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Finite Element Modelling of Setup Effect during Conductor Casing Installation with Coupled Eulerian-Lagrangian Method

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Abstract.
The first tubular section installed in drilling operations is the conductor casing. Usually run by hammering or driving, the casing is responsible for guaranteeing well stability, isolating fluids from formation, and providing areas for installing equipment such as wellhead and christmas tree assembly. By inspecting soil behaviour during the installation process, it is notable that pore pressure disturbance triggers what is called the Setup Effect, a phenomenon where conductor load capacity increases over time due to pore-water pressure dissipation. This study applies the Finite Element Method (FEM) to model a Conductor Casing installation employing Coupled Eulerian-Lagrangian (CEL) technique to evaluate the setup effect. CEL technique is well suited to large deformations problems; however, pore pressure measurement is not supported in Abaqus/Explicit; thus, a Vectorized User Material (VUMAT) subroutine was implemented to take into account that effect. Mohr-Coulomb model represents soil's constitutive behaviour, and the results are compared with data obtained from Brazilian cases in soft clay soil. This kind of study helps to increase the safety of drilling operations and the structural well integrity analysis since pore pressure estimation is necessary to determine the ideal weight of the drilling fluid, preventing fracture, formation damage, and fluid loss, ensuring the borehole stability during drilling.

Keywords: Numerical Modelling, Mohr-Coulomb, Pore pressure, Abaqus, FEM

1 Introduction

Conductor casing is the first tubular section of an oil well, and its installation can be done by jetting, drilling or driving. Each type of installation causes different levels of disturbance in the soil surrounding the conductor. These disturbances in normally consolidated or lightly overconsolidated clays alter the stress state, generating excess pore pressures, reducing effective stresses and therefore reducing bearing capacity. Over time, the pore water pressure will dissipate and lead to the increase of the conductor load capacity in a phenomenon called soil setup.

This structural casing is mainly responsible for guaranteeing well stability, isolating fluids from formation, and providing areas for equipment installation such as wellhead and christmas tree assembly. Satisfactory setup quantification implicates a better understanding of soil behavior, which can subsidize well design decisions and contribute to the safety of the operations, especially in the beginning of the consolidation process (American Petroleum Institute [1]).

+++++++——–Introdução do problema (MODELAGEM)——

2 Setup Effect

As a pile is driven into the ground, the adjacent soil is displaced and subjected to great stresses. For saturated clayey soils, there is a generation of positive excess pore water pressure during pile driving. After the foundation is installed, excess pore pressure is dissipated due to radial consolidation and the soil structure is partially reconsolidated - thixotropic recovery (Velloso and Lopes [2]). This process leads to the increase of the effective stresses and ensuing increase of the pile's bearing capacity over time in a phenomenon called soil setup or setup effect.

Soil setup is mainly influenced by the type of soil, elapsed time, pile installation method, occurrence of plugging, and pile dimensions. The dissipation of excess pore pressure generated during driving occurs slowly in cohesive soils (such as clay soils) due to its low permeability. In this type of soil, shear strength of the reconsolidated soil (after setup period) is usually 50 to 60 % higher than in undisturbed soils (Randolph and Wroth [3]).

Setup phenomenon can be divided into three phases: beginning of excess pore water pressure dissipation at a non-linear rate, complete dissipation of excess pore pressure in a linear behavior, and soil aging. (Komurka et al. [4]). Soil aging effect refers to the time-dependent changes in soil properties at a constant effective stress (Long et al. [5]).

The excess pore pressure distribution (Δu_0) immediately after driving can be estimated by equation 1 proposed by Randolph and Wroth [3]:

$$\Delta u_0 = \begin{cases} 2S_u \cdot ln(R/r), r_0 \leq r \leq R \\ 0, R < r \leq r* \end{cases} \tag{1}$$

where r_0 is the radius of the pile.

The region delimited by $r_0 \leq r \leq R$ is the plastic zone and R is the radius of the mobilized region where there is generation of excess pore pressure. $R = r_0[G/S_u]^{1/2}$, where G is the shear modulus and S_u is the undrained shear strength. The region $R < r \leq r*$ defines the elastic zone - where excess pore pressure is negligible ([3]). The excess pore pressure is maximum at the pile-soil interface and decreases exponentially until it is totally dissipated when the radius is equal to R.

Static and dynamic pile load tests show the increase in bearing capacity over time, especially in soft clay soils (Silva [6]). Liu et al. [7] carried out field tests to evaluate setup effect: they performed load tests immediately after driving, after 30 minutes, 17 and 75 days. Tests like these show that the influence of the setup effect on strength is predominantly a function of the increase in shear strength.

There are several methodologies to quantify setup effect, which include empirical and numerical approaches. Bogard et al. [8] define setup (α) as the ratio of bearing capacity at a given time (F) and ultimate bearing capacity (F_u), and propose equation 2 based on the analysis of experimental data from large diameter piles driven in highly plastic normally consolidated clays.

$$\alpha = F/F_u = 0.3 + 0.7U \tag{2}$$

where U is the degree of consolidation, given by $U = (t/t_{50})/(1 + t/t_{50})$. And t_{50} is the time when 50% of consolidation has occurred; this value is related to the radial consolidation coefficient (c_r) and pile radius (r) by the equation: $c_r = r^2/t_{50}$.

Khanmohammadi and Fakharian [9] model pile setup using ABAQUS/Standard and quantitatively differentiate setup effects due to pore pressure dissipation from soil aging process. Modeling involved three steps: establishment of geostatic stresses, pile installation applying prescribed displacements, and simulation of Static Load Tests (SLT) at a few times after installation to evaluate the influence of soil setup on bearing capacity. The results were validated with SLT performed on an instrumented pile driven in soft marine clay. Numerical results indicated that pore pressure dissipation is initially more relevant for setup quantification and that the increase in shaft friction occurs mostly within the first 4 days when about 70% of the excess pore pressure has dissipated.

Abu-Farsakh et al. [10] evaluated thixotropic and consolidation effects on soil setup modeling static and dynamic load tests in ABAQUS. Pile installation was modeled combining volumetric cavity expansion and vertical displacement. The following step allowed excess pore pressure to be dissipated in order to simulate load tests at different elapsed times. Numerical results showed good agreement with field tests 13 and 208 days after driving, and it was estimated that the influence zone for deformation analysis is equal to 4 diameters. Cavity expansion method was also employed by Lopes [11] to evaluate setup effect of torpedo anchors.

3 Numerical Methodology

Citar qual estratégia adotada para que a poropressão fosse extraida das tensões totais do ABAQUS.

Se basear no paper do algorítmo Pegasus, no paper sobre modelagem de spudcans, etc.

4 Computational model

Seção para descrever detalhes do modelo desenvovlido para o ABAQUS, ex: dominio de simulação e detalhes de malhamento, etc.

5 Results

6 Conclusions

Acknowledgements. This section should be positioned immediately after the Conclusion section. Type Acknowledgements in boldface, 10 pt Times New Roman type from left margin, leaving 20 pt line spacing before and 12pt after.

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