Amirkabir Journal of Civil Engineering

Amirkabir J. Civil Eng., 53(5) (2021) 411-414
DOI: 10.22060/ceej.2020.17159.6479

Evaluation Behavior of Circular Footings Located on Sand Bed Reinforced with Geocell

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ABSTRACT: The rigid base proximity (such as stiff rock) under a relatively thin sand stratum and employing a 3D reinforcement (e.g. geocell) can tend to significant improvement in the bearing capacity of shallow footings. In this study, the behavior of circular footings located on unreinforced and geocell-reinforced thin sand layers was investigated. The simultaneous or individual effects of footing dimensions, sand layer thickness, and geocell reinforcement on the bearing capacity and settlement of footing were studied by conducting large-scale model tests. The influence of soil layer thickness on footing behavior was elucidated by considering optimum dimensions and location for geocell reinforcement. Based on the results, improvement in the bearing capacity and settlement reduction for both unreinforced and reinforced footing beds were observed when the sand layer thickness is lower than two times the footing width. Additionally, the effective depth of the rigid base for both cases was obtained two times of footing width. The combination of geocell-reinforcement and rigid base as lateral and vertical confinement factors led to an increase in the bearing capacity and settlement reduction at the failure point up to 45% and 53%, respectively. The test's results were served to define new factors extending classical bearing capacity equations for footings located on thin soil at reinforced and unreinforced cases. The comparison of results with the previous investigations confirmed their good agreement.

Review History:

Received: Oct. 05, 2019
Revised: Jan. 21, 2020
Accepted: Jan. 22, 2020
Available Online: Jan. 29, 2020

Keywords:

Circular Footing
Bearing Capacity
Sand
Rigid Base
Geocell

1- Introduction

First-generation bearing capacity equations such as by Terzaghi require modifications for boundary and reinforcement effects. Soil reinforcement or replacement may be used for the footings when the soil is of poor quality. Geocell reinforcement, especially in the sand has been proved to increase bearing capacity and stability of footings significantly [1-7]. Geocell as a 3D reinforcement makes lateral and vertical confinements and prevents soil lateral movement beneath the footing. The proximity of a rigid base near a shallow foundation influences the failure mechanism, vertical confinement under the footing, bearing capacity, and settlement [8-13]. Previous studies showed that footing bearing capacity factors are a function of layer thickness to footing width (*H/B*) and soil friction angle (φ). The influence of rigid base or geocell-reinforcement on the footing behavior has been investigated in the literature individually but the simultaneous effects of these two confinements have been not studied. In this study, some laboratory large-scale model tests in the presence/absence of the rigid base and geocell reinforcement are performed. Based on the results new dimensionless factors are defined to extend classical relationships for determining footing bearing capacity in the presence of geocell and/or rigid base. In this study, to estimate the bearing capacity of shallow foundation on the sand in the presence of geocell reinforcement and rigid base, the following equation is suggested:

$$q_{ult} = 0.3\gamma B N_\gamma^* R_\gamma = 0.3\gamma B R_\gamma K_\gamma N_\gamma \quad (1)$$

where γ= soil unit weight, B= footing width, N_γ^*= bearing capacity factor, K_γ= correction factor, R_γ^*= reinforcement factor.

2- Methodology

Poorly graded sand with average grain size 0.25 mm, friction angle 36° at 68% relative density was used and geocell characteristics are given in Table 1. The mechanical properties of sand and geocell, sand classification were examined according to ASTM standards.

Plate load tests were performed in a large box on a geocell-reinforced and unreinforced sand layer. A square test box with 2400×2400 mm plan dimensions and 1400 mm height was used to house all test components. The box was made of

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Table 1. Geocell characteristics

Geocell properties	Values
Geocell material	Polyethylene
Size of cell, (mm)	250×210
Height of cell, (mm)	150
Thickness of Strip, (mm)	1.5
Density, (gr/cm^3)	0.94
Short term yield resistance, (kN/m)	21
Elastic modulus, (MPa)	270
Equivalent cell diameters, *d* (mm)	183

