A New Proposed Type of Open-Ended Pipe Pile (Open-Ended Pipe Pile with Tapered Tip Pile (OE-TTP))

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Abstract
The present study investigates the behavior of the plug on pile load capacity for new proposed open-ended pile has a new modification in comparison with the traditional one, this modification performed by making the pile tip tapered with special dimensions. The open end has a diameter equal to half of the pile diameter while the length of the tapered part is equal to the pile diameter. The efficiency of the proposed type studied by modeling and manufacturing the two piles types (40mm diameter) and investigating the behavior of these piles. Complete setup manufactured for installing and loading the piles in a constant rate of penetration. Two lengths to diameter ratios considered in this study (L/D=15 and L/D=20). The model piles tested in loose dry sand. The soil plugging phenomenon and the Incremental Filling Ratio IFR were studied. The obtained results show that the proposed type has higher bearing capacity of (28%-36%) than the traditional type. This increase attributed to the tapered end of the pile that continues to push and compacting the soil below it during its driving into the soil.

Keywords: open-ended pile, tapered tip, soil plug/incremental filling ratio, loose sand.

Introduction
Open-ended pipe pile is widely used for the construction of foundations in both offshore and land. Open-ended pipe pile is classified as a low displacement pile and has a low effect on the surrounded soil during installation. During drive pile into ground, the soil will move up inside the pile and formed soil plug. The entrance of soil will continue until the inner soil cylinder mode develops sufficient resistance to prevent further soil intrusion. If the stresses in the inner soil are sufficient to resist and prevent further soil intrusion inside the pipe pile, the pile will act as a full plugged (closed-ended pile). Thus, if the shear resistance developed along the length of the column of the soil plug more than the end bearing capacity at the base of the soil plug, the pile will fail in plugged mode. On the other hand, pipe pile will fail in unplugged mode when the shear failure occurs between the soil plug and the pile shaft.

The problem is complicated by the fact that the pile may have as a closed-ended pile during static loading although it does not plug during installation.

Szechy (1958) investigated the effect of the wall thickness of the pipe pile on bearing capacity and soil plug formed inside the pipe pile. It has found that wall thickness did not affect on bearing capacity and soil plug while the effect may occur on driving resistance.

Kishida and Isemoto (1977) have explained experimentally that effect of arching action of soil within open pipe piles make a high value of internal friction. If axial stress is increased at the base of the soil plug, due to arching, the increased axial stress will lead to a corresponding increase in the lateral stress and hence the skin friction. As a result, the shear capacity of the soil plug is increased considerably. If the shear capacity greater than the end-bearing capacity of the pile, the pile will fail in a plugged mode. Development of arching in the internal soil plug depends on a number of factors such as depth of soil, relative movement between pile and soil, soil density, pile diameter, etc. Thus, the plugging in the soil is a complex phenomenon. Bearing capacity of a pipe pile largely depends on the skin friction of the soil within and outside the pile. Internal skin friction depends on the arching of the internal soil.

Norlund (1963) investigated the behavior of driven tapered piles into dry cohesionless soil. showed that the ultimate bearing capacity of tapered is much higher than those traditional open-ended pipe pile.
Paikowsky et al (1990) studied the effects of the soil plugging on pile performance and design and examined by in reference to the aspects: ultimate static capacity, time-dependent pile capacity, and dynamic behavior. The investigation does not attempt to provide solutions to the associated engineering problems and the results presented cannot be applied to all pile diameters.

Abdullah and Al-Mhaidib (1999) investigated the driven tubular pile under compression load testing, the effect of soil formed inside pipe pile during installation and the pile embedment, and length on bearing capacity of open piles were studied. It has suggested that the bearing capacity of the open-ended pile can be reduced by factor 0.49 for a pile that tested in sandy soil.

Paik and Salgado (2003) stated that the soil density and pile specification are effective on soil insertion and formation of soil plug inside the pipe pile. Besides, the study explains that the length of formed soil inside the pile equal the length of the pile then the pile behaves as the unplugged pile that described as a non-displacement pile. If the soil formed inside pile prevent soil to continues move to inter inside the pile, then the pile behave fully plugged and described displacement pile.

Jaing and Gao (2003) studied the behavior of cylindrical piles and tapered piles under compression test. The results show that the bearing capacity of cylindrical piles is lower than tapered piles.

Liu, J et al. (2012) explained the effect of taper angle on bearing capacity of pile and settlement that find the increases in taper angle causes increases in skin friction resistance and make increases in strength (radial interaction between soil and pile) that causes increases in bearing capacity of pile and reduce the settlement of pile.

