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Building A Software To Calculate The Stuck Free Point In Extended Reach And Horizontal Wells

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Abstract:
Extended- reach drilling engineering suffers from high non-production costs due to stuck incidents of drill strings. Therefore, determining the depth at which stuck occurs is important in this process. Measurement techniques are used to identify stuck locations, but these processes are time-consuming. and costly. Due to current operational limitations, calculation methods are still used to estimate stuck point depth. The analytical techniques used nowadays are only applied to vertical wells and do not take into account the inclination and azimuth changes as well as friction factors.
The paper introduces a vivid software that can calculate the stuck free point in extended reach and horizontal wells quickly and preciously with applying tension load or tension and torque. The new software gives 3D-Plan for the well and makes its iterations for calculating the torque and drag and then get the stuck free point. The new software will contribute to the development of the drilling operation and change thinking in creating alternative methods for the ones that are used nowadays, such as logging tools that is costly and time consuming. The paper also discussed the factors affecting stuck point depth such as mud type, mud weight, and friction factors.
The software is validated with three stuck cases in horizontal well where free point tool is deployed. The implantation has yielded significant results with the stuck point indictor tools, revolutionizing well intervention and drilling operations. Field testing demonstrated enhanced accuracy compared to logging tools methods, reducing the time needed to diagnose and resolve sticking issues. Additionally, the software's predictive capabilities will help in minimizing downtime, resulting in substantial cost savings.

Keywords: Extended Reach Drilling, Stuck Pipe, Torque and Drag, Free Point Tool, Software

I. Introduction:

One of the primary goals of drilling operations is to reduce non-production time (NPT), and this is especially true in offshore operations where drilling rates are typically higher compared to onshore operations. Non-productive drilling time, which includes stuck pipe incidents, is one of the major sources of unnecessary costs in the drilling industry. Stuck Pipe incidents have been shown to account for up to 25% of non-productive drilling time, or the equivalent of two years of drilling operations, according to a 2012 study by Moqeem et al [1-3].

Stuck pipe incident is an important issue that needs effective solutions to achieve NPT reduction and increased process efficiency. Extended-reach drilling operation is a complex process and requires significant efforts and huge costs. One of the main challenges faced in this context is the occurrence of stuck in the drill string. Sticking disrupts the drilling process and causes significant delays and additional costs [4].

To overcome this problem, depth must be determined at which stuck incident occurs, which is the crucial first step. In traditional operations, stuck depth allocation is identified using measurement techniques like logging tools, but these operations are time-consuming and require significant efforts and costs. Due to limitations of current operational procedures, calculation methods are still used to estimate stuck point depth [5].

Analytical techniques are available for calculating stuck point depth, but they apply only to vertical wells and do not take friction into account. This means that when it comes to calculating stuck point in extended reach and horizontal wells, torque and drag along the drill string must be considered. Pulling or rotating the drill-string may cause most of the forces used in the drilling process to be lost due to frictional and torque forces [6,7]. Therefore, this paper introduces a software built based on an analytical technique and introduces well inclination, azimuth and friction between holes; open or cased and drill string

II. Literature Review

In early 1990, a method for determining the stuck free point in extension wells and horizontal wells was proposed based on the concept of drill-string weight calculation [8]. The well extends from the surface to the drill bit. The drill string includes several elements extending along the length of the well from the upper end of the wellbore through the free point to the lower end of the wellbore. The elements below the free point are stuck and the elements above the free point are free to move. The method involves slack on the drill string and determining the observed hook load of the drill string during slack. The free point is estimated. Then calculate the hook load, assuming a truncated drill-string, where the truncated drill-string includes the drill-string elements between the top end of the wellbore and the estimated free point. Calculated and observed hook loads are compared. The steps of free point estimation, hook load calculation and comparison are repeated until the calculated hook load matches the measured hook load within a pre-determined tolerance. The free point is found to correspond to a given estimated free point if the hook load calculated based on a cut drill string extending between the top end of the wellbore and the estimated free point corresponds to the observed hook load within a predetermined tolerance [8].

In 1994, Haduch discovered a method that calculates the free stuck point in the extended reach and horizontal wells based on torque and drag calculations on the concept that "equals the friction along the entire drill string to the stuck point". The challenge faced by this method is how to know whether the force has moved to the stuck point or not [9]. This can be done by reversing the order of calculations in the existing torque and drag program and stopping when measuring the depth of the stuck point. Instead of setting the force on the bit as a known value, start with a given measured weight, and solve the same series of equilibrium equations starting at the surface. If the problem is treated as linear and the calculation is for a true equilibrium, the choice of which direction to use is governed only by what is known and what is unknown. The difficulty with this method is that the pulling forces will not all be in the same direction. The only way to calculate torques and drag forces is to use the finite difference element equation which when converged gives the forces everywhere along the drilling and the direction as well. The difficulty of these calculations is that they require many repetitions of the required value, which requires a complex computer system, which in turn requires more time to give the results.

Aaadnoy,2003[10] created a method for calculating the stuck free point in extended reach and horizontal wells taking into consideration the well inclination and profile which helped in improving the results for identifying the stuck point, the problem in this method is the assumption that the drag forces are equal along the entire drill string which has affected the accuracy of the results [10].

