Performance of Geogrid Reinforcement on Load Carrying Capacity of Stabilized Soil Slope

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Abstract: Central zone of India is mostly covered with black cotton soil which is having very poor strengthening properties in terms of load-carrying capacity. Such soil needs proper treatment to be used for the construction of highway em- bankments or steep slopes. The current paper shows the effect of the insertion of geogrid reinforcement on the load-carrying capacity of a strip footing constructedon a steep stabilized soil slope. A number of laboratory model tests including un- reinforced cases were performed by various parameters such as the number of geogrid layers, vertical spacing, and depth to the topmost layer of geogrid reinforcement. Laboratory model test results will then be analyzed to observe the re- lationships between the load-carrying capacity and the varying reinforcement pa-rameters. It is expected that the load-carrying capacity of strip footings on stabi- lized soil slopes can be improvised by the insertion of reinforcement sheets in the slope. Based on the test parameters, it can also be seen that the load-settlement characteristics as well as the bearing capacity of the rigid footing will increase with the insertion of a reinforcement layer at the proper position in the fill slope.
Keywords: Embankments, Geogrid, Bearing capacity, Reinforcement.

1. Introduction:

Nowadays, Reinforced soil slopes provide cost-effective solutions for new constructions. Reinforced soil slopes are such forms of mechanically stabilized earth that assimilates planar reinforcing elements in constructed earth-sloped structures with much steeper slopes. The primary purpose of using reinforcement in engineering slopes is to enhance the stability, load carrying capacity of the slope and to provide a better compactive surface at the edges of a slope, thus decreasing the tendency for surface failure. Based on the detailed literature study it can be indicated that the problem of the behavior of a footing located in the vicinity of the crest of a stabilized reinforced slope has received only limited attention. The available literature provides a wide range of information only for a single or double layer of reinforcement that too in sand or fly ash-filled slopes. The experimental work on strengthening the load-carrying capacity and reducing the corresponding settlement for clayey soil slope is very scanty. Hence in order to have a better understanding and to add information in this regard, an attempt has been made to carryout experimental study for the effect of various parameters of stabilized reinforced earth slope on bearing capacity and settlement characteristic of footing. A strip footing subjected to central vertical load, placed on an unreinforced and reinforced earth slope has been used in model tests. For this, tests in plain strain condition on an 80mm × 450mm size footing on unreinforced unstabilized, unreinforced stabilized, and reinforced stabilized soil slopes were performed for the central vertical load. Tests planned on biaxial geogrids were conducted by varying the distance of footing to the edge of the slope at the top surface, the depth of the top reinforcement layer from the base of footing, and vertical spacing between reinforcement. The results obtained from model tests have been verified by the available literature.

