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Horizontal Load – Deformation Behaviour of Shallow Circular Footing

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Abstract. The bearing capacity of foundations has always been one of the subjects of major interest in soil mechanics and foundation engineering. Evaluations of bearing capacity of vertically loaded shallow foundations on various soils have been studied by many researchers. There are structures where horizontal loading has greater influence and much research has not been carried out to evaluate the horizontal load bearing capacity of shallow foundations. In this paper, extensive investigations are carried out to study the load-settlement behaviour of circular footing subjected to horizontal loads (H). The reduction in lateral compression of soil by providing micropiles beneath the footing is also studied. The research involved non-linear finite element analyses using the FE software PLAXIS 2D and the results were compared with those obtained from laboratory scale load tests. The parameters studied are influence of vertical load (P), embedment depth (D) on lateral displacement of footing and effect of combined lateral and vertical load on rotation of footing. It is observed that depth of foundation and vertical load influences the lateral load bearing capacity of footings. It is observed that the lateral deformation decreases with the increase in depth of foundation and vertical load. The rotation of the footing is also found to decrease with depth when the footing is subjected to combined lateral and vertical loading. Lateral compression of soil and rotation of footing can be reduced further by providing micropiles beneath the footing.

Keywords: Shallow Foundations, PLAXIS 2D, Horizontal load bearing capacity

1 Introduction

Foundations are the base from which all structures are constructed. The loads of a structure are transmitted to the ground through its foundation. The foundation design aims at providing a means of transmitting the loads from a structure to the underlying soil without causing any shear failure or excessive settlement of the soil under the imposed loads. Foundations are of different types such as shallow, deep etc. The bearing capacity of foundations has always been one of the subjects of major interest in soil mechanics and foundation engineering. Evaluations of bearing capacity of vertically loaded shallow foundations on various soils have been addressed by previous researchers. Vertical bearing capacity of shallow foundations can be found out by Terzaghi's analysis; Meyerhof's method etc and that of deep foundations can be found out by static pile load formula, pile load test etc. Horizontal load bearing capacity of deep foundations can be found out by elastic theory of Reese and Matlock (1956) and Plastic theory of Hansen(1951), Mayerhof(1973) etc. It is difficult to provide pile foundations for all structures due to its cost and difficulty in construction. Hence it is essential to study horizontal load bearing capacity of shallow foundations.

Many researchers studied the vertical load bearing capacity of shallow foundations. But there are many structures in which horizontal load bearing capacity is of greater importance.

Taiebat H.A et al. (2000) did numerical studies on shallow foundations on cohesive soil subjected to combined loading. They did 3D Finite element analysis of circular foundations on cohesive soil under combined loading and proposed new equation for failure locus in terms of all three components. Horikoshi et al. (2003) studied the performance of piled raft foundations subjected to static horizontal loads. Horizontal stiffness of foundation and proportion of load carried by raft and piles were studied. Philip S.K et al. (2007) did simplified lateral load analysis of fixed head piles and pile groups and developed characteristic load method to estimate deflection and bending moment and found that it is limited to cases where lateral load on pile is applied at ground surface. Sawadan et al. (2014) conducted centrifugal model tests on piled raft, pile groups, rafts alone Fig 1 and showed vertical displacement due to horizontal load affects vertical resistance of piles. Gang Zheng et al. (2019) studied the effect of inclined loading on bearing capacity of strip footing on sand layer as in Fig 2 and they did parametric study and proved that failure mechanism depends on geometric parameters and soil properties (D/B, C/γB , φ). Abbasali et al.(2019) studied influence of using composite soils under shallow foundations. 3D Finite element analysis was done and studied bearing capacity improvement and shows that Sand clay mixture shows better performance than gravel clay mixture. In this paper, extensive investigations are carried out to study the load-settlement behaviour of circular footing subjected to horizontal loads. The reduction in lateral deformation of soil by providing micropiles beneath the footing is also studied. The study involved non-linear finite element analyses using the FE software PLAXIS 2D and the results were compared with those obtained from laboratory scale load tests. The parameters studied are influence of vertical load (P), embedment depth (D) on lateral displacement of footing and effect of combined lateral and vertical load on rotation of footing.

