Carrying Capacity of Model Steel Pile Foundation with Different Cross Section Shapes in Sand

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Abstract. In present time the steel piles are widely used for foundation of various structures constructed on shore and offshore. They are getting popularity because of easy availability, handling and splicing and also durable. In the present investigation, the load carrying capacity were compared of model steel piles having different cross-section shapes under vertical load in sand by keeping the equal cross-sectional area and equal length of pile. For this purpose model steel piles of different shapes i.e. solid circular, hollow circular , L- shape, and H-shape pile having equal cross sectional area (A= 1.767cm^2) and equal embedded length 30cm and total length of 33cm were used. For this work the effect of shape of single model pile and model pile group of 2x2 with spacing 3d, 4d, 5d on load carrying capacity were studied in sand of two different relative densities under vertical load. For experimental work, circular tank of diameter 90 cm and height 60 cm was used and natural Bahadarpur sand near Sankheda, Vadodara district of Gujarat having angle of internal friction (φ)=34˚ and density (ρ)=1.687 g/cm^3 (60% relative density) and angle of internal friction (φ)=40˚ and density (ρ)= 1.747 g/cm^3 (80% relative density) was used. The load was applied at the centre of pile cap through jacking mechanism and pile cap was kept 3cm above the soil layer to neglect the effect of cap in the capacity of pile. From investigation of results it has been observed the load carrying capacity of H-shape single pile is more as compare to all other cross section shapes in 60% as well as 80% relative density. In pile group all shapes of pile shows increasing in load carrying capacity with increasing in spacing from 3d to 4d and 5d but capacity trend is different in H-shape pile as here the load capacity decreases with increasing spacing in both 60% and 80% relative density. Consequently in pile group the hollow circular pile shows maximum capacity with increasing spacing and relative density.

Keywords: Carrying capacity; Model steel pile; Cross-section shapes, Relative density.

1. Introduction

The pile foundation is used to transmit the load of a superstructure to the strong soil strata lying at greater depth. The cross–section shapes of pile, relative density of soil (sand), pile spacing , pile installation process are important factors influence the load carrying capacity of pile and pile group. Model pile load test performed in large test tank plays an significance role to understand the load-settlement behavior of pile model tests are better than real field tests irrespective of good control on soil

condition and also better to understand the soil- structure interaction process during installation process during however small laboratory model tests do not perfectly reflect the real test data due to some scale and boundary effect of chamber and piles model. Some researches **Parkin (1980), Schnaid Houlsly (1981), Salgado (1988)** have noted the certain limit ratio of tank diameter to pile diameter should be considered during model test and it should be at least 50. Steel piles are used world-wide for the foundation of a variety of structures. These are manufactured in various shapes, lengths and dimensions providing for both vertical and lateral load capacity. These piles have advantageous over the other piles as they are easy to handle, splicing and drive into the ground. **Salgado, 2008** performed tests on H-pile and solid circular pile under vertical load in sand and concluded that results as in solid circular pile the load capacity is mainly due to frictional resistance and end-bearing resistance. However the frictional resistance has more effect on load carrying capacity as compare to end-bearing resistance because of less area of soil is come in contact with base. Behavior of hollow circular pile is different from solid circular pile. **Szechy (1961)** test results show that blow count necessary for hollow circular pile is less than the solid circular for driving a pile under same condition of sand. However results of **Smith (1986), Brucy (1991**) have showed that the mode of pile driving is important factor to predict the driving resistance of pile .If pile is driven under fully plugged mode, the plugged soil already attached to the surface of pile will resist the further entering of soil. According to test results of **Mohammed Y. Fattah and Wissam H.S. Al- Soudani-2**) performed test on hollow and solid circular pile under vertical load in sand and concluded that hollow circular pile will behave as a solid circular pile if soil inside the hollow circular pile is in partially or fully plugged mode. Also the settlement of hollow circular pile is more than the solid circular pile. H-pile is generally considered as a partial displacement pile because while inserting this pile into soil the displacement means volume change of pile is small. It works between fully displacement pile and non displacement pile. **Salgado and Kim (2008**) performed the test on H-shape pile and solid circular in multilayered soil under vertical load and conclude that the shaft capacity of H-pile is 20% less than the solid circular pile and this may be due to plugging behavior of the H-pile driven in sand on the other sand base capacity of H-pile is almost twice as large as that of solid circular pile because of the difference in base area contact with the soil and thus the different influences zone below the base of pile.The information about load carrying capacity of L-shape pile is still missing and no detail research has been founded about this pile. Generally the information about load carrying capacity of different cross- section shapes (solid circular, hollow circular, L-shape, H-shape) of pile by keeping the cross section are equal and equal length has not been founded in researches, so in the present investigation the load carrying capacity of different cross- section shapes i.e. solid circular, hollow circular, L-shape, H-shape of pile model under the equal cross section area and length has been investigated under vertical load in sand by considering two different relative density of 60% and 80%..

