Rod String Design Software – Well Simulation Using Sandia's Downhole Load Cell

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ABSTRACT

A companion paper is being made to show the graphical analyses for the wells that Sandia measured surface and downhole loads at various depths with a special downhole diagnostic tool.

This paper provides an analysis of the operating conditions that were occurring that resulted in these downhole dynagraphs. Additionally, these operating conditions were then entered into three, commercially available, industry rod string design programs that included: QRod, SRod, and RodStar to see how accurately these design programs predicted the actual, measured loads.

BACKGROUND

Previously, a technical paper was presented in 2004 that compared surface dynamometer loads measured at different vertical wells with the predicted results from a number of available rod string design programs. These included: QRod, RodStar, SRod, Lufkin's Load Cal B, and a proprietary program developed by Conoco based on the Modified Goodman Diagram.[1]

A comparison was made between the actual surface dynamometer measurements and related downhole loads with those predicted by the programs. Figure 1 shows the accuracy of prediction between the various versions of the programs available at that time with 100% showing the loads were the same. Any changes above or below the 100% accuracy were the amount of deviation the programs had with the actual loads. Figure 2 provided a similar accuracy comparison for a vertical well with steel rod string and the addition of a small amount of sinker bars. The lack of any important rod string principle loads shown in the graphs was due to the design programs not providing these data or similar main non-dimensional load and/or speed parameters.

The results of these comparisons prompted the software design companies to include all the principle loads that are required to design and troubleshoot sucker rod string installation to be provided. Additionally, most companies started providing the major non-dimensional operating parameters. However, the main result of these analyses showed that the design software did a good job of allowing a sucker rod lift system to be installed and be operated without quick failure; but, the programs were not completely accurate. Adjustments still had to be made by going to the well after installation, measuring the principle loads and recording the various operating parameters after the well reached stable operating conditions. This then allowed changes to be made in the rod string design to accommodate the differences.

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Since the time of the prior comparison paper, most design companies have further developed their rod string design software programs and included capabilities such as deviated and longitudinal well designs, along with including new equipment and design loading conditions. Recent discussions of the potential loss the results from the downhole dynagraphs measured from Sandia provided another opportunity to compare the current design accuracies using the current versions of the software but using known downhole loads obtained at various locations in the wells included in the field measurement study.

Electronic Downhole Load Cells (EDLC) were used during the field testing of sucker rod lifted wells in the mid-1990s to acquire the effective loads placed on the rod strings typically at the surface, at changes of the rod string taper, and at the pump. The technology for the downhole dynamometer diagnostic tool (DDDT) that used the EDLC was originally developed by Glen Albert, founder of Albert Engineering, Longmont, CO.[2]

This tool was an approximate one foot long, cylindrical steel tube that included strain gauges, and an accelerometer, along with pressure and temperature gauges. Six USA wells were selected primarily in the Permian Basin. Downhole loads were measured in the field from February to December 1996. The resulting well loads were saved in a Downhole Dynamometer Data Base (DDDB).

The DDDB used available software to obtain downhole dynagraphs of load versus related stroke length at the well depth on the rod string using Microsoft Windows 3.11, Windows 95 and Windows NT. However, as pointed out in the companion paper by O. L. Rowlan and J. N. McCoy, these operating systems are no longer supported and the DDDB graphs would be lost if not processed and currently available presentation software used to provide the dynagraphs for each position, at each depth, for each well.[3]

DISCUSSION

Tables 1, 2, and 3 provide the various operating conditions of the six wells where the field measurements were made. This includes:

- The completion information showing well depths ranged from 2780 ft. to 9270 ft.
- Both entire steel and mixed steel and fiberglass rod strings were monitored.
- Steel rod strings ranged from 66 C grade to 86 D grade to 77 Norris 97 grade
- Some wells had sinker bars and some wells had rod guides
- Operating speed ranged 3.9 to 11 spm.
- Stroke lengths ranged from 86-in to 306-in.

