Response of Footings on Encapsulated Granular Trenches in Clay Soil

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ABSTRACT: With the increasing demand for basic infrastructure and the diminishing availability of land for development, it becomes imperative to use land with weak soils for construction of buildings. Replacement of the parent soil with soil having better properties is the simplest and cheapest method in vogue for strengthening weak soils. To ensure the most efficient use of granular soils, the cross sectional shape and size of the fill which gives optimum enhancement of soil properties for a given quantity of the fill material is required to be found out. In the investigation reported herein, the response of strip footing resting on granular trench encapsulated with geosynthetic is considered. Rectangular and triangular trenches of various sizes were tested. Attempt has been made to bring out the optimum trench dimensions of the encapsulated granular trench for the given footing configuration. It was concluded from the study that for a given volume of soil used as refill material, the rectangular shape is more efficient than the triangular shape in reducing the settlements.

1 INTRODUCTION

Diminishing availability of land has restrained the choice of type of foundation to deep foundations especially in weak and filled up soils. Although use of deep foundations will result in viable alternatives in case of multi-storeyed commercial buildings, the high cost of foundation will affect the viability of residential buildings especially low-rise flats and apartments. This has obviated the necessity for design of alternate methods for strengthening of the existing poor quality soils to bring down the cost of foundation. Replacement of the poor quality soil by soil having better strength parameter is an effective solution for soil problems.

In the current study an attempt is being made to examine the improvement in the performance of a strip footing supported on granular trench in a soft soil deposit. Granular trench (GT) is a two dimensional plane strain variant of stone column. An encapsulated granular trench (EGT) is formed by wrapping a geosynthetic around the granular trench. Numerical simulations are carried out to find the improvement in the soil properties due to the adopted techniques. Large number of attempts have been made to understand the behaviour of granular trench in clay. From the studies conducted by Madhav et al (1978) it has been found that a granular trench significantly reinforces weak clay deposits. Further studies by Das (1988) shows that the bearing capacity increases with the increase of the depth of the granular trench to a maximum value and remains constant thereafter. Studies were conducted by Unnikrishnan et al (2010) on the influence of providing a granular trench below strip footings on loose sand deposits. The investigations by Unnikrishnan (2011) revealed the additional benefit of encapsulating such a granular trench with a geosynthetic.

2 MATERIALS USED

The materials used in the study were fine grained soil, river sand and geosynthetics. The cohesive bulk soil used in the model tests was collected from the Kuttanad region and is identified as inorganic silt of low compressibility according to the unified soil classification system. Properties of the bulk soil are given in Table 1.

Table 1. Properties of soft soil

Properties	Values
Specific gravity	2.58
Liquid limit (%)	49
Plastic limit (%)	34
Plasticity index (%)	15
Clay content (%)	22
Silt content (%)	49

The replacement sand used in the study was river sand. Granular trenches were placed in layers by raining technique where sand is allowed to rain through air at a controlled discharge rate and height of fall. Based on several trials, a fall height of 25cm was chosen. The raining technique adopted in the study provided a uniform relative density of approximately 35% with a unit weight of 16.9 kN/m^3. Properties of the replacement sand are given in Table 2.

Table 2. Properties of river sand (Replacement Sand)

Properties	Values
Specific gravity	2.65
Effective particle size (D_{10})	0.50
Mean particle size (D_{50})	1.90
Minimum density (kN/m^3)	14.35
Maximum density (kN/m^3)	17.65
Uniformity coefficient	4
Coefficient of curvature	2.56

Two different types of geosynthetics were used to encase the granular trench in the present study. The properties of these geosynthetics are listed in Table 3.

Table 3. Properties of geotextiles

Properties	Grid 1	Grid 2
Mass per unit area (g/m^2)	240	265
Thickness (mm)	1	5
Opening size (mm)	Diamond 2 x 2	Square 3.7 x 3.7
Ultimate tensile strength (kN/m)	1.2	11.35

3 METHODOLOGY

Plate load tests were conducted in the lab on soft soil with and without granular trench and the load settlement graphs were plotted. The behaviour of the footings in fine grained soils after provision of granular trenches of rectangular and triangular cross sections of different proportions were analysed using PLAXIS software and the optimum shape and its proportions were arrived at from the theoretical analysis. The theoretical analysis obtained was validated with the lab results to verify the same.

The tests were conducted in three series. Series I consisted of testing footings on the surface of natural soft soil deposit. Series II and III were performed on the footings resting on granular trenches of optimum dimensions as obtained from PLAXIS with and without geogrid reinforcement respectively.

4 EXPERIMENTAL SET UP

Model tests were carried out to study the behaviour of footing with partial replacement of parent soft soil with river sand. The test setup consists of a steel tank having inside dimensions of 0.75 x 0.75 x 0.75m and a reaction load set-up. The loading system consists of a hand-operated hydraulic jack and a proving ring. A model strip footing made of steel plates having a width of 0.138m was used. Two dial gauges of least count 0.01mm were used to monitor the settlements. In order to record the load applied, a proving ring of 20kN capacity is used.

