Experimental and Numerical Study of Load-Bearing and Settlement Behavior of Circular Skirted Foundations compared to Other Types of Foundations

Sajjad Gholipour [1] Masoud Makarchian[2]

1. Introduction

Geotechnical engineers have always been researching and developing appropriate methods for replacing surface and deep foundations, so that they could meet the requirements of bearing capacity and settlement of surface foundations. Using the vertical plates below the circumference of surface foundation as skirt has developed a new concept of foundation called skirted foundation, which consists of a top raft as footing and a relatively thin plate as skirt beneath the foundation circumference. The skirts with creating lateral confinement of soil and forming an integrated system transfer the loads to the soil at the level of skirt tip.

In spite of extensive studies and the development of empirical relationships for estimating bearing capacity and settlement of surface and deep foundations, there are no corresponding correlations for skirted foundations. Therefore, in this research, the bearing capacity and settlement of circular skirted foundations resting on sand under vertical compression loading was studied by physical modeling and numerical analysis with considering the effect of different parameters including skirt depth, foundation diameter, sand density, and surface roughness of the foundation models. In order to compare the performance of skirted foundations with that of embedded foundations in the depths of skirt tip, and also, semi-deep foundations, a series of numerical modeling were performed.

2. Literature Review

The behavior of square skirted foundations resting on laterally confined sand by skirt was studied by Eid in 2013. The enhancement in bearing capacity increases with increasing skirt depth and decreasing shear strength of sand. The influence of soil confinement on the performance of circular foundations was investigated by other researchers. Confining cylinders with different heights and diameters were used to confine the sand. The results indicated lateral confinement of soil underneath the footing leading to a significant improvement in the bearing capacity up to 17 times, along with decreasing lateral displacement of the soil. The bearing capacity enhancement in the range of 1.5 to 8.1 times and settlement reduction up to 90% have been reported for foundation models by some researchers due to skirt inclusion within sand.

3. Modeling Program

The laboratory model tests were carried out on the small-scale models (1g) to study the behavior of circular skirted foundations. The testing setup (Figure 1) used in this investigation consisted of a rigid test tank, sand raining hopper, a loading system, the footing model, and data acquisition system. The laboratory tests were carried out on circular and square steel foundation models having the diameters (B) of 100, 75, 50 mm. The skirt depth (D) to the foundation model width ratios (D/B) of 0.0, 0.5, 1, 1.5, and 2.0 were used for the present study.

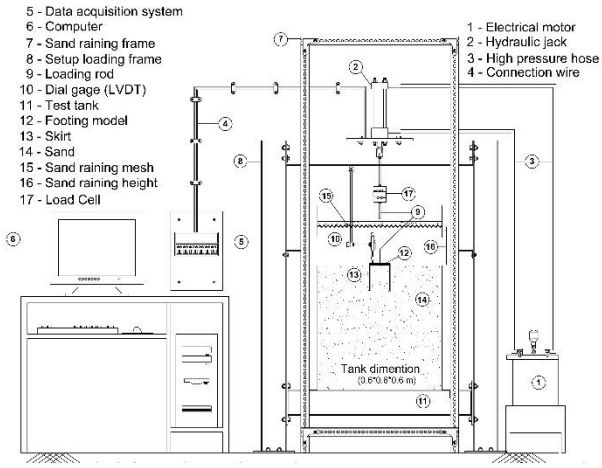

Figure 1. Schematic view of the testing setup

The extensive finite element analysis was carried out using the PLAXIS software to investigate effects of the skirt existence on the behavior of surface foundations resting on sand. Fifteen-node wedge elements were used to simulate elemental mesh. The numerical modeling was carried out on circular foundation models having the diameters (B) of 100, 75 mm for small-scale models and 1, 2, 4 m for large-scale models.

The sand, considered as the foundation soil, was clean medium-grained sand called Firoozkooh sand. The strength properties of sand such as internal friction angles and modulus of elasticity were determined using direct shear and triaxial compression tests (Table1).

4. Results and Discussion

The improvement in bearing capacity of surface foundations was represented using the bearing capacity ratio, $BCR=q_{sk}/q_{su}$, which is defined as the ratio of the bearing capacity of skirted foundation (q_{sk}) to that of surface foundation (q_{su}). To evaluate the behavior of skirted foundation models in terms of settlement, the settlement values of skirted foundation models (s_{sk}), and those of surface foundation models (s_{su}) at an applied stress level equal to 50% of the ultimate bearing capacity of a surface foundation were compared and as a dimensionless parameter like settlement ratio (s_{sk}/s_{su})

[1] PhD in Civil Engineering Department, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran.
[2] Corresponding Author. Assistant Professor in Civil Engineering Department, Faculty of Engineering, Bu-Ali Sina University, Hamedan, Iran.
Email: makarchian@basu.ac.ir

which is defined as settlement reduction factor ($SRF=s_{sk}/s_{su}$), was considered.

