STEEL PIPED PILE FOUNDATION FOR EMERGENT CONSTRUCTION

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ABSTRACT

Loading tests on short steel pipe piles were conducted in the steel drum filled with clayey soil. The aim of this study was to find the ultimate load carrying capacity of these piles for emergent construction of shelters in calamity hit areas. The pile was three feet long and three inches outside diameter. The steel drum was fabricated for this purpose. It had depth of four feet, diameter of three feet. A reaction beam was welded to the diametrically opposite columns on the top open end of the drum. The reaction beam had a clearance of 1 foot above the top open end of the drum. The basic, index and engineering properties of both disturbed and undisturbed clay were determined in the Soil Mechanics laboratory. Four different densities having a water content of 5%, 10%, 15%, and 20% were used to find the ultimate load carrying capacity of these piles. The ultimate load carrying capacities were found in three conditions of pile both ends open, lower end closed and upper end closed. When the above data were plotted, the conclusion of the study was that ultimate load carrying capacity of the short pipe pile in soft clay could be estimated from the field moisture content or density of the clayey soil. Moreover, the 3rd condition of the pile foundation was recommended as the pile could easily be penetrated to the closed top end in which case it would derive ultimate end bearing capacity at the bottom of pile because the enclosed clay in the pipe would act as a solid piped pile.

Keywords

Piles, Foundation, ultimate load, bearing capacity

I. INTRODUCTION

It is a common practice to construct a temporary structure on shallow foundation of long or wall footing in Pakistan. But where its urgent and emergent use is required the shallow foundation may be uneconomical and time consuming, as it needs more time for excavation, more labor and more money. In catastrophic situations like earthquake or floods, the rehabilitation of victims is the task of major concern. The rehabilitation process must be accomplished. The shallow foundation in such situations is obviously time-consuming and uneconomical especially in a country like Pakistan, where infrastructures leading to such far flung areas are difficult to use and in more cases these facilities are even not available. For quick relief, the method and type of foundation is thought to be steel piped pile foundation. The driving of steel piped pile foundation is considered to be an easy task in clayey soils. Structural columns can be constructed on these driven short piles installed on four corners of the building for immediate shelters. The aims and objectives of the project are to devise a speedy construction method for foundation system in areas hit by disasters where immediate shelters are needed and to find the load carrying capacity of steel piped pile foundation of shorter length in clayey soils.

2. PREVIOUS WORK ON STEEL PIPE PILES:

Senior Engineer C.F SOO, Deputy Director C.C LIN and Engineer R.F WANG of Taiwan Power Company in association with C.D OU and Z.C MOH of Moh and Associates worked on same research. They studied the behavior of steel pipe piles in clayey soil and made some conclusions on the basis of their work. They used steel piles for construction of Hsin-Ta steam power plant in southern Taiwan. The construction started in 1978. During construction work full scale test piles were driven for pile test. They, in later stages, compared open end and closed end pipe piles. They tested piles in both sand and clayey soil. It was found that close end pipe pile have more resistance as compared to open end pipe piles in sand but the case was totally reverse in clay. In clay soil it was found that open end pipe pile have more resistance to hammering as compared to closed end pipe pile. However the investigation on steel pipe pile is inadequate due to lack of measurement records of prototype piles in the field. (Craig, 2012)

3. THEORETICAL LOAD CAPACITY OF STEEL PIPE PILES:

Steel pipes have broadened its use in pile industry. Steel pipe piles have load carrying capacity due to both skin friction and end bearing. They are very strong however it must be tested for its tensile and compressive strength especially for failure due to buckling. One main point must be under consideration that steel pipe piles are smooth and may have low frictional resistance; moreover, in stiff consistency of clayey soils, the grip is not tight because of some annular space developed due to vibration / hammering of the pile driving. But if the clay is very soft, this factor may not disturb the load carrying capacity very much. For this purpose, an adhesion factor ‘α’ is used which depends upon the coil consistency and nature of material of pile. This value ranges between 1 and 0.6. (Brames,2010). The load support of the pile from end bearing or base bearing is a function of cohesion, c, area of the base, Ab, and bearing capacity factor Nc. Theoretically, on the basis of laboratory tests on clayey soil, short pile may be designed for their load carrying capacity. These piles may be used for supporting light structure, like temporary light weight structures, used for rehabilitation of victims of disasters and calamity. As shallow foundation, in such case, is uneconomical and time consuming method, steel pipe piles may be economical as well as can be installed quickly. (Punmia,1973) Therefore the following three cases are considered for research study:

3.1 Both ends open:

In this case a hollow pipe of proposed pile length (L) was driven in soil. The pipe has interaction with soil externally as well as internally. In early stages of this research the load carrying capacity of both end open pipe pile was estimated on the basis of its fully activated cross sectional area. Further working on this topic clears that this design concept is not correct. It was cleared that load carrying capacity depends on effective length of the pile.

- *Cohesion, c=4.6 lbs/in^2 = 662.5 lbs/ft^2.*
- *angle of internal friction, f= o^o*
- *external radius of the piped pile, r_e= 2”*
- *internal radius of the piped pile, r_i= 1.9”*
- *length of the steel piped pile, l= 3 ft*
- *co-efficient of lateral earth pressure, ks=0.8*
- *unit weight of the soil, g= 104 lb/ft^3*
- *adhesion factor, a= 0.9*
- *total load carrying capacity of the piped pile due to friction,* $Q_t=Q_e + Q_i$
- $Q_t = 2\alpha\pi r_e L(C + \sigma_n Tan\varphi) +2\ \alpha\pi r_i L(C + \sigma_n Tan\varphi)$ = **935 lbs + 890 lbs = 1825 lbs = 0.9012Tons**

3.2 Lower end closed:

The load carrying capacity of such pipe piles are same as a simple friction cum pile. In this case one end plugged pipe of length ‘L’ is driven in soil. The pile has skin friction with soil and has end bearing on plugged end.

- *Cohesion, c = 4.6 psi = 662.5 psf;*
- *Angle of internal friction, $\Phi = 0^o$,*
- *external radius of steel pipe, r_e = 2 inches;*
- *length of piped pile, L = 3 feet;*
- *coefficient of lateral, k_s = 0.8;*
- *unit weight of soil, γ = 104 lbs/ft^3;*
- *Adhesion factor, α = 0.9,*
- *Bearing capacity factor, N_C = 9 and*
- *base area of piped pile, A_b = 0.1256 ft^2*
- *Total resistance = $Q_t = Q_e + Q_s$*
- $Q_t = cN_cA_b + 2\alpha\pi r_e L(c + \sigma_n Tan\varphi)$ **= 748.89 lbs + 1872 lbs =2620 lbs =1.31 Tons**

3.3 Upper end closed:

This case is ultimate case having advantages of both open-end and close end pipe piles. In this case the upper end of pipe pile is closed while its lower end remains open. Soil plugged in pipe pile. The pipe has load carrying capacity because of external skin fiction, internal skin friction due to plugged soil and end bearing at its upper end. This case has one more extra advantage that the pile was driven easily at the start. At start its was easy to drive the pile in clay as compare to closed-end pipe pile but later when the closed upper end comes in contact with soil the driving resistance increases.

- *Cohesion, C = 4.6 psi = 662.5 psf;*
- *angle of internal friction, $\Phi = 0^o$;*
- *external radius of the pipe, r_e = 2 inches;*
- *internal radius of the pile, r_i = 1.9 inches;*
- *length of the pile, L = 3 fee;*

- *coefficient of lateral earth pressure, $k_s = 0.8$,*
- *unit weight of the soil, $\gamma = 104\ lbs/ft^3$*
- *Adhesion factor, $\alpha = 0.9$,*
- *bearing capacity factor, $N_C = 9$ and*
- *area of the base of pile, $A_b = 0.1256\ ft^2$*
- $Q_t = Q_{ext} + Q_{end} + Q_{int}$

$$Q_t = \alpha 2\pi r_e L(c + \sigma_n Tan\varphi) + cN_c A_b + \alpha 2\pi r_i L(c + \sigma_n Tan\varphi)$$

$$\mathbf{Q_t = 1872\ lbs + 748.00\ lbs + 1778.00\ lbs_t = 4398.00\ lbs_t = 2.20\ Tons}$$

4. EXPERIMENTATION PROCEDURE:

The soil sample was collected from ring road Hazarkhwani area for which the soil was excavated 10 feet. The soil sample was put in polythene sheets to maintain its moisture content and brought to CECOS University Soil Mechanics laboratory for testing. Part of the soil sample was placed in open air for air drying, while some was placed in oven for oven drying and some was placed.

