BEHAVIOUR OF THE ULTIMATE BEARING CAPACITY OF SINGLE FLEXIBLE BATTER PILE UNDER HORIZONTAL LOADS IN HOMOGENEOUS SAND

PERILAKU DAYA DUKUNG ULTIMIT TIANG MIRING TUNGGAL FLEKSIBEL DENGAN BEBAN HORIZONTAL PADA TANAH HOMOGEN

Fabian Johanes Manoppo
Lecturer, Civil Department Faculty of Engineering SamRatulangi University Manado
Jl.Kampus Unsrat Bahu Manado 95115 Sulawesi Utara
Email: fabian_jm@yahoo.com

ABSTRACT

Behaviour of the ultimate bearing capacity of single flexible batter piles in homogeneous sand under horizontal and its applicability is discussed experimentally. Model tests were carried out using instrumented flexible piles of wide-ranging flexibilities. The piles were buried in loose, medium and dense homogeneous sand at batter angles β= 0^0, ±15^0 and ±30^0 were subject-ed to incrementally increasing horizontal loads. The results of model tests on single vertical and batter piles under horizontal loads in homogeneous sand shows that the batter angle (β) and the unit weight of soil (γ) significantly influenced the ultimate bearing capacity of the piles. Batter angles β= -15^0 or negative batter piles were higher compared then vertical piles and positive batter piles. The proposed value to analysis the ultimate bearing capacity of single flexible batter pile at batter angle β= -15^0 was 25% or 1.25 of the theoretical ultimate bearing capacity under horizontal loads.

Keywords: batter pile, bearing capacity, horizontal load, homogeneous sand

ABSTRAK

Penelitian ini membahas tentang perilaku daya dukung ultimit tiang miring tunggal feksibel dalam tanah homogen dengan beban horizontal dan aplikasinya dengan eksperimen. Pengujian dilakukan dengan menggunakan model tiang dengan berbagai tingkat fleksibilitas. Tiang ditanam dalam tanah pasir homogen yang lunak, sedang dan padat pada kemiringan β = 0^0, ±15^0, ±30^0 dan diberikan beban yang meningkat secara horizontal. Hasil dari pengujian model tiang tunggal vertikal dan miring yang dibebani secara horizontal pada tanah pasir menunjukkan bahwa sudut kemiringan (β) dan berat volume tanah (γ) memberikan pengaruh yang signifikan pada daya dukung ultimit tiang. Sudut kemiringan β = -15^0 atau tiang miring negatif mempunyai daya dukung tertinggi dibandingkan tiang vertikal dan tiang miring positif. Pada analisis daya dukung ultimit tiang tunggal fleksibel yang miring dengan sudut β = -15^0 disarankan 25% atau 1,25 dari daya dukung ultimit teoritis dengan beban horizontal.

Kata kunci: tiang miring, daya dukung, beban horizontal, pasir homogen

INTRODUCTION

Batter piles are usually employed when the lateral load exceeds an allowable limit for vertical piles (Mc Nulty, 1956; Peck et al., 1953) and widely used to support lateral loads caused on the foundation of many civil engineering constructions such as bridge abutments, transmission towers, offshore structures and quay walls. Analyses of laterally loaded piles of various stiffnesses in homogeneous elastic soils indicates (Meyerhof, 1979b ; Meyerhof and Yalcin, 1973) that free head piles may be considered as a rigid for practical purposes if their relative stiffness $K_r \geq 0.01$ and flexible piles if their relative stiffness $K_r \leq 0.01$. An out batter or a positive batter pile has horizontal load acting in the opposite direction to the batter, while a negative batter pile has horizontal load acting in the same direction of the batter as shown in Figure1.

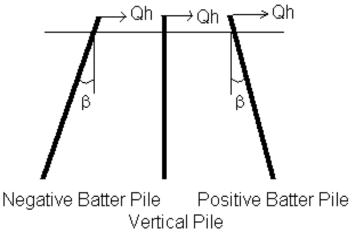

Figure 1. General type of vertical and batter piles

Earlier extensive theoretical and experimental studies have been made to analyze the behaviour of single vertical and batter piles in various soils under various loads such as (Award and Petrasovits,1968; Brinch-Hansen,1961; Kubo,1965; Meyerhof and Ranjan,1973; Meyerhof,1979b; Meyerhof et al.,1981; Murthy, 1964; Poulos and Davis,1980; Takahashi,1985; Tschebotarioff, 1953; Meyerhof and Yalcin,1993; Manoppo and Koumoto,1998a; Manoppo and Koumoto,1998b; Sastry et al.,1995). All of the above research was among the contributed on this research.

The aims of this research are to analyze the effect of batter pile and the density of sand in order to increase the ultimate bearing capacity of pile under horizontal load. The result of ultimate bearing capacity from laboratory test will be compared with the theoretical ultimate bearing capacity suggested by (Meyerhof and Ranjan 1973).

