

# New Method for Predicting Casing Wear in Highly Deviated Wells Using Mud Logging Data

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## Original Article

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## Title

# New Method for Predicting Casing Wear in Highly Deviated Wells Using Mud Logging Data

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## Abstract

Casing wear is an essential and complex phenomenon in oil and gas wells. Research is being conducted to predict this phenomenon. This study was conducted at a well in southwestern Iran. In this paper, first examine the force exerted on the drill string. Next, the contact force between the drill string and the casing is calculated. Finally, the wear volume and the depth of the wear groove are determined. These calculations were performed using MATLAB and Python software. In addition, due to the high accuracy of coding, mud log data was used to make the results more accurate. It has also been shown that increasing RPM increases the depth of wear and attempts to drill a highly deviated wells as a sliding mode. Finally, compared the results and matched them with the wireline logs recorded from the well.

Keywords: Casing wear; Casing wear prediction; Mud Logging data; Numerical study

## 1 Introduction

Casing wear is a significant factor in well design and drilling operations, particularly in directional, very deep, horizontal, extended-reach drilling (ERD), and multilateral wells. Disregarding it can provoke a lot of costs and abandon the well before it reaches the target or, in other special cases to blowout, wear occurs with increasing drilling depth, drilling time, and contact load. [1-5]

Bradley and Fontenot determined wear in rotating, tripping, and wireline operations by investigating the effect of time, rotation speed, mud conditions, pipe wear capability, wear resistance, dogleg severity, and tension at the wear point. Moreover, they studied the factors affecting casing wear in these operations and showed that the least wear happens within the wireline and tripping operations. They introduced the wear volume as a linear function of the contact force. [1] The impact of pipe reciprocating was explored, and it was found out that its effect is less than rotation. [6]

Casing wear is a complicated phenomenon that depends on temperature, mud type, percentage of abrasives in mud, tool joint hardfacing, rpm, the diameter of the tool joint, contact load, etc. Williamson ascribed this phenomenon to contact pressure, and his experiments showed that it had a secondary relationship with casing wear rate. [2] Best investigated the effect of tool

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joint hardfacing and wear mechanism. Furthermore, he indicated that the use of weighted mud reduces wear rate. He considered the importance of solids-removal equipment effectiveness, and they minimized wear by removing abrasive cutting, sand, and silt. [7] White and Dawson modified the Wear-Efficiency model, which related to removing casing metal and the amount of energy dissipated by friction in the wear process. They showed that sand does not affect casing wear. They performed their experiments in different physical and chemical conditions for P-110, N-80, and K-55 casing types and various mud conditions. Under similar conditions, the P-110 was worn faster than the N-80 and K-55. [3] Hall et al. developed the CWEAR computer program, which was based on 300 laboratory tests. They demonstrated that by choosing the appropriate hardbanding for the tool joint, the wear coefficient could be reduced. [8]

Schoenmakers found that by reducing the drill string diameter from 5 in. to 3 1/2 in., the wear volume in the running-in wear is doubled. Roughening of hardfaces will not prevent casing wear. [4] Hall and Malloy obtained the wear rate by performing more than 475 tests and creating a casing/riser wear database, relating it to the pressure threshold concept for estimating the final wear groove depth to derive a relation from the test results. These results showed that the casing wear coefficient is not constant and decreases with increasing wear groove depth. [5] Gao et al. investigated the effect of drill pipe diameter on casing wear in ERD wells. They concluded that the casing wears groove geometry is having a substantial impact on the wear groove depth. [9]

Mitchell and Xiang examined the effect of tortuosity and the use of a rotary steerable system in decreasing dogleg to diminish wear volume. [10] Gao and Sun developed a model based on contact pressure and showed that less wear occurs with increasing tool joint external diameter. [11] Sun et al. reduced the wear rate by adding limestone to the drilling fluid. [12] Zhang et al. strengthened polycrystalline diamond blocks on the tool joint to reduce wear, which reduces the coefficient of friction at high loads and speeds. [13]

Zhang et al. predicted wear in underbalanced gas drilling and observed that wear would increase in this case. They analyzed the effect of RPM, ROP, and dogleg and concluded that wear increases with increasing casing degree. [14] Yu et al. examined the wear with in situ stress. [15] Tan et al. investigated the additional wear from the buckled drilling string in the ERD well. [16] Humood et al. studied the effect of additives on oil-based drilling mud, thereby reducing friction and wear. [17]

According to the works done in previous years in predicting casing wear, in this paper, casing wear prediction in Iranian Southwestern wells has been coded using mud logging and survey data by MATLAB and Python software. Finally, they were compared to the Circumferential Acoustic Scanning Tool (CAST) log. As a result, the importance of prediction using mud logging data becomes essential. It should be noted that MATLAB has not been integrated with Python to solve these calculations. Just to show that calculations can be done with both of them.

## **2 Force Calculations**

### **2.1 True and Effective Forces**

To understand these forces, one must refer to Archimedes' law, which pronounces that when an object is wholly or partially immersed in a liquid, an upward pressure equal to the weight of the displaced liquid is applied. In addition to the buoyancy force, there are other known forces, including the weight force, the force due to the change in diameter between the

elements of the drilling string, the buckling stability force, the drag force, the bottom pressure force, and the weight on bit. The distributions of these forces are shown in Fig. 1. Therefore, the magnitude of the forces will be equal to: [18, 19]

$$F_t = \sum [W_s \cos \theta + F_D + \Delta F_{area}] - F_{bottom} - WOB \quad (1)$$

$$W_s = L * W \quad (2)$$

$$F_{bs} = (P_o + \rho_o u_o^2) A_o - (P_i + \rho_i u_i^2) A_i \quad (3)$$

$$F_e = F_t + F_{bs} \quad (4)$$

Where  $F_t$  is true force, lb; L is the element length, ft; W is the element weight per feet, lb/ft;  $\theta$  is the inclination, degree;  $F_D$  is the drag force, lb;  $\Delta F_{area}$  is changing in force as a result of a change in the area, lb;  $F_{bottom}$  is the bottom pressure force, lb;  $WOB$  is the weight on bit, lb;  $F_{bs}$  is the buckling stability force, lb;  $P_o$  is the outside pressure, psi;  $\rho_o$  is the external fluid mass density, ppg;  $u_o$  is the external fluid velocity, ft/s;  $A_o$  is the external cross-sectional area, in<sup>2</sup>;  $P_i$  is the inside pressure, psi;  $\rho_i$  is the inside fluid mass density, ppg;  $u_i$  is the inside fluid velocity, ft/s;  $A_i$  is the inside cross-sectional area, in<sup>2</sup>;  $F_e$  is the effective force, lb.

