# Bearing Capacity of Closed and Open Ended Pipe Piles in Clayey Soil

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## ABSTRACT

This paper investigates the impact of close and open ended condition on the capacity of pipe piles installed in medium clayey soil using pressed or jacked and hammered techniques and tested under the effect of vertical static compression load. 36 experimental model steel pipe piles (18 models for each open and closed ended) introduced and analyzed to clarify the influence of soil plug formation on the behavior of pipe piles. Different parameters are studied such as pile diameters (2.5, 3.5 and 4.1) cm, piles lengths (30, 40 and 50) cm and type of installation methods (pressed and hammered) . Results of the test program indicated that the ultimate load capacity of open-ended pipe piles tended to increase as the pile diameter and length increase for both pressed and hammered. The plugging of open piles does not contribute significantly on the capacity of pile in clay. For all model pile tests the load capacity of the closed ended piles is (5 – 30) % greater than that of the open ended for both type of installation (pressed and hammered) under the same geometric conditions.

**Keywords:** pipe piles; (open-close) ended penetration; bearing capacity; plug; clay

## INTRODUCTION

As steel pipe piles can be either closed or open ended, the demeanor of open ended piles is more complicated than that of closed ended due to potential to form of soil plug inside it during driving [1]. There is deficiency of exploratory information available concerning plugging influence for piles installed in clay. The plug of an open ended pile is mobilized when the collected inside skin friction exceeds the ultimate static bearing capacity of the soil beneath the toe of the pile and the pile then behaves similar to the closed ended pile.

Generally, the degree of soil plugging is adequately quantified by the plug length ratio (PLR) or the incremental filling ratio (IFR) [2]:



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$$\mathrm{PLR} = \frac{\mathrm{L_P}}{\mathrm{D}} \quad \dots (1)$$

$$\mathrm{IFR} = \frac{\mathrm{dL_P}}{\mathrm{dD}} \times 100 \quad \dots (2)$$

Where:

$L_P$ is the length of soil plug above pile penetration depth D, $dL_P$ is an increment of soil plug length above an increment of pile penetration dD. The IFR varies from 1.0 when the pile is fully coring (soil enters the pile at the same rate as it advances), to 0 when the pile is fully plugged (no further soil enters the pile).

Eide [3], recommended that the bearing capacity of friction piles in soft clays was regarding to the horizontal effective stress $\sigma_h'$ after reconsolidation.

Randolph [4], demonstrated that the radial displacements caused by plugged penetration were about three times as great as those caused by open ended penetration with little plugging.

Miller and Lutteneger [5] concluded that the hammered piles never completely plugged while the pressed piles plugged completely after only a few increments of penetration. The depths of complete plugging occurred for the pressed piles consistent generally with that the range of depths between 10 and 20 of the pile diameter anticipated by Paikowsky and Whitman [6], also they observed that the plugging conduct of hammered piles was more random than that exhibited by the pressed piles. Furthermore, they assumes that the external resistance and internal shaft resistance were both equivalent and unaffected by plugging. They deduced that since the base resistance gives a relatively small proportion of the overall pile resistance, inequality in the total pile capacity, arising from increased base resistance due to plugging would be small. The pipe piles are expected to plug when $Q_p$ reaches $Q_{closed}$ at depth ratio of D/d = 10-20.

Paik and Salgado [7], concluded that the pile capacity is increased with increasing hammer weight at the same driving energy and with increasing hammer weight at the same fall height. Also, they observed that the jacked piles have higher bearing capacities than identical driven piles under similar conditions. Salgado [8], stated that the ultimate bearing capacity of a closed-ended pipe pile is larger than that of an open-ended pile under the same load and soil conditions.

Gallagher and Gavin [9] revealed that the radial total stresses measured on an open ended pile conducted at the soft clayey silt soil were somewhat lower than those recorded on closed-ended piles and the plug resistance was just 5-10% of the CPT resistance.

Doherty and Gavin [10] portrayed found that, the shaft resistance mobilized by an open ended pile was being approximately 5% lower than a closed ended pile, and proposing a limited effect of end condition on the fully equalized shaft resistance.