III. Calculations of the Stuck Free Point in Extended Reach and Horizontal Wells

Since all the previous methods are having defects in the application of the calculations, logging tools are being run to determine the stuck free point, which is consuming too much time and very costly. A new software has been built to calculate the stuck free point in extended reach and horizontal wells taking into account the torque and drag forces and the well profile as well. The new software is able to calculate the stuck point using two methods; pull test method and combined test method. The pull test method is used in case that the tension force is can be transmitted to the assumed stuck depth and the combined test method is used in case that the tension force only can't be transmitted to the assumed stuck depth, so rotating and pulling the drill string at same time is required to make sure that the force can be transmitted to the deepest point of the drill-string.

3.1- Pull Test Method

In this test the stuck free point is calculated using the survey data from the directional driller including (inclination, azimuth, measured depth, true vertical depth and dogleg severity) then get the string weights in different positions (in each length of the drill string), then the drill string is divided into ''n'' arbitrary elements based on the well profile (vertical section, build up section, drop off section and/ or horizontal section. Then calculate the weight of the drill string in air, after that apply tension force just above the string weight in air and then reverse out the equations used in the calculations of the drag forces from surface down to the assumed stuck point. After that it checks if this force has been transmitted to the stuck point or no.

This can be done by checking the value of the tension force to the last value obtained from the calculations; if it is positive this means that the force has been transmitted and if it is zero or negative this means that the force has not been transmitted and the tension force needs to be increased. If the force has been transmitted to the assumed stuck point, then apply another force just above the last applied force and calculate the stretch of each element and get the cumulative of the elongation, after that get the depth to the stuck point as follows:

- Assume stuck point
- Divide drill-string into ''n'' arbitrary elements
- Keep the pipe under tension to be just above the string weight in air
- Calculate drag from the surface down assumed stuck point as follows[11]:

In the vertical section the losses of tension force due to drag forces is obtained from equation (1):

Consider the tension force (Ft)

$$F1 = Ft - (\beta \Delta Lw) \quad (1)$$

In the straight section the losses of the tension force due to drag is obtained from equation (3.2):

$$F1 = F2 - \beta \Delta Lw(\cos\alpha + \mu \sin\alpha) \quad (2)$$

In the curved sections the losses of the surface tension due to drag is obtained from equation (3)

$$F1 = \left(F_2 - \beta \Delta Lw\left(\frac{\sin\alpha_2 - \sin\alpha_1}{\alpha_2 - \alpha_1}\right)\right) / e^{\mu|\theta_2|} \quad (3)$$

Angle θ_2 is obtained from equation (3.4):

$$\cos\theta_2 = \sin\alpha_2 * \sin\alpha_1 * (\cos\alpha_2 - \cos\alpha_1) + (\cos\alpha_2 * \cos\alpha_1) \quad (4)$$

In the horizontal section the losses of the tension force due to drag is obtained from equation (5)

$$F1 = F2 - \beta \Delta Lw(\cos\alpha + \mu \sin\alpha) \quad (5)$$

- Check if the tension force is transmitted to the stuck point (by checking the losses of the surface tension being lost due to friction
- If the force is transmitted to the stuck point (value is positive), so calculations start
- If the force is not transmitted (value is negative or zero), then increase the tension force and repeat the steps again.
- Calculations if the force is transmitted to the stuck point will be as follows:
- Divide the drill string into segments
- Best practise for dividing the drill string is to divide it as follows:
- Vertical section
- Bend section or build up section
- Straight section
- Build up section or drop off section
- Horizontal section
- Calculate the losses of the tension forces due to drag using equations from (1) to (5)
- Calculate the stretch or elongation in each segment using equation (3.6):

$$dL_i = \frac{L_i dF_i}{E_i \cdot A_i} \quad (6)$$

- Get the cumulative stretch along the drill string using the equation (3.7):

$$dL = \sum_{i=0}^{n} \frac{L_i dF_i}{E_i A_i} \quad (7)$$

- Compare with observed stretch on the surface
- If agree with pre -determined value, then the assumed depth is the stuck depth
- If the value doesn't agree with a pre-determined value, then change the point and repeat the calculations.

HWSCP can summarize all these steps, as the elongation in the drill-string is given with the tension force resulted in this elongation. The software makes its iterations for finding the depth that achieves the given elongation.

3.2- Combined Test Method

If the tension force can't be transmitted to different assumed stuck points, then combined test must be applied. Drill-string is needs to be exposed to both tension force and torsional force which makes the force easier to be applied to the assumed stuck point.

All the steps used in the calculations using Pull Test are the same, but the difference is taking into consideration the pipe rotation. Using the equations used in the calculations of the torque and drag for combined tension and rotation, the force can be evaluated whether it can be transmitted or no.

The drill string is divided in ''n'' elements based on the well profile and then apply torque and tension just using string weight in air and torque just less than the torque before getting stuck.

