Numerical Modelling of Conductor Casing Settlement Using a Two-phase Model

Jamerson B. Omena[1], Mávyla S. C. Tenório[2], Jennifer M. F. Melo[2], Beatriz R. Barboza[2], Jose L. G. Marinho[1], João P. L. Santos[2], Rafael Dias[3], Fábio Sawada[3]

[1]*Center of Technology, Federal University of Alagoas*
Av. Lourival Melo Mota, 57072-970, Alagoas/Maceió, Brazil
jamerson.omena@ctec.ufal.br, jlmarinho@ctec.ufal.br
[2]*Laboratory of Scientific Computing and Visualization, Federal University of Alagoas*
Av. Lourival Melo Mota, 57072-970, Alagoas/Maceió, Brazil
mavyla.tenorio@lccv.ufal.br, jennifer.ferreira@lccv.ufal.br, beatriz@lccv.ufal.br, jpls@lccv.ufal.br
[3]*Petrobras Av. Horácio Macedo, 21941-915, Rio de Janeiro/Rio de Janeiro, Brazil*
fabiosawada@petrobras.com.br, rafael_dias@petrobras.com.br

Abstract. Oil exploration in subsea wells involves several technical challenges, including conductor casing installation, which is crucial for the well's structural stability. The jetting method is promising for clay soils as seabed sediments behave like fine mud. This study aims to numerically analyze conductor settlement by jetting. An eulerian-eulerian two-phase model was adopted, with the soil phase modeled as a non-Newtonian fluid. Computational fluid dynamics (CFD) was used to address large deformation issues inherent in other numerical methods. Ansys Fluent software, based on the Finite Volume Method (FVM), provided robustness and precision for fluid dynamic simulations. The Herschel-Bulkley model characterized the soil, relating strain and stress in a non-linear manner. Results indicated that seabed excavation via jetting is significantly influenced by jet speed, showing an almost linear relationship between jet speed and excavation depth. Additionally, the consistency index (K) of the soil was found to be crucial, with lower K values leading to deeper and wider cavities.

Keywords: Jetting excavation; computational fluid dynamics; clayey soil

1 Introduction

In recent years, the need to increase oil exploration has become evident due to the growing demand for oil and oil products. In Brazil, total oil production in 2022, including pre-salt, post-salt and onshore areas, reached an average of 3.02 million barrels per day, surpassing the record of 2.95 million barrels per day seen in 2020. Notably, production in the pre-salt has increased annually, reaching 2.3 million barrels per day in 2022, representing 76.3% of the total. Projections for 2030 indicate that total production will be 5.3 million barrels per day, with 81% of this volume coming from the pre-salt, or 4.3 million barrels per day. Natural gas production in 2022 was also a record, with an average of 138 million m³ per day, 3% more than the volume of 134 million m³ per day in 2021 [1].

The exploration of areas with increasingly greater water depths has demanded the improvement of well drilling techniques. Two main methods for initiating offshore wells are jetting and driving. In turn, jetting is highly efficient for installing conductor casing in deep-water sediments, which are typically poorly consolidated and have low diagenesis. This method avoids failures due to the fragility of the surface geological formations. For this reason, jetting is widely used as the predominant drilling technique [2], [3]. Figure 1 shows an overview of the installation of the conductor casing by jetting. The conductor casing penetrates the ground using a drill bit that jets fluids to remove sediment.

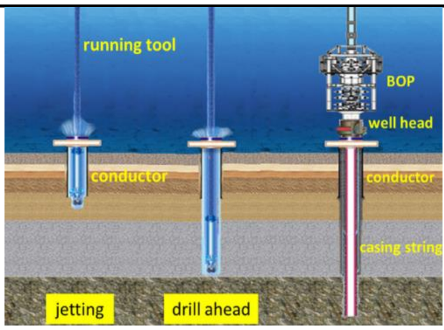

Figure 1: The process of conductor installation by jetting [4]

The submarine soil is a deformable material exhibiting properties between those of a linear elastic solid and a viscous liquid, and its behavior is described by the general theory of rheology. It has been observed that soil flow only begins when the stress surpasses the yield stress. Once this threshold is exceeded, the soil flows similarly to viscous fluids, with the flow rate proportional to the amount of stress above the yield stress. Conversely, when the shear stress applied is below the yield stress, the viscoplastic fluid behaves like a solid [5]. The soil model in question adheres to the Herschel-Bulkley viscoplastic framework [6], as outlined by Equation 1.

$$\tau = \tau_0 + k(\dot{\gamma})^n, \tag{1}$$

where τ is the shear strength, τ_0 is the yield stress, k is the consistency factor, $\dot{\gamma}$ is the strain rate and n is the power-law index.