From the previous studies included in this paper little of works, studies and information were focused on the behavior of steel pipe piles impeded in clay, therefor it is intended in this paper to study the subject to assess the general behavior of it.

## Experimental Work

36 model steel pipe piles (18 models for each open and closed ended) were installed in medium clayey soil using pressed and driven techniques and tested under the effect of vertical static compression load. Influence of different parameters on pile behavior such as type of pile end (open or closed), outside diameter of pile (2.5, 3.5

and 4.1) cm, pile length (30, 40 and 50) cm and method of pile installation (pressed and hammered).

## Soil Conditions

The soil used in this study was obtained from Al- Nahrawan (35 km) east of Baghdad Governorate. The physical and chemical properties of the soil are determined according to ASTM and BSI specification; it is classified as (CL) soil according to USCS as clarified in (Table 1).

**Table (1): Physical and Chemical Properties of the utilized Soil**

| no. | Index Property | Index Value | Specification |
|---|---|---|---|
| 1 | Liquid Limit (%) (L.L) | 44 | (ASTM D4318-10)[11] |
| 2 | Plastic Limit (%) (P.L) | 16 | (ASTM D4318-10)[11] |
| 3 | Shrinkage Limit (%) (S.L) | 12 | |
| 4 | Plasticity Index (%) (P.I) | 28 | (ASTM D4318-10)[11] |
| 5 | Activity (At) | 0.78 | |
| 6 | Specific Gravity (Gs) | 2.68 | (ASTM D854-14)[12] |
| 7 | Gravel (%) (G) | 0 | |
| 8 | Sand (%) (S) | 16 | |
| 9 | Silt (%) (M) | 29 | |
| 10 | Clay (%) (c) | 55 | |
| 11 | Classification (USCS) | CL | (ASTM D2487-11)[13] |
| 12 | Organic Matter (%) (O.M) | 2 | |
| 13 | SO3 Content (%) | 0.9 | BSI 1377, Part 3[14] |
| 14 | Gypsum content % | 2.3 | Hydration Method |

## Model Setup Formulation

The tests were carried out using steel container, piles and installation system, the steel container had cubic shape with internal dimension 75 cm, the steel container is made of five separated parts one for the base and the others for the four sides, also elevated from the ground level with four legs in corners.

The piles used for the test were nine open ended and nine closed ended steel pipe piles utilized in the experimental programmer of the compression static loading. The pile diameter to thickness ratios were chosen depending on the suggestion of Jardine and Chow [15] ratios between 15 and 45. In addition, the slenderness ratio of the model piles should not exceed 120 [16].

The installation system separate in two pressed and hammer system, the pressed system consist of a hydraulic jack fixed on steel frame with maximum load (1 ton), also a manual system is fixed to control hydraulic intensity. The hammer system consists of a base plate which involved three holes, these holes are considered as place of guide focus with the help of catcher designed to catch the pile as through embedment stage in soil without tilting. The main part in driving hammer is the Aluminum rod, it contains steel helmet in the rod head and steel cylinder which is utilized as a base for dropping the hammer weight shown in Figure (1). The 4 Kg hammer weight was chosen based on the weight of pile to hammer ratio ($W_P/W_r$) weight of pile to the weight of hammer which is about (1-1.5).

## Preparation of Model Test

To prepare a bed of soil medium clay of (33) kPa undrained shear strength trials tests were performed to control the efficiency of the method of preparation. The results of the control tests are shown in Figure (2).

The tests were conducted at liquidity index LI = 0.18 after through blending, the wet soil was kept inside plastic nylon bags for a period of two days to get uniform moisture content. After that the soil was placed in eight layers inside the steel container. Each layer was tamped in order to remove entrapped air. The upper surface was scraped and leveled, then a setting pressure of 5 kPa was applied for 24 hours.

