XL CILAMCE
IBERO-LATIN AMERICAN CONGRESS ON COMPUTATIONAL METHODS IN ENGINEERING
NOVEMBER 11-14, 2019
Praiamar Natal Hotel & Convention
Natal, RN-BRAZIL

AN AUTOMATED STRATEGY FOR SIMULATION OF WELLBORE DRILLING IN SALT ROCKS

Jonathan F. Francisco
Ricardo A. Fernandes
Catarina N. A. Fernandes
Eduardo N. Lages
jonhff@gmail.com
ricardoaf@lccv.ufal.br
catarina@lccv.ufal.br
enl@ctec.ufal.br
Laboratório de Computação Científica e Visualização, Universidade Federal de Alagoas
Av. Lourival Melo Mota s/n, Cidade Universitária, 57072-900, Maceió, Alagoas, Brasil
Luiz F. M. Almeida
Jorel L. R. Anjos
Emílio C. C. M. Silva
luizfelippe@petrobras.com.br
jorel.anjos@petrobras.com.br
emiliosilva@petrobras.com.br
CENPES/PETROBRAS
Av. Horácio Macedo - 950, 21941-915, Rio de Janeiro, Rio de Janeiro, Brasil

Abstract. This work proposes an automated strategy for simulation of wellbore drilling in salt rocks. Drilling operations in salt rocks are often complex due to the creep behavior of such materials inducing borehole closure. In many cases, this behavior may lead to stuck pipe problems and, once the drilling equipments get stuck, they cannot be freed without damaging the well, not to mention that it can delay the well execution for several days. To avoid such undesirable event, numerical simulations are used to predict the closure of the borehole, providing support in backreaming operations. Also, the information of salt response in some zones may lead to a better decision-making process of drilling or not in an area of interest, once the technical and economical feasibility of the operation can be better evaluated. In this context, this work presents an automated strategy for simulation of wellbore drilling in salt rocks. The model is based on finite element analysis using Abaqus software. Python routines are developed using the abaqus scripting API to automate the modeling and simulation procedures for different scenarios considering user-defined variations on geometric and material properties and allowing a proper visualization of obtained results. Case studies are presented in order to verify the reliability of the proposed strategy.

Keywords: Wellbore drilling, Salt rocks, Automated simulation

1 Introduction

In the past few years, new challenges were brought to the oil industry, especially due to the presence of salt rock layers along the trajectory of offshore wells in pre-salt fields of Brazil. Salt rocks are chemical sedimentary rocks formed through precipitation, typically when water evaporates. Hydrocarbons, such as oil and gas, are usually found in porous rocks covered by a layer of these impermeable rocks or minerals.

Despite being desirable structures for trapping hydrocarbons, since salt layers feature low permeability and porosity, they may create operational problems, such as the inprisonment of the drill string inside the wellbore and casing collapse (Wang and Samuel [1]), as shown in Fig. 1. According to Muqeem et al. [2], stuck pipe incidents are known to cause a significant amount of time loss and associated costs, not to mention that the well integrity may be affected by the attempts to release the stuck equipments. The imprisonment problems occur due the creep behavior of salt, that tends to deform permanently even under constant stress, leading to the borehole closure (Orozco et al. [3]).

In order to avoid these problems and support the technical feasibility analysis of a well, it is important to predict the behavior of salt, thus, it is possible to schedule corrective operations like backreaming, the practice of pumping and rotating the drillstring while pulling out of the hole (Yarim et al. [4]). This work presents an automated strategy to simulate the drilling of wells in salt rocks, such as halite and tachyhydrite, using Python 3.7 routines (Van Rossum and Drake Jr [5]) to automate ABAQUS 2018 (Dassault Systèmes [6]) finite element simulation and ease the analysis of the obtained results.

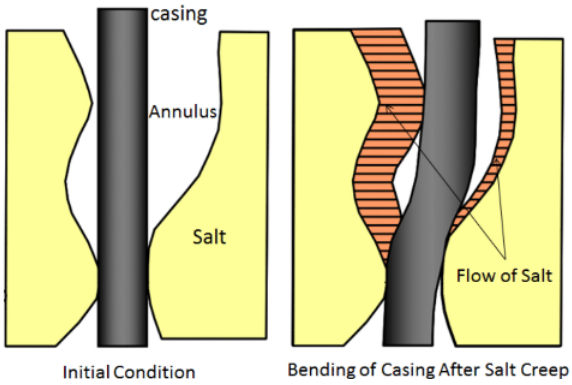

Figure 1. Borehole closure illustration (Wang and Samuel [1]).

2 Methods

The methodology of this work is based on three main steps: the definition of the study scenario, the automation of the modeling and simulation procedures using ABAQUS scripting API, and the post-processing and analysis of results (Fig. 2)

The model is based on finite element analysis using Abaqus software. Python routines are developed using the abaqus scripting API to automate the modeling and simulation procedures for different scenarios considering user-defined variations on geometric and material properties and allowing a proper visualization of obtained results.