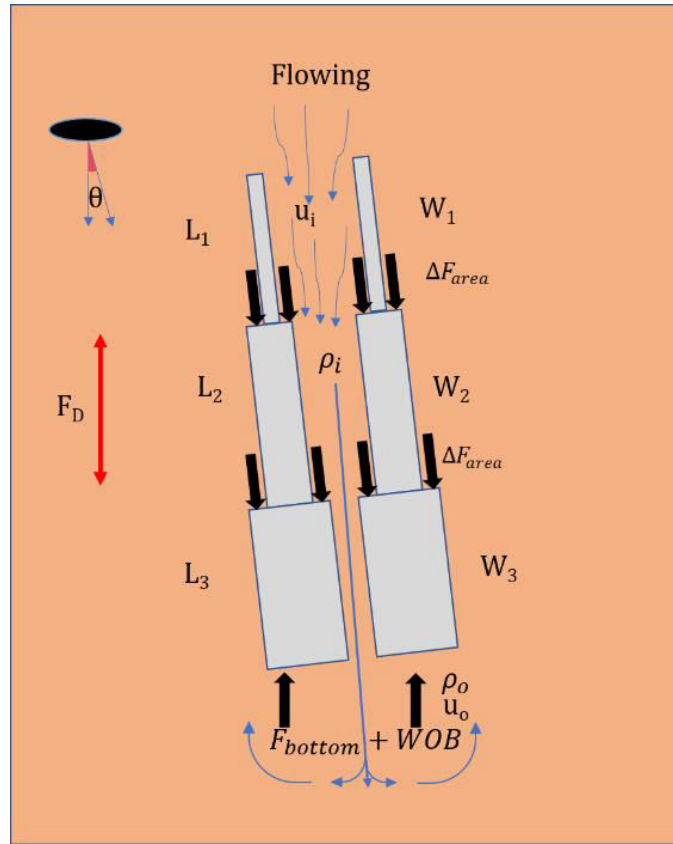


Figure 1: Force Distribution

## 2.2 Contact Force

To accurately calculate the casing wear volume, the contact force between the casing and the drill string must be done accurately. After determining the characteristics of the drill string, survey data, and coefficient of friction, the calculations start from the bottom of the drill string and move upwards. Each element of the drill string increases the magnitude of the axial load. [20] The forces on the drill string are shown in Fig. 2, and the contact force magnitude is equal to:

$$F_n = \left[ (F_e \Delta\alpha \sin \bar{\theta})^2 + (F_e \Delta\theta + W \sin \bar{\theta})^2 \right]^{1/2} \quad (5)$$

Where  $F_n$  is the contact force, lb;  $F_e$  is the effective force, lb;  $\Delta\alpha$  is increasing the azimuth angle between two stations, degrees;  $\bar{\theta}$  is the average inclination angle between two stations, degrees;  $\Delta\theta$  is increasing in the inclination angle between two stations, degrees;  $W$  is the element weight per feet, lb/ft.

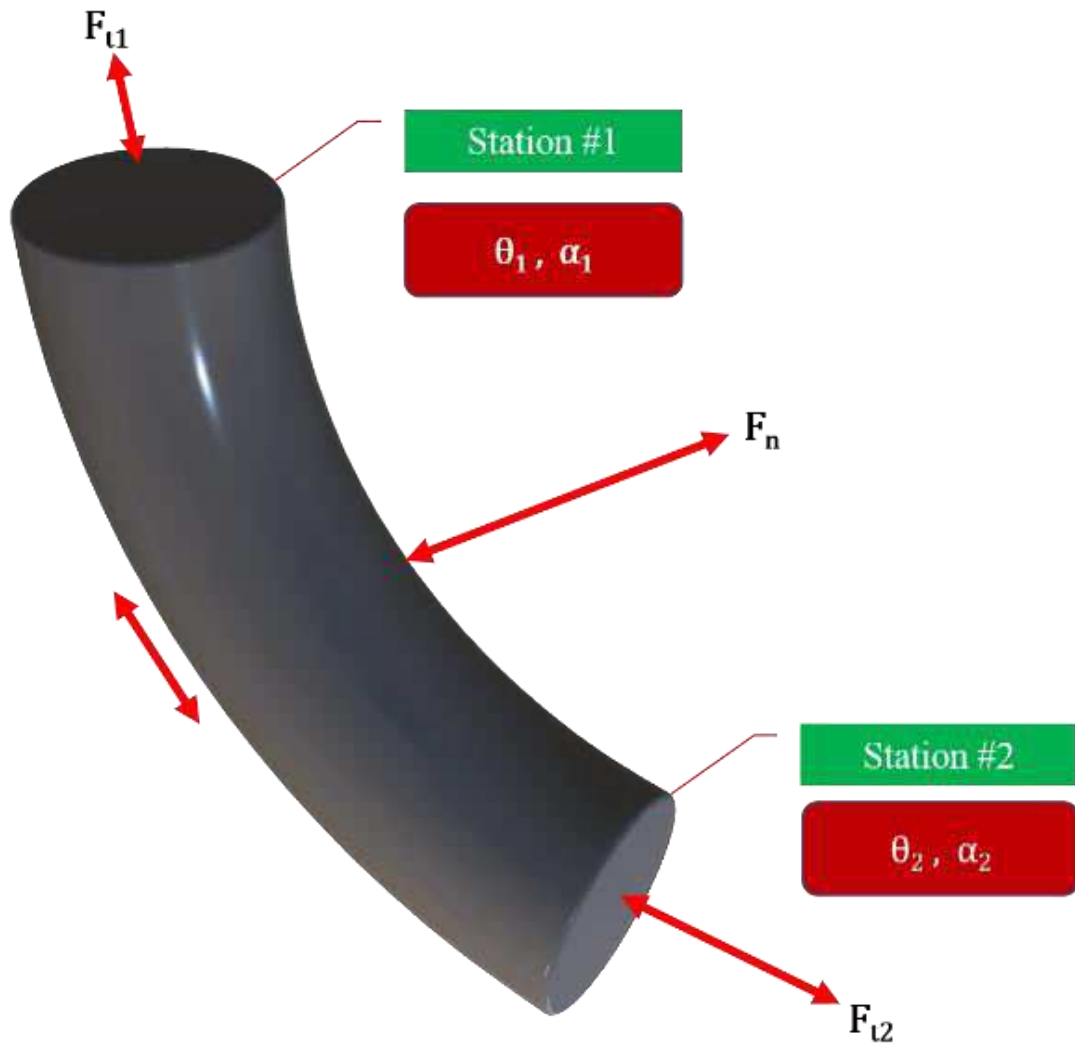


Figure 2: Existing forces on the drill string

### 3 Casing Wear Model

#### 3.1 Wear volume

The calculation of the wear volume is based on the assumption that when the tool joint rotates, its collisions with the inner wall of the casing cause a crescent-shaped groove in the inner wall of the casing. The basic assumption of this model was that the volume of steel removed from each casing length unit at a point on the casing inner surface is proportional to the friction work done at that point by the tool joint in contact with the casing. Its magnitude will be calculated by Eq. 6 in the rotationally drilling and by Eq. 8 in the sliding drilling. [8, 21, 22]