For the vertical section the force will normally be transmitted so if force Ft is applied then equation (1) can be used for calculating the loss of the applied force.
for straight sections the force reached to the bottom part of the section is obtained from equation (8):

$$F_1 = F_2 - \beta w \Delta l[\cos\alpha + \mu \sin\alpha \sin\psi] \quad (8)$$

For curved section the force reached to the bottom part of the section will be obtained from equation (9):

$$F1 = \left(F_2 - \beta \Delta L w \left(\frac{\sin\alpha_2 - \sin\alpha_1}{\alpha_2 - \alpha_1}\right)\right) / \left(1 + \sin\psi \left(e^{\mu|\theta_2|} - 1\right)\right) \quad (9)$$

For horizontal section the equation, the force reached to the bottom part of the section is obtained from equation (10):

$$F_1 = F_2 - \beta w \Delta l[\cos\alpha + \mu \sin\alpha \sin\psi] \quad (10)$$

All above steps are summarized in the software and has been programmed for easier calculations. The collected data taken from directional driller and driller are put in the software, then ask the driller to apply tension force and then ask to increase it to get the physical or observed drill string elongation all these are inputs to the software then it applies its iterations for finding the stuck point which achieves given elongation. If it failed to find the point, then the software gives indication that the Pull Test is not applicable in this case, please go for the combined test. In this case pulling speed need to be known and drill string rotation (RPM) need to be known to find out the angle created between the axial motion and rotation (**ψ**).

Ask the driller to apply tension force and torque with known (RPM) then get the physical elongation created from the applied rotation and tension forces then the software will make its calculations for finding out the point which achieves given elongation.
Combined test is more accurate as the force can be transmitted to the point easily by applying tension and rotation in the same time. Knowing the RPM and the pulling speed, apply for the equation and get the value of the (**ψ**)

$$\boldsymbol{\psi = \tan^{-1} \frac{60\, x\, v_h}{2\pi N_r r}} \quad (11)$$

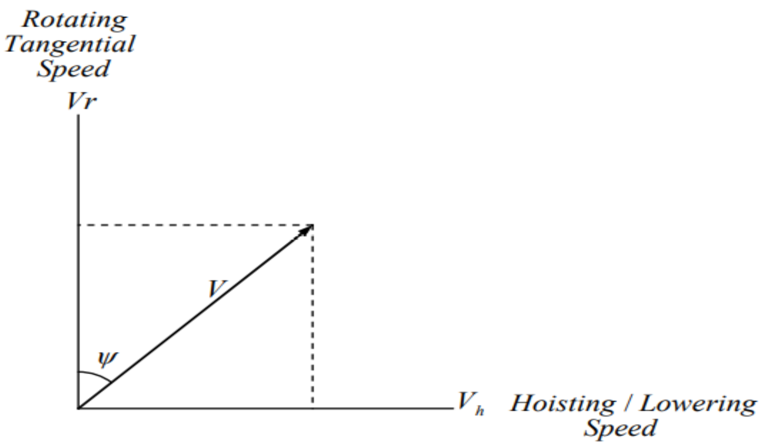

Fig.1. Angle between The Direction of the Tension Force and the Direction of the Rotational Force.[10]

3.3- HWSPC interface:
The software has been designed in the form of a website that can be accessed everywhere over the world by a subscription and just by entering the personal data.

