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Extended Abstract

Numerical Modeling of Salt Formation Creep Effects on the Mechanical Behavior of Casing Strings: A Case Study from a Southern Iran Oil Field

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Abstract

Maintaining well structural integrity throughout the field lifecycle is a fundamental prerequisite for sustainable oil and gas production. Among the various challenges, casing collapse in creep-prone formations particularly salt-bearing intervals represents one of the most critical operational concerns. This study investigates the influence of salt formation creep on the mechanical behavior of casing strings in the Lower Fars Formation of the Persian Gulf. To realistically simulate geomechanical conditions, a one-dimensional (1D) mechanical earth model was first developed using real-field data from a well in one of the Persian Gulf fields; its outputs were subsequently employed as primary inputs for three-dimensional (3D) numerical modeling in ANSYS software. Results demonstrate that salt creep progressively induces an increase in circumferential (hoop) stresses, reduces the annular space between the casing and the formation, and promotes the accumulation of casing deformation over time ultimately compromising wellbore structural stability. Furthermore, critical casing zones, especially those in direct contact with salt layers, were precisely identified through stress and deformation contour analyses. The findings of this research can serve as an efficient tool for collapse risk prediction, optimized casing design, and implementation of preventive measures in oil wells traversing salt-bearing formations.

1. Introduction

Casing collapse in oïl and gas wells is predominantly attributed to the creep behavior of salt formations, which, under long-term in-situ stresses, undergo continuous deformation and progressively exert increasing lateral pressure on the casing [1, 2]. Although prior studies on the mechanical behavior of casing strings and cement sheaths under diverse downhole conditions involving in-situ stresses, internal and external pressures, formation creep, and thermal effects have established a robust scientific foundation, most have treated creep phenomena either statically or through simplified constitutive models. Indeed, few investigations have addressed the time-dependent creep response of the Lower Fars Formation and its influence on the dynamic stress distribution within the casing ; moreover, many existing models lack calibration against field-measured well data. To address this research gap, the present study proposes a two-stage modeling framework. First, a one-dimensional (1D) mechanical earth model was developed using real-field data from a well in the Persian Gulf. Subsequently, the outputs of this model were integrated as inputs into a three-dimensional (3D) finite element model in ANSYS to simulate the isolated effect of salt creep on casing collapse. This approach, while deliberately excluding corrosion-related complexities, enables precise identification of critical zones and reliable

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prediction of the long-term mechanical behavior of casing strings.

2. Methodology

To develop a reliable three-dimensional (3D) numerical model in ANSYS, accurate geomechanical inputs are required, including Young's modulus, Poisson's ratio, uniaxial compressive strength (UCS), cohesion, internal friction angle, pore pressure, and in-situ stresses. However, direct measurement of these parameters through laboratory testing or well logging is often challenging due to high costs and operational complexities. To overcome this limitation, a one-dimensional (1D) mechanical earth model was developed to estimate petrophysical and geomechanical properties, serving as the primary input for the subsequent 3D simulation in ANSYS.

Using compressional and shear wave transit time logs alongside bulk density data, compressional and shear wave velocities were extracted, and Poisson's ratio was derived. Uniaxial compressive strength, static Young's modulus, internal friction angle, cohesion, and tensile strength of the formation were calculated using the empirical correlations proposed by Amiri et al. (2019) [3]. Pore pressure was estimated via the modified Eaton method and validated against Repeat Formation Tester (RFT) data. Furthermore, the in-situ stress field was computed based on poroelasticity theory and calibrated using Leak-Off Test (LOT) results.

The outputs of the 1D mechanical earth model including boundary conditions and formation mechanical properties were transferred to the 3D model to realistically simulate the time-dependent influence of salt formation creep on casing behavior. In this study, a depth of 1,120 m, corresponding to the salt-bearing interval, was selected as the reference depth for numerical modeling due to its pronounced creep activity and mechanical sensitivity.

The 3D finite element model in ANSYS was developed through four sequential stages: (1) geometric construction, (2) element type selection and mesh generation, (3) assignment of mechanical properties, and (4) application of boundary and loading conditions derived from the 1D mechanical earth model. The final local model domain was defined with dimensions of 5 × 1 × 4 m at the target depth of 1,120 meter a scale that ensures sufficient accuracy in stress and creep analysis while significantly enhancing computational efficiency.

3. Results and Conclusions

The influence of von Mises equivalent stress and casing deformation was evaluated through both two-dimensional contour plots and quantitative time-series graphs at intervals of years 1, 5, 10, and 14. Numerical simulation results indicate that during the initial analysis stage, the highest concentration of von Mises stress occurs in the lower section of the casing string, adjacent to the wellbore bottom. As time progresses and salt formation creep advances, high-stress zones gradually expand and migrate upward from the lower to the upper casing regions. This trend reflects a progressive increase in the effective load imposed on the casing due to time-dependent stress redistribution within the surrounding formation. The expansion of the stress concentration zone—which appears as increasingly extensive red-colored regions in later-year contours—provides an early-warning indicator of potential long-term mechanical degradation, even in the absence of corrosion or chemical factors. This finding underscores the critical importance of incorporating salt formation creep behavior into the long-term design of casing systems.

Time-series analysis of von Mises stress in the lower casing region reveals that, under salt creep influence, stress increases nonlinearly and time-dependently: exhibiting a steep initial slope during the first few years, followed by a gradual reduction in slope in subsequent years. This pattern reflects delayed load transfer and progressive formation deformation, leading to stress accumulation in the sensitive lower zone and eventual approach toward a dynamic equilibrium between formation creep rate and casing structural resistance. The risk of plastic yielding or onset of collapse was assessed by comparing computed von Mises stress values against the yield strength of N-80 grade steel casing (~552 MPa).

Contour analysis of casing deformation indicates that maximum displacement occurs in the upper casing section near the wellhead, whereas the lower section adjacent to the wellbore bottom experiences minimal deformation. This pattern reflects greater kinematic freedom in the upper region, allowing this section to deform more readily under initial creep loading, with displacement concentrating preferentially in this zone. In contrast, the lower section, constrained by geometric boundary conditions and connection to the wellbore bottom, exhibits higher resistance to displacement. This contrasting behavior clearly elucidates the localized and spatially heterogeneous influence of salt creep on the mechanical response of the casing string. Over time, accumulation of such displacements may lead to permanent deformation and eventual reduction in the casing's load-bearing capacity. Quantitative displacement graphs show that maximum displacement increases progressively and reaches approximately 12 cm by year 14. This trend reflects gradual salt formation deformation and progressive load transfer to upper regions, predicting continuous development of critical zones and displacement concentration in sensitive casing sections potentially leading to localized collapse or asymmetric deformation in later stages.

Analysis of creep strain distribution within the salt formation reveals a strong dependence on radial distance from the wellbore: creep strain is negligible in regions far from the well, whereas it increases exponentially in the immediate vicinity of the wellbore wall. This pronounced gradient indicates concentration of time-dependent plastic deformation within the borehole-affected zone. This pattern arises from the non-uniform distribution of geomechanical stresses around the wellbore, where stress gradients are amplified near the wall due to perturbation of the initial in-situ stress field. Consequently, the salt formation adjacent to the wellbore exhibits significantly higher sensitivity to time-dependent loading and enters the creep regime earlier than distal regions.

4. References

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