2. Review of Literature

Mittal S. et al. [2009][15] investigated the behavior of shallow surface footing on reinforced and unreinforced earth slopes experimentally. The results of the study indicate that the bearing capacity of strip footings on the sloping ground can be increased by incorporating the reinforcement layers in the slope. Gill K.S. et. al. [2013][11] performed a series of tests on unreinforced and reinforced fly ash embankment slope numerically and experimentally. It was observed from the test that edge distance up to 3B and reinforcement layers up to 4 are having a significant impact on load-carrying capacity. Altalhe E. B. [2015][9] et al. conducted several laboratory model tests on strip footing modeled on the reinforced sand slope to evaluate the bearing capacity. Test results shows that the bearing capacity ratio increases from 1.09 to 7.73 for double-reinforced slope and 2 to 8 for triple-reinforced slope. They further concluded that an increase in the bearing capacity depends not only on the geotextile layout but also on the location of footing with respect to the slope face. Nadaf M. B et al. [2016][6] performed a series of laboratory model tests on an unreinforced and reinforced fly ash slope with slope angle 60^0 on a rigid base to check the performance of reinforcement in improving load carrying capacity and stability of the slope. Based on the experimental results they concluded that for all types of reinforcement cases slope with reinforcement length of 0.7H supports maximum for strip loading before failure as compared to UDL type of loading. Nadaf et al. [2019][4] conducted a series of laboratory model tests and numerical simulations on unreinforced and cellular reinforced fly ash slopes under different loading conditions. The results of the fly ash slopes overlaying fly ash bed under strip loading at 5 mm settlement show an increase in load carrying capacity i.e., 1.83 times and 1.81 times the capacity of unreinforced slopes for experimental and FES tests respectively. Whereas under uniformly distributed loading conditions the improvement observed was 1.70 for (experimental) and 1.67 for (FEM) times only. Li-Hui Li et al. [2020][2] performed a series of tests on reinforced retaining walls comprised of different reinforcement materials and layers to determine the deformation characteristics and earth pressure distribution on physical model walls. Based on the experimental results and analysis it was concluded that an increase in the number of reinforcement layers increases the load-carrying capacity of rigid footing by up to 90%. It was also seen that retaining walls reinforced with waste tires exhibit improved deformation resistance as compared with other reinforcement materials. Bhat Tahir et al. [2021][1] summarized the results of a series of numerical analyses to determine the effect of the use of fly ash as fill material placed over an earthen slope using the program PLAXIS-2D v 8.2, multiple types of tests were carried out to study the impact of geogrid-reinforcement layers on load carrying capacity of strip footing. The results of the study indicated that the strength and loading capacity of soft clay soil present on slopes or under foundations can be significantly enhanced when partial replaced by fly-ash layer. It also evidently shown that use of geogrid as a reinforcement in the substituted fly-ash layer not only increases the load-carrying capacity but also decreases the depth of the replaced fly-ash over a soft clay layer.

3. Experimental Study

Clayey Soil

For model study black cotton soil was used for the construction of reinforced stabilized soil slope. The soil was collected from the campus of Government college of engineering Amravati and shown in Figure 1. Laboratory properties of test soil is shown in Table No. 1.

Figure 1. Clayey Soil used in Experimental Investigations

Table 1. Laboratory Properties of Soil Used in The Experimental Investigation

Sr. No.	Characteristics	Values
1.	Optimum Moisture Content (OMC) (%)	24 %
2.	Maximum Dry Density (kN/m3)	14.12
3.	Liquid Limit (%)	47
4.	Plastic Limit (%)	35.11
5.	Plasticity Index (%)	11.89
6.	Specific Gravity	2.203

Fly-Ash

Fly-ash is the finely divided powder in power generation power plants that is a by-product of burning pulverized coal and is carried by exhaust gases from combustion chamber. In current research, fly ash was procured from Ratan India Power Ltd. Amravati, Maharashtra and is shown in Figure 2.

Figure 2. Test Fly ash used in Experimental Investigation

Various laboratory test has been carried out on test fly ash and the properties of same is reported in table 2.

Table 2. Properties of Fly Ash Used for Experimental Investigation

Sr. No.	Characteristics	Value
1.	Specific gravity	2.01
2.	Max dry density (kN/m^3)	12.5
3.	Cohesion (kN/m2)	3
4.	Angle of Internal Friction (^{O})	13

Model Test Tank and Footing

A rectangular mild steel tank having size 700 mm (L) x 400mm (B) x 500 mm (D) was used in the model test. Schematic diagram of experimental setup is shown in Figure 3. One side of the tank was made opened for making the slope and front side was covered with Perspex sheet to observe the failure patterns during the test. Inside surface of tank was lined with oil so as to reduce the frictional effect during the test process. The test tank placed on iron channels rigidly fixed with the foundation base. A horizontal metal beam was fixed on the vertical posts to support the loading device across the middle of the tank, details of the test tank are shown in Figure 4.

A strip footing of mild steel plate 80 mm x 400 mm and having thickness of 10 mm was used. The base of the footing was made rough, to simulate the actual footing. Small groove was provided at the centre of footing facilitate the application of load centrally through a loading plunger and also to avoid tilting of footing. The level of footing was checked by spirit level.