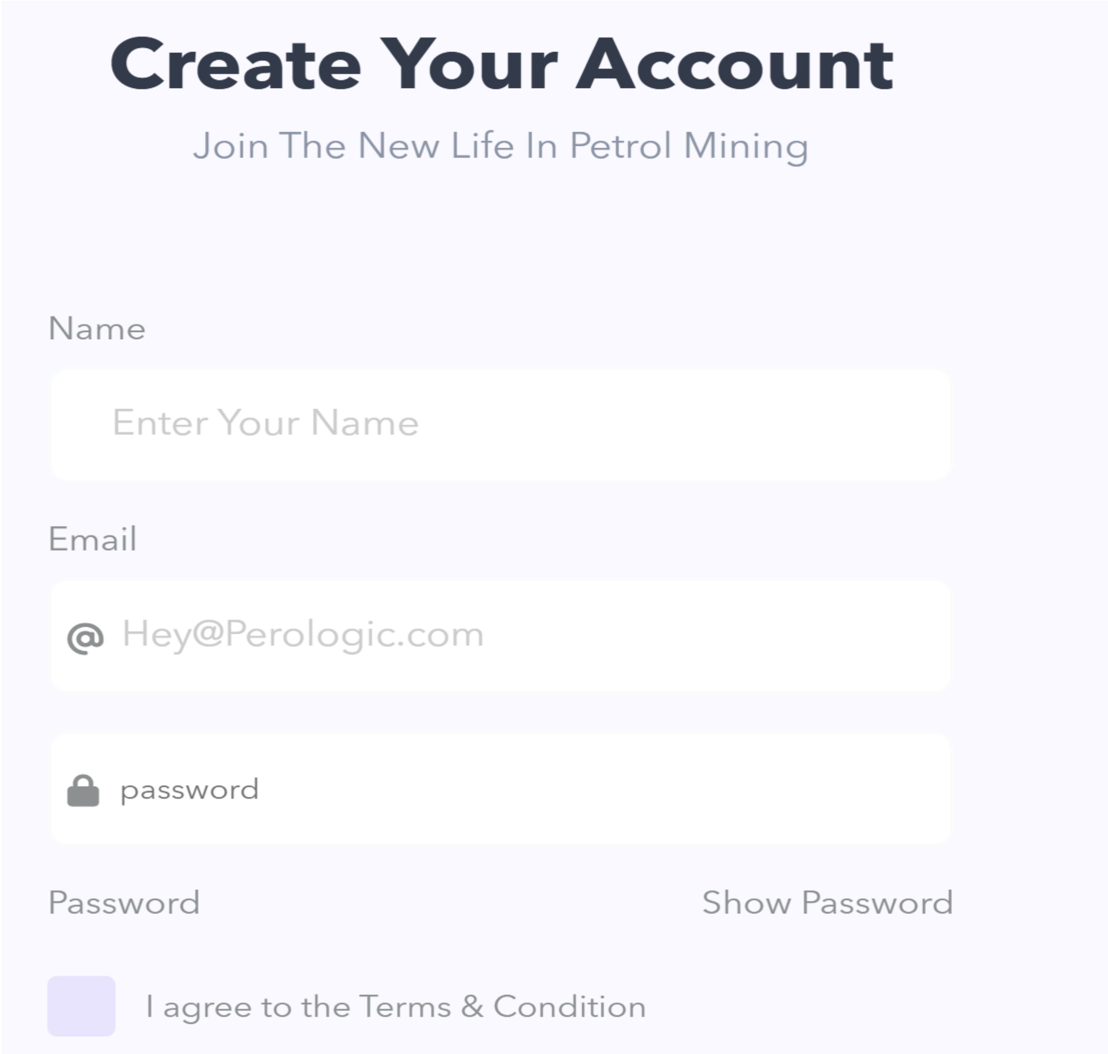

Fig.2. HWSPC Registration Page.

After the subscription, accessibility will be opened for the user and can use the software for getting the stuck depth for any well profile.

3.3.1- Software Usage

Calculations of the stuck free point in extended reach and horizontal wells can be easily calculated by entering the required data that is needed for the calculations. First the survey data is needed which can be collected from the directional driller and then put in the below table or can also be easily retrieved as an excel sheet.

Fig.3: Survey Data Inputs

Then by just choosing the fluid type used the friction factor can be calculated taking into consideration the hole inclination.
Bottom hole assembly is also required for the calculation with the weight of each item to be able to get the string weight which is considered the key factor in the calculations. Also, the casing points are required for the calculations as it helps in the calculations of the friction factors.

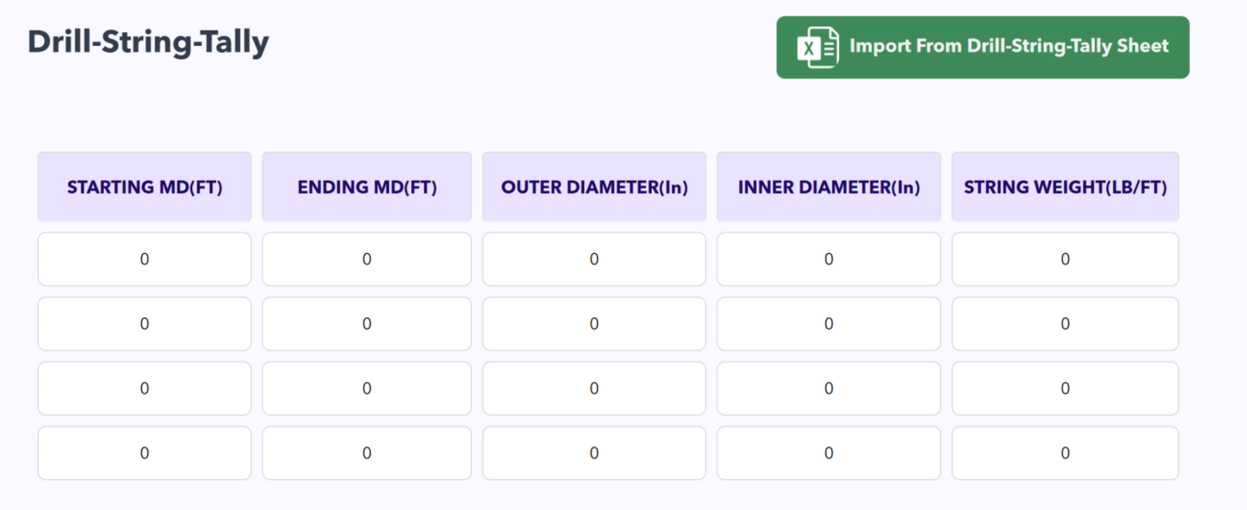

Fig.4.: Drill-String Tally Inputs

After entering all the inputs required then the most important part of the calculations is the value of the elongation of the drill string on the surface as this value the software calculations are based on this value; it makes its iterations and gets the value of the stuck point using this value.

