Kufa Journal of Engineering
Vol. 12, No. 3, July 2021, P.P. 1-11
Article history: Received 7 September 2020, accepted 21 September 2020

EFFECT OF SOIL DENSITY AND PLUG CHARACTERISTICS ON BEHAVIOR OF SINGLE PIPE PILE EMBEDDED IN COHESIONLESS SOIL AND SUBJECTED TO UPLIFT FORCE

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HTTP://DX.DOI.ORG/10.30572/2018/KJE/120301

ABSTRACT

It is a significant issue to analyze and understand the pile's behavior as well as to predict the piles' capacity exposed to uplifting load when designing a foundation. Experimental model tests have been conducted for a single pile embedded in cohesionless soil and subjected to uplift force. The experimental tests were performed using open-ended steel pipe piles with circular cross-sectional area an outer diameter of 50 mm in steel soil box (0.5*0.5) with four different height (0.30, 0.50 and two with 0.40 m). The tested piles have been embedment with penetration ratios (PR=L/D) of 10. Three different densities (25%, 50% and 75%) have been used to perform the tests. In addition three tests have been made with relative density of 50% to investigate the function the developed soil column inside the pile (soil plug) during installation. The results revealed that the behavior of single piles depends mainly on soil density and the ultimate pull-out capacity of the pile increases with the increasing of the soil relative density and used the data from this tests to presented formula to estimate the IFR and takes the soil state parameter as a qualitative variable. The results showed also that the removing of plugging soil decreases the pile's pull-out capacity by about 85%. Whilst, using of closed-end or filled with concrete give higher capacity than that of open-end pipe pile by about 33% and 87% respectively.

KEYWORDS: Pipe pile, Uplift loading, Soil Plug, Soil density, Cohesionless soil.

1. INTRODUCTION

Pile foundations are often used to transmit the loads superstructure to the strong soil layer(s) if the subsurface soil is of inadequate strength. In cohesionless soils, the shaft resistance is an important source of pile capacity under axial loading, especially when the pile is subjected to uplift loading. Pile under uplifting loads happens at bridge foundation, buttresses and while enforcing high structure that is exposed to turn over powers against, for instance, winds as well as any kind of wave. Also, uplifting powers are applied upon any pile because of the swell happened to the adjacent soil, Where the pile resisted such this uplifting powers by its private weight and skin friction advanced along pile's surface (Gaaver, K. E, 2013).

Studying the behavior of piles under uplift forces as well as the parameters affecting the uplift capacity of piles is one of the most important and interesting areas of research in geotechnical engineering, particularly when that related with the soil effect.

Pipe piles built in two kinds closed-ended and open-ended. The first one is used to rise the pile capacity to due soil densification that is caused from lateral movement of the soil during pile driving. While, the second type is used to rise the easiness of penetration of the piles, particularly when piles driven in dense sand layers. When driving open pipe piles made of steel in the soils, a column of soil might advance inside it, this phenomenon is named (plugging soil).The soil movement inside pipe piles not stopped but limited (Kikuchi et. al., (2010) and Al-Garawi, (2016)).

In pipe piles, the applied uplift load is resisted by the sum of shaft resistance developed between the pile and the soil, soil plug capacity inside the pile and its weight. A new method to predict the behavior of pile-soil interaction under axial tension forces in sand soil and load against displacement curve presented by Aser et al., (2017).

As it is known, full-scale field tests is much better in terms of results, but it is costly and difficult to perform. For that reasons, laboratory tests of a small model conducted on piles embedded in sand under controlled conditions may serve the purpose to some range (Gaaver, K. E, 2013).

The present study aims to examine the effect of soil state (relative density) on the pull-out piles capacity as well as formation of soil’s plugging and make statistical analysis and suggest regression models IFR which have been investigated experimentally. Also, study the plug condition influence upon the piles capability to resist pull-out load.