4.1 Basic, Index and Engineering Properties of the soil

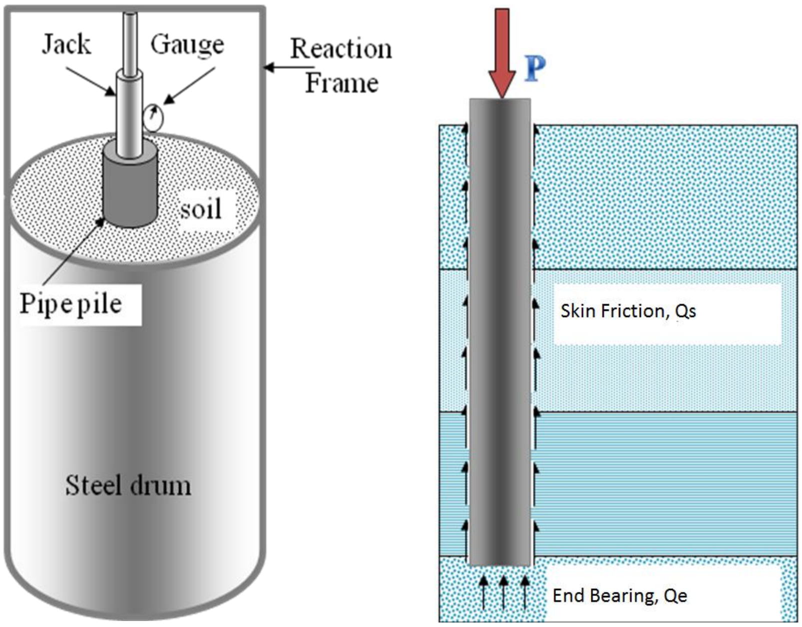
The soil used in this research study on the load carrying capacity of short steel piped pile tested in a steel drum was classified as grayish clay of low plasticity (CL) as per Unified Soil Classification System (USCS). The natural moisture content was found to be $\mathbf{w_n}$ = 9.3% and the unit weights were □$_t$=112 lb/ft^3 (wet) and □$_d$ =104 lb/ft^3 (dry). The liquid limit, plastic limit were found to be **LL** = 23.3% and **PL** = 13.3% respectively. Specific gravity of soil solids was found to be Gs = 2.7. Cohesion from unconfined compression shear test was determined as $\mathbf{c_u}$ = 605 lbs/ft^2 (4.2 psi) and angle of internal friction in undrained state was estimated as □$_u$ = 0^o. Internal angle of friction for direct shear test was 21.15^0 and cohesion was 6.42 psi. Using same data as shown in table:1

Table 1:

S. no	Test description	Result
1	On site moisture content	9.3%
2	Specific gravity	2.7 (clay)
3	Wet Unit weight	112 lb/ft^3
4	Dry unit weight	104.2 lb/ft^3
5	Liquid limit	23.6%
6	Plastic limit	13.6%
8	Optimum moisture content	11.2%
9	Maximum dry density	134 lb/ft^3
11	Unconfined compressive strength	9.2 psi
12	Unconfined compression test, cohesion	4.6 psi
13	Cohesion (direct shear test)	6.42 psi
14	Internal friction angle (direct shear test)	21.15^0

4.2 Piped Pile Load Tests:

These tests are performed to estimate the ultimate load carrying capacity of piped piles in clayey soil filled in steel drum .The Data Collected from these tests are plotted for ultimate load capacity of piped Pile against unit weight of soil & next step against the Moisture Content of soil. The ultimate load capacity of pile is plotted against unit weight of soil for the following three conditions. The first type of test is piped pile with both ends open, to find the ultimate load carrying capacity due to friction both inside & outside the pipe.



