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Behavior of Single Pile Subjected to Eccentric Loading in Cohesionless Soils

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Abstract. Pile foundation of engineering structures, such as bridges, offshore structures, and retaining walls are frequently subjected to eccentric loads. Many deep foundation structures experience excessive settlement if subjected to eccentric loads. Several researchers have analyzed the problem and studied the behavior of deep foundation structures analytically. The main aim of this project report deals with the bearing capacity of single pile under vertical eccentric load in cohesionless soils. The purpose of the thesis is to study the load displacement response of single pile installed in soil bed when subjected to vertical eccentric loading for 60% and 70% relative densities. Single piles were fabricated with diameter 42mm, 49mm, 75mm and 100mm for constant length of 500mm. Tests were conducted using manual loading with four number of dial gauges. Most of the studies relate to the case of a vertical load applied centrally to the foundation. However, when loads are applied axially and eccentrically to the foundation, the bearing capacity is different from centrally loaded pile model. Ultimate bearing capacity has been found out for central as well as eccentric loading conditions. This paper aims to investigate the response of the pile subjected to eccentric load; and comparative results of the effect of diameter, the effect of relative densities and the effect of eccentricity.

Keywords: Pile foundation, Eccentricity, Single pile

1 Introduction

A single Pile carry large loads from superstructure if its capacity is sufficient. Engineering structures, such as bridges, retaining walls, and offshore structures which are supported by pile foundations frequently subjected to eccentric loads. These pile foundations experience excessive settlements if it is subjected to eccentric loads and the structure may tilt or rotate due to this eccentricity. Behavior of rigid piles and pile groups under eccentric vertical loads in sand and in clay has been studied by Kishida and Meyerhof [1965] and Saffery and Tate [1961] respectively. Response of Four Pile Group Subjected to Eccentric Loading is studied by V. Padmavathi et al. [2019]. Response of 3 × 3 Pile Groups in Silt Subjected to Eccentric Lateral loading has been studied by L. G. Kong et al. [2015]. The effect of the eccentricity on the ultimate capacity by model tests on pile groups is investigated by Komatsu et al. [2004]. This paper investigates the response of single pile subjected to vertical eccentric loading in sand beds at 60% and 70% relative densities. The load-displacement responses of a single piles under eccentric loading are investigated by model tests. Load-displacement responses of the single piles are analyzed to quantify the effects of diameter, the effect of relative density and the effect of eccentricities. Piles used in this investigation is shown in Fig.1.

Fig. 1. Steel pipe piles

2 Methodology

Model tests were performed on single pile installed in sand bed placed in a circular tank of diameter 60cm and height 71cm. The test setup (Fig.2.) consists of the following components: (a) Test tank, (b) Model piles, (c) Foundation medium i.e. sand, (d) Arrangement for application of loads and (e) Measuring devices (four dial gauges). The pile cap is made of is square in shape of size 12cm, 15cm, 17cm,20cm for 42mm, 49mm, 75mm, 100mm diameter piles respectively. The sand was compacted in 5 layers with relative densities of 60% and 70% respectively. The properties of the sand used in this is shown in Table 1 and it is classified as poorly graded sand (SP) as per IS classification. Piles of diameter 42mm, 49mm, 75mm, 100mm for constant length of 500mm, have been studied in the model test tank. A total of 32 tests were performed on the single pile which were subjected to normalized eccentricities (e/s) and axial load. Tests data was obtained using a proving ring and four number of dial gauges (Fig.2.).

Table 1. Properties of Sand

Soil properties of sand	Value
Coefficient of Uniformity (C_u)	3.63
Coefficient of Curvature (C_c)	0.85
Specific Gravity (G)	2.65
Cohesion (c)	0
Maximum Dry Unit weight (γ_d)	1.85g/cc
Minimum Dry unit weight (γ_d)	1.57g/cc
IS classification	SP
Angle of shearing resistance	D_r 60% = 36º
	D_r 70% = 38º

(a) (b)