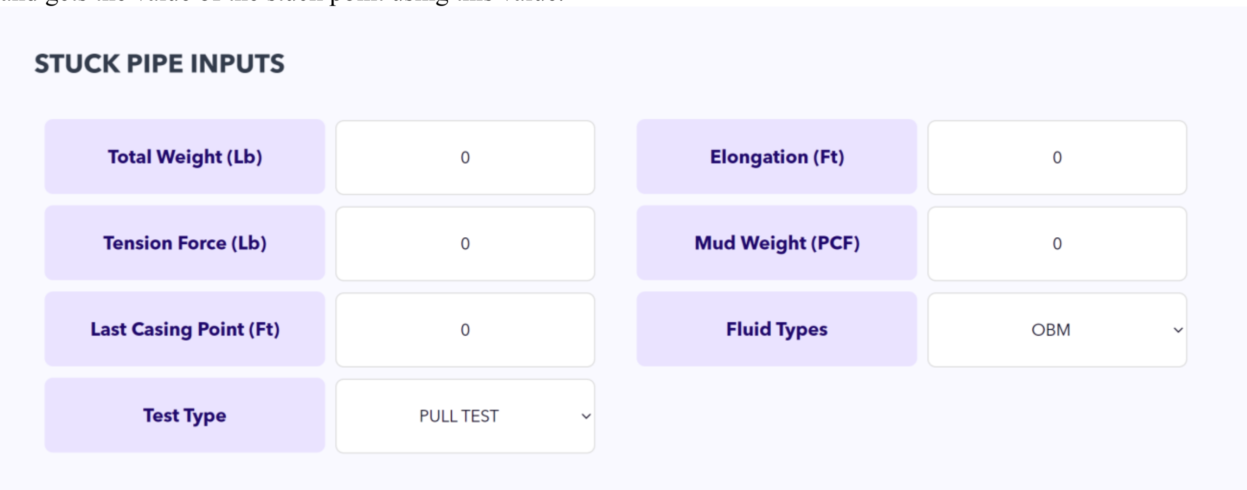

Fig.5: Inputs for Pull Test Method Calculations

In case of using the combined test, method the pipe rotation is also required which will be used directly in the software.

Fig.6: Inputs for Combined Test Method Calculations

After entering all required data the press submit button in the software and get the results. The well will be graphed in three-dimensional plan ;taking into consideration the drill-string turns.

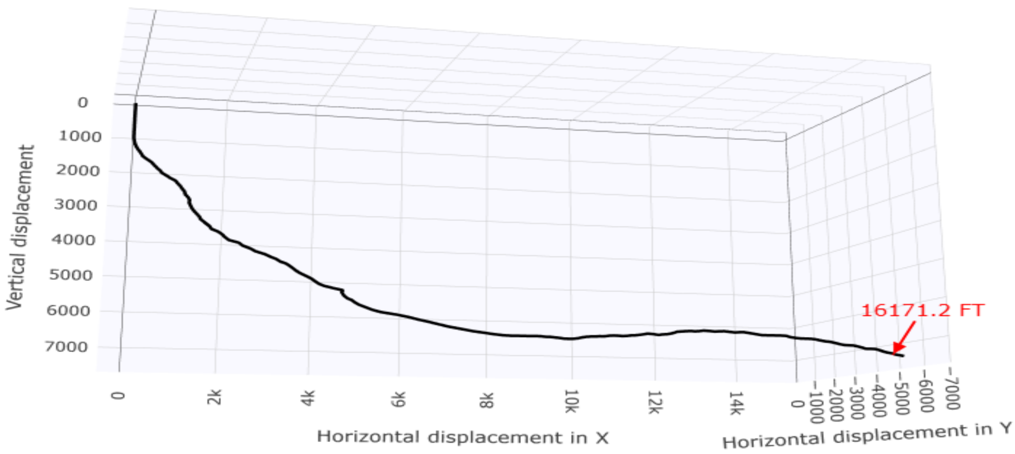

Fig.7: Output of Well Profile in 3-D Plan

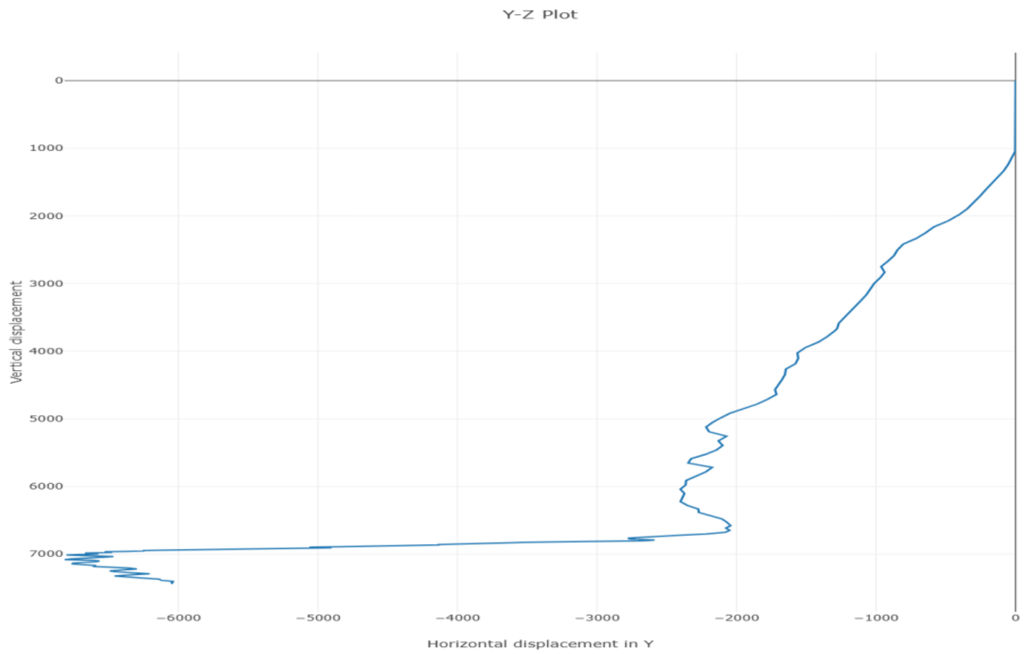

Fig.8: Output of Horizontal Displacement in Y Direction.