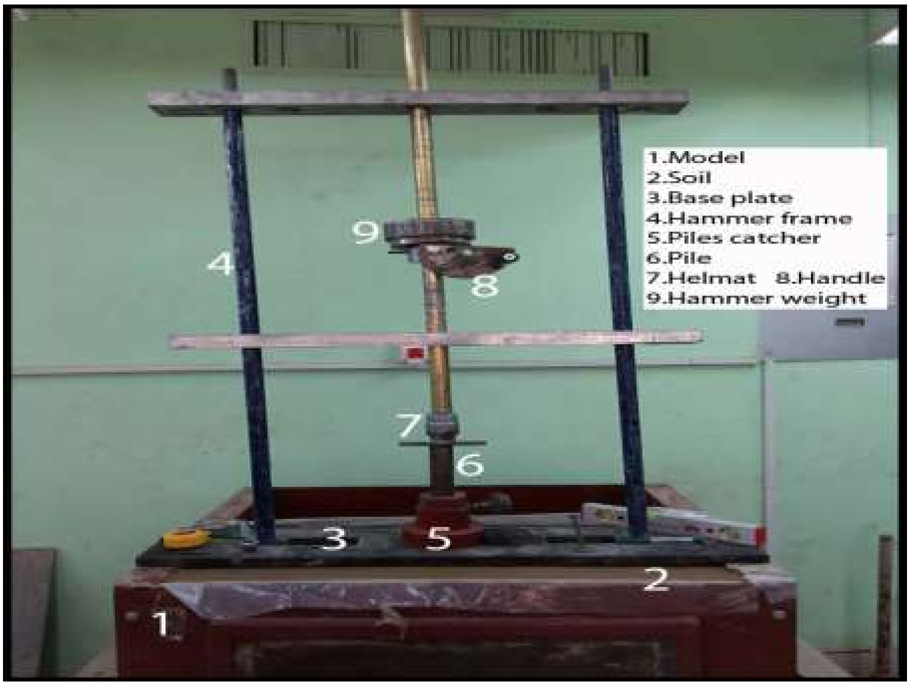
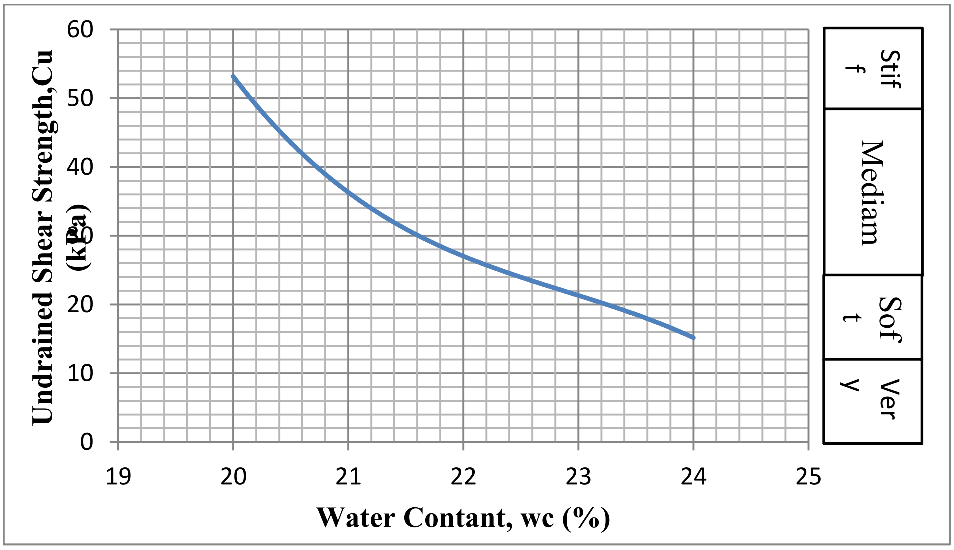



**Figure (1): Model and Pile driving hammer device.**




**Figure( 2). Variation of un drained shear strength with water content**

**(after two days)**

## Installation and Testing of Piles

After the completion of the preparation of the bed of clayey soil, theoretical static equation (FHWA) method [17], and dynamic Hiley formula [18], were employed to obtain the ultimate pile capacity for model pressed and driven piles consecutively. Meanwhile the incremental filling ratio (IFR) for open ended piles measured each 25 mm using a Measuring Tape. Then the model piles tested according to ASTM D1143– 07[19] using the Quick Test through Applying a vertical load by means of 1-ton capacity hydraulic jack, a constant loading rate has been adopted in the whole testing program. The load is read from a digital weighing indicator connected to the load cell, the centric displacement of the pile is read by two dial gage of 0.01 mm sensitivity. The load increments are continuing till the recorded settlement exceeding 15% of the pile diameter according to ASTM D1143 – 07[19].

