SOIL STRUCTURE INTERACTION OF A LATERALLY LOADED MINIPILE

Toyohashi University of Technology WONG Mok Far
Japan Minipile Association TUZUKI Tomio
Toyohashi University of Technology Member NIIRO Tadashi
Toyohashi University of Technology Member KURIBAYASHI Eiichi

1. Introduction

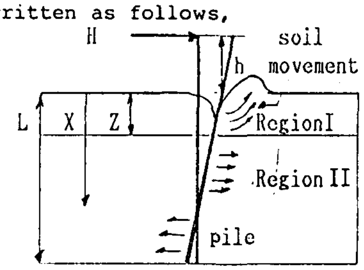
The configuration of a minipile is confined to pile with embedment length less than three meters and diameter less than twenty centimeters. This paper presents a solution for the minipile with due consideration given to soil surface discontinuity and avoid using coefficient of subgrade reaction which is affected by pile diameter and non-linear load-displacement response, to evaluate its lateral resistance.

2. Method of Analysis

The proposed solution is intended for the minipile with embedment length, L less then L_{mo}, where L_{mo} is defined as the first depth of zero moment for semi-infinite length type of pile. The pile with ratio $L/L_{mo} < 0.6$ behaves like a rigid body and the effect of bending behavior can be neglected, however bending behavior do affect pile with $0.6 < L/L_{mo} < 1.0$, but is neglected here as an approximation.

The soil along embedment length is divided into region I and region II. When a pile is subjected to a lateral load, the soil rupture occurs in region I and progresses gradually from the ground surface down to a deeper depth with increasing lateral load. The soil in front of pile moves in upward direction, whereas soil at the back moves downward to fill the void or remain in active state. Failure wedge as shown in Fig.1 is assumed and ultimate soil reaction per unit length is given by Reese et al(1974) and Kishida et al(1977), which can be rewritten as follows,

$$P_{bu} = A_s X^2 + B_s X \quad \text{for sand, and}$$
$$P_{bu} = A_c X + B_c \quad \text{for clay where,}$$
$$A_s = \gamma \frac{K_o \tan\phi \sin\beta}{\tan(\beta-\phi)} + \frac{\tan^2\beta \tan\alpha}{\tan(\beta-\phi)} + K_o \tan\beta(\tan\phi\sin\beta - \tan\alpha)$$
$$A_c = \gamma D + 2\sqrt{2}C_u$$
$$B_s = D\gamma(\tan\beta/\tan(\beta-\phi) - K_a)$$
$$B_c = 2C_u D \qquad (1)$$



Defination

γ is defined as the unit weight of soil, D is the width of pile, K_o is the at rest soil pressure coefficient, K_a is the active soil pressure coefficient and C_u is the cohesion value. In region II, the failure pattern assumed is shown in Fig. 2 and ultimate soil reaction is quoted from Kishida et al(1979) as follows,

$$P_{us} = \gamma X K_p = \gamma X\left[\frac{\cos(\pi/4-\phi/2)(1-\sin\phi)}{\cos(\pi/4+\phi/2)\cos\phi}\,\mathrm{Exp}((1.5\pi-\phi)\tan\phi) - K_a\right]$$

for sand and $P_{uc} = 9C_u$ for clay. (2)

The soil in this region is in elastic state when Eqn. 2 is not violated and when pile deflection is taken to be a linear function then the elastic soil reaction can be expressed by the following equation.

$$P_s = a_s X^2 + b_s X + c_s \quad \text{for sand, and} \quad P_c = a_c X + b_c \quad \text{for clay} \qquad (3)$$

The following solution is obtained by considering the continuity condition between region I and region II, and force equalibrium at a point near the ground surface.

