Behavior of batter pile group models embedded in sandy soil under monotonic loading

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Abstract. This paper introduces an attempt to examine the effect of vertical monotonic load on the batter pile group models on its ultimate vertical load capacity. A fourteen steel solid pile models are used in this research. Three lengths of piles are selected (300, 400, and 500 mm) for embedment ratios (depth to width) 15 and 25, respectively. Batter piles are embedded in three different relative densities of sand bed (loose, medium and dense). The constant rate penetration test (CRPT) method was selected using a manufactured driving hammer to install the pile models in a steel box with dimensions (1000, 750 and 700) mm. The vertical cyclic load is conducted by a special hydraulic apparatus. The results indicate that the batter-vertical load capacity (BVLC) ratio increased by the increase in the embedded pile length. The batter pile group has a higher capacity at 20 degrees batter angle as compared with the vertical groups. Vertical pile groups exhibited more efficiency, which increases when pile length increases while decreases when the relative density is increased. The batter-vertical load capacity ratio increases when the embedded pile length increases and decreases with the increase in the relative density.

Keywords
Batter Pile, Bearing Capacity, Dry Sand, Monotonic Test.

1. Introduction

Many fields use batter piles, especially when the resultant of forces inclined, such as retaining walls, bridge abutment and slope stability. On the other hand, these piles are preferable in resisting lateral and seismic loads. But, when the potential for negative skin friction is developed, batter piles should be avoided because the magnitude of down drag on the outer side of batter piles are significantly larger than the inner vertical piles and the settling of soil moving away from the inner piles.

The research work focused on the batter pile groups under vertical load are very limited; therefore, the information and experimental data about it are not available widely; therefore, this study will explain the behavior of batter pile groups with different parameters (pile number, relative densities of sand and the length to diameter ratio of pile) then compare it with vertical pile groups.

Full-scale test on groups of vertical and batter piles at Nock No. 25, in Missouri, have been reported by Feagin (1953). The tests involved two groups of all vertical piles, two groups of all batter piles, and four groups of different combinations of vertical and batter piles. Only one angle of batter of 20 degree with vertical was used for batter piles. It was shown that the groups of batter piles combined with vertical piles were more resistant to lateral load than the corresponding groups of vertical piles.
The resistance to lateral load against the batter was greater under the vertical load than for no vertical load, whereas for a lateral load in the direction of the batter, the resistance was substantially the same either with or without vertical load.

Wen (1955) conducted a series of small scale model tests on two and three pile bents with various configurations of vertical and batter piles. A single pile inclination of 18.4 degrees was used for a bent batter pile. It was found that the distribution of external loads to the different piles in a laterally loaded pile foundation was largely dependent on the foundation displacements and the high lateral loads. Pile groups with batter piles had more resistance to lateral loads than those with only vertical piles.

Murthy (1964) was the first to perform a comprehensive test program on instrumented model batter piles. His program included four series of small scaled model tests, comprised static load tests on single piles of (-45, -30, -15, 0, +15, +30, +45) batters, under static and cyclic loading. Results of the single pile tests under static loading showed that positive batter piles were less resistant to lateral load than negative batter piles, the resistance to lateral loads increased in the order of the batter angle of +45, +30, +15, 0, -15, -30, -45, the positive batter piles were subjected to greater moments than the negative batter piles for the same lateral load at ground line.

Zhang et al. (1999) conducted a study to examine the effects of pile batter and soil density upon the lateral resistance of the single batter pile in loose, medium and dense sand conditions. They concluded that the piles with negative batters were more resistant to the lateral loads than the vertical piles, and effects of the pile inclination were significant in the medium sand.

Shakarchi et al. (2004) carried out an experimental work on the single batter pile in sand subjected to uplift loads of inclinations 0°, 15°, 30°, 45°, 60°, 75° and 90°. It was found that the uplift capacity of vertical and batter piles under inclined pulls increased with increasing the inclination of pull with the vertical and the maximum value was at horizontal pull.

Manoppo (2010) discussed experimentally the behavior of the ultimate bearing capacity of single flexible batter pile in the homogeneous sand under horizontal load buried in loose, medium and dense homogeneous sand at batter angles β: 0, ±15 and ±30. The results showed that the batter angle (β) and the unit weight of soil (γ) significantly influenced the ultimate bearing capacity of the piles, and negative batter piles had higher resistance to lateral load than vertical piles and positive batter piles.