## Presentation and Analysis Results:

The test were consist of 36 model (18 models for both open and closed ended) steel pipe piles.

## Effect of piles diameter on the ultimate load capacity

Figure 3 demonstrates that a larger pile diameter leads to increase in pile capacity for the same pile length. As well as, the rate of increasing in pile capacity for the same diameter increases with increasing in the pile length. This behavior may explain as a reason: for close ended piles, the increase of adhesion areas and end bearing capacity of pile causes a reduction in the imposed pressure on the pile tip resulting a less settlement; while for open ended piles is attributed to the increase in both internal and external adhesion force. Also, for the same pile length, the closed ended piles have a larger load capacity than the open ended piles in both (hammered and pressed) models, because the closed ended piles cause a large displacement in the surrounding soil, which leads to increasing in the stress bulb than that of open ended piles. Also, it is clearly seen that the pressed piles developed much greater capacity during static load testing compared with hammered piles for both close and open ended which causes soil disturbance through pile driving process. These results are agree with Tomlinson [20] that stated "during pile driving in stiff clay, a gap and/or disturbed zone of soil develops between the surrounding soil and upper portion of the pile shaft". Also, similar results were observed by Miller & Lutenegger, [5], who marked differences in capacity for the hammered and pressed piles.

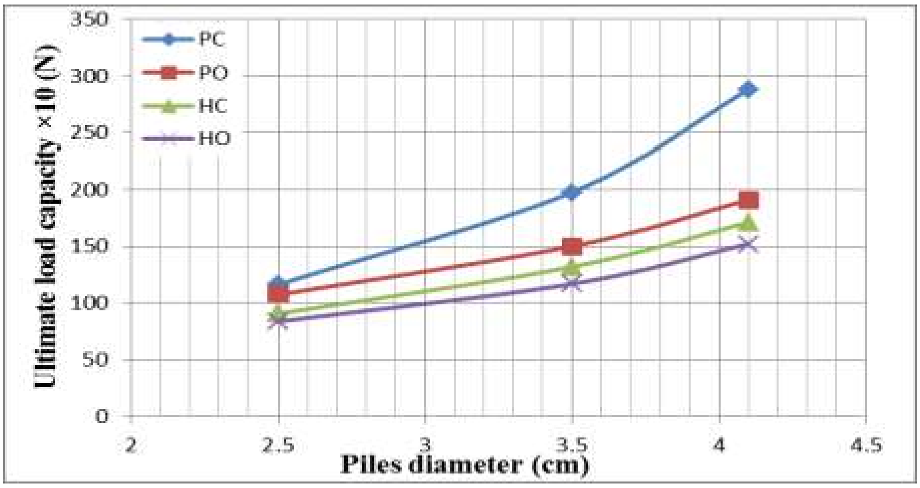



**Figure (3) Effect of pile diameter on the ultimate load capacity (L=50cm).**

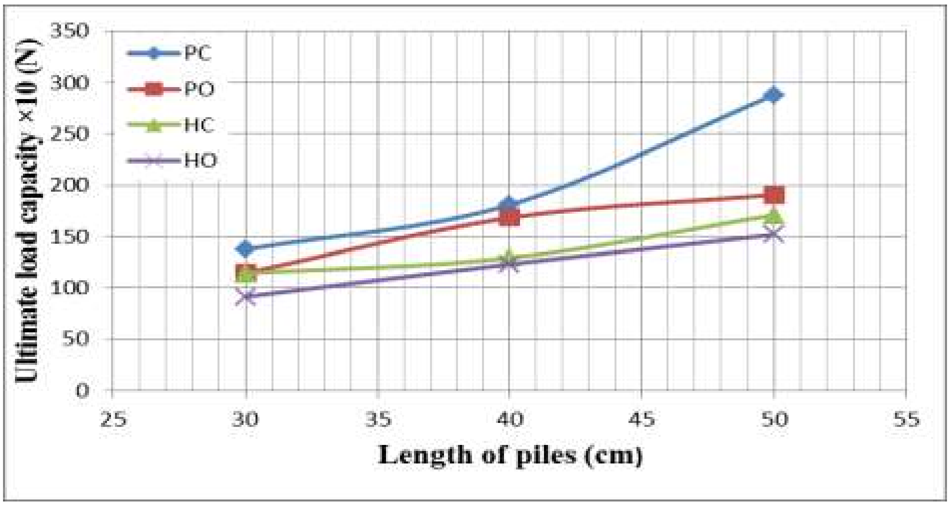



