Interpretation of Load-settlement curves from Graphical Methods

Naga Sireesha Ghanta[1] and Sujit Kumar Pal[2]

[1, 2] Department of Civil Engineering, National Institute of Technology Agartala, Tripura, India
sireeshaghanta77@gmail.com, skpal1963@gmail.com

Abstract. Bearing capacity of pile depends mainly on the type of soil through which it rests, and on the method of installation. Many empirical and analytical formulae developed based on the field and laboratory experiments to estimate the pile group bearing capacity. The present investigation is carried out to get the load-settlement characteristics of different configuration of pile groups, such as 1×1, 2×2 and 3×3. In many projects, some of the manufactured piles are loaded to determine the pile bearing capacity. This is the most reliable way to determine the pile capacity. However, it is not easy to determine the point where the pile has reached its ultimate capacity on the load-settlement curve. By using different graphical methods, the ultimate bearing capacity is calculated from load-settlement data. Among these methods, there are considerable differences between the graphical ultimate bearing capacities of the piles which decrease to 35% for the piles loaded up to the collapse load, and increases up to 120% for the piles loaded to the failure load. Improvement ratio and settlement ratio are calculated using load-settlement curves. Model plate load test is used to determine the load-settlement curves. It is time and cost efficient, easy to perform and reliable. Experiments are conducted on dry, clean, poorly-graded sand. Steel pipe piles of length 30 cm, diameter 2 cm, 2.5 cm are used in this experiment. The spacing between the piles is taken as 3d.

Keywords: Pile Group, Bearing Capacity, Settlement Ratio.

1 Introduction

Increase in population growth in the current scenario has led to increase in the need of housing and infrastructure and the availability of space is becoming very less. So, many agencies are forced to exploit the poor soil condition; this has led to development of pile foundation and pile driving system. Pile driving into long depths, due to non-homogeneity of soil and lack of suitable analytical method, the determination of bearing capacity is complex. The designer should know the pile bearing capacity and settlement before starting construction. Many empirical formulae and experimental methods are available to find ultimate bearing capacity, but soil conditions should be predictable to find the ultimate bearing capacity from empirical methods. To determine accurate capacity values large scale load tests which represent the actual pile behaviour are available. However, the ultimate bearing capacity values obtained from load tests are distinct; so, many interpretive methods are available to find the ultimate bearing capacity.

1.1 Different Interpretation Methods to Find Ultimate Bearing Capacity

Davisson off-set Limit Load Method

Davisson proposed an off-set limit load method [1] to interpret the ultimate bearing capacity. It is widely used in western countries, Canada and U.S. Q_u is the load at which the settlement exceeds the elastic compression (QL/AE) of a pile by the value of 0.15inches (4 mm) plus the value of D/120, where Q = Load, L= Length of pile, A = Area of the pile, E = Young's Modulus of pile, D = Diameter of pile in inches.

Brinch Hansen 80% Method

According to Brinch Hansen method [2] the ultimate load as the load that corresponding to four times the settlement as obtained for 80% of that load. In this method, ultimate load can be calculated directly from load-settlement curves. To determine accurate loads this method can be plotted as a square root of settlement value divided by its load value and plotted against the settlement. The ultimate bearing capacity of foundation is represented as

$$Q_u = \frac{1}{2(\sqrt{C_1}\sqrt{C_2})} \qquad (1)$$

Where Q_u = Ultimate bearing capacity; C_1= Slope of the straight line; and C_2 = y- Intercept of the straight line.

Chin-Konder Method

According to Chin-Konder Method [3], the graph is plotted between load divided by settlement against load values. The points on a graph show a linear trend at a particular point. The inverse of the slope ($1/C_1$) of that linear line gives the ultimate bearing capacity.

Tangent Intersection Method

In the tangent intersection method [1], two tangents are drawn from initial and final points of the load-settlement curve. The intersection point of these two tangents gives the ultimate bearing capacity.

Fuller and Hoy Method

According to Fuller and Hoy Method [4], the ultimate bearing capacity is determined at a point, where the line has slope of 0.127 mm/kN.

2 Materials and Methodology

The experimental work starts with the collection of sand, piles and pile cap. Model experiments are carried out in the laboratory to measure the pile behaviour under static vertical load. Models are properly scaled down so that the bearing behaviour of pile measured from the small-scale models that can be used to interpret the behaviour of prototype pile foundations. The materials which are used in this work are discussed below.

