Effect of diameter on the load carrying capacity of Closed-Open Ended Pipe piles

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Abstract

This study investigates the behavior of the components on the pile loading capacity and the effect of removing the components. The sand is used as a fine, sandy soil. It was prepared with different densities using rain technology. The soil plug was removed by a device that was manufactured to remove the soil column trapped inside the piles of the pipes during installation by driving and pressing devices. The present study focuses on determining the effect of soil plug on the maximum load capacity of the open-end steel pipe pile and comparing it with the closed pipe pile. A new type of piles of pipes is proposed; piles of open-ended organic pipes driven and compressed in sandy soils of different densities (medium and dense) where axial pressure tests were carried out on the piles of the model. The end of the pile will be open at a predetermined depth in order to facilitate the penetration of the pile base and close it at a distance to increase the resistance of the pile base. The open pile models were modified by closing the ends of the pile by a welded plate at a distance of two, three, and four D (where D is the diameter of the pile) by the pile.

It was concluded that increasing the diameter of the pile from 20 mm to 40 mm caused increase in the pile bearing capacity by about 275 – 615%, while in closed-ended piles, the same increase in pile diameter caused increase in the bearing capacity of about 320 – 860%. On the other hand, in closed-open-ended piles, this increase improves the bearing capacity by about 490 – 1020%. The results prove the controlling importance of the pile diameter in the proposed type of piles; closed-open-ended type.

Keywords

Pipe pile, plug, sand, diameter, closed-ended.

1. Introduction

Most researchers who studied the mechanism of transferring the load of components from the pile to the sand agree that the open piles behave as closed cocoons when they are consistently loaded (O’Nell and Raines, 1991, Randolph et al., 1991, Kraft, 1991, and Raines et, 1992). The problem is complicated by the fact that the pile may act, the pile is closed during the hard load even though it is not connected during installation.

Abdullah and Al-Muhaidib (1999) studied the ability of carrying a tubular pile driven in sandy soil under axial loads. The effect of the length of the pile and the length of the soil plug was studied on the
carrying capacity of the open piles. It was suggested that the reduction factor be used to calculate the load capacity of open piles in a fixed form, where it was 0.49 for the sandy soil used in the study.

According to Paik and Salgado (2003), while driving piles of open pipes, a quantity of soil will initially enter the hollow pipe. Depending on the state (dense or loose), type (fine or coarse), diameter, pile length, and driving technique, the soil may or may not allow the soil to enter the tube. If the soil enters the tube during the driving process, it is said that the driving is done in full drill mode, and the behavior is like the behavior of the non-displaced. However, if the soil forms a plug in the base of the pile that does not allow the soil to enter again, the command is said to be in a fully connected position.

Description of Paik et al. (2003) to the ability of the driving response and the fixed bearing capacities of the open-end piles affected was by the soil plug formed inside the pile while driving on the pile. In order to investigate the effect of soil stoppage on the static and dynamic response of open-end compartments and load capacity of pipe piles in general, pile load tests were carried out on open and closed piles driven in sand. For the open pile, the length of the soil plug was continuously measured while driving the pile, allowing for the computation of the incremental fill ratio. The cumulative hammer hit of the open pile was 16% lower for the closed pile. The maximum resistance of the unit column and the base resistance of the open pile unit was 51% and 32% lower than the corresponding values of the closed pile.

Fattah and Al-Sudani (2016) investigated the behavior of components on pile loading capacity and the effect of removing components. Different parameters such as diameter to length ratio, type of driving in bulk sand, and removal of components were considered in three phases (50%, 75% and 100%) with respect to the length of the components. The sands of Karbala from Iraq, were used as a soil of poor sandy foundation clean. It has been concluded that the percentage decrease in the loading capacity of the open-ended pile ends with the length of removal of the soil plug. The open pipe pile acts as a closed lock if the soil plug formed inside piles is in the case of a partial plug or a complete plug. Failure of the plug to connect while driving does not necessarily mean that the connection will not be there during the static load, because the inertia effects while driving are absent during the static load.