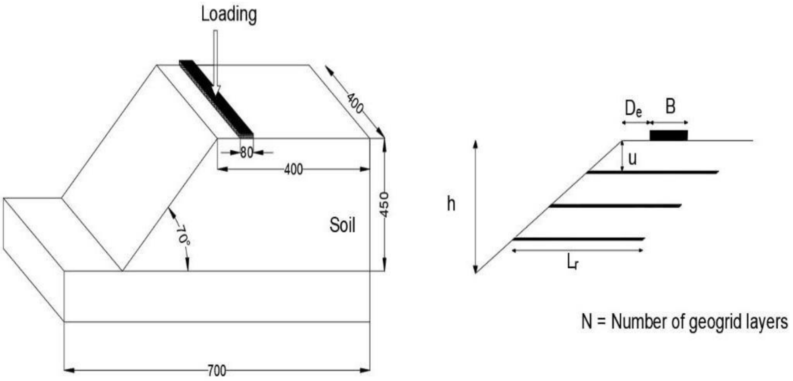

Figure 3. Schematic Diagram of Experimental Setup

Loads are applied on the footing with the help of screw jack through a calibrated proving ring of 25 kN capacity. The purpose of using screw jack over hydraulic jack was to avoid the pressure release problem.

Figure 4. Test Setup View

A plunger was attached to the proving ring to transfer the load from screw jack to footing. The horizontal cross beam was bolted to the vertical posts to facilitate the vertical movement of the beam. Settlement under the applied load was measured with the help of two dial gauges of 0.01 mm least count and total run of 25 mm. The dial gauges were fixed through magnetic base to the rigid beams of the tank.

Reinforcement Used

Geogrid is a geosynthetic substance made of polymeric material that is used to stabilize soils, rocks and similar materials. Commercially available biaxial geogrid (SG3030) was used for reinforcing the soil slope. Properties of geogrid used for model test is shown in Table 3. A reinforced soil foundation (RSF) consisted of layers of a geogrid reinforcement placed below a footing to create a composite material with improved performance. Biaxial geogrid as shown in Figure 5 was used for experimental investigations.

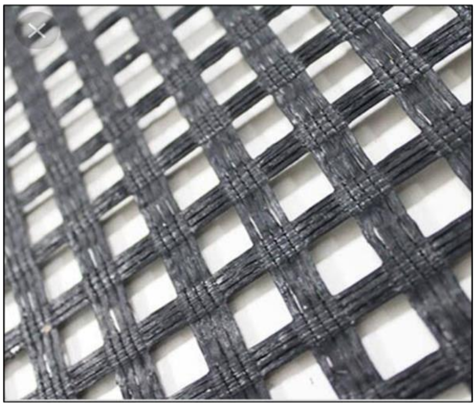

Figure 5. Biaxial Geogrid Reinforcement used in Experimental Investigation

Table 3. Properties of Geogrid used for Experimental Investigation

Sr. No.	Characteristics	Direction	Value
1.	Ultimate tensile strength (kN/m)	MD	30
		CD	30
2.	Elongation at break (2%) (Tolerence ± 4)	MD	13
		CD	13
3.	Tensile strength strain (kN/m2)	MD	7
		CD	6.5
4.	Tensile strength at 5% strain (kN/m2)	MD	13
		CD	12
5.	Aperture size (mm)	MD x CD	26 x 26
Note: MD – Machine Direction, CD – Cross Direction			

Parametric Study

The following parameters were investigated in model test:

1. Unreinforced unstabilized soil slope
   a. Footing distance from edge of slope at crest (D*e*)
2. Unreinforced stabilized soil slope
   a. Footing distance from edge of slope at crest (D*e*)
3. Reinforced stabilized soil slope
   a. Footing distance from edge of slope at crest (D*e*)
   b. Depth of first layer of reinforcement (*u*)
   c. Vertical spacing between the reinforcement (S*v*)

The details of the test parameters is given in Table 4

Table 4. Test Parameters

Parameters	Values
1. Unreinforced unstabilized soil slope.	
Footing distance from edge of slope at crest (D*e*/B)	0.5, 1.0, 1.5, 2.0
2. Unreinforced stabilized soil slope	
Footing distance from edge of slope at crest (D*e*/B)	0.5, 1.0, 1.5, 2.0
3. Reinforced stabilized soil slope	
Footing distance from edge of slope at crest (D*e*/B)	0.5, 1.0, 1.5, 2.0
Depth of first layer of reinforcement (u)	0.5
Vertical spacing between the reinforcement (S_v)	0.5, 1.0, 1.5, 2.0