Matsumiya et al. (2015) studied the effect of use tapered tip pile by testing five pile with different tapered tips (D,0.95D,0.9D,0.8D,0.7D) where D is the diameter of the pile (D=76.3 mm) and the length of the tapered tip is (0.3D). These piles installed by in different density of sand and testing under static compression straight pipe pile and result explained the pile resistance and generation of soil plugging for tapered tip pile decreases when compared with the straight shaft pile.

Fattah, M.Y., and Al-Soudani, W.H. (2016) showed that the pipe pile can be full plugged or partial plugged and may behave as closed-ended. The external and internal skin friction will mobilize during driving the pile into the ground.

Mohammed Y. Fattah and Wissam H.S. Al-Soudani (2016) explained that when soil inter inside pipe pile during installation and the pile can be full plugged or partial plugged then pile behave as closed ended and explain the external skin friction and internal skin friction will be mobilized during driven the pile into ground.

The present study investigates the behavior of the plug on pile load capacity for new proposed open-ended pile has a new modification in comparison with the traditional one, this modification performed by making the pile tip tapered with special dimensions.

**Experimental work**

Description and details of the properties of the soil and soil preparation for testing, apparatus, and loading frame fabrication of the pile driven system have explained in this section. Four steel open-ended pipe piles (traditional open pipe piles and the new model of open-ended pipe piles) are used to follow out the testing (static compression loading) within loose sandy soil. To avoid the variation of the stresses level between field and experimental test, the size of model pipe piles was determined to reveal the scale factor 1/5.

**Soil Characterisation**

Al Attaba sand from Karbala in Iraq has used in the present study as a foundation soil. It is clean, poorly graded sand. Sieve No.4 has used to remove coarse particles. The physical and mechanical properties of the sand have determined according to the ASTM standards. These properties have shown in the table (1).

| Table 1. Physical properties of the sand used in the present study. |
Model Setup Formulation

The new loading system is manufactured to simulate that of the field test. It comprises the following parts:
1. Steel Structure of Frame Model;
2. Steel Tank Container;
3. Steel Moveable Girder Loading System;
4. Steel Moveable Axial Loading System;
5. Compression Load Cell Type (s);
6. Mechanical Jack;
7. Gear Box;
8. Digital Weighing Indicator;
9. AC Drive (speed regulator);
10. Raining system;
11. Dial gage indicator;
12. Pile driving installation system;
13. Reading Board;

Steel Structure of Frame Model.
The loading frame model was manufactured from steel section with length 1.56 m, width 1.74 m and height 2.00 m. The steel section of the base frame is TUB 100*100*4 mm and the dimensions of the base, 1.56 m in length, 1.74 m in width. The steel section of roof frame is HEB100, UPN100 and the dimension of roof frame is 1.56 m in length, 1.74 m in width. The steel section of columns is TUB 100*100*4 mm with 1.80 m in height, as shown in Figure (1).

Steel Tank Container
The steel box container was manufactured from steel plate thickness 6 mm, and consists of five disconnected parts, four sides and base. These parts connected by steel angle section L 50*50*5 mm with steel bolt diameter 19 mm, the dimensions of the container, 1200 mm in length, 1200 mm in width, and 1200 mm in height, as shown in Figure (1).

**Steel moveable girder loading system.**
A steel moveable girder loading system was manufactured by steel section HEB100 for this study to carry the steel moveable axial compression loading system, and Steel moveable beam raining system as shown in Figure (1).

**Steel moveable axial loading system.**
A Steel moveable axial loading system consists of three parts mechanical jack, gearbox motor, and load cell, these parts connected as one unit to move in the horizontal direction at any distance along with the steel moveable girder loading system. The load cell fastened with the mechanical jack which is fastened by a gearbox motor. The speed of the motor has controlled by AC Drive (speed regulator). The extremity load reach about 0.5 tons. The loading rate is to maintain at one mm/min as devised by ASTM 1143D-2013, see Figure (1).

**Compression load cell type (S-beam).**
To measure the applied axial compression load on the pile during testing, the load cell type SS300 and LS300 “SEWHA, Korea” model S-beam stainless steel, was used and the maximum capacity is 0.5 ton, the calibration was done during each test, as shown in Figure (1).

**Mechanical jack.**
Mechanical jack is used to apply axial loading on pile used, with an extremity load can be applied to two tons in weight., as shown in Figure (1).

**Gear box**
The gearbox is a mechanical motor with high torque, it has a capacity of 2 horsepower. The speed of rotation can be control through AC drive. A cross shaft has used to connect the Gearbox with the mechanical jack.

**Digital weighing indicator**
A digital weighing indicator’s, Korea” model SI 4010, is used for displaying the applied axial load amount with an input sensitivity of 50 gm as shown in Figure (2).

**Control the speed of an electrical motor (ac drive)**
An ac drive is an apparatus that is used to regulate the speed of an electrical gear motor., as shown in Figure (2).