The default design assumptions when each well's operating conditions were loaded into the three commercially available rod string design programs, QRod, SRod and RodStar were:

- Assumption for pump/plunger friction = -200 pounds
- While some wells reported with guides, deviation surveys not available so assumption all wells vertical
- Assumed friction coefficient = 0.2 no guides; 0.3 w/guides
- One program did not have the Rotoflex geometry in analysis capabilities; so CW Conventional unit was used

The graphical analyses of each of the six wells dynagraphs for the load cell at the surface and the load cell close to right above the pump were obtained from Ref. 3 and are shown in Figures 4 through 9.

The main loads predicted by the design programs were compared to the actual field results measured at the surface and at the EDLC measured above the pump. An accuracy of the predicted load to the actual load and the load results are shown in Tables 4 through 9 for the wells 1 through 6, respectively. Only the peak polished rod load (PPRL) and minimum polished rod load (MPRL) for the surface dynamometer and the minimum pump load (MPL) are compared. A more detailed comparison can be conducted of the principle loads at each of the EDLC positions would require the design programs to provide corresponding loads at each of the downhole tool locations. A summary of the major accuracy results showed:

- Three Sandia wells measurements had a negative load as the MPL but the magnitude ranged from -34 to -93 pounds
- Three Sandia wells measurements had positive MPL with the tange from +217 to +804 pounds
- Program 2 appeared to be the most accurate for the surface and MPL loads, but, it appeared the MPL defaulted to an expected “0” pound value for each case
- Program 3 had the next best accuracy for surface loads but, was consistently off approximately -200 pounds on the MPL. This may be related to the minimum pump friction assumed in the program of -200 pounds while the actual MPL never showed values approaching this amount and could not account for the ~+200 to 800 pounds of positive load on the pump
- Program 1 was the least accurate when the default values, including the assumed pump friction, and other consideration of loads were predicted. The MPL ranged from -744 to -4,403 pounds but the corresponding inaccuracy ranged from +138% to -4,502%.
- The accuracy calculation using: (actual Sandia load – predicted MPL)/actual MPL may not represent the actual accuracy efficiency, especially when comparing program 2 with the MPL always defaulting to “0.”

CONCLUSIONS AND RECOMMENDATIONS

1. Currently program 2 &3 are very close to the same accuracy
2. Program 3 had a consistent -200 pound minimum pump load (MPL) which was related to the 200 pound of assumed pump friction
3. If this friction was removed, then MPL would be very close
4. Program 1 had consistently the worse accuracy and dramatically over-estimated MPL
5. Programs 1 & 3 have provided all the load and non-dimensional pumping parameters while program 2 still is missing N/No’
6. While there were instances where there was a negative MPL, these loads did not increase nor stay applied over the plunger stroke length
7. As such the amount of applied load and the duration may not provide significant bending or buckling of the rod string
8. Three of the wells had MPL with a positive value showing there were no negative loads, insignificant bending and no buckling

ACKNOWLEDGEMENTS

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REFERENCES

1. Hein, Jr., N.W. and Stevens, R., “A Current Comparison of Sucker Rod String Design Programs” SWPSC, April 21-21, 2004, paper #7.
2. “New CD-ROM available free from Sandia National Laboratories reveals the nitty gritty of downhole oil well environment,” News Release, October, 20, 1997, Sandia National Laboratories.
3. Rowlan, O. L. and McCoy, J. N., “Effective Loads from Sandia Downhole Dynamometer Testing, SWPSC, Lubbock, TX, April 22-23, 2015.

