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A Review of Experimental and Numerical Investigations on Reinforced Soil Slopes

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ABSTRACT: Soil stabilization is a technique of enhancing the shear strength parameters of soil and thus increasing the bearing capacity of the soil. It is generally required when the soil under the foundation for construction is not suitable to carry the load of the structure. Stabilization method include adding lime, cement, other agents and using geosynthetic materials for reinforcement. The shear strength of soils depends on effective confining stresses. Soils have high compressive strength when confined whereas it is having low tensile strength. Reinforcing the soil with tensile inclusions enables soils to resist tensile stresses and increases the shear strength and stiffness of soils. Soil reinforcement may be employed to construct selected fills at steeper slope angle or to improve the load bearing capacity of fills or the ground. Paper presents the results of several experimental, numerical analyses performed by various researchers.

KEYWORDS: Black cotton soil, Geogrid, Soil reinforcement, Load bearing capacity, Infill material, Slope stability.

I. INTRODUCTION

Nowadays, as population growth leads to a scarcity of available land, people are opting to build their houses on slopes. However, this choice may give rise to future problems as the stability of these slopes decreases, causing landslides. The performance of such structures heavily relies on the stability of both the slope and the soil's bearing capacity. When a slope has a shallow foundation with axial load, its bearing capacity is lower compared to a foundation on flat ground. Consequently, the investigation of slope stability in conjunction with foundation stability plays a crucial role in geotechnical engineering. Many situations necessitate the placement of foundations on top of or on the surface of slopes, such as bridge abutment foundations, tower footings for electrical transmission lines, and small to medium-rise buildings in hilly regions. Conducting research on foundations situated on slopes will enhance our understanding of their stability and bearing capacity. In order to provide optimal solutions and improve construction efficiency, it is essential to approach the study of foundations on slopes from various para-metrical perspectives.

Recently, the reduced availability of land due to extensive construction has become a significant concern. Fly ash, a material known for its stabilizing properties, is widely utilized in civil engineering, particularly in road and embankment construction. The use of fly ash allows for cost-effective soil stabilization and the construction of embankments. In areas where land availability is limited, constructing stabilized embankments with steep slopes can be a viable and economical choice. Reinforced soil slopes are commonly employed in highway construction and offer a 50 % cost reduction compared to retaining walls. In conclusion, conducting research on foundations on slopes and exploring alternative stabilizing materials like fly ash will contribute to the advancement of knowledge and improvements in stability and bearing capacity. These studies will enable the development of optimized and cost-effective solutions for construction on slopes. This review paper aims to elucidate the strengths, limitations, and comparative performance of various slope stabilization and reinforcement strategies. By synthesizing empirical evidence, case studies, and technical analyses, we aim to provide insights into the selection, design, and implementation of appropriate interventions tailored to diverse geological and environmental contexts.

II. LITERATURE REVIEW

Various researchers determined the load bearing capacity of different footings placed on the soil slopes experimentally and numerically. Waste materials were also added or mixed so as to enhance the bearing capacity of such structure. Following section shows the research done on stabilization of soil slopes experimentally.

K. S. Gill *et.al* (2013) conducted large scale model footing tests in the laboratory to find out the effectiveness of use of single and multilayer geosynthetic reinforcements in improving the load bearing capacity of coal ash slope. The large-scale load tests were conducted in an open – ended tank having dimensions of 4.65 x 2.1 m in plan and 1.50 m in depth. Footing made of good quality well – seasoned Sal wood of size 2.0 x 0.45 x 0.065 m was used for conducting the large-scale load tests. The tank was fitted with a 12 mm thick Perspex sheet on front side to observe the failure pattern during the tests as shown in the figure 1.



Figure 1. Typical Coal Ash Slope

The experimental tests were conducted considering various parameters which were embedment depth, number of geogrid layers, depth of top layer of reinforcement. From figure 2(a) it was observed that the BCR increases with the increase in geogrid reinforcement layer N , and the rate of increase in BCR decreases when the value of N becomes equal to three and after that rate of improvement is much lower and the trend of BCR do not change with D_e/B ratio.

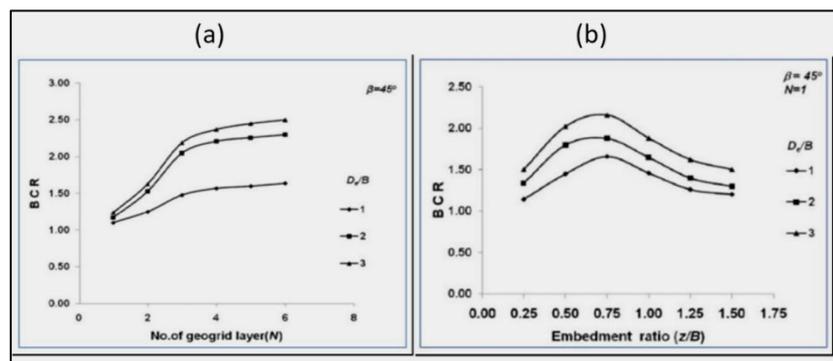


Figure 2. (a) BCR vs No. Of geogrid layers (b) BCR vs embedment ratio

From figure 2(b) it was noticed that BCR increases with an increase in embedment depth ratio (z/B) up to certain critical value and thereafter any further increase in Z/B ratio actually decreases BCR. The critical value of z/B was found to be $0.75B$. This trend remains the same for three edge distance ratios considered in the investigation.

