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Use of Reinforced Soil Foundation (RSF) to Support Shallow Foundation

Introduction

The presence of a weak soil supporting structural foundations results in low load bearing capacity and excessive settlements, which can cause structural damage, reduction in durability, and/or deterioration in performance level. Conventional treatment methods replace part of the weak cohesive soil with an adequately thick layer of stronger granular fill, increase the dimensions of the footing, or combine both methods. However, an alternative and more economical solution uses geosynthetics to reinforce soils, which can be done by either reinforcing cohesive soil directly or replacing poor soils with stronger granular fill in combination with the inclusion of geosynthetics. The resulting composite zone (reinforced soil mass) will improve the load carrying capacity of the footing and provide better pressure distribution on top of underlying weak soils, reducing associated settlements.

Benefits of including reinforcements within soil mass to increase the bearing capacity and reduce the settlement of soil foundation have been widely recognized. Many hypotheses have been postulated about the failure mode of reinforced soil foundation (RSF). However, the failure mechanism of reinforcement is still not fully understood in RSF as compared to other reinforced soil applications. Therefore, it is important to investigate the reinforcement mechanism of reinforcing soils for foundation applications.

Objective

The main objective of this research study is to investigate potential benefits of using the reinforced soil foundations to improve the bearing capacity and to reduce the settlement of shallow foundations on soils. This includes examining influences of different variables and parameters contributing to the improved performance of RSF, investigating the stress distribution in soil mass and the strain distribution along reinforcements, and developing analytical solutions for the design of reinforced soil foundations.

Scope

This research project included conducting small-scale laboratory model footing tests on silty clay soil, sandy soil, and crushed limestone in addition to large-scale field tests on silty clay soil. The model footings used in the laboratory tests were 1-in. thick steel plates with dimensions of 6 in. × 6 in. and 6 in. × 10 in. The model footing used in the field tests was 8-in. thick; reinforced precast concrete blocks with dimensions of 1.5 ft. × 1.5 ft. were proposed to calculate the bearing capacity of RSF for different soil types. The parameters investigated in these tests included (1) top layer spacing (*u*), (2) the number of reinforcement layers (*N*), (3) total depth of reinforcement (*d*), (4) vertical spacing between reinforcement layers (*h*), (5) the type and stiffness of reinforcement, and (6) the embedment of the footing (*Df*).

LTRC Report 423

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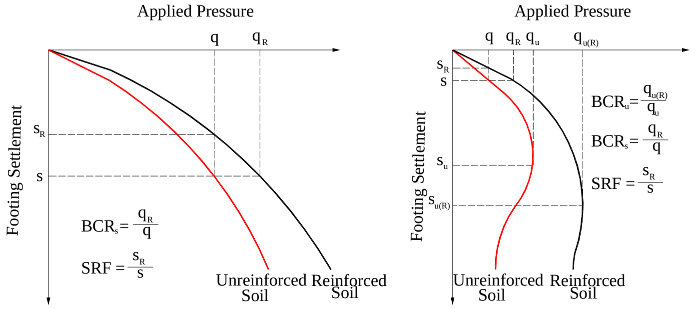
Methodology

Small- and large-scale model footing tests were conducted on three soil types (sand, silty clay, and crushed limestone) and reinforced using nine types of geosynthetics (eight geogrid types and one geotextile type), one type of steel wire mesh, and one type of steel bar mesh.

The laboratory model footing tests were conducted inside a steel box with dimensions of 5 ft. (length) × 3 ft. (width) × 3 ft. (height). The model footings used in the tests were 1 in. thick steel plates with dimensions of 6 in. × 6 in. The footings were loaded with a hydraulic jack against a reaction steel frame. The testing procedure was performed according to ASTM D 1196-93. The load and corresponding footing settlement for unreinforced and reinforced soils were measured using a ring load cell and two dial gauges, respectively. The test sections were instrumented with earth pressure cells to measure the vertical stress distribution in the soil and electrical resistance strain gauges to measure the distribution along the reinforcement.