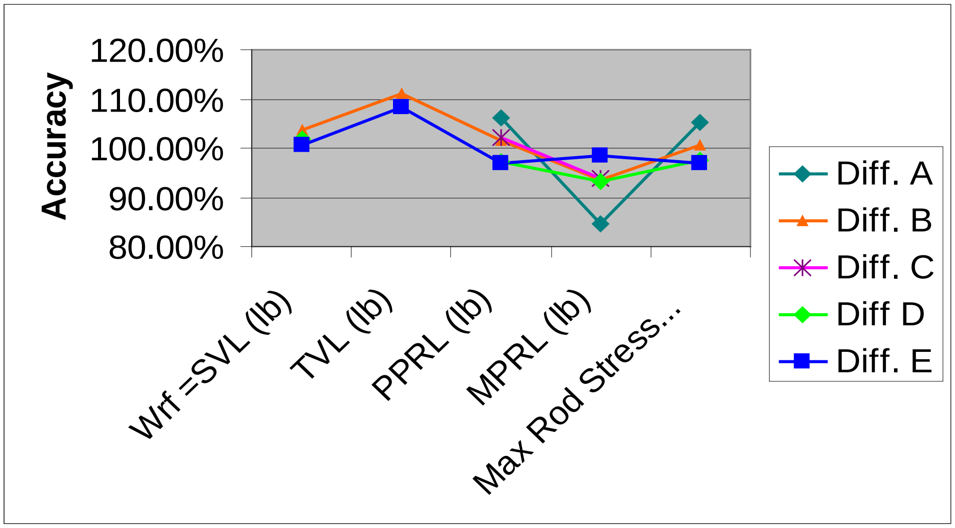

Figure 1 - Accuracy of predicted versus measured loads for a steel rod string in vertical well #1 for the various design programs. (Ref. 1)

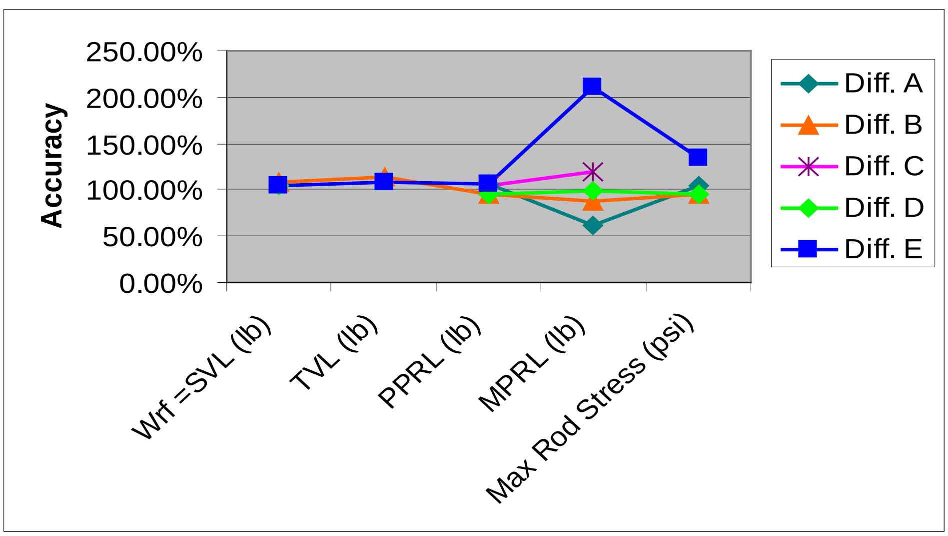

Figure 2 - Accuracy of predicted versus measured loads for a steel rod string in vertical well #3b with the inclusion of sinker bars for the various design programs. (Ref. 1)

Table 1 - The various well completion summaries for the six Sandia field wells

Well No.	Depth PBD (ft)	Casing (in)	Tubing (in)	Seat Nipple Depth (ft)	TAC Depth (ft)	Rod No. & grade	Coupling Size	Guides Installed
1	2780	5.5	2.875	2710	2647	66/C	FS	2/rod
2	7799	7	2.875	7655	6168	1.25" FRP to 4362'; 1.0" D to 7564'	SHSM - FRP; FSSM - D	0
3	9270	5.5	2.875	9220	8968	87/D w 408' 1.0" D SB	SHSM - 1"; FSSM 7/8"	0
4	3090	5.5	2.875	3061	3058	76/D w 300' 1.25" SB	FS	0
5a	5278	5.5	2.875	5060	4970	86/D w 250' 1.5" SB	SH - 1"; FS - rest	2/rod on 3/4"
5b	5278	5.5	2.875	5060	4970	86/D w 250' 1.5" SB	SH - 1"; FS - rest	2/rod on 3/4"
6	2975	5.5	2.875	2909	2603	77/N-97 w 500' 1.5" SB	FSSM	0

Table 2 - The major operating conditions and rod pumping equipment installed on the six field wells.