Deep Foundation

Fig.1: Typical sketch of Piped Pile Load test apparatus.

4.2.1 Both end open pipe pile (Prototype test):

A pipe open (hollow) at both ends of length three feet and diameter four inches was driven in drum containing soft clayey soil compacted in equal four layers, each one foot thick, at increasing moisture content. For sake of accuracy pipe pile was driven three times (R1, R2, R3). The ultimate load mobilized through skin friction between the pipe and soil under different moisture contents are tabulated in table 2 and the graph between unit weight and ultimate load carried by the piped pile is shown in Fig.2. As % moisture content increases, dry density decreases, and ultimate load decreases. Field density shows positive relationship with ultimate load (Fig.2)

Table 2:
Prototype tests results of ultimate load and moisture

Moisture content (%)	Dry density (lbs/ft^3)	Stresses (psi)				Ultimate load (Tons)
		R1	R2	R3	Ave	
5	127.5	1619	1625	1589	1611	1.18
10	134	1756	1789	1743	1762.6	1.3
15	100.4	1058	1123	1136	1105.6	0.81
20	87.5	876	923	889	896	0.65

4.2.2 Lower end closed pipe pile (prototype test):

A pipe open at top but closed at bottom (lower end) of length three feet and diameter four inches was driven in drum containing soft clayey soil compacted in equal four layers, each one foot thick, at increasing moisture content. For sake of accuracy pipe pile was driven three times (R1, R2, R3). The data derived from these prototype tests are tabulated, plotted and analyzed in Table 3 and in Fig.2

Table 3:
Prototype tests results of ultimate load and moisture.

Moisture content (%)	Dry density (lbs/ft^3)	Stresses (psi)				Ultimate load (Tons)
		R1	R2	R3	Ave	
5	127.5	1535	1510	1489	1511.3	1.1
10	134	1623	1652	1646	1640.3	1.2
15	100.4	974	956	989	973	0.7
20	87.5	719	723	719	725.6	0.5

The smaller value from the prototype tests may be due to the less overburden effect & small scale of the test. But the trend of the results from the prototype test plotted in Fig.4.2 is that it exponentially increases with increase in density of the soil. From Table 4.3 it can also be seen that the ultimate load capacity is maximum at some moisture content and then decreases with increase in moisture content.

4.2.3 Upper end closed pipe pile (prototype test):

A pipe open at bottom (hollow) but closed at top (upper end) of length 3 feet and diameter 4 inches was driven in drum containing soft clayey soil compacted in equal four layers, each 1 foot thick, at increasing moisture content. For sake of accuracy pipe pile was driven 3 times. The data is given in table 4 and are plotted in Fig.2

Table 4:
Ultimate load capacity against moisture content and density of clayey soil

Moisture content (%)	Dry density (lbs/ft^3)	Stresses (psi)				Ultimate load (Tons)
		R1	R2	R3	Ave	
5	127.5	1835	1820	1790	1815	1.3
10	134	1910	1935	1898	1914.3	1.5
15	100.4	1612	1632	1651	1631.6	1.2
20	87.5	1284	1275	1289	1282.6	0.91

When the data are analyzed, it can be seen that increase in ultimate pile load capacity with increase in density but again dependent upon some unique value of moisture content.

4.3 Comparisons of all three pile cases:

The data collected from all nine tests for ultimate pile load capacity in different unit weights are plotted in Fig 2. It is evident from it that piped pile with top end closed gives maximum values that is attributed to three factors of end bearing, inside and outside skin friction. Moreover, it is easy to install this type of piped pile with ease as it first the skin friction has to be overcome during penetration of the pile. And when the top closed end touches the soil, the end or base bearing will add to its resistance i.e. load carrying capacity of the pile.

