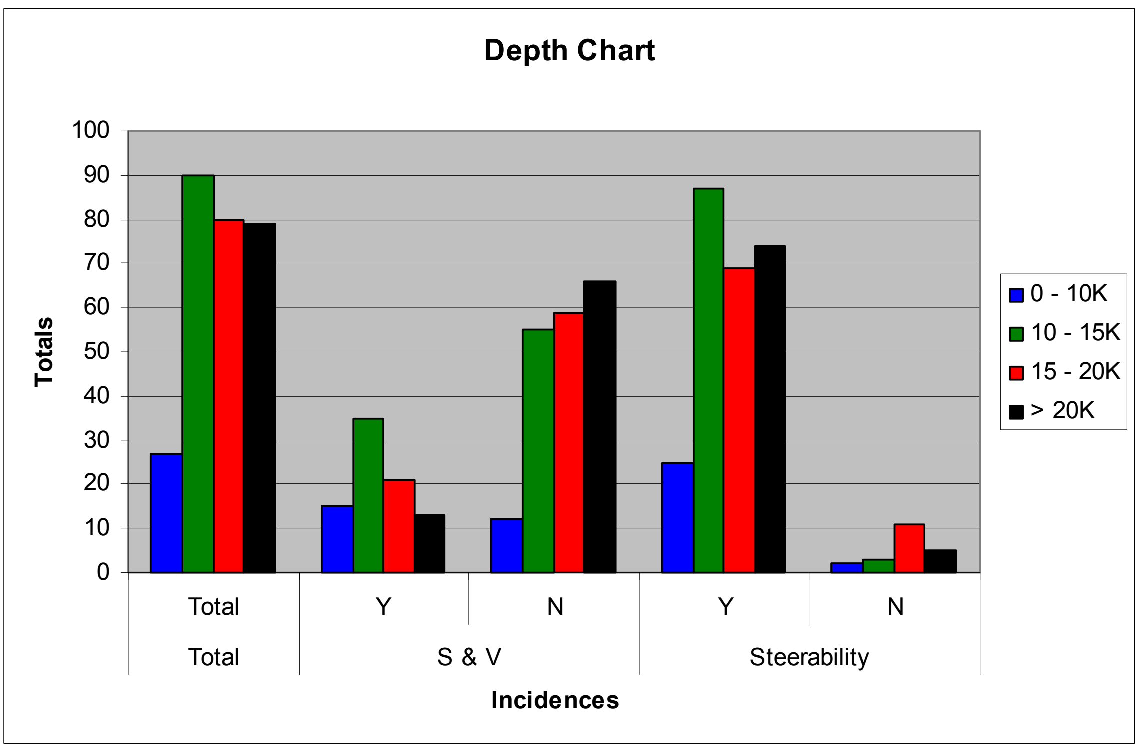

Figure 8. Distribution of bit runs and those with S & V and steerability issues related to depth (ft). Y for S & V means that an S & V event occurred, and N for steerability means that a steering problem occurred.