Well No.	Pump Dia (in)	Pump Length (Ft)	Unit Size	Motor (HP)	Tubing Pressure (psi)	Casing Press (psi)	Produced Fluid G
1	1.5	12	228-213-86	20	60	0	0.995
2	1.5	30	M640-305-144	75	45	76	1.027
3	2.25	35	Rotoflex 1100-500-306	100	40	40	1.019
4	1.5	26	M640-305-168	40	20	0	1
5a	2	24	M640-305-168	60	205	180	0.982
5b	2	24	M640-305-168	60	205	180	0.982
6	2.25	24	456-305-144	72	43	vacuum	1.015

Table 3 - Continuation of well operating conditions and locations of the EDLC for each field well

Well No.	N (spm)	S (in)	Fluid Level FAP (ft)	Tool Depths (ft)	
1	11	88	2710	#1- below pump - Not Work (NW); #3 - 2482' (in 3/4"); #5 - Below PR @2'	#2 - above pump @288 #4 - 1010' (in 3/4");
2	8.2	144	428'	#1 - below pump; #3 - 7488' (76' above pump) - NW; #5 - 4286' (76' above x)	#2 - above pump @768 #4 - 4382' (FG to 8ll x);
3	3.8	308	88	#1 - above pump 8229'; #3 - 8786' (in 1" 8B); #5 - 7608' (in 7/8")	#2 - 8087' (in 1" 8B); #4 - 7868' (8B to 7 x);
4	4.68	168	243	#1 - below pump; #3 - 2708' (8B to 8 x); #5 - below PR @2'	#2 - above pump @3010'; #4 - 1008' (8 to 7 x);
5a	8.1	168	4787	#1 - below pump; #3 - 4741' (8B to 7 x); #5 - below PR @2'	#2 - above pump @4888'; #4 - 4714' (26' above x);
5b	8.6	168	4787	#1 - below pump; #3 - 4741' (8B to 8 x); #5 - 1612 (7 to 8 x)	#2 - above pump @4888'; #4 - 3114' (8 to 7 x);
6	7.1	143.6	1064	#1 - below pump; #3 - 2783' (in 8B); #5 - below PR @2'	#2 - above pump @2880 #4 - 2868' (8B to 7 x

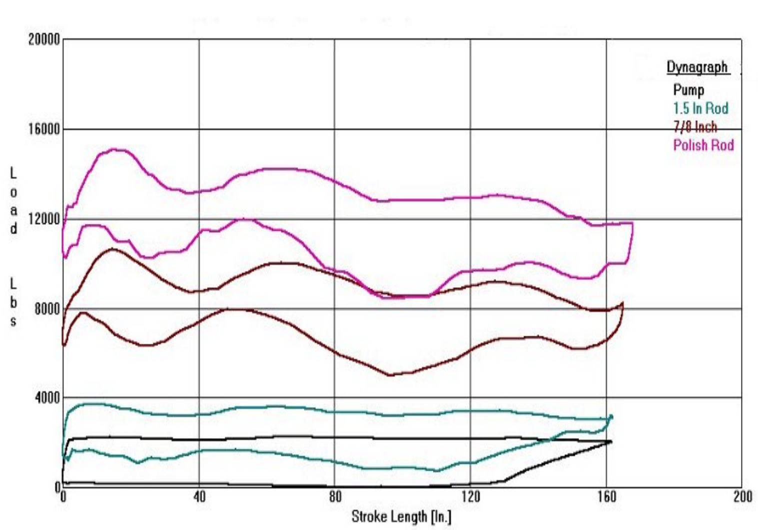

Figure 3 - Example dynagraphs showing load and stroke length positional graphs for the various placements of the EDLC in a well. (Ref. 3)

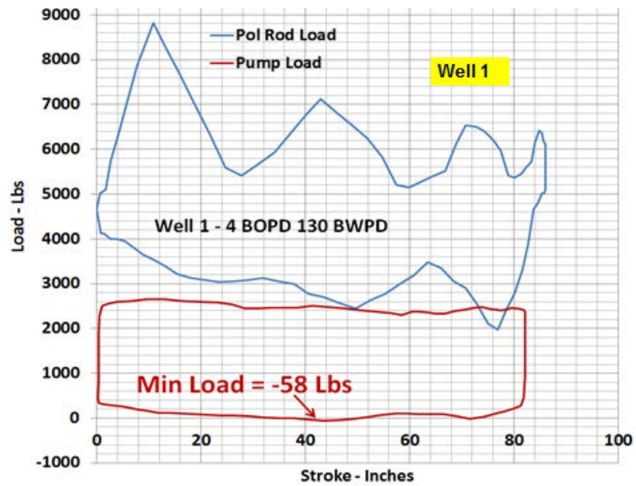

Figure 4 - Graphical results comparing surface and downhole loads above the pump for well 1. (Ref. 3)

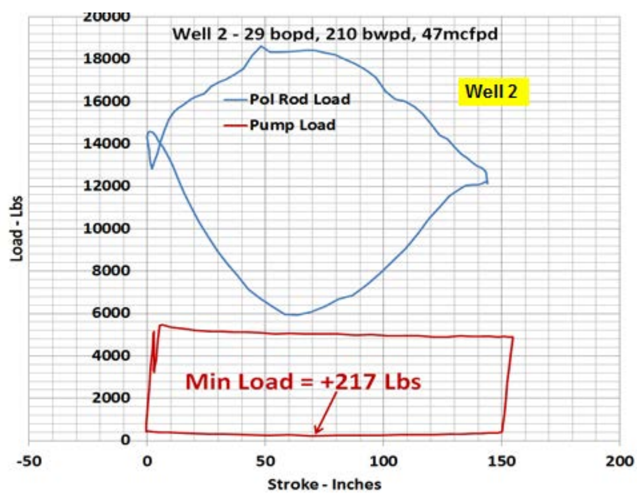

Figure 5 - Graphical results comparing surface and downhole loads above the pump for well 2. (Ref. 3)

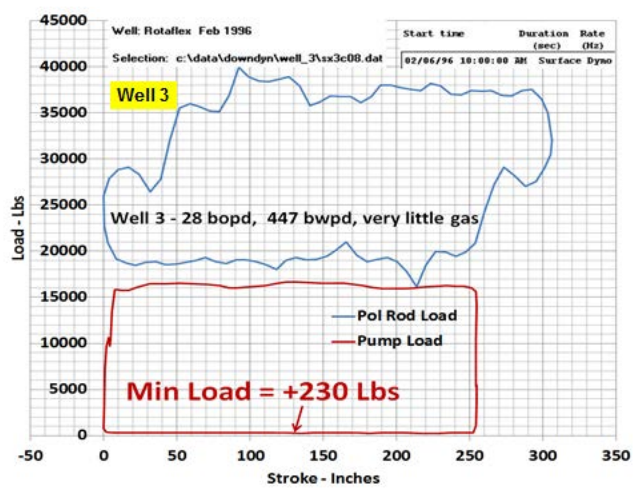

Figure 6 - Graphical results comparing surface and downhole loads above the pump for well 3. (Ref. 3)

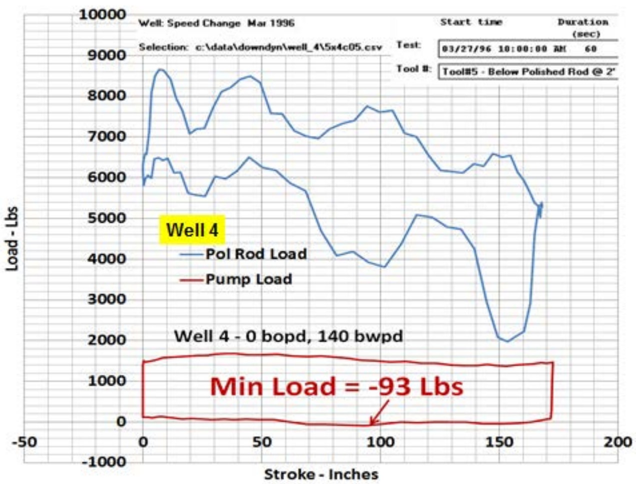

Figure 7 - Graphical results comparing surface and downhole loads above the pump for well 4. (Ref. 3)