Hirani et al., (2013) stated that the pile group in loose to medium sand has found vast application worldwide. The result shows that when piles are placed at 5° battered angle, it offers 40% - 50% more resistance as compared to vertical pile group, when piles are placed at 10° battered angle it offers 9%-11% more resistance as compared to plumb pile group and the optimum angle of a battered pile group under for vertical loading is 5°.

Al-Neami et al., (2016) conducted an attempt to examine the effect of batter angle of a 32 single pile model with three embedment ratios (depth to width, L/D) = 15, 20 and 25, on its ultimate vertical load capacity. The constant rate penetration test (CRPT) method was selected using a manufactured driving hammer to embed the pile models in three different relative densities of sand (loose, medium and dense sand bed). The results indicate that there is an optimum batter angle (20°) that gave a higher load capacity. Pile load capacity is highly affected by relative density and less affected by L/D ratio.

2. Material Used
The piles used in this study are circular steel solid piles with a 20 mm diameter and different heights (300, 400 and 500) mm. The head of piles was manufactured as screw cylinder 7mm diameter and 25mm height. Three different configurations of piles were used in the pile models. The model groups
consist of (1×2), (2×2), and (2×3) piles as shown in Figure (1). Three steel plates [(2×1), (2×2), and (2×3)] with dimensions (120×60×4), (120×120×4), and (180×120×4) mm, respectively, were manufactured to ensure that the piles are embedded in the desired location in the sand model by putting them below the pile driving hammer device. Each guide plate has circular holes of (21) mm each and the spacing center to center between the holes was (3D) as shown in Figure (2).

Air dry sand with three different densities; loose, medium, and dense sand was used and the tests were performed according to ASTM specifications. The soil is classified as poorly graded sand (SP) as shown in figure (3). Table 1 summarizes the properties of the sand used.

3. Sand Deposit Preparation
The sand deposit is prepared in a steel box with dimensions (1000×750×700) mm as shown in Figure (4), using a modified compactor manufactured for this purpose. Three cases of relative densities are chosen (40% for loose sand, 60% for medium sand and 80% for dense sand), this means that the weight required to achieve the relative density is predetermined since the unit weight and the volume of the sand are predetermined also, the weight is divided into six equal weights (10 cm height of each layer).
The soil of each layer is compacted to a predetermined depth. After completing the final layer, the top surface is scraped and levelled by a sharp edge ruler to get as near as possible to a flat surface.

4. Installation of Model Driven Piles
After the preparation of the sand bed, the driving hammer is fixed to the container and the guideline plate is put under the base of the pile driving hammer device to insert the pile models to the required length with a counted set.

The pile model is vertically installed in the hole that is there in the hammer plate and the rod of the hammer is lowered on the model piles until the screw of the pile enters inside the rod of the hammer as shown in Figure (5).

The driving process begins by dropping the weight at the required height, and the results of the number of blows are recorded for the final (25mm) of model pile length.

Table 1. Physical properties of the used sand.

| Property                         | Value                  |
|----------------------------------|------------------------|
| Effective size, D_{10}, D_{30}, D_{50}, D_{60} | 0.29, 0.45, 0.7, 0.9  |
| Coefficient of uniformity, Cu    | 3.10                   |
| Coefficient of curvature, Cc     | 0.78                   |
| Classification (USCS)            | SP                     |
| Specific gravity, Gs             | 2.66                   |
| Maximum unit weight, γ_d (max.) kN/m3 | 19.4             |
| Minimum unit weight, γ_d (min.) kN/m3 | 16.2              |
| Maximum void ratio, e_max        | 0.642                  |
| Minimum void ratio, e_min        | 0.371                  |
| Relative density, %              | Loose = 40 Medium = 60 Dense = 80 |
| Dry unit weight (γ_d) kN/m3       | 17.3 18.0 18.7         |
| The angle of internal friction (φ), deg. | 33 37 40            |
| Void ratio (e)                   | 0.53 0.48 0.42         |
5. Model Test and Test Procedure
A special testing apparatus was used. The apparatus has the capability of applied monotonic and cyclic loads. After the installation of the pile model, the container moves along the rails and is fixed in position in such a manner that the center of the aluminium base plate of the piston coincides with the center of the pile model.

The constant penetration test is used in testing as explained in ASTM D1143-07. The static loading is applied gradually through the hydraulic jack with a displacement rate of 0.03mm/Sec. The loading is continuing till failure occurs, the testing apparatus is shown in Figure (6).