Fig. 2. Schematic of test setup: (a) cylindrical tank, (b)Measuring devices

3 Experimental Procedure

The sand was filled in 6 layers i.e. 14cm, 6cm, 8cm, 14cm, 14cm, 11cm from the bottom of the tank respectively. The total weight of sand filled in the tank for the required relative densities of 60% and 70% respectively is shown in Table 2. Total number of 32 tests was done in the tank on single pile models with different diameters, axially and at different eccentricities. The single pile model is installed on the sand bed such that the load is applied at required position after the sand is compacted up to depth of 20cm. The soil is compacted to required density by rammer weighing 8.9kgs. This process is continued for the rest of the layers with required weight of sand till the height of 67cm and compacted cautiously by maintaining the pile in the vertical position and leveling is done to maintain it horizontally, at required eccentricity and relative density. The pile verticality and eccentricity were checked for each before the test. The relative density during the test is cross checked by small bins which are already placed in the tank and it is almost same. A load is applied through the hydraulic jack which is supported to the loading frame. Hydraulic jack is used for applying loads vertically on the pile. The proving ring which is placed between the hydraulic jack and the pile cap is used to record the values at small increments when a load is applied through the hydraulic jack, which is supported to the loading frame. Four number of dial gauges are placed above the pile cap.

Table 2. Total weight of soil required for each pile

Pile diameter (mm)	Total weight of soil (kg)	
	D_r = 60%	D_r = 70%
42	326.33	331.13
49	325.9	330.9
75	323.94	329.52
100	321.1	326.7

3.1 Calculation of load carrying capacity of pile

The method for estimating the load carrying capacity of a pile foundation can be static method, dynamic method, in- situ penetration tests, pile load tests.
The ultimate bearing capacity of a single pile in sand is obtained by,

$$Q_u = Q_p + Q_s$$

$$Q_u = A_p q^{I} N_q + f_{av} Pl$$

$$Q_u = A_p q^{I} N_q + (k\, \sigma_o \tan\delta)\, Pl$$

4 Results and Discussions

4.1 Comparison of effect of relative density

Case – 1: Pile Diameter 42mm

Fig.3. shows the effect of relative density with settlement for different loads is plotted for eccentricity, e = 0mm. Ultimate loads for relative densities 60% and 70% increases from 302.12kg to 488.04kg. The ultimate load is increased by 61.53% from relative

density 60% to relative density 70%. The ultimate load and the settlement of the pile increases with increase in relative density. Similarly, for e = 2mm (Fig.4.), e = 4mm (Fig.5), e = 6mm (Fig.6) the ultimate load of the pile increased with increase in relative density and it is shown in Table 3.

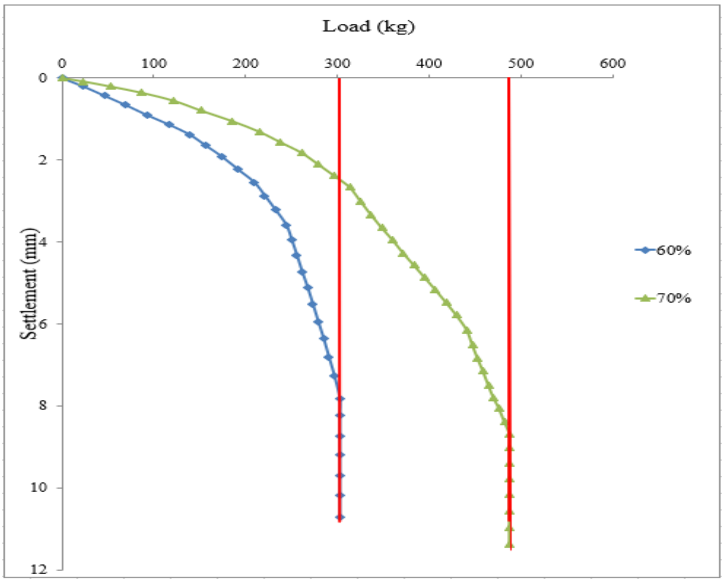

Fig. 3. Effect of D_r on pile capacity (42mm diameter pile loading at center)

