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Experimental Study of Circular Shallow Footing on the Top of Slope

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Abstract. Shallow footings are extensively used when hard strata exist near ground level. Design of foundations must satisfy ultimate bearing capacity and allowable settlements (Meyerhof, 1957). The bearing capacity of foundations depends on density, deformation and shear characteristics of soil. Footing on sloping ground becomes important due to limit of land availability, right of way, cost effectiveness and many more. In hilly regions, construction of footings on slopes becomes essential which require appropriate designs with a suitable factor of safety. It is found that research is limited on rigid footing resting on sloping ground. Researchers majorly focused on shallow footing resting on sloping ground either of cohesive or cohesionless. In this context, it is necessary to address the behavior of shallow footing resting on steep (>30°) sloping ground consisting c-ϕ soil. Hence, the present experimental study on a lab scale model is an attempt to understand the behaviour of circular shallow footing of size 0.11 m in diameter (B) resting on the top of a 45° sloping ground having c-ϕ soil i.e., clayey sand having c = 14 kN/m^2 and ϕ=28° with varying D_e/B ratios of 1. Load-settlement behavior of footing is observed and presented.

Keywords: Shallow footing, Circular footing, Experimental study, Sloping ground, Offset distance, Bearing capacity.

1 Introduction

In general, most of the building foundations are often constructed on slopes and adjacent to slopes in hilly areas; and near the open excavations. Moreover, shallow foundations are generally adopted in the case of low to medium rise buildings. The investigation of bearing capacity of loaded slopes is very important during the construction of foundations nearer to slopes due to their more susceptible to failure (Shields et al., 1990). The design of foundations must satisfy safe bearing capacity and allowable settlements (Meyerhof, 1957). The properties of soil and the footing characteristics plays a major role on soil ultimate load carrying capacity. In practice, a reasonable factor of safety is applied to the ultimate values to produce the allowable values of bearing capacity of foundations, depending on the uncertainty of soil behavior and the loading conditions. However, it's quite complex to model and analyze foundations which are constructed on sloping ground for their ultimate load carrying capacity by considering many of the parameters and site conditions.

As per the literature, many researchers considered various assumptions and evaluated bearing capacity of shallow foundations which are constructed on slopes consist cohesionless or cohesive properties. (Shields et al., 1977; Saran et al., 1989; Narita and Yamaguchi, 1990; Castelli and Motta, 2010). Moreover, most of the studies were performed on sandy slopes using strip footing rather than circular or square footings (Castelli and Lentini, 2012; Salih Keskin and Lemon, 2013; Azzam and EI-Wakil, 2015; Acharya and Dey, 2017). However, very few researchers carried tests on c-φ soil using spread footing resting on the top of slope (Leshchinsky 2005; Acharyya et al., 2018). Based on the literature review, it is necessary to address the behaviour of shallow footing resting on steep (>30^o) sloping ground consisting c-φ soil. Hence, the present study is an attempt to develop bearing capacity of the shallow circular foundation resting on the top of 45^o sloping ground for certain c-φ soil at a setback distance through practical approach. Finally, the objective of the present research is to evaluate the bearing capacity of an isolated circular footing near the slope; specifically, to determine the contribution of D_e/B (Offset distance, D_e to Footing width, B) on the bearing capacity.

2 Materials

The c-φ soil used for the experimental work was collected from surrounding village of the Institute known as A. Rangampet, Tirupati, Andhra Pradesh, India. According to BIS standards, the soil physical properties were found out. The soil was collected from the field in large sacks and the state of field soil seems to have a small amount of moisture. Hence, the collected soil was dried to remove the soil natural humidity by placing in an oven for 24 hrs. At the end of 24 hrs, the dried soil particles came together and formed as many numbers of large lumps. Hence, the formed lumps were broken into fine powder form using wooden hammer and is sieved according to the experimental conditions. Table 1 shows the properties of c-φ soil used in the present laboratory model test.

Table 1. Properties of soil used in the present research

S. No.	Property	Value
1.	Specific gravity (G)	2.66
2.	Liquid limit (w_L)	42 %
3	Plasticity index (I_p)	23 %
5.	Sand	81 %
6.	Silt	8 %
7.	Clay	11 %
8.	IS Classification	SC
9.	Maximum dry density	20 kN/m^3
10.	Optimum moisture content	14 %

11.	Cohesion (c)	14 kN/m^2
12.	Angle of internal friction (ϕ)	28°
13.	Young's modulus, E (kN/m^2)	7501 kN/m^2
14.	Poisson's ratio, μ	0.35

Test Tank and Footing Plate

The test tank used for the present model tests was a rectangular tank having dimensions of 1200 mm (L) x 800 mm (B) x 800 mm (H). Two sides of the test tank were covered with non-acrylic thick wooden sheets and remaining one side consist an acrylic sheet of 8 mm thickness. The following wooden and acrylic sheets were fixed with nut and bolt arrangement. A rigid circular footing having a size of 110 mm having a thickness of 12 mm made with mild steel was used as a model footing for the present model tests.