Sixty tests were conducted on the model pile by Fattah et al. (2016) to investigate the behavior of plugs on pile load capacity and plug removal effects. Different parameters were taken into consideration, such as the diameter of the pile to its length, the types of stabilization in the sand of different densities, and the removal of the plug in three stages (50, 75 and 100%) with respect to the length of the plug. Changes in the length of soil plug and incremental filling ratio (IFR) with penetration depth during pile drive show that the open piles are partially connected from the beginning of the pile drive. The pile reached a complete connection to compact piles in loose, medium sand and partially blocked (IFR = 10%) in dense sand. For paid piles, the IFR is about 30% in bulk sand, 20% in medium sand, and 30% in thick sand.

The present study focuses on determining the effect of soil plug on the maximum compression capacity of the open-end steel pipe pile and comparing the piles of closed tubes. A new type of pipe piles is proposed, which is the piles of closed open ended piles driven or compressed in sandy soils with different densities (medium and dense) where axial pressure tests were carried out on the piles of the model. The end of the pile will be open at a predetermined depth in order to facilitate the penetration of the pile and close it at a distance to increase the resistance of the pile base.

**Experimental Work**

This section describes the material properties, basic soil preparation, loading frame and devices, test program techniques, and manufacturing preparation for the implementation of piles of compressed and
fixed-loading models. 20 steel pipe piles (open and closed ends) are used to conduct static pressure loading tests on loose sandy soil. Experiments were performed under 1g condition. Thus, there will be some differences from the state of the field due to different pressures in this area, especially for sandy soil. Test results are limited to low-level pressure.

**Soil Characterization**

Kerbala sand, which is used as a foundation soil in the present study, is poorly graded clean sand from Iraq. The sand was sieved on sieve No. 4 to get rid of the coarse particles. Standard tests were followed to find the physical properties of sand. Details of these properties are summarized in Table 1.

| Index property                  | Value   | Specification                        |
|---------------------------------|---------|--------------------------------------|
| Grain size analysis             |         | ASTM (D 422-2001)                    |
| D10 (mm)                        | 0.35    |                                      |
| D30 (mm)                        | 0.6     |                                      |
| D60 (mm)                        | 0.9     |                                      |
| Uniformity coefficient (C_u)    | 2.57    |                                      |
| Curvature coefficient (C_c)     | 1.42    |                                      |
| Classification of soil (USCS)   | SP      |                                      |
| Specific gravity (Gs)           | 2.66    | ASTM (D 854-2005)                    |
| Maximum dry unit weight (kN/m^3)| 18.5    | ASTM (D 4253-2000)                   |
| Minimum dry unit weight (kN/m^3)| 15.2    | ASTM (D 4254-2000)                   |
| Maximum void ratio              | 0.41    |                                      |
| Minimum void ratio              | 0.71    |                                      |

USCS = Unified soil classification system.

The direct shear box test was performed according to ASTM D 3080-98. The values of $\phi$ for the loose, medium and dense sand were determined to be 31°, 37° and 43°, respectively.

**Model Setup Formulation**

To simulate the pile load test in the field, a new apparatus was manufactured. It consists of the following parts:

1. Steel container.  
2. Steel base.  
3. Steel loading frame.  
4. Axial loading system.  
5. Raining frame.  
6. Impact hammer device.  
7. Mechanical jack.  
8. Load cell.  
9. Digital weighing indicator.  
10. Gear box.  
11. AC Drive (speed regulator).  
12. UPS (universal power system).  
13. Pile driving system –pressing system installation.  
14. Soil plugs removal and measurement devices.

A steel loading frame was manufactured to support the mechanical jack, axial loading system and gear box motor, as shown in Figure 1.

The pile driving system is shown in Figure 2. Mechanical jack was used for driving pile into the soil under a constant rate. This jack is fixed to the pile installation system as shown in Figure 3.
In this study, the soil plug was removed by a device manufactured to remove the soil column entrapped inside the pipe piles during installation by driving and pressing device. This tool consists of aluminum tube 400 mm long and 15 mm in diameter, inside a steel tube 470 mm long and 8 mm diameter, and a spring of 70 mm length, in the bottom of aluminum tube.

