Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Influence of Moment on Load-Settlement Behaviour of Circular Footing resting on Clayey Soil

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Abstract. Foundations of certain structures are subjected to large moments and relatively small vertical and horizontal forces. Moments on the foundation base are mainly caused by horizontal forces acting on the structure. It tends to tilt the footing. This tilt increases with the increase of load eccentricity, and consequently the bearing capacity is reduced. Short bored pile or pier foundations are widely used in situations where moment-carrying capacity is the dominant design requirement. But such foundations are very costly and cannot be adopted for small structures. Published literature on the moment-deformation behaviour of shallow foundation is very scarce. This paper investigates the influence of moment acting on the structure, on the settlement and angular distortion of the footing by carrying out a series of laboratory scale load tests on model circular footing in clayey soil. The parameters varied are magnitude of moment, magnitude of vertical load, depth of foundation, etc. Finite element analyses are also carried out and the results are compared with those obtained from laboratory studies for validation. It is observed that tilt increases with increase in moment initially and thereafter decreases. It is also observed that tilt decreases with increase in depth of footing. Moment acting on the structure influences the load-settlement behaviour also Load- settlement behaviour improves due to the addition of reinforced foundation bed below the footing.

Keywords: Moments, tilt, load eccentricity, shallow foundation, load-settlement behaviour

1 Introduction

Foundations for overhead catenary systems carrying electrical power in railway networks, transmission towers, and for large road and railway hoardings and other elevated commercial signs have to be designed mainly to resist large moments and relatively small vertical loads. Moments on the foundation base are mainly caused by horizontal forces acting on the structure. Horizontal forces act on a structure due to earth pressure, wind pressure, seismic force, hydrostatic pressure etc. The non-uniformity of the soil pressure caused due to horizontal/eccentric loads tends to tilt the footing. This tilt increases with the increase of load eccentricity, and consequently the bearing capacity is reduced. Short bored pile or pier foundations are widely used in situations where moment-carrying capacity is the dominant design requirement. But such foundations are very costly and cannot be adopted for small projects. Published literature on the moment-deformation behaviour of shallow foundation is very scarce.

Much research has been carried out in different foundations subjected to moments and eccentric loads [2], [5], [7;8] and [1]. Laboratory investigation and numerical analyses were carried out by [3;4] to study the behaviour of one sided skirted strip footing subjected to eccentric load. [6] studied the behaviour of ring footing resting on loose sand and/or compacted randomly distributed fiber reinforced sand when subjected to eccentric, inclined and eccentric-inclined loadings by using finite element (FE) software PLAXIS 3D.

This paper investigates the influence of moment acting on the structure, on the settlement and angular distortion of the footing by carrying out a series of laboratory scale load tests on model circular footing resting on clayey soil. . Finite element analyses are carried out with the FE software *PLAXIS 2D* and the results are compared with those obtained from laboratory studies for validation.

2 Laboratory Scale Load test

The load tests are conducted in a combined test bed and loading frame assembly. The test beds are prepared in a tank of internal dimension 1000 mm length x 750 mm width x 750 mm depth. The test tank is constructed with 230 mm thick brick masonry walls. The model circular footing has a diameter of 100 mm, thickness 20 mm and is fabricated with mild steel. The clayey soil is filled in the test tank to the required level with compaction done in layers of 50 mm thickness. The water content of the clayey soil is maintained at 15.61%. To achieve the desired density of the soil, the layered filling technique is used. 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 50 kN. The applied vertical load is measured using a proving ring of capacity 100 kN. Moment is applied by eccentric loading on the footing in addition to the vertical load. The eccentricity in all the tests is 245mm. Eccentric load is measured using an additional proving ring of capacity 50 kN. The tilt of the model footing is measured using two dial gauges of 0.01 mm sensitivity kept diametrically opposite to each other 350 mm apart. The photograph of experimental setup is shown in Fig. 1. Locally available clay is used as foundation soil. The properties of clay are listed in Table 1.The improvement in load-settlement behaviour due to the addition of reinforced foundation bed is also investigated. Reinforced Foundation Bed is formed by placing a layer of sand reinforced with biaxial geogrid beneath the footing.

Fig. 1. Experimental Setup

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 Parameters used in the study

The geometrical parameters in this study are presented in Fig. 2. The diameter and depth of circular footing are 'B' and 'D' respectively. Diameter of the model footing is 100 mm. Distance between two dial gauges is fixed as 350 mm. Eccentric load (P2) is increased at regular intervals. The eccentric distance (e) of eccentric load P2 is fixed as 245 mm. The experimental setup is shown in the Fig. 3 and parameters varied in Table 2. The thickness of reinforced foundation bed is represented as 't'. The number of geogrid layer (N) is varied as 1 and 2.