**Figure (4) Effect of pile length on the ultimate load capacity (d=4.1).**

**Effect of piles embedded length on the bearing capacity**

The results showed that the increase in pile length leads to increase linearly or quasi linearly in the pile capacity for the same pile diameter, as in Figure 4. This increase because the large surface area subjected to the shearing during the loading will increase. Moreover, the rate of increasing in pile capacity for the same diameter increases with pile length increase. This behavior is due to increase of bearing surface area in closed ended piles and increase in both internal and external adhesion areas in open ended piles.

**Effect of soil plug length on the ultimate load capacity of piles**

The effect of soil plug length on the ultimate load capacity of piles embedded with pressed and hammered technique into cohesive soil are indicated in Figures 5 and 6. In general for pressed and hammered piles, the ultimate load capacity of piles tends to increase with increasing of pile diameter and length. These findings are compatible with findings of Paikowski & Whitman, [6], whom stated that (the plugging of open piles in clay does not contribute significantly to the capacity of the pile) and with findings of Gallagher & Gavin, [9], whom stated that (the plug capacity was relatively low throughout installation, being only 5-10% of the $q_c$ value).

Figure 7 indicates that the decrease in Plug Length Ratio (PLR = Soil Plug Length/Pile Penetration) leads to increase in the ultimate bearing capacity to ratio ($q_{ult}/C_u$) and vice versa for pressed open-ended pipe piles, while hammered piles show the randomness behavior which cannot be represented by curve.

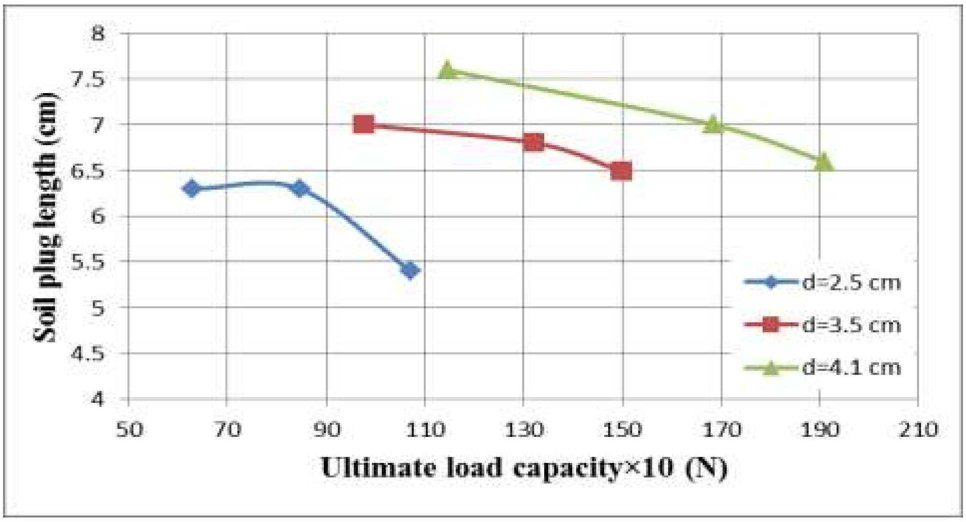
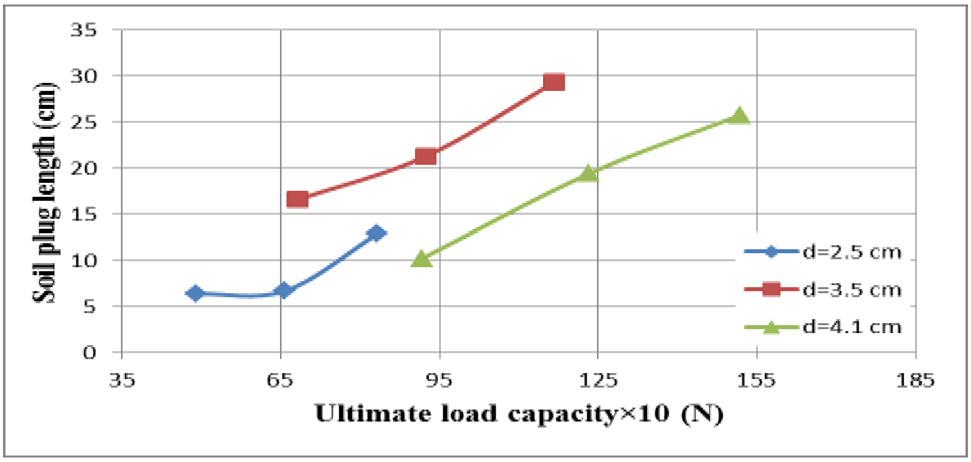