Table 1. Material properties used in the numerical analysis

Parameter	Soil (there sand type)	Surface foundation and skirt (steel)	Semi-deep and embedded foundation (concrete)
Stress-strain model	Hardening	Linear elastic	Linear elastic
Unit weight (kN/m^3)	15.9-16.3-16.6	78	22
Poisson's ratio	0.3	0.3	0.2
Young's modulus (MN/m^2)	16-21-24	2.1e5	2e4
Peak friction angle (degrees)	38-41-43	-	-
Dilatancy angle (degrees)	8-11-13	-	-
Interface strength factor	-	0.6-0.9	0.6-0.9

Variation in the bearing capacity ratio, in terms of skirt depth ratio (Figure 2) showed that soil confinement due to skirt existence leads to a significant improvement in the bearing capacity of surface foundations regardless of different parameters. The enhancement in *BCR* values increases with increasing *D/B*. Analysis of the findings showed that skirt inclusion beneath a surface foundation increases the bearing capacity by a factor about 1.73 for *D/B* of 0.5 and 4.95 for *D/B* of 2.0, without considering the side roughness and sand density. The obtained results indicate a 500% improvement in the performance of surface foundation in terms of bearing capacity.

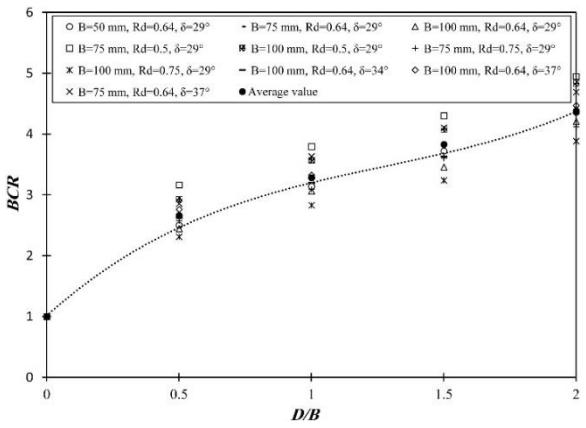

Figure 2. Variations in the BCR in terms of *D/B*

Variations of settlement ratio values against the skirt depth ratios showed that skirt inclusion remarkably reduces the settlement of shallow foundations. Such settlement reduction is directly proportional to the *D/B* values. Based on the results analysis as shown in Figure 3, values of settlement reduction factor of skirted foundation models obtained in the range of 0.08-0.64, so that reflects a minimum settlement reduction 36% for *D/B* of 0.5 and a maximum settlement reduction 92% for *D/B* of 2.

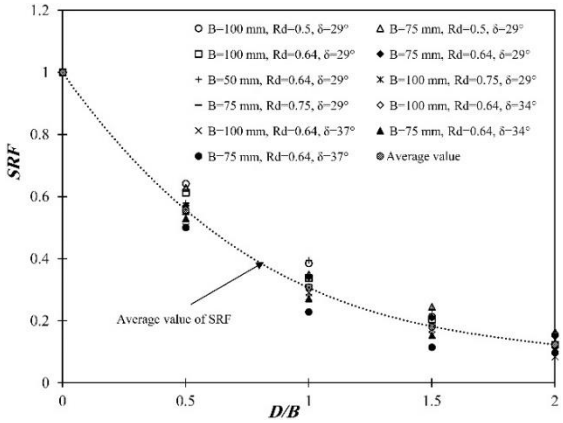

Figure 3. Values of SRF against the skirt depth ratios (*D/B*)

Variations in the values of bearing capacity ratio in terms of R_d, shows that more efficiency in increasing bearing capacity and decreasing settlement of the shallow foundations due to the skirt existence is obtained in the case of sand with low relative density. Therefore, using the skirt to improve the performance of surface foundations in the soils with low shear strength is more preferable.

5. Conclusion

Considering the conditions and parameters considered in this investigation, the following conclusions can be drawn:

- Sand lateral confinement due to the existence of skirts beneath the shallow foundations resting on sand leads to considerable improvement in bearing capacity of shallow foundation models. The magnitude of improvement enhances with increasing the ratio of skirt depth to foundation width. In this study, for small-scale models, the enhancement values of bearing capacity were measured in the range of 2.3 to 4.95, depending on different parameters.
- Using skirts surrounding shallow foundations resting on sand modifies the pressure-settlement behavior and considerably reduces settlement of foundations. The maximum reduction of settlement were measured to be approximately 92%.
- Analysis of the results revealed that the enhancement in bearing capacity values and settlement reduction of skirted foundations increases with increasing side roughness of the foundation models.
- Comparison of the results showed that bearing capacity values of skirted foundations are close to those of semi-deep foundations with the same depth and width.
- Based on the results, charts were developed to estimate the bearing capacity improvement and settlement reduction of skirted foundations resting on sand in terms of different parameters studied in this research.