$$WV = W_f * F_{ntj} * \pi * D_{tj} * RPM * 60 * t * \frac{L_{tj}}{L_p} \quad (6)$$

$$F_{ntj} = F_{nft} * \frac{L_{tj}}{L_p} \quad (7)$$

$$WV = W_f * F_{ntj} * d_{slid} * 12 * \frac{L_{tj}}{L_p} \quad (8)$$

$$d_{slid} = MD_{end} - MD_{srt} \quad (9)$$

Where  $WV$  is the Wear volume, in<sup>3</sup>/ft;  $W_f$  is the casing wear factor, 1/psi;  $F_{ntj}$  is the side force per feet of tool joint, lbf/ft;  $D_{tj}$  is the tool joint OD, in;  $RPM$  is the rotary speed of drill string, rpm;  $t$  is the operation time, hrs;  $L_{tj}$  is the length of tool joint, ft;  $L_p$  is the length of drill pipe, ft;  $F_{nft}$  is the side force per feet of drill pipe, lbf/ft;  $d_{slid}$  is the total sliding distance, ft;  $MD_{srt}$  is the start depth of operation, ft;  $MD_{end}$  is the end depth of operation, ft.

#### 3.2 Wear Groove Depth

The groove depth is shown in Fig. 3 due to the tool joint contact with the casing inner wall. After calculating the wear volume, Eq. 10 will be used to calculate the groove depth. [23]

$$WV = 12 (\beta r^2 + 2\sqrt{P(P-R)(P-r)(P-S)} - \alpha R^2) \quad (10)$$

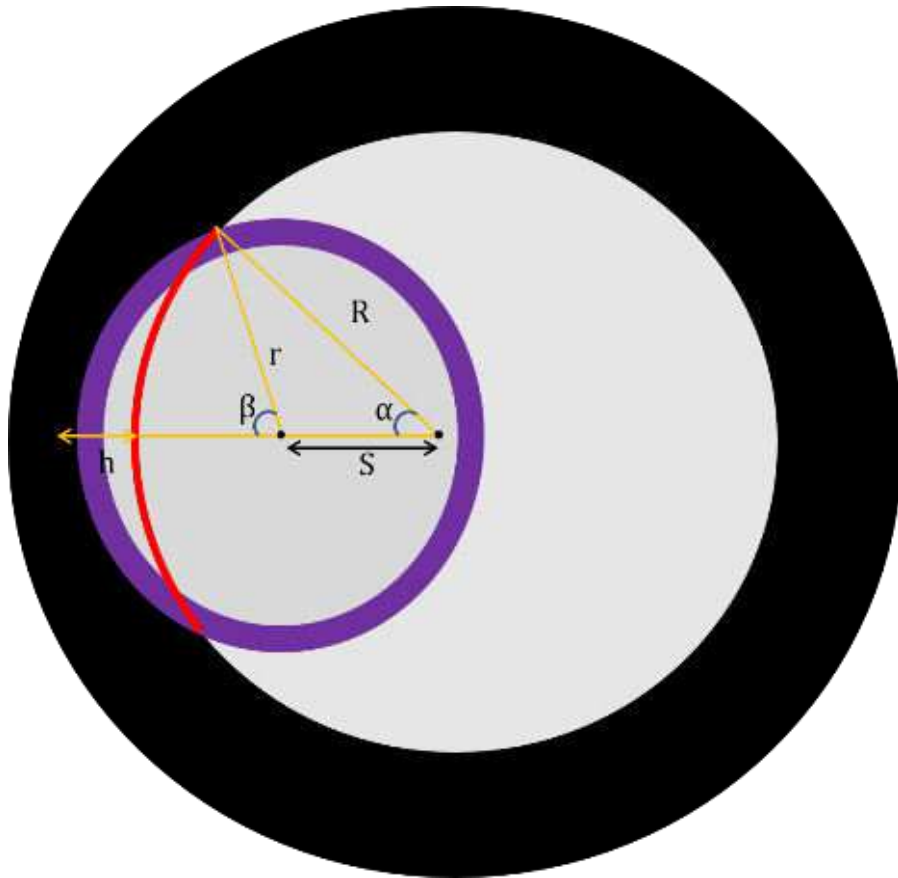
$$S = R - (R - h) \quad (11)$$

$$P = \frac{R + r + S}{2} \quad (12)$$

$$\alpha = \cos^{-1} \left( \frac{(R^2 + S^2 - r^2)}{2RS} \right) \quad (13)$$

$$\beta = \tan^{-1} \left( \frac{R * \sin \alpha}{R * \cos \alpha - s} \right) \quad (14)$$

Where  $h$  is the wear depth, in.;  $r$  is tool joint outer radius, in.; and  $R$  is the casing inner radius, in.



*Figure 3: The groove depth was created by the result of the tool joint with the casing inner wall.*

#### 4 Case Studies

This study was performed for two wells in Southwestern Iran that had not been predicted before. The schematic of the wells is shown in Fig 4. These wells are highly deviated based on build and hold trajectory (J type). Well (A) has been drilled vertically to a depth of 2350 m. Then, the angle was increased to a depth of 3737 m to reach the target. Similarly, well (B) has been drilled vertically to a depth of 2295 m. Afterward, the angle was increased to a depth of 3800 m to reach the target. The specifications of the casing are given in Table 1, and the specifications of the drill string are shown in Table 2. After drilling the reservoir, the internal diameter of the casing was measured using the CAST log. In well (A) from 1443.9 m to a depth of 2799.7 m and well (B) from 1829.5 m to a depth of 2787.7 m per 10 cm.

The mud logging data utilized included WOB, RPM, standpipe pressure, drilling fluid internal and external density, drilling time, and flow rate for each drilling depth. Using the mud logging data in these wells, after calculating the forces, wear volume is calculated per 10 meters of drilling. The novelty of this article is its calculations for any desired area. For the analysis of these two wells for every 10 meters. Because in these 10 meters, the change of the parameters is not much. The method is such that the calculations of forces for the first ten meters are obtained. According to the drilling conditions, the relevant equation is selected, and the volume wear is calculated. This continues until the final depth is reached, and the volume of cumulative wear from the excavation is calculated every 10 meters. Finally, according to the solution of Equation 10, the wear depth is obtained. However, commercial software that has been developed over the

years to calculate and predict wall wear has two significant problems. The first problem is that to drill a significant length of the hole, and the input parameters must be averaged. The second problem is entering parameters one by one, which is a time-consuming task, and this coding method solves these two problems by inputting data from Excel files.