2. ULTIMATE CAPACITY OF PILE

After driving a steel pipes pile with open-ended in the soil, column of soil inside the pile may grow enough internal shaft resistance to stopped more soil from entering the pile. This phenomena identified as a "soil plugging" (Karlowskis, 2014).

Pile may be perfectly plugged, imperfectly plugged or unplugged. The soil plugging effect on pipe pile by increasing the pile capacity due to additional friction generated along the internal pile surface and drivability analysis (driving resistance) (Shooshpasha, 2014).

Pile resists the uplift force by skin friction that developed on the pile-soil interface in addition to the effective weight of the pile. For a time there were some doubts whether the frictional pull-out resistance of a pile in sand was same as the frictional resistance of compression pile. Tschebotarioff in 1973 stated that the examination of frictional resistance by Delft cone indicated that exactly the same frictional resistance for upward and downward movement (Shooshpasha, 2014). However, some researchers showed that the unit skin friction of tension pile do not be larger than that of compression pile (Gaaver, K. E, 2013).

Formation of a soil plug in an open-ended pile is a very important factor in determining pile behavior both during driving and during static loading. It is well-known that the behavior of single pile proportional to the soil strength which is relate to the soil state (soil compactness). The soil state can be measured by relative density (D_r) (Fattah et al., 2019; and (Fattah et al., 2016).

3. MATERIALS AND EXPERIMENTAL MODEL

Several geotechnical problems alike pile's behavior can be tackled using physical models. Physical modeling may be done either by centrifuge or via 1-g tests. Centrifuge modeling is considered as one of the most important growths in geotechnical engineering. It has been the appropriate method for tackling complex geotechnical problems (Charles, 2014). Centrifuge tests are conducted below higher gravitational acceleration. It while, in 1-g modeling the tests are achieved under gravitational acceleration field. In this study, 1-g modeling have been adopted due to unavailability and expensively of the other method (centrifuge tests). The details of used materials, testing and modeling procedure are clarified in the following sub-sections.

3.1. STEEL BOX

The experimental tests were done on model piles in soil box of steel. Fig. 1 clarifies the representation diagram of the test systems. A square cross section steel container of (50*50) cm plane dimensions which industrial with 4 mm thick steel plate used in this study.

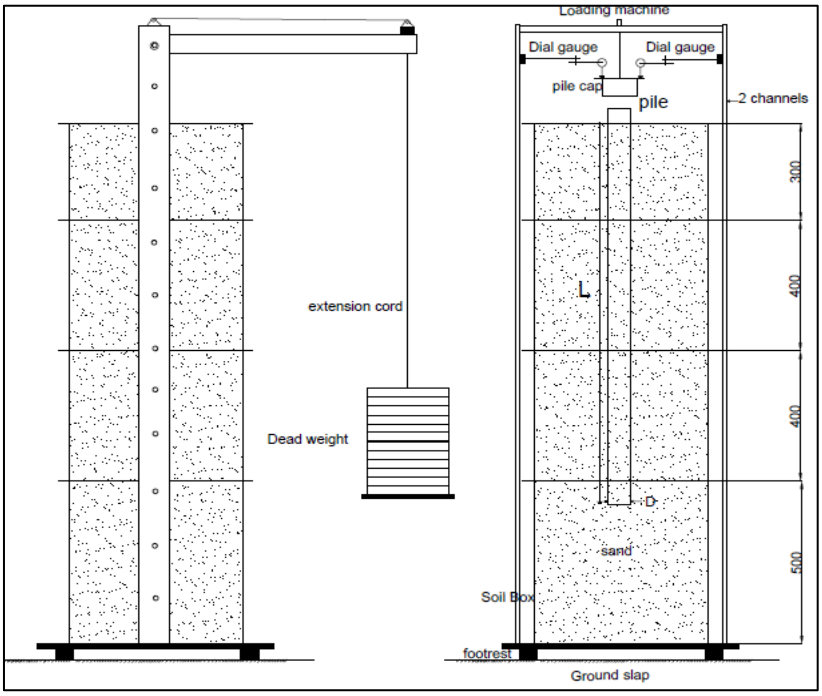

Fig. 1. The typical diagram of the test box.