2. Materials Properties

2.1Model Piles

Pile model of different shapes were constructed using mild steel and following important properties have been listed here in Table 1.

Sr. No.	Properties or Specifications	Solid circular	Hollow circular	L-shape	H-shape
1	Area (mm2)	1.767 x 10^2	1.767 x 10^2	1.767 x 10^2	1.767 x 10^2
	Dimensions-				
	I. Pile cap thickness (mm)	20	20	20	20
	II. Flange width (mm)	-	-	-	24.45
	III. Web height (mm)	-	-	-	10
	IV. Flange and web thickness (mm)	-	-	-	3.0
	V. Two leg length equal in (mm)	-	-	30.95	-
	VI. Thickness of both leg (mm)	-	-	3.0	-

Pile testing program

For initial increment of loading and for finding the single pile and group of pile ultimate load capacity was calculated on a single and group of pile using IS-2911 (part-I) and for load application IS-2911 (part-IV) followed.

Fig.1. Final setup of pile load testing program.

3. Results and Discussion

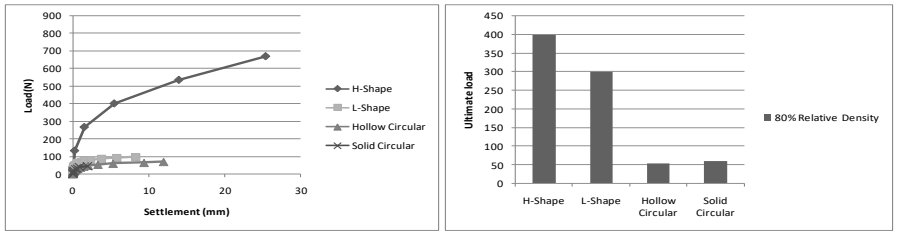
The tests were performed on a single pile and group of piles of slid circular, hollow circular, L-shape and H-shape pile under vertical load in sand of 60% and 80% relative density by placing the pile through pre -installation and driving process..Following results were obtained for ultimate load of all tests for both densities , which are listed here below in **Table 2.**

Table 2. Values obtained from present investigation of ultimate load.

Description of shapes of pile	Pile-Single / Group (Spacing)	Driving process	Ultimate Load (N) (60% R.D.)	Ultimate Load (N) (80% R.D.)
Solid circular	Single	Pre-installation	60	75
	Group-3d	Pre-installation	300	335
	Group-4d	Pre-installation	470	490
	Group-5d	Pre-installation	1640	1878
Hollow circular	Single	Pre-installation	52	128
	Group-3d	Pre-installation	727	1230
	Group-4d	Pre-installation	3520	4080
	Group-5d	Pre-installation	4340	4363
L-shape	Single	Driven	300	363
	Group-3d	Driven	1055	1260
	Group-4d	Driven	1407	1550
	Group-5d	Driven	1583	1609
H-shape	Single	Driven	400	430
	Group-3d	Driven	2420	2520
	Group-4d	Driven	2100	2120
	Group-5d	Driven	1750	2100