Initially soft soil was soaked and was mixed thoroughly. A 10cm thick layer of sand was provided at the base of the tank to facilitate drainage. The tank was perforated near the bottom edges to allow free movement of water. Soft clayey soil layer was then placed up to the full height. The layer was pre-loaded to accelerate consolidation. Water content and the consistency of soft soil were monitored continuously. The preload was removed on achieving necessary shear strength. The consistency was thereafter maintained for all the tests.

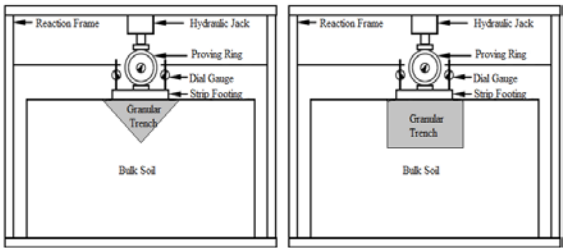

Fig. 1 Schematic diagram of experimental set up

5 FINITE ELEMENT ANALYSIS

Two dimensional plane strain finite element analyses were carried out using PLAXIS software. Fifteen noded triangular elements were chosen to model the soil and the footing. In order to account for the size effect, the analysis was carried out in a boundary of size 4mx4m for undrained conditions. Here the bulk soil, sand and footing were modelled using Mohr Coulomb model, Hardening Soil model and Linear Elastic model, respectively. The input parameters in PLAXIS software are listed in Table 4.

Table 4. Material parameters used in the numerical analysis

Input Parameters	Soft Soil	Sand	Footing
E_{50}^{ref} (kN/m^2)	60	40000	2.1 x 10^8
E_{ode}^{ref} (kN/m^2)		30000	
E_{ur}^{ref} (kN/m^2)		80000	
Cohesion (c) (kN/m^2)	1.5	1	
Friction angle (φ)	5.2	44	
Soil unit weight (kN/m^3)	14.8	16.9	
Poisson's ratio	0.35	0.3	

6 RESULTS AND DISCUSSIONS

For the purpose of comparison of the performance of various configurations of shapes and proportions, a non dimensional factor termed Bearing Capacity Ratio (BCR) is being used. It is defined as the ratio of the ultimate load taken by the granular trench supported footing (q_r) and that of the footing without trench (q):

$$BCR = q_r / q$$

6.1 *Effect of width of the trench*

In order to study the influence of width of the trench, the depth of the trench was kept constant and the width was varied. Analyses were performed for both triangular and rectangular trenches. Depth of the trench was maintained at 20 cm. Fig. 2 shows the variation of BCR with the normalised width in the case of triangular trench.

Normalised width is the ratio of width of trench (B_T) to the footing width (B_F). It can be seen that beyond a width of 2.5 times the footing width, the rate of improvement of load carrying capacity of the footing on the granular trench decreases. A similar pattern was observed in the case of rectangular trench as shown in the Fig. 3. Also the BCR of the footings on EGT is slightly more when compared with those on the GT.

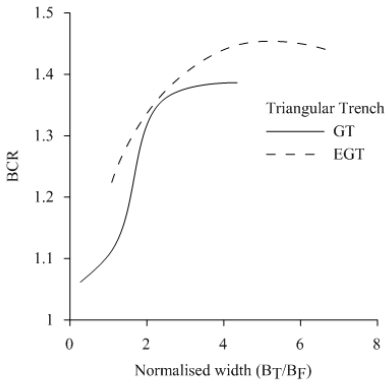

Fig. 2 BCR Vs Normalised width for triangular trench with encapsulation and without encapsulation (FEA)

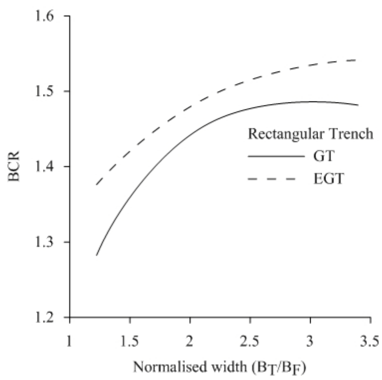

Fig. 3 BCR Vs Normalised width for rectangular trench with encapsulation and without encapsulation (FEA)

6.2 *Effect of depth of the trench*

The depth of fill was varied keeping the width constant. Comparison is made based on dimensionless variable. Figs. 4 and 5 shows the variation of BCR with the normalised depth in the case of triangular and rectangular trench. Normalised depth is the ratio of depth of trench (D_T) to the footing width (B_F). The width of the fill was kept constant at 15cm. Fig. 5 shows a steady increase in the load carrying capacity with increase in depth of fill. The same trend was observed for encapsulated trenches in both triangular and rectangular cases. It is also seen that the rate of increase of strength decreases with increase in the normalised depth.

