Influence of Geometry and Separation Walls on The Behaviours of Pull-out Pipe Piles Embedded in Sandy Soil

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Abstract. Predicting of piles capacity and their behavior is always an important and serious problem for a safe geotechnical engineering design. In the present study, experimental model tests have been conducted on a single steel pipe piles driven in sandy soil and subjected to pull-out force. The experimental tests were conducted on vertical open-ended piles with circular and square cross-sectional area and three various diameters 3 cm, 4 cm and 5 cm in a steel soil box have been used. The tested pile's model has embedment with three penetration ratios (PR=L/D) of 10, 15 and 20. All tests were done in medium density soil (Dr = 50%) with open ended pipe pile to study the effect of pile geometry on pile behavior, and three other tests were conducted on the 5cm diameter and 10 penetration ratio in medium soil density to study the importance of addition of separating wall. The study discovered that the capacity of single piles with circle cross-section area under pull-out force increasing by 211% and 458% with the increasing of pile diameter (width) from 3cm to 4cm and 5cm respectively, and increasing by 210%, 448% and by 112%, 288%. Also, by 79% and 211% with increasing penetrating ratio (PR) from 10 to 15 and 20 for diameters 3cm, 4cm and 5cm respectively, with respect to reference pile. And the same behavior for square cross-section pipe pile, when the pull-out capacity increasing with the increase of pile width and penetration ratio due to the increasing in the friction area. Besides that, It was also found that the separation walls increased the coefficient of lateral pressure in addition to the friction area. At the same time, there are an optimum number of separation walls that can be used to increase the pile pull-out capacity and that when using three separation walls.

1. Introduction

The foundation is the part of structure that provides support to it by transferring loads from the superstructure to the strong soil layer(s). Hence, the layer(s) in which the loads are transferred must be have adequate capacity and low compressibility so that there are no risk of shear failure in the soil mass and no the settlement stay within the tolerable amount. There are several types of foundation which are adopted depending on many considerations such as location of water table, total load of the superstructure, soil conditions, cost and available resources of materials…etc. Piles are the common type of the deep foundation that are used for traditional buildings, tall buildings, bridges, towers, etc. The main uses of the piles are to resist vertical compression, uplift and lateral loads (horizontal or inclined loads). Pile under uplift loads occurs at bridge foundation, abutments and in the case of overturning loads exist on the structure such as tall buildings, for instance, winds and waves loads. Also, the piles are used as settlement reducers when their tips are located above highly compressible soil layer (i.e. bearing capacity). The uplift force on the pile is resisted by its own weight and skin friction developed along pile's surface [1].
Analysis and understanding the behavior of pipe piles under pull-out forces in addition to the parameters affecting the pull-out capacity of piles is one of the most important and curious areas of study in geotechnical engineering. In cohesionless soils, the shaft resistance is an important source of pile capacity under axial loading.

Pipe piles constructed in two types closed-ended and open-ended. The first one is used to increase the pile capacity due to soil densification that is resulted from lateral displacement of the soil during pile driving. While, the second type is used to make the penetration process of the piles easier, especially when piles driven in dense sand layers. When driving open end pipes made of steel within the soils, a column of soil may develop inside it, this phenomenon is called (soil’s plugging). Upward soil movement inside pipe piles not stopped but restricted to a certain limit [2,3].

It is well known that the skin friction resistance plays, in general, an important role in determining pile capacity especially for pull-out pile capacity where in this case pile capacity is the sum of skin friction of outer and inner pile surfaces in contact with the soil and the weight of the pile itself. In order to increase capacity of open-ended pile, the inner skin friction resistance should be increased. Some researchers have proposed practical procedures to achieve this increasing by increasing the friction or/and the contact surface of the pile with plugged soil, Yamahara [5] and Matsumoto [4] suggested two methods of increasing the inner skin friction resistance by providing of friction legs inside the pile to make high friction coefficient between the inner surface area and the soil plug and the other method using of separation walls along a specified length of the pile near its tip and/or inner pile with smaller diameter to increase the contact surface area.

The current study aims to investigate the effect of pile geometry on the pull-out piles capacity besides the addition of separating wall inside the pile to increase pile’s capacity of open-end type.

2. Ultimate pile capacity

When driving a steel pipe pile with open-ended in the ground, column of soil inside the pile may develop significant internal shaft resistance to prevent more soil from entering the pile. These phenomena known as a "soil plugging" [6].