MODEL TEST

Soil and Pile Data

Sand used in the test was uniformly graded having effecttive size = 0.12 mm and uniformity coefficient = 1.67. The minimum and maximum void ratios of the sand were 0.61 and 0.96, respectively and the porosity of 47% gave a unit weight of about 14.0 kN/m^3 and the friction angle $\phi=31.0^0$ (Koumoto and Kaku,1988). Based on the above test, for unit weight 15.0 kN/m^3 and unit weight 15.5 kN/m^3 were given friction angle $\phi=37.0^0$ and friction angle $\phi=39.2^0$.

Assuming isotropy, the values of horizontal modulus elasticity of soil E_s along the embedded length of pile was back calculated from vertical rigid pile tests buried in the same sand.

The value of E_s was zero at the ground level, and linearly increasing to a value of 365.000 kN/m^2 at a depth of 380 mm. Based on that test the values of E_s at unit weight 15.0 kN/m^3 and 15.5 kN/m^3 are 761.215 kN/m^2 and 1376.365 kN/m^2. The model piles were made of alumunium, acrylic, hard rubber pipes and steel having an outside diameter B of about 16 mm, 30 mm, 40 mm and wall thickness of 1 to 4 mm. Twelve piles were used. The piles were buried to the length L of 160 mm, 320 mm, 380 mm and 640 mm in sand. The relative pile stiffness K_r ranged from 69×10^{-1} to10^{-5}. The details of piles tested are summarized in Table 1.

Table 1. Physical properties of piles

Pile	**L (mm)**	**B (mm)**	**d (mm)**
Alumunium			
A1	160	16	14.0
A2	320	16	14.0
A3	640	16	14.0
A5	380	30	-
A6	380	40	-
Acrylic			
P1	160	16	13.0
P2	320	16	13.0
P3	640	16	13.0
Hard Rubber			
R1	160	15	6.5
R2	320	15	6.5
Steel			
S1	380	30	-
S2	380	40	-

Test Details

The experimental setup is shown in Figure 3. Sand was rained and compacted in a square tank 48 × 48 cm and 80 cm depth. When the soil surface reached the required level, the pile was placed at a required batter angle $\beta = 0^0$, $\pm15^0$ and $\pm30^0$ to the vertical. The raining was continued until the tank was full. The horizontal load was applied in 10 to 20 increments, each being 0.0005 to 0.0200 kN depending on the estimated failure load.

Figure 3. Experimental box

The load was applied 20.0 mm and 25.4 mm above the ground level, through a wire passing over a pulley and attached to the pile top. The loading tests results load Q and deflection Y curves are being presented typically in Figure 4.

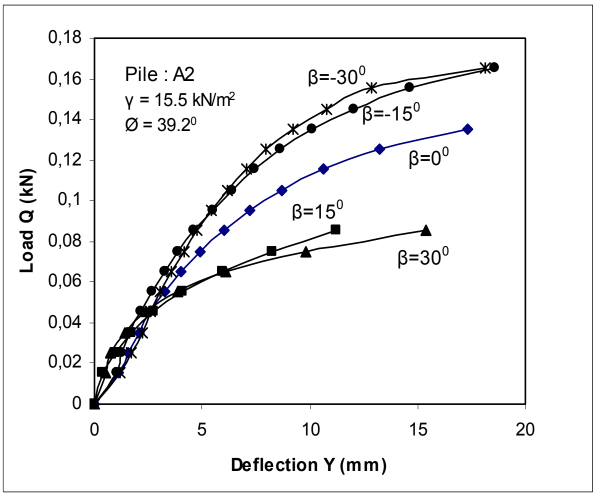

Figure 4. Typically load Q and deflection Y curves

ANALYSIS OF RESULTS

The ultimate bearing capacity of each batter pile from the laboratory test were computed based on fitting method suggested by (Manoppo and Koumoto, 1998a; Manoppo and Koumoto, 1998b). The theory of ultimate bearing capacity Q_{ut} of rigid batter piles was computed using the theory suggested by (Meyerhof and Ranjan, 1973), which assumes the rigid batter pile as a vertical rigid pile subjected to an inclined load,

$$\{(Q_{ut} \cos \varepsilon) / Q_a \}^2 + \{(Q_{ut} \sin \varepsilon) / Q_n \}^2 = 1 \qquad (1)$$

$$Q_a = \gamma\, L\, N_q\, A_t + K_s\, \gamma\, L \tan \delta\, A_s/2 \qquad (2)$$

where, Q_a is the axial capacity, γ is the unit weight of soil, L is the length of the pile, N_q is the bearing capacity factor, A_t is the area of the pile toe, A_s is the area of the pile shaft, K_s is the average earth pressure coefficient on the shaft and δ is friction angle between sand and pile material.

