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Modeling the Influence of Contact Type on the Response of the Soil-Pile interface

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Abstract. *This work presents a comparison between Coulomb's frictional contact based on the penalty method and cohesive contact for the study of the pile-soil interface response, through a global finite element modeling, in order to understand the influence of interaction type on the structural elements-soil interfaces in general. A three-dimensional pile-soil interaction model, implemented in Abaqus software, processed by a two-dimensional axisymmetric analysis, presents the case of a vertical pile installed in sand and subjected to pull-out load. A very forward behavior law is used to represent the sand while the pile is treated as a rigid elastic body. Very interesting results depend largely on the contact type description of the Pile-soil interface area. Finally, it has been shown that cohesive contact taking into account adhesion phenomenon can produce more reasonable results than frictional contact by the penalty method.*
Key words: Deep foundation, pile-soil interface, soil behavior laws, contact and friction, finite elements method

1. Introduction

Among the typical geotechnical structures, deep foundations have been much studied. In such a structure, the characterization of contact between the soil and the structural element (pile, footing…) plays a major role in defining the stability conditions of the structure. The problem of their sizing has been the subject of much research, which highlights the fundamental role of the pile-soil interface behavior. Indeed, the transmission of pile forces to the soil is through the thin layer of soil in contact with the pile called "interface". The rupture is often observed within this interface layer which is the seat of complex mechanical phenomena because it generates significant deformation locations and stress concentrations. These phenomena are strongly influenced by the mechanical characteristics of the granular soil and the pile structural element, usually very contrasted. As a result, for correct modeling of a geotechnical work, it is important to take into account the particular behavior of this highly requested interface.

Considerable research has been done to develop the appropriate methods of deep foundation construction, through which we have been able to understand the load-bearing mechanisms of the latter [1-4]. Further work has been devoted to developing analytical models to study the interaction between the pile structural element and the soil that confines it, the majority of which are based on the p-y method for the elastic linear case of soil [5-7]. Still in the interaction context, not long ago some interesting works were done, which are based on the contact stresses. We can cite the works of [8-9]. Currently, the focus is on the pile's behavior, more particularly, the use of frictional contact in the interfaces modeling. In this regard, a significant number of works have been published, the majority of which have adopted Coulomb's frictional contact model [10- 12].

Finally and after thorough bibliographic research, it was found that cohesive contact was not much used for this type of interface, the only work detect is that of Terfaya et al [13] who defined and formulated for the elastic case a cohesive model coupling contact, friction and adhesion by the RCCM model. As pointed out by Terfaya et al [13], this model was cited by [14-15].

In this work, the pile-soil interaction is simulated by contact between two deformable bodies. The problem is solved using two types of contacts in order to make a comparison. The first type represents coulomb's frictional contact based on the penalty method, while the second represents cohesive contact (taking into account adhesion). The sand is represented by a very advanced law of behavior. The ABAQUS version study code is used to obtain all the results of this work, so that interested readers can reproduce the analysis.

2. Contact and friction

Consider a system of solid bodies in contact. Unilateral contact between deformable bodies must satisfy the three following conditions, known as the Signorini condition:

$$x_n \geq 0, R_n \geq 0, R_n . x_n \geq 0 \quad (1)$$

- ✓ Impenetrability ($x_n \geq 0$) which is a kinematic condition
- ✓ Non adhesion ($R_n \geq 0$) represents the static condition
- ✓ Non-contact ($R_n . x_n \geq 0$)

Where x_n represents the gap between the contact node and the target surface, R_n is the normal contact reaction between the slave and master body. The graph of this relation is showing in fig. 1.

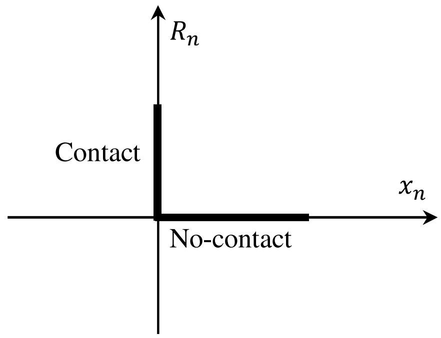

Fig. 1. Signorini graph.