Ultimate pile capacity of a single pile represents the total of the shaft capacity and tip resisting. The net pile's weight works in the same sense of the applied load, so from the theoretical point of view it had to subtract from the computed pile capacity. But the net pile's weight is considered as a small amount so it is neglected in calculating the ultimate pile capacity [7].

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Q_u = \sum Q_s + Q_b - W
\]

where: Qs: is the ultimate shaft resistance.
Qb: is the ultimate base (tip) resistance.
W: is the weight of pile.

The above equation applies when the pile is subjected to a compression load, but when the pile under tension load, the ultimate load capacity is coming from the weight of the pile plus the ultimate shaft resistance only. Sowa [8] studied the possibility of estimating the uplift capacity of piles by constructed concrete cast in-situ bored piles in sandy and cohesive soils. The study showed that the uplift capacity in sand more difficult to estimate than in cohesive soil. Also, Das presented a procedure to compute the ultimate uplift capacity of rough rigid piles in sand by using small scale laboratory testing for three series tests [9]. Suleiman and Coyle [10] suggested a t-z method to predicted the pile response under tension loads in medium density of poorly graded sandy soil, the offered t-z curves done by laboratory tests on steel pipe piles in sandy soil [10]. The researchers discovered that the ultimate uplifting capacity is increased with depth and related to the soil properties. The most important factors effected on pile capacity are the pile shape, pile diameter (width) and penetrating ratio, and these factors can be denoted as "pile's geometry" [10].

3. Materials and experimental model

Many geotechnical problems like pile's behaviour can be modelled and inspected carefully using principles of physical modelling in geotechnics. Physical modelling may be done either by centrifuge
or by 1-g tests. Centrifuge modelling is considered as one of the most important developments in geotechnical engineering. It has been the suitable method for tackling complex geotechnical problems [11]. Centrifuge tests are conducted under higher gravitational acceleration. While, in 1-g modelling the tests are performed under gravitational acceleration field. In this study, 1-g modelling have been adopted due to unavailability and expensively of the centrifuge tests. The following sub-sections clarify the details of materials used in the modelling process and testing procedure.

3.1 Steel Box

The experimental tests were performed on model piles in a steel soil box. Figure (1) explains the representation diagram of the test system. steel container of (50*50) cm plane dimensions which manufactured of 4 mm thick steel plate was used. It is stated in the literature that the influence of driving pile in cohesionless soil extended to distance between 4.5 to 5.5 times diameter from the face of the pipe pile [8]. The height of the steel container was changed to be suitable for the model pile length. Generally, soil bed of thickness more than 5 times diameter was supplied beneath the tip in all tests. Hence, four containers were made with different heights one of 50 cm, two of 40 cm and one of 30 cm.

![Figure 1. the representation diagram of the test setup](image)

3.2 The used soil

The soil used in this study is obtained from a site at center of Al-Najaf city in Iraq, which is used as a foundation soil. The physical and chemical tests were performed in order to classify the soil. The grain size distribution of the sand is shown in Figure (2) and conducted according to (ASTM D 422-2001). The soil is classified as SP soil (poorly graded sand) based on the Unified Soil Classified System (USCS) and all tests were conducted on sand in accordance with ASTM standards.

Table (1) shows the physical and mechanical properties of the soil used in the current work also some chemical tests were performed on the soil used. Also, Table (1) shows the friction angles for relative densities(Dr) adopted in the tests.
Table 1. Physical and mechanical properties of the soil used

| Property      | Value and units |
|---------------|-----------------|
| $D_{60}$      | 0.44 mm         |
| $D_{30}$      | 0.30 mm         |
| $D_{10}$      | 0.21 mm         |
| Gravel        | 0 %             |
| Sand          | 100 %           |
| Silt and Clay | 0 %             |
| Cu            | 2.10            |
| Cc            | 1.65            |
| Gs            | 2.62            |
| $d_{(\text{max})}$ | 16.21 kN/m$^3$ |
| $d_{(\text{min})}$ | 14.06 kN/m$^3$ |
| $e_{\text{max}}$ | 0.83           |
| $e_{\text{min}}$ | 0.58           |
| Loose         | 35°             |
| Medium        | 38°             |
| Dense         | 41°             |

3.3 Details of model piles

Model piles were designed and manufactured from smooth mild steel tubes with three different outside diameters and wall thickness. Three embedment length of the model piles were used in the work which is denoted as penetration ratios (PR = L/D) of 10, 15 and 20.