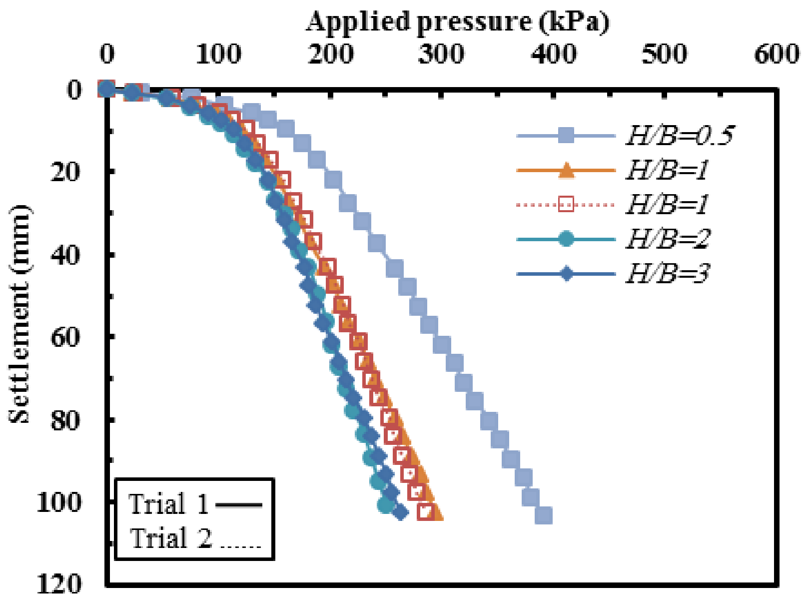

Fig. 1. Pressure-settlement curves on unreinforced sand at different H/B values

steel plates with rigid construction. The floor of the box was fabricated from rough concrete. The box was connected to the rigid loading frame with a manually operated hydraulic jack. A circular steel plate with 30 mm thickness and 400 mm diameter was used. This diameter is approximate twice the equivalent diameter of one cell pocket of the geocell reinforcement and all the cell walls are covered completely by footing edges. The bottom of the rigid footing is glued with rough sandpaper. During loading, the load remained perfectly and centrally vertical. The load was transmitted to the footing via the rigid frame. To measure the displacement magnitude of the footing, two Linear Variable Differential Transformers (LVDTs) jointed to the data logger were employed diametrically opposite edges of the footing. The Pluviation method was employed to prepare the sand bed and filling the geocell pockets. To ensure uniform condition, the sand test box was filled in 100 mm thick layers. According to prior studies, the efficiency of a single footing on geocell-reinforced sand is optimal when b/B=4 and u/B=0.1, where b and u are geocell width and thickness of sand cover on the geocell, respectively. Therefore, the geocell with dimensions of 1600×1600 mm was placed at a depth of 0.1B. The height (h) and pocket-size (D) values of geocell were h/B=0.38, D/B=0.46. The load data were recorded using a load cell jointed to the data logger. The bearing capacity was defined as the load corresponding to S/B=10%. Four tests were conducted on unreinforced sand (H/B=0.5, 1, 2, 3) and three tests were performed on the geocell-reinforced bed (H/B=1, 2, 3). To verify the repeatability of the test data, two tests were repeated two times resulted in 3-6% deviations in bearing capacity.

3- Results and Discussion

The pressure-settlement data for unreinforced beds are presented in Fig. 1.

As H/B increases, the footing bearing capacity decreases. The decreasing effect of H/B on the bearing capacity is seen at approximately H/B≈2. This value might be considered a limiting value of the rigid boundary effect.

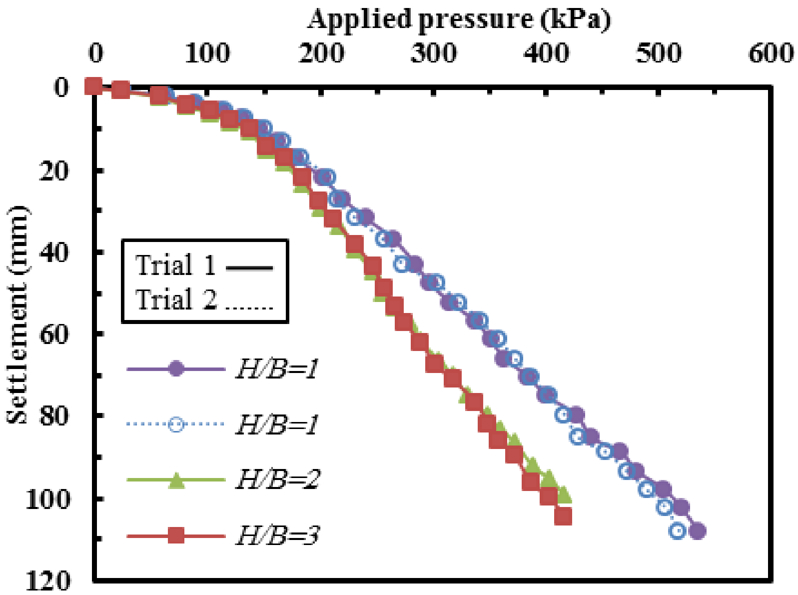

Fig. 2. Pressure-settlement curves on geocell-reinforced sand at different H/B values

Table 2. Summary of laboratory test results

Rein type	H/B	Bearing capacity (kPa)	$N\gamma^*$ or $R_\gamma N_\gamma^*$	K_γ or $R_\gamma K_\gamma$
Unrein.	0.5	251	136	1.46
	1	189	103	1.11
	2	172	93	1
	3	172	93	1
Rein.	1	274	149	1.60
	2	236	128	1.38
	3	236	128	1.38

The pressure-settlement responses for geocell-reinforced beds are shown in Fig. 2. Mostly, with the geocell reinforcement, no well-defined failure point is observed requiring interpolation. The slight reduction noted in pressure-settlement rate is due to distributing footing pressure by the geocell over a larger area and linear behavior of the geocell even at high pressure. As observed in the figure, the critical depth of the rigid base is estimated at approximately H/B=2, noting that the geocell doesn't substantially influence critical depth compared to unreinforced cases.

The variation in bearing capacity factors at different H/B defined in Eq. (1) are presented in Table 2.

4- Conclusion

Some experimental tests were carried out on large-scale circular footings supported by unreinforced and geocell-reinforced sand overlying a rigid base. The effects of rigid base location and geocell reinforcement on the footing pressure-settlement behavior were investigated individually and simultaneously. The following main conclusions may be drawn from the analysis:

- Geocell reinforcement in combination with rigid base in a thin packet of poorly-graded sand can enhance the bearing capacity by around 37 to 45% and improve settlement performance by around 47 to 53% depending on rigid base location compared to the unreinforced infinite medium.
- The critical depth of rigid base for reinforced and unreinforced cases is approximately 2B beyond which, no influence on the bearing capacity was observed.
- The geocell reinforcement effectiveness on the bearing capacity at higher settlement is more than the rigid base. More research however is needed to be more conclusive on footing geometry and sand relative density effects on bearing capacity and settlement.

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HOW TO CITE THIS ARTICLE

P. Fazeli Dehkordi, M. Ghazavi, N. Ganjian, Evaluation Behavior of Circular Footings Located on Sand Bed Reinforced with Geocell. Amirkabir J. Civil Eng., 53 (5) (2021) 411-414

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