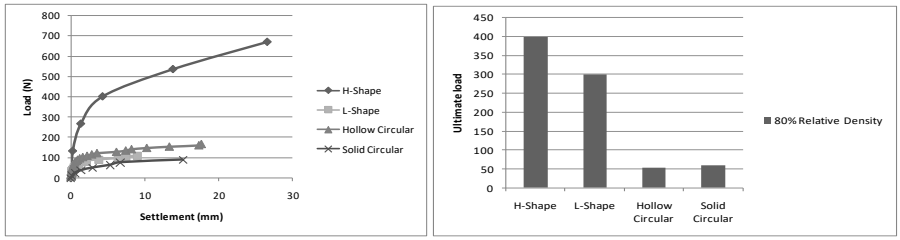
4.1 Load Vs Settlement analysis

For pile of all shapes the tests were performed on single and group of piles (2x2) of 3d,4d,5d for 60% and 80% and following tests results have been found.



(a) (b)

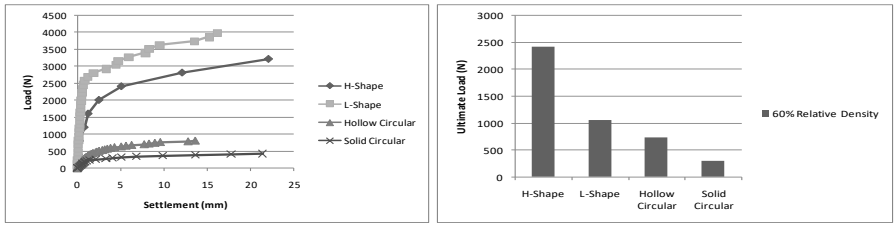
Fig. 2 (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of all single pile corresponding to 60% Relative Density of sand.



(a) (b)

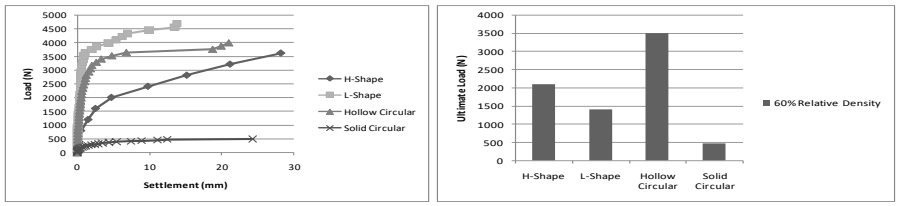
Fig.3. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of all single pile corresponding 80% Relative density of sand.

From fig.2(a) the load carrying capacity of single pile is more in H-shape pile as compare to other cross-section shapes. It is seen the capacity of H-pile is about 7.6 times more from hollow circular pile and about 6.6 time more than solid circular pile and around 1.3 times of L-shape pile. Similarly the L-shape pile capacity is about 5.7 times more from hollow and about 5 times more than solid circular pile. Load carrying capacity of hollow circular and solid circular pile is not so much different.. Also from fig. 3(a) the load carrying capacity of all single pile is more for 80% relative density as compare to 60% relative density of sand. The load trend is same as in 60% relative density, except the hollow circular showing increase in capacity as compare to solid circular pile. Again seen that the H-pile capacity is about 5.6 times more from solid circular and 3.3 times more from hollow circular pile and from L-shape it is not so much different. Similarly the capacity of L-pile is 4.4 times more from solid circular and 2.6 times from hollow circular pile. The capacity of hollow circular pile is observed 1.7 times the solid circular in this case. Now the comparison was also done between all four shapes of pile for centre to centre spacing of 3d, 4d and 5d. The following graph has been plotted for various spacing for 60% and 80% relative density of sand.



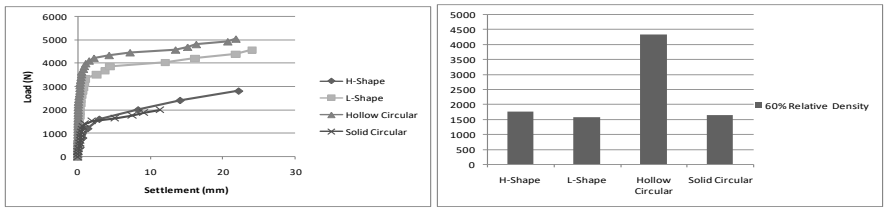
(a) (b)

Fig. 4. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 3d (Where d=1.5cm) for 60% Relative Density of sand.