As reported in the literature, the influence of driving pile in cohesionless soil extend to distance between 4.5 to 5.5 times diameter measured from the side of the pile (Paik and Salgado, 2003). The height of the steel container was changed to fit for the model pile length. In general, soil bed of thickness more than 5 times diameter was provided beneath the tip in all tests. Hereafter, four containers were made with different heights one of 50 cm, two of 40 cm and one of 30 cm.

3.2. THE SOIL USED IN THE STUDY

The soil used is obtained from a place at center of Al-Najaf city in Iraq, which is used as a foundation soil. The chemical and physical tests were determined to classify the soil. The grain size distribution of sand used in this study is shown in Fig. 2. The soil used is classified as SP soil (poorly graded sand) depends on the Unified Soil Classified System (USCS) and all tests were conducted on sand in accordance with (ASTM).

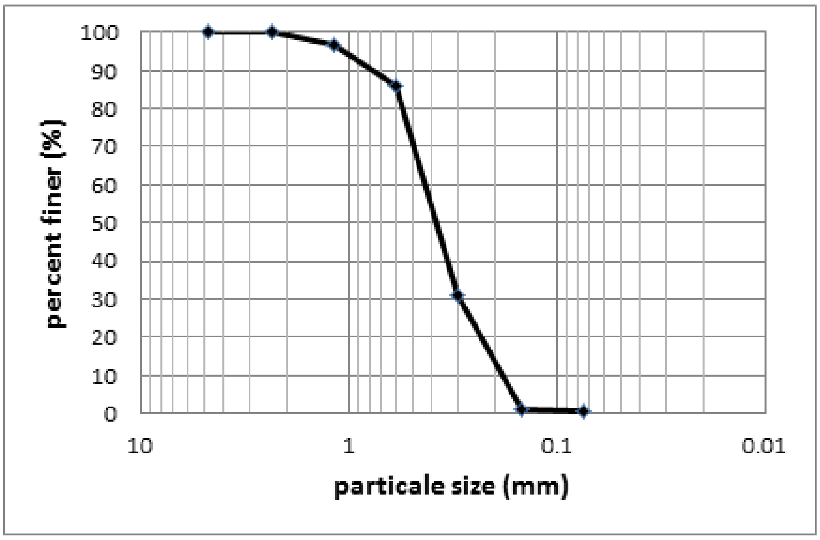

Fig. 2. Grain size distribution of the soil used.

Table 1 shows the mechanical and physical properties of the soil used in this work also some chemical tests were achieved on the soil used. As well as the results of some chemical tests, by the adopted friction angles.

Table 1. Mechanical and physical properties of the used soil.

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
□$_{d(max)}$		16.21 kN/m^3
□$_{d(min)}$		14.06 kN/m^3
e_{max}		0.83
e_{min}		0.58
Ø	Loose	35^o
	Medium	38^o
	Dense	41^o

3.3. DETIALS OF MODELED PILE

Modeled piles were manufactured and designed used a plane mild steel tubes with one external diameter and wall thickness. One embedment length of the modeled piles were used in the work which is signified as penetration ratios (PR = L/D) of 10.

3.4. MODELED PREPARATION AND TESTING

Six modeled piles have been tested in the current work to achieve the main aims of the research. Each model test comprised three main steps. These steps are:

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

2. Model installation, the pile was derived in foundation soil by using manufactured manual hammer.

3. The pile was tested by applying pullout (tension) load that increase incrementally till the failure was achieved and record the corresponding movement of the pile by using two digital dial gages with accuracy (0.001 mm).