3.4 Model Preparation and Testing

Twenty-one model pile tests were carried out throughout this study to achieve the main goals of the research. Each model test comprised three main stages. These stages are:

1- preparation of the foundation soil (soil bed), by using dry tamping technique to achieve the required relative density in the box. Put the soil by sub-layers each one of 5 cm till the total thickness of the foundation soil was achieved.

2- Install of the model pile, when driving in foundation soil in the box by using manufactured manual hammer.
3- Test of the pile by applying pull-out (tension) load incrementally till the failure was achieved when the load corresponding the point at which upward movement suddenly increases excessively (sharpest curvature on the load-movement curve), and then record the corresponding movement of the pile by using two digital dial gages with accuracy (0.001 mm).

All steps mentioned above was explained in Figure 3.

![Figure 3](image)

Figure 3. summarizes the above steps of Model Preparation and Testing.

4. Discussion of results

Test results are sets of figures representing the behavior of single piles under pull-out force. The following sections discuss the obtained results in detail:

4.1 Effect of Pile Geometry

For the purpose of investigating the influence of pile's geometry, two types for cross sectional area were taken (circular and square), with three various diameters 3 cm, 4 cm and 5 cm and three various penetrating ratio 10, 15 and 20. All tests were done in medium density soil with open-ended pipe pile.

Figure (3, a, b and c) illustrate the load–movement curves for circular cross section pile of various diameter with three penetrating ratios. It is noticed that all curves yield the same trend. Evidently, there is an increase in ultimate pile’s pull-out capacity when increasing of penetrating ratio. This can be ascribed to increasing the pile’s surface area in contact with soil. As an example Figure 4 illustrates loading–movement to three different penetrating ratio with diameter of 3 cm. The pull-out capacities are 53 N, 165 N and 290 N for 10, 15 and 20 penetrating ratio respectively. Also, the increasing of pile diameter will increase pile’s pull-out capability because of increasing of skin friction resisting. These findings are confirmed with some researchers Xu et al., [12], Shanker et al., [13], Chattopadhyay and Pies [14], Das [9].
Table (2) contains the pull-out capacities of the circular piles with different penetrating ratio and pile’s diameters. One could note about the same penetrating ratio, there will be a decrease in the increasing ratio in pull-out capacity when there is an increase in the pile’s diameter. But, for the same diameter increasing ratio in the pull-out capacity increases as the penetrating ratio increases and that happened for all pile diameters.

Figure 4. Load-movement curve for piles with different penetration ratio (circular cross-section) and with three different diameters (a= 3cm, b=4cm and c=5 cm).
Table 2: Pull-out capacities and increasing ratios of the piles with circular cross section

| D (cm) | PR | \( T_o \) (N) | Increasing ratio with respect to reference pile | Surface area \((A_s), \text{cm}^2\) |
|--------|----|--------------|---------------------------------------------|-----------------------------|
| 3      | 10 | 53          | -                                           | 282.6                       |
|        | 15 | 165         | 210 %                                       | 423.9                       |
|        | 20 | 290         | 448 %                                       | 565.2                       |
|        | 10 | 165         | -                                           | 502.4                       |
| 4      | 15 | 350         | 112 %                                       | 753.6                       |
|        | 20 | 640         | 288 %                                       | 1004.8                      |
|        | 10 | 296         | -                                           | 785                         |
| 5      | 15 | 530         | 79 %                                        | 1177.5                      |
|        | 20 | 920         | 211 %                                       | 1570                        |

Similar technique was followed for model pile of square cross sectional area. This means that three different pile width and three different penetrating ratio were selected. While the foundation soil was in the medium state only.

Figures (5, a, b and c), shows the load – movement of square cross-section area to the pipe piles of three different penetrating ratio and three various pile width. It can be noted that the square does not differ from the circular in terms of the influence of penetrating ratio on the pull-out capacity where it increases with the increasing of penetrating ratio. Also, it (pull-out capacity) increases with the increasing of the pile width.