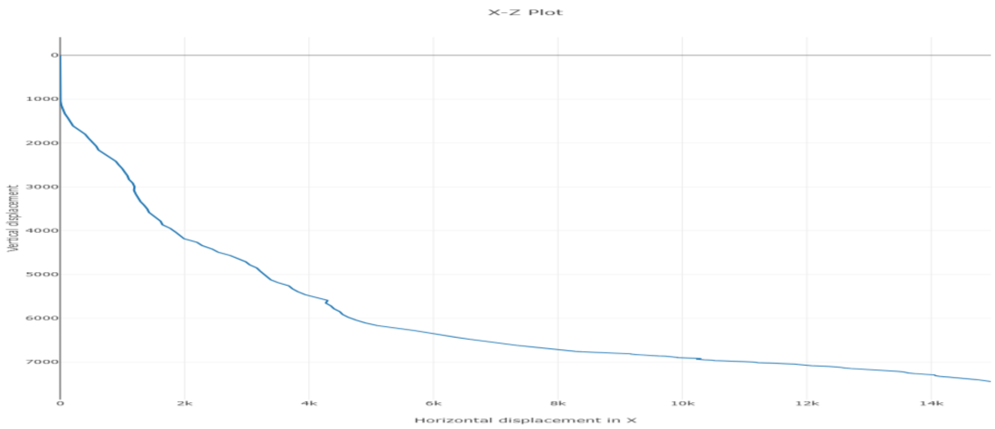

Fig.9: Output of Horizontal Displacement in X Direction.

Then Stuck point is shown directly in the software based on the given data

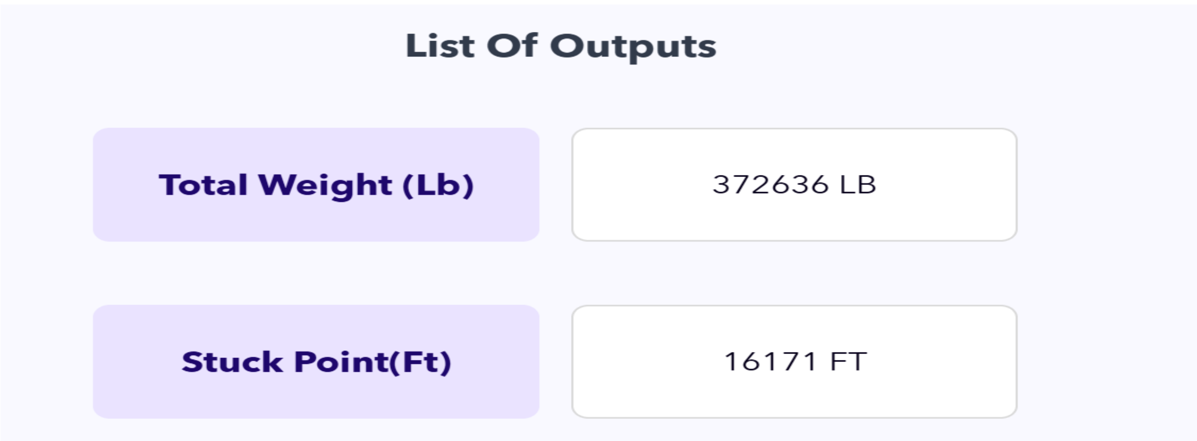

Fig.10: Outputs of total weight and Stuck Depth

HWSPC can be easily used once the data inputs are collected and the type of test can be chosen in the software whether Pull Test or Combined Test. The outputs of the software is very obvious and can give the user a picture of the well profile that is graphed in three dimensional plan.

IV. Results and Discussions

Three wells have been tested for the software accuracy and compared the results with the results obtained from free point indicator tools (logging tools), the software has shown 99% accuracy for the three tested wells as per below results:

4.1- Well A

Well A is a well drilled in (IRAQ), 12 ¼" Hole was drilled to 7232 ft and cased with 9 /8" casing to depth 7232 ft and then started drilling 8.5" hole with 85 pcf Oil Based Mud and after reaching TD at 10367 ft, the hole was circulated clean and started to pull out of hole, the string got stuck and after many trials, was unable to get the string free.

Logging tools was run to determine the stuck depth and it was determined at 9289 ft. HWSPC was used to get the stuck depth and it was calculated 9245 ft while pulling with 340,000 lb.

4.2- Well B

Well# B is a Well drilled in (IRAQ) drilled to 9 5/8", 12 ¼" hole was drilled and cased with 9 5/8" casing at 8101 ft, then started drilling 8.5" hole with 78 PCF OBM, continued drilling the well to depth 16423 FT, then while making a connection the drill-string got stuck, tried to work the string up and down with no success, pumped stuck pipe freeing pills with no success, then decided to cut the drill-string.

A logging tools was run to get the stuck free point and it was determined at 16209 ft. Using HWSPC to get the stuck free point numerically, was calculated at 16171 ft with an accuracy of about 99 %.