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2.1 Sand

Dry sand is used in the experiment. Sand is collected from the Haora river. Specific gravity, Sieve analysis, Relative density and direct shear tests are conducted on the three sand samples. The tested properties of the sand used in the present experiment are shown in Table1.

Table 1. Physical Properties of the Sand

Sl. No	Property	Value
1	Effective size (D_{10}), mm	0.16
2	Uniformity Coefficient (C_u)	2.187
3	Coefficient of curvature (C_c)	1.4
4	IS Classification	SP
5	Mean Specific gravity	2.62
6	Maximum dry density,	1.785
7	Minimum dry density, gm/cc	1.51
8	Relative density of sand (%)	65
9	Optimum Moisture content	11.2
10	Angle of internal friction (in degree)	32

SP = Poorly graded Sand

2.2 Model Piles

The model piles used in this experiment are smooth, hollow steel pipe of length 30 cm with two different diameters 20 mm and 25 mm. Different types of configuration of piles such as single pile, 2×2 and 3×3 are used.

2.3 Pile Cap

Mild steel plate is used as a pile cap. Different sizes of pile caps are used in this experiment. The spacing between the piles is maintained as three times the diameter of pile.

2.4 Test Procedure

The soil tank of size 700 mm ×700 mm × 600 mm that is made of iron and glass fiber is used in the experiment. The test is conducted by following IS: 2911 part IV (1979). As per code, vertical loads are applied in small increments on pile cap. Load is applied using hydraulic jack which is mounted on pile cap, the other end of hydraulic jack is fixed to loading frame. Strain gauges of sensitivity 0.02 mm are used to measure the settlement. The loading is continued to twice the design load (3.5 kN).

3 Experimental Load-Settlement Curves

Figs. 1, 2 and 3 show the load-settlement curves of different configurations of pile groups; those are single pile, 2×2 pile group and 3×3 pile group respectively. Diameter and length of piles used in the experiment are 2 cm and 30 cm respectively. Loads are applied on the pile cap up to twice the safe load as per IS: 2911 Part IV (1979).