Details of Model Piles
Eight open-ended and two closed-ended steel pipe piles of 20 mm diameter and 1 mm thickness adopted used as model pile in the experimental program of the compression static loading. The length (embedment length) of the model piles depends on the ratio of embedment length to pile diameter, (L/d) ratio. The pile type, outside diameter, and length of every pile model are given in Table 2.

Interpretation of Pile Load Capacity
The Civil Engineering Code of Practice No.4, 1954 recommends the pile load carrying capacity as the load at which the rate of settlement continues at a constant value.

Presentation of Test Results
Open – ended pipe pile was selected as a reference pile to make a comparison with all other types of model pile load capacity, settlement and failure pile load capacity.

Open-ended piles
Twenty four open-ended piles have been tested and these piles are divided into four groups:
I. Open – ended piles with full plug: in this type of piles, the soil column inside the pipe is not removed before pile test.
II. Unplugged open – ended piles: in this type of piles, 100% of the total length of the soil column inside the pipe is removed before pile test.

Closed ended piles

Table 2: Model pile type and dimensions used in the model piles.

| Pile No. | Pile type       | Soil plug situation | Diameter D (mm) | Length (mm) |
|---------|-----------------|---------------------|----------------|-------------|
|         | Closed-ended    | -                   |                |             |
| 2-a     | Open-ended      | Fill Plug           |                |             |
| 2-b     | Open-ended      | 0% Unplugged        | 20             | 300 400     |
| 3       | Closed-Open-ended | 2D               |                |             |
| 4       | Closed-Open-ended | 3D               |                |             |
| 5       | Closed-Open-ended | 4D               |                |             |

Figures 4 to 6 present the load- settlement curves for model open-ended piles (full plug and unplugged) and show the effect of removing of the soil column inside the pile. In these figures, the term "full plug" refers to mobilization of full plug inside the pipe pile while the term "un plug" means that the pile plug has been removed out by the special device.
Twelve models of the closed pile were tested under constant pressure loading. Piles were installed by two types of mounting and pressing systems in the sand with varying relative density (loose, medium and dense). The load adjustment relationships observed in figures 7 and 8 are described.

It can be observed that the open pile clearance is larger than the closed pile under the same loading conditions as the soil. This means that if the final loading capacity is defined by reference to a standard settlement of 10% of the pile diameter, for example, the load capacity of open-ended piles is usually lower than that of closed piles. The capacity of the open pile column should be similar to that developed by the closed piles, indicating a limited impact of the end state on the entire column resistance. Unlike column resistance, the core capacity depends largely on the conductivity. Load capacity in dense sand is many times greater than bulk and medium sand loads, especially when there are closed or open-end piles because the pile of pipes can produce external and internal friction of the skin as well as the end bearing resistance that makes the total pile capacity is close to the closed pile.

On the other hand, removing the soil plug reduces the loading capacity on the pile. This decline becomes apparent in the dense sand. The load was reduced by 45-63%, (55-63)% and (51-79%) in loose, medium and dense sand, respectively.

Closed-open-ended piles
Twenty-four models of open piles were modified by closing the pile ends with a welded plate at a two-dimensional, three-dimensional and 4-dimensional distance (where $D$ is a diameter of the pile) from the pile tip. These piles are installed on sand in different densities (loose and medium) by two types of installation, driving or pressing. Figures 9 to 11 show load adjustment curves for this type of pile.

It can be observed that the open portion of the pipe pile has a limited length and that it is found to be 3D. This length revealed the maximum pile capacity due to the development of internal and external skin frictions as well as the final resistance. In addition, at this length, the soil column was compressed into the tube and thus intensified, resulting in increased skin resistance.

When the open part of tube is 4D, there will be some spaces within the soil column and cannot get dense soil. Therefore, the load capacity of closed open ended pile loads with a 4D soil plug is smaller than that of the three-dimensional soil plug.