2.1 Scenario definition

In this study, an axisymmetric model of the salt layer rotated around the vertical well axis is considered, as shown in Fig. 3. Temperature, overburden stress, and mud weight effects are also present in the simulation. It it considered that the salt layer is drilled completely at once. The visco-elastic behavior of salt materials is analysed using the Double Mechanism creep law described in Costa et al. [7].

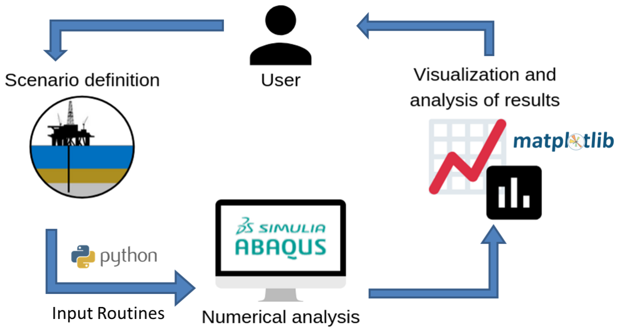

Figure 2. Workflow diagram.

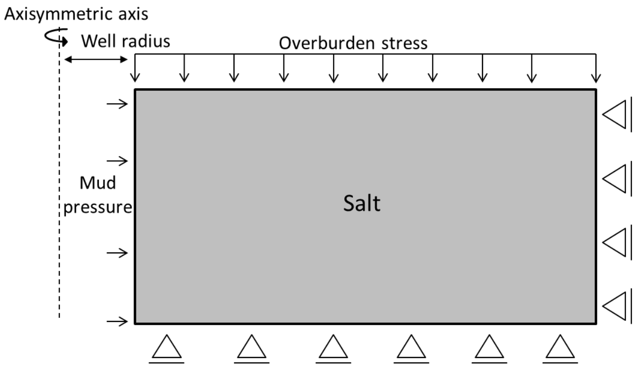

Figure 3. Axisymmetric model of the salt layer.

2.2 Automatic modeling and simulation

After the definition of the well model, the complete generalization of the geometrical, lithological and geomechanical parameters was made, allowing the adjustment of the model to any user-defined variations. Thus, from a Python input routine, the user is able to set properties such as diameters, drilling fluid density, geostatic stress, well depth, lithology, number and thickness of layers and viscoelastic properties of the materials. Python routines are responsible for gathering all this information, creating the user-specified associated computational model and submitting it to simulation without the user having to change anything through Abaqus GUI. Scripts can be executed completely through the command prompt.

2.3 Visualization and Analysis of Results

The result of interest of this problem is the well actual diameter as a function of time, once creep behavior of the salt rocks is a time-dominated process. Thus, Python Matplotlib library (Hunter [8]) is used to display two interactive graphs to the user: A depth *versus* borehole diameter of the well for a specified time that can be changed through a slider, and a diameter *versus* time 2D graph for a specified depth, that also can be defined.

3 Results and Discussion

In order to evaluate the functionality of the strategy, a case study proposed by Costa et al. [7] was reproduced. The considered well has a diameter of 0.4445 m and crosses a salt interval from 2600 m to 4600 m, composed by anhydrite, halite and tachyhydrite, as shown in Fig. 1. Tachyhydrite is known to be one of the most mobile types of salt, halite is relatively slow-moving, while anhydrite is essentially immobile (Costa et al. [7]). Halite and tachyhydrite elastic and visco-elastic properties used were proposed by Poiate Junior [9]. Furthermore, the temperature at the top of the salt interval is 313.15K and at the base 333.15K. A 1434 kg/m^3 mud is used as drilling fluid. For lithostatic stress, a 38.29 MPa overburden load is used at the top of the interval. 79400 quadratic (with 8 nodes) axisymmetric elements are employed in the finite element model. Table 1 summarizes the simulation parameters.

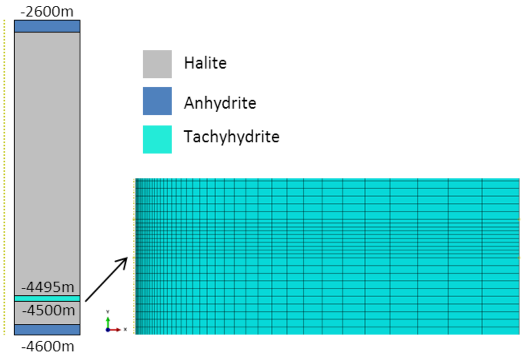

Figure 4. Geological profile and mesh discretization used in case study.

Table 1. Simulation parameters

Integration Scheme	Reduced
Number of horizontal elements	80
Element size ratio (outer / inner element size)	50
Outer radius	50 m

Figure 5 shows the diametral closure of the well after 528 hours of simulation. A maximum diametral closure of 0.0508 m was defined and it is represented by a blue dashed line at the figures. Halite presented a low closure rate, as expected, since its visco-strain rate is lower than other salt. The layer of tachyhydrite presented an intense deformation, as shown in Fig. 6.

