Load-settlement response of circular footing resting on reinforced layered system

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ABSTRACT

Removal of unsuitable soil and replacement with a strong material is one of the oldest and simplest ground improvement techniques. During this process, a layered soil system with a strong layer overlying a weak layer is achieved. Studies on the load-settlement response of footing on such layered system are limited. An experimental study is carried out to obtain the load-settlement response of a model circular footing resting on (a) unreinforced aggregate layer overlying a sandy soil layer, and (b) geogrid-reinforced aggregate layer overlying a sandy soil layer. A large-scale test chamber of size equal to 1m x 1m x 1m is used to perform the experiments. Actuator of 10T capacity is used to apply the loads in a displacement-rate controlled mode. A plate vibrator is used to prepare uniform sand and aggregate layers inside the test chamber. Relative density equal to 70% is maintained for both the layers during the entire test program. The improvement in the load carrying capacity of model footing with the increase in the thickness of aggregate layer and with the introduction of geogrid reinforcement in the aggregate layer is proposed in the study.

Keywords: layered soil, aggregates, geogrid, and circular footing

1. INTRODUCTION

Due to non-availability of land, construction over marginal soils has become inevitable and ground improvement techniques have gained prominence in such projects. One of the simplest and oldest ground improvement methods is to excavate marginal soils and replace them with competent material. In places where aggregates are readily available, they can be filled over sand deposits to increase the load carrying capacity of footing. This requires estimation of load carrying capacity of footing resting on a two-layered system. Many experimental and analytical studies are available on reinforcing sand layer with geosynthetic reinforcement (Fragaszy and Lawton (1984), Madhav and Poorooshab (1988), Yetimoglu et al. (1994), Adams et al. (1997), DeMerchant et al. (2002), Basudhar et al. (2007), Phani Kumar et al. (2009), Chen et al. (2009), and Latha and Somwanshi (2009)). However, studies on load carrying capacity of footing on reinforced layered system are limited. Accordingly, an experimental study is undertaken to study the improvement in the load carrying capacity of model circular footing on reinforced layered system (reinforced aggregate layer overlying sand layer) with respect to unreinforced layered system (unreinforced aggregate layer overlying sand layer).

2. MATERIALS USED

Locally available river sand was used for testing. Grain-size distribution, the maximum density, and the minimum density for this sand were obtained according to ASTM D422, ASTM D4253, and ASTM D4254, respectively. The maximum density of sand was obtained using vibratory method and was found to be equal to 1.78 g/cc. Figure 1 shows the grain-size distribution curve of the sand. The coefficient of uniformity, C_u, and the coefficient of curvature, C_c, were equal to 1.89 and 1.13, respectively. It is classified as poorly-graded sand (SP) as per the Unified Soil Classification System (USCS). The morphological features of the particles were obtained using Scanning Electron Microscope (SEM) performed at a magnification of 60x. The shape of the sand particles was found to be sub-angular to angular (Figure 2). To prepare a strong aggregate layer overlying a sand layer, locally available aggregates of average size equal to 6mm were used above the sand layer. Reinforcement consisted of a geogrid (make: NAUE-Secugrid 40/40) with aperture size equal to 30mm x 30mm (Figure 3). Table 1 gives the physical properties of the geogrid.

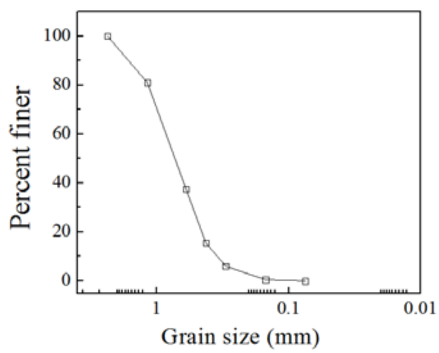


Fig. 1 Grain-size distribution curve of river sand

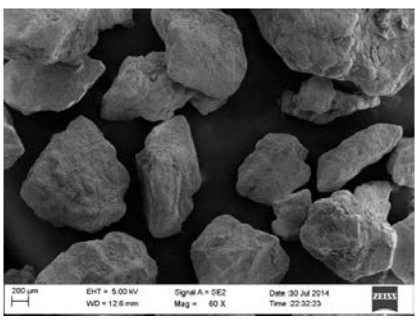


Fig. 2 Morphological features of river sand using SEM

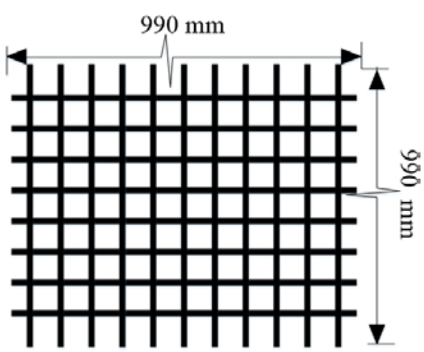


Fig. 3 Schematic diagram of geogrid reinforcement

Table 1. Properties of geogrid reinforcement

Property	Value
Mass per unit area (g/m^2)	240
Maximum tensile strength, md/cmd* (kN/m)	≥40 / ≥40
Tensile strength at 2% elongation, md/cmd* (kN/m)	16/16
Tensile strength at 5% elongation, md/cmd* (kN/m)	32/32