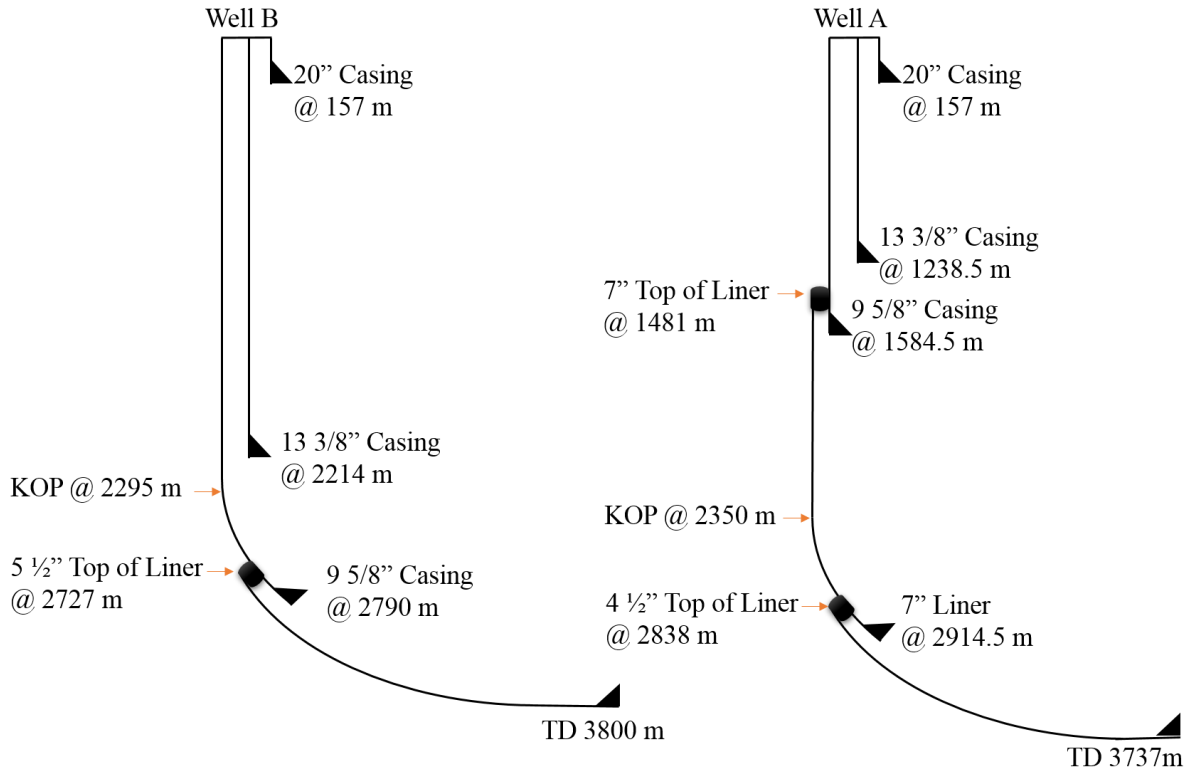


Figure 4: Well Schematic

Table 1: Casing Specifications

Well	Casing	OD (in.)	ID (in.)	Weight (lb/ft)	Grade	Shoe (m)
A	Surface Casing	20"	19.124	94	K-55	157
	Intermediate Casing	13 3/8"	12.415	68	N-80	1239
	Production Casing	9 5/8"	8.681	47	L-80	1584.5
	Liner #1	7"	6.184	29	L-80	2911.5
	Liner #2	4 1/2"	3.92	13.5	L-80	3737
B	Surface Casing	20"	19.124	94	K-55	157
	Intermediate Casing	13 3/8"	12.415	68	N-80	2214
	Production Casing	9 5/8"	8.681	47	L-80	2789.5
	Liner	5 1/2"	4.67	26	T-95	3800



*Table 2 : Drill string Specification*

Well	Type	Length (m)	OD (in.)	ID (in.)	Weight (lb/ft)
A	PDC BIT	0.2	6 1/8	--	--
	HWDP	250.42	3 1/2	3 1/8	47
	Drill pipe #1	1560	3.5	2.764	13.3
	Drill pipe #2	1926.38	4.5	3.5	22.82
B	PDC BIT	0.3	8 1/2	--	--
	HWDP	279.24	5	3 1/8	47
	Drill pipe	3520.46	5	4.276	19.5

MATLAB and Python software has been used for prediction in this paper. These results are compared and demonstrated with CAST log data. The CAST log has a scanner that rotates rapidly during operation to measure parameters such as the inside diameter and thickness of the casing. The purpose of running this log is to check the quality of the cement or the presence of fluid behind the casing. Its inner diameter measurements are used in this paper.

Well (A) has been drilled in sliding drilling and well (B) in rotational drilling. Using the mud logging data in these wells, after calculating the forces, wear volume is calculated per 10 meters of drilling. Ultimately, wear depth is obtained. According to Table 1, well (A) casing 9 5/8 in. with an inner diameter of 8.681 in. and well (B) casing 9 5/8 in. with an inside diameter of 8.681 inches, and liner 7 in. with an inside diameter of 6.184 in. have been considered. The calculations for these two wells are shown in Figs. 5 to 10.

Figs. 5 and 6 are for well (A). The calculation results are shown with the CAST log. Since wireline logging is recorded only for the liner part, to display the results, first for this part appropriately, it appeared in Fig. 5, and then in Fig. 6, these results were demonstrated for liner and casing.