2 Laboratory Scale Load test

The load tests are conducted in a combined test bed and loading frame assembly as shown in Fig.1. The test beds are prepared in a tank which is designed keeping in mind the size of the model circular footing to be tested. The internal dimension of the test tank is 1000mm length x 750 mm width x 750 mm depth, which has 23 cm thick brick masonry walls on the three sides. The front side of tank is formed using a frame work of steel channels and angles. For test with clay alone, the weak soil is filled in the test tank to the required level with compaction done in layers of 5 cm thickness. The water content of the clayey soil is maintained at 25%. To achieve the desired density of the soil, the layered filling technique is used. The pre-determined density of clay is used to calculate the desired weight of soil required to fill the tank in layers of 50mm height. A uniform density of 15.61 kN/m3 for clay was maintained in all the tests. The clay was compacted by ramming. The compactive effort required to achieve the required density was determined by trial and error. The loading tests are carried out in a loading frame fabricated with ISMB 300. The vertical load is applied using a hand operated- mechanical jack of capacity 50kN. The applied vertical load is measured using a proving ring of capacity 100kN. Arrangement for lateral loading is welded in the loading frame. Lateral load is measured using a proving ring of capacity 50kN.The lateral displacement of the model footing is measured using two dial gauges of 0.01mm sensitivity kept diametrically opposite to each other. The tilt due to combined vertical and horizontal loading is also measured using two dial gauges of 0.01mm sensitivity kept diametrically opposite to each other. The model footing is placed exactly beneath the centre of loading jack to avoid eccentric loading.

Fig. 1. Loading Frame & Test Tank

Table 1. Properties of Clay

Sl No	Properties	Values
1	Specific gravity	2.68
2	Optimum Moisture Content (%)	18
3	Maximum Dry Density (kN/m^3)	15.61
4	Liquid Limit (%)	58
5	Plastic Limit (%)	22
6	Shrinkage limit (%)	16.2
7	Permeability, k (m/s)	3.03×10^{-6}
8	Unconfined Compressive Strength, UCC (kN/m^2)	140.08

9	IS Classification	CH
10	Friction angle, Φ (^{0})	5
11	Cohesion , c (kPa)	25

2.1 Geometric Parameters used

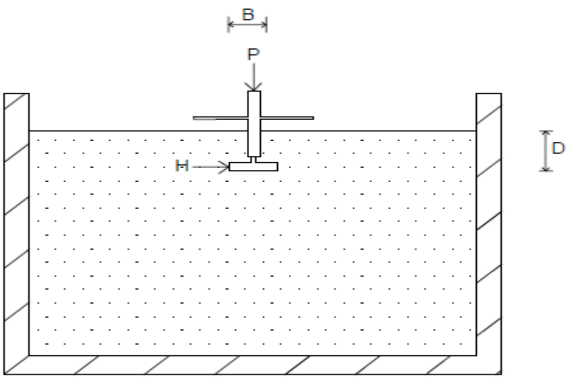

Fig. 2. Geometric Parameters

Diameter of circular footing (B) is kept constant and it is 10cm.the vertical load (P) is varied as 0N, 90N, 130N & 160N. Depth of embedment of footing(D) is varied as D/B=0,0.5&1. Distance between two dial gauges is fixed as 30.5 cm. Horizontal load (H) is varying and it is applied at regular intervals.

The arrangement for vertical and lateral loading is shown in Fig 2 , Fig 3 and Fig 4 respectively.

Fig. 3. Arrangement for vertical loading

Fig. 4. Arrangement for lateral loading

3 Finite Element Analysis

In the present study, the experimental results obtained are validated by carrying out finite element analysis. The software PLAXIS 2D is commercially available software for carrying out the finite element analyses. The geometric model in the finite element analyses is shown in Fig 5.

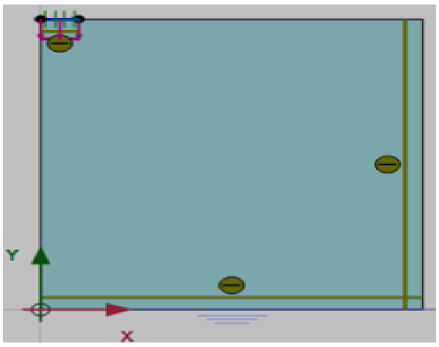

Fig. 5. Geometric Model

There are different constitutive models available in the FE software for simulating the soil-behaviour. Mohr-Coulomb model is adopted in the present study. The soil parameters obtained from direct shear tests; internal friction angle and cohesion intercept, is adopted in this non-linear model. The axisymmetric model is used in the analysis, since circular footing is symmetric about its central axis. The non-zero prescribed displacements is used to simulate the settlement of the rigid footing. Fig. 6 shows the typical deformed shape obtained after loading in the FE software.