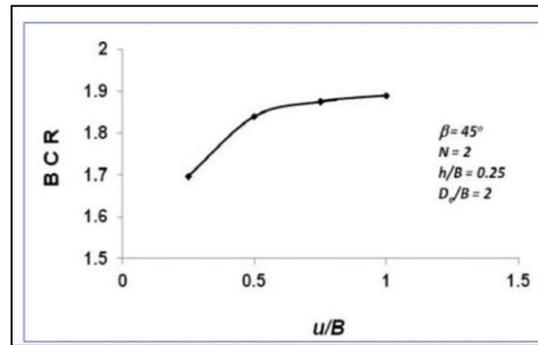


Figure 3. BCR vs u/B ratio

From figure 3, it is noticed that initially the value of load carrying capacity increases with increase in depth of first layer until it attains a maximum value and thereafter increase is insignificant with further increase in u/B. The maximum improvement in BCR was obtained when depth ratio (u/B) of top geogrid layer is 0.6.

The conclusions that were reached based on the experimental investigations are as follows.

1. When a single geogrid layer is inserted at different depths, the bearing capacity ratio, increases with a maximum increase in embedment ratio up to $z/B = 0.75$ and thereafter it decreases irrespective of the edge distance of the footing from the slope crest.
2. The load carrying capacity increases with an increase in the number of reinforcement layers within the slope. The maximum improvement occurs when the number of reinforcement layers is three.
3. Initially, the BCR increases with the increase in depth ratio (u/B) but when depth ratio of the top geogrid layer becomes 0.6, there is no significant change in load carrying capacity.

Patil. V. N *et al.* (2016) conducted laboratory model tests on unreinforced and reinforced fly ash slope having an angle of 45° and the pressure-settlement behaviour of strip footing was examined. The various parameters considered were embedment ratio ($Z/B = 0.30$) i.e. the depth of first layer of polyester geogrid reinforcement with different footing edge distances ($D_e = 1B, 2B, 3B$). From the experimental results pressure and settlements were measured and pressure settlement curves were drawn and the results of unreinforced and reinforced cases were compared.

Fly ash used to have specific gravity of 2.09, $MDD = 13.24 \text{ kN/m}^3$, $OMC = 20\%$. The friction angle and cohesion were 12.95° and 7.85 kN/m^2 respectively. Geogrid use was commercially available 1mm thick polymeric coated polyester geogrid (PET).



Figure 4. Model Test Setup

The model tests were conducted in an open-ended model test box (figure 4) having inside dimensions of $2400 \text{ mm} \times 310 \text{ mm}$ in plan and 900 mm in depth with a loading frame holding hydraulic jack. The 30 kN capacity proving ring was calibrated and attached to hydraulic jack on loading frame with the height adjustment attachment. Three sides of

the model tank were covered with 12 mm thick transparent Perspex acrylic sheet, so that the observer could visualize the failure of the embankment. For experimental tests strip model footing made up of Sal wood of size 300 mm x 100 mm was used, with a thickness of 100 mm. The base of footing was made rough by fixing thin sand layer on the bottom of model footing with the epoxy glue.

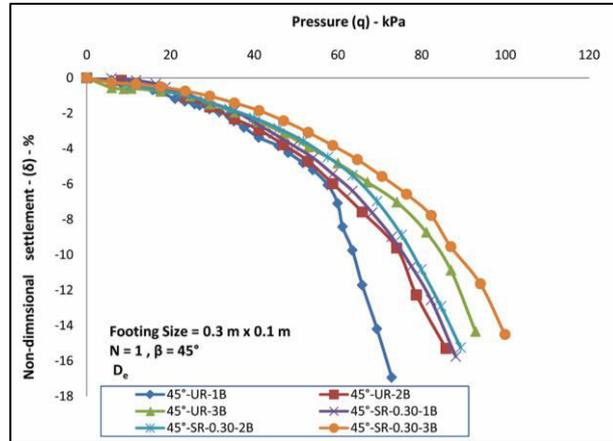


Figure 5. Pressure – Settlement curve for Unreinforced and Reinforced Case

The comparison of ultimate bearing capacity of unreinforced and reinforced fly ash slope for different edge distances is given in Table 1 and the pressure settlement curve is given in figure 5. It was observed that the load carrying capacity was increased with an edge distance in both cases i.e. unreinforced and reinforced slope. The values mentioned in Table 4 indicate that the increasing trend of the bearing capacity is obtained with the inclusion of single geogrid reinforcement and it was also observed that bearing capacity ratio decreases with increase in edge distance.

Edge Distance	Unreinforced Slope		Geogrid Reinforced Slope		BCR
	UBC of Unreinforced Slope (qu)	Settlement Ratio $\delta = (s/B) \times 100\%$	UBC of Reinforced Slope (qR)	Settlement Ratio $\delta = (s/B) \times 100\%$	
1B	55	5.50	60.00	5.80	1.09
2B	60	6.20	64.00	6.20	1.07
3B	77	7.80	80.00	7.20	1.04

Table 1. Experimental Values of the Bearing Capacity (q_u) of Unreinforced and Reinforced Fly Ash Slope

Following were the conclusions drawn from the experimental test results,

1. Load carrying capacity of footings located on slopes improves due to the insertion of geogrid reinforcement layer at suitable location into the slope fill.
2. The increasing edge distance of footing on unreinforced and reinforced slope improves the load carrying capacity.
3. The bearing capacity ratio (BCR) increases with inclusion of single layered reinforcement irrespective of the edge distance from slope crest.

