

Study of Shallow Foundations on Granular Soils

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Abstract— The bearing capacity and settlement study of shallow footings is a subject which needs consideration for design of a foundation. Most of the studies relate to the case of a vertical load applied centrally to the foundation. However, when loads are applied eccentrically to the foundation, the bearing capacity is different from centrally loaded footings. Meyerhof (1953) developed empirical procedures for estimating the ultimate bearing capacity of foundations subjected to eccentric loads. Based on the review of the existing literature on the bearing capacity of shallow foundations, it shows that limited attention has been paid to estimate the ultimate Bearing capacity of eccentrically loaded square foundation with depth of embedment D_f . Hence the present work attempts to investigate the bearing capacity of eccentrically loaded square embedded footing. Square footings of size 10cm x 10cm are used for load-test in the laboratory. Embedment ratio D_f/B is varied from zero to one and the eccentricity ratio e/B varying from zero to 0.15 with sand of relative density (D_r) equal to 69%. Ultimate bearing capacity has been found out for central as well as eccentric loading condition. An empirical equation has been developed for the reduction factor in predicting the bearing capacity of eccentrically loaded square embedded foundation. The results of the previous investigators are also analysed and compared with the present experiment. An Artificial Neural Network model is developed to estimate reduction factor (RF_s) for settlement. Based on the laboratory model test results taken from Patra et al. (2013) a mathematical equation have been developed by ANN to determine the settlement of eccentrically loaded embedded strip footings. Also the model equation for reduction factor obtained from ANN analysis have been compared with empirical equation proposed by Patra et al. (2013). The predictability of ANN model is found to be better than empirical one.

Keywords: ANN, RF_s, Granular Soils

I. INTRODUCTION

Foundation is the important part of any structure. While design of any foundation it is necessary to know the type of soil, its behavior and bearing capacity. A foundation is that part of the structure which forms the interface across which the loads are transmitted to the underlying soil or rock. Foundations are classified according to the depth of founding, D_f (depth of base of foundation below ground level) compared to the width of the foundation, B . Shallow foundations are placed at shallow depths that are depth is equal to or less than its width, B . The design of shallow foundation is accomplished by satisfying two requirements: (1) bearing capacity and (2) settlement. In geotechnical engineering, bearing capacity is the capacity of soil to support the loads applied to the ground. The bearing capacity of soil is the maximum average contact pressure between the foundation and the soil which should not produce shear failure in the soil.

The conventional method of footing design requires sufficient safety against failure and the settlement must be kept within the allowable limit. These requirements are dependent on the bearing capacity of soil. To have the safe design, the bearing pressure on the underlying ground has to be kept within the safe allowable limit. Thus the estimation of load carrying capacity of footing is the most important step in design of foundation. All the bearing capacity estimation methods may be classified into the following four categories: (1) the limit equilibrium method; (2) the method of characteristics; (3) the upper-bound plastic limit analysis; (4) slip line method and (5) the numerical methods based on either the finite-element method or finite-difference method. Footings are very often subjected to eccentric loads. This problem has been studied in detail by few investigators. The effective width method by Meyerhof (1953) is widely used for calculating the bearing capacity of eccentrically loaded footings. A stability analysis based on a slip surface derived from experimental results is presented by Purkayastha and Char (1977) for eccentrically loaded strip footings resting on sand. Footings are often subjected to eccentric loading due to (1) Moments with or without axial forces; (2) The oblique loading; and (3) Their location near the property line. Due to load eccentricity, the overall stability of foundation decreases along with settlement and tilting of the foundation which reduces the bearing capacity. The increase of stress in soil layers due to the load imposed by various structures at the foundation level will always be accompanied by some strain, which will result in the settlement of the structures. The estimation of settlements of shallow foundations in cohesionless soils is still considered as a serious geotechnical problem, both from practical and theoretical point of view. In general, settlement of a foundation consists of two major components - elastic settlement (S_e) and consolidation settlement (S_c). For a foundation supported by granular soil, the elastic settlement is the only component that needs consideration. Different methods are available for the determination of settlement of shallow foundation on cohesionless soil. But, most of the available methods fail to achieve consistent performance in predicting accurate settlement and most of them are based on foundations subjected to centric vertical load.