6. Model Test Results
The failure criterion of bearing capacity proposed by ASTM D1143 (2013) is used [the failure load is defined as the load required to cause settlement corresponding to 15% of the pile diameter].
The results of 36 pile model tests performed on the dry sand subjected to a vertical static compression load using different relative densities are presented and discussed below.

The batter pile groups tested at an angle 20°, since the angle of 20° has higher load capacity than other inclination angles as proved by Al-Neami et al., (2016). In order to study the behavior of the batter pile group under monotonic load in sandy soil, the pile groups are tested under different (length to diameter ratio, pile groups configuration, and relative densities). The following sections present the effect of each of the above parameters on load carrying capacity.

6.1 Effect of Length to Diameter Ratio

The ultimate load capacity of pile groups was highly affected by (L/D) ratio for the same pile group configuration and relative density. It can be noted from Figure (7) that the increase of battered groups load capacity was approximately 20%, 25% and 40% corresponding to L/D 15, 20 and 25, respectively. The BVLC is batter vertical load capacity ratio that is the batter load capacity divided by vertical load capacity. The average percent of this increment is 6% of the increase of 33% L/D, while it is 24% when L/D is increased to 66%. This is due to the increase in a pile length, and hence, more skin friction resistance mobilized more load capacity.

The pile group efficiency is increased as the L/D ratio increases as shown in figure (8), this phenomenon related to the interaction decreases as the length of pile increases.

Figure 7. Effect of length to diameter ratio on the batter to vertical load capacity ratio for relative density 40%.
6.2 Effect of Piles Number

The ultimate load capacity ratio was less affected by piles number, as noted from figure (9). The increment percentage of battered groups ranges in between (10 - 40) %, (15 - 40) % and (25 - 45) % for pile groups configuration (2×1), (2×2) and (2×3), respectively. The average percentage of increment was 5% when the number of piles was doubled, and for a triple, the increment was by 9%. Indeed, the increase in the number of piles would increase the pile loading capacity. The vertical group’s efficiency is higher than batter groups’ as shown in figure (10), that may be attributed to the batter groups’ interaction which is higher than vertical groups’, as clarified in figure (11).

Figure 8. Relationship between L/D ratio and efficiency in RD 40%.

Figure 9. Effect of pile groups configuration on the batter to vertical load capacity ratio for relative density 40%.
6.3 Effect of Relative Density
The effect of relative density was studied on 2×2 pile group. This was because such configuration has a symmetric shape. Figures (12 and 13) show the relationship between load capacity and settlement ratio (settlement to pile diameter) for different relative densities and L/D ratios for both vertical and batter pile groups.

Figure 10. Relationship between efficiency and number of piles.

Figure 11. Zones of Group interaction for vertical and batter pile.
The ultimate load capacity ratio has been exhibiting a higher percent of increasing the lower relative density and this percent decreased as the relative density increased. At a 40% relative density, the increasing percent is 34% and 24% for L/D 25 and 15, respectively. On the other hand, for 80% relative density the increasing percent was 6%, almost it was equal for both L/D ratios (15 and 25) as shown in Figure (14). The reason for such behaviour is the percent of batter-vertical load capacity (BVLC) decreased as the relative density increased because the lateral earth pressure coefficient decreased due to the increase of relative density as suggested by Chi-in (1957), and lead to a decrease in horizontal stress as relative density increased.

The pile group efficiency is decreased as the relative density increases for both vertical and batter groups as shown in figure (15), which is because the group interaction increased as the relative density increased, as cited by Sayed and Bakeer (1992).
Figure 14. Effect of relative density on the batter to vertical load capacity ratio for L/D 15 and 25.
7. Conclusion
Based on the results of 36 monotonic test models carried out on batter and vertical pile groups embedded in sand, the following conclusions are drawn:
1. The batter pile group capacity at inclination of 20 degrees is higher than vertical groups.
2. The efficiency of vertical pile groups is higher than batter groups and it is increased as the length of pile increases and decreased as the relative density increases.
3. The pile group load capacity is increased by the increase of pile length, also the BVLC ratio increased by the increase in the embedded pile length. The pile groups load capacity increased as the number of piles increased.
4. The pile group load capacity is increased as the relative density increases for both vertical and batter. On the other hand, the BVLC ratio decreases as the relative density increases.

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