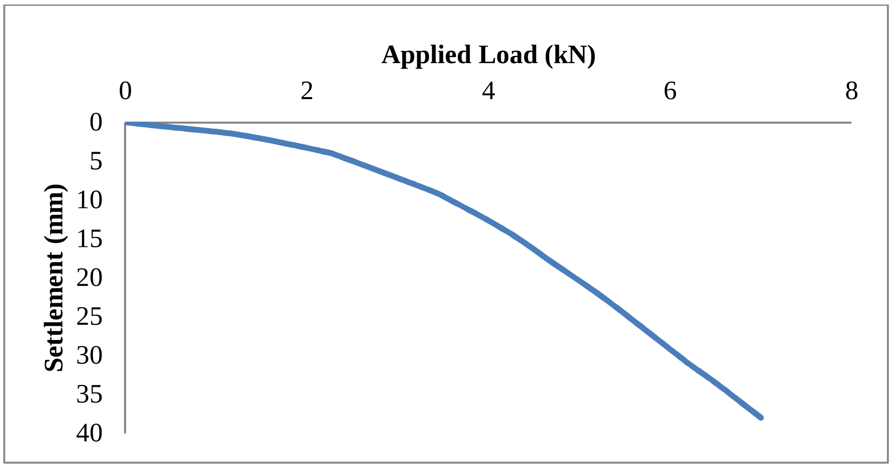

Fig. 1. Load-Settlement curve for a single pile of 25mm diameter

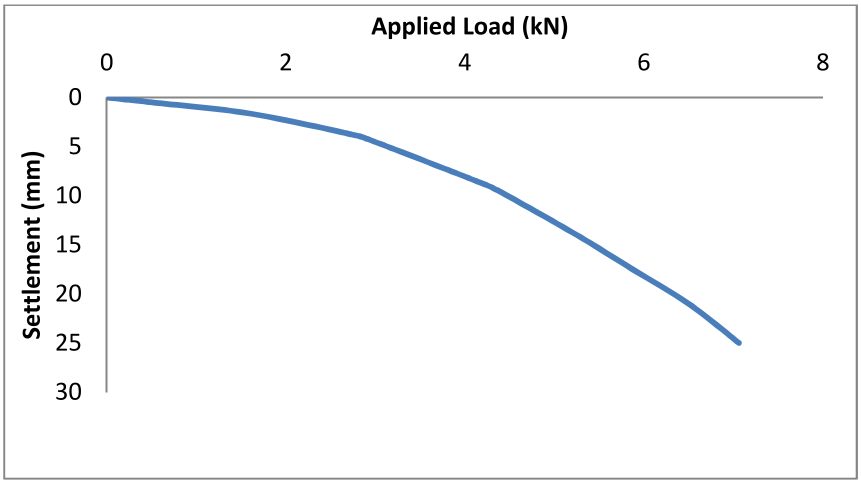

Fig. 2. Load-Settlement curve of 2×2 Pile group

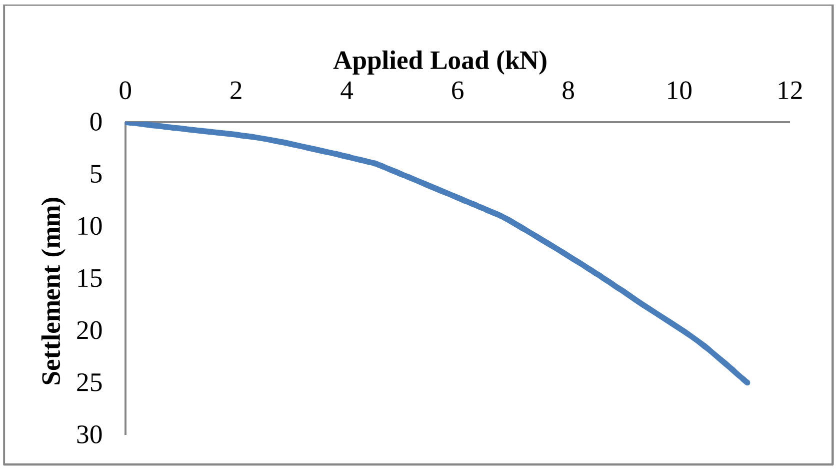

Fig. 3. Load-Settlement curve of 3×3 Pile group

4 Discussions of Experimental Results

Load vs. settlement curves drawn from experiments are non-linear. These curves are not showing peak behavior; that means; with increase in pile settlement the vertical load increases. Hence, by using pile load test data, it is not possible to find the failure loads. So, there are many interpretation methods available to find the failure loads, which are already mentioned above.

Load Improvement ratio is calculated from experimental results. It is a non-dimensional parameter which shows the variation in load carrying capacity with the change in the number of piles in a group. From experimental results it's concluded that the load improvement ratio (L.I.R) increases with the increase in the number of piles. As it is found that the L.I.R obtained as 3.57 for 2×2 pile group and increases to 8.55 for 3×3 pile group.

The Settlement ratio of a pile group defined as the total settlement of a pile group divided by the settlement of a single pile at the same average load per pile. The settlement ratio decreases with the increase in the number of piles in a group.

5 Interpretation of Ultimate Bearing Capacity from Graphical Methods

Table 2. Failure loads for different configuration of pile groups

Bored piles	Diameter of pile (mm)	Failure loads(kN)				
		Brinch Hansen	Chin Konder	Fuller and Hoy	Davissons off set	Tangnet
Single pile	25	8.1	7.7	6.8	5.2	4.4
2×2		28.4	27.3	24.3	17.8	15.1
3×3		68.2	65.4	58.2	44.6	37.7
Single pile	20	6.5	6.2	5.4	4.2	3.5
2×2		22.7	21.8	19.4	14.3	12.1
3×3		54.5	52.4	46.6	35.7	30.2

Figs. 4 to 8 shows the load-settlement curves of 25mm diameter single pile which are plotted based on the pile load test data. There is no specific procedure to find the bearing capacity of piles. Different interpretation methods available to find ultimate bearing capacity; so, average load is considered as the ultimate bearing capacity.