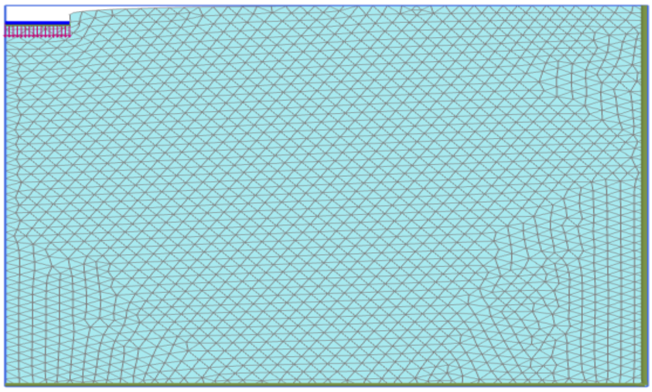

Fig. 6. Typical Deformed Shape

4 Results and Discussions

4.1 Influence of vertical load on lateral load- deformation behaviour

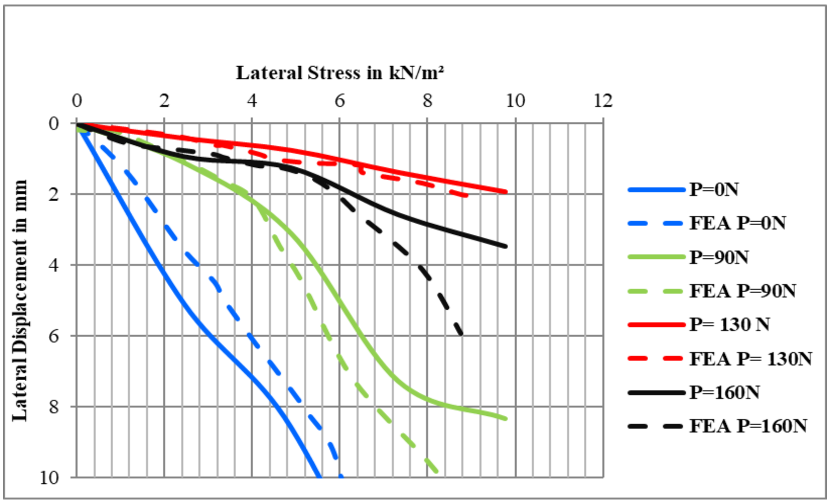

Fig. 7. Influence of vertical load on lateral load- deformation behaviour when D/B = 1 for clay

The variation in lateral stress v/s settlement curve of circular footing resting in clayey soil of D/B=1.0 where D is embedment depth of footing and B is the width of footing by varying the vertical loads P=0N, P=90N, P=130N & P=160N is presented in Fig.7. From the curves it is observed that as lateral stress increases, lateral displacement increases. As vertical loading (P) increases, lateral displacement decreases. This is because as vertical load increases, normal stress beneath the footing increases and thereby increasing the force of friction which causes decrease in lateral displacement of footing. It is seen that there is slight variation between the results obtained from Finite Element Analysis and experimental studies.

4.2 Influence of embedment depth of footing on lateral load- deformation behaviour

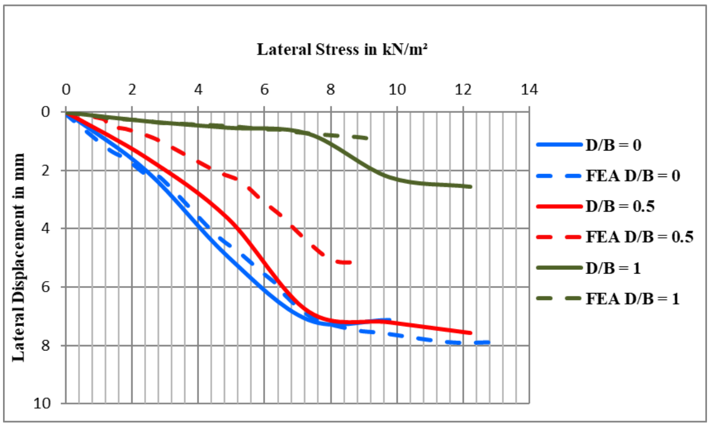

Fig. 8. Influence of embedment depth of footing on lateral load- deformation behaviour when P=130N for clay

From the Fig 8, it is observed that as lateral stress increases, lateral displacement increases. As depth of footing increases, lateral displacement decreases since the confinement of footing increases. Displacement is found minimum at D/B= 1. Displacement is observed maximum when the footing is at the surface. It is seen that the results obtained from Finite Element analysis almost agree with experiment results.