3 Experimental Program

c-φ soil was used for the present model tests and test soil was placed in the test tank and compacted at its maximum dry unit weight as mentioned in Table 1. Initially, the amount of soil required for filling the tank up to its total height with a soil slope angle of 45° is 1.1 tonnes. The calculated amount of soil was placed in the test tank layer wise and compacted uniformly using tampers. A total 22 layers of soil is compacted with a tamping rod of 3.25 kg with a height of fall of 30 cm to achieve the maximum dry unit weight of soil. The consistency of the soil compaction was determined by using core-cutter method. After preparation of the soil bed, the test tank was dismantled except on one side to create horizontal fixity as depicted in Fig. 1a. A hand operated hydraulic jack was used for the load application on the footing. Vertical load is applied by fixing hydraulic jack within the connecting rod setup. To determine the footing displacement during loading, the dial gauges were placed on both sides of connecting rod as shown in Fig. 1b. To determine the effect of offset distance (i.e., distance from footing edge to the slope surface, D_e) on footing load carrying capacity, the test was performed by maintaining the ratio of $D_e/B = 1.0$. It means the model footing was placed at a distance of 110 mm from the slope surface. The complete schematic diagram of the test setup is as depicted in Fig. 2.

Fig. 1a. Embankment placed in the test tank with an angle of 45°

Fig. 1b. Total test arrangement of the footing placed on soil bed along with hydraulic jack and dial gauges

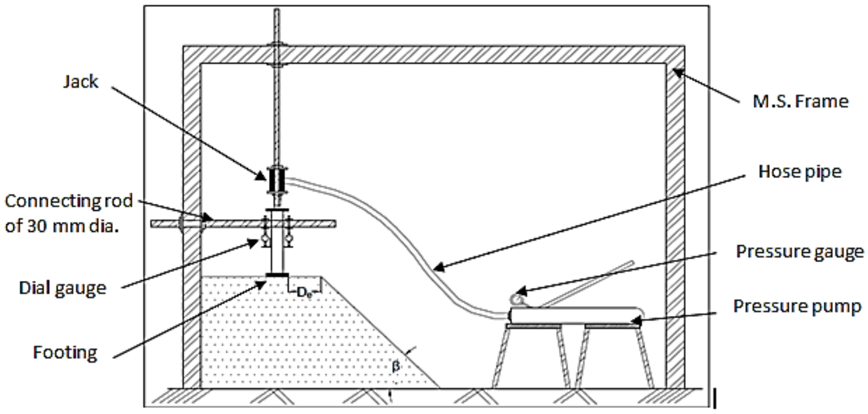

Fig. 2. Schematic view of total test set-up

3.1 Numerical Program

For the present research, a Plaxis 2D finite element analytical software was used to perform the numerical analysis. During the anlaysis, a denser mesh was formed with a number of 15 node triangular elements. As per the literature, 15 node triangular element mesh gives more accurate results as compared other node models. Hence, the deformation of the soil at failure can be accurately measured. Fig. 3 presents a sample of a finite element mesh of the numerical model defined in PLAXIS. Table 2 depicts the model soil properties used in the numerical analysis of the present research.

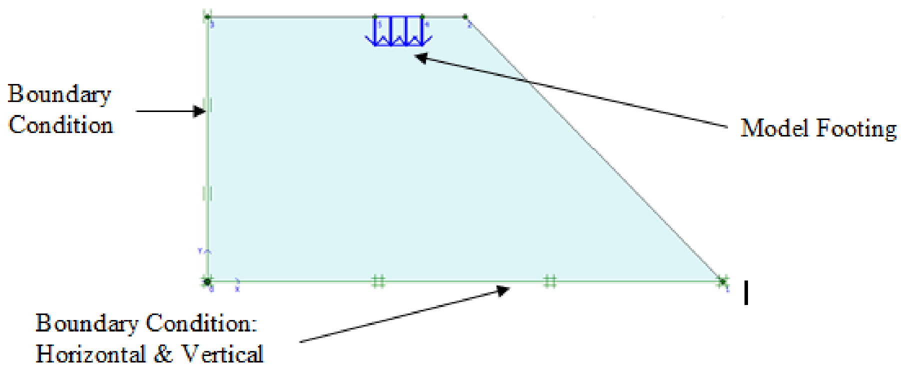

Fig. 3. Boundary condition for the numerical model

Table 2. Soil properties used in the Plaxis 2D Model

S. No.	Property	Value

1.	Young's modulus, E (kN/m^2)	7501
2.	Poisson's ratio, μ	0.35
3.	Angle of dilatancy, ψ (°)	0
4.	Material type	Undrained
5.	$\gamma_{unsaturated}$ (kN/m^3)	20.27
6.	$\gamma_{saturated}$ (kN/m^3)	22.8
7.	Cohesion, c (kN/m^2)	14
8.	Angle of internal friction, ϕ (°)	28
9.	Coefficient of permeability, k (m/day)	1.08E-04