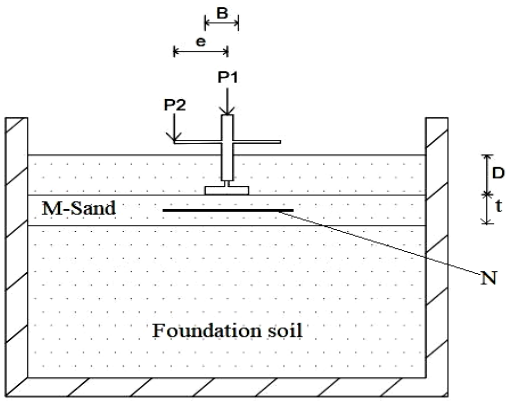

Fig. 2. Geometric Parameters

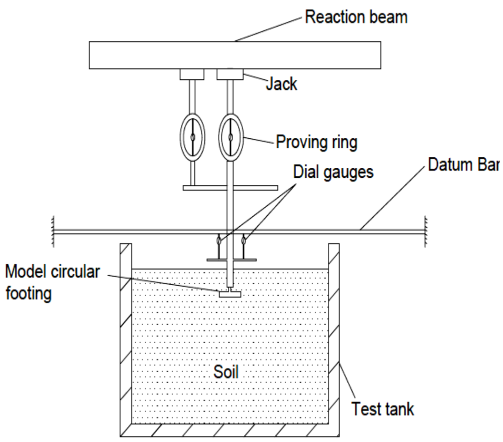

Fig. 3. Schematic representation of test setup

Table 2. Parameters varied

Parameter	Vertical Load P_1 (N)	D/B	Moment M (N-m)	t/B
Values	0, 90, 130, 170	0, 0.5, 1	0, 0.56, 1.13, 1.69	0.25, 0.5, 0.75

3 Finite Element Analysis

In the present study, the experimental results obtained are validated by carrying out finite element analysis and comparing the resuts. PLAXIS 2D is acommercially available software for carrying out the finite element analyses. The geometric model in the finite element analysis is shown in Fig 4.

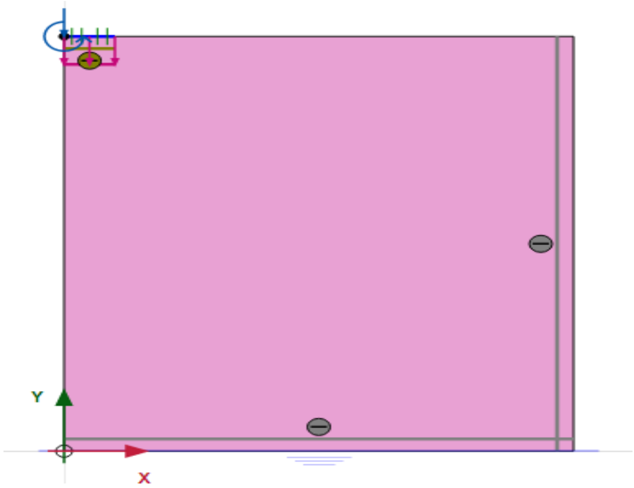

Fig. 4. Geometric Model

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. 5 shows the typical deformed shape obtained after loading in the FE analysis.

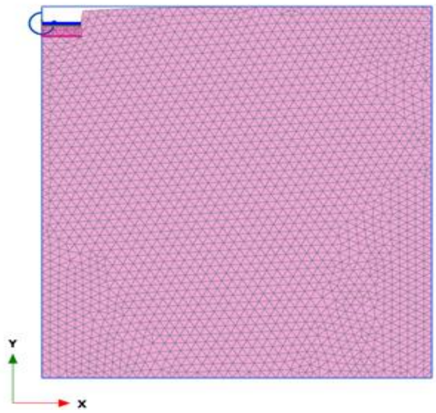

Fig. 5. Typical Deformed Shaped

4 Results and Discussions

4.1 Influence of depth of footing on rotation

Fig. 6. Moment versus Rotation curves for P1= 130 N and different depths of footing

Moment versus tilt curves for constant vertical load P_1=130 N and different depths of footing are presented in Fig. 6. It is observed that depth of embedment influences the tilt of footing. For a constant vertical load, as the depth of embedment increases the tilt of footing reduces. The rotation is found to be minimum for D/B =1.0. Maximum rotation is observed when the footing is at the surface. When moment is applied, one side of footing moves down and other side moves up. The downward movement is restricted by contact pressure. The upward movement of footing is restricted by the weight of soil above the footing. As depth increases, the bearing resistance increases and the weight of soil above the footing increases. This increases the moment resisting capacity of footing.