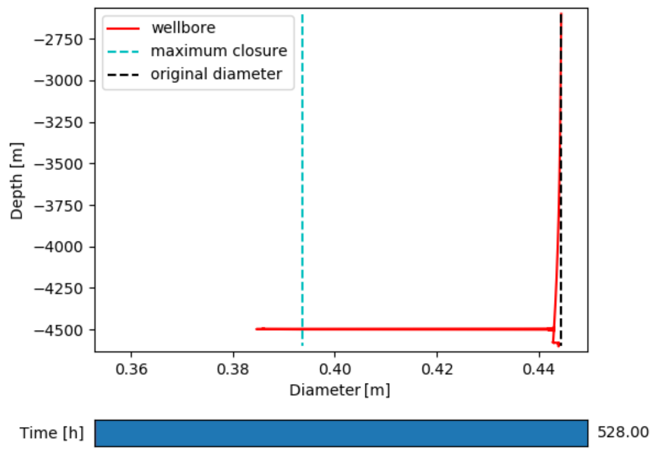

Figure 5. Wellbore diameter at t = 528 h.

After 528h, the well diameter was 2.42% smaller than the reference value. The difference between the obtained results and the ones presented by Costa et al. [7] is probably associated with the absence of some information on the studied scenario such as lithological parameters, integration scheme and creep properties of salt rocks. In the context of being a support tool in drilling operations, it was possible to clearly see the borehole closure after 419 hours. At this point, a backreaming maneuver must be scheduled in order to avoid pipe sticking.

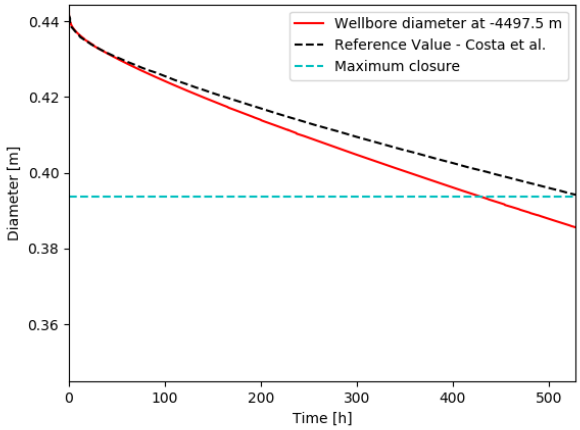

Figure 6. Closure evolution at the layer of tachyhydrite.

4 Conclusions

This work presented a methodology to simulate the mechanical behavior of salt rocks when drilled by vertical wells. The proposed strategy has proven to be efficient as a closure prediction tool, helping to schedule backreaming operations, especially in critical conditions. The general behavior shown by the rocks was just as expected by Costa et al. [7], with halite presenting a low closure rate as opposite to tachyhydrite, which can close completely the well in just a few days.

Acknowledgements

The authors acknowledge Petrobras for the financial support (cooperation term 5850.0104857.17.9) and CNPq for granting the Research Grant to the fourth author.

References

[1] Wang, H. & Samuel, R., 2016. 3D geomechanical modeling of salt-creep behavior on wellbore casing for presalt reservoirs. *SPE Drilling & Completion*, vol. 31, pp. 261 – 272.

[2] Muqeem, M. A., Weekse, A. E., & Al-Hajji, A., 2012. Stuck pipe best practices - a challenging approach to reducing stuck pipe costs. *SPE Saudi Arabia Section Technical Symposium and Exhibition*.

[3] Orozco, S. O., Pino, J., Paredes, M. A., Vásquez, J. L., & Xavier, A., 2018. Managing creep closure in salt uncertainty while drilling. *52nd US Rock Mechanics/Geomechanics Symposium.*

[4] Yarim, G., Ritchie, G. M., & May, R. B., 2008. A guide to successful backreaming real-time case histories. In *SPE Annual Technical Conference and Exhibition*, Denver.

[5] Van Rossum, G. & Drake Jr, F. L., 1995. *Python tutorial*. Centrum voor Wiskunde en Informatica Amsterdam, The Netherlands.

[6] Dassault Systèmes, 2018. ABAQUS 2018. Dassault Systèmes Simulia Corporation, Rhode Island.

[7] Costa, A. M., Poiate, E., Amaral, C. S., Pereira, A., Martha, L. F., Gattass, M., & Roehl, D., 2011. Geomechanics applied to the well design through salt layers in brazil: A history of success. In Borja, R. I., ed, *Multiscale and Multiphysics Processes in Geomechanics*, pp. 165–168, Berlin, Heidelberg. Springer Berlin Heidelberg.

[8] Hunter, J. D., 2007. Matplotlib: A 2D graphics environment. *Computing in Science & Engineering*, vol. 9, n. 3, pp. 90–95.

[9] Poiate Junior, E., 2012. *Mecânica das rochas e mecânica computacional para projeto de poços de petróleo em zonas de sal*. PhD thesis, Pontifícia Universidade Católica do Rio de Janeiro, RJ.