M. B. Nadaf *et.al* (2019) studied the use of fly ash as filling material in waste plastic polyethylene terephthalate (PET) bottles used as reinforcement for slopes. The PET bottles having diameter of 50 mm with variable heights of 15 and 30 mm were used. Length of cellular reinforcement strip used was 0.7 H with coverage ratio (Cr) of 0.6. The plastic bottles were connected together in the form of three-dimensional strips with the help of tie wires. To eliminate the escaping of fly ash jute geotextile was wrapped at the slope facia to the plastic bottle internally throughout the width. Several tests were conducted to study the effect of change in length with constant spacing of strip on the footing capacity over the backfill. The size of test tank was 700 x 400 x 500 mm. The length and height of slope was 500 mm and 300 mm respectively. The slope angle was considered as 60°. For strip loading system, a steel plate was used of thickness 8 mm having its length 360 mm and width 100 mm. Figure 6 shows the slope before and after failure. Table 2 shows the experimental test details.

Model	Cellular reinforcement H= height of slope			
	Dimensions	Aspect ratio (h=d)	Vertical Spacing (Sr)	Length (L)
	CR50 ₁₅	0.3	0.3H	0.7H
	CR50 ₃₀	0.6	0.3H	0.7H

Table 2. Experimental test details

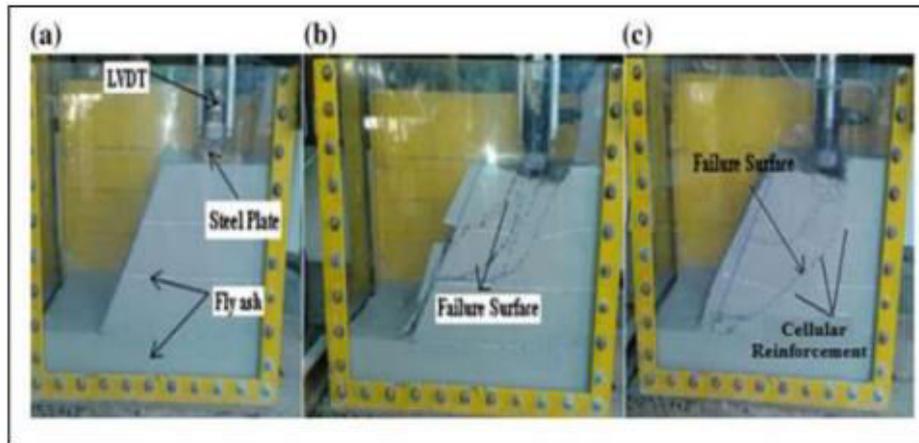


Figure 6. (a) Unreinforced slope before strip loading test (b) Unreinforced slope after failure (c) Reinforced slope after failure

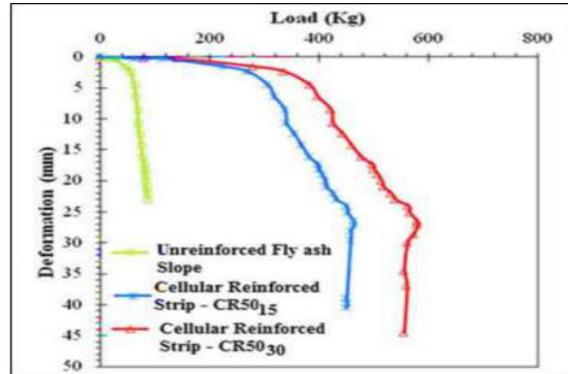


Figure 7. Load-Deformation Responses of Loading Plate over Slope under Strip Loading

Figure 7, shows the results of load settlement response of loading plate over slope under strip loading, from figure it was observed that cellular reinforcement having height 30 mm carry more load as compared to others. From the results it was concluded that, Cellular reinforced strip of steep fly ash slope can take more load than that of unreinforced fly ash slope. Cellular reinforced strip of (CR50₃₀) carries more load when compared with (CR50₁₅).

Mohammad Nurul Islam (2020) conducted the laboratory model tests to investigate the effect of footing shape and three different slope angles on both with and without reinforcement on the sloped surface. To evaluate the effect of footing shape three types of footings i.e. square, rectangular, circular were considered. Similarly, to evaluate the effect of slope angle, three slope angles were considered i.e. 35°, 40°, and 45°. To study the reinforcement effect, tests on both unreinforced and reinforced soil were performed. For experimental investigation Universal Testing Machine (UTM) with an electric load cell was used to apply load through the footings and they apply load at the centroid of the footing to avoid the eccentric loading effect. The data logger was used to measure the settlement and record the load every 0.5 mm deformation interval until the sloped surface failed.

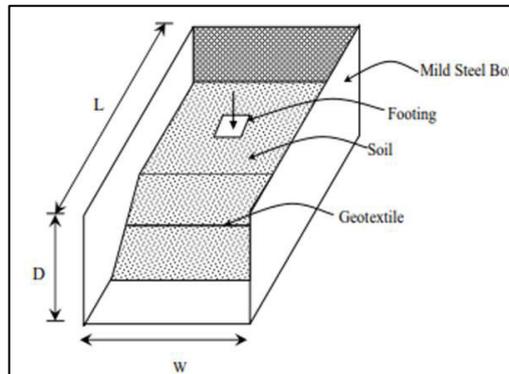


Figure 8. Model Set-up

The test setup dimensions were 45.72 cm x 45.72 cm x 60.96 cm as shown in figure 8. Cohesive type of soil was used having specific gravity = 2.61, liquid limit = 52%, plastic limit = 26%, shrinkage limit = 23%. Cohesion and angle of internal friction were 5kPa and 33° respectively. Type of geotextile used was multifilament woven having thickness 1.90.

