



HYBRID ANALYSIS OF STABILIZING STEEL TUBE PILES IN CLAYEY SLOPE

ANALYSE HYBRIDE DES PIEUX EN TUBE D'ACIER STABILISANT UN TALUS ARGILEUX

Réception : 30/06/2018

Acceptation : 09/09/2018

Publication: 08/01/2019

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Abstract-Slope stability is one of the major concerns of the geotechnical field. Reinforcing slopes by installing piles is a widely accepted reinforcement technique. It increases the safety of the slope and diminish the risk of the slide. The design of slope stabilizing piles is based generally on pressure or displacement methods and numerical methods. Nevertheless, a new hybrid method was proposed in 2012, this method gathers both analytical techniques with the finite element numerical analysis. In this paper, the simplified decoupled model of the hybrid method was adopted to investigate the behavior of slope stabilizing steel piles in clayey slope. The critical embedment depth and the pile spacing effect were sought. It was found that the critical embedment depth (L_e) is equal to the depth of the sliding mass (H_u), and for embedment depth $L_e < H_u$, the pile rotates and no bending takes place. Regarding pile spacing, it was found that the resisting force offered by piles increases for a lower pile to pile spacing.

Keywords : Piles, Slope, Hybrid, Embedment.

Résumé - La stabilité des talus est l'une des principales préoccupations du domaine géotechnique. Renforcer les talus en installant des pieux est une technique de renforcement largement acceptée : elle augmente la sécurité des talus précaires et diminue le risque de glissement. La conception des pieux stabilisateurs se base généralement sur des méthodes de pression ou de déplacement et des méthodes numériques. Néanmoins, une nouvelle méthode hybride a été proposée en 2012. Cette méthode regroupe les techniques analytiques avec l'analyse numérique par éléments finis. Dans cet article, le modèle découplé simplifié de la méthode hybride a été adopté pour étudier le comportement des pieux en acier stabilisant un talus argileux. La profondeur d'ancrage critique et l'effet d'espacement des pieux ont été étudiés. Il a été constaté que la profondeur d'ancrage critique (L_e) est égale à la profondeur de la masse glissante (H_u), pour les ancrages dont $L_e < H_u$, le pieu pivote (pas de flexion). En ce qui concerne l'espacement entre pieux, la résistance offerte par les pieux augmente pour les espacements les plus faibles.

Mots - clés : Pieu, Talus, Hybride, Ancrage.

1-Introduction

Slope reinforcement by mean of piles is a widespread technique for landslides mitigation. In order to design slope stabilizing piles, the two following methods are frequently used: pressure or displacement-based methods, Refs. [1, 2, 3] and numerical methods, Refs. [4 & 5].

Kourkoulis et al., [6] proposed a hybrid method for the design of slope-stabilizing piles that gathers both the analytical techniques with the finite elements numerical analysis. This paper highlights the behavior of slope stabilizing steel piles from a prospective of the hybrid methodology.

2-The hybrid method for analysis and design of slope stabilizing piles

The hybrid method gets its name from its philosophy of combining both analytical techniques with the numerical simulation. It has two steps; the first one is an analytical step, in which, the resisting force that is needed to be added to reinforce the precarious slope is calculated. The second one is a numerical step, in which, a simplified finite element model is analyzed in order to define the piles configuration that stabilizes the precarious slope. Figure 1 clarifies the simplified model of the hybrid method: it consists of a stable part and an unstable part separated by an interface. The length of the model is ten times the diameter of the pile (10D), while the width is two times the pile to pile spacing (2S). H_s is the sliding depth and L_e is the embedment of the pile into the stable soil. The slide is modeled by a uniform displacement profile applied on the unstable part.

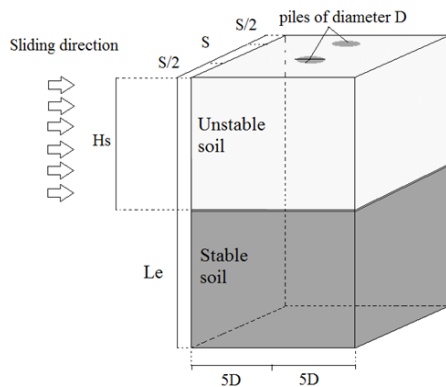


Figure 1. The configuration of the simplified model.

Figure 1. Configuration du modèle simplifié

3-The numerical model

In the numerical model (Fig. 2), a Mohr-Coulomb failure criterion is used to describe soils, because this criterion was adopted to build the simplified model of the hybrid method, (Ref. [6]). However, piles are modeled as linear elastic. Dimensions of the model, boundary conditions and interactions are identical to those used in the hybrid method. The software Abacus CAE was used in this study.

Regarding the mesh of the model, the structured hexahedral elements were adopted. The length of the model is 4m (10D), the width varies with the pile to pile spacing (S), while the height varies with the embedment depth (L_e).

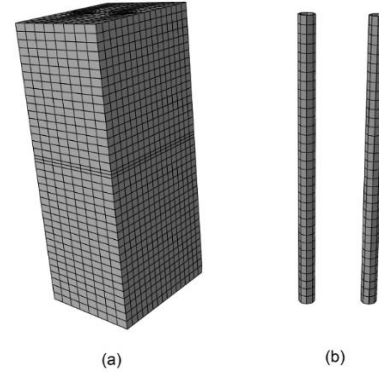


Figure2: Meshed parts: (a) soil's mesh, (b) tube pile's mesh

Figure2 : Maillage des composants : (a) maillage du sol, (b) maillage du pieu en tube d'acier

4- Material properties

The moving part of the slope consists of a soft clay; however, the stable part is a stiff clay with an undrained shear strength $C_u = 71$ KPa. Piles are steel tubes with a diameter $D = 400$ mm and thickness $e = 9.5$ mm. Soil and piles properties are presented in Tab. 1 and Tab. 2 respectively.