4.3-Well C

Well# C was drilled in (IRAQ) to 9 5/8" casing at depth 6291 ft, then started drilling 8.5" hole with 82 PCF OBM, continued drilling the well to depth 9293 FT, then while making a connection the drill-string got stuck, tried to work the string up and down with no success, pumped stuck pipe freeing pills with no success, then decided to cut the drill-string.

A logging tools was run to get the stuck free point and it was determined at 8930 ft. Using HWSPC to get the stuck free point numerically, was calculated at 8874 ft with an accuracy of about 99 %.

Figures 11,12& 13 show the outputs of the software results

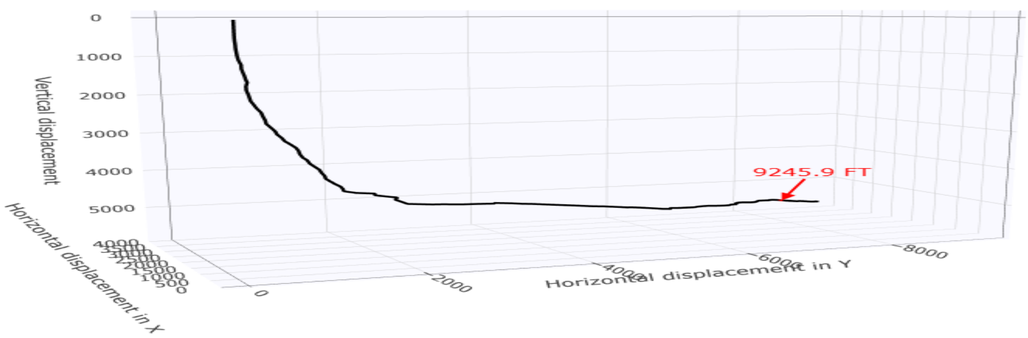

Fig11: Stuck Depth Identification in 3 D plot for Well A

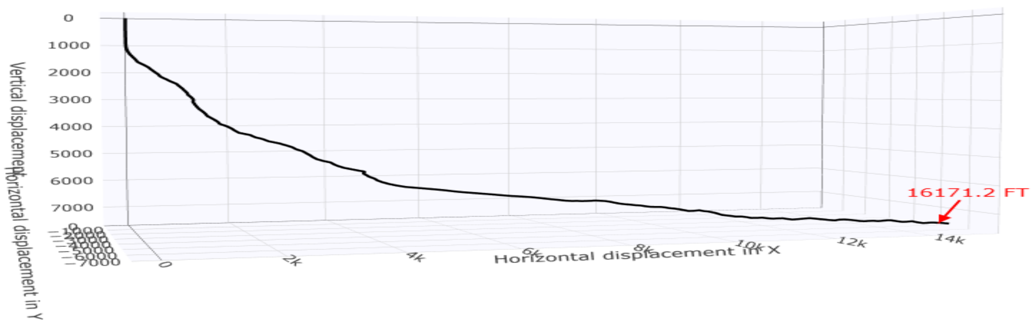

Fig12: Stuck Depth Identification on 3 D plot for Well B

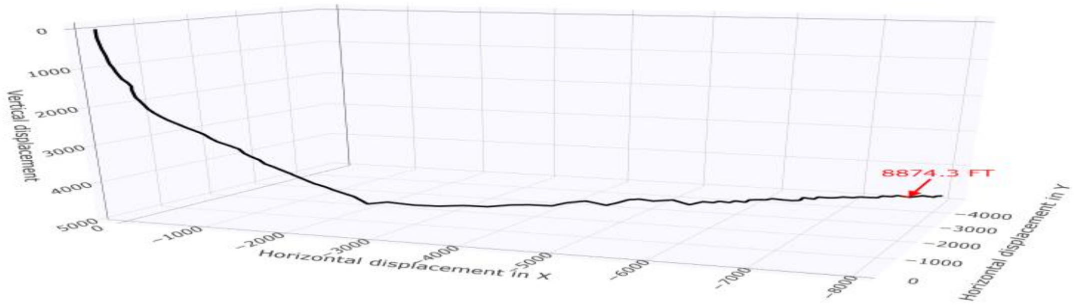

Fig13: Stuck Depth Identification on 3 D plot for Well C

4.4- Combined Test Method Results

Well A, Well B& Well C have been tested using combined test method with the same pull force and it has been observed that the stuck has become shallower because the force transmitted to the assumed stuck depth is higher than the force transmitted using pull force only with no rotation. Figures 14,15& 16 show the output of the software results using combined test method for the three wells A, B& C respectively.