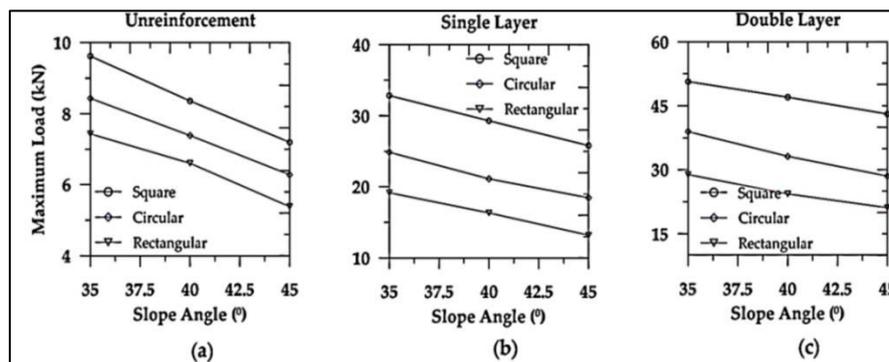


Figure 9. Maximum load carrying capacity (a) unreinforced soil (b) single layer geotextile (c) double layer geotextile

From the result as shown in figure 9, the conclusions that were reached based on the experimental investigation are as follows;

1. Maximum load carrying capacity decreases with rise in slope angle.
2. In contrast, the resistance in soil increased with the reinforcement application.
3. Maximum load carrying capacity of square footing was more as compared to rectangular and circular footing.

Dr. A. I. Dhatrik *et al.* (2022) performed model plate load test on cohesive soil in accordance with IS 1888-1982 in order to determine the load bearing capacity of strip footing on the reinforced 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 quantity of water corresponding to the optimum moisture content (OMC). The moist soil was placed in the air tight container for 24 hours 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 weighting 12 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 maintained 450 mm during the test program. The footing was placed at the required location from crest. The jack on the loading beam were adjusted at the center of footing and fitted with the proving ring with plunger at the bottom. 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 setting load was applied. The initial reading of the dial gauges and proving were recorded. Loads were applied in equal increments only when the settlement was reasonably

constant. The readings of the dial gauges were recorded before each increment and the procedure was continued until the footing fails. The details of the test carried out are listed in Table 3. A rectangular mild steel tank having size 700 mm x 400 mm x 500 mm was used in the model test. A strip footing of mild steel plate 80 mm x 40 mm and having thickness of 10 mm was used. Screw jack was used to apply the load on the footing.

Test Parameters	No. of reinforcement layers (N)	De/B	u/B	S _v /B
Unstabilized-Unreinforced	0	0.5,1.0,1.5,2.0
Stabilized-Unreinforced	0	0.5,1.0,1.5,2.0
Stabilized-reinforced	1,2,3	0.5,1.0,1.5,2.0	0.5,1,1.5

Table 3. Test Parameters for Laboratory Model Tests

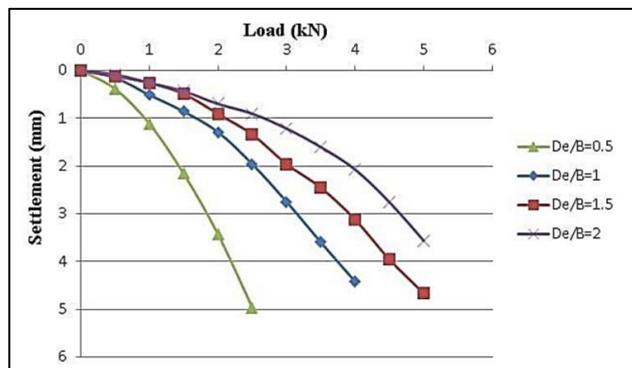


Figure 10. Load vs Settlement Curve for Unreinforced Unstabilized Soil Slope

Load carrying capacity of strip footing was determine by conducting model plate load test on unreinforced unstabilized soil slope for different De/B ratio. The results from the test are shown in figure 10. The results showed that for De/B=2, load carrying capacity of strip footing on unstabilized unreinforced soil slope was increased as compared with other parameters.

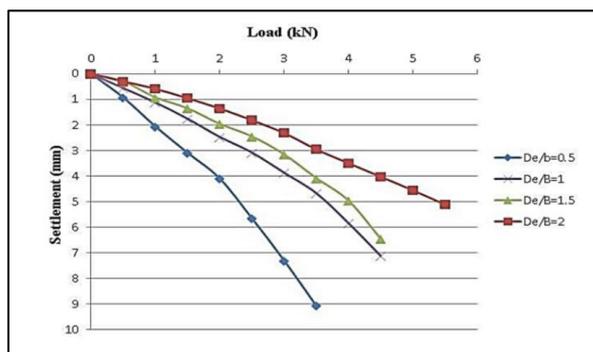


Figure 11. Load vs Settlement curve for Unreinforced Stabilized Soil Slope

For the preparation of stabilized soil slope, oven dried black cotton soil was mixed with optimum percentage of fly ash which was obtained from unconfined compressive strength test results i.e. 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 as shown in figure 11. It was observed that the test that for De/B = 2, load carrying capacity of strip footing on stabilized unreinforced soil slope is increased and corresponding settlement is also increased. For reinforced stabilized soil slope, the slope is reinforced with biaxial geogrid with 70 mm spacing and length equal to 0.7H, where ‘H’ is height of slope. For reinforced stabilized soil slope, particularly when number of geogrid layer is equal to 1 and 2, from figure 12, it was observed that for De/B ratio and load carrying capacity was observed to be increased.

