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Parametric Study of the Influence of Casing Wear on Well Foundation Design

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Abstract. During oil well drilling operations, the drill string may come into contact with the inner wall of the casing, generating lateral forces which, combined with the string's rotation, lead to wear. Excessive casing wear reduces mechanical strength and may compromise the structural integrity of the well. The objective of this work is to conduct a parametric analysis of casing wear variations in order to assess their impact on the results of oil well foundation design. The proposed methodology assumes continuous and varied casing wear along the length of the string, leading to a reduction in internal diameter. Mechanical resistance, load capacity, and safety factors are evaluated and compared for worn and unworn scenarios across various foundation types, including perforated and cemented, jetted, torpedo based, and driven casings. Different levels of casing wear were simulated, ranging from 0% to 30% of the original wall thickness, in order to evaluate the system's behavior. A finite element software was employed to model the geometric changes and assess their effects on well integrity. The results of the parametric analysis indicate that casing wear has the greatest impact when it occurs in the surface casing, with a reduced influence observed in subsequent casing strings. These results highlight the need to account for casing wear already in the design phase, especially for wells with a higher likelihood of contact between the drill string and the casing, such as those with deviated or horizontal trajectories. The application of numerical models based on finite element analysis proved effective in predicting these variations and their impacts on the outcomes.

Keywords: Finite element analysis, Parametric analysis, Foundation design, Casing wear.

1 Introduction

Over time, oil has established itself as one of the most significant and widely used energy sources in the world. According to [1], advancements in the petrochemical industry have enabled the production of many essential goods from this raw material. As noted by [2], oil field development is a multidisciplinary process involving several stages, from reserve discovery to hydrocarbon production. [3] recommends that casing design for oil wells account for both anticipated and permissible wear, along with continuous monitoring of potential steel loss during drilling operations.

One of the earliest studies on wear mechanisms in oil well casings was conducted by Bradley and Fontenot [4], who addressed the effects of rotation, displacement, and inspection practices. [5] used experimental methods and proposed the use of contact pressure instead of contact force to estimate wear, as it showed a stronger correlation with the wear growth rate.

[6] carried out over 300 laboratory wear tests and developed a mathematical model that describes casing wear as a function of well geometry, casing material, mud composition, and the drilling program, incorporating the concept of a wear factor. [7] introduced a linear model for estimating wear rate, assuming that the removed volume is directly proportional to the energy dissipated by friction.

Subsequently, [8] expanded upon earlier studies by introducing the concept of limiting contact pressure, leading to a nonlinear evolution of the wear factor over time. Recent studies, such as [9], propose predictive models that quantify wear depth and area based on operational and geometrical parameters, emphasizing that tool joint diameter and the dynamic accumulation of frictional energy significantly affect casing wear severity.

2 Methodology

A jetted well with a 900-meter-long surface casing is considered, with the first 600 meters cemented. The well foundation design comprises five stages, corresponding to the following casing strings: conductor pipe, surface casing, two intermediate casings, and production casing. In this study, two distinct methodologies are considered: (i) a diameter-reduction-based approach, and (ii) the methodology proposed by [7], which more realistically represents the geometry of the worn section. Moreover, the application of methodology (ii) enables the calculation of bending moments induced by eccentricity. Fig. 1 illustrates the parameters required for determining the geometric properties used in methodology (ii).

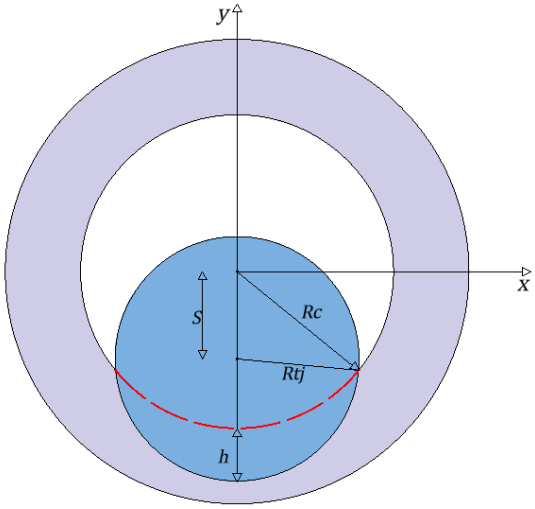


Figure 1. Geometry of wear caused by the rotation of tool joints.

