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Numerical analysis of short pile under oblique pull out in sandy soil

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ABSTRACT: In many cases, piles have been used to counteract the pull-out force for engineering purposes. In this research, the behavior of short piles with a slenderness ratio (λ = L / B) less than 10, at oblique pull-out loading with different (inclination) angles in sandy soils was investigated using nonlinear models of Flac3D software. The Mohr-Coulomb behavioral model was selected for soil and the analyzes were performed in large strain conditions. In this study, a reinforced concrete pile with a cross-section of 1.2x1.2 m2 in dense sandy soil and buried depth of 10 m was considered. According to the results of numerical analysis, the relations provided by Das and Seeley (1975) were challenged. The load-displacement curves were presented with different uplift load inclination angles. These curves showed that the uplift capacity of the pile increases with the addition of the horizontal component of force. For instance, the load inclination angle of 60o, the uplift capacity of the pile was increased by 12% higher than the net uplift state. Furthermore, vertical displacement and pile deflection versus load application angle was plotted based on the numerical results. Also, a significant relationship has been found between the coefficient β introduced by Ismael and Al-Sanad (1994), and the slenderness ratio (λ) according to other laboratory studies and numerical results of this study.

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1- Introduction

Piles are columnar elements that transmit axial, flexural, and shear loads interacting with the layers in contact with the underlying layers. Piles can be divided into two categories: 1- Short or rigid piles with a buried depth less than 10 times its horizontal dimension (10> λ = L / B) and 2- Long or flexible piles with a buried depth greater than or equal to 10 times its horizontal dimension (10≤λ = L / B). [11]

Although there are several theoretical methods for separate vertical, uplift, and lateral loads (Poulos & Davis 1980; Prakash & Sharma 1990; Chattopadhyay & Pise; Tomlinson & Woodward 2008; Shaoyun pu et al. 2020) But little research has been done on the combination of uplift and lateral loads. In the case of oblique pull-out loading, we can refer to the researches carried out by (Ismael 1989, Reddy & Ayothiraman 2014, Das & Seeley 1976 and Shanker, Basudhar & Patra 2007). These studies are based on numerical and laboratory studies.

In this paper, numerical modeling is used, so different uplift load inclination angles are included in the modeling and the results of the modeling are presented in the form of load-displacement curves and axial and lateral displacement diagrams of the pile. In this regard, the interaction of shear force and uplift force on pile displacement have been studied.

2- Methodology and assumptions

For pile modeling in Flac3D software, the following assumptions are considered:

1) Soil mass is considered an isotropic environment. This assumption provides sufficient ease in the calculations.

2) For simplicity, the elastic properties of soil such as bulk modulus and shear modulus, were assumed to be constant and independent of the stress level.

3) In the study of the pile-soil interaction, the body of the pile is modeled elastically with the specifications in Table 1.

4) The Mohr-Coulomb model is considered for the soil; the parameters are assumed according to reference [13], as depicted in Table 2. As Das & Seeley 1975 [2] have pointed out, considering the friction angle between the soil and the pile equal to %67 the friction angle of soil shows the best approximation in the test results. Karthigeyan, Ramakrishna & Rajagopal 2006 [13] have also used this ratio.

Nicholas Stromblad 2014 [12] investigated the effect of zero dilation angle on sandy soils, according to which small dilation angles (less than 8 degrees) have no significant effect on the results. Therefore, zero dilation angle in this calculation is considered. Das, B. M. [3] considered the relative density of dense sandy soil to be 80%.

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Table 1. The pile specification [13]

Type of material	pile cross-section	Cross section dimensions (m)	Young's modulus (MPa)	Poisson's ratio	Shear modulus (MPa)	Bulk modulus (MPa)	Density $\left(kN/m^3\right)$
concrete	Uniform square	1.2×1.2	25000	0.15	10900	11900	25

Table 2. Properties of the sand soil [13]

Type of soil	Relative density	Friction angle (φ)	Density $\left(kN/m^3\right)$	Young's modulus (MPa)	Cohesion (kPa)
Dense sand	80%	36	20	50	0
Dilation angle (ψ)	**Poisson's ratio**	**Shear modulus (MPa)**	**Bulk modulus (MPa)**	**the angle of friction between the soil contact surface and the pile $(\delta = 0.67\varphi)$**	
0	0.3	19.23	41.7	24	