**md=machine direction, cmd=cross machine direction*

3. EXPERIMENTAL TEST SET-UP

In this study, a large-size test chamber with dimensions equal to 1m x 1m x 1m was used to study the load-settlement behavior of model circular footing with diameter and thickness equal to 150mm and 30mm, respectively. Load was applied using a computer-controlled, servo hydraulic actuator of 10T capacity. The loading system consisted of a hydraulic power unit (HPU), and a hydraulic service manifold (HSM). The actuator was attached to a reaction frame with a clearance height equal to 3.5m (refer Figure 4).

Fig. 4 Photograph of the test frame

4. PREPARATION OF SAND BED

A pneumatically-operated, impact-type piston vibrator manufactured by NAVCO *(Model: BH-2 IGO)* was used to compact the sand beds to a desired relative density. The vibrator was connected to a pressure source through a pressure line, and a square steel plate (300 mm in length, 300 mm in width, and 10 mm in thickness) was attached to the bottom of the compactor to facilitate compaction of the samples inside the test chamber. The weight of vibrator with the steel plate was about 18 kg. The sand bed was compacted in layers by traversing the vibrator over the sand bed to achieve a target relative density, RD, equal to 70%. Compaction of sand layer was done in four layers of 200mm thickness. This method of sample preparation was found to produce uniform sand samples inside the test tank. A straight edge was used to level the top surface of the sand bed, and aggregate layer was placed on top of it. The compaction of aggregates was carried out by placing the aggregates in 50-mm thick layers, and compacted to a relative density equal to 70%.

5. TEST PROGRAM

Figure 5 shows the schematic view of reinforced layered system. The thickness of top aggregate layer (H_1) was varied from 0.33B-to-1.0B, where B is the diameter of the model footing. For the case of reinforced aggregate layer, the depth of geogrid reinforcement, d_r, was varied from 0.3B-to-0.6B. Tests were performed under displacement-controlled mode with a rate of 1mm/minute, and the load carrying capacity of model circular footing are obtained for the following test cases with footing on -

a) Sand only
b) Unreinforced aggregate layer overlying a sandy soil for various thickness ratios of aggregate layer (H_1/B = 0.33, 0.66, and 1.0)
c) Geogrid-reinforced aggregate layer overlying a sandy soil for various depth ratios of reinforcement placement (d_r/B = 0.3, 0.45 and 0.6) for the case of H_1= 100mm

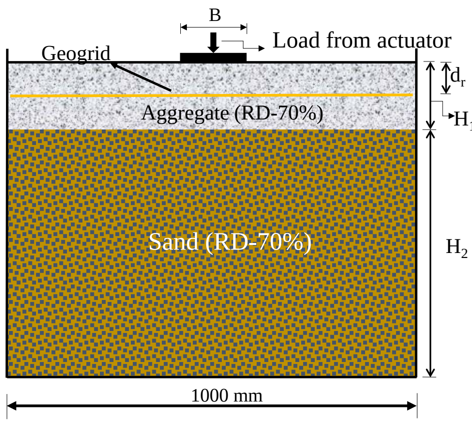


Fig. 5 Schematic view of the test bed

6. RESULTS AND DISCUSSIONS

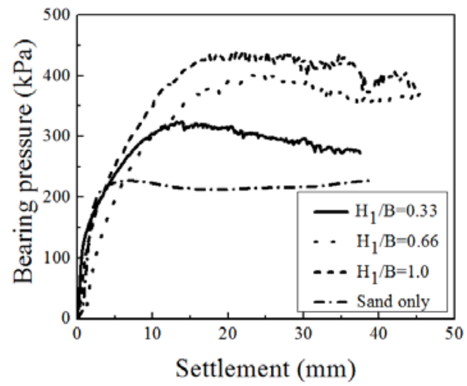
Load improvement factors are obtained for unreinforced and reinforced layered system corresponding to various settlement ratios. Load improvement factor (I_f) is defined as

$$I_f = q_r/q_o \quad (1)$$

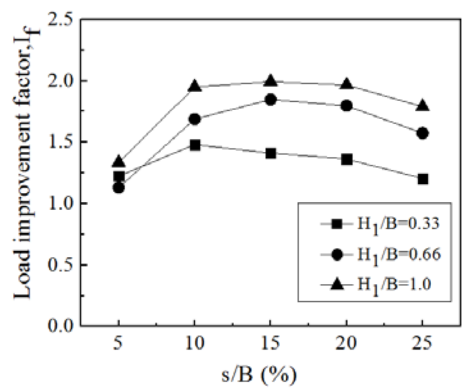
where, q_r is the bearing pressure under the footing resting on unreinforced or reinforced layered system at a given settlement, and q_o is the bearing pressure under the footing resting on sand at the same footing settlement.

