Performance of Batter Piles under Lateral Loads in Sand

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ABSTRACT: In view of the frequent applications of batter piles in foundation to resists lateral loads, a considerable amount of theoretical work has been done besides field and laboratory tests to evaluate the performance of such piles. In this paper, the deflection of flexible batter under lateral loads in sand and its applicability is discussed experimentally. Model tests were carried out using instrumented piles of wide-ranging flexibilities. The rigid and flexible piles were buried in loose sand. Piles were installed at batter angles $\beta = 0^0$, $\pm 15^0$ and $\pm 30^0$ and were subjected to incrementally increasing lateral loads. The deflection of each piles from the laboratory test were computed based on the fitting method suggested by Manoppo and Koumoto. The deflection from the laboratory test was compared than the theory suggested by Poulos and Davis, Sastry et al. and Chang. The result of deflection shows that for flexible piles Chang and Sastry et al. method was better than Poulos and Davis method. On the other hands, for rigid pile Poulos and Davis method was applicable to used

Keywords: Batter pile, deflection, lateral load, model test, sand

1. INTRODUCTION

Batter piles are usually employed when the lateral load exceeds an allowable limit for vertical piles (Peck et al. 1953; McNulty, 1956) and widely used to support lateral loads caused on foundation of many civil engineering constructions such as bridge abutments, transmission towers and offshore structures. Analysis of lateral loaded piles of various relative stiffness in homogeneous elastic soils indicates (Meyerhof,1979, Meyerhof and Yalcin, 1984) that free head piles may be considered rigid for practical purposes if their relative stiffness Kr $\geq$0.01 and flexible piles if their relative stiffness Kr $\leq$ 0.001. An out batter or a positive batter pile has lateral load acting in the opposite direction to the batter, while a negative batter pile has lateral load acting in the same direction. Earlier extensive theoretical and experimental studies have been made in the past to analyzed the behavior of single vertical and batter piles in various soils under various loads, for example,(Brinch Hansen, 1961; Meyerhof and Ranjan, 1973; Meyerhof et.al, 1981;Chang, 1973; Poulos and Davis, 1980; Sastry, Koumoto and Manoppo, 1994; Sastry, Koumoto and Manoppo, 1995) were among the contributions based on this experimental work. This paper presents the method of Sastry et. al for determining the deflection of batter piles under lateral loads in sand. The working load for determining the deflection was computed based on fitting method suggested by Manoppo et al. [illegible].

2. MODEL TEST

2.1 *Soil and Pile Data*

Sands used in the test was uniformly graded having effective 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 γ of about 14.0 kN/m^3 and the friction angle ϕ=31.0^0. 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 ϕ=37.0^0 and friction angle ϕ=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 burried in the same sand. The value of E_s was zero at the ground level, and was 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(A2, A3), acrylic (P2,P3)and steel(S1) having an outside diameter B of about 16 mm and 30 mm and wall thickness of 1 to 4 mm. Five piles were used in this research. The piles were buried to the length L of 320 mm, 380 mm and 640 mm in sand. The relative pile stiffness K_r ranged from 69×10^{-1} to10^{-5}.

2.2 *Test details*

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. 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 horizontal deflection of the load point was measured by a LVDT (Linear Voltage Differential Transducer).

The loading tests results load Q and deflection Y curves are being presented typically in Fig.1.

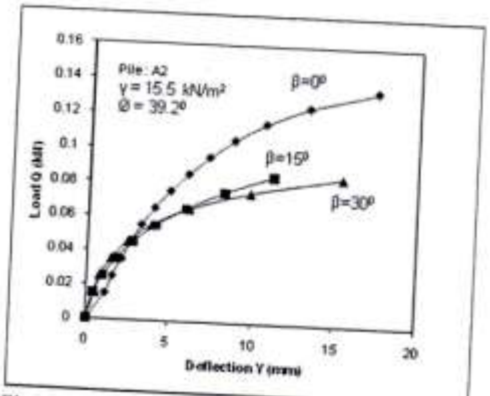

Figure 1. Typically results load Q and deflection Y curves

3. RESULTS AND ANALYSIS

Based on the ultimate bearing capacities computed by using the fitting method (Manoppo, F.J and Koumoto, T, 1998), the observed deflection of flexible batter pile could be determined. The observed deflection values were compared with theoretical estimates derived from three methods as follows:

The lateral ground line deflection Y and rotation ϑ of rigid pile of length L under a working lateral load Q = $Q_u/2 \sim Q_u/3$. (Q_u is the ultimate bearing capacity derived with the fitting method) acting at a height h above the ground surface are estimated by using the theory of Poulos and Davis, 1980

$$Y_o = Q \times \left(I_{\rho h} + I_{\rho m} \times {h}/{L}\right) / E_s \times L \times F_\rho \quad (1)$$

$$\theta_o = Q \times \left(I_{\theta h} + I_{\theta m} \times {h}/{L}\right) / E_s \times L^2 \times F_\theta \quad (2)$$

$$Y_1 = Y_o + \tan(\theta_o) \times h \quad (3)$$

Where, Y_o and θo are the ground surface deflection, Y_1 is the load level deflection, E_s is the modulus elasticity of sand, $I_{\rho h}$, $I_{\rho m}$= $I_{\theta h}$ and $I_{\theta m}$ are elastic influence factors of sand for a rigid pile, F_ρ and F_θ are yield deflection and rotation factors of sand, respectively. This method is referred to as method 1.

In the case of of flexible pile, the method suggested by Sastry, Koumoto and Manoppo, 1995,1996 were used, in which the length L of pile was replaced with the length effective L_e

$$L_e/L = 2{,}3 \times K_r^{\,0,2} \leq 1 \quad (4)$$

$$K_r = E_p I_p / E_s' L^4 \quad (5)$$

Where, K_r is the relative stiffness of pile. Considering average constant values of $I_{\rho h}$=7.5, $I_{\rho m}$= $I_{\theta h}$=9, $I_{\theta m}$=12. The Y_1 values are then computed according to equation 3. This approach is referred to as method 2.

Deflection values due to a working lateral load Q acting at a height h above the ground level on a flexible pile of length L embedded in a soil with a uniform normal secant modulus of E_s' are also computed by Chang, 1973

$$Y1 = Q\{(1+\beta)3 + 0{,}5\} / 3 \times E_p \times I_p \times \beta^3 \times F_\theta \quad (6)$$

$$\beta = \left(E_s'/4E_p I_p\right)^{0.25} \quad (7)$$

This approach is referred to as method 3.

The results of the observed deflection values based on the fitting method and the theoretical deflection values are presented in Figure 2, 3 and 4.

Generally the results show that rigid pile method 3 was usually under estimated and method 1 was close to the observed deflection. On the other hands, method 2 and method 3 were closed to the observed for flexible piles as shown in Figure 2,3 and 4. The effect of unit weight γ shows that the deflection decreases as the unit weight increases. The most significantly influenced to the deflection was the relative stiffness K_r of piles as shown in Figure 2,3 and 4.

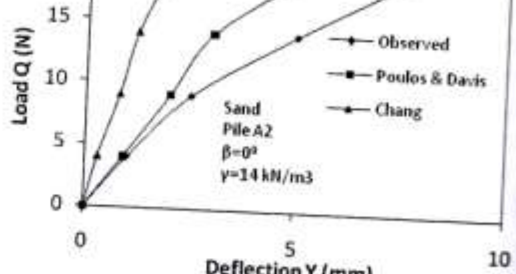

Figure 2. Typically relationship between lateral load Q and load level deflection Y

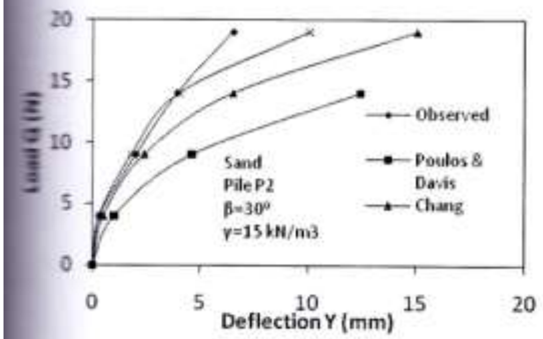

Figure 3. Typically relationship between lateral load Q and load level deflection Y

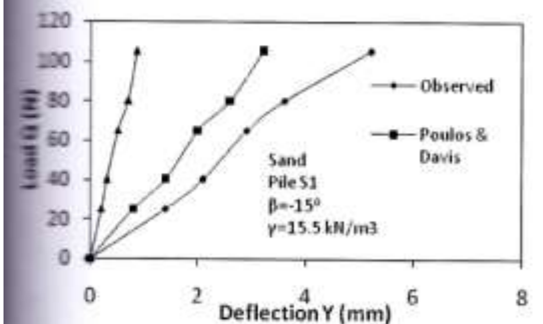

Figure 4. Typically relationship between lateral load Q and load level deflection Y

4. CONCLUSIONS

The result of deflection shows that for flexible piles Chang and Sastry, Koumoto and Manoppo method was better than Poulos and Davis method. On the other hands, for rigid pile Poulos and Davis method was applicable to used. Although the method of analysis in this study are reasonably, it is believed that further testing in the field are needed.

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