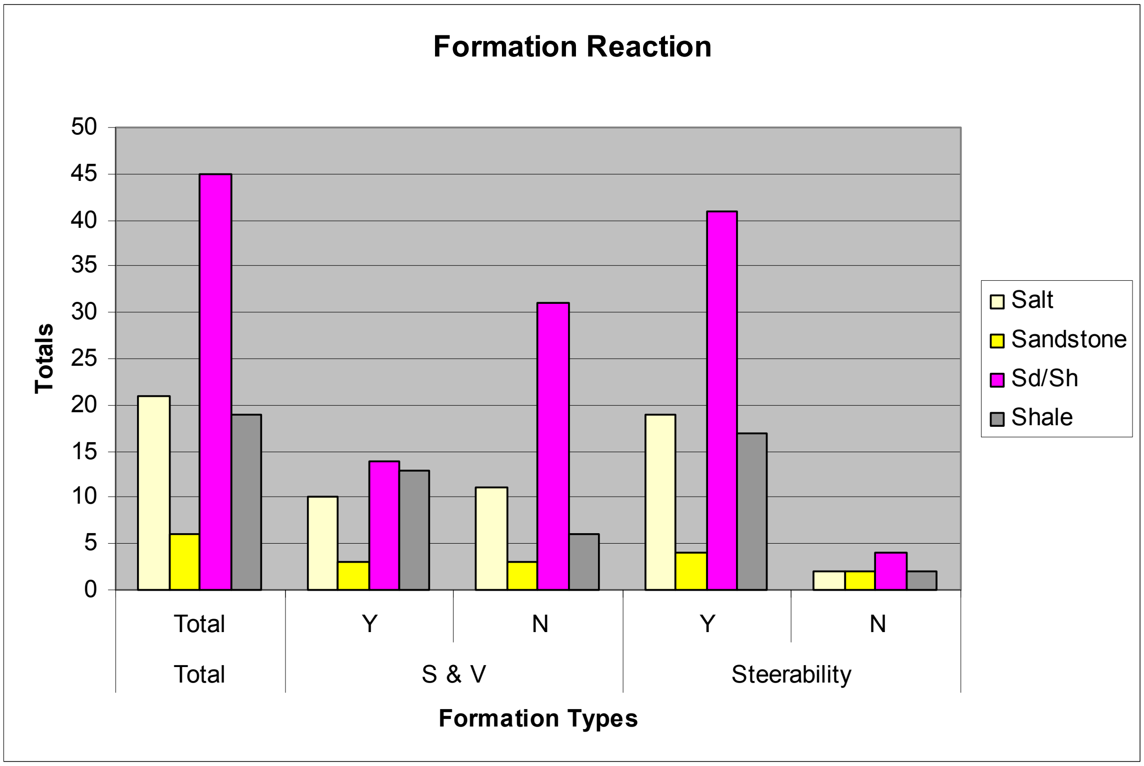

Figure 9. Distribution of total bit runs and those with S & V and steerability issues related to formation type. Y for S & V means that an S & V event occurred, and N for steerability means that a steering problem occurred.