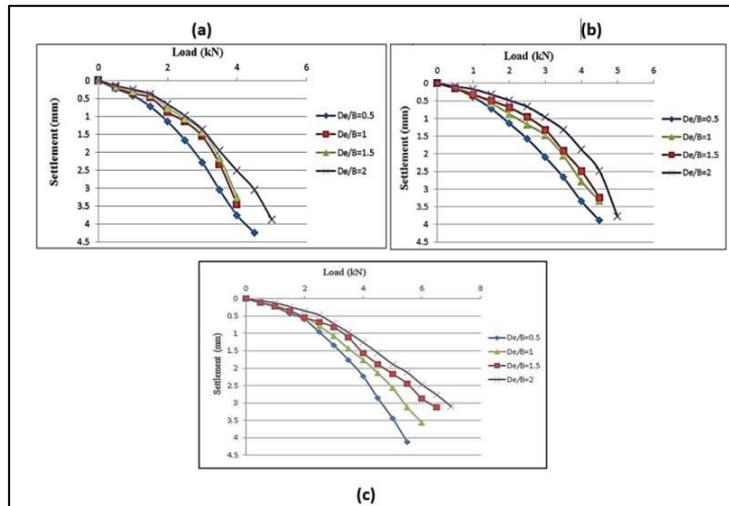


Figure 12. Load vs Settlement Curve for Reinforced Stabilized Soil Slope for (a) N=1 (b) N=2 (c) N=3

The conclusions that were reached based on the experimental investigations are as follows.

1. The soil slope stabilized with fly ash as a stabilizing material provide more strength than unstabilized soil slopes.
2. Provision of geogrid reinforcement layers increases the bearing capacity of stabilized soil slope.
3. As the number of geogrid layer increases, the bearing capacity also increases. There is a significant increase in bearing capacity up to three layers of reinforcement.

M. B. Nadaf and J. N. Mandal (2019) performed a series of laboratory model tests on unreinforced fly ash slope and cellular reinforced fly ash slopes under UDL and strip loading with an inclination of 60 degree overlaying fly ash foundation to verify the efficiency of reinforcement in improvement of load carrying capacity and stability of slope. Laboratory model tests were carried out by varying the diameter of geocell (50 and 75 mm) and height of geocell (10 and 20 mm) with constant vertical spacing of 100 mm and length of reinforcement layer of 0.7H (where H= height of the slope). A numerical analysis using PLAXIS 3D software was conducted to validate the laboratory model test results. The dimension for the numerical model was kept same as that of the laboratory model test. In PLAXIS 3D software, two materials were modeled, one is fly ash as a backfill material and other one is cellular reinforcement i.e. geocell. Here, fly ash modeled with Mohr-Coulomb failure criteria as linear elastic plastic material and waste plastic bottles which were used as cellular reinforcement was modeled as elastoplastic material. Rectangular steel tank dimension was 1000 x 500 x 750 mm. Rigid steel plate (UDL) and rigid steel plate (strip) having dimensions 500 x 360 x 10 mm and 500 x 100 x 10 mm respectively. Load cell is of 50 KN capacity. Vertical settlement is measured with the help of LVDT. Figure 13 shows the line sketch of test setup for both UDL and strip type of loading.

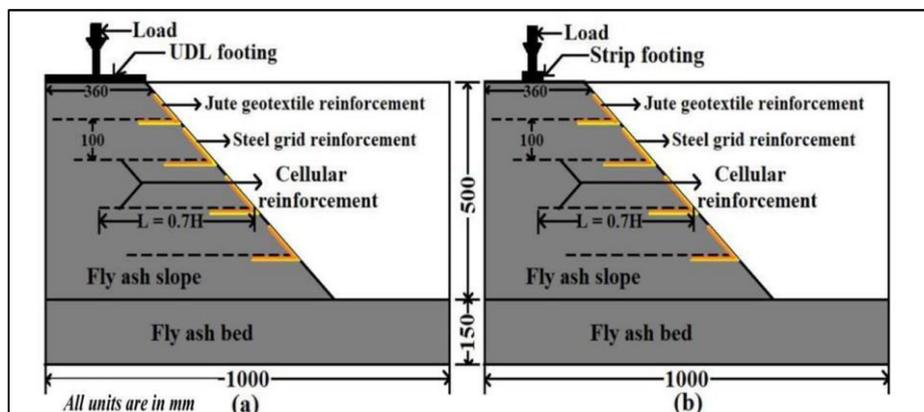


Figure 13. Line sketch of test set up (a) UDL (b) Strip loading

Model	Cellular reinforcement (CR)		
	Dimensions	Aspect ratio (h/d)	Parameter
Model-1: Unreinforced test (UDL and Strip)	Constant: $\alpha=60^\circ$ Variable: B=360 mm and 100 mm
Model-2: Cellular reinforcement mattress (UDL and Strip Loading)	CR50 ₁₀	0.2	Constant: L=0.7H; $\alpha=60^\circ$ Sr/H=0.2 Variable: B=360 mm and 100 mm
	CR50 ₂₀	0.4	
	CR75 ₁₀	0.13	
	CR75 ₂₀	0.26	

Table 4. Experimental and Numerical program for fly ash slopes overlaying fly ash bed

The experimental and numerical program for fly ash slopes overlaying fly ash bed is shown in table 4. Their study was divided into two models, one is for Unreinforced case and one for Cellular reinforced case namely Model 1 and Model 2 respectively. Figure 14. shows experimental and numerical pressure-settlement curves of loading plate over slope (a) UDL (b) Strip loading.