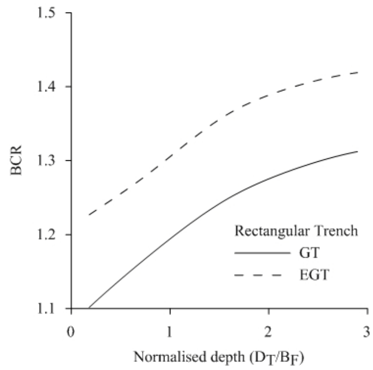

Fig. 4 BCR Vs Normalised depth for rectangular trench with and without encapsulation (FEA)

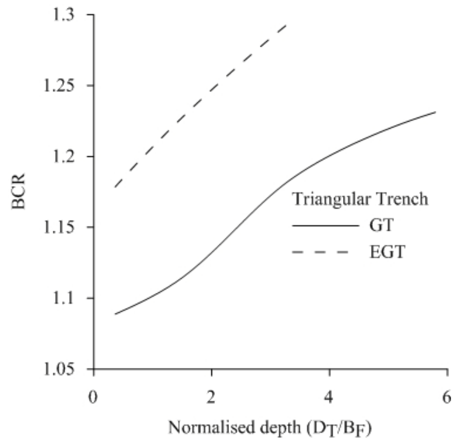

Fig. 5 BCR Vs Normalised depth for triangular trench with and without encapsulation (FEA)

6.3 *Effect of stiffness of the geosynthetic*

The load carrying capacity was worked out for various stiffness values of the encapsulating geosynthetic. The variation shown in the Fig. 6 indicates an increase in strength with increase in the stiffness of the geosynthetic and implies that for getting cost effective solution, the stiffness has to be chosen at the optimum level.

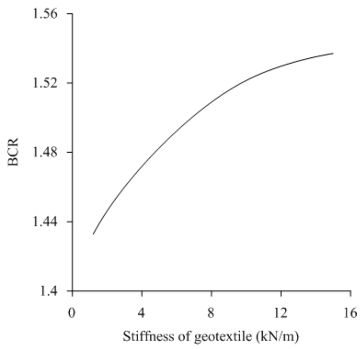

Fig. 6 BCR Vs stiffness of geotextile (FEA)

6.4 *Effect of shape of the trench*

A cost effective solution for granular refill is obtained when the increase in the strength is maximum for a given volume of refill material. To compare the efficiencies of rectangular and triangular shape for refill, increase in load carrying capacity has been worked out for both shapes for a given volume. Fig. 7 shows that the increase in the load carrying capacity is more for rectangular shape than for triangular shape for a given volume of refill. Thus it can be inferred that rectangular shape is more efficient than triangular one for achieving increase in strength with granular refill.

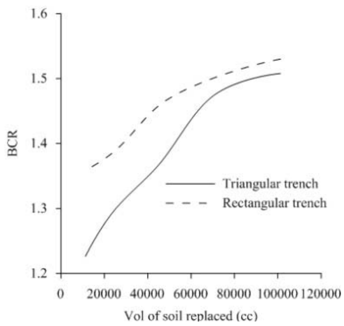

Fig. 7 BCR Vs volume of soil replaced for triangular trench and rectangular trench (FEA)

6.5 *Experimental Results*

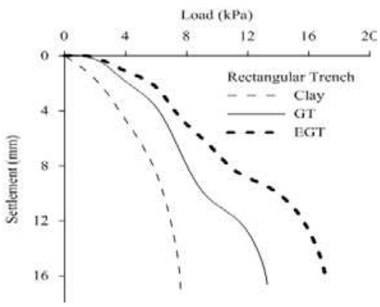

Fig. 8 Load settlement behaviour of rectangular trench with and without encapsulation

Fig. 8 shows that for a given load, a rectangular trench without encapsulation decreases the settlement by 57%. In the case of encapsulated rectangular trench, the decrease in settlement is up to 75%. Thus granular refill improves the settlement behaviour. Encapsulation of the trench further improves the settlement characteristics. However it can be seen that the percentage incremental decrease in settlement due to encapsulation is less than that for ordinary refill.

7 CONCLUSIONS

Provision of granular trenches below the strip footing improves the load carrying capacity. For a given volume of soil used as refill material, the rectangular shape is more efficient than the triangular shape in reducing the settlements. The efficiency of rectangular and triangular fills depends on the geometric proportions of these shapes. In case of rectangular trench, the optimum increase in the load carrying capacity is obtained when the width of trench is twice the width of foundation. In case of triangular trenches, the optimum width of trench was found to be 2.5 times the width of the footing. Provision of geosynthetic encapsulation improves the load carrying capacity for a given settlement. However, in all cases the additional improvement obtained by encapsulation was marginal. This is because, the inherent weakness of the bulk material predominates the macro behaviour. With increase in stiffness of geosynthetic used for encapsulation, the settlement decreases. However the rate of such decrease of settlement decreases beyond an optimum value of stiffness.

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