This model enables the representation of the worn area along the tube, as described in Eq. 1 and 2. The wear width w_i can be determined based on geometric considerations, as shown in Eq. 3.

$$A_{wear} = 2\int_0^{w_i}\left(S + \sqrt{R_{tj}^2 - y^2} - \sqrt{r_c^2 - y^2}\right)dy \tag{1}$$

$$I_{yy_{wear}} = \frac{2}{3}\int_0^{w_i}\left(S + \sqrt{R_{tj}^2 - y^2} - \sqrt{r_c^2 - y^2}\right)^3 dy \tag{2}$$

$$w_i = \sqrt{r_c^2 - \frac{(r_c^2 + S^2 - R_{tj}^2)^2}{4.S^2}} \tag{3}$$

To validate the exclusive consideration of wear in the surface casing, an analysis was performed using methodology (i), comparing: (a) variation only in the surface casing, and (b) variation also in subsequent casings from Phase Two onward. Wellhead displacement and triaxial stress are determined using finite element software. Following [11], the analysis adopts the von Mises criterion in combination with Lamé's equations as the strength model. Triaxial stress is evaluated at the top of the cemented section.

For this study, wear variations ranging from 0% to 30% are considered for both methodologies. It is expected that methodology (i) will result in significantly greater variation compared to methodology (ii). Each project phase comprises one or more operations, with the corresponding load cases defined for each, as specified in Guideline [10].

3 Results

The information presented follows methodology (i), aiming to visualize the influence of result variations caused by considering casing wear beyond the surface casing. Fig. 2 shows the wellhead displacement values for cases (a) and (b), assuming 30% wear.

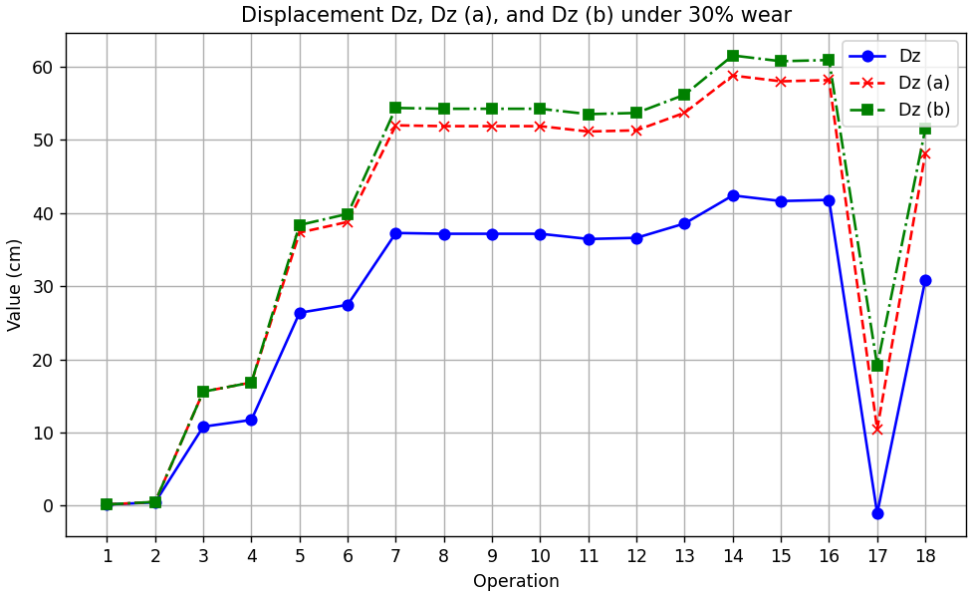


Figure 2. Displacement values obtained using methodologies (i), (ii) and wear effects neglected.

