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Behaviour of Flexible Batter

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Summary

The behaviour of single free head model flexible batter piles buried in sand and subjected to horizontal loads is investigated. The theoretical estimates of ultimate load, location and magnitude of maximum bending moment for the piles were obtained by considering a vertical rigid pile under inclined load and using semi empirical relations. The length of the equivalent rigid pile was based on the relative stiffness factor of the pile. Model tests were carried out using instrumented flexible piles of wide ranging flexibilities. The piles were buried in loose sand at batter angles of $\beta = \pm\ 30^o$, $\pm\ 15^o$ and were subjected to incrementally increasing horizontal load. The pile capacities and the variation of bending moment along the pile shaft were measured. The observed values agreed reasonably well with the estimated values.

Introduction

The present investigation consists of instrumented single model flexible batter piles of wide ranging flexibilities, buried in loose sand and subjected to increasing lateral loads. The results are compared with theoretical estimates based on the effective embedment depth of equivalent rigid piles reported earlier [5].

Model Tests

Dry Toyoura sand having a friction angle of 31^o was used in the tests.. Flexible batter model piles consisted of 16 mm diameter pipes of aluminium, acrylic and hard rubber. The details of piles tested are summarized in Table 1.

Table 1: Physical Properties of Piles

RELATIVE STIFFNESS OF PILE Kr(x10^{-4})					
LENGTH L (mm)	L/B	$\overline{E}_n$(MPa)	ALUMINIUM E_p= $6.3x10^4$MPa	ACRYLIC E_p=0.3x1‘0^4MPa	HARD RUBBER E_p= $0.003x10^4$MPa
160	10	0.077	16.620A1*	1035.3P1*	14.25R1*
320	20	0.154	519.4A2*	32.4P2	0.45R2*
640	40	0.197	25.4A3*	1.58P3*	

Note: E_p= Modulus of elasticity of pile $\overline{E}_n$ = Weighted average horizontal secant modulus of soil in length L;* = Pile number.

Sand was rained from a constant height of 50 cm in a square tank 48 x 48 cm and 80 cm deep. When the soil surface reached the required level, the pile was

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placed at the required batter angle ± β with the vertical (Fig.1) and the raining was continued until the tank was full. The horizontal load was applied in 10-12 increments, each being 0.8-10 N depending on the estimated failure load. The measured lateral capacities of piles at batter angles of $\beta = \pm\ 30^o$ are presented in Fig. 2. The variations of bending moment with distance along the pile, under failure load and working loads, for pile A3 at a batter of $\beta = 30^o$, were given in Fig. 3. The maximum bending moments measured under failure loads in the piles at $\beta = \pm\ 30^o$ are presented in Fig. 4.

Analysis Of Results

The ultimate failure load on a rigid batter pile, $Q_{n,}$ acting perpendicular to the batter pile is approximately equal to the lateral capacity of the same pile oriented vertically. In other words, for small batter angles, of up to 30^o, the normal capacity $Q_{n,}$of the pile is independent of the value of β and is given by

$$Q_n = 0.125\gamma BL^2K_b \tag{1}$$

Where γ is the soil density, B is the pile diameter, L is the length of the pile, K_b is the earth pressure coefficient for pile [3] [4]. The axial capacity of the batter pile $Q_{a,}$ for small batter angles is approximately equal to that of a vertical pile and can be obtained from

$$Q_a = \gamma DN_qA_t + K_s\gamma Dtan\delta A_s/2 \tag{2}$$

Where N_q is the bearing capacity factor, A_t is the area of the pile toe, A_s is the area of pile shaft, K_s is the average earth pressure coefficient on the shaft and δ is the friction angle between sand and pile material. Consequently the lateral capacity of a rigid batter pile $Q_u$can be computed from an empirical relation [2] by considering it as a vertical rigid pile subjected to an inclined load, so that

$$(Q_ucos\varepsilon/Q_a)^2 + (Q_usin\varepsilon/Q_n)^2 = 1 \tag{3}$$

Where ε is the angle between the axes of the pile and the load. In the case of flexible pile of length L, it is replaced by an equivalent rigid pile of Length L_{eu} as shown in Fig. 6, and is given by

