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Discussion: Comparative study of Y-shaped and circular floating piles in consolidating clay

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The approach used in the paper of Lv et al. (2016) to estimate the unit limit skin friction of pile embedded in a saturated clay may not be suitable, because the cohesion of a saturated clay is not considered. To illustrate the limitations of the calculation approach used by Lv et al. (2016), the following discussions on the calculation methods of the unit ultimate skin friction of pile are given in the present paper.

Since around 1950, many empirical methods have been proposed to predict the unit ultimate skin friction of pile, and can be grouped into four main categories.

(1) The α Method (the so-called total stress approach), in which the unit ultimate skin friction of pile embedded in a saturated clay, f_s , is primarily correlated to the undrained shear strength, S_u (Tomlinson 1971; Meyerhof 1976):

$$[D1] \quad f_s = \alpha S_u$$

where α is the adhesion factor, and its value is related to the undrained shear strength, pile diameter and pile length embedded in the saturated clay.

(2) The β Method (the effective stress method), in which the unit limit shaft resistance of pile is primarily related to the in situ vertical effective stress (Chandler 1968; Burland 1973):

$$[D2] \quad f_s = K \tan \delta \sigma'_v = \beta \sigma'_v$$

where K is the coefficient of earth pressure; σ'_v is the effective overburden pressure at the given depth under consideration; and δ is the friction angle of the pile-soil interface.

The product $K \tan \delta$ is sometimes denoted by β , and Eq. (D2) is known as the ' β method'. In practice, the pile installation method and pile geometry may have great influence on the value of K . In the β method, the value of K or β is rather difficult to determine without proper analysis.

(3) The λ Method, in which the unit ultimate skin friction of pile is determined by an empirical

combination of undrained strength and effective strength parameters (Vijayvergiya and Focht 1972):

$$[D3] \quad f_s = \lambda(\sigma'_v + 2S_u)$$

(4) The cone penetration test (CPT) method, primarily relating the ultimate shaft friction to the tip resistance measured in CPTs.

Based on the T-bar penetration tests, the shear strength of a saturated clay can be deduced (see Fig. 3), and the relationship between the undrained shear strength, S_u , and the depth below the clay surface, h , can be established, as shown in Fig. D1.

Based on the material parameters listed in Table 3 (Lv et al. 2016) and the design methods for the analysis of the unit ultimate skin friction, e.g., Eqs. (D1), (D2), and (D3), the unit limit skin friction, f_s , of the model test pile embedded in the saturated clay can be determined, and can be summarized as below.

(1) In the calculation of the unit limit skin friction, f_s , using the α Method, the value of α can be adopted as 1.25 following the suggestion of Tomlinson (1971). Based on Eq. (D1) and the fitted equations of the T-bar tests 1 and 2 at 60g level (see Fig. D1), the unit limit skin friction, f_s , of pile can be computed as $f_s = 1.25 \times [1.307 \times (16.8 + 8.665)] = 41.70$ kPa and $f_s = 1.25 \times [1.253 \times (16.8 + 9.566)] = 41.30$ kPa, respectively.

(2) In the calculation of the unit limit skin friction, f_s , using the β Method, the value of K is simplified adopted as the in situ earth pressure coefficient $K_0 = 1 - \sin \phi'$, and the value of δ can be adopted as Eq. (4) of Lv et al. (2016). Based on Eq. (D2), the unit limit skin friction, f_s , can be computed as $f_s = (1 - \sin \phi') \times [(\sin \phi' \times \cos \phi') / (1 + \sin^2 \phi')] \times (p + \gamma' h) = (1 - \sin 25^\circ) \times [(\sin 25^\circ \times \cos 25^\circ) / (1 + \sin^2 25^\circ)] \times (45 + 6.3 \times 16.8) = 28.31$ kPa. Note that p represents the surcharge load and can be adopted as 45 kPa following the suggestion of Lv et al. (2016), and γ' is the effective unit weight of soil.

(3) In the calculation of the unit limit skin friction, f_s , using the λ Method, the value of λ can be

adopted as 0.1875 following the suggestion of Vijayvergiya and Focht (1972). Based on Eq. (D3) and the fitted equations of the T-bar tests 1 and 2 at 60g level (see Fig. D1), the unit limit skin friction, f_s , can be computed as $f_s = \lambda[(p + \gamma' h) + 2S_u] = 0.1875 \times [(45 + 6.3 \times 16.8) + 2 \times 1.307 \times (16.8 + 8.665)] = 40.76$ kPa and $f_s = 0.1875 \times [(45 + 6.3 \times 16.8) + 2 \times 1.253 \times (16.8 + 9.566)] = 40.67$ kPa, respectively.

From the computed results of the unit limit skin friction derived from Eqs. (D1), (D2) and (D3), respectively, it can be concluded that the value of f_s estimated from the β Method is approximate 28 kPa, and is smaller than that derived from the α Method and the λ Method, e.g., about 41 kPa. In the paper of Lv et al. (2016), the β method expressed as Eq. (D2) is used to calculate the unit ultimate skin friction, f_s . From Eq. (D2) it can be concluded that the unit limit skin friction is supposed to be zero when the soil depth is adopted as zero. However, Fig.8 shows that the unit limit skin friction of the circular and Y-shaped piles can be adopted as 11.33 kPa and 9.12 kPa at the ground surface, respectively, while the unit limit skin friction of the circular and Y-shaped piles can be adopted as 44.25 kPa and 35.26 kPa at the pile end, respectively. This seems self-contradictory.

The β method expressed as Eq. (D2) may not be suitable for the analysis of the unit limit skin friction of pile embedded in a saturated clay, because the cohesion of the saturated clay is not considered in Eq. (D2). For the pile embedded in the saturated clay in the model test of Lv et al. (2016), the cohesion of the saturated clay, C , should be considered, and Eq. (D2) can be modified as:

$$[D4] \quad f_s = K \tan \delta \sigma'_v + C = (1 - \sin \phi') \left(\frac{\sin \phi' \cos \phi'}{1 + \sin^2 \phi'} \right) (p + \gamma' h) + C$$

Note that the value of C is not given in the paper of Lv et al. (2016), and may be back-analyzed as 14.16 kPa and 14.98 kPa in the T-bar tests 1 and 2 at 60g level, respectively. The average value of the cohesion of the saturated clay can be adopted as 14.57 kPa. Based on Eq. (D4), the unit limit skin friction,

f_s , of pile embedded in the saturated clay can be computed as $f_s = (1 - \sin 25^\circ) \times [(\sin 25^\circ \times \cos 25^\circ) / (1 + \sin^2 25^\circ)] \times (45 + 6.3 \times 16.8) + 14.57 = 42.88$ kPa. The modified value of the unit limit skin friction computed using Eq. (D4) is consistent with the unit limit skin friction calculated using the α Method and the λ Method, and agrees well with the unit limit skin friction of Lv et al. (2016) calculated using the program ABAQUS, e.g., average value of f_s of 39.76 kPa.

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Figure Caption:

Fig. D1 Relationship between undrained shear strength, S_u , and depth below the clay surface, h

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Fig. D1 Relationship between undrained shear strength, S_u , and depth below the clay surface, h