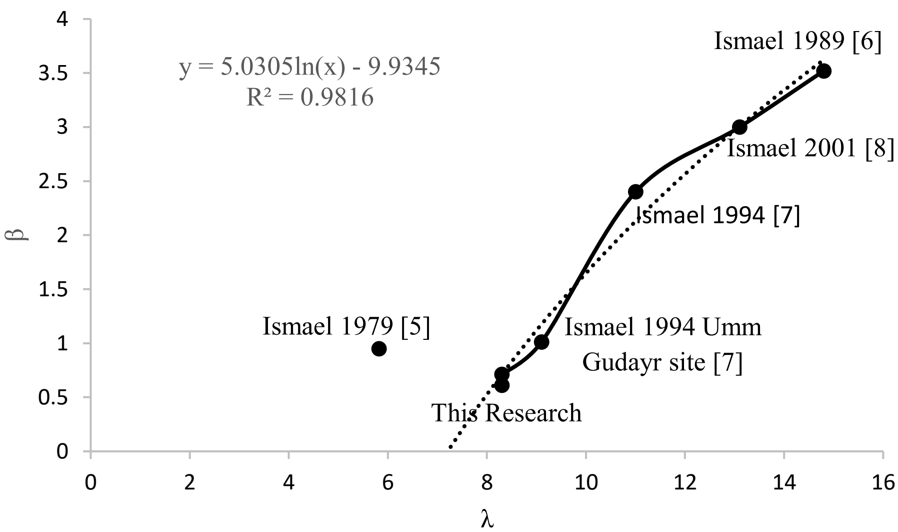

Fig. 1. "λ-β" curve

According to t the point of intersection of the initial and final tangents to the load-displacement curve, the failure loads in shear and uplift were 4300 and 3300 kN, respectively. The amount of failure load in shear calculated from equation presented by Ismail 1989 [8] obtained from Broms 1964 [1] is almost the same as the failure load resulting from numerical modeling. Regarding the failure load in uplift obtained from numerical modeling and its comparison with the uplift capacity resulting from the equation presented by Das & Seeley 1975 [2], the value of the coefficient K_u obtained from numerical modeling is 1.38 and the value of the coefficient K_u obtained from the diagrams provided by Das & Seeley 1975 and the soil characteristics in Table 2 is 2. Therefore, based on this, the coefficient β is plotted against the slenderness ratio of the pile λ, which increases with increasing the slenderness ratio of the pile. Based on this, the relationship between the coefficient β and slenderness ratio is proposed according to Equation 1.

$$\beta=5.0305\mathrm{Ln}(\lambda)-99345 \quad (1)$$

Based on Equation 1 and considering that the slenderness ratio for the short pile used in numerical modeling is (λ = L / D) 8.3, the coefficient β is obtained from the diagram in Figure 1 equal to 0.711. Now, according to the soil characteristics used, the results of this modeling and the use of the Equation provided by Ismael and Al-Sanad (1994) [9], the coefficient β is equal to 0.61 and the closeness of the result indicates the accuracy of the numerical modeling results.

3- Results and Discussion

According to Equation 1, increasing the slenderness ratio for short piles causes an increase of 20% to 60% in the coefficient β, which increases with increasing slenderness ratio. Also, in Equation 1, the minimum value of slenderness ratio 8 is considered and values less than slenderness ratio 8 are equal to this value.

Table 3 shows the failure load by considering the weight of the pile for each loading angle. The values of the failure load are selected according to the slope tangent method at the point of intersection of the initial and final tangents to the load-displacement curve. As can be seen, the load values decrease with increasing loading angle relative to the horizon line. By comparing the vertical components of failure load at different angles, it can be seen that by increasing the load angle relative to the horizon line, the uplift capacity (vertical force component) increases, which is reversed at the load angle of 90 and the amount of failure load is reduced. The reason for this process is due to the increase of more friction between the pile and the soil when there is a horizontal load component

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4- Conclusions

The short concrete pile in sandy soil was modeled under oblique pull-out loading in Flac3D software. From the numerical results of the models, it can be concluded that:

Under uplift load, the coefficient K_u obtained from the diagrams provided by Das & Seeley 1975 is different from the value calculated from numerical modeling. In this study, the coefficient $\hat{a} = K_u \tan\varphi$ was introduced and it was found that the coefficient β increases with increasing slenderness ratio λ = L / B for short piles.

The effect of the horizontal force component on the axial and lateral displacement of the pile is considerable.

The turning point of a short pile changes from 57% of the pile length to 20% of the pile length with increasing force.

The maximum resultant displacement of the head pile was observed at a load inclination angle of about 15 degrees because of the interaction of the uplift force and the shear force applied to the pile.

Table 3. Total failure load values at different inclination angles

inclination angle	90	75	60	45	30	15	0
Failure load (kN)	4300	4200	4100	4000	3700	3500	3300
Vertical component (kN)	0	1087	2050	2828	3204	3380	3300

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