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Pullout capacity of batter pile in sand

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Abstract Many offshore structures are subjected to overturning moments due to wind load, wave pressure, and ship impacts. Also most of retaining walls are subjected to horizontal forces and bending moments, these forces are due to earth pressure. For foundations in such structures, usually a combination of vertical and batter piles is used. Little information is available in the literature about estimating the capacity of piles under uplift. In cases where these supporting piles are not vertical, the behavior under axial pullout is not well established. In order to delineate the significant variables affecting the ultimate uplift shaft resistance of batter pile in dry sand, a testing program comprising 62 pullout tests was conducted. The tests are conducted on model steel pile installed in loose, medium, and dense sand to an embedded depth ratio, L/d, vary from 7.5 to 30 and with various batter angles of 0°, 10°, 20°, and 30°. Results indicate that the pullout capacity of a batter pile constructed in dense and/or medium density sand increases with the increase of batter angle attains maximum value and then decreases, the maximum value of P_α occurs at batter angle approximately equal to 20°, and it is about 21–31% more than the vertical pile capacity, while the pullout capacity for batter pile that constructed in loose sand decreases with the increase of pile inclination. The results also indicated that the circular pile is more resistant to pullout forces than the square and rectangular pile shape. The rough model piles tested is experienced 18–75% increase in capacity compared with the smooth model piles. The suggested relations for the pullout capacity of batter pile regarding the vertical pile capacity are well predicted.

Introduction

Batter piles are commonly used to support offshore structures, towers, and bridges since this kind of structures are subjected to overturning moment due to wind, waves, and ship impact. In order to transfer the over turning moment to a compression and tension forces, a combination of vertical and batter piles are used. In the literature the pullout capacity of batter pile in sand has been the subject of few studies. Experimental studies showed a wide discrepancy exists among them. It was found from the full scale results reported by Meyerhof [1] that the pullout capacity for batter piles in sand increases due to an

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increase of inclination angle, α, of the pile with respect to the vertical, in this study the tests are performed on dense sand. On the other hand Awad and Ayoub [2] showed that the pullout capacity of these piles decreases due to an increase of the angle, α. An empirical equation was developed for determining the ultimate pullout capacity of inclined piles.

$$P_\alpha = P_o\{\cos\alpha/(\cos\alpha + \tan\alpha)\} \quad (1)$$

where P_α = net ultimate pullout capacity of batter pile, P_o = net ultimate pullout capacity of vertical pile, and α = inclination angle of the pile in degrees. Hanna and Nguyen [3] confirmed the observation of Meyerhof [1] for the shaft resistance of single piles subjected to compression loading. The experimental results reported by Afram [4] showed that no significant change on the pullout capacity of batter piles due to an increase of the pile inclination. This investigation is performed on medium density sand having an angle of shearing resistance of 35°. Hanna and Afram [5] conducted experimental investigation to evaluate the pullout capacity of vertical and batter piles. From this investigation it was found that the shaft resistance was not highly affected by the inclination of pile. They suggested an empirical formula to evaluate ultimate pullout resistance for inclined pile in sand.

$$P_\alpha = P_o\cos(\alpha/2) \quad (2)$$

The theoretical analysis results reported by Chattopadhyay and Pise [6] concluded that for equal length piles, the ultimate uplift capacity of inclined pile increases with increase in inclination of pile and decreases after reaching maximum value at inclination angle, α, 20. Sharma and Pise [7] carried out extensive work on uplift behavior of anchor piles in sand under axial pulling loads. They concluded that uplift capacity increases with increase in pile friction angle, depth of embedment and L/d ratio. al-Shakarchi et al. [8] concluded that the vertical pile has ultimate uplift load greater than the batter pile. Different theories regarding behavior of piles under different loading conditions have been developed over the years. The reliability of the theories can be demonstrated only by comparison of experimental results on model or field piles with the theoretical predictions. Full-scale field tests, though highly desirable, are generally expensive and difficult to perform. Due to the conflicting conclusions reported in the literature for the pullout capacity of batter pile, an extensive model study is performed to support the published results. In the absence of resources and scope of testing prototype small scale laboratory model test conducted on piles in foundation prepared under controlled condition may serve the purpose to some extent. Properly conducted laboratory tests, with known parameters affecting the soil–pile response under pulling loads would provide information on qualitative and quantitative contributions of such parameters on ultimate resistance of piles in the absence of field test results. Compared to previous studies in this area, this investigation proposes to consider wider range of parameters and their effects on the uplift capacity of piles.

Experimental

Model test tank

Tests were conducted in a specially fabricated steel tank, having inside dimensions of 1.00 m × 0.60 m in plan and 0.75 m in depth. The tank is made from steel with the front wall made of 20 mm thick glass and is supported directly on two steel columns as shown in Fig. 1. These columns are firmly fixed in two horizontal steel beams, which are firmly clamped in the lab ground using four pins. Axial pullout loads were applied to the piles through double pulley arrangement the steel loading frame, movable along the length of chamber with an inverted pulley was used to align the axis of batter pile and wire rope. The non-extensible steel wire rope was attached to the pile top by bolting. The wire rope was taken first through an inverted pulley and then over the second pulley. Loading pan where dead weights were put for loading was fixed at the other end of wire as shown in Fig. 1. The position of first pulley was fixed according to the alignment of the wire rope and pile axis as per the inclination of the pile. A long steel flat plate was placed along the width of the chamber to mount magnetic base of two dial gauges. Two dial gauges were fixed equidistant from pile axis. The loads were applied by dead weights in the loading pan starting the smallest with gradual increase in stages. Dial gauge readings were observed for both dial gauges for each increment of loading when it becomes stable. Average value of displacement as recorded from both the dial gauges have been taken as axial displacement of the pile corresponding to the pullout load applied.

Sand bed

The sand used in this research is medium to coarse sand, washed, dried and sorted by particle size. It is composed of rounded to sub-rounded particles. The sand has a very low impurity level with a quartz (SiO_2) content of 97%. The specific gravity of the soil particles was determined by the gas jar method. Three tests were carried out producing an average value of 2.654. The maximum and the minimum dry unit weights of the sand were found to be 17.99 and 14.15 kN/m^3 and the corresponding values of the minimum and the maximum void ratios are 0.305 and 0.593, respectively. The particle size distribution was determined using the dry sieving method. The effective size (D_{10}), the mean particle size (D_{50}), uniformity coefficient (C_u), and coefficient of curvature (C_c) for the sand were 0.15 mm, 0.50 mm, 4.07 and 0.77, respectively.

Sand beds were placed in 50 mm thick layers by a raining technique in which sand is allowed to rain through air at a controlled discharge rate and different heights of fall to give uniform densities. The relative density achieved during the tests was monitored by collecting samples in small cans of known volume placed at different locations in the test tank. The raining techniques adopted in this study provided uniform relative densities of 25%, 50% and 81%, representing loose, medium density and dense sand conditions. The corresponding average unit weights are 14.95, 15.84 and 17.06 kN/m^3 respectively. No particle segregation was noticed during raining and uniformity tests showed that the obtained relative densities from the three samples did not depend on the location of the cans. The estimated internal friction angle of the sand determined from direct shear tests using specimens prepared by dry tamping at the same relative densities were 30.50°, 36° and 43.5° respectively.

Model anchor piles

Tests under axial pullout have been carried on Piles. The shaft was made of mild steel hollow pipes having out side diameter