II. MATERIAL USED

A. Sand

The sand used in the experimental program was collected from the river bed of Koel River. It is made free from roots, organic matters etc. by washing and cleaning. The above sample was then oven dried and properly sieved by passing through 710 micron and retained at 300 micron IS sieve to get the required grading. Dry sand is used as soil medium for the test as it does not include the effect of moisture. The geotechnical properties of the sand used is given in Table 3.1. The grain size distribution curve is plotted in Figure 3.1. All the tests were conducted in 69% relative density. The unit

weight for 69% relative density is 14.36 kN/m^3 and the friction angle at 69% relative is 40.8° which are found out from direct shear tests.

B. Experimental Procedure

All the model tests were carried out in the Geotechnical Engineering Laboratory of NIT Rourkela, India. The model tests were conducted in a mild steel tank measuring 1.0m (length) X 0.504m (width) X 0.655m (height). The two length sides of the tank are made of 12mm thick high strength fiberglass. All four sides of the tank are braced to avoid bulging during testing. Two sizes of the model foundation have been taken, one is square footing having dimension 100mm (width B) 100mm (length L) 30mm (thickness t) and other is rectangular footing with 100mm (width B) 200mm (length L) 30mm (thickness t). These are made from a mild steel plate. The bottom of the footing was made rough by applying glue and then rolling the model footing over sand. Sand was poured into the test tank in layers of 25mm from a fixed height by raining technique to achieve the desired average unit weight of compaction. The height of fall was fixed by making several trials in the test tank prior to the model test to achieve the desired unit weight. The model foundation was placed at a desired D_f/B ratio at the middle of the tank. Load to the model foundation was applied by a loading assembly manually. Figure 3.3 shows the photographic image of experimental setup of laboratory model tests. The load applied to the model foundation is measured by Proving ring. Settlement of the model foundation is measured by dial gauges placed on two edges along the width side of the model foundation. Figure 3.3 shows the photographic image of prepared sand sample with two dial gauges arranged diagonally over the square footing for the test.

C. Problem Definition

The model tests were conducted for embedment ratio D_f/B varying from zero to one, the eccentricity ratio e/B varying from zero to 0.15 and with two relative densities (D_r) i.e. 69% and 51% respectively as per Figure 4.1. A strip footing of width 10cm was used for all the tests. The details of the tests and its procedure have been mentioned in Patra et al. (2012a). Total twenty four numbers of laboratory model tests were conducted. Using the results of laboratory model tests, a neural network model is developed to estimate the reduction factor.

In the present study, the feed forward back propagation neural network is trained with Levenberg-Marquardt algorithm. Based on the trained weights of the developed neural network different sensitivity analysis are carried out to study the important parameters and Neural Interpretation Diagram (NID) is constructed to find out the direct or inverse effect of input parameters on the output. A prediction model equation is developed using the trained weights of the neural network model. Finally, the result obtained from present analysis is compared with the empirical equation proposed by Patra et al. (2013).

D. Sensitivity Analysis

Sensitivity analysis is carried out for selection of important input variables. Different approaches have been suggested to

select the important input variables. The Pearson correlation coefficient is considered as one of the variable ranking criteria in selecting proper inputs for the ANN. Garson (1991) proposed a method, later on modified by Goh (1995), for partitioning the neural network connection weights in order to determine the relative importance of each input variable in the network. It is important to mention that Garson's algorithm uses the absolute values of the connection weights when calculating variable contributions, and therefore does not provide the information on the effect of input variables in terms of direct or inverse relation to the output. Olden et al. (2004) proposed a connection weights approach based on the NID, in which the actual values of input-hidden and hidden-output weights are taken. It sums the products across all the hidden neurons, which is defined as S_i . The relative inputs are corresponding to absolute S_i values, where the most important input corresponds to highest S_i value.

Parameters	e/B	D_f/B	D_r	RF_s
e/B	1	0.044	-0.036	-0.452
D_f/B		1	0	0.848
D_r			1	.046
RF				1

Table 1: Cross-correlation of the input and output for the reduction factor

E. Centric Loading Conditions

The model tests are performed (i.e. $e/B = 0$) in centric vertical loading condition. The details of the test parameters are shown in Table 5.1. Basically there are five different methods to interpret the ultimate bearing capacity from the load-settlement curve namely Log-Log method (DeBeer 1970), Tangent Intersection method (Trautmann and Kulhawy 1988), 0.1B method (Briaud and Jeanjean 1994), Hyperbolic method (Cerato 2005), and Break Point method (Mosallanezhad et al. 2008). For the present test results, the ultimate bearing capacity is determined by Tangent Intersection method