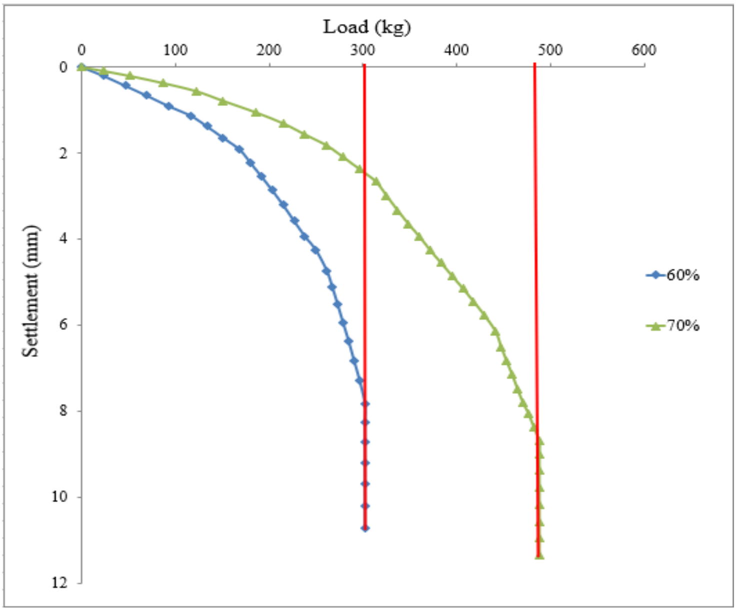

Fig.4. Effect of D_r on pile capacity (42mm diameter pile loading at e =2mm)

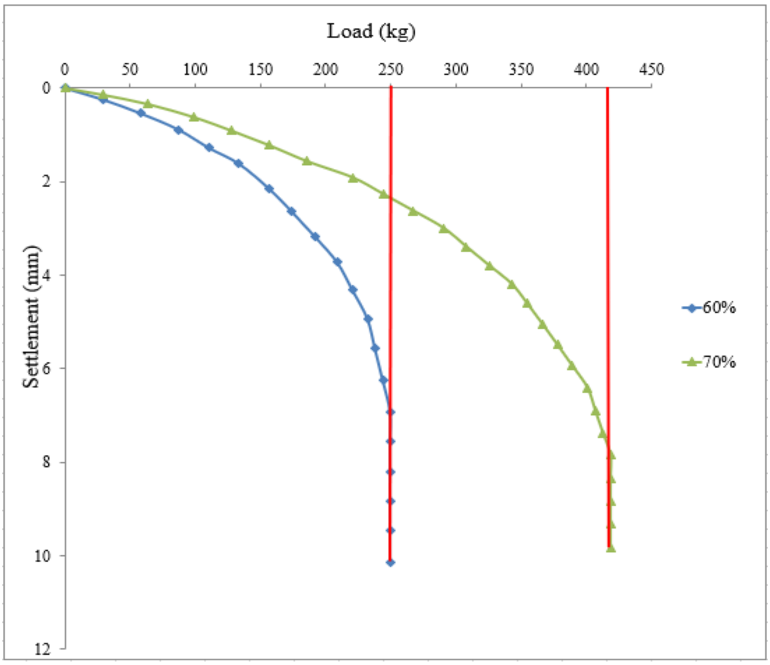

Fig.5. Effect of D_r on pile capacity (42mm diameter pile loading at e = 4mm)

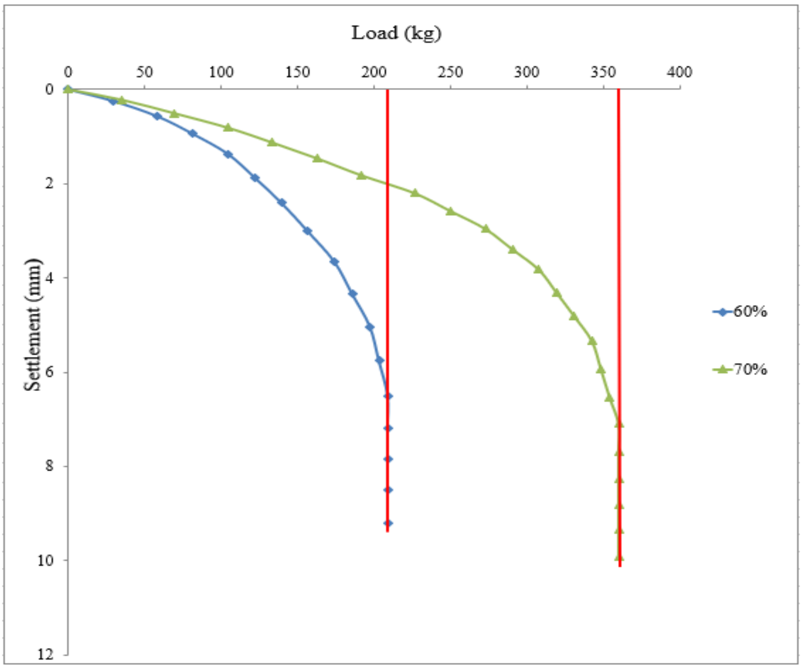

Fig. 6. Effect of D_r on pile capacity (42mm diameter pile loading at e = 7mm

Table 3. % Increase in pile capacity for different pile diameters at different eccentricity, e