It is observed that the consideration of wear according to method (a) results in only a slight variation when compared to method (b). Fig. 3 presents the displacement values for the proposed design, considering wear variations ranging from 0% to 30%, thereby providing the designer with the corresponding results for all operational stages.

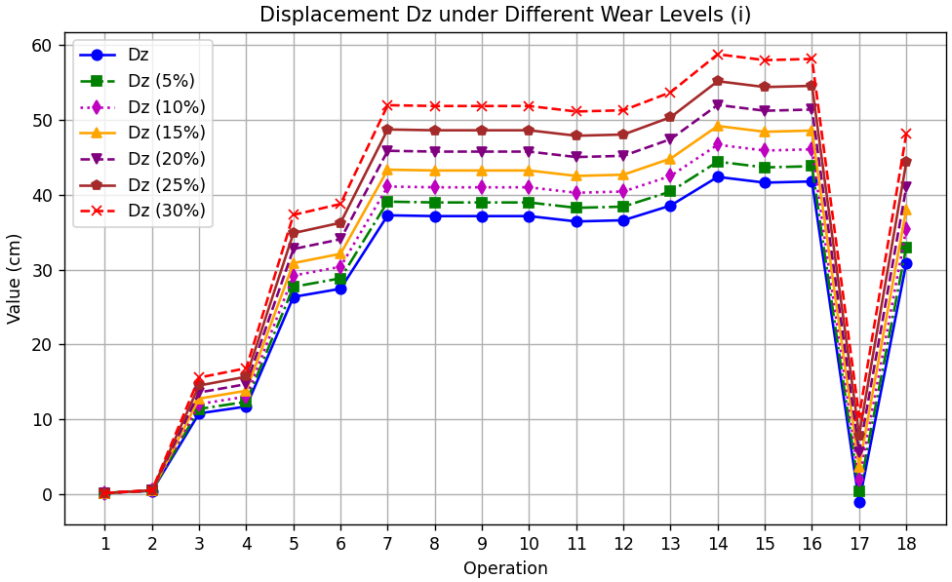


Figure 3. Displacement values obtained using methodologies (i)

The parametric study of von Mises stress exhibited behavior consistent with that of displacement. When applying methodology (ii) in the design, it is observed that the stress values exhibit less variation compared to

methodology (i), since wear is restricted to the contact region with the tool joint. It is important to emphasize that the results obtained using methodology (ii) do not account for the bending moment generated by eccentricity in the von Mises stress calculation.

For this analysis, a tool joint radius of 6 inches (in) was adopted. Bending moment values were determined as a function of 30% wear variation, with eccentricity maintained constant throughout all operations, at a magnitude of −0.188 inches (in). It was observed that design values obtained using methodology (i) are higher than those from methodology (ii), as expected due to the simplified modeling assumptions of the latter. A low bending moment was observed; however, the proposed methodology represents an initial effort to visualize the consequences arising from this bending moment.

4 Conclusions

Parametric analysis serves as a valuable tool to support casing system design, providing preliminary estimates of design parameters during the conceptual phase. The results presented herein pertain specifically to the analyzed case and are not intended to be generalized to other casing scenarios. It was observed that in the parametric analysis, the increase in wear did not result in a linear variation of the results.

For the design analyzed, it was observed that, for certain wear levels, commonly adopted design limits such as a maximum displacement of 50 cm and elevated triaxial stress values were exceeded when using methodology (i). In contrast, methodology (ii) exhibited smaller variations in these parameters. However, the occurrence of a bending moment was identified, which requires correction but was not considered in this stage of the study.

The present work focuses on wear analysis in well casings while also providing results relevant to petroleum well foundation design, thus offering a necessary basis for its development. Additionally, other factors such as eccentricity are addressed. The results indicate that the evaluated design exceeds established limits at certain wear levels, for example, displacements greater than 50 cm, leaving the consideration of these observations to the discretion of the responsible designer.

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Authorship statement. The authors hereby confirm that they are the sole liable persons responsible for the authorship of this work, and that all material that has been herein included.

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