**UPS (universal power system).**
Universal power system was used to provide constantly and constant electric current.
Raining System

The raining system consists of two parts (movable raining frame and steel tank), the movable raining frame made by steel channel section UPN75 with length 1500 mm. This frame is fixed on the top of steel structure of steel frame model by rail line made from steel channel section UPN50 and sliding roller in order to facilitate the horizontal movement of the steel tank as shown in Figure (2). A steel tank, with dimensions of (1100 mm in length, 400 mm in width and 500 mm in height), which is ended with an inclined gate mounted above the steel container tank that used as a hopper to pour the testing material from different heights through roller, as shown in Figure (2).

Figure 1. Steel Structure of loading Frame Model: Steel Tank Container, Steel moveable girder loading system and Steel moveable axial loading system.

Figure 2. Raining Frame System.

Dial Gage Indicator.
In the present test two dial gauges was used type (INSIZE) company with accuracy (digit up to 0.01 mm) and length of dial gage is 5 cm as shown in Figure (1).

**Pile Penetrating System Installation.**

The pile penetrating system installation consists of two parts. First part is a base frame for driving hammer tower made from steel angle section L75x75x5 mm with dimensions of (1300 mm × 350 mm) as shown in Figure (3). The second part is a driving hammer tower consists of driving tower frame and hammer system, the driving tower frame made from steel Tube section 35x15x3 mm with height 1100 mm and sliding guide railway of hammer system, as shown in Figure (3).

The hammer system consists of a movable frame hammer and rod hammer. The rod hammer represented by as stainless-steel rod with weight 4.5 Kg and helmet in the head of the rode and helmet in the bottom of the rod, these helmets are made by plastic Teflon the details of hammer system are shown in Figure (3). The bottom helmet which is used to decreases the driving stress effect on the pile head. Square plastic Teflon with dimension (400mmx350mm) fixed in the bottom of the base frame with a hole (diameter d=43 mm) in the centre, as shown in Figure (3).

To prevent pile tilting during the driving process and ensure the piles are not moving or changing the vertical direction for pile penetration, these systems are designed to moving vertical direction parallel with pile penetration in soil during pile driving by linkage the hammer system by sliding roller move along the guide railway, these parts are shown in Figure (3).

The weight of hammer equals to 1.5 kg was used to strike the model piles. This weight was chosen according to the ratio (P/W) where the W is the weight of hammer mass and P is the weight of pile. the strike energy depends on these ratios. Half-plastic plate with shaft that fastened to steel cylinder were used to lifting the hammer mass to an apportioned height and let’s to drop on self-weight to strike the head of pile.

![Figure 3. Pile Driving System.](image-url)
Reading bored consisting of a movable steel frame sliding on the steel structure of the frame model by steel roller. This frame includes the electrical bored switch with AC drive and the two digital weight indicators for load cells. This system as shown in Figure (4).

**Figure 4.** Reading Board System.

**Pile Testing Arrangements.**

Figure (5) show the model pile testing arrangement. The horizontal spacing between the model pile and inner face of steel container equal to 300 mm (7.5 D where D is pile diameter) and the horizontal spacing centre to centre between model pile equal to 600 mm (15 D).

**Figure 5.** Pile Testing Arrangements.

Details of piles model: -
Tow traditional open pipe piles and two new models of open pipe piles with open taper tip were considered. The modification of the new model is performed by making the pile tip tapered with special dimensions. The open end has a diameter equal to half of the pile diameter while the length of the tapered part is equal to the pile diameter. These piles are (40mm diameter). Two lengths to diameter ratios considered in the present study (L/D=15 and L/D=20) these piles are shown in figure (6).

Identification of piles in the present study:

The model piles are used in the current study are identified by symbols as listed in the table (2). The identification of each pile according to the L/D ratio and the new technics of pipe piles.

| No | L/d Ratio | Length (mm) | Type of installation | Type of pile                  | ID Pile  |
|----|-----------|-------------|----------------------|------------------------------|----------|
| 1  | 15        | 600         | Driven               | Open-Ended                  | OE-600   |
| 2  | 20        | 800         | Driven               | Open-Ended                  | OE-800   |
| 3  | 15        | 600         | Driven               | Open-Ended-Taper Tip Pile   | OE-TTP-600 |
| 4  | 20        | 800         | Driven               | Open-Ended-Taper Tip Pile   | OE-TTP-800 |

Testing stages

The stages of the testing were performed according to the following steps:
1. Prepare the soil in the form of layers in the steel container by raining techniques.
2. Install piles model by Pile driving through the use of pile penetrating system installation.
3. Applied axial compression load by system of applied loading consists of load cell, electrical motor gear, mechanical jack and dial gauge, the model pile press to penetrate into soil to reach the required penetrating depth of pile length as shown in Figure (1).