A total of six large-scale model footing tests were performed in an outdoor test pit constructed next to the Louisiana Transportation and Research Center (LTRC) building. The test pit has a dimension of 12 ft. (length) × 12 ft.(width) × 6 ft. (height). The load was applied on the footing by a hydraulic jack supported against a steel beam-piles reaction frame. A load cell was used to measure the applied load. The settlement was measured using dial gauges mounted on reference beams. The model footing used in the field tests was 8-in. thick, reinforced 1.5 ft. × 1.5 ft. concrete blocks. The soil selected for large-scale model tests was silty clay soil. Large-scale tests were performed according to ASTM D 1196-93.

Benefits of RSF were evaluated using two terms: (1) the bearing capacity ratio (BCR), which is defined as the ratio of the bearing capacity of RSF to that of the unreinforced, and (2) the settlement reduction factor (SRF), which is defined as the ratio of the settlement of RSF to that of the unreinforced. Two different types of load-settlement behavior were observed. For the first type of load-settlement curve as shown in Figure 1a, the failure point is not well defined. Benefits of RSF were then evaluated in terms of BCR at a specific settlement (BCR_s) and RSF at a specific surface pressure. Figure 1b depicts the second type of load-settlement curve that has a well-defined failure point. For this type of load-settlement behavior, BCR at a specific settlement (BCR_s), BCR at the ultimate bearing capacity (BCR_u), and SRF at a specific surface pressure were used to evaluate the improved performance of RSF.



(a) **(b)**

Figure 1
Definitions of BCR and SRF

Conclusions

- The optimum location of the first reinforcement layer was estimated to be at 0.33*B* below the footing, where *B* is the width of footing.
- The influence depth of reinforcement was found to be at approximately 1.5*B* below the footing.
- The effective length of geogrid reinforcement is about 5.0*B*. BCR values increase with an increasing geogrid tensile modulus and with decreasing the vertical spacing of reinforcement layers. Improvements in BCR values ranged from 1.5 to 3.
- The inclusion of reinforcement will redistribute the applied load to a wider area, thus minimizing stress concentration underneath footing. This will help reduce the total consolidation settlement of underlying weak soils.
- Stability analyses were conducted to evaluate the contribution of reinforcement in terms of the increase in soils' bearing capacity, and new models were developed for RSFs of three soil types. The proposed models provide good predictions of laboratory and field test results of this study and previous research studies.

Recommendations

Based on extensive laboratory and field model footing tests, the following step-by-step procedure is recommended for the design of reinforced soil foundations.

1. Assume the footing width, *B*.
2. Determine the bearing pressure along the bottom of a shallow foundation, *q*.
3. Select the geogrid with specific tensile modulus (*J*). Typical design parameters for reinforcement layout are recommended in Table 1.
4. Determine the possible failure mode of reinforced soil foundation based on the soil type in the field.
5. Determine the tensile forces, T_i, developed in reinforcement layers using methods proposed in this study.
6. Calculate the ultimate bearing capacity of unreinforced soil foundation, $q_{u(UR)}$.
7. Calculate the ultimate bearing capacity of reinforced soil foundation, $q_{u®}$, using the proper equation for soil type.
8. Calculate the allowable bearing capacity of reinforced soil foundation, $q_{a(R)} = q_{u(R)}/F.S.$, where *F.S.* is the factor of safety.
9. If the allowable bearing capacity of reinforced soil foundation, $q_{a(R)}$, is lower than the bearing pressure, *q*, repeat steps (1) through (7) for a different reinforcement layout.

Table 1
Recommended design parameters for reinforcement layout

Parameter	Typical value	Recommended
u/B	0.2 ~ 0.5	1/3
h/B	0.2 ~ 0.5	1/3
d/B	1.3 ~ 1.7	1.5
l/B	4 ~ 6	5

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