4.3 Influence of lateral load on rotation of footing

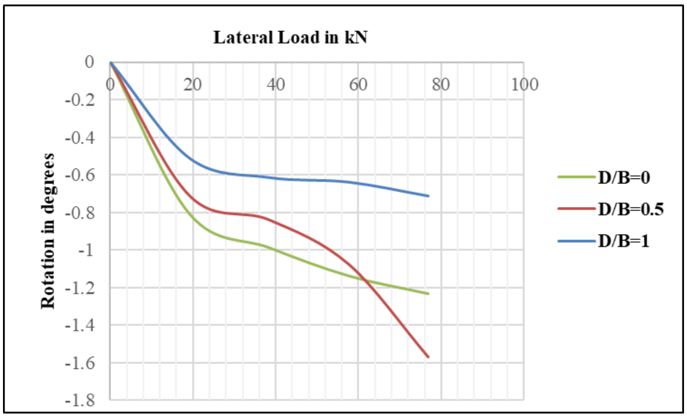

Fig. 9. Influence of lateral load on rotaion when P=130N for clay

Fig.9 shows lateral load versus rotation behaviour of circular footing at different embedment depth to width ratios (D/B) 0, 0.5 & 1 under vertical load of 130 N. From the curve it is observed that as lateral loading increases, rotation increases. Rotation decreases with increase in embedment depth found minimum at D/B=1. Decrease in rotation is due to increase in confinement of soil with depth.

4.4 Influence of micropiles on reduction in lateral displacement and rotation of footing

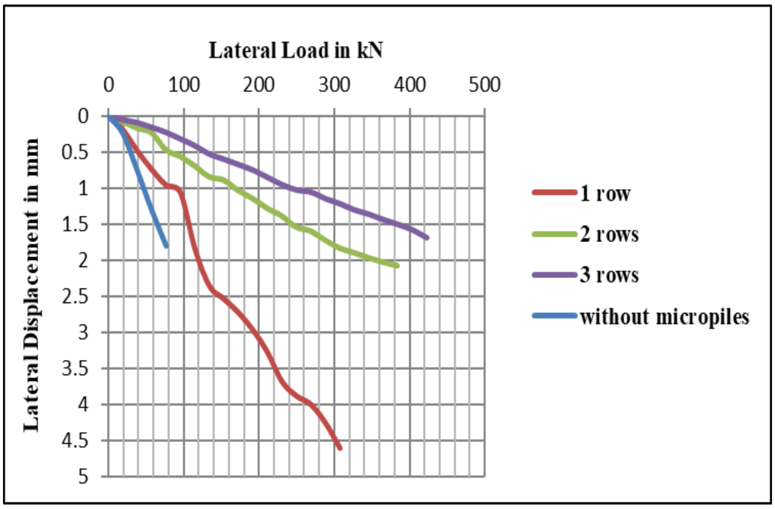

Fig. 10. Infuence of Micropiles on lateral load - lateral displacement behaviour

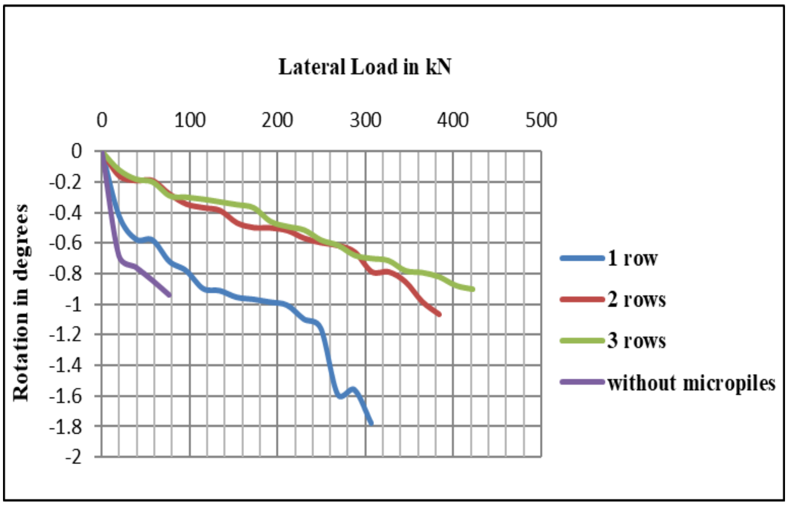

Fig. 11. Influence of Micropiles on lateral load - rotation behaviour

Fig 10 & Fig 11 shows the reduction in lateral displacement and rotation of footing by the provision of micropiles for P=90N & D/B=1. With an increase in the number of rows of micropiles the behaviour improved. The addition of micropiles increases the stiffness of soil beneath the footing and thereby reducing rotation and lateral displacement.

5 Conclusions

The effects of lateral load on a model circular footing resting on clayey soil are investigated by carrying out a series of laboratory scale load tests and non-linear finite element analysis using the FE software PLAXIS 2D. The influence of vertical load, embedment depth and addition of micropiles on the lateral load – deformation behaviour and lateral load – rotation behaviour is particularly studied. The results of laboratory scale load tests are validated by carrying out finite element analyses. Based on the results observed, the following conclusions are drawn.

1. Lateral displacement decreases with increase in vertical loading due to increase in normal stress.
2. As depth of footing increases, lateral displacement & rotation of footing decreases due to increase in confinement
3. As the number of rows of micropiles increases, both lateral displacement and rotation of footing decreases.

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