6.1 Effect of thickness of aggregate layer overlying sand layer

Figure 6(a) shows the bearing pressure versus settlement for footing on sand only and on layered system for various thicknesses of aggregate layer (H_1/B = 0.33, 0.66, and 1.0). Bearing pressure-settlement plots show a peak behavior followed by a plateau. For the case of footing on sand only, peak behavior was observed for settlement of footing in the range 5-to-7mm. While, for aggregate layer overlying a sand layer, the peak behavior was observed at larger settlements in the range of 10-to-15mm. For settlement ratio (s/B) equal to 10%, the bearing pressure increased by 48%, 69% and 95% for H_1/B ratios equal to 0.33, 0.66 and 1.0 compared to that for sand only. Figure 6(b) shows the variation of load improvement factors with the settlement ratios.



(a)

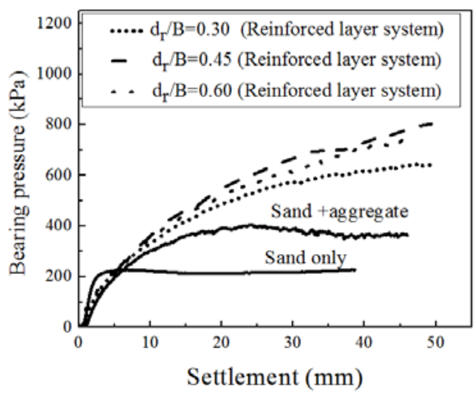


(b)

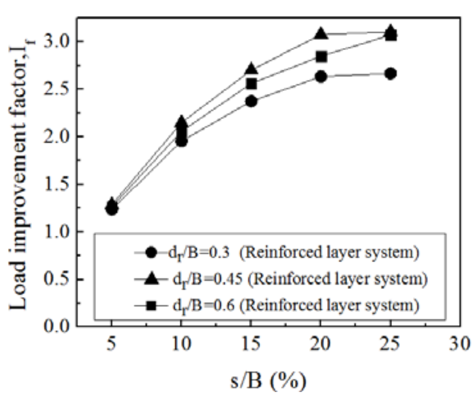
Fig.6 Effect of aggregate thickness- (a) variation of bearing pressure with settlements, and (b) variation of load improvement factor with settlement ratio

6.2 Effect of depth of reinforcement in aggregate-reinforced sand

Figure 7(a) shows the bearing pressure versus settlement for various depths of placement of reinforcement in the aggregate layer. For a given footing settlement, the bearing pressure increases as d_r/B ratio increases from 0.3 to 0.45. With further increase in d_r/B ratio from 0.45 to 0.6, the bearing pressure decreases. The resistance offered by the geogrid reinforcement will be mainly due to the interlocking of aggregate particles within the apertures of geogrid. Load improvement factors, I_f, at different s/B ratios for d_r/B=0.3, 0.45, and 0.6 are proposed in Figure 7(b). The optimum depth of reinforcement is found to be equal to 0.45 times the width of the model footing. The optimum depth from this study is found to be in agreement with the studies reported in the literature. Raymond and Ismail (2003) performed tests by varying the depth of reinforcement in aggregate layer, and reported that the optimum depth of reinforcement is equal to 0.5 times the width of the footing. DeMerchant et al. (2002) performed plate load tests on reinforced aggregate and reported that the bearing pressure decreased beyond optimum depth of placement of reinforcement, as was observed in the present study.



(a)



(b)

Fig.7: Effect of depth of placement of reinforcement for H_1/B=0.66- (a) variation of bearing pressure with settlement, and (b) variation of load improvement factor with settlement ratios

7. CONCLUSIONS

- The improvement in the load carrying capacity of model footing with the increase in the thickness of aggregate layer and with the introduction of geogrid reinforcement in the aggregate layer is proposed in the study.
- The bearing pressure for the case of aggregate-sand layered system increases by 48%, 69%, and 95% compared to the bearing pressure for the case of sand only for aggregate thickness ratios (H_1/B) equal to 0.33, 0.66 and 1.0, respectively, for settlement ratio equal to 10%.
- The optimum depth of reinforcement in aggregate layer is found to be 0.45 times the width of the footing. The inclusion of geogrid at d_r/B=0.45 in aggregate gives 22% improvement in the load factor compared to that for d_r/B=0.3 corresponding to s/B ratio equal to 10%.

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