4. DISCUSSION OF RESULTS

Test results are sets in figures that representing the behavior of single piles subjected to uplift loading. The following sub- sections discuss the obtained results in detail:

4.1. SOIL DENSITY EFFECT

Three different cases of soil state (compactness) have been selected (Dr = 25%, 50% and 75%) for preparing the soil bed (foundation soil) to investigate the effect of soil relative density on the pile's behavior. Fig. 3 illustrates the load–movement curves for three mentioned cases.

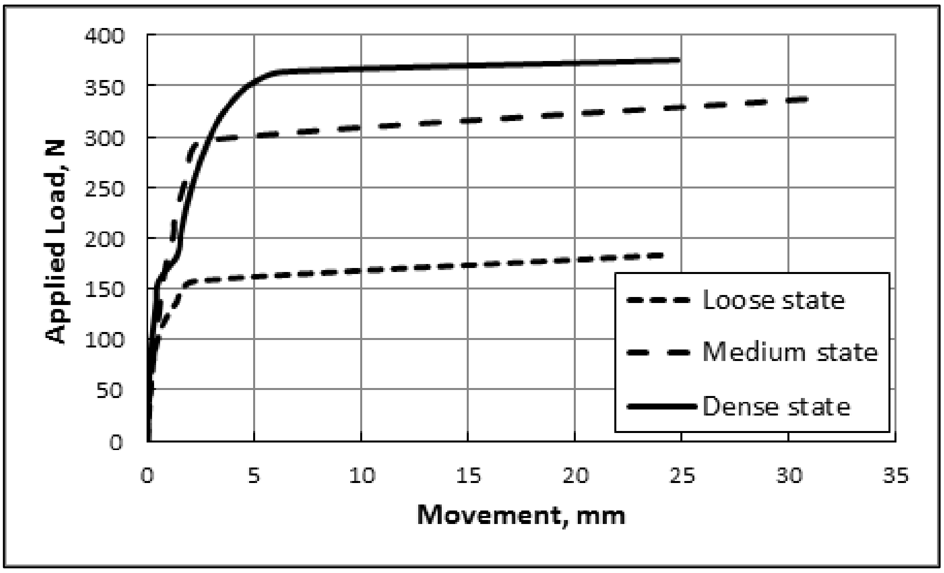

Fig. 3. Loading-movement curves for different relative densities of the foundation soil.

It can be noted that the pile in all cases behaves in the same trend. But the changing of soil state yields significant change in the pile capacity. This notice agrees with the prior knowledge about the effect of soil strength. The ultimate pull-out capacity of the pile increases with the increasing of the soil relative density which was 158 N, 294 N and 366 N for loose, medium and dense states respectively.

The pile's capability in the loose state gets increased by about 86% and 132% respectively when the soil changing to medium and dense states. The increasing in the pile capacity, once there is a change in soils loosing to be moderate, is greater than the increasing because of changing in soil's state as of medium to dense. This can be attributed to the point of view which states that the driving of pile into cohesionless soil causes densification of the soil (increases soil density) due to permanent rearranging in the soil's particle due to vibration plus displacement (Poulos and Davis, 1980). While, the driving of pile within dense soil makes the soil to be loosen because of dilatancy (Karlowskis, 2014).

The most important factor in the studying the behavior of open-ended pile is the formation of soil plug inside the pile. This factor is measured by two main amounts which are denoted as "plug length ratio-PLR" (soil length inside pile to the pile length) and "incremental filling ratio-IFR" (increment increase in soil length inside pile corresponding to each incremental increase in the pile length inside the soil). Several researchers suggested empirical equations to estimate the value of IFR based on the corresponding value of PLR. The value of IFR depends on many other parameters such as: pile geometry, relative density of the soil and installation method. All suggested formulas took only the value of PLR based on results of different relative density of the soil and method of installation. Such correlations were suggested by Paik and Salgado, (2003):

$$IFR_{(\%)} = 109(PLR) - 22 \tag{1}$$

and Fattah et al. in 2016 (Fattah and Al-Soudani, 2016; and Fattah et al., 2016) [13,14] :