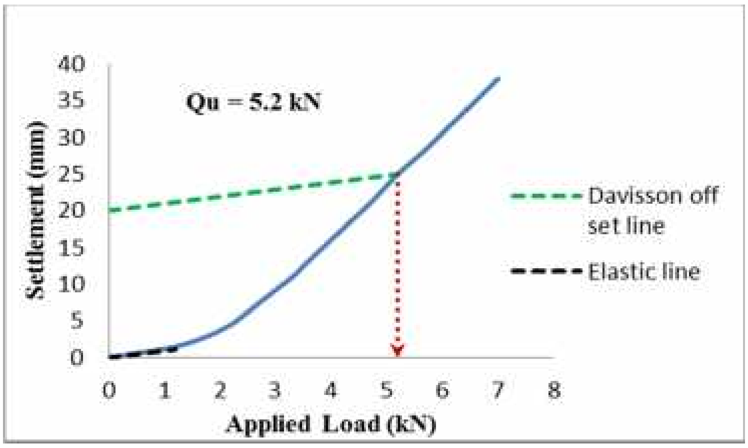

Fig. 4. Load-settlement curves by Davisson's off-set limit load method

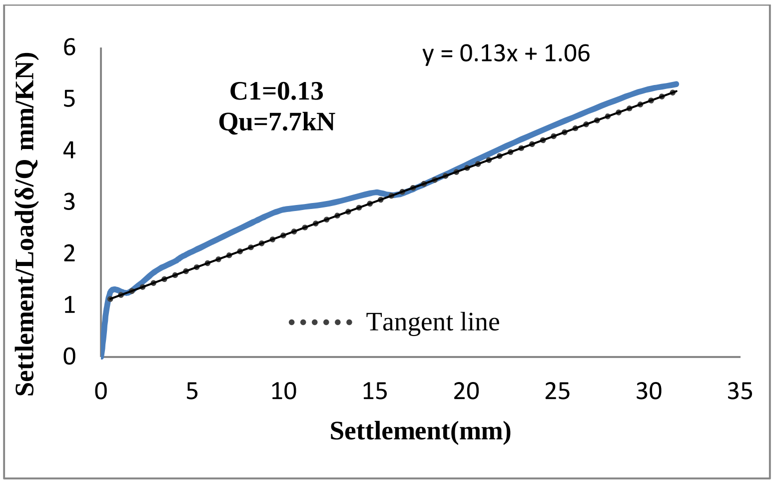

Fig. 5. Load-settlement curves by Chin Konder method

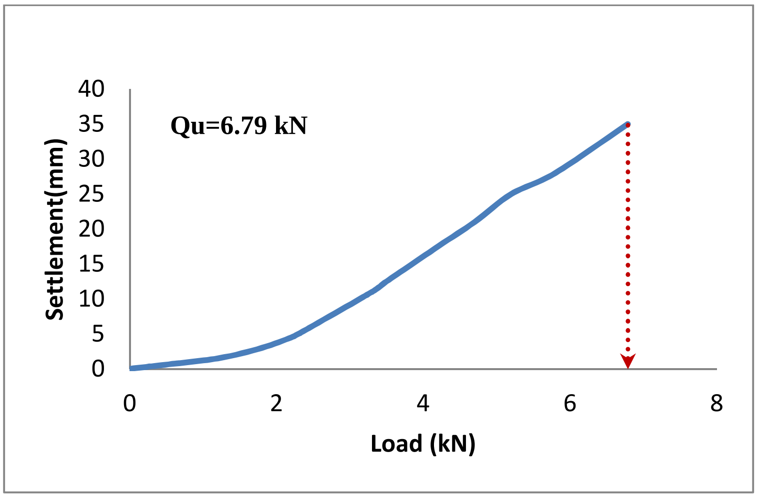

Fig. 6. Load-settlement curves by Fuller and Hoy method

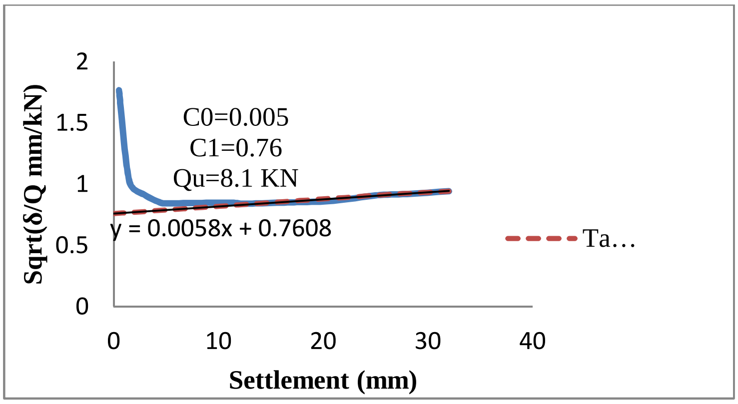

Fig. 7. Load-settlement curves by Brinch Hansen Method

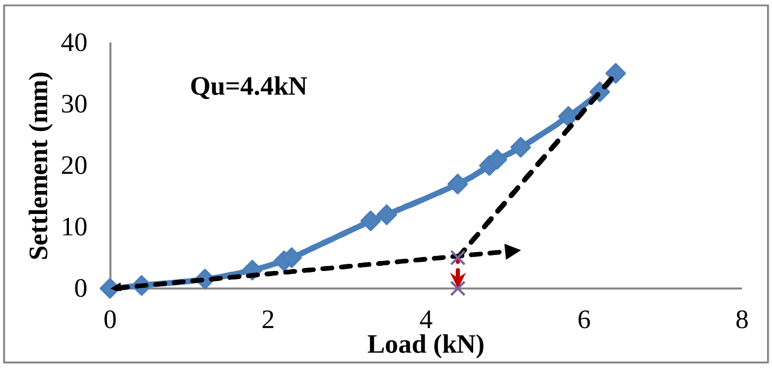

Fig. 8. Load-settlement curves by Tangent intersection method

Table 3. Q_g/Q_m ratios for different configuration of pile groups

Interpreted methods	single pile(Q_g/Q_m)		2×2(Q_g/Q_m)		3×3(Q_g/Q_m)	
	25 mm Dia	20mm Dia	25mm Dia	20 mm Dia	25 mm Dia	20 mm Dia
Brinch Hansen	1.22	1.22	1.19	1.19	1.19	1.16
Chin Konder	1.10	1.1	1.09	1.09	1.09	1.05
Fuller and Hoy	0.97	0.97	0.97	0.98	0.97	0.99
Davisson’s off-set	0.74	0.74	0.71	0.71	0.74	0.71
Tangent Intersection	0.68	0.68	0.63	0.63	0.66	0.63

6 Discussions about Ultimate Bearing Capacities Obtained from Graphical Methods

Table 3 shows the Q_g/Q_m values based on different methods, where Q_g = Graphical ultimate bearing capacity; and Q_m = Measured ultimate bearing capacity. From graphical methods following discussions are drawn.

1) The average of Q_g /Q_m varies from 1.2 to 0.65 for the Brinch Hansen and Tangent intersection method respectively.

2) Fuller and Hoy method estimated the accurate failure loads. The ratio of Q_g/Q_m value nearly to1. This shows that the interpreted and measured failure loads are same.

3) Brinch Hansen and Chin Konder methods show more failure loads, first one shows the relatively more failure loads compare to later.