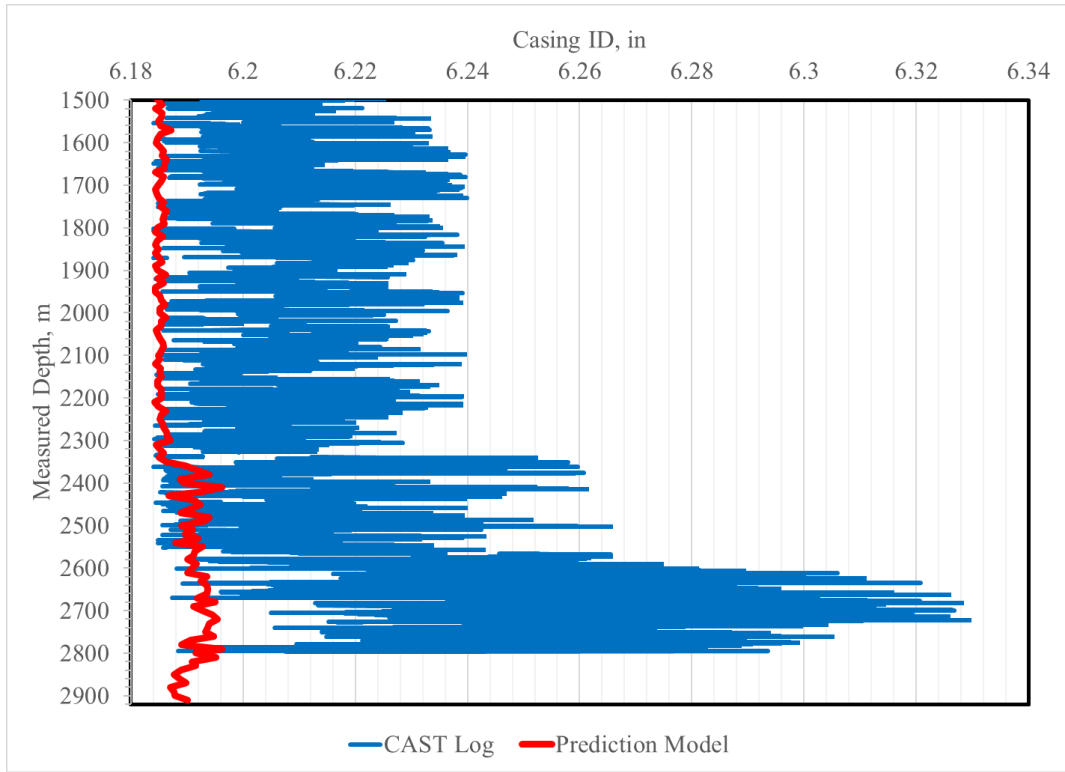


Figure 5: CAST Log and prediction model for liner section in well (A)

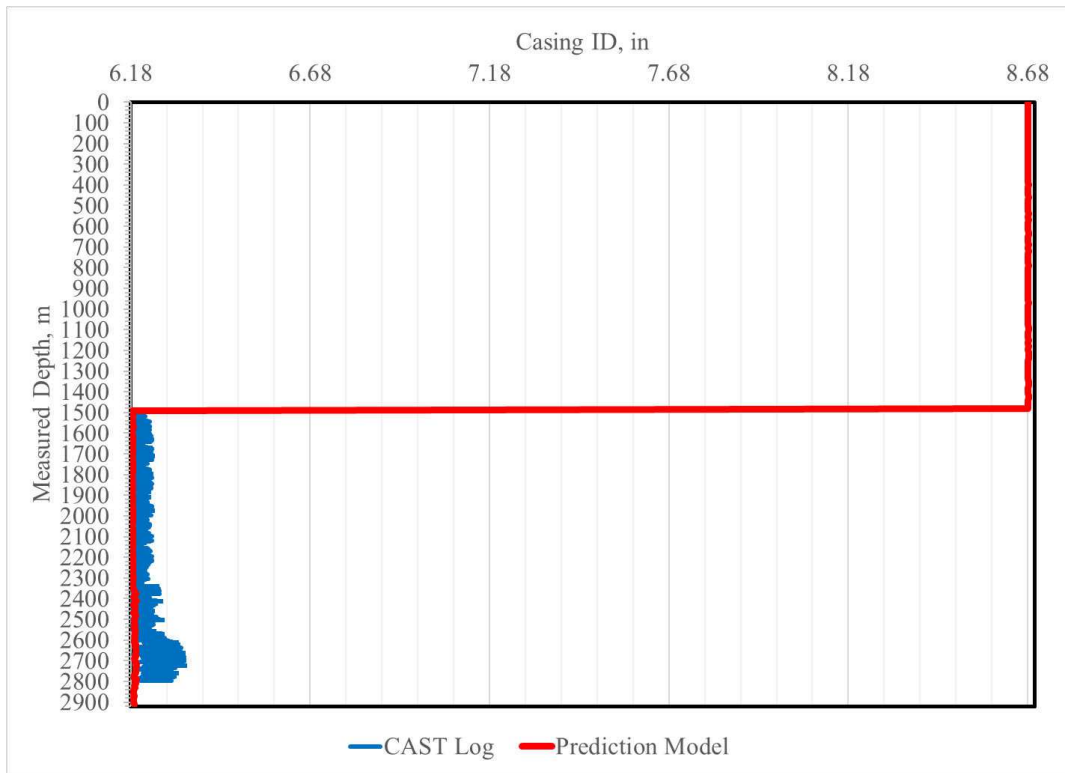


Figure 6: CAST log and prediction model for casing and liner section in well (A)

Figs. 7 and 8 are for the well (B). The results of the calculations are shown with the CAST log. Considering that wireline logging has been done for the part of the casing mentioned before, to show the results for this part, first properly, it was established in Fig. 7, and in Fig. 8, these results were shown for the whole casing.