$$IFR_{(\%)} = 117.8(PLR) - 30.2 \tag{2}$$

In the present study an empirical formula is proposed based on regression analysis to estimate the IFR based on the value of PLR and soil state (loose, medium or dense) based on the results of twenty seven case ($n < 30$). It should be stated that the significant level (α) selected for this study is 5%. This formula takes the soil state parameter as a qualitative variable with code number of 1, 2 or 3 for loose, medium and dense states respectively. The proposed equation gives high agreement with the observed IFR values with R^2 of 92%:

$$IFR_{(\%)} = 197.3(PLR) - 1.2(soil - state - code) - 93.2 \quad (3)$$

Fig. 4 demonstrates the scatter plot of the observed and predicted IFR for all data used in the regression analysis. It can be seen that there is a good agreement especially for the dense soil state.

Fig. 5 represents comparison of the results for the available formulas with the results of the proposed equation, for the obtained data from experimental results. It can be noted that the results of the proposed equation (3) gives an accurate results when compared with the other equations.

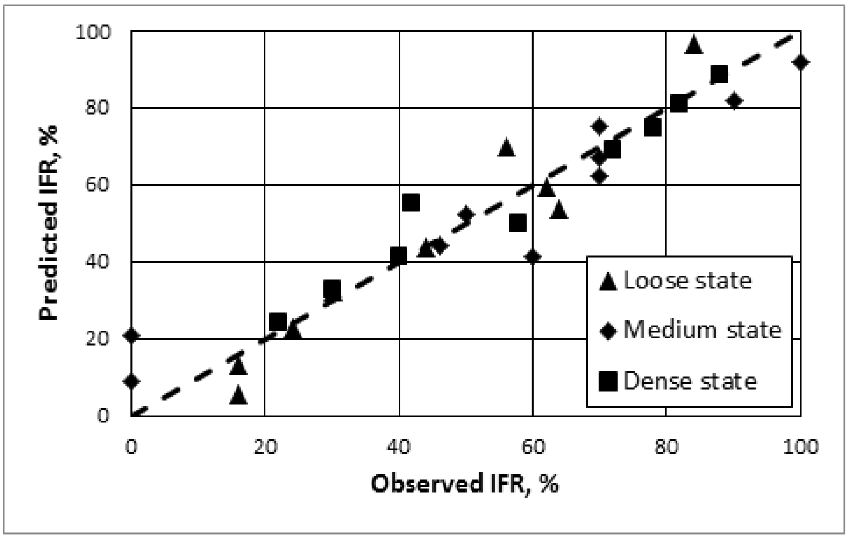

Fig. 4. Scatter plot of the observed and predicted IFR of Equation (3) for all data used in the regression analysis.

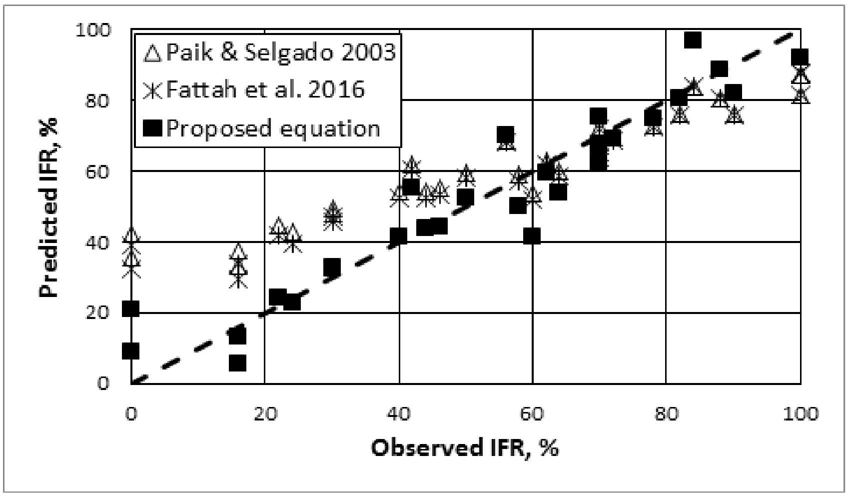

Fig. 5. Comparing the scatter plot of observed with the predict IFR for proposed and available equations.