Thus, this study aims to understand the behavior of the soil under specific conditions, using the Herschel-Bulkley viscoplastic model mentioned above to characterize the rheological behavior of the clayey marine soil when subjected to the shear forces exerted by the impinging drilling fluid jet.

2 Methodology

In this study, the Ansys Fluent software, version 19.2 [7], was used to conduct the simulations, taking advantage of its robustness in computational fluid dynamics (CFD). Fluent uses the Finite Volume Method (FVM), known for its precision in discretizing and solving the flow equations.

A domain was assumed to be 20 meters wide by 23 meters high, with 15,5 meters being the height of the domain from the ground. The conductor is 36" in diameter and 1.5" thick, the drill string is 5" in diameter and the drill bit is 17" 1.2 in diameter and 15 cm high [2]. The value of the stick-out bit, which is the distance between the drill bit and the bottom of the conductor, is - 40 cm, as shown in Fig. 2.

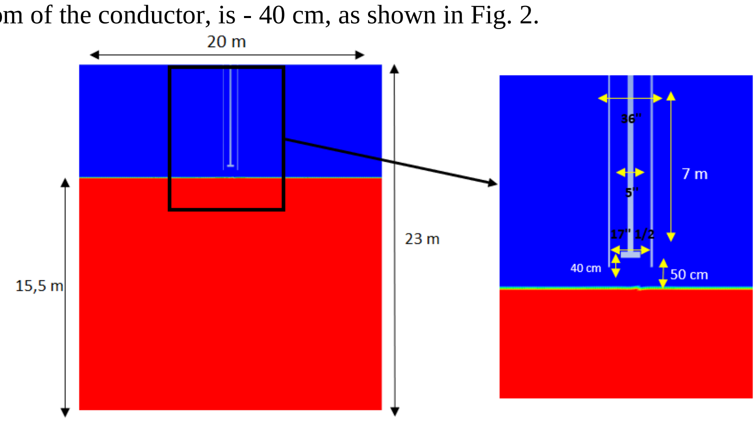

Figure 2. Domain of the jetting numerical model

This work modeled the soil as a Herschel-Bulkley fluid, using the equation for numerical simulations, as described in eq. (1). Table 1 details the parameters of the equation, such as the specific mass [8], yield stress [9], Power-law index [10], Consistency index [5] and critical shear rate [11], as well as the physical properties of seawater under the specific conditions.

Table 1. Rheological parameters of the fluids

	Soil	Seawater
Specific mass (kg/m³)	2300.0	998.3
Viscosity (Pa.s)	-	0.001
Yielding viscosity (Pa.s)	-	-
Yield stress (Pa)	40000.0	-
Power-law index (n)	0.23	-
Consistency index (Pa.s)	216960.0	-
Critical shear rate (1/s)	5.11	-

The drag model adopted was that of Schiller and Naumann because it is the standard method and is widely acceptable for general application in all fluid-fluid phase pairs [6]. It was assumed that the jet velocity at the drilling nozzles is uniform and that the reference pressure at the fluid outlet at the top of the domain is zero. We consider a no-slip wall condition.

3 Results and discussion

In this study, we analyze two parameters - the velocity, which is inherent to the jet, and the consistency index of the seabed model, which is inherent to the soil. The profile of the cavity excavated from an incident vertical jet, using seawater as the drilling fluid, on the seabed model with VoF = 0.50 is shown - as the aim is to evaluate the depths obtained after the excavation process. The deformation in the soil caused by the jet was quantified in terms of depth at speeds of 10 m/s, 12 m/s, 14 m/s, and 16 m/s for 5 seconds.

The depth observed was around 33 cm, 49 cm, 64 cm and 75 cm which is equivalent to approximately 2.13%, 3.16% and 4.84% respectively for the 15.5 m depth of the soil region. Figure 3 shown in the paper clearly illustrates the profile of the excavated cavity for each of the speeds tested.