4. Laboratory Model Test & Results

Model plate load test were conducted in accordance with IS 1888 – 1982 to determine the load carrying capacity of strip footing on the stabilized soil slope. Testing program is classified into three stages viz. unreinforced unstabilized soil slope, unreinforced stabilized soil slope and reinforced stabilized soil slope. For the preparation of slope, dry black cotton soil was collected, weighed and then mixed with a predetermined amount of water corresponding to the optimum moisture content (OMC). The moist soil was placed in the air tight container for 24hrs for allowing uniform distribution of moisture within the soil. The well mixed soil was then spread in the tank in layers. The solid mild steel rammer weighing 012 kg was used for compacting soil layers. Uniform compaction of each layer was achieved by giving blows uniformly spread over the layers. The thickness of each layer was 50 mm. The height of fall of rammer was kept as 300 mm. To maintain the height of fall, marking of 300 mm was made on one side of the tank. The top surface of compacted soil layer was scratched with knife before placing the next layer and procedure was repeated until the desired height was achieved. The height of slope was kept 450 mm during the test program. The footing was placed at the required location from crest. The loading beam and jack were placed at the center of footing and fitted with the proving ring and plunger. While placing the model footing, sufficient care was taken to ensure that model footing was placed horizontal so that the load is always applied vertical. The plunger was lowered and desired seating load was applied. The initial reading of the dal gauges and proving were recorded. Loads were applied in equal increments only when the settlement was reasonably constant. Before each increment of the load, the readings of the dial gauges were recorded and the procedure was continued till the footing fails.

Number of tests were performed on all the three cases. The details of the test carried out are listed in Table 5.

Table 5. Test Parameters for Laboratory Model Tests

Test Parameters	No. of Reinforcement Layers (N)	De/B	*u*/B	Sv/B
Unstabilized Unreinforced	0	0.5,1.0,1.5,2.0	---	---
Stabilized Un-reinforced	0	0.5,1.0,1.5,2.0	---	---
Stabilized Re-inforced	1,2,3	0.5,1.0,1.5,2.0	0.5	0.5, 1, 1.5

Unreinforced Unstabilized Soil Slope

Load carrying capacity of strip footing was determined by conducting model plate load test on unreinforced unstabilized soil slope for different De/B ratio. The results from the tests are shown in Figure. 6.

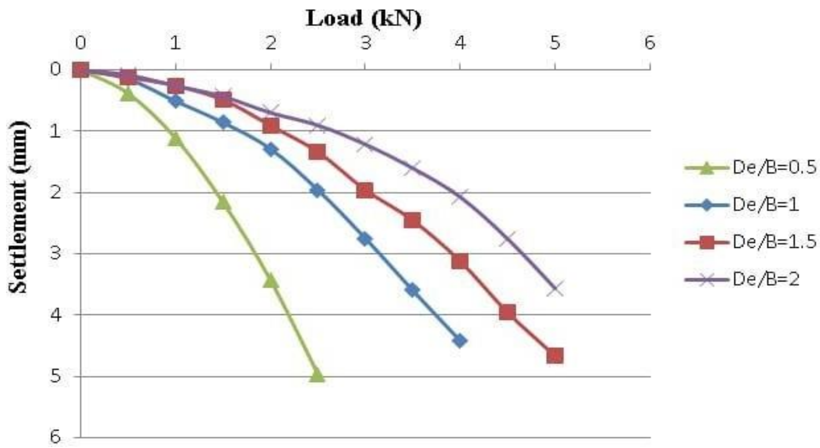

Figure 6. Load v/s Settlement Curve for Unreinforced Unstabilized Soil Slope

It can be seen from the test that for De/B = 2, load carrying capacity of strip footing on unstabilized unreinforced soil slope is increased as compare with other parameters.