(a) (b)

Fig. 5. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 4d (Where d=1.5cm) for 60% Relative Density of sand.

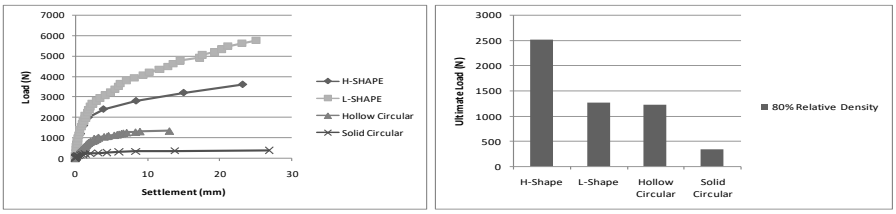


(a) (b)

Fig. 6. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 5d (Where d=1.5cm) for 60% Relative Density of sand.

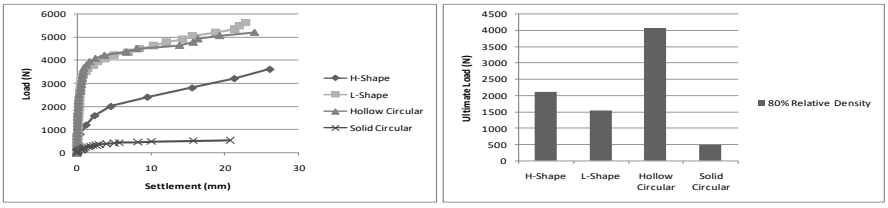
It is seen from curves of fig.4, fig.5, fig.6 that in pile group ultimate load will increases as compare to single pile means group pile has load carrying capacity more as compare to single pile. The loading trend is same as was in single pile and the capacity of H-pile is about 8 times more from solid circular, 3.3 times from hollow circular pile and 2.2 times from L-pile. Similarly capacity of L-pile is 3.5 times more as compare to solid circular and 1.4 times more from hollow circular and the hollow circular pile's capacity is 2.4 times more from solid circular pile in 60% relative density. Similarly from fig. 5(a) it is seen that in pile group of 4d spacing ultimate increases in all shapes except H-shape compare to 3d spacing. It means maximum

increase in capacity is observed in hollow circular pile as compare to other piles. In hollow circular pile the capacity is about 1.6 times more from H-pile, 2.5 times from L-pile and 7.6 times from solid circular pile. Similarly H-pile capacity is about 4.4 times more from solid circular pile and 1.4 times from L-pile. In L-pile the capacity is 2.9 times more as compare to solid circular in 60% relative density case. Now from fig.6(a).The capacity of solid circular pile is slightly more as compare to L-shape pile.The hollow pile capacity is around 2.5 times from all other shapes pile. Same way if compare the load carrying capacity for 80% relative density the following graph obtain for 3d, 4d, 5d spacing as shown below-



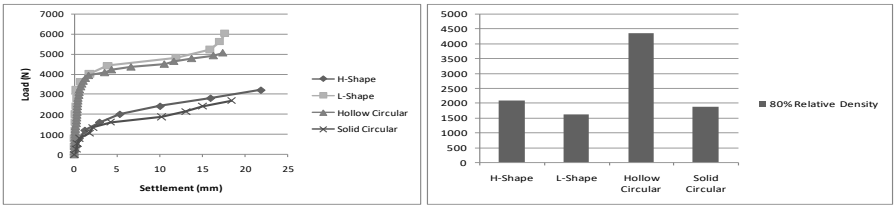
(a) (b)

Fig. 7 .(a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 3d (Where d=1.5cm) 80% Relative Density of sand.



(a) (b)

Fig. 8. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 4d (Where d=1.5cm) for 80% Relative Density of sand.