**Figure (5) Effect of soil plug length on the ultimate load capacity for pressed Piles with different diameters**




**Figure( 6) Effect of soil plug length on the ultimate load capacity for hammered Piles with different diameters**

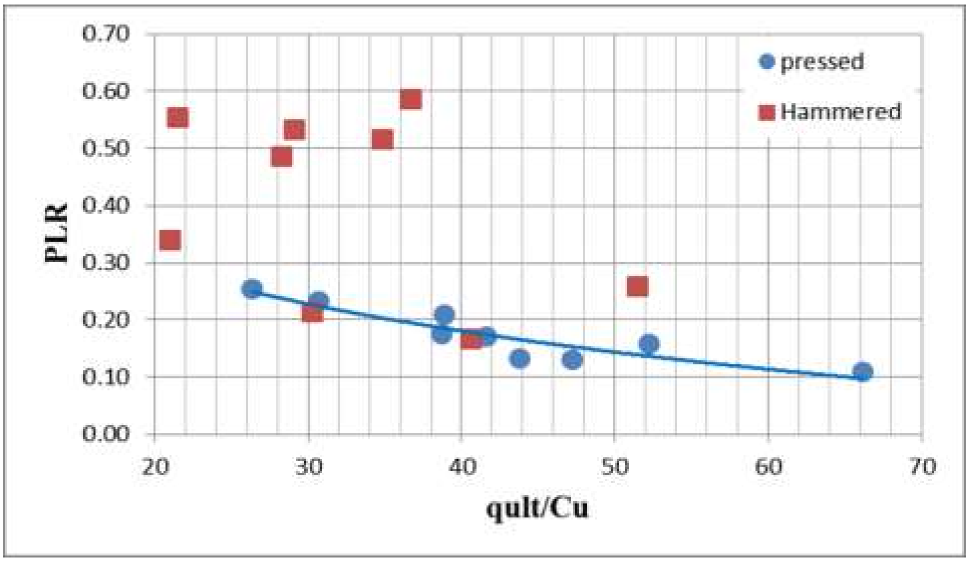



**Figure ( 7). Relationship between PLR and the ultimate bearing capacity ratio for pressed and hammered Piles.**

## CONCLUSIONS

1. The ultimate load capacity of open-ended pipe piles tends to increase as the pile diameter and length increases for both pressed and hammered. Therefore, plugging of open ended piles does not contribute significantly to the capacity of pile embedded in clayey soil.
2. The pressed piles developed (20 – 45) % much greater capacity during static load testing than did hammered piles for both close and open ended. This behavior referred to soil disturbance resulting from the pile driving process.
3. The close-ended pile has (5 – 30) % larger capacity than the open-ended for both of pressed and hammered mode with the same pile diameter and length. Because the close ended pile cause a Large displacement with penetration depth in the soil surrounding as opposed to the much smaller soil displacements of open ended pile with depth.

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