F. Surface Footing with Centric Loading Conditions

For 10cmx10cm size footing it is observed that for central loading definite failure point is observed. This curve shows the characteristics of General shear failure. Tangent intersection method is used to obtain ultimate bearing capacity of footing. It is found that for centrally loaded Square footing ultimate bearing capacity, q_u is 121 kN/m^2 . For 10cm x 20cm sizes rectangular footing it is observed that for central loading a definite failure point is observed as shown in Fig. 5.4. This curve also shows the characteristics of General shear failure. It is found that for centrally loaded rectangular footing ultimate bearing capacity; q_u is 125 kN/m^2 .

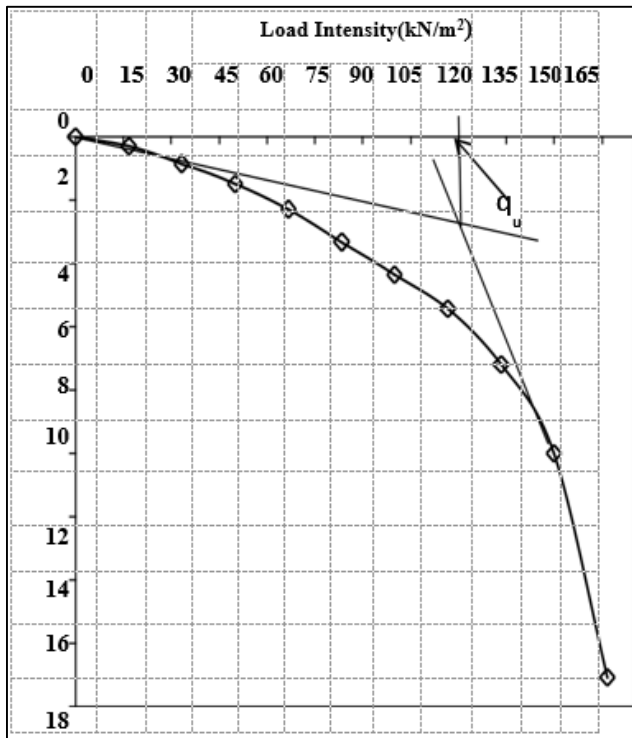


Fig. 1: Interpretation of Ultimate bearing capacity q_u by Tangent

The experimental ultimate bearing capacities for eccentrically loaded foundations ($e/B = 0, 0.05, 0.1$ and 0.15 , $D_f/B = 0, 0.5$ and 1) are plotted along with the bearing capacities obtained by using Meyerhof's effective area method (Eq. 2.6). This is shown in Figure 5.18 and Table 5.5. The nature of decrease of bearing capacity with the increase in eccentricity as observed from experimental results are with those using Meyerhof's method (1953). It can be seen from Fig. 5.18 that the difference in experimental UBC and computed UBC by Meyerhof's method is more at higher eccentricity and higher depth of embedment. Michalowski and You (1998) revealed that for purely frictional (granular) soil and relatively small surcharge loads, the effective width rule over- estimates the best upper bound to the average bearing pressure. Also for a surface footing with eccentricity $e/B = 0.25$ this overestimation is 35%, and it increases with an increase in e/B . Yamamoto and Hira (2009) also used finite elements to calculate the bearing capacity of surface foundations on frictional soils under eccentric loadings, and for a friction angle of 35° and an eccentricity $e = (1/3) B$, they found a bearing capacity equal to about 45% of the one determined by the effective width approach.

III. CONCLUSIONS

A neural network model equation is developed for prediction of settlement of strip footing in eccentric condition based on the trained weights of the ANN from the existing data set.

$$RF = 0.5 * (RF_n + 1) * (1.635 - 0.524) + 0.524$$

- Load tests have been conducted in the laboratory for embedded square footing (10cm x 10cm) under eccentric load.
- From the present experimental results, an empirical equation has been developed for reduction factor in predicting q_u for eccentric loading condition.

- The ultimate bearing capacity by reduction factor developed from present experiments is in well agreement with existing theory by Meyerhof.
- The Ultimate bearing capacity for Rectangular footing is more than square footing in surface condition.
- For the eccentric loaded square footing the Bearing Capacity increases with increase in embedment.

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