4 Results and Discussion

Fig. 4 shows the load-settlement results of footing during the experimental model tests. The load carrying capacity of the footing goes on increases with increase in footing settlement (s). However, after certain settlement, the footing load carrying capacity diminished as marked in Fig.4. Finally, Fig. 4 revealed that the load carrying capacity at footing failure or ultimate load carrying capacity is 6.20 kN (i.e., 652.4 kPa) at a corresponding settlement of 8 mm i.e., s/D of 7.27%. Similarly, Fig. 5 depicts the load-settlement results of the footing during numerical analysis. The numerical test results also show that the footing ultimate load carrying capacity is 6.34 kN (i.e., 667.14 kPa) at the corresponding s/D of 6.82%. Therefore, it is evident from the results that the numerical test results are well matched with the experimental test values.

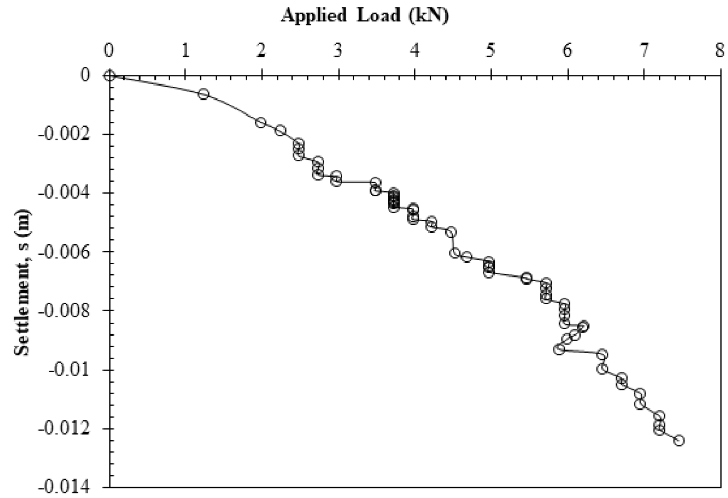

Fig. 4. Load-Settlement curves of footing during experimental model test

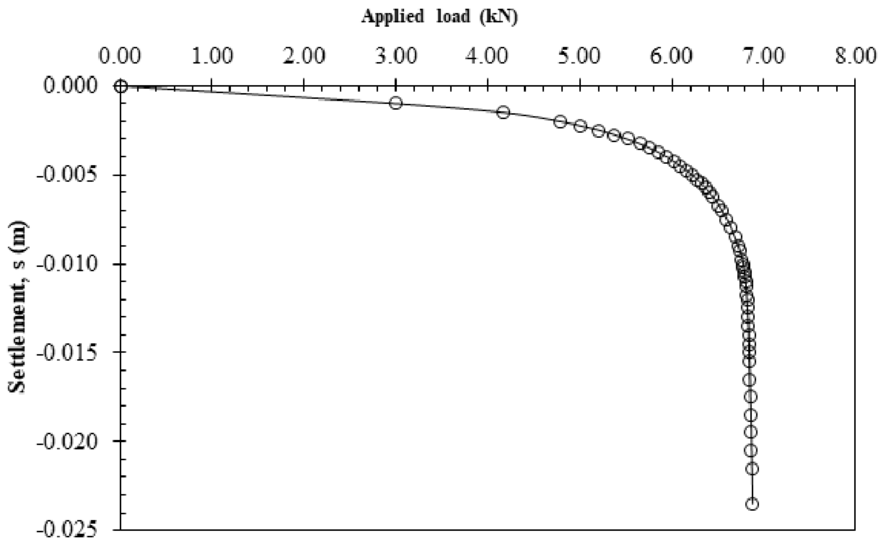

Fig. 5. Load-settlement curve of footing during numerical anlaysis

5 Conclusion

The present model test results of the shallow footing placed at an offset distance to footing size ratio (D_e/B) of 1.0 show that the ultimate load is 652.4 kPa. Further, the results from the numerical analysis using Plaxis 2D, were also matched well with the experimental test results. Hence, it is possible to understand the load-settlement behavior of the shallow footing for further conditions such as larger offset distances (i.e., D_e/B>1) and slope angle by performing the numerical analysis in future using the same model soil parameters as used in the present study.

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