Pile diameter (mm)	Load applied at e (mm)	Ultimate load (kg) @ D_r = 60%	Ultimate load (kg) @ D_r = 70%	Increase in pile capacity (kg)	% increase in pile capacity
42	0	302.12	488.04	185.92	61.53
	2	302.12	488.04	185.92	61.53
	4	249.83	418.32	168.49	67.44
	7	209.16	360.22	151.06	72.22
49	0	411.6	656.53	244.93	59.5
	3	370.44	598.43	227.99	61.54
	5	346.92	551.95	205.03	59.10
	8	311.64	505.47	193.83	62.19
75	0	917.28	1261	343.72	37.47
	4	852.6	1158.4	305.8	35.86
	8	776.16	1052.52	276.36	35.60
	12	705.6	940.8	235.2	33.33
100	0	1534.68	2175.6	640.92	41.76
	6	1393.56	1963.9	570.34	40.92
	11	1275.96	1787.52	511.56	40.09
	16	1158.36	1611.12	452.76	39.08

4.2 Comparision of effect of eccentricity

Case – 1: Pile Diameter 42mm

Fig.7. depicts load versus settlement responses of a single pile for e = 0mm, 2mm, 4mm and 7mm at relative density, D_r = 60%, for diameter 42mm. The ultimate load for axially loaded pile of diameter 42mm is 302.12kg and for eccentricities of 2mm, 4mm, 7mm are 302.12kg, 249.83kg, 209.16kg respectively. The ultimate loads for eccentricities 2mm, 4mm, 7mm are decreased by 0%, 17.30%, 30.76% respectively, when compared to axial load. The ultimate load of the pile decreases and the settlement decreases with increase in eccentricity of the applied load. The pile capacity for D_r = 70% at e = 0mm, 2mm, 4mm and 7mm is 488.04, 488.04, 418.32, 360.22 kg respectively is shown in (Fig.8). The ultimate loads for eccentricities 2mm, 4mm, 7mm are decreased by 0%, 14.28%, 26.19% respectively, compared to axial load and is shown in Table 4.

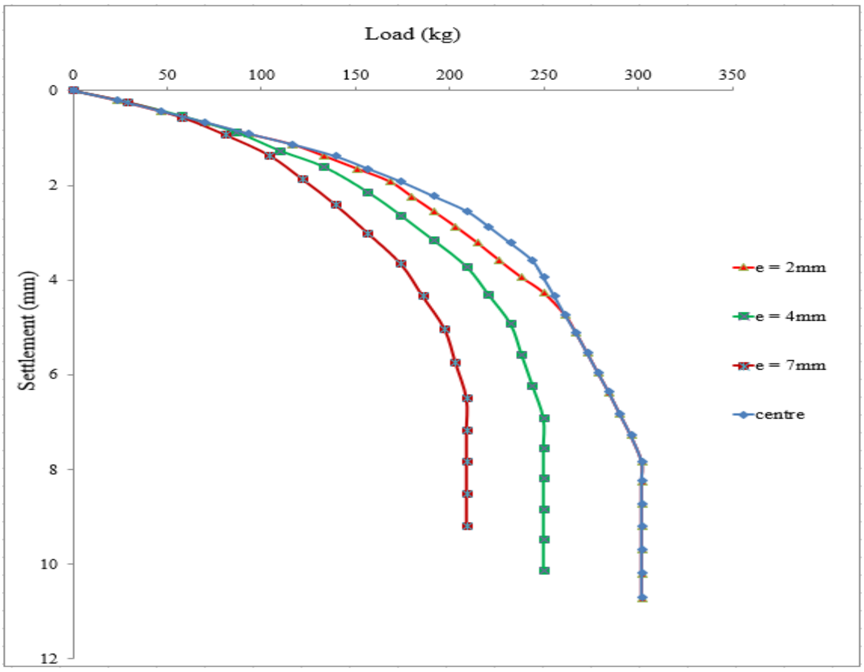

Fig. 7. Effect of e on pile capacity (42mm diameter pile $D_r = 60\%$)