(a) (b)

Fig. 9. (a) Characteristic Load vs. Settlement curve & (b) Bar Chart for ultimate load of pile group (2x2) of c/c spacing of 5d (Where d=1.5cm for 80% Relative Density of sand.

Form fig.7(a) the capacity is more in H-pile as compare to all other pile. Capacity of H-pile is around 2 times more from L-pile and hollow circular pile and 7.5 times from solid circular pile. Similarly capacity of L-pile and hollow circular pile is approximate same and around 3.7 times more from solid circular pile. Similarly from fig.8 (a) the load carrying capacity is observed maximum in hollow circular pile as compare to all other piles. In hollow circular pile capacity is approximately 8.3 times, 2.6 times and 1.9 times more from solid circular, L-pile and H-pile respectively. Similarly capacity of H-pile and L-pile is about 4.3 times and 3.2 times of solid circular pile. Fig.9(a) showing the curves for load carrying capacity of pile group of c/c spacing of 5d, in which the capacity of hollow circular pile is approximate 2 times of all other piles.

Also in this analysis the settlement was calculated at particular value of loads and compared within all shapes for single and pile group and for all c/c spacing of 3d, 4d, 5d with 60% and 80% relative density of sand. The value of settlement has been shown in tabular form below:-

Table 3. Settlement values for single pile.

Load (N)	Relative Density (%)	Settlement(mm) Closed Ended	Hollow	L Shape	H-Shape
20	60	0.15	0.10	0.045	Nil
	80	0.15	0.09	0.035	Nil
40	60	1.915	0.065	0.16	0.1
	80	1.345	0.155	0.085	0-1

Table 4. Settlement values for pile group (c/c- 3d spacing).

Load(N)	Relative Density (%)	Settlement(mm) Close Ended	Hollow	L Shape	H Shape
50	60	0.22	0.06	Nil	Nil
100		0.45	0.17	0.15	0.02
150		0.65	0.34	0.16	0.04
200		1.05	0.50	0.20	0.06
50	80	0.52	0.07	Nil	Nil
100		0.26	0.15	0.02	0.02
150		0.56	0.21	0.07	0.02
200		1.04	0.28	0.10	0.05

Table 5. Settlement values for pile group (c/c- 4d spacing).

Load(N)	Relative Density (%)	Settlement (mm) Close Ended	Hollow	L Shape	H Shape
50		0.01	Nil	Nil	0.01
100		0.08	Nil	0.01	0.05
150		0.35	0.01	0.04	0.075
200		0.90	0.02	0.06	0.11
50		0.06	Nil	Nil	0.02
100		0.24	Nil	0.01	0.05
150		0.66	Nil	0.02	0.075
200		0.96	0.5	0.05	0.11

Table 6. Settlement values for pile group (c/c- 5d spacing).

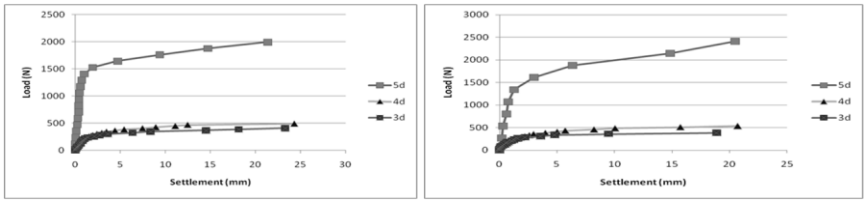
Load(N)	Relative Density (%)	Settlement(mm) Close Ended	Hollow	L Shape	H Shape
50		Nil	Nil	Nil	0.035
100	60	0.01	Nil	Nil	0.07
150		0.03	0.01	0.02	0.10
200		0.02	0.01	0.03	0.15
50		Nil	Nil	Nil	0.03
100	80	0.11	Nil	0.05	0.07
150		0.12	Nil	0.09	0.10
200		0.18	0.01	0.10	0.15