All unilateral contact must be completed by a frictional law. The most used friction law today is Coulomb's, which is represented in fig. 2 and writing by the following inequalities:

$$\begin{cases} R_t = -\mu R_n \; si \; \dot{u}_t > 0 \\ |R_t| < \mu R_n \; si \; \dot{u}_t = 0 \\ R_t = \mu R_n \; si \; \dot{u}_t < 0 \end{cases} \quad (2)$$

Where $\dot{u}_t$ represents the tangent relative velocity, μ the coefficient of friction and R_t the tangential relative velocity.

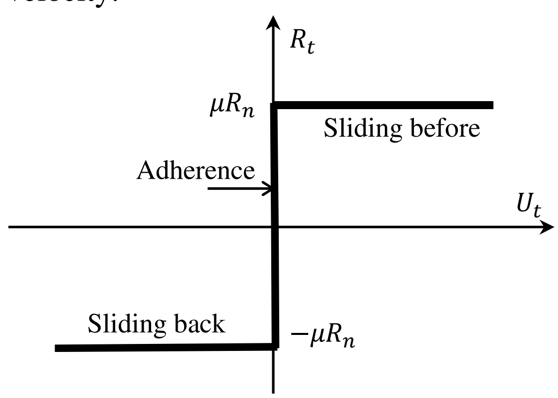

Fig. 2. Coulomb's law graph.

3. Penalty method (P. M)

The penalty method is the most used for contact modelling [16-18], it consists in supplementing the functional potential energy with terms which represent the additional penalty energy of contact constraints.

$$\Pi(u) = G(u) - q_i u_i \quad (3)$$

Where q represents the nodal load vector and $G(u)$ is the strain energy.

Finally, this method applies the approximate compatibility by a penalty factor K_n , the contact reaction becomes:

$$R_n = \begin{cases} K_n x_n & if \ \ x_n \leq 0 \\ 0 & if \ \ x_n > 0 \end{cases} \quad (4)$$

The big problem inherent in this method is the choice of penalty factor because the penetration of a material point in another body depends on the value of the latter. If the value of this coefficient is too low, the penetration is too high, and vice versa if it is a high value the contact conditions are satisfied but sometimes a high value can introduce high frequencies into the system and therefore lead to a significant decrease in the time step.

4. Cohesive zone model (C. Z. M)

In reality, the effect of physicochemical phenomena is essentially reflected in the appearance of a reversible adhesion force, this force has been taken into account by several authors to study the rupture of different materials [19-22].

Cohesive contact breaks when the normal force reaches a traction failure threshold. The adhesion is reversible, which is to say, that a broken cohesive contact can be reformed at any time during the evolution of the particle system.

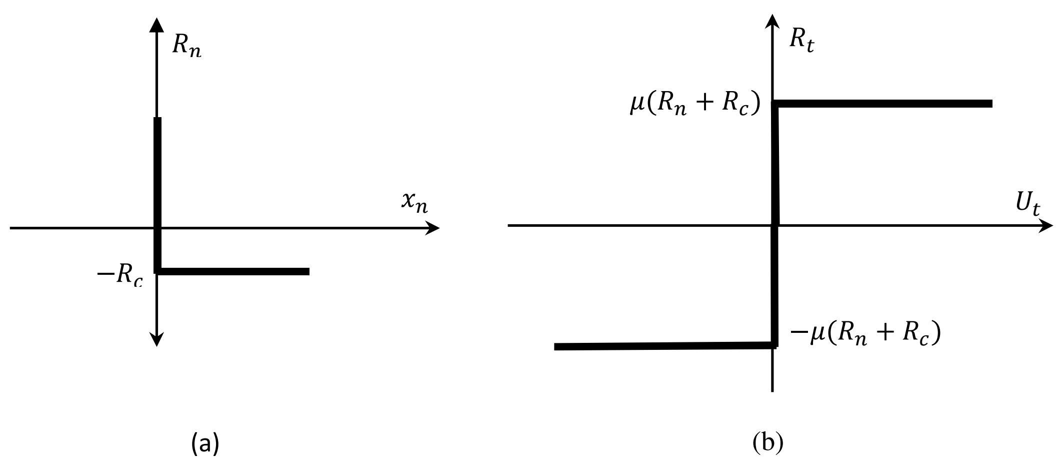

Fig. 3. Signorini (a) and Coulomb (b) graphs for a cohesive contact of threshold $-R_c$.