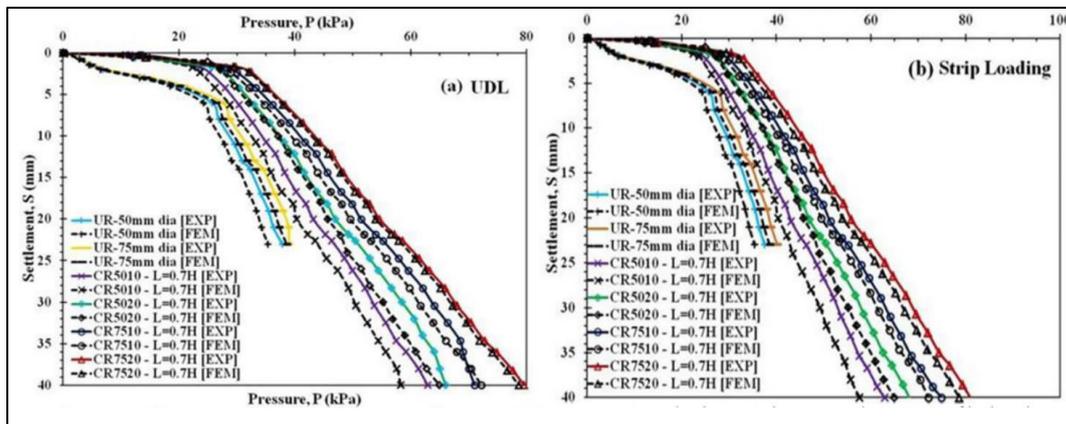


Figure 14. Experimental and Numerical pressure-settlement curves of loading plate over slope (a) UDL (b) Strip loading

From the test the major findings were,

1. Increasing geocell height with geocell diameter indicates better performance in terms of load carrying capacity.
2. The observed pressure at failure condition was more for CR75₂₀ indicating better performance over other cellular reinforcement parameter.
3. The results obtained for all models from the numerical analysis were mostly lower than those obtained from the experimental tests. The trend of the obtained curves from the numerical analysis is same with that from experimental tests.
4. The finite element analysis results were in reasonable agreement with experimental results.

T. V. Salunkhe *et al.* (2015) conducted model tests in the laboratory without and with Plastic recycled polymer in fly ash steep slopes overlaying soft foundation bed like fly ash and powai soil bed to evaluate the stability of steep slope. Fly ash is used as a filling material and Plastic recycled polymers of diameter = 3 mm and length = 4 mm were made from waste plastic product (lower grad plastic product). The properties of Plastic recycled polymers and fly ash were determined and from the experiments tests result, load and settlement had measured. A finite element method (F.E.M) was also evaluated using PLAXIS 3D version. The failure pattern, deformations and factor of safety were reported based on analytical program. The results from experimental work and analytical work were compared and reported.

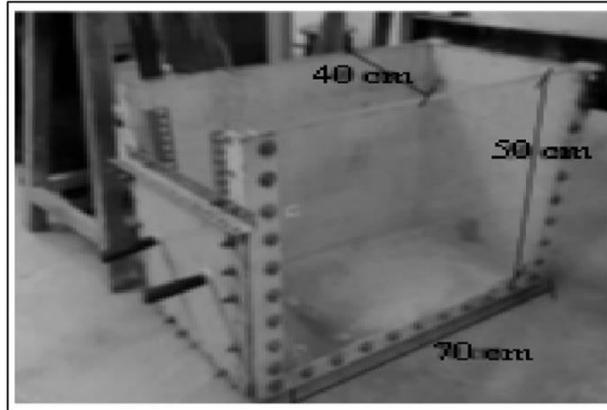


Figure 15. Test setup

The dimensions of test tank were as follows: length = 70 cm, width = 40 cm and height = 50 cm, the photograph is shown in figure 15. One side of the model setup was covered with Perspex sheet to observe the failure pattern. The experimental and numerical study was divided into four models as shown in figure 16. Model 1 was for fly ash slope overlaying fly ash bed. Model 2 was for fly ash slope with plastic recycled polymer overlaying fly ash bed. Model 3 was for fly ash slope overlaying powai soil and Model 4 was for fly ash slope with plastic recycled polymer overlaying powai soil.

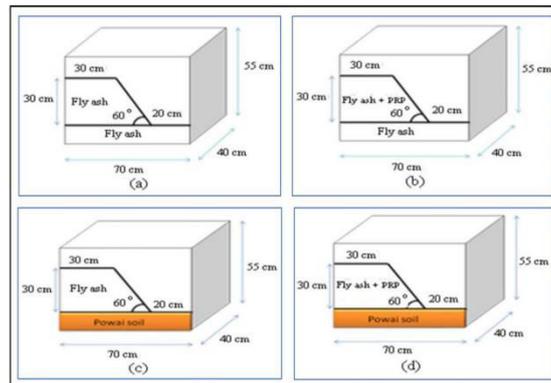


Figure 16. (a) Model 1: Fly ash slope overlaying fly ash bed (b) Model 2: Fly ash slope with plastic recycled polymer overlaying fly ash bed (c) Model 3: Fly ash slope overlaying Powai soil (d) Model 4: Fly ash slope with plastic recycled polymer overlaying Powai soil