Table 3 contains the pull-out capacities of the square piles with different penetrating ratio and pile width. One could see about the same penetrating rate that the increase ratio in pull-out capacity will decrease when there is an increase for pile’s size. Also, increasing ratio in pull-out capacity increases as the penetrating ration increases for all pile diameter. However, the pile pull-out capacity for circular section is in general more than that of the square section. This is may be due to the disturbance of the soil near the corners of the section. But for the pile width 5 cm the pull-out capacity is more than that of circular section for all penetrating ratio. This is may be attributed to the high difference between pile surface area than that for smaller pile sections (3 cm and 4 cm).
Table 3: Pull-out capacities and increasing ratios of the piles with square cross section

| B (cm) | PR | $T_u$ (N) | Increasing ratio with respect to reference pile | Surface area $(A_s), \text{cm}^2$ |
|--------|----|-----------|---------------------------------|------------------|
| 3      | 10 | 82        |                   | 360              |
| 15     | 105| 28 %      |                   | 540              |
| 20     | 220| 168 %     |                   | 720              |
| 10     | 212| -         |                   | 640              |
| 4      | 233| 10 %      |                   | 960              |
| 20     | 465| 119 %     |                   | 1280             |
| 10     | 365| -         |                   | 1000             |
| 5      | 760| 108 %     |                   | 1500             |
| 15     | 1160| 218 %     |                   | 2000             |
4.2 Effect of Separation Walls

For present study the separation walls were used within small pipe pile. The separation walls were welded alongside pile’s entire length. Three tests were considered with used of one, two and three separation wall. So, the cases made two, three and four surface areas. The results of those tests are compared here with the reference case of ordinary pile (without separation walls). All tests were conducted for the open-ended pile of circular cross sectional area with 5 cm diameter and penetrating ratio of 10 in medium foundation soil.

Figure 6 illustrates variety of the soil’s plugging length (as explained within the previous sections) having the penetrating deepness for three different configurations of separation walls and the reference pile (open-ended pipe pile). According to the Figure, distinguishable finding can be noticed about the length of the soil’s plugging to have greater value for open-ended pile without separated wall, then the soil’s elevation within the pile decreases when adding inner walls. Highest value of soil’s plugging is accomplished when the pile is divided into two segments only. The final soil’s plugging lengths are 26.8, 19, 12 and 11 cm for non-walled pile model, one, three and four separation walls respectively. This behavior is due to decreasing in the available space for soil insertion inside pile. The presence of separation walls generates friction stress that works in impeding the entry of the soil inside pile. This conclusion agrees with that stated by Murthy [15].

Figure 7 demonstrates load-movement curves for the four cases mentioned above. It can be noticed that the piles’ behavior for all cases follow the same trend. The failure load for the case of non-walled pile model, one, three and four separation walls are 295 N, 270 N, 360 N and 340 N respectively. The existence of one separation wall inside pile decreases the pile pull-out capacity. This is because of the soil disturbance during pile’s drive because of using thick wall (separation wall thickness is 3 mm). This disturbance of the soil causes a decrease in the skin rubbing resisting. While the presence of three and four walls yield high pull-out pile capacities compared with the cases of no and one separation wall. However, the use of separation walls do not work in increasing the friction surface only as stated by Yamahara [5] and Matsumoto [4]. But, also, they work for increasing the factor for rubbing amid soils with pile’s surface. Therefore, four separation walls case gives pull-out capacity less than that determined for three walls even though the inner contact surface for the last one is the smaller contact area.

Figure 6. Load-movement curves for different cases (open-ended pile with $D = 5\text{cm}$ and $PR = 10$).
5. Conclusions

Experimental tests were conducted on single piles under pure uplift loading. The test results are presented and discussed in this paper. Based on the previous study, the following main conclusions are drawn:

1- For circular and square shapes, there is an increase in the pile’s pullout capacity when increasing both pile diameter (width) and penetrating ratio due to the increasing in the friction area. The pull-out capacity of the circular section is more than that of square section except for pile with 5 cm section where the difference in the surface areas is higher than that for both 3 cm and 4 cm sections.

2- The increasing in the pullout capability due to the increase of the pile’s length is more than that due to increasing of the pile diameter for both shapes.

3- The soil’s plugging length decreases with the presence of separation walls inside the pile section due to the decreasing of the available space for plugging.

4- Some researchers concluded that the separation walls increase the friction area, but in the present study it is the separating wall also work to increase the coefficient of lateral pressure.

5- There is an optimum number of separation walls that can be used to increase the pile pull-out capacity. In this study the optimum case achieved when using three separation walls.

6. References

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