Table 5:

S. no	Test description	Result
1	Theoretical Ultimate load capacity of both ends open pipe pile	1.6 Tons
2	Theoretical Ultimate load capacity of lower end closed pipe pile	1.18 Tons
3	Theoretical Ultimate load capacity of upper end closed pipe pile	2.0 Tons
4	Practical Ultimate load capacity of both ends open pipe pile.	1.3 Tons
5	Practical Ultimate load capacity of lower end closed pipe pile.	1.2 Tons
6	Practical Ultimate load capacity of upper end closed pipe pile.	1.5 Tons

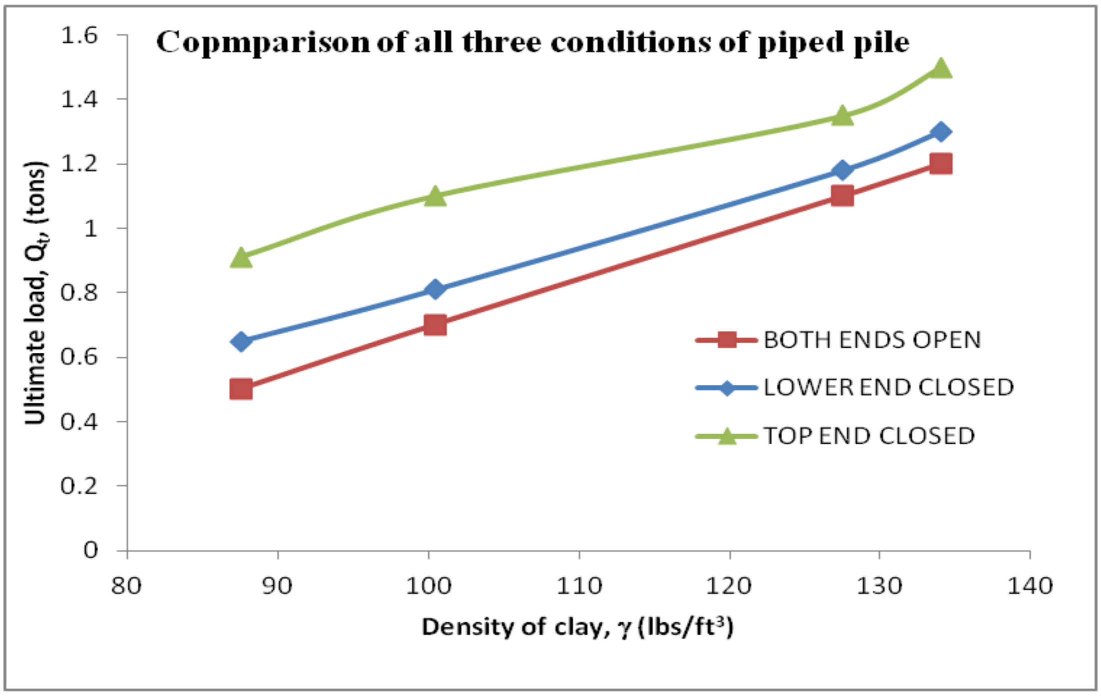


Fig. 2 : Comparison of the ultimate load capacity of piped pile in clayed soil for three cases.

4.4 Ultimate Load Capacity of piped pile against moisture content:

Since it is seen that the ultimate load carrying capacity of the piped pile in clayey soil is a function of soil moisture content, therefore, it is better to show its trend graphically in Fig.3 But it should be noted that the ultimate load carrying capacity of the piped pile is also a function of dry density of soil. The graph shows that in all the three cases of piped pile, maximum ultimate load carrying capacity is at some unique moisture content where the dry density is also maximum from the proctor tests results. It is known that the amount of soil solids is maximum at maximum dry density; therefore, it will also offer more resistance to penetration as compared to other state of compactness i.e. relative compaction other than maximum will give less resistance to penetration. Moreover, the same relative compaction has got two moisture contents; one is dry side of the optimum moisture content the other one is rather wet side of the optimum content. The dry side will give more resistance to penetration than the wet side of optimum moisture content for the same relative compaction.