Effect of Pile Diameter
Figures 12 to 15 present comparisons between the three types of piles with two diameters; 20 and 40 mm and two L/D ratios; 15 and 20 embedded in loose sand. Table 3 summarizes the ultimate load carrying capacity of different pile models.

In open-ended piles, the increase of pile diameter from 20 mm to 40 mm caused increase in the pile bearing capacity by about 275 – 615%, while in closed-ended piles, the same increase in pile diameter caused increase in the bearing capacity of about 320 – 860%.

On the other hand, in closed-open-ended piles, this increase improves the bearing capacity by about 490 – 1020%. The results prove the controlling importance of the pile diameter in the proposed type of piles; closed-open-ended type.
**Figure 1.** Steel loading frame and axial loading system.

**Figure 2.** Pile driving system installation.

**Figure 3.** Pile pressing system installation.
Figure 4. Load-settlement relations for open-ended driven piles in loose sand, $L=40$ cm, $L/D = 20$.

Figure 5. Load-settlement relations for open-ended driven piles in medium sand, $L=40$ cm, $L/D = 20$.

Figure 6. Load-settlement relations for closed-ended driven and pressed piles in sand, $L=40$ cm, $L/D = 20$.

Figure 7. Load-settlement relations for closed-ended driven and pressed piles in sand, $L=40$ cm, $L/D = 20$.

Figure 8. Load-settlement relations for closed-ended driven and pressed piles in sand, $L=30$ cm, $L/D = 15$.

Figure 9. Load-settlement relations for closed-open-ended piles driven in loose sand, $L=40$ cm, $L/D = 20$. 
Figure 10. Load-settlement relations for closed-open-ended piles pressed in loose sand, L=40 cm, L/D = 20.

Figure 11. Load-settlement relations for closed-open-ended piles driven in medium sand, L=40 cm, L/D = 40.

Figure 12. Load-settlement relations for open-ended, closed-ended and closed-open-ended piles driven in medium sand, D = 40 mm, L/D = 15.

Figure 13. Load-settlement relations for open-ended, closed-ended and closed-open-ended piles driven in medium sand, D = 40 mm, L/D = 20.

Figure 14. Load-settlement relations for open-ended, closed-ended and closed-open-ended piles driven in medium sand, D = 20 mm, L/D = 15.

Figure 15. Load-settlement relations for open-ended, closed-ended and closed-open-ended piles driven in medium sand, D = 20 mm, L/D = 20.
| Model            | L/D | Diameter (mm) | Bearing capacity (N) |
|------------------|-----|---------------|----------------------|
| Open-ended       | 15  | 40            | 495                  |
| Closed-ended     | 15  | 40            | 630                  |
| Closed-open ended| 15  | 40            | 981                  |
| Open-ended       | 20  | 40            | 1001                 |
| Closed-ended     | 20  | 40            | 1530                 |
| Closed-open ended| 20  | 40            | 2215                 |
| Open-ended       | 15  | 20            | 132                  |
| Closed-ended     | 15  | 20            | 150                  |
| Closed-open ended| 15  | 20            | 165                  |
| Open-ended       | 20  | 20            | 140                  |
| Closed-ended     | 20  | 20            | 159                  |
| Closed-open ended| 20  | 20            | 197                  |

Conclusions
1. Open-ended pipe piles behave as a closed-ended if the soil plug formed inside piles in state partial plug or full plug. Pile plug length relies on the kind of installation and sand relative density.
2. Although the total stress developed during installation is proportional to the degree of soil plugging, the lateral effective stress that controls the shaft resistance is shown to be independent of the mode of penetration (driving or pressing).
3. The increase of pile diameter from 20 mm to 40 mm caused increase in the pile bearing capacity by about 275 – 615%, while in closed-ended piles, the same increase in pile diameter caused increase in the bearing capacity of about 320 – 860%. On the other hand, in closed-open-ended piles, this increase improves the bearing capacity by about 490 – 1020%. The results prove the controlling importance of the pile diameter in the proposed type of piles; closed-open-ended type.

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