5. Numerical modeling procedures

The numerical example deals with a two-dimensional axisymmetric analysis the pulling of a rigid concrete pile out, buried in a cap plastic sand, of mechanical characteristics $c = 0{,}002\ KN/m^3$, $\varphi = 51°$, $R = 0{,}4$, $\varepsilon_{vol}^{in}\big|_0 = 0$, $\propto = 0{,}11$, $K = 1$,

$\rho = 3{,}72 KN/m^3$, $E = 1{,}44 * 10^6\ KPa$, $\nu = 0{,}3$. The pile is considered as elastic, and contains the parameters $\rho = 3{,}8\ KN/m^3$, $E = 30 * 10^6 KPa$ and $\nu = 0{,}2$.

Fig. 4 shows the geometrical characteristics and boundary conditions. For the contact and friction treatment by penalty method (P.M), we used the Coulomb's frictionless law with a coefficient of friction equal to 0,3. As for the cohesive zone model of contact (C.Z.M), we adopted an elastic stiffness of the adhesive in normal direction $K_{nn} = 84$ MPa and elastic stiffness of the adhesive in shear directions $K_{ss} = K_{tt} = 100{,}8$MPa.

Numerical simulations were carried out using ABAQUS Student Edition software, linear axisymmetric quadrilateral elements with four nodes were used both for the ground and for the pile.

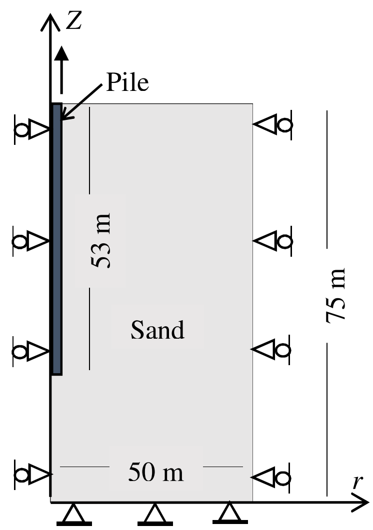

Fig. 4. Geometric characteristics and boundary conditions.

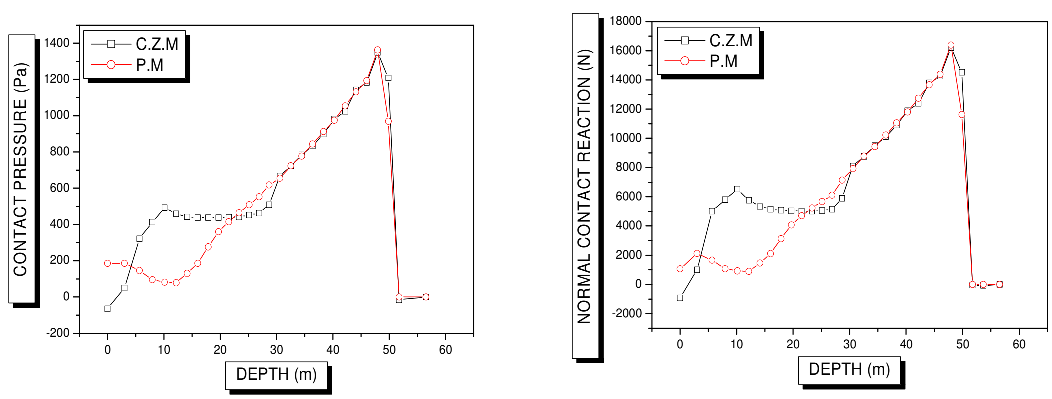

Fig. 5. Contact pressure and reaction at the interface for Penalty method (P.M) and cohesive zone model (C.Z.M).