4.2. EFFECT OF PLUG CHARACTERISTIC

In order to study the importance of the soil's plugging developed inside the pile during the installation, four tests have been performed as follows:

1. Open-ended pile,
2. Pile with removing plug,
3. Close-end pile, and
4. Replacing plug by concrete mix inside the pile.

Fig. 6 shows the load - movement curves to the four mentioned cases. From Fig. 6, it can be able to seen that the pullout capacity decreases from 294 N to 250 N when the soil's plug get is removed from pile. The reason for this behavior can be ascribed for losing the internal pile skin friction. It can be concluded that the internal friction in this case makes about 15% of the total friction (pile capacity). Besides that, the soil surrounding soil reveals higher densification than the soil inside the pile. Also, it can be noted that the closed-end pile yields pullout capacity more than that of plugged pile (390 N compared with 294 N) due to the high densification of the surrounding soils during pile installation. Finally, the pile filled with concrete gives the highest failure load (550 N) when it is compared with the other three cases. This increase in the pile's capability may be attributed to the increasing of the pile's weight. Therefore, the pile's weight plays important role in prediction of pullout capacity of pile. Consequently, the use of pipe pile filled with concrete is more significant than the use of open-ended pipe pile to resist pull-out loading. The filling concrete, also, gives more rigidity for the pile section that yields high resisting to the lateral loads too (Prakash and Sharma, 1990).

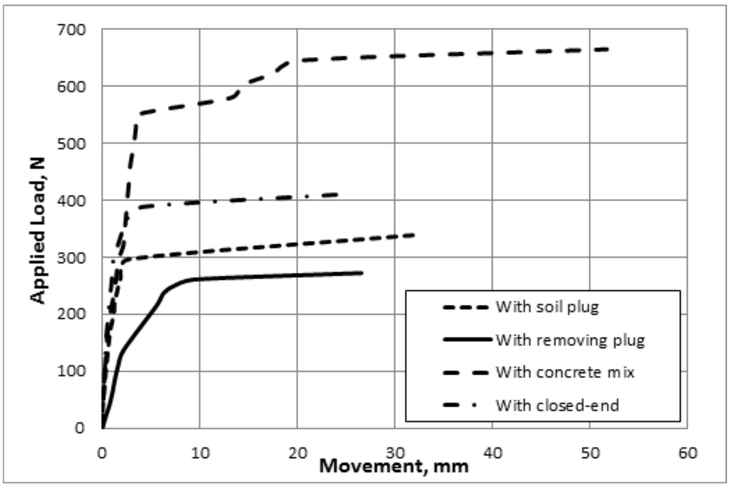

Fig. 6. Loading-movement curves for different cases of plug conditions.

5. CONCLUSIONS

Experimental trials were conducted on molded single piles under uplift loading. The test results are offered and discussed in this paper. Based on the current work, the following main conclusions are drawn:

1. The ultimate pull-out capacity for piles depends on the soil densities. When relative density changed from loose to medium then to dense the pullout pile capacity by 86% and 132% respectively.
2. The vanishment of the soil state from the previous proposed formulas for prediction IFR and depending on PLR only gave inaccurate guessing for IFR. Therefor the proposed formula obtained from this study (Equation (3)) can be used with high accuracy because it holds both soil state (loose, medium or dense) and PLR.
3. Removing of soil’s plugging reduced the pile’s pull-out capability by about 15% due to lose of internal soil-pile friction.
4. Using piles with closed-end or filled with concrete gave higher capacities than that of open-end pile by about 33% and 87% due to densification of the surrounding soil and the increasing in the pile's weight respectively.

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