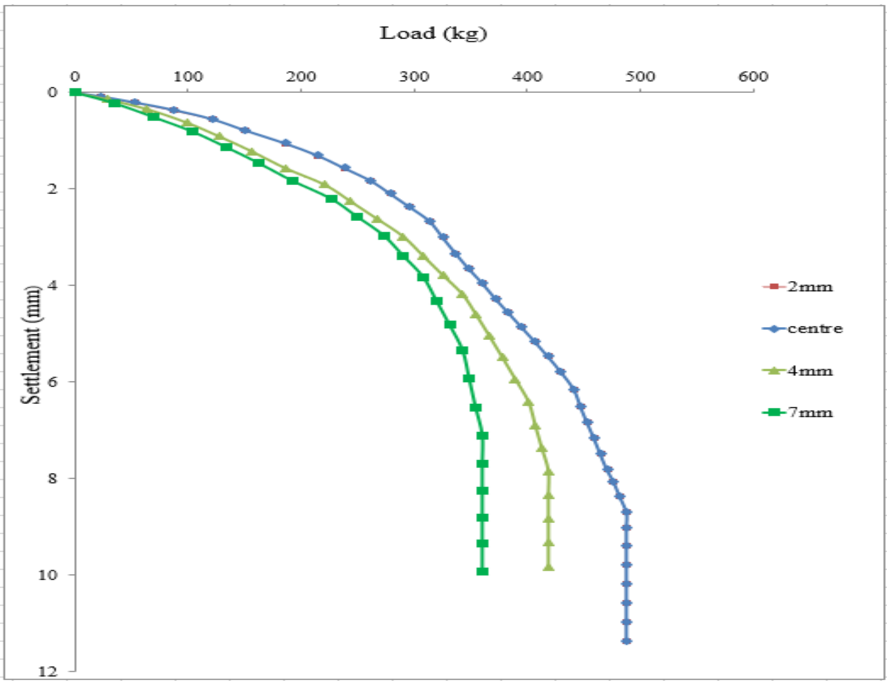

Fig. 8. Effect of e on pile capacity (42mm diameter pile $D_r = 70\%$)

Table 4. % Decrease in pile capacity for different pile diameters at different eccentricity, e

Pile diameter (mm)	Load applied at e (mm)	Ultimate load D_r = 60% (kg)	decrease in pile capacity (kg)	% decrease in pile capacity	Ultimate load D_r = 70% (kg)	decrease in pile capacity (kg)	% decrease in pile capacity
42	0	302.12	0	0	488.04	0	0
	2	302.12	0	0	488.04	0	0
	4	249.83	52.29	17.30	418.32	69.72	14.28
	7	209.16	92.96	30.76	360.22	127.82	26.19
49	0	411.6	0	0	656.53	0	0
	3	370.44	41.16	10	598.43	58.1	8.84
	5	346.92	64.68	15.71	551.95	104.58	15.92
	8	311.64	99.96	24.28	505.47	151.06	23
75	0	917.28	0	0	1261	0	0
	4	852.6	64.68	7.05	1158.4	102.6	8.13
	8	776.16	141.12	15.38	1052.52	208.48	16.53
	12	705.6	211.68	23.07	940.8	320.2	25.39
100	0	1534.68	0	0	2175.6	0	0
	6	1393.56	141.12	9.19	1963.9	211.7	9.73
	11	1275.96	258.72	16.85	1787.52	388.08	17.83
	16	1158.36	376.32	24.52	1611.12	564.48	25.94

4.3 Comparison of effect of diameter

Case – 1: D_r = 60%

Fig.9. depicts load versus settlements response of a single pile at relative density 60% for different pile diameters i.e., 42mm, 49mm, 75mm, 100mm. The ultimate load for axially loaded piles of diameter 42mm, 49mm, 75mm, 100mm are 302.12kg, 411.6kg,

917.28kg, 1534.68kg respectively. The ultimate load of the pile increases with increase in pile diameter. This is due to the contact area of sand at the end of the pile increased with increase in the pile diameter, so the end bearing resistance is increased. The surface area increases with increase in the pile diameter, as a result the frictional resistance of the pile is increased. So, the load carrying capacity is increased with increase in end bearing resistance and frictional resistance by increase in pile diameter. The effect of diameter on pile capacity for axial capacity at D_r = 70% for different piles is depicted in (Fig.10). The ultimate load for axially loaded piles of diameter 42mm, 49mm, 75mm, 100mm are 488.04kg, 656.53kg, 1261kg, 2175.6kg respectively.