The test begins by mobilizing the mechanical jack with two tons capacity to applying the vertical axial compression load at a constant rate of loading. The dial gauge with 0.01 mm sensitivity is used to
measures the displacement of the pile model. The load growth was continuous until the applied vertical load became stationary, while the growing of the measured settlement continuous.

4. **Control of strain:**
The test was performed by a constant rate of penetration (CRP) according to American Society for Testing and Materials (ASTM) 1143 D (2013); the loading rate was kept constant at one mm/min. The same procedure was followed for all pile models. JOSHI (1989) stated that the constant rate of penetration (CRP) is recommended and quickest to determine the ultimate pile capacity.

**Interpretation of pile load capacity**
The Civil Engineering Code of Practice CP, no 4, 1954, defined the load at failure as 'the load at which the rate of settlement continues undiminished without further increment of load'. Table (3) shows the interpretation of pile load capacity according to this method for 60 cm and 80 cm long open-ended piles and open-ended with an open tapered tip pile driven into loose density sand.

| Pile (ID) | L/D | Length of pile (mm) | Civil Engineering Code of Practice CP, No 4, 1954, (N) |
|-----------|-----|---------------------|-----------------------------------------------|
| OE        | 15  | 600                 | 520                                           |
| OE        | 20  | 800                 | 1030                                          |
| OE-TTP    | 15  | 600                 | 705                                           |
| OE-TTP    | 20  | 800                 | 1325                                          |

**Presentation of load-settlement curves**
The reference pile is open-ended pipe pile to compare with the new model of open-ended with tapered tip pile. The settlement and failure load of pile capacity have recorded. Figures (7 and 8) showed the behaviour of load-settlement curves for traditional open-ended piles (partial plug) and new model open-ended with open tapered pipe pile. These figures show the new model open-ended with open tapered pipe pile exhibit ultimate capacity more than reference open-ended pipe piles for both pile length (L=600 mm and L=800).

Table (4) explain the gain percentage in pile load capacity when using the open tapered tip in the pile bottom. This increase due to the combination of compacted soil below the pile tip and compacted soil inside the open pile.

| Pile (ID) | L/D | Length of pile (mm) | Increasing Percentage % at Failure Load |
|-----------|-----|---------------------|----------------------------------------|
| OE-TTP    | 15  | 600                 | 36                                     |
| OE-TTP    | 20  | 800                 | 28                                     |
Measurement of soil plug and plug length ratio (PLR)

During driven model pile in the soil, the soil tends to enter inside the pile and make a column of compacted sand inside it. The length of the sand column will increase with continues pile penetration. At the end of driving, the length of the sand column can be measured. Soil plug formation during driven open-ended pipe piles is representing the main factor that effects on pile load capacity for open-ended pipe piles. The degree of formation of plugging soil phenomenon can be determined by measuring the incremental filling ratio (IFR) and plug length ratio (PLR). Iskander (2010) stated that IFR represents the rate of increases in soil plug formation length inside pile per unit increases of pile penetrate depth into the soil. During the installation of the pile, the IFR can be scaled in this study the IFR measured for every 5 blows of the hammer to measure the length of the soil plug formed.

Figures (9, 10,11 and 12) show the length of soil formed as a column inside the reference pipe pile and open-ended pipe (OE) pile with open tapered tip pile (OE-TTP). From the figure, it is clear that the length of soil column formed in OE-TTP is less than OE because the tapered tip decreases the soil inters inside pipe pile and make a uniform path of soil to continues entering inside pile during driving. From these figures, it can be shown that the ratio of the length of soil formed as a column inside the OE reaches (50 %) and for OE-TTP reach (31.6 %) for pile length 600 mm and the OE reach (35.6 %) and for OE-TTP reach (26.8 %) for pile length 800 mm.

Full Coring (Unplugged State) this mode occurs when the length of the pile embedment into ground is equal to the length of soil formed as a column inside pipe piles during penetrating into ground.
Figures (13 and 14) illustrate the variation of the plug formation within the driven pile into the soil by calculation the incremental filling ratio (IFR). From the figures, it is clear that the IFR of the new model of the pile (OE-TTP) reached full plugged mode at depth of penetration less than the reference one (OE) due to the tapered tip that plays an important effect on the path of soil movement inside the pipe pile.
Conclusions:

1. The length of the soil column formed inside the new model pile of pipe pile (OE-TTP) is less than the reference open pile (OE).
2. The incremental filling ratio (IFR) for new model pile (OE-TTP) reached full plugged mode at a penetration depth of the pile less than the reference pile (OE) due to the open tapered tip that plays an important effect on the movement of the soil inside pipe pile.
3. The ultimate bearing capacity of the open-ended pipe pile with open tapered tip is more than the reference pile (OE). The increases percentage was (36% and 28%) for pile length (600 mm and 800 mm) respectively.

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