Model No.	Loading	Slope material	Foundation soil	Experimental Deformation in mm	FEM method Deformation in mm
1	UDL	Fly ash	Fly ash	6.20	5.11
2	UDL	Fly ash + Plastic recycled polymer	Fly ash	12.35	18.24
3	UDL	Fly ash	Powai soil	6.8	7.14
4	UDL	Fly ash + Plastic recycled polymer	Powai soil	22.30	17.19

Table 5. Comparison between Experimental and FEM deformation under uniformly distributed loading

Model No.	Loading	Slope material	Foundation soil	Experimental F.O.S	FEM method F.O.S
1	UDL	Fly ash	Fly ash	0.975	0.991
2	UDL	Fly ash + Plastic recycled	Fly ash	1.937	1.792

		polymer			
3	UDL	Fly ash	Powai soil	0.64	0.954
4	UDL	Fly ash + Plastic recycled polymer	Powai soil	2.29	2.525

Table 6. Comparison between Experimental and FEM factor of safety under uniformly distributed loading

The variation for deformations and factor of safety are shown in Table 5 and 6 respectively. The variation of experimental values for factor of safety and deformation of slope were somewhat reasonably lower as compared to Plaxis 3D software results.

From the test the following conclusions were made:

1. The load carrying capacity of mixture of fly ash with plastic recycled polymers slope was more than that of fly ash slope. The deformation of plastic recycled polymers slope was slightly more than that of fly ash slope.
2. In case of fly ash slope overlaying fly ash bed, the factor of safety was increases with inclusion of plastic recycled polymer in fly ash and the same trend was seen in case of Powai soil.
3. Plastic recycled polymer can be used as a stabilized fly ash slope material to make it steeper and stable.

T. K. Rajak *et al.* (2016) preformed analysis of slope stability of native soil which were collected from an embankment slope of north-east region i.e. Agartala, Tripura, India, and stabilized soil with fly ash by Fast Lagrangian Analysis of Continua (FLAC) slope software. To calculate the factor of safety, study was done by considering different slope height at constant slope angle in case of both summer and rainy season. Further from the results optimum percentage of fly ash has been suggested for stabilizing the soil slope of certain height which was found to be 30 %.

The analysis for slope stability of embankment for native soil and soil stabilized with fly ash were carried out for different slope height and constant slope i.e. 37°. The height of slope varies from 8 m to 14 m at every 2 m interval for both summer and winter season. In case of rainy season water table were simulated at 1 m and 2 m from the toe of the slope.

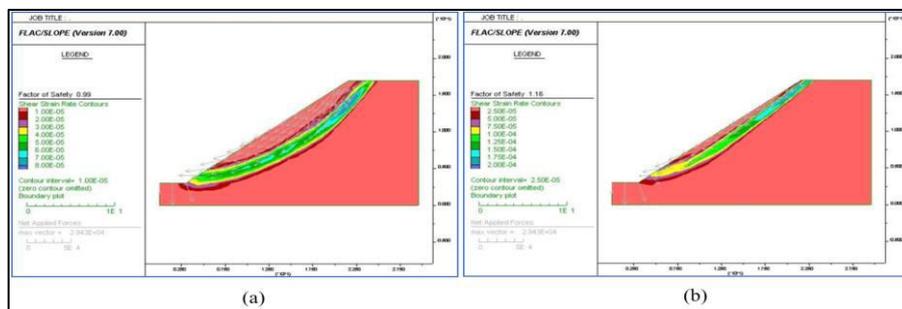


Figure 17. Shear Strain rate contour for slope of 14 m height at 2 m water level with (a) Native soil and (b) Stabilized soil with 30% Fly ash

The shear strain rate contour for slope of 14 m height at 2 m water level with native soil and stabilized soil with 30 % fly ash are shown in figure 17(a) and Figure 17(b) respectively. Similarly, FoS has been calculated for other conditions. The variations in FoS for all the conditions are shows in figure 18.

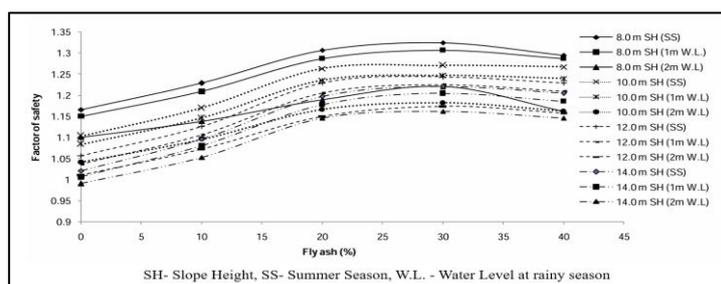


Figure 18. Variation in FoS with different Slope height and Fly ash content at summer and rainy season.

Based on the numerical modelling following conclusions were drawn,

1. Numerical modelling concluded that by addition of certain amount of fly ash, slope height can be raised even with the presence of water level.
2. Based on the value of FoS optimum value of fly ash is 30% for stabilizing the soil.
3. It was observed from the results as shown in figure 13, that the FoS increases with increase in percentage of fly ash up to 30%, after that slight reduction in FoS is observed.