4.2 Influence of vertical loading on rotation

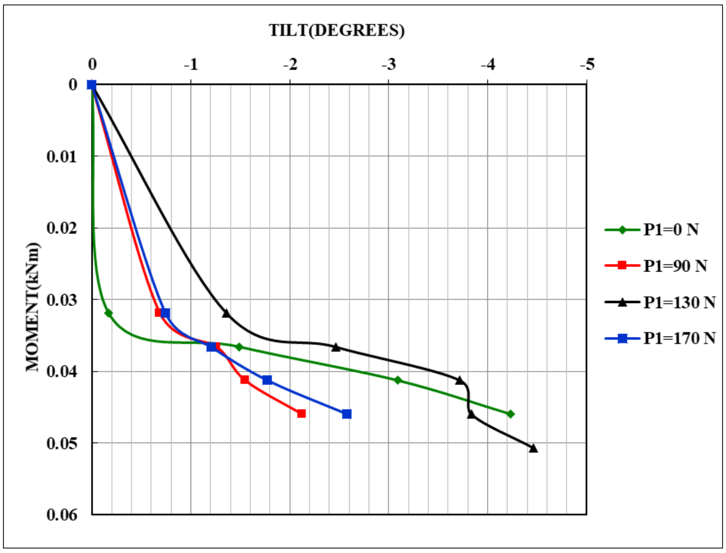

Fig. 7. Moment versus Rotation curves for D/B=0.5 and varying vertical loads

Moment versus rotation curve for constant depth D/B=0.5 and varying vertical loads is given in Fig. 7. Vertical load influences the tilt of footing. For constant depth, when vertical load increases, the tilt increases upto P1=130 N and further increase in vertical load tilt reduces. Maximum tilt is found at vertical load of 130 N.

4.3 Influence of moment acting on the structure on settlement

The load-settlement curve of circular footing resting on surface (D/B=0) for varying the moments is given in Fig.8. It is seen that the load-settlement behaviour is influenced by the moments acting on the structure. For a constant depth of footing, when the moment increases, the settlement also increases. The moment is applied by applying an additional eccentric load. Hence as the moment increases, the total vertical load also increases.