In settlement analysis from Table 3 it has been observed that for 60% relative density in single pile for 20N load the maximum settlement was observed in solid circular pile i.e. of 0.15mm and minimum of nil settlement was observed in H-pile as compare to other shapes of pile. Similarly for 80% relative density the same trend was observes as in 60% and For 40 N load in 60% relative density the maximum settlement i.e. 1.91 mm was observed in solid circular pile and minimum was observed in hollow circular pile of 0.065mm. Similarly for same load in 80% relative density maximum settlement of 1.345 mm was observed in solid circular pile and minimum settlement of 0.1mm was observed in H-pile. It is seen from Table 4 for pile group in c/c spacing of 3d and for 50, 100, 150, & 200N the maximum settlement of 0.22, 0.45, 0.65 & 1.05mm was observed in solid circular pile and minimum settlement of nil, 0.02, 0.04 & 0.06 was in H-shape pile for 60% relative density. Similarly for 80% relative density and for same order of load as in 60% relative density the maximum settlement and minimum settlement pattern was same as in 60% as shown in same table..For pile group in c/c spacing of 4d and for 50, 100, 150, & 200N the maximum settlement of 0.01, 0.08, 0.35 & 0.90 mm was observed in solid circular pile and minimum settlement of nil, nil,0.01 &0.02 was in hollow

circular pile for 60% relative density. Similarly for 80% relative density the trend was same as was in 60% as shown in Table 5. Same here for c/c 5d spacing and 60% relative density maximum settlement was observed in H-shape pile and in other shapes approximate equal settlement was observed for all range of load and for 80% relative density maximum settlement was observed in H-shape and minimum was observed in hollow circular pile and for other shapes shown in Table **6.**

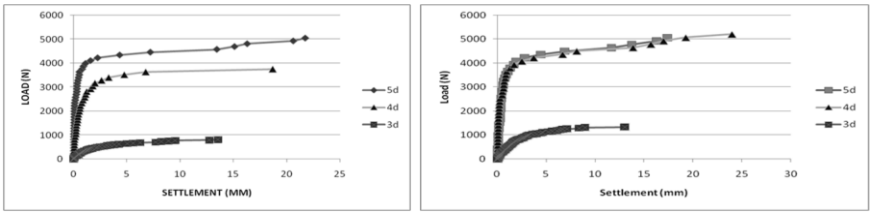
4.2 Ultimate load Vs Spacing of pile group Analysis

In this analysis the effect of spacing i.e.3d, 4d, and 5d on the ultimate load of pile has been done.



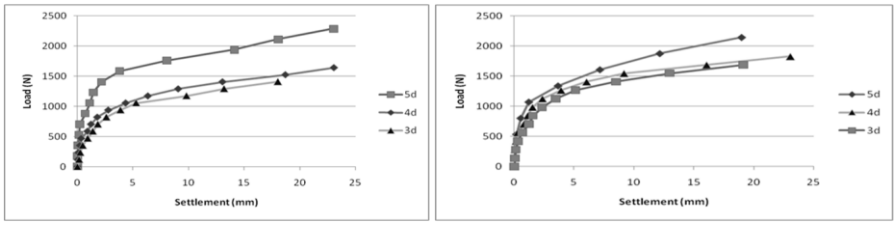
(a) (b)

Fig. 11. Characteristics Load Vs Settlement curves for solid circular pile for 3d, 4d, 5d spacing in (a) 60% relative density of sand (b) 80% relative density of sand.



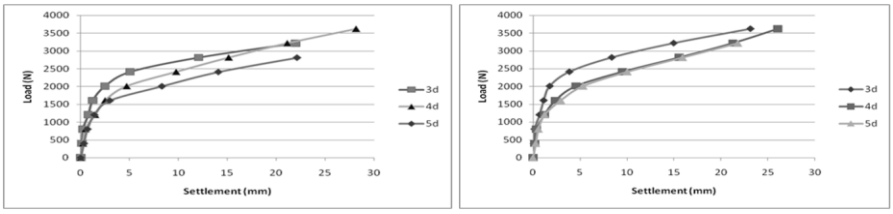
(a) (b)

Fig.12. Characteristics Load Vs Settlement curves for hollow circular pile for 3d, 4d, 5d spacing in (a) 60% relative density of sand (b) 80% relative density of sand.