Table 1 : Soil properties

Tableau 1 : Propriétés du sol

	Unit Weight (kN/m^3)	Undrained shear strength C_u (kPa)	Young modulus E (kPa)
Soft clay	13.6	19	14 000
Stiff clay	16	71	47 000

Table 2: Pile properties**Tableau 2:** Propriétés des pieux

	Unit Weight (kN/m ³)	Young modulus E (MPa)	Poisson's ratio
steel	78	210 000	0.3

5-Investigation of the critical embedment depth

The pile's fixity in the stable ground is ensured by the length of the part of the pile embedded in this stable ground, this length is called the critical embedment depth.

In order to investigate the critical embedment depth, three models were analyzed varying the embedment depths as : $Le = 0.5 H_u$, $Le = H_u$ and $Le = 1.5 H_u$ (where $H_u = 4m$). The following results were obtained (Fig.3), they represent the variation of the resisting force (R_f) offered by piles per 1m of slope width, with respect to pile head displacement.

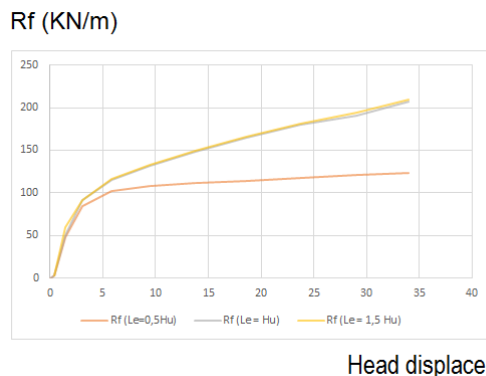


Figure3: investigation of the critical embedment depth : the resisting force offered by piles per 1 m of slope width with respect to pile head displacement (cm)

Figure 3 : étude de la profondeur d'ancrage critique : la résistance offerte par les pieux par 1 m de largeur de talus par rapport au déplacement de la tête de pieu (cm)

One can notice that the resisting force offered by piles par 1 m of slope width for pile embedment $Le = H_u$ and $Le = 1.5 H_u$ is the same, however, for pile embedment $Le = 0.5 H_u$, the resisting force is noticeably smaller comparing to that of $Le = H_u$ and $Le = 1.5 H_u$. This can be explained by the fact that for pile embedment $Le = 0.5 H_u$, the piles rotate, which means that the structural capacity of the pile was not exploited and no bending takes place (Fig.4). The critical embedment depth in this study is then : $Le = H_u$.

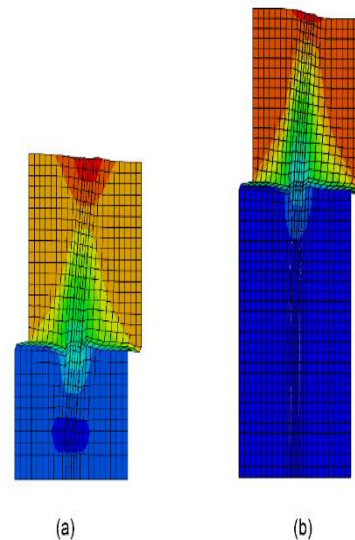


Figure4 : Lateral displacement contours : (a) embedment depth $Le = 0.5 H_u$, (b) embedment depth $Le = 1.5 H_u$

Figure 4 : Contours de déplacement horizontal (a) ancrage $Le = 0.5 H_u$, (b) ancrage $Le = 1.5 H_u$

6- Effect of pile spacing on the resisting force offered by piles

To investigate the effect of piles spacing on the resisting force offered by piles per 1m of slope width, three models were analyzed varying spacing between piles as $S = 3D$, $S = 4D$ and $S = 5D$, keeping an embedment of $Le = H_u = 4m$. The following results (Fig. 5) were obtained :

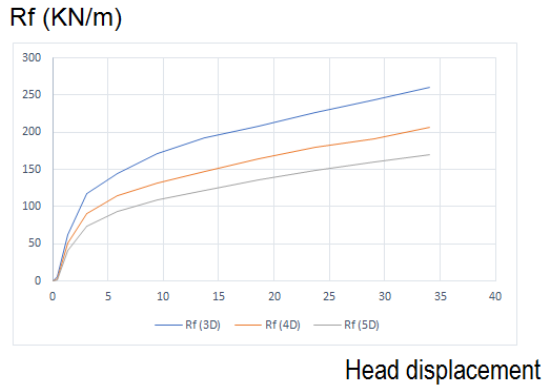


Figure 5: Resisting force with respect to pile head displacement (cm) at spacing: $S = 3D$, $S = 4D$ and $S = 5D$

Figure 5 : Résistance des pieux par rapport au déplacement de la tête du pieu (cm) aux espacements : $S = 3D$, $S = 4D$ et $S = 5D$

It is clear that the resisting force offered by piles increases with the decrease of pile to pile spacing.

Conclusions

In slope reinforcement using piles, the embedment depth, and the pile to pile spacing are key parameters for an adequate design. The of are mentioned parameters decide the efficiency of the piles, their number, and their depth (the reinforcement cost eventually).

The presented paper objective is to investigate the effect of the pile embedment into the stable ground, and the effect of pile to pile spacing in slope reinforcement from a prospective of the hybrid methodology. After analyzing the explained models using Abacus CAE, the following is concluded:

- The critical embedment depth (Le) is equal to the depth of the sliding mass (H_u), for pile embedment $Le < H_u$, the piles rotate, which means that the structural capacity of the pile is not exploited.
- The resisting force offered by piles increases with the decrease of pile to pile spacing.

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