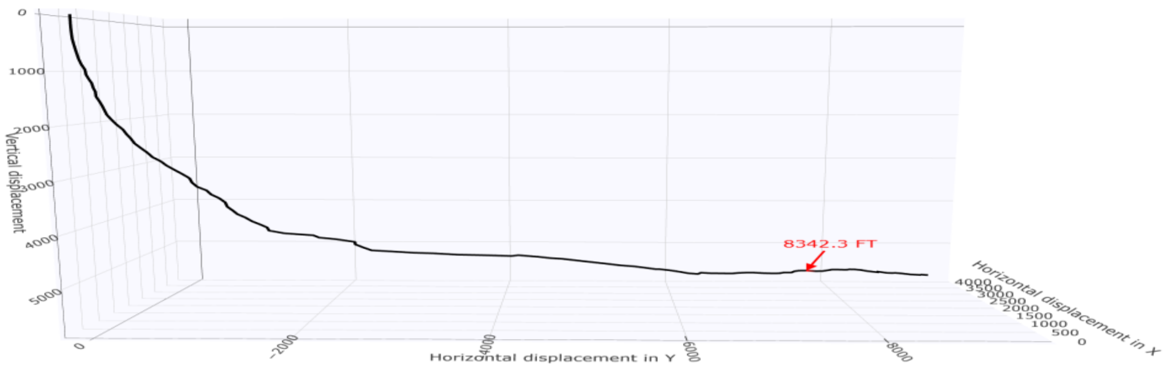

Fig.14: 3D-Plot for Well A Using Combined Test Method

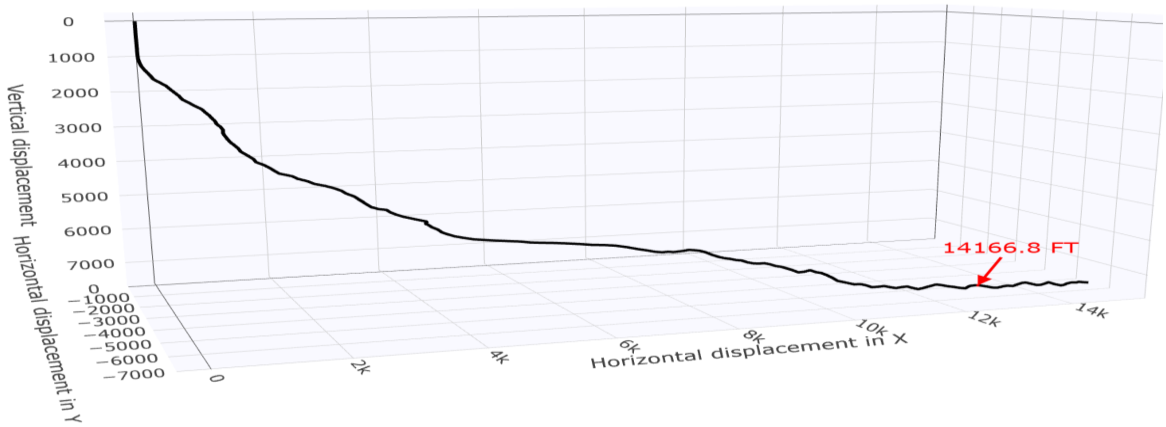

Fig.15: 3D-Plot for Well B Using Combined Test Method.

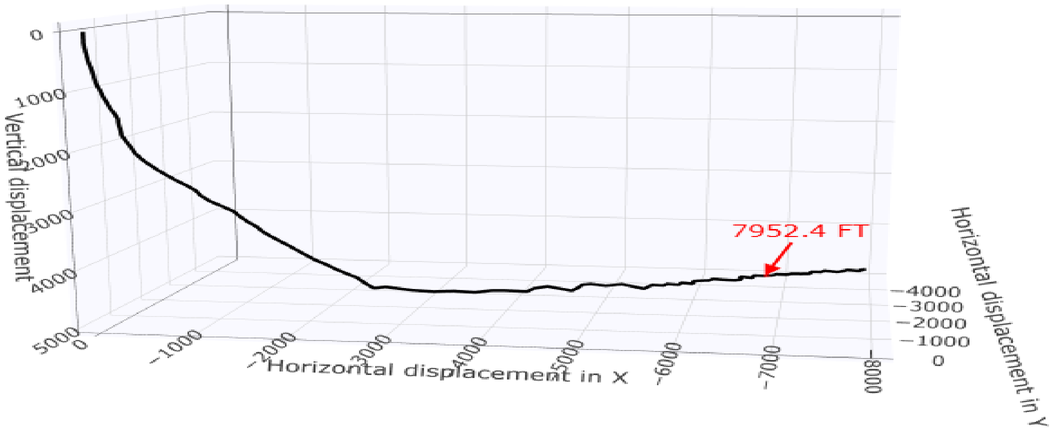

Fig.4.47: 3D-Plot for Well B sing Combined Test Method.

V. Conclusions and Recommendations

The developed software introduces an efficient solution for determining the stuck-free point in extended and horizontal wells. The software minimizes inaccuracies commonly encountered with traditional methods. This precision directly contributes to safer and more cost-effective drilling operations.

The software is designed with user-friendly as a priority, the software simplifies complex calculations, making it accessible to both experts and field operators. Its adaptability to various wellbore geometries and operational scenarios ensures its applicability across a range of drilling projects.

By providing rapid and reliable stuck-free point calculations, the software reduces downtime during fishing operations and mitigates risks associated with stuck pipe incidents. This functionality supports the industry's demand for operational efficiency in challenging well trajectories.

The software leverages innovative 3D frictional models and combines them with input parameters like torque, drag, and tension measurements. This holistic approach enhances its predictive accuracy, particularly in highly deviated and horizontal wells, where conventional models often fall short.

Field testing demonstrates the software's effectiveness in real-world drilling scenarios. Its ability to accurately predict stuck-free points aligns closely with measured field data, validating its reliability and performance.

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