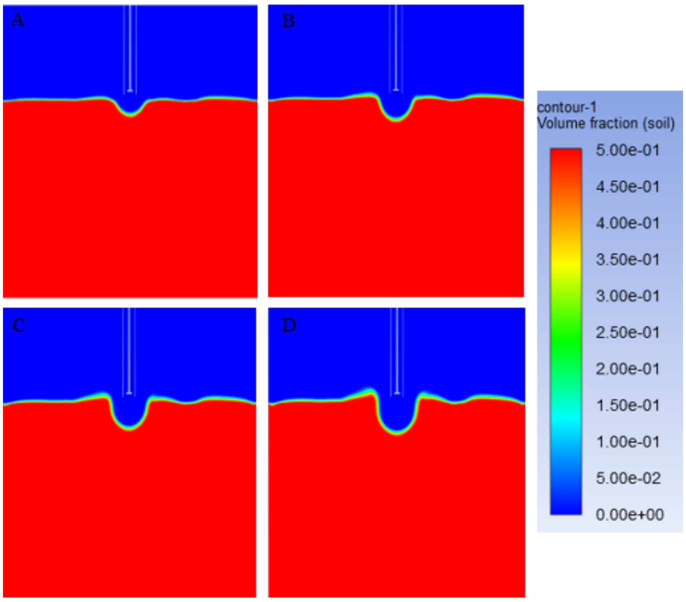

Figure 3: Profile of the excavated cavity at v = 10 m/s (A), v = 12 m/s (B) 14 m/s (C) and 16 m/s (D) after 5 seconds

These measurements indicate that the excavated cavity increases almost linearly with the jet velocity, as shown in Fig. 4, highlighting the importance of controlling the jet velocity to avoid excessive erosion of the seabed.

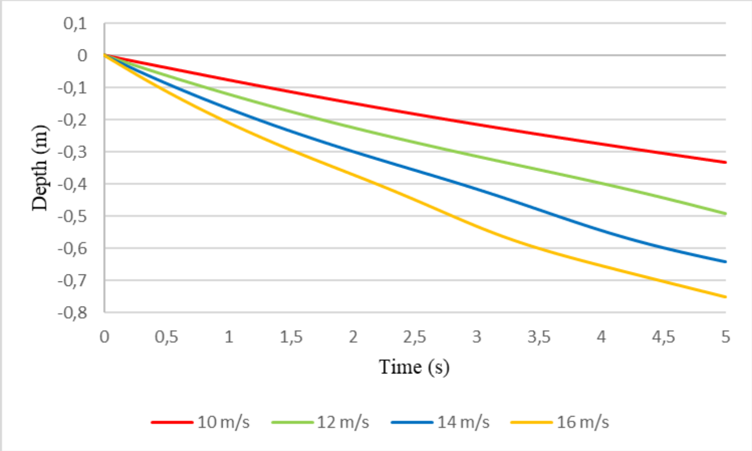

Figure 4: Depths reached for different values of speed

In addition, the effect of the consistency index (K) was evaluated based on Wang's work, for values of 10848.0 Pa.s, 108480.0 Pa.s and 216960.0 Pa.s. It was observed that the cavity profile increases as the K value decreases, due to the decrease in the soil's cohesive force. This relationship suggests that soils with a lower consistency index are more susceptible to erosion when subjected to drilling jets, resulting in deeper and more extensive cavities. Figure 5 illustrates the profile of the excavated cavity for the 10 m/s speed and K values tested.

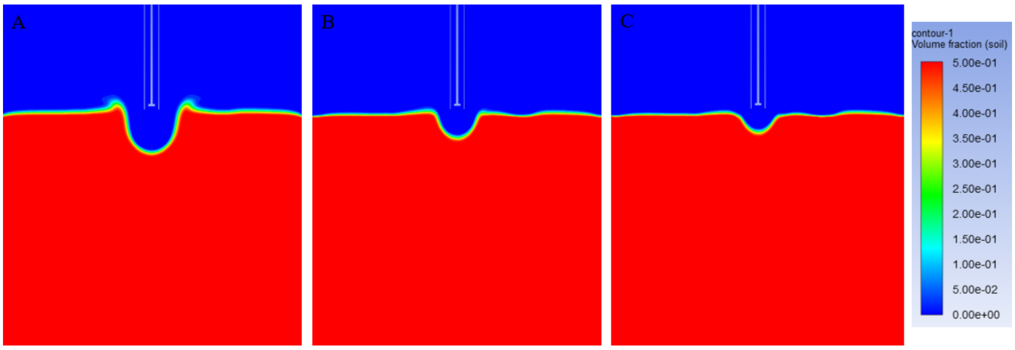

Figure 5: Profile of the excavated cavity at v = 10 m/s with consistency index = 10848.0 Pa.s (A), 108480.0 Pa.s (B) and 216960.0 Pa.s (C) after 5 seconds.

Figure 6 shows the depths reached, which were 32 cm, 45 cm and 78 cm, equivalent to approximately 2.13%, 2.90% and 5.03% respectively for the 15.5 m depth of the soil region.