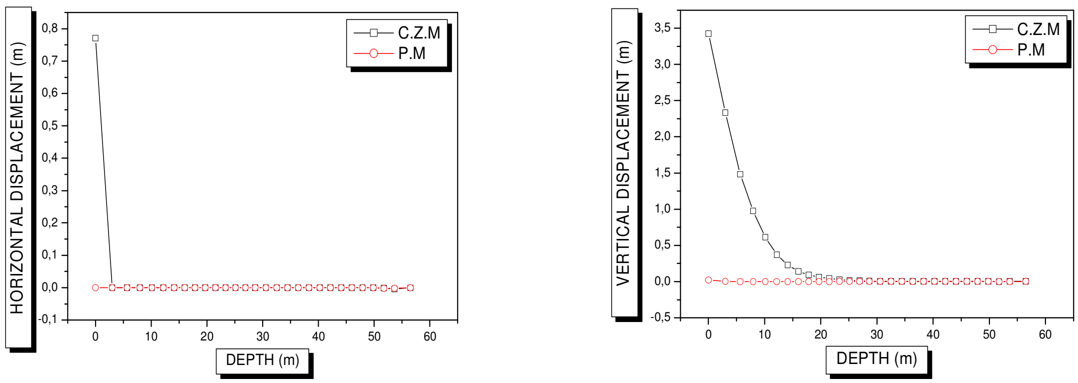

Fig. 6. Horizontal and vertical displacement at the interface for Penalty method (P.M) and cohesive zone model (C.Z.M).

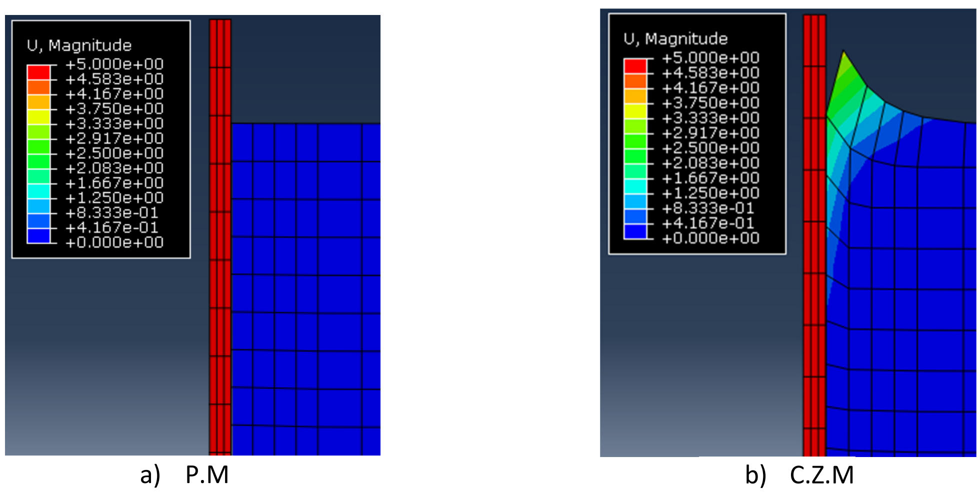

Fig. 7. The model deformation of the interface for a) Penalty method (P.M) and b) Cohesive zone model (C.Z.M).

For both simulation cases, the pile was successfully pulled out where a very significant sliding was produced along of the pile-soil interface. By examining the previous fig. 5, it emerges from these graphs that for the distribution of pressures and contact reactions increase with the interface depth. We can also observe that these distributions are almost the same along the lower half of the interface, unlike the upper half where it is clear that they are much more important for the case of a cohesive zone model.

We clearly notice in fig. 6 which illustrates the evolution of the horizontal and vertical displacements of the interface that for the contact by penalty method the interface remains in its initial position after the pulling of the pile out, which is abnormal, unlike the cohesive zone model where these displacements are very important at the upper part (vertex). This and translated by the effect of the shear tangential forces which causes a lifting of the ground at the upper surface, which is logical and reasonable.

Finally, fig. 7 illustrates the deformed meshes, which explains well and shows that for the pull of a pile out, the cohesive model is very reasonable than a penalty approach.

6. Conclusion

This numerical study showed the influence of the interaction type and the method used for the pile-soil interface response. The obtained results allow us to envisage a better understanding of the soil and structural element interface behavior, they have shown clearly that to study the interaction of any structural element with the ground, the cohesive contact can produce more precise and reasonable results than the frictional contact by the penalty method.

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