$$L_{eu}/L = 1.65K_r^{0.12} \leq 1 \tag{4}$$

Where $K_r$is the relative pile stiffness and is given by

$$K_r = E_pI_p/\overline{E}_nD_4 \tag{5}$$

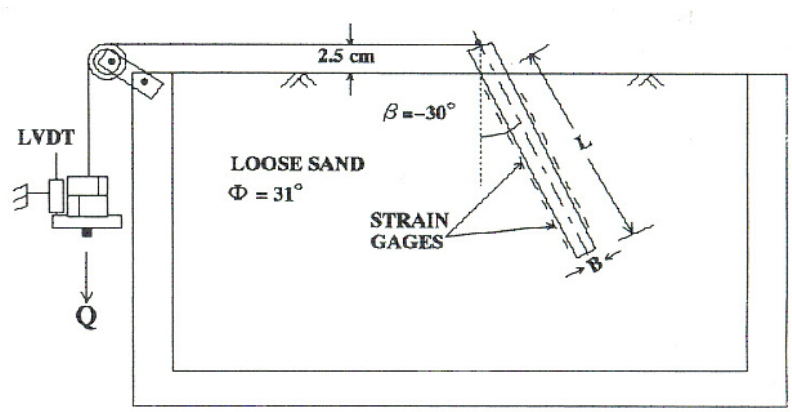

Fig. 1 Experimental setup.

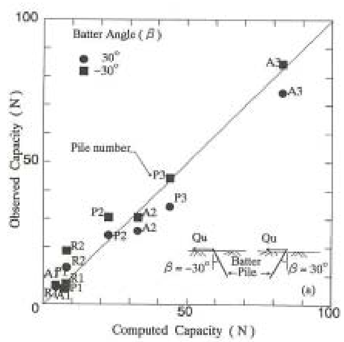

Fig. 2 Computed and observed capacities of batter piles at (a)β = ±30° (b) = ±15°

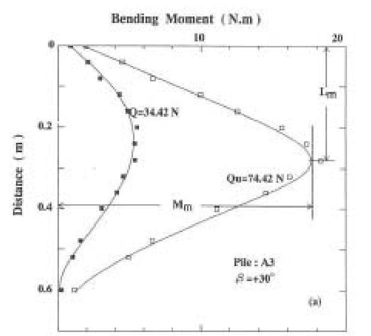

Fig. 3 Variation of bending moment with distance

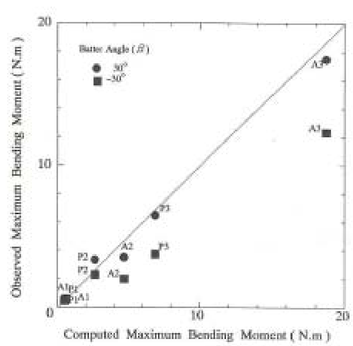

Fig. 4 Computed and observed maximum bending moments

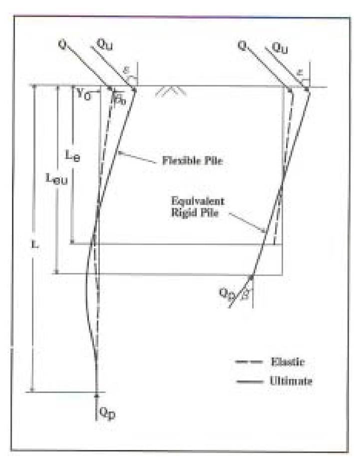

Fig. 5 Schematic diagram of flexible and equivalent rigid piles.

Where E_pI_p is the flexural rigidity of the pile $\overline{E}_n$is the weighted average normal secant modulus of soil in length L. The computed capacities for the piles tested agreed closely with the observed capacities as shown in Fig. 2 . The variation of bending moment along the shaft with the magnitude of load (Fig. 3) was similar to that observed in the case of vertical piles. The maximum bending moment M_m induced in a flexible batter pile under $Q_u$is obtained by once again considering an equivalent rigid batter pile of length L_{eu} so that,

$$M_m = 0.5 Q_n L_{eu} \tag{6}$$

The computed maximum bending moments agreed reasonably with the measured values as shown in Fig. 4.

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