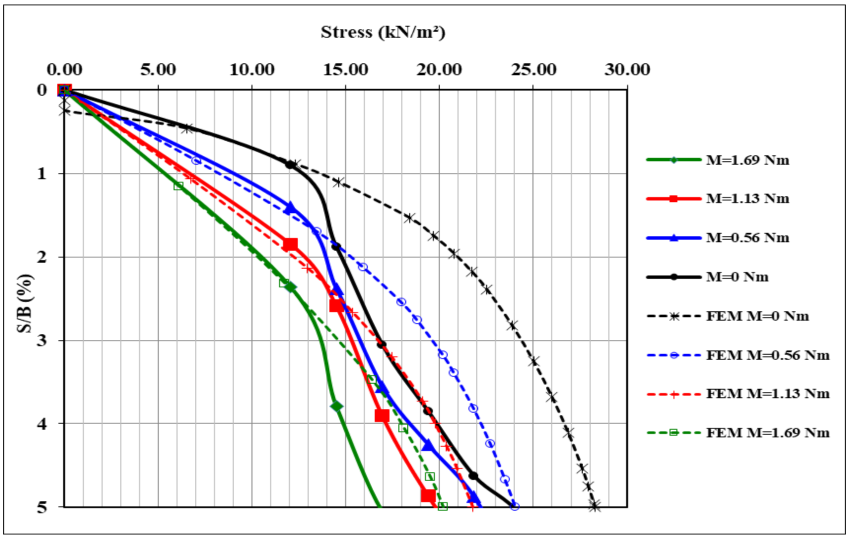

Fig. 8. Load-settlement curves for D/B=0 and varying the moments

4.4 Influence of depth of footing on load-settlement behaviour

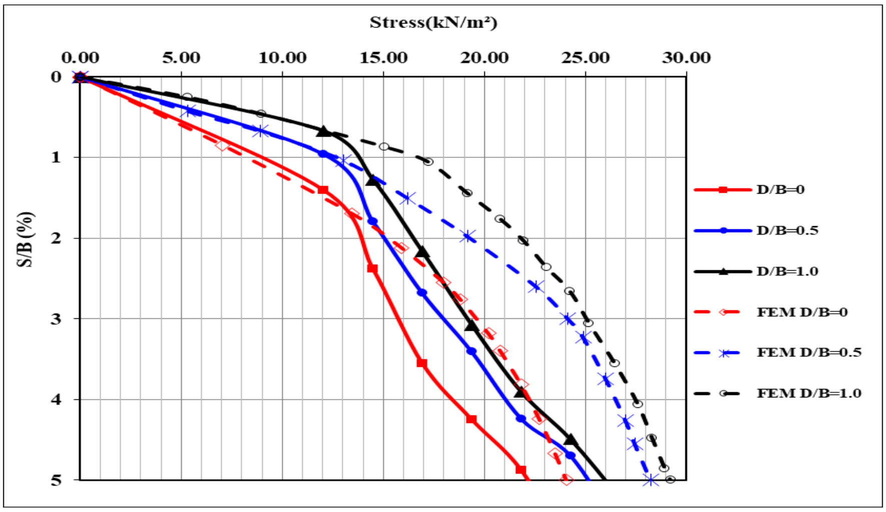

Fig. 9. Load-settlement curves for constant moment M=0.56 N-m and different depths of footing

The load-settlement behaviour of circular footing resting at different depths for constant moment M= 0.56 N-m is presented in Fig. 9. It is observed that depth of embedment influences the settlement of footing. For a constant moment, as the depth of embedment increases the settlement of footing reduces. The settlement is found to be minimum for D/B =1.0. Maximum settlement is observed when the footing is at the surface.

4.5 Influence of reinforced foundation bed

The improvement in load-settlement behaviour of model circular footing for D/B=0.5 and M=1.69 N-m due to the addition of reinforced foundation bed is presented in Fig. 10.

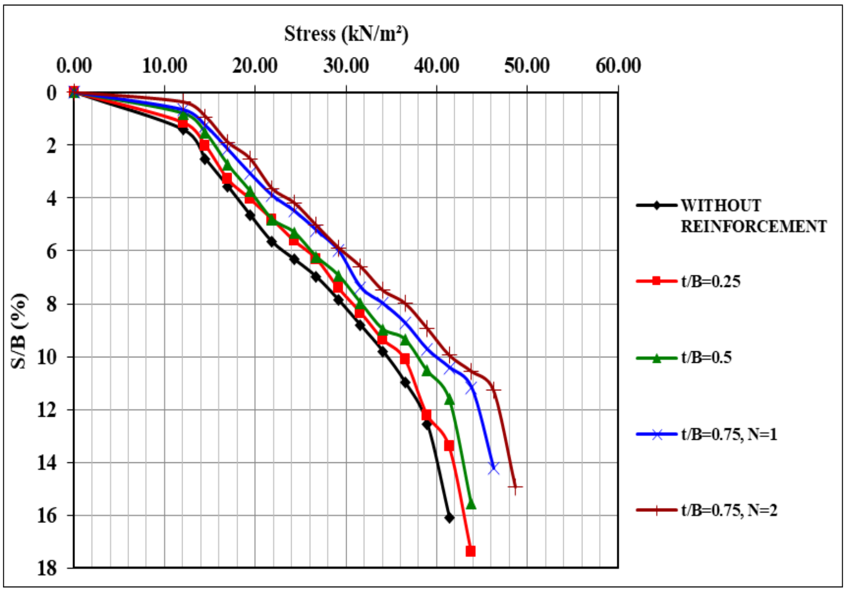

Fig. 10. Load-settlement curves for D/B=0.5 and M=0.56 N-m in reinforced foundation bed

It is observed from the results that as the thickness of reinforced foundation bed increases the load-settlement behaviour improves. As the number of geogrid layers increases, the settlement reduces.

5 Conclusions

Moment- rotation behaviour and load -settlement behaviour of circular footing is investigated by carrying out a series of laboratory scale load tests and finite element analyses. The following conclusions are deduced from this study:

1. Depth of embedment reduces the tilt of footing and settlement of footing.
2. Moment acting on the footing adversely influences the load-settlement behaviour.

3. Vertical load acting on the footing significantly influences the tilt.
4. The rotation is found to be minimum for D/B =1.0.
5. Maximum rotation is observed when footing is at surface.
6. The load- settlement behaviour under a combination of moment and vertical load improves due to the addition of reinforced foundation bed.

Acknowledgement

The financial support received from TEQIP Four Funds of LBS Institute of Technology for Women, Thiruvananthapuram is gratefully acknowledged

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