$$Q_n = 0.125\, \gamma\, B\, L^2\, K_b \qquad (3)$$

Q_n is the normal capacity, B is the diameter of pile, K_b is the earth pressure coefficient for pile (Meyerhof, G. G., Mathur, 1981). ε is the angle between the axes of the pile and the load. In the case of the flexible pile the length L is replaced with ultimate effective length L_{eu} by using the equivalent rigid pile method suggested by (Sastry and Meyerhof, 1994).

where,

$$L_{eu} /L= 1.65\, K_r^{0.12} \leq 1 \qquad (4)$$

$$K_r=E_pI_p/E_sL^4 \qquad (5)$$

K_r is the relative stiffness of piles (Poulos and Davis, 1980), E_pI_p is flexural rigidity of pile, E_s is horizontal modulus elasticity of soil. The effect of batter angle (β) on the Q~Y curves shows that the negative batter appear higher than those for vertical and positive batter piles as shown typically in Figure 5.

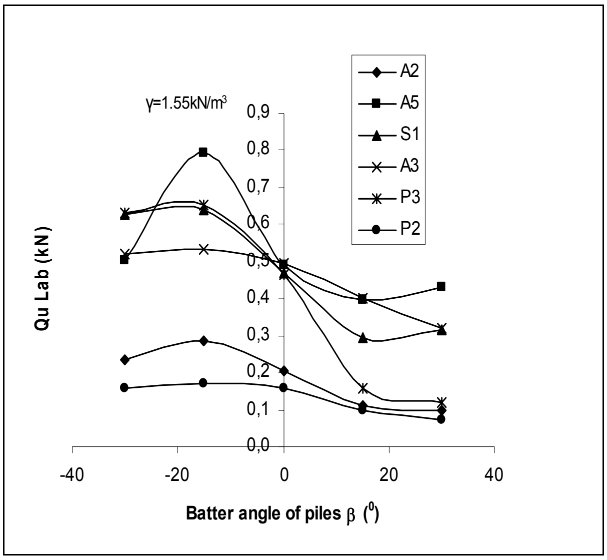

Figure 5. Typically pile loading test results

The ultimate bearing capacity increased as the sand density increased. This effect is shown in Figure 6.

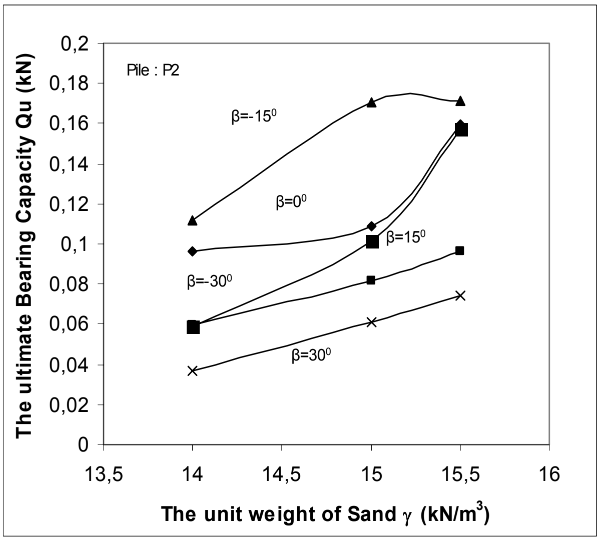

Figure 6. Typically relationship between the unit weight of sand γ and the ultimate bearing capacity Q_u

The conditions of piles after loading, for rigid pile cases, the piles are rotated following the general theory of rigid pile, where that failure of soil are occurred before failure of the pile it self. However, for flexible piles, the yield moment of the pile which may be reached before full mobilization of the ultimate soil resistance. The yield moment of the piles roughly occurred at one third of the embedded length L

CONCLUSSION

An analytical investigation was made to determine the ultimate bearing capacity of pile loading test results load Q and deflection Y curves for single flexible batter pile in homogeneous sand under horizontal loads.

The results of model tests on single vertical and batter piles under horizontal loads in homogeneous sand shows that the batter angle (β) and the unit weight of soil (γ) significantly influence the ultimate bearing capacity of the piles.

The negative batter piles at batter angel (β) -15^0 are more resistant to horizontal load than the vertical piles and positive batter piles. On the other hand the theoretical ultimate bearing capacity was given higher at batter angel (β) -30^0 because the theory was applied for vertical pile under inclined loads.

The proposed value to compute the ultimate bearing capacity of single flexible batter pile at batter angle β= - 15^0 was 1.25 of the normal or horizontal ultimate bearing capacity Q_n.

Although the methods of analysis in this study where shown negative batter piles higher then vertical and positive batter piles, it is believed that further testing of model single batter piles and group piles in the field are needed to verify the proposed concepts.

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