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Effect of 3D Geogrid and Glasgrid in the Bearing Capacity of Square Footing Over Soil Slope

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***Abstract:** Many civil engineering structures such as buildings, bridges, and road embankment etc. require the construction of foundations over soil slope. Reinforcement technique is a low-cost method of enhancing the load carrying capacity of such foundations. Over the past three decades, geosynthetics have been successfully used as a reinforcing material. In the present study, a series of small-scale model footing tests were conducted on the geosynthetics reinforced soil slope. A bi oriented 3D geogrid and glasgrid were used as a reinforcing material. The results obtained from laboratory model footing tests over a geosynthetics reinforced earth slope are analyzed and presented. Pressure settlement curves and improvement factor (IF) were studied by measuring the results of different settlement ratios. Various parameters like edge distance (D) and slope angle (β) were studied to check the effect of slope geometry. Some other parameters like optimum value of initial reinforcement depth (u), influence depth of reinforcement (d), and number of reinforcements (N) were also considered to check the effect of geosynthetic in the enhancement of load carrying capacity of footing over reinforced earth slope. Experimental results demonstrate that load carrying capacity of foundation resting over soil slope significantly improved by the placement of geosynthetics in the soil. On the basis of the experimental work, critical values of geosynthetic parameters for the optimum reinforcing effect are suggested.*

***Index Terms:** 3D Geogrid; Glasgrid; Square footing; Bearing capacity; and soil slope.*

I. INTRODUCTION

Various civil engineering projects require the construction of foundations on conventional slopes or grounds with high gradients. Such foundations are prone to low bearing capacity and higher settlements. The development in bearing capacity and reduction in excessive footing settlement resting over soil slope can be achieved using different geosynthetics like geogrid, geotextile, and geocell etc. Over the past few years, geosynthetics is successfully used in the soil reinforcement, enhancing the load carrying capacity of foundation, pavement subgrade, and embankments etc.

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First comprehensive study on the influence of reinforcement in the development of bearing capacity of soil was put forward by [1] wherein an aluminum strip was used to reinforce the sand beds. Since then, various experimental, numerical and analytical studies on this topic have been studied by many researchers [2-7].

[2] analyzed the performance of geogrid in the improvement of stability of soil slope and reported a significant improvement in the bearing capacity of the foundation soil due to placement of horizontal geogrid layers in slope. [8] performed several tests using FEM analyses on a small-scale model footing over soil slope to validate with the results obtained from the experimental works on the same model.

Based on experimental works and FEM analysis, they suggested the optimum values of the reinforcement parameters for maximum reinforcing effect. [9] performed several model footing tests in the laboratory to analyse the behaviour of geogrid reinforced stiff clay foundation system. The footing was considered as a circular footing and tests were conducted in loading frame. Test results showed that the geogrid substantially improves the performance of the stiff clay foundation bed. In the present research, small scale model footing tests have been carried out to analyze the performance of geogