MODIFIED EVERITT-JENNINGS CALCULATED DOWNHOLE DATA COMPARED TO MEASURED SANDIA DATA

Victoria Pon
Weatherford

ABSTRACT

In the case of a vertical well, the rod string can be compared to an ideal slender bar. Therefore the propagation of stress waves occurring from cyclic loading and un-loading during a pumping cycle becomes a one dimensional phenomenon.

The most accurate way of computing downhole data, is therefore by solving the one-dimensional damped wave equation. The Modified Everitt-Jennings algorithm combines finite differences with other state of the art innovative algorithms to provide precise downhole data, accurately reflecting present downhole conditions.

In the 1990's, Sandia National Laboratories were contracted to measure actual position and load data at different depths of the rod string through a series of downhole tools.

In this paper, results from the Modified Everitt-Jennings methodology are compared to actual field measurements, captured by the Sandia National Laboratory experiment.

I. INTRODUCTION

In this paper, results from the current Modified-Everitt-Jennings package are compared to actual dynamometer readings from SANDIA data. This paper is meant as an update of [2]. The current MEJ package is described and the new results updated. The same example wells from Sandia are used for this research.

In rod lifted wells, downhole data and surface data must be obtained for appropriate control of the well. Since measurements are always more accurate than calculations, ideally, downhole data can be obtained through downhole dynamometers. However, this is an expensive and impractical method of obtaining downhole data.

Instead, it is common practice to calculate downhole data from surface data using the 1D wave equation. The wave equation models the propagation of stress waves down the rod string, see[14].

Other methods for solving the wave equation include the method of characteristics by Snyder, see [13], separation of variables and Fourier series by Gibbs, see [4-7], and finite difference by Knapp, see [8]. In 1976, Everitt and Jennings applied finite differences to the wave equation and outlined an algorithm for iterating on the net stroke and damping factor, see [3, 12]. The Everitt-Jennings method has been implemented and modified by Weatherford International.

In Section 2, the MEJ package is described. For more details on MEJ package and methods, see [9].

In Section3, results from the modified Everitt-Jennings package are compared with actual measurements from SANDIA data.

Conclusions follow in Section 4.

II. MATERIAL AND METHODS

The Modified Everitt-Jennings method uses finite differences to solve the 1D wave equation. Finite differences involve the creation of a mesh in both space and time, which allows the solution of the wave equation to be solved at each of these finite difference nodes downhole. The partial derivatives in the 1D wave equation are replaced by simple quotient, to make the solution of the wave equation linear at each step.

The modified Everitt-Jennings package also incorporates an iteration on damping. The iteration on damping has evolved from a simple algorithm see [3], to iteration on dual damping see [10, 11], where the algorithm iterates over separate upstroke and downstroke damping factor.

Also the results from the MEJ are combined with a powerful Pump Fillage Calculation capable of calculating accurate pump fillage regardless of downhole conditions present, see[1].

In order to improve the convergence of the iteration on damping as well as the calculation of the fluid level, a Fluid Load Line Calculation was set in place. The FLLC computes a series of fluid load lines, which is capable of diagnosing the presence of mechanical friction and control the card accordingly, inferring the concavity of the downhole data for appropriate damping as well as computing the fluid load.

Finally, since the position and load can be output at any finite difference node down the taper, the maximum stress, minimum stress and maximum allowable stress are computed at every node down the rod string. Moreover, the stress values are interpolated using cubic splines so that the stress values can be output at any depth specified by the user.

For more information on the above methods, see [9].
In the next section, results from the MEJ are compared to SANDIA measurements.

III. RESULTS

In this section, results from the modified Everitt-Jennings and Gibbs method are compared to actual downhole dynamometer data from the Sandia National Laboratory.

The Sandia National Laboratory data is a compilation of test data collected with a set of five downhole tools built by Albert Engineering under contract to Sandia National Laboratories. The necessary memory tools were deployed in the sucker rod string and equipped with sensors that were capable of measuring pressure, temperature, load and acceleration. The position was calculated by integrating the acceleration twice, yielding a load versus position downhole dynagraph. The results of these tests were presented by Waggoner in [15].

Each test conducted by the Sandia National Laboratory was designed to represent different conditions arising in the field. In Section 3.1, a well representing average conditions is analyzed. In Section 3.2, a well having fiberglass rods is considered. A Rotaflex unit is analyzed in Section 3.3 and a well with variable speed drive is analyzed in Section 3.4. Two more sets of data were analyzed by the Sandia National Laboratory, but these wells are not presented in this paper.

For each well, a description of the well is given, then a summary of Waggoner’s findings and remarks, followed by the comparison to the modified Everitt-Jennings downhole data to the SANDIA tool readings. It is important to note that the iteration on the net stroke and damping factor is not possible since the essential input variables required for that part of the code were unavailable.
Due to time constraints, only three wells from the SANDIA database are shown in this paper.

For each of the test wells, surface data and downhole data and readings are presented. In Figures 1, 3 and 5, the surface data is displayed as the graphical representation of the surface card. Figures 2, 4 and 6, show the graphical representation of the downhole data calculated with the MEJ package as well as the SANDIA tool readings.

3.1. Test Data 1: Rocky Mountain Oilfield Testing Center, Wyoming.

In this subsection, a well with as close to normal operating conditions as possible is presented.

This well has a depth of 2700' with a 0.75" API Grade 'C' steel rod string and a 1.5" RWA pump in 2.875" tubing. The pumping speed is 11 SPM with an 86" surface stroke. The dynamometer tools were installed in the rod string as follows:

1. below the pump,
2. above the pump at 2708',

3. at 2456',
4. at 1004', and
5. at 2'.

It is important to note that Tool #1 failed and no data was acquired from below the pump.
According to Waggoner [9], this well was chosen for its normal operating characteristics, representative of a fairly large number of wells. In [9], the results presented by Waggoner include dynagraph cards from the bottom of the well when the pump is full at 9:07 AM (SX1c03, 5X1c07 and 2X1c07) and when the well pumps off at 10:47 AM (SX1c05, 5X1c13 and 2X1c13). Cards were taken from data gathered at the surface, right below the polished rod and right above the pump at 2708'. Data representing a full pump and a pumped off condition at 1004' and 2056' are also available for the comparison.

In Figure 1, the surface data for test well 1 is displayed. In Figure 2, downhole data for test well 1 is displayed. The solid line represents the downhole data calculated with MEJ, while the dashed line represents the reading from the SANDIA tool above the pump.

As can be seen from Figure 2, the resulting downhole data from MEJ matches the tool readings for test well 1. The overall shape of the cards are similar as well as matching stroke fluid loads approximately equal to 2500 lbs. The downhole netstroke for the calculated card is 81.31 while the downhole netstroke for the SANDIA reading is 82.44. Also the downhole card corresponding to the MEJ calculations is smooth, which is a product of the small surface data sample used for the calculations.

For additional details about this well data and the tools used, see [15].

3.2. Test Data 3: Rotaflex unit.

In this sub-section, a well with a Rotaflex pumping unit is considered.

This well has a depth of 9300' with an API Grade 'D' steel rod string consisting of 1" and 0.875", a 2.25" diameter tubing pump, and 2.875" tubing. The well operated at 3.9 SPM with a surface stroke of 306". During the tests, the variable frequency drive was run at 3.8, 3.5, 2.9 and 2.4 SPM. The tools were installed in the rod string as follows:

1. above the pump at 9231',
2. at 1" rods at 9089',
3. in 1" rods at 8787',
4. at the lower 0.875" rod/1" rod crossover at 7660', and
5. in the 0.875" rods at 7508'.

This well was chosen in an effort to observe the dynamics of the Rotaflex pumping unit at different pumping speeds and the dynamics of the rod string affected by the rapid direction changes during operation. In [9], results include dynagraphs cards for 3.8 SPM and 2.4 SPM. Waggoner observed that the loads and shape of the cards were similar, while the downhole stroke length was about 5% longer at the faster pumping speed. Results from above the pump using the modified Everitt-Jennings method at 3.8 SPM and 2.4 SPM were compared to the Sandia results of Tool #1 at similar speeds (SX3d05, 1X3d05 and SX3d08, 1X3d08) in an effort to reproduce the longer stroke length phenomenon at the faster speed.

In Figure 3, the surface card for test well 3 is displayed. In Figure 4, the graphical representation of the downhole data calculated with MEJ is compared to the readings from the SANDIA tool above the pump. In this example, the results from MEJ are almost an identical match to the SANDIA readings, the shape, fluid load and netstroke of the cards are very close.

3.4. Test data 4: Varied pump speed and pump fillage test data.

In this sub-section, a well with varying pump speed and pump fillage is considered.

This well has a depth of 3100' with an API Grade 'D' steel rod string consisting of 0.875" and 0.75" rods, with 1.25" sinker bars, a 1.25" insert pump and 2.875" tubing. Tests were conducted using pump speed of 8.8, 6.7 and 4.6 SPM. The tools were installed in the rod string as follows:

1. below the pump,
2. above the pump at 3010',
3. at the sinker bar/0.75" rod crossover at 2708',
4. at the 0.75" rod/0.875" rod crossover at 1006', and
5. below the polished rod at 7508'.

According to Waggoner in [9], this well was chosen to explore the effects of both different pumping speeds and varying pump fillages on the dynamics of the sucker rod string. Results include dynagraph data from full pump fillage at 8.8 and 4.6 SPM (SX4c05, 2X4c05 and SX4c11, 1X4c11) and from pumped off conditions at the same speeds (SX3c08, 2X4c08 and SX4d05, 2X4d05).

Waggoner observed that the dynagraph data at the slower speed yields more regular downhole cards. Waggoner also remarked that the downhole tools and the surface tools were not synchronized to record data at the same time. Hence, Waggoner noticed that, in the case of the pumped off well, it was difficult to establish a uniform pumping condition over the one minute recording interval. The effect of this was that the strokes during this interval were not consistent. It was observed that even though the surface card showed about 15% pump fillage, the downhole cards at Tool #2 and Tool #1 showed pump fillages of 30% and 50% respectively.

Results from the application of MEJ to SANDIA test well 4 are shown in Figures 5 and 6. In Figure 5, the surface card for test well 4 is displayed. In Figure 6, the graphical representation of the downhole data calculated with the MEJ is compared to the readings from SANDIA tools above the pump. For this example, the fluid load and netstroke match closely to SANDIA readings but the downhole data obtained through MEJ shows discrepancies at the beginning and end of the stroke. This could be attributed to noise in the input data. Indeed any small fluctuations, especially in a sample with few data points can increase significantly during the solving of the wave equation. Also as mentioned previously, since not all the required inputs are available and iteration on damping is not possible for this example.

Overall, the downhole data calculated with the MEJ package match closely readings from SANDIA tools.
This can be seen through similar shapes in the graphical representation of the downhole data as well as comparison for net stroke and fluid load. The above examples show the accuracy of the MEJ algorithm in solving the wave equation and getting results that closely fit the actual readings from the SANDIA tools.

As mentioned above, due to time constraints, only a subset of SANDIA database was used to produce these results.

A continuation of this research will be presented at the 2016 Southwestern Petroleum Short Course, in which all six test wells from SANDIA will be analyzed and downhole data presented for every tool down each well.

IV. CONCLUSIONS.

In this paper, the modified Everitt-Jennings algorithm and its implementation are described and results from the modified Everitt-Jennings method are compared to actual Sandia National Laboratory downhole dynamometer readings.

When applied to test wells from the SANDIA database, the downhole data calculated using the MEJ package matches the readings collected through the SANDIA tools. The calculated data shows a match in shape, fluid load and netstroke in all cases proving that the calculated data obtained by applying MEJ to the wave equation produces reliable and accurate downhole data.

To summarize, using the modified Everitt-Jennings algorithm allows for accurate determination of operating conditions from improved downhole pump cards, accurate pump displacement values from calculation of the net stroke, and therefore reliable calculated pump efficiency values.

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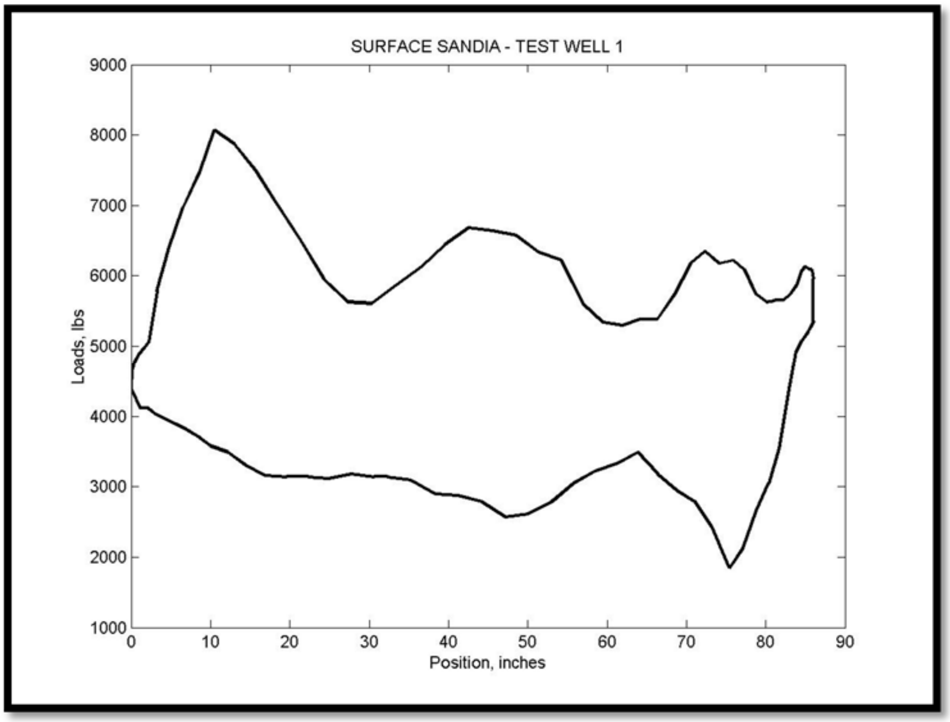

Figure 1 - Test Well 1 Surface Card.

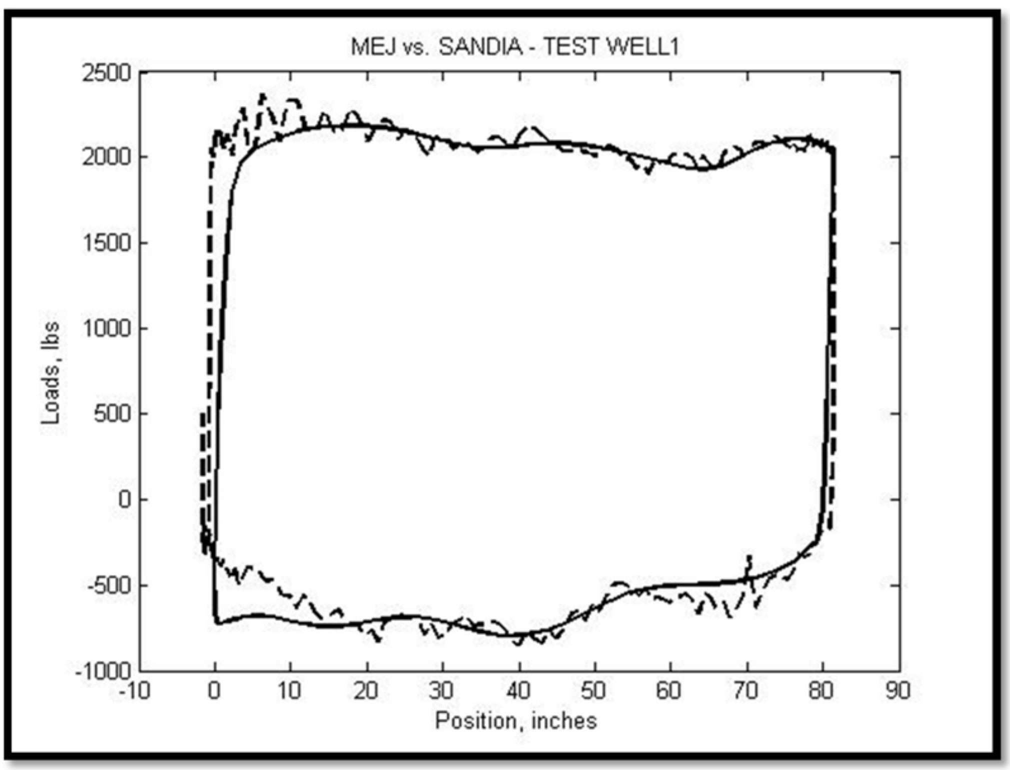

Figure 2 - Graphical representation of calculated downhole data using MEJ (solid) vs. SANDIA tool reading (dashed) for test well 1.

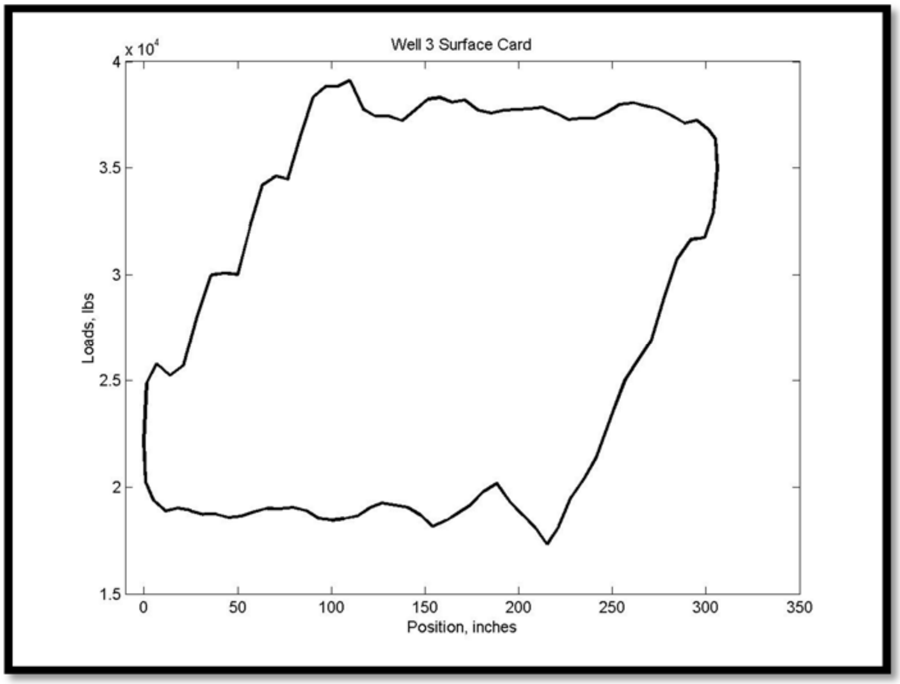

Figure 3: Test Well 3 Surface Card.

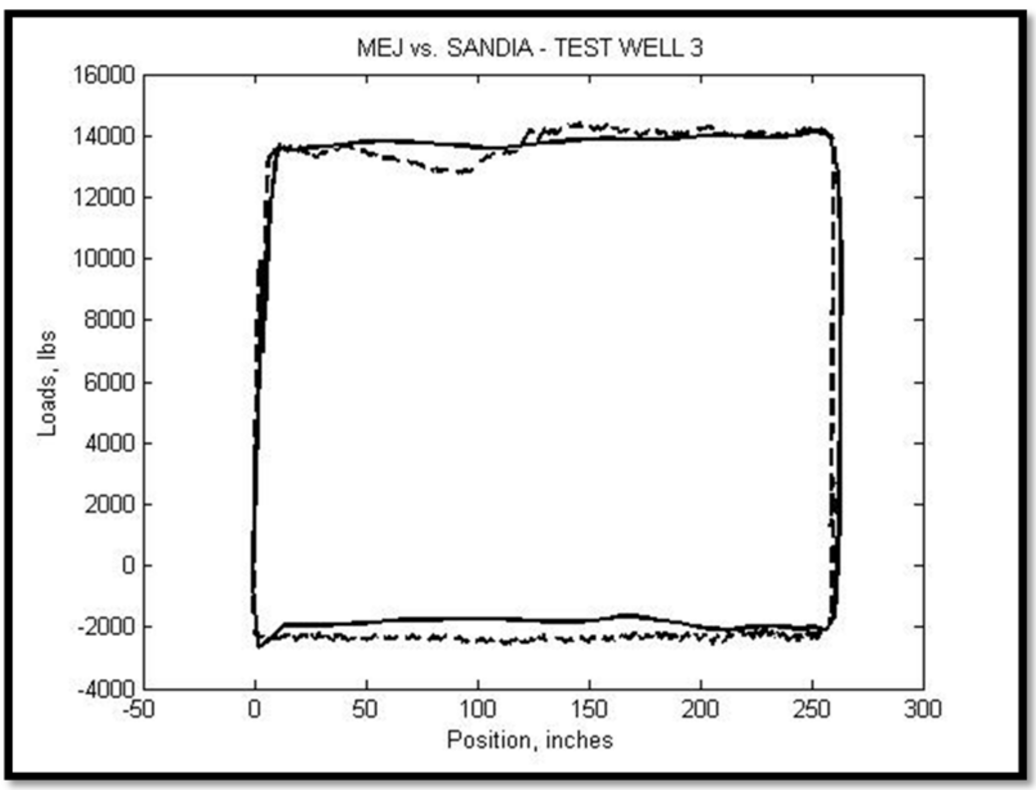

Figure 4 - Graphical representation of calculated downhole data using MEJ (solid) vs. SANDIA tool reading (dashed) for test well 3.

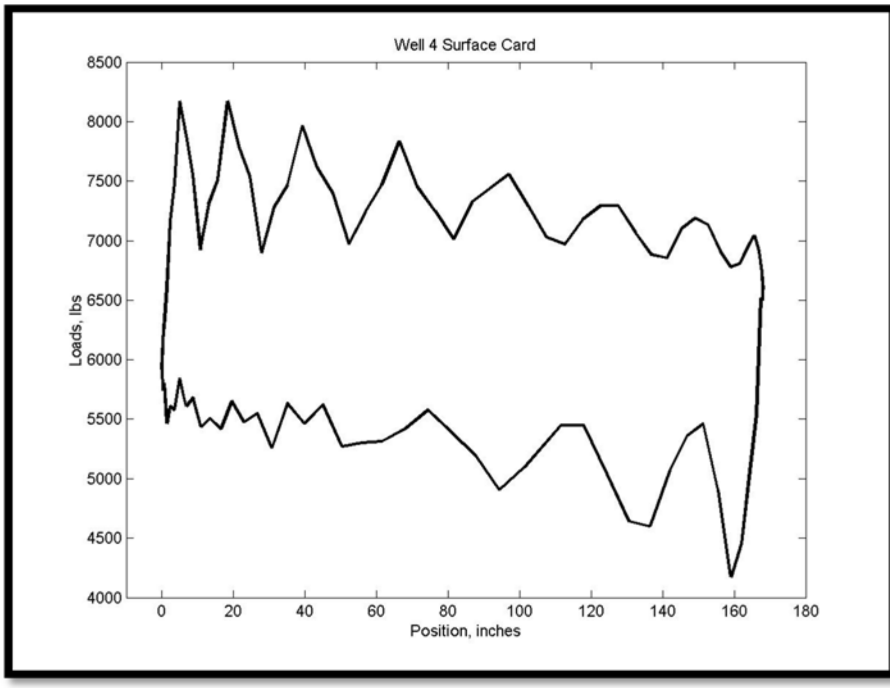

Figure 5: Test Well 4 Surface Card.

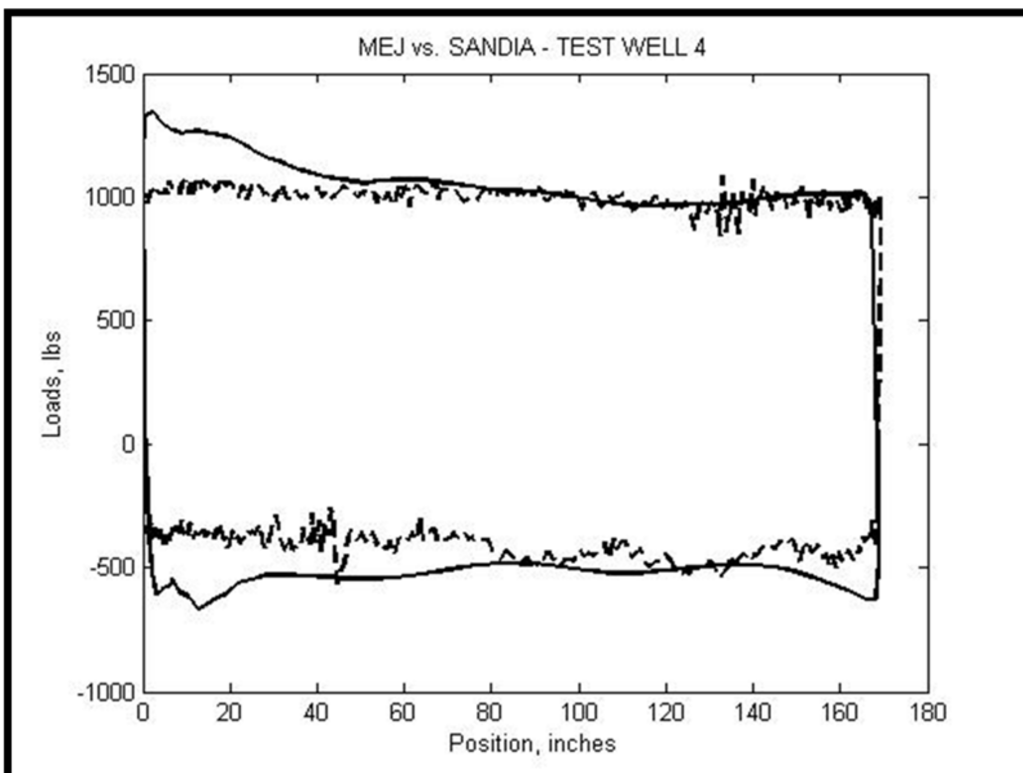

Figure 6: Graphical representation of calculated downhole data using MEJ (solid) vs. SANDIA tool reading (dashed) for test well 4.