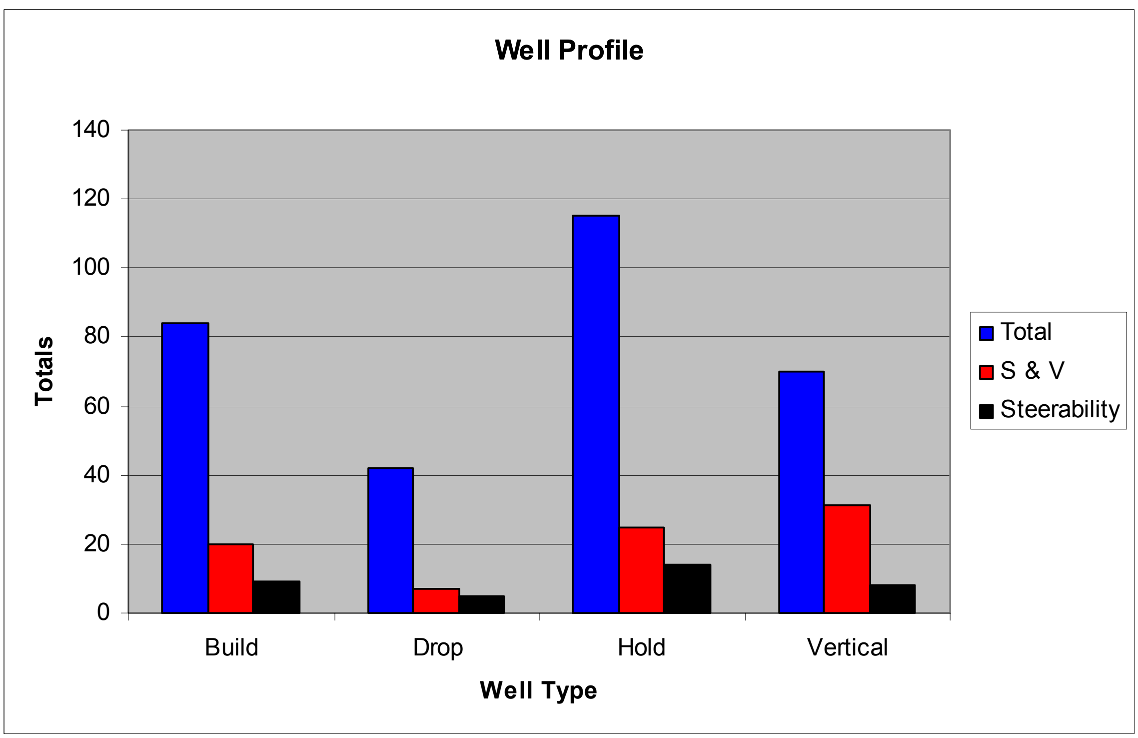

Figure 10. Distribution of total bit runs and those with S & V and steerability problems related to well profile.

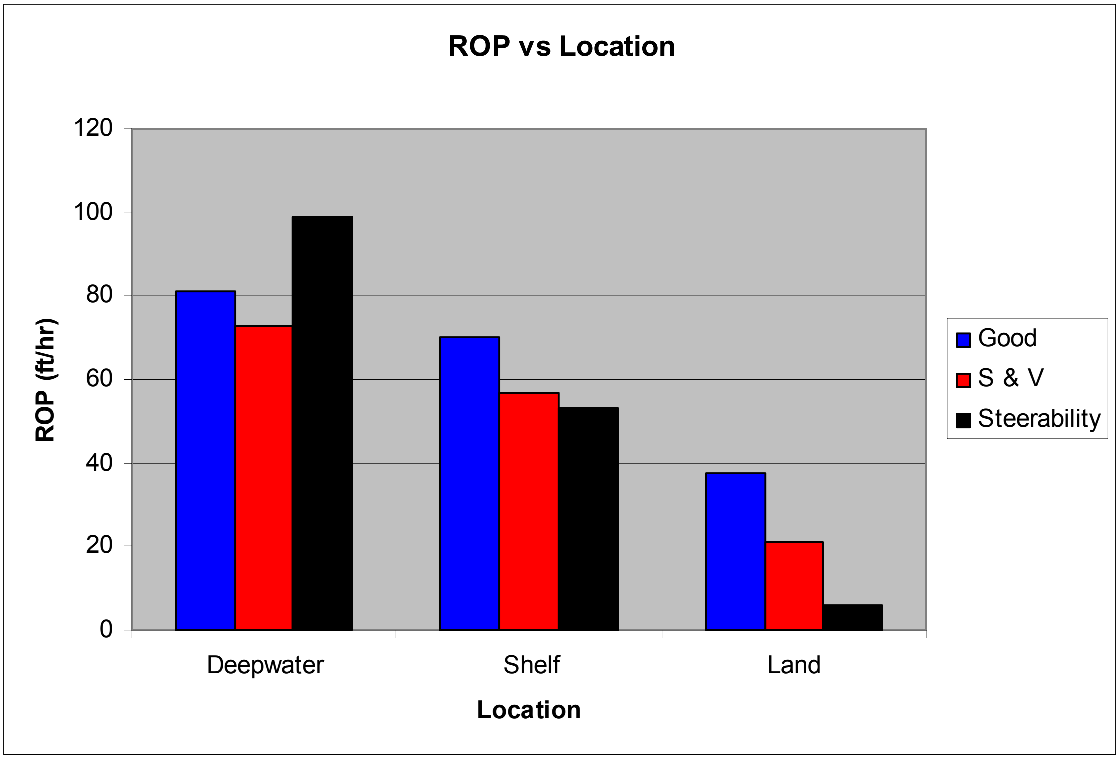

Figure 11. For three GOM locations, the overall ROP (ft/hr) for good runs compared to those with S & V and steerability problems.