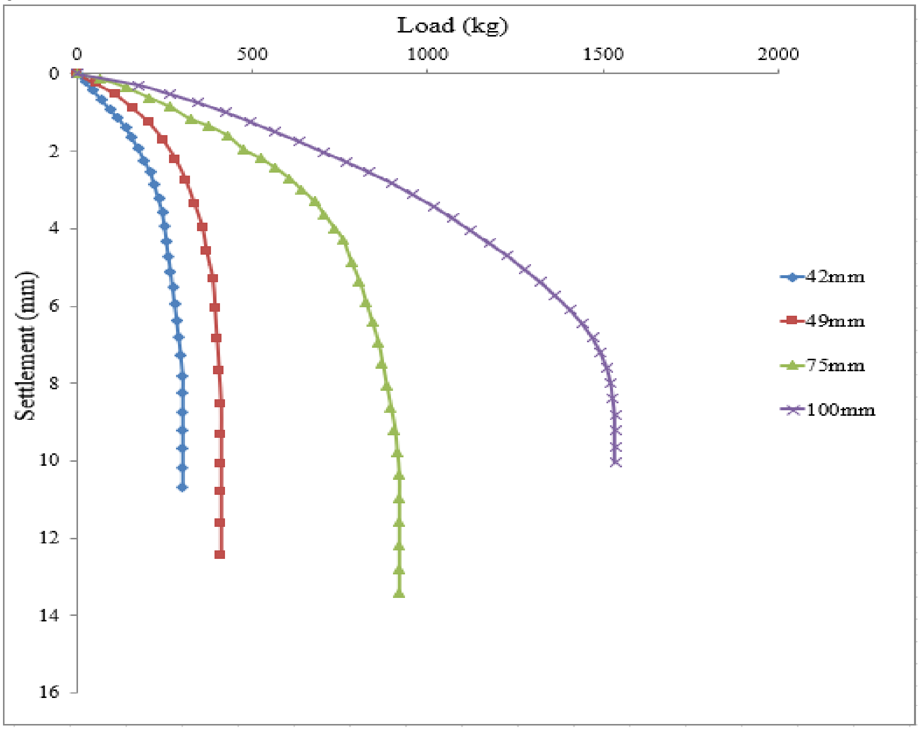

Fig. 9. Effect of diameter on pile capacity (axial loading at D_r = 60%)

Case – 2: D_r = 70%

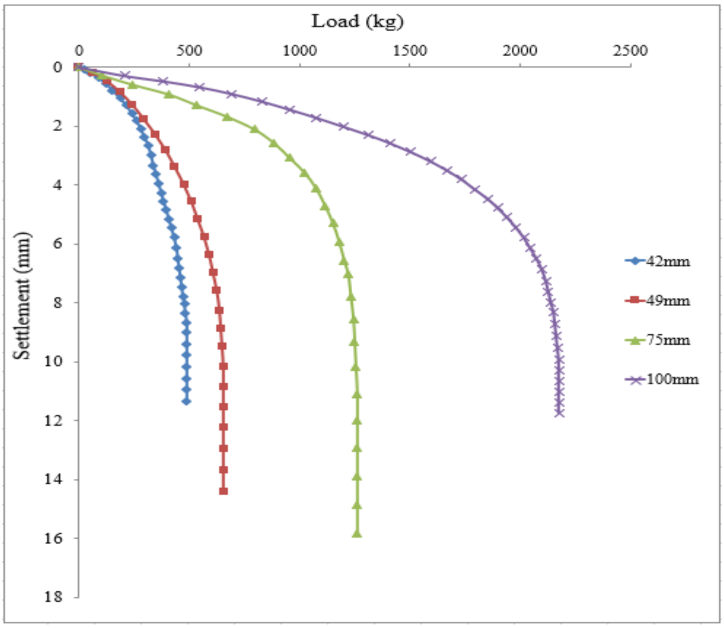

Fig. 10. Effect of diameter on pile capacity (axial loading at D_r = 70%)

5 Conclusions

The tests results were compared and conclusions were made based on the practical observation and are presented below.

1. Ultimate load carrying capacity of the pile is increased with an increase in the pile diameter.
2. Ultimate load carrying capacity of the pile is increased with increasing the relative densities, D_r of the sand.
3. Ultimate load capacity of the pile is decreased eccentrically when compared to the axially loading pile.
4. The ultimate load of the pile practically is increased nearly by 15%, when compared with the theoretical values.

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