Unreinforced Stabilized Soil Slope

The model plate load tests were conducted on footing placed on unreinforced stabilized soil slope, to evaluate the load carrying capacity and settlement of footing. For preparation of stabilized soil slope, oven dried black cotton soil was mixed with optimum percentage of fly ash which was obtained from laboratory test results. Unconfined compressive strength test was conducted to know the optimum percentage of fly ash. From the laboratory results, optimum percentage of fly ash content was observed as 25%. After preparation of soil bed, the model footing was placed on the slope at a different crest distance from edge and the results of the model tests are shown in Figure 7.

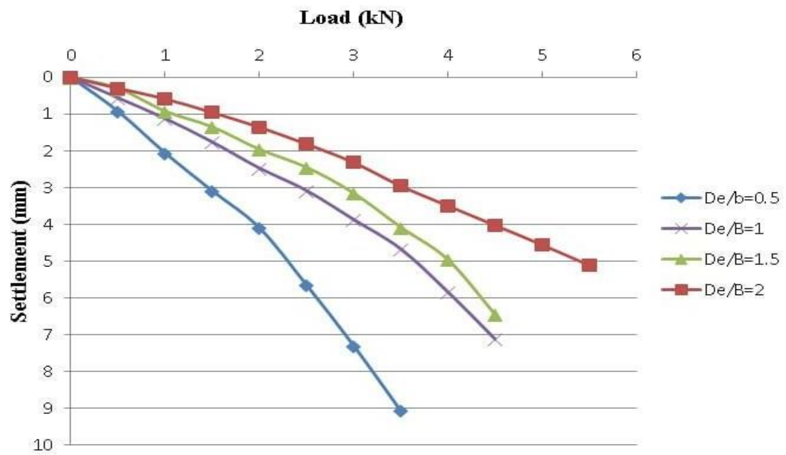

Figure 7. Load V/S Settlement Curve for Unreinforced Stabilized Soil Slope

It is observed from the test that for De/B = 2, load carrying capacity of strip footing on unstabilized unreinforced soil slope is increased and corresponding settlement is also increased.

Reinforced Stabilized Soil Slope

The model plate load test was conducted on footing placed on reinforced stabilized slope bed, to evaluate the ultimate bearing capacity and settlement. In this case of reinforced slope, the reinforcement layers were placed at desired locations during compaction. The first layer of geogrid was placed directly on the foundation layer and rigidly connected to the full height facing panel. The backfill is reinforced with biaxial geogrid reinforcement with 70 mm spacing and length equal to 0.7H, where 'H" is height of slope. After preparation of soil bed, the model footing was placed on the slope at a different crest distance from edge. Load settlement curve for number of reinforcements is shown in figure 8, 9 and 10.

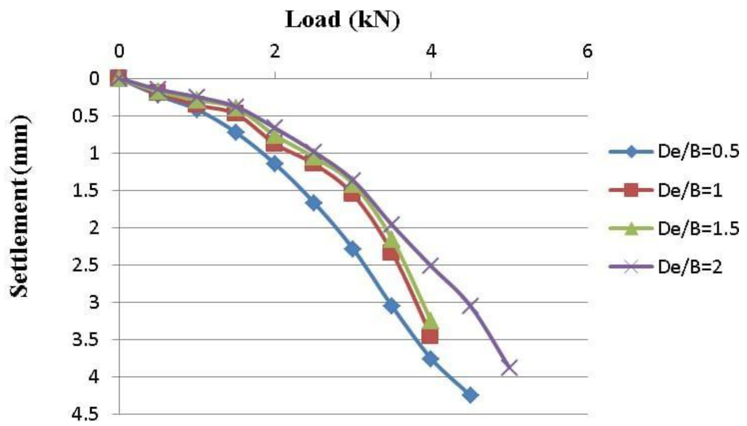

Figure 8. Load v/s settlement curve for reinforced stabilized soil slope for N = 1

For reinforced stabilized soil slope, particularly when number of geogrid layer is equal to 1, It was observed that for De/B = 2, load carrying capacity of strip footing is more as compared with other parameters.