Influence on Shear strength:

Compaction increases the number of contacts resulting in increased shear strength, especially in granular soils. In clays, shear strength depends on dry density, molding water content, soil structure, method of compaction, strain drainage condition etc. optimum (flocculated structure) will be higher than those compacted wet of optimum (dispersed structure). Increase in compaction increases the density and number of contacts between soil particles. This results in increased shear strength, hence bearing capacity increases which are a function of density and moisture content. (Prasad)

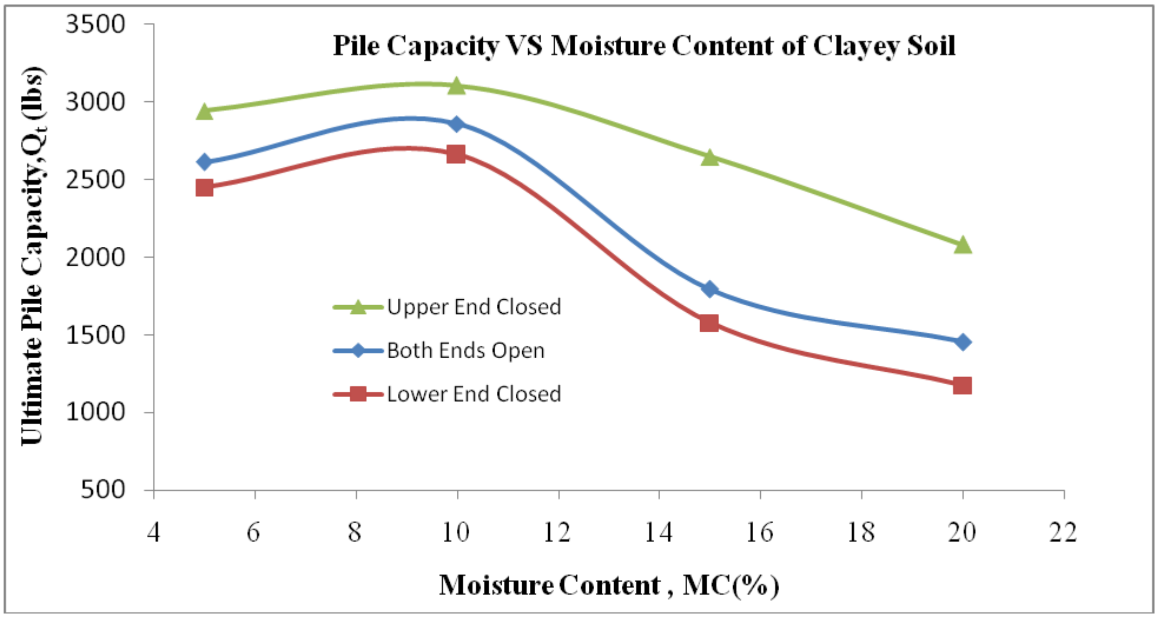


Fig.3
Ultimate Load capacity of piped pile and moisture content of clayey soil

5. CONCLUSION

From tests on short steel piped pile in clayey soil under moisture content of 5%, 10%, 15% & 20% with corresponding dry unit weights of 127..5 lb/ft3, 134 lb/ft3, 100.4 lb/ft3 & 87.2 lb/ft3, it was revealed that ultimate load capacity due to inside & outside skin friction only increased with dry unit weight but decreased with moisture content. So in the field graphs for this condition will be useful to estimate this capacity from the density & moisture content of the soil. Accordingly the weight of the emergent shelter can be estimated from the ultimate pile load capacity. In this case the contribution from inside friction was missing & ultimate load capacity was due to end bearing & outside skin friction, Again the ultimate capacity increased with dry unit weight & decreased with increase in moisture content. But the case of penetration of such pile in soil for emergent construction was found to be difficult & time consuming. Although it resulted in higher values than those for the 1st case of pile. It was seen from the results of these tests that maximum values of the ultimate load capacity as compared to the two cases. This is attributed to the three agencies of load supports from inside, outside and end bearing of the top closed end. Moreover, it was found easy to penetrate the pile up to the touch of top end against the ground surface the further penetration of which results in added capacity due to end bearing.

It is evident from it that piped pile with top end closed gives maximum values that is attributed to three factors of end bearing, inside and outside skin friction. Moreover, it is easy to install this type of piped pile with ease as it first the skin friction has to be overcome during penetration of the pile. And when the top closed end touches the soil, the end or base bearing will add to its resistance i.e. load carrying capacity of the pile.

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