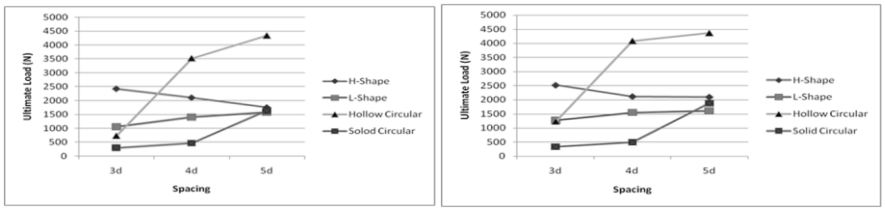
(a) (b)

Fig.13. Characteristics Load Vs Settlement curves for L-Shape pile for 3d, 4d, 5d spacing in (a) 60% relative density of sand (b) 80% relative density of sand



(a) **(b)**

Fig. 14. Characteristics Load Vs Settlement curves for H-Shape pile for 3d, 4d, 5d spacing in (a) 60% relative density of sand (b) 80% relative density of sand



(a) (b)

Fig. 15. Line chart of variation of ultimate load with spacing (3d, 4d, 5d) for cross section shapes of pile (solid circular, hollow circular, L-shape, H-shape) for (a) 60% Relative density (b) 80% Relative density

From fig.15 (a) & (b) the line chart variation shows the load carrying capacity of solid circular pile increases as increase c/c spacing of pile group from 3d to 4d & 5d spacing for 60% and 80% relative density of sand respectively, means in solid circular pile effect of spacing and relative density of sand have significance effect on load carrying capacity of pile group. Similarly the load carrying capacity of hollow circular pile increases as increase c/c spacing of pile group from 3d to 4d & 5d spacing for 60% and 80% relative density of sand respectively, means in hollow circular pile the effect of spacing on load carrying capacity of pile has significance effect but the relative density of sand has not so much effect in 4d and 5d spacing. Also the load carrying capacity of L-Shape pile increases as increase c/c spacing of pile group from 3d to 4d &5d spacing for 60% and 80% relative density of sand respectively alsovthe load carrying capacity of H-pile decreases as increase c/c spacing of pile group from 3d to 4d & 5d spacing for 60% and 80% relative density of sand respectively, means in H-Shape the trend is completely different as compare to other shapes where the load carrying capacity decreases instead of increase.

4. Conclusion

In present investigation the load carrying capacity has been analyzed of different cross section shapes of pile i.e. solid circular, hollow circular, L-Shape pile, H-Shape

pile by keeping equal cross sectional area and length. From results of test graph it has been concluded that in single pile the load carrying of H-Shape pile was more as compare to other shapes in both relative densities. With increasing density all shapes shows increase in load carrying capacity but it was not true for spacing because in all shapes generally the with increasing spacing load carrying was increasing but it was different in H-Shape pile as in this pile the capacity was observed decreased with increase in spacing. Also the effect of relative density was not so much effect on the pile group in all shapes of pile as compare to single pile. The maximum effect of load carrying capacity was observed in hollow circular pile and with increasing spacing it showed maximum increment in load carrying capacity in single as well as group and also in both relative density. Means with increasing density and c/c spacing of pile group the hollow piles carry maximum load as compare to all other pile group on equal cross sectional area. Also on the basis of equal cross sectional area, it has been found that with increasing relative density from 60% to 80%, the load carrying capacity always increases in any shape of single and group of pile under the same loading condition. Also the load carrying capacity of group of pile is more as compare to single pile. Load carrying capacity of model test pile in group action also increases with increase in spacing from 3d to 4d and 5d in all shapes of pile except H-shape pile. Also the efficiency of all shapes of single pile increased in both relative density but in pile group all shapes except H-shape pile showed increase in efficiency as in this decrease in efficiency was observed with increasing spacing of pile groups. Maximum efficiency was observed in hollow circular pile.

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