7 Conclusions

Following conclusions are drawn from the pile load test, load-settlement curves, and from five different graphical methods (i.e., Brinch Hansen, Chin Konder, Fuller and Hoy, Davisson's off-set and Tangent intersection method).

1) The behaviour of load vs. settlement curve is shown non-linear. All tests indicate that the load-settlement curves do not show a peak behaviour, i.e., with increase in pile settlement the vertical load increases.

2) The maximum failure load varies from 7 kN to 50 kN from a single pile (25 mm diameter) to 3×3 pile group.

3) Load improvement ratio is 8.55 for 3×3 pile group and it is 3.57 for 2×2 pile group.

4) Settlement ratios are decreasing with increasing in the number of piles in a group. Settlement ratio for 2×2 pile group to 3×3 pile group decreases from 0.66 to 0.25.

5) Comparison of interpreted and measured failure loads showed that the Brinch Hansen and Chin Konder over-estimate the failure load; remaining three methods under-estimate the failure loads.

6) Fuller and Hoy method approximately gives the same interpreted and measured failure loads .

7) Considerable differences are observed between the graphical ultimate bearing capacities of the piles which decrease to 35% for the piles loaded up to the collapse load, and increases up to 120% for the piles loaded to the failure load.

8) Davisson's off-set method gives the poorer results compared to remaining all methods after tangent intersection method.

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