$$FAA = A_s Z^4/12 + 2A_s ZL^3/3 - A_s Z^2L^2/2 + B_s L^3/3$$

$$FBB = -A_s Z^3/3 - A_s L^2 Z + A_s LZ^2 - B_s L^2/2$$

$$FQQ = (L^4/4 - 2ZL^3/3 + L^2Z^2/2 - Z^4/12)/(L^3/3 - L^2Z + LZ^2 - Z^3/3)$$

$$H(h + FQQ) + FAA + FBB*FQQ = 0.$$

$$a_s = (H - A_s Z^3/3 - A_s L^2 Z + A_s LZ^2 - B_s L^2/2)/(L^3/3 - L^2 Z + LZ^2 - Z^3/3)$$

$$b_s = 2A_s Z + B_s - 2a_s Z$$

$$c_s = a_s Z^2 - A_s Z^2 \qquad (4)$$

, where H is lateral load and h is eccentricity

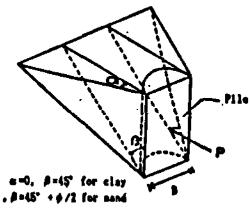


Fig.1 Failure wedge assumed for region I

For any given load level the soil reaction and moment can be obtained by solving the depth of region I defined by Z in Eqn.4. The maximum lateral load can be evaluated by solving the maximum depth ,Zmax of region I by equating Eqn.1 and Eqn.2 and check against the ultimate soil reaction in region II. If this condition is violated, the solution may be obtained by successive trial with a Z value that less than Zmax. Deflection at ground surface can be estimated by $Y_s = b_s/k$, where k is the coefficient of subgrade reaction.

3. Comparation with test result

The proposed solution was compared with model test results[1),2)] using the same soil parameters provided in the references. The results are shown here in table 1 and 2 respectively. Comparation with results from site test will be presented during the meeting.

4. Conclusions and Remarks

a) Lateral resistance of a minipile can be estimated by assuming the soil with elastic perfectly plastic response.

b) The proposed solution shows good result for pile with ratio $L/L_{mo} < 0.6$ and good approximation for pile with ratio $0.6 < L/L_{mo} < 1.0$ as shown in table 1 and 2.

c) The proposed method of analysis can be extended to clay material.

d) The solution may be used to estimate the percentage increase in maximum lateral load if the diameter of region I is increased. The last column of Table 2 shows the estimated increase if diameter in region I increased to threefold, however these values need further confirmation.

References

1) K.Takahashi, M.Sawaguchi:Experimental Study on the Lateral Resistance of a Well,Report of The Port and Harbour Research Institute,Vol.16,No.4,12/77

2) K.Kubo:Lateral Resistance of Short Piles,Report of The Port and Harbour Research Institute,Vol.5,No.13,9/1966

TABLE 1:Comparative result with model test in reference 1)

Total Length = 2.0 (meters)				
Diameter = 0.508 (meters)				
K_p = 8.3 ; φ = 40° γ = 1.1 g/cm³ ; δ = -15°				
L (meter)		1.83	1.85	1.95
Eccentricity		0.12	0.10	0.0
Test Result	H_y	1.4 (t)	1.5 (t)	1.6 (t)
Solution by Eqn.4	H	1.49 (t)	1.54 (t)	1.81 (t)
Ratio H_y/H		1.06	1.03	1.13

TABLE 2: Comparative result with model test from reference 2)

K_p = 50 ; φ = 45° ; γ = 1.78 g/cm³							
D(cm)	h(cm)	L(cm)	L/L_{mo}	H_y (kg)	H (kg)	H/H_y	% increase for 3D in region I
7	15	31.5	0.66	20.3	20.0	0.99	40.
7	10	54.6	0.96	118.5	105.0	0.89	22.
7	10	44.6	0.78	59.5	59.0	0.99	29.
7	9	35.5	0.70	31.0	33.0	1.06	38.
7	38.5	38.5	0.83	25.2	19.0	0.75	42.
5.09	15	48.0	0.88	61.8	53.0	0.86	23.
10.5	10	80.0	0.58	245.9	246.0	1.0	

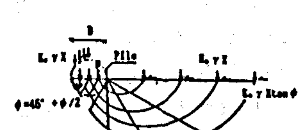


Fig.2 Failure pattern assumed for region II

Note: K_p = passive coefficient
H_y = maximum lateral load by model
H = maximum lateral load by Eqn.4