V. K. Chakravarthi *et al.* (2018) conducted a case study to improve engineering properties of clayey sand of lateritic origin stabilized with fly ash, and also conducted the numerical study to check the effect of stabilized soil bed on the stability of slope embankment in terms of FOS. Tests were carried out on soil blended with fly ash at 0, 5, 10, 15, 20, 25, 30%. Index and engineering properties namely, O.M.C, M.D.D and Unconfined compressive strength of blended soil at different fractions were determined. Using the slope/w software 5 m high embankment and side slope 1:2 was modelled with considering the properties of stabilized soil as ground. The stability is computed for un-stabilized and stabilized ground and later compared. Clayey sand used to have specific gravity of 2.67, liquid limit = 41.2 %, plastic limit = 16.82 %, OMC = 20.6 %, MDD = 1.72 g/cc. Similarly, fly ash used was having specific gravity of 2.14, and which is non plastic.

Table 7. Variation of OMC, MDD and UCS with fly ash

% Fly ash	OMC (%)	MDD (g/cc)	UCS (kPa)
0	20.6	1.72	22
5	16.4	1.83	54
10	16.2	1.85	66
15	17.2	1.78	58
20	19.6	1.73	50
25	19.2	1.65	42
30	21	1.62	35

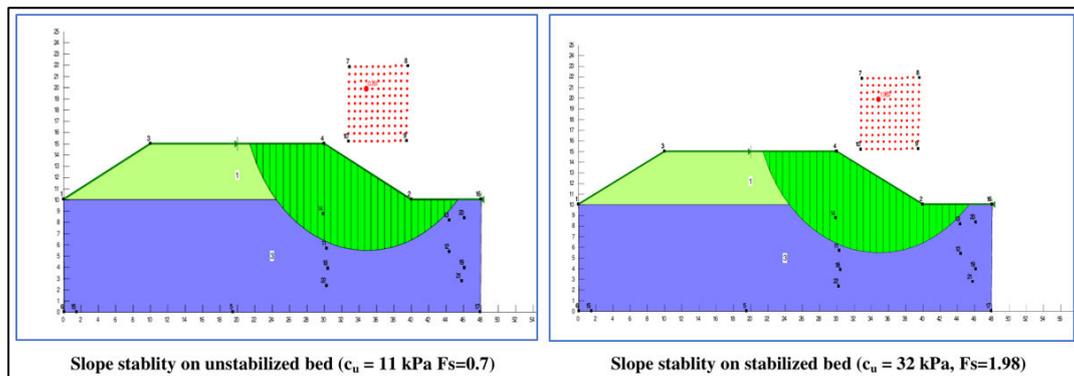


Figure 19. Slope stability on Unstabilized and Stabilized bed

From Table 7 and figure 19, following conclusions were drawn,

1. Fly ash was found to be effective in reducing OMC with increase in fly ash content up to 10 %, and it was found effective in increasing dry density up to 10 %. Similarly, fly ash was found effective in increasing compressive strength of sandy clay soil up to 10 % addition.
2. The FOS can enhance by 1.5 times with embankment constructed on stabilized bed.
3. Work highlights the proper utilization of natural hazard in ground improvement applications with three-fold advantage in consumption of hazard, improvement of weak soils and optimization of fly ash content.

III. CONCLUSIONS

From the brief literature review it can be concluded that many studies have been carried out experimentally and analytically on stability of unreinforced and reinforced fly ash slope for various reinforcement types. Study on performance of slope constructed with clayey soil stabilized with fly ash has not done earlier. As most part of southern India is covered with black cotton soil there is a need to improve the engineering properties of soil to make it fit for construction purpose. This reveals that the effect of position of footing, shape of footings, reinforcement configuration, and slope angle on bearing capacity and settlement of footing on reinforced slope is need of the future.

From the literature review it can also conclude that very little work on numerical analysis for reinforced slope have been done earlier. There is a need to conduct numerical analysis considering various parameters such as angle of soil, footing shape, different type of reinforcement, scale factor etc.

REFERENCES

- [1] Gill, K. S., Choudhary, A. K., Jha, J. N., & Shukla, S. K. (2013). Large model footing load test on reinforced coal ash slope. *International Journal of Geotechnical Engineering*, 7(3), 257–265.
- [2] Patil, V. N., & Chore, H. (2016). Bearing capacity of embedded strip footing on Geogrid-Reinforced fly ASH. *Open Journal of Civil Engineering*, 06(02), 179–187
- [3] Nadaf, M. B., & Mandal, J. N. (2019). Numerical simulation of cellular reinforced fly ash slopes. *Geo-Congress 2019*.
- [4] Islam, M. N. (2020). Small scale experiments to assess the bearing capacity of footings on the sloped surface. *Eng*, 1(2), 240–248.
- [5] Dhatrak A. I., Langote R. V., & Dighade V. S. (2022), “Performance of geogrid reinforcement on load carrying capacity of stabilized soil slope”, IGC 2022, Kochi.
- [6] Nadaf, M. B., & Mandal, J. N. (2019). Numerical simulation of cellular reinforced fly ash slopes. *Geo-Congress 2019*.
- [7] Salunkhe, T. V., Nawghare, S. M., Nadaf, M. B., Dutta, S., & Mandal, J. N. (2015). Stabilization of fly ash slope using plastic recycled polymer and finite element analysis using Plaxis 3D. Zenodo (CERN European Organization for Nuclear Research).
- [8] Rajak, T. K., Yadu, L., & Pal, S. K. (2018). Analysis of slope stability of fly ash Stabilized soil slope. In *Lecture notes in civil engineering* (pp. 119–126).
- [9] Chakravarthi V. K., & Babu D. C. (2018), “Stability of embankment on fly ash stabilized soil bed – a case study”, *International Journal of Advance Research in Science and Engineering*, Volume No. 07, Special Issue No. 2, February 2018. ISSN: 2319-8354.



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