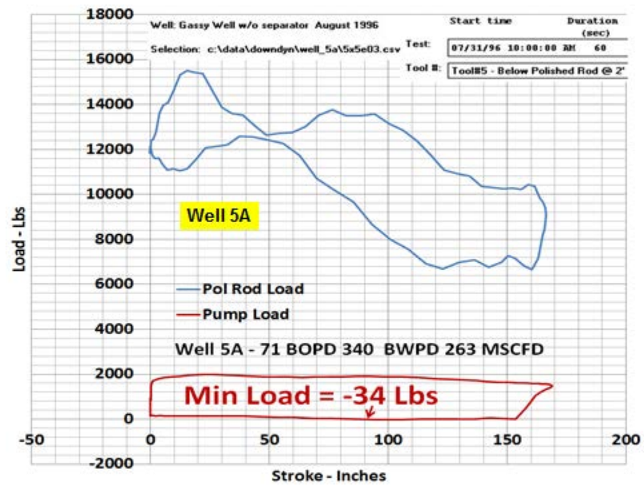

Figure 8 - Graphical results comparing surface and downhole loads above the pump for well 5A. (Ref. 3)

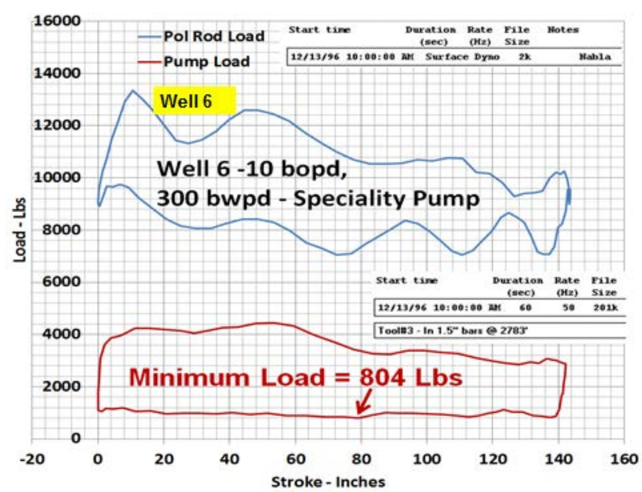

Figure 9 - Graphical results comparing surface and downhole loads above the pump for well 6. (Ref. 3)

Table 4 - Comparison results for well 1

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	8815	8661	-1.7	8746	-0.7	8736	-0.9
MPRL	1979	1600	-19.1	1797	-9.2	2167	-0.9
MPL	-58	-744	+138	0	1	-200	+245

Table 5 - Comparison results for well 2

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	18.613	21,221	+14	20,484	+10.0	20,669	-+11.0
MPRL	5932	6074	+2.4	6224	+4.9	5547	-6.5
MPL	+217	-2838	-1208	0	1	-200	-7.8

Table 6 - Comparison results for well 3

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	39,972	52,459	+31.2	42,639	+10.6	40,799	+2.1
MPRL	16.148	21,457	+32.9	14,134	-11.5	14298	-11.5
MPL	+230	-3367	-2710	0	1	-200	-13.2

Table 7 - Comparison results for well 4

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	8,656	8.946	+3.3	10,280	+18.7	8,462	-2.2
MPRL	1,977	3,673	+85.8	2,201	+11.3	2,470	+24.9
MPL	-93	-2,613	-2710	0	1	-200	+115

Table 8 - Comparison results for well 5

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	15,507	16,389	+5.68	15,701	+1.25	16.926	+9.1
MPRL	6651	7161	+7.7	7054	+6.1	6980	+4.9
MPL	-34	-4403	-4502	0	1	-254	-647

Table 9 - Comparison results for well 6

Load	Sandia	Prog 1	%	Prog 2	%	Prog 3	%
PPRL	13,344	15,276	14.5	12,743	-4.5	10,582	-20.7
MPRL	7040	4485	-36.3	4295	-39.9	2793	-60.3
MPL	+804	-2788	-2467	0	1	-200	-75.1