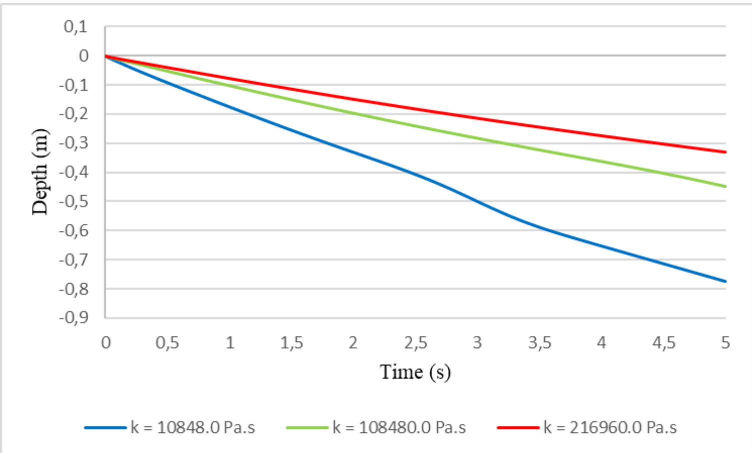

Figure 6: Depths reached for different values of consistency index

4 Conclusions

The finite volume method was used in the numerical model to analyze the excavation of the seabed using drilling jets, simulating the jetting process. The results of the simulations showed that the deformation of the soil caused by the jet was considerably affected by both the speed of the jet and the consistency index (K) of the soil. The depths reached indicated that the increase in jet velocity led to the formation of deeper cavities, suggesting an almost linear relationship between velocity and excavation depth. This implies that controlling jet velocity is essential for managing the extent of seabed erosion during drilling operations. Furthermore, analysis of the different consistency indices (K) revealed that soils with lower K are more prone to erosion, resulting in deeper and wider cavities. This observation underlines the importance of considering soil properties together with the speeds applied when planning jetting operations. This type of study is relevant to the industry due to the possible improvements in the jetting process, which can reduce well drilling time and, consequently, reduce operating costs.

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 as part of the present paper is either the property (and authorship) of the authors, or has the permission of the owners to be included here.

References

[1] J. M. Morais, Petróleo em águas profundas: uma história da evolução tecnológica da Petrobras na exploração e produção no mar, 2023.
[2] C. Kan, J. Yang, X. Yu, R. Xie, Y. Wu, Y. Li, H. Chen, S. Guan, H. Liu, C. Gu, S. Lin, H. Wang, and F. Abimbola, "Investigação experimental de campo do stick-out da broca para diferentes resistências do solo durante a injeção de condutor em águas profundas," Jornal de Ciência e Engenharia de Petróleo, vol. 825, no. 836, pp. 825–836, 2018.
[3] T. J. Akers, "Jateamento de revestimento estrutural em ambientes de águas profundas: Projeto de trabalho e práticas operacionais," In: Conferência e Exposição Técnica Anual da SPE, San Antonio: Sociedade de Engenheiros de Petróleo, pp. 24-27, 2006.
[4] B. Zhou, et al., "Model and experimental study on jetting flow rate for installing surface conductor in deep-water," Applied Ocean Research, vol. 60, pp. 155-163, 2016.
[5] T. Wang and H. Li, Numerical Simulation of Jet Excavation in Conductor Jetting Operations, China University of Petroleum, 2014.
[6] A. Saasen and J. D. Ytrehus, "Viscosity models for drilling fluids—Herschel-bulkley parameters and their use," Energies, vol. 13, no. 20, p. 5271, 2020.
[7] Ansys, Inc., Ansys Fluent – User's and theory guide, 2019.
[8] E. M. A. Pacheco and J. P. L. Santos, "Numerical evaluation of clayey soil under jetting procedure using lattice Boltzmann method," In: Associação Brasileira de Métodos Computacionais em Engenharia. Proceedings of the Ibero-Latin-American Congress on Computational Methods in Engineering, Foz do Iguaçu, 2020.
[9] T. Wang and B. Song, "Study on deepwater conductor jet excavation mechanism in cohesive soil," Applied Ocean Research, vol. 82, pp. 225-235, 2019.
[10] L. T. Ferreira, Numerical Estimation of Impact Pressure on Soil-Structure Interactions with the Material Point Method, 2022.
[11] M. Salam, N. S. Al-Zubaidi, and A. A. Al-Wasiti, "Enhancement in lubricating, rheological, and filtration properties of unweighted water-based mud using xc polymer nps," Journal of Engineering, vol. 25, no. 2, pp. 96–115, 2019.