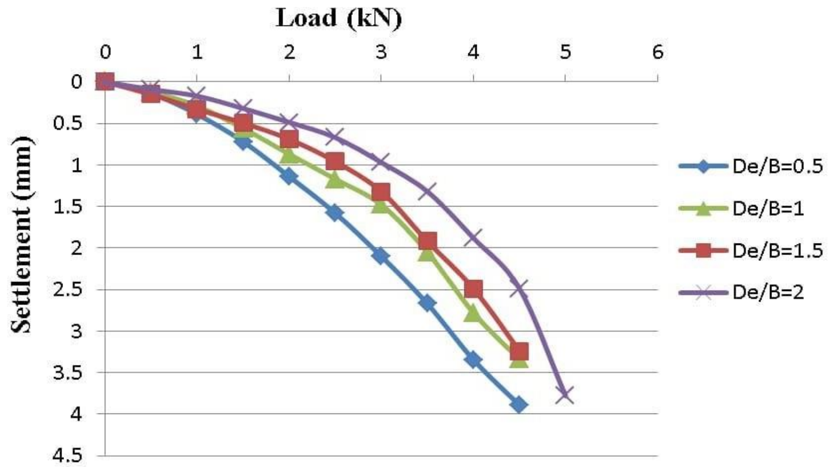

Figure 9. Load v/s settlement curve for reinforced stabilized soil slope for N = 2

For reinforced stabilized soil slope, particularly when number of geogrid layer is equal to 2. It was observed that the load carrying capacity and the corresponding settlement of strip footing is significantly increased for De/B = 2.

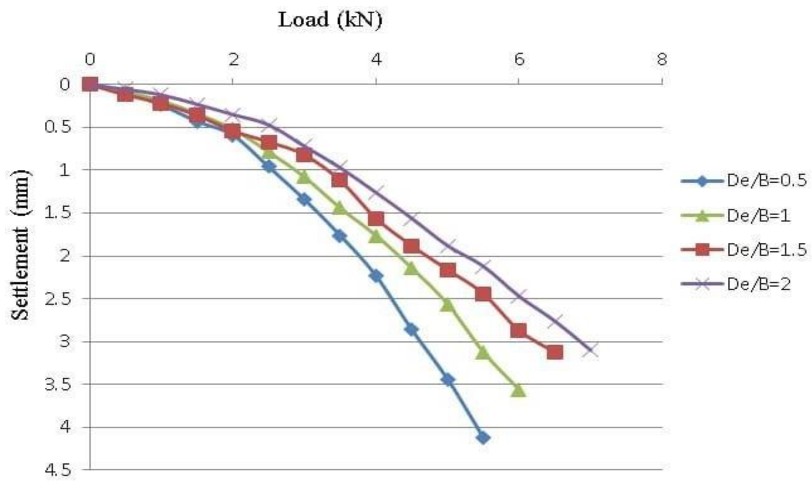

Figure 10. Load v/s settlement curve for reinforced stabilized soil slope for N = 3

For 3 layers of geogrid reinforcement, it is evidently seen that settlement of the footing is significantly decreased for the increase in De/B ratio and the load carrying capacity was observed to be increased.

5. Conclusions

Based on the outcomes of the current study, the following relevant conclusions are drawn.

1. Steep reinforced stabilized slope proving to be a cost-effective alternative for conventional structures with much more stable slopes.
2. Soil slopes stabilized with fly ash as a stabilizing material ensures more strength than the unstabilized soil slopes.
3. The behavior of the strip footing on reinforced earth slope is greatly affected by the geogrid reinforcement, the distance of footing from the edge of the slope, and vertical spacing between the reinforcement.
4. The load-carrying capacity of footing situated on the crest of sloping ground can be significantly increased by the inclusion of layers of geogrid. It can be seen that an increase in the load-carrying capacity depends not only upon the geogrid layout but also on the location of footing with respect to the slope face.
5. Provision of geogrid reinforcement layers increases the bearing capacity of stabilized soil slope. As the number of geogrid layers increases, the bearing capacity also increases. There is a significant increase in bearing capacity up to three layers of reinforcement.
6. Load carrying capacity of footing increases as footing distance from the crest increases. However, the increase in bearing capacity is significant only up to De/B = 1.

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