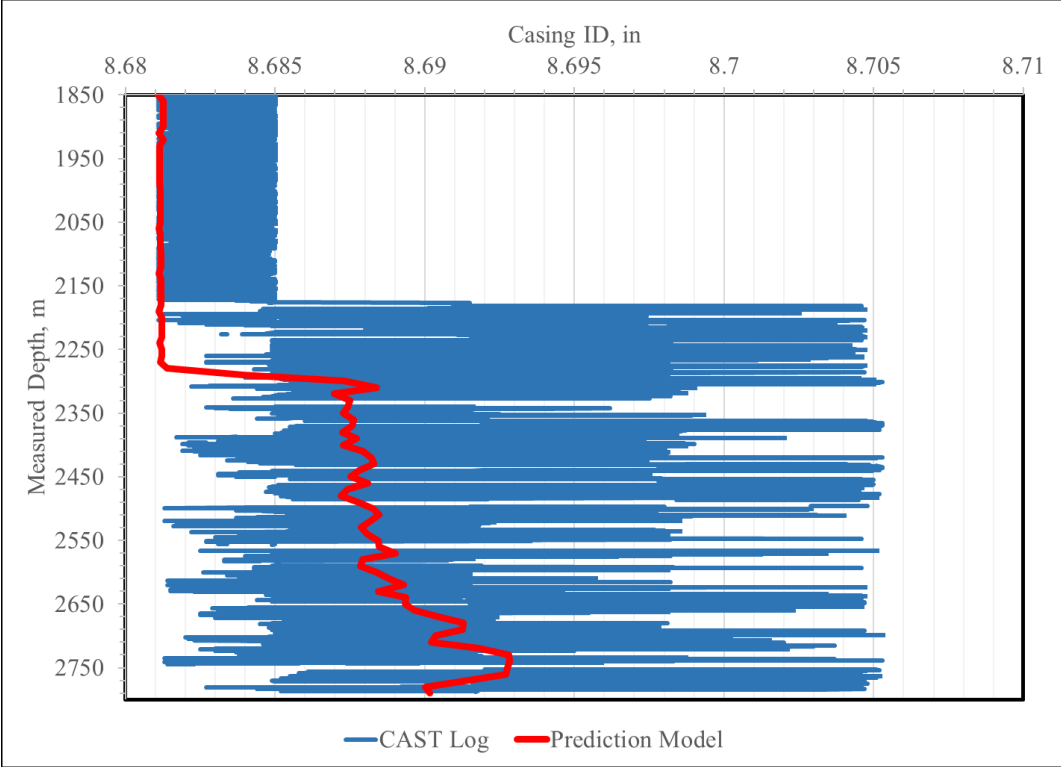
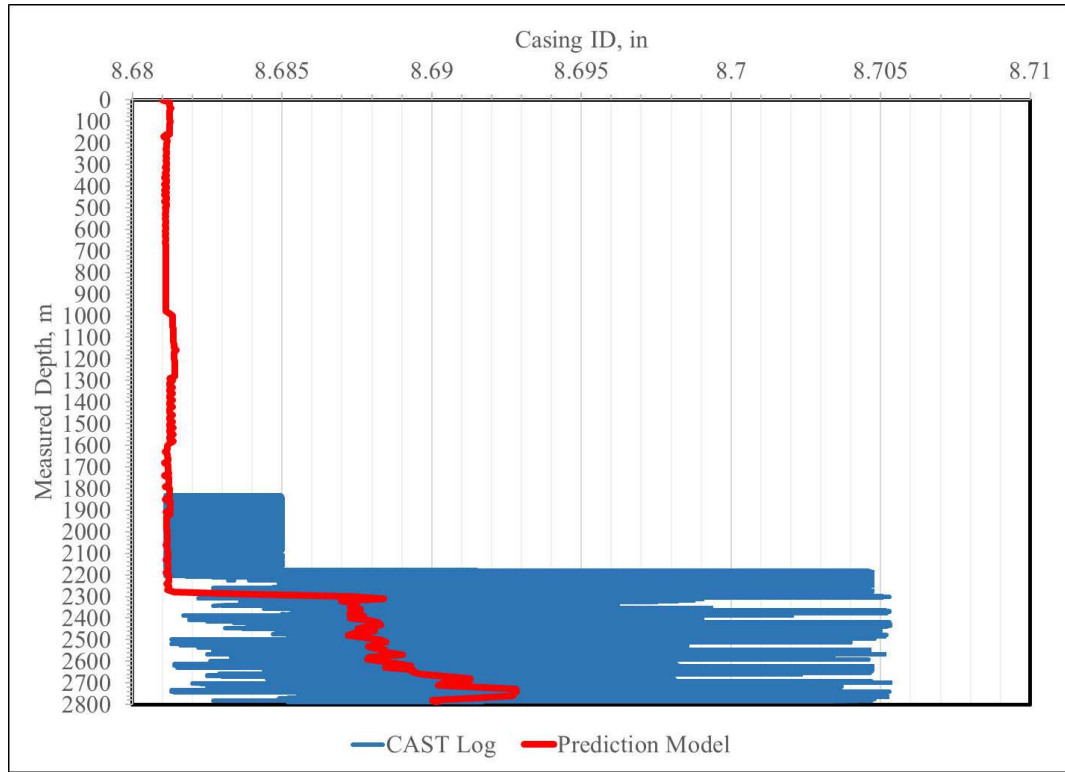
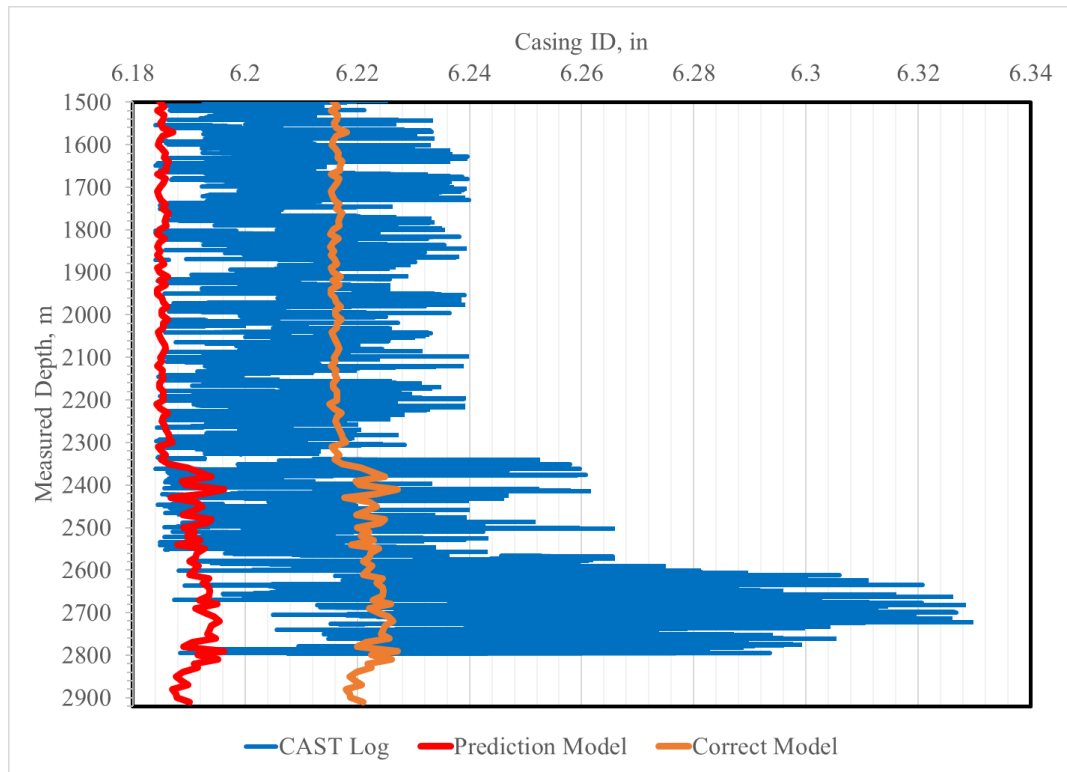


Figure 7: CAST log and prediction model for part of casing section in well B

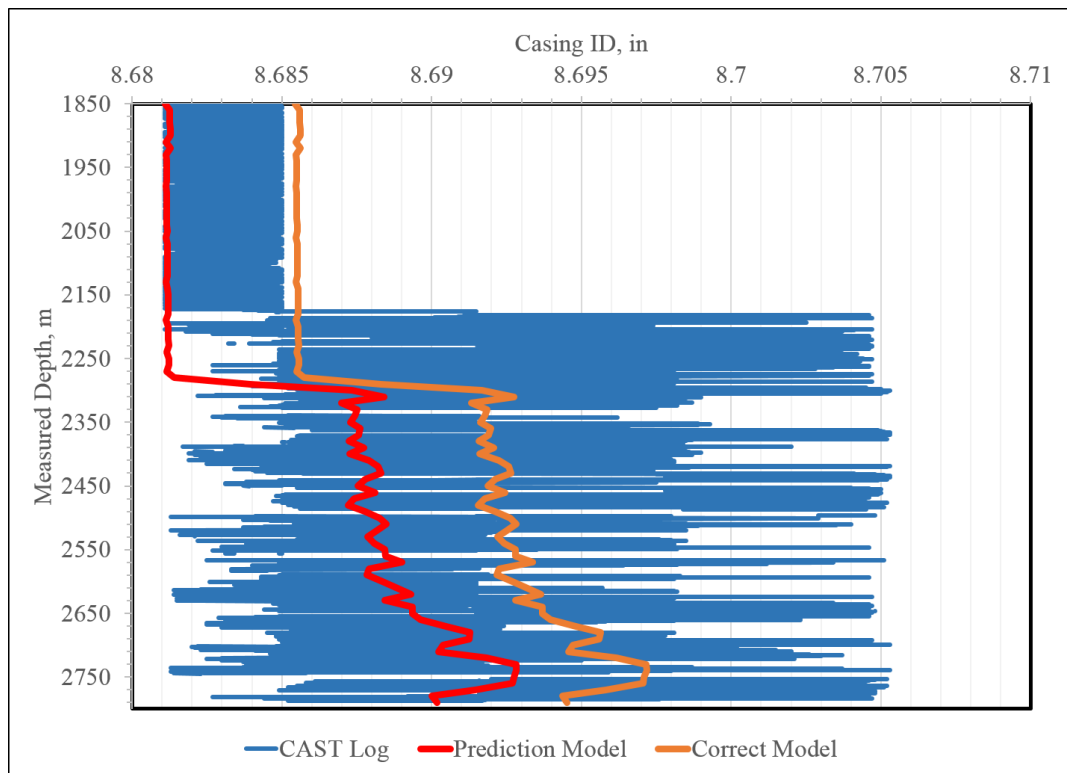


**Figure 8: CAST log and prediction model for the whole of casing section in well B**

This paper only examined drilling wear. To achieve better results, they were multiplied by a safety factor to compensate for this miscalculation, such as tripping wear. These coefficients are 1.0005 for well (A) drilled at sliding mode and 1.005 for well (B) drilled in rotary mode and shown in Figs. 9 and 10, respectively. Due to the chart scale on the x-axis, these differences are very small.



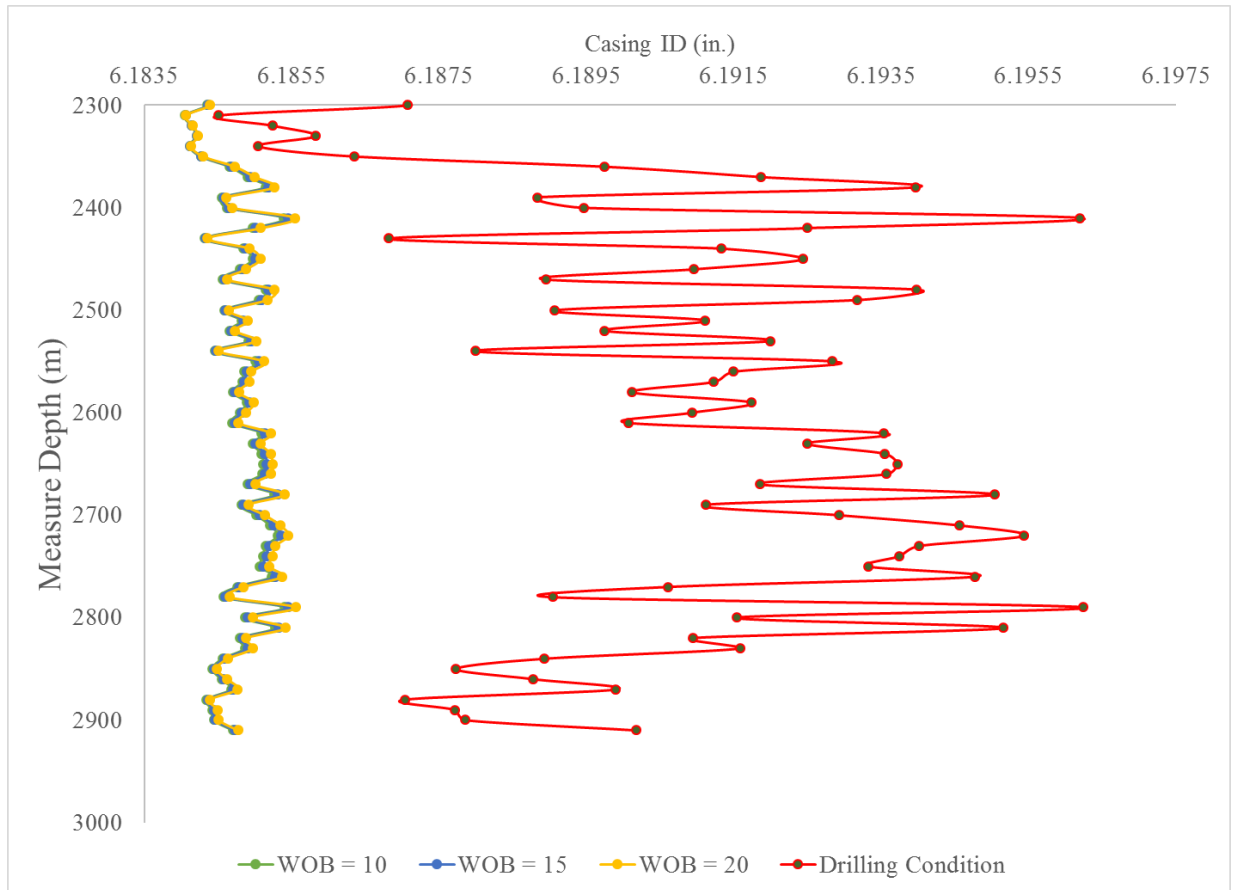
**Figure 9: CAST log, prediction model, and correct model for well A**



**Figure 10: CAST log, prediction model, and correct model for well B**

In this case study, the effect of WOB and RPM parameters is also analyzed, assuming that other parameters remain constant, to find the optimal WOB and RPM with sensitivity analysis. As mentioned, well A is drilled sliding, and well B is rotationally drilled, with equations for calculating their wear. According to the sensitivity analysis performed, the WOB can be Changed in well A, and the WOB and RPM in well B. The results of this analysis are shown in Figures 11 and 12. Because the numbers on the graphs are so close together, the depth was demonstrated in the range where the differences could be seen.

In well A, the same WOB indicates that wear depth is reduced. In well B, the lower the RPM, the lower the amount of wear depth than in reality, and vice versa. The WOB in well A did not have much effect; however, increasing it increased the wear depth, reducing the casing strength. The WOB and RPM in well B give attractive results. According to this analysis, the lower the RPM, the lower the wear depth at maximum WOB. At RPM equal to 20 will have the least wear, and at RPM equal to 40 will have the most wear. The choice of these numbers is according to the drilling conditions. It should also be noted that these parameters should be selected to reduce the drilling rate. These results will be very effective before drilling and for the drilling program so that a well does not tolerate severe wear.



**Figure 11. Sensitivity analysis of casing wear depth in different WOBs for well A**

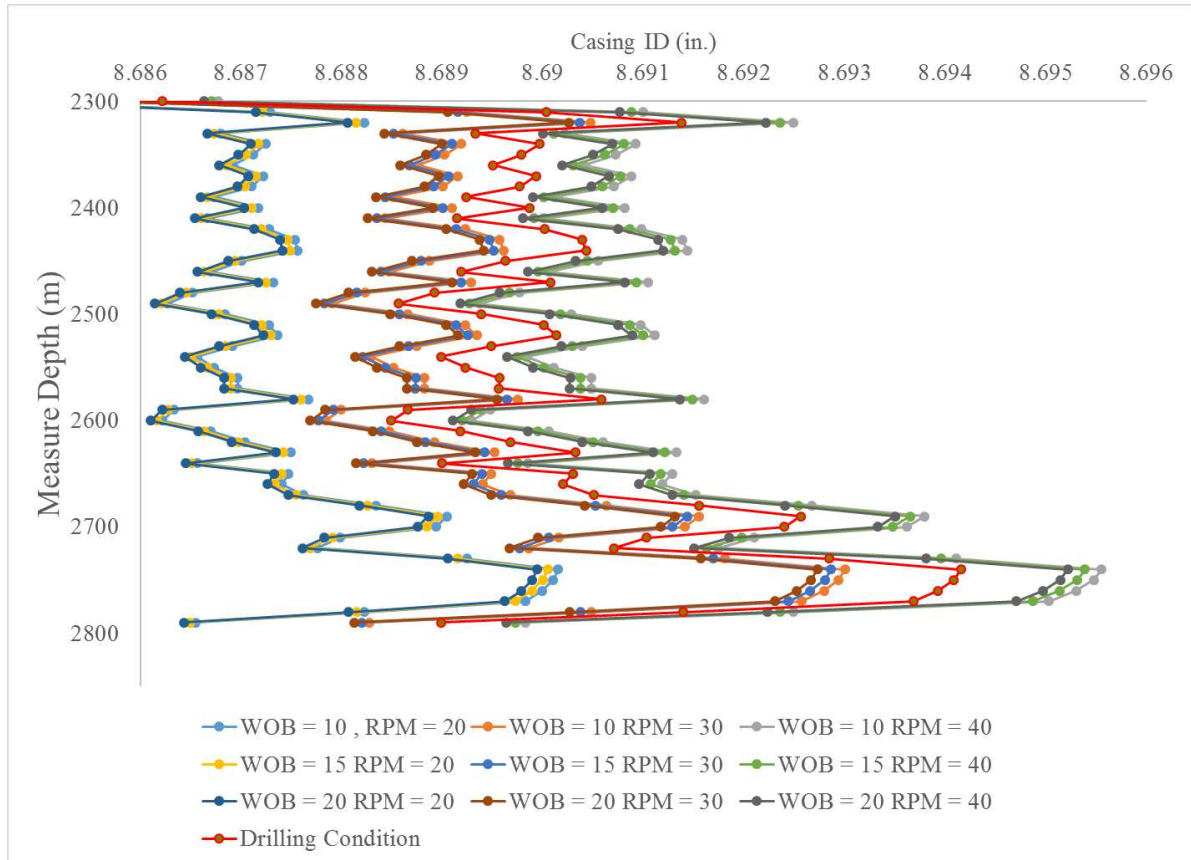


Figure 12. Sensitivity analysis of casing wear depth in different WOB and RPMs for well B

## 5 Conclusions

This paper shows how to calculate forces and wear depth based on mud logging data and developed code. It can be concluded:

1. The difference between the prediction results and wireline logging is 1.005 and 1.0005 on average in wells A and B, respectively.
2. The small difference between the prediction and the wireline logging is not considered wear related to other drilling operations, such as tripping.
3. Points that were apt to severe wear can be identified by the prediction made.
4. It was demonstrated that this phenomenon could be predicted with high accuracy without taking logs and additional costs.
5. In increasing the depth of wear, RPM is a more effective parameter than WOB.
6. In high deviated wells, it is preferable to drill by sliding method to reduce the amount of casing wall wear. If the compulsion to rotate is from the surface, it is recommended to use low rotations.

## Declaration

### Availability of data and materials

Due to the nature of this research, the participants in this study did not agree with sharing their raw data publicly, but how to analyze the data is mentioned in the article. Therefore support data is not available.

### **Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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### **Authors' contributions**

Asgar Eyvazi Farab: Conceptualization, Methodology, Software, Formal analysis, Writing - Original Draft.

Khalil Shahbazi: Conceptualization, Writing - Review & Editing, Supervision, Visualization, Validation.

Abdolnabi Hashemi: Review & Editing, Supervision, Validation.

Alireza Shahbazi: Data Curation.

All authors read and approved the final manuscript.

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### **Nomenclature**

$A_i$	Inside cross-sectional area, in <sup>2</sup>
$A_o$	External cross-sectional area, in <sup>2</sup>
$d_{sld}$	Total sliding distance, ft
$D_{tj}$	tool joint OD, in
$\Delta F_{area}$	Changing in force as a result of a change in the area, lb
$F_{bottom}$	Bottom pressure force, lb
$F_{bs}$	Buckling stability force, lb
$F_D$	Drag force, lb
$F_e$	Effective force, lb
$F_n$	Contact force, lb
$F_{nft}$	Side force per feet of drill pipe, lbf/ft
$F_{ntj}$	Side force per feet of tool joint, lbf/ft
$F_t$	True force, lb
$h$	Wear depth, in
$L$	Element length, ft



$L_p$	Length of drill pipe, ft
$L_{tj}$	Length of tool joint, ft
$MD_{end}$	End depth of operation, ft
$MD_{srt}$	Start depth of operation, ft
$P_i$	Inside pressure, psi
$P_o$	Outside pressure, psi
R	Casing inner radius, in
r	Tool joint outer radius, in
RPM	Rotary speed of drill string, rpm
t	operation time, hrs
$u_o$	External fluid velocity, ft/s
$u_i$	Inside fluid velocity, ft/s
W	Element weight per feet, lb/ft
$W_f$	Casing wear factor, 1/psi
WOB	Weight on bit, lb
WV	Wear volume, in <sup>3</sup> /ft

### Greek symbols

$\theta$	Inclination, degree
$\bar{\theta}$	Average inclination angle between two stations, degrees
$\rho_i$	Inside fluid mass density, ppg
$\rho_o$	External fluid mass density, ppg
$\Delta\alpha$	Increasing the azimuth angle between two stations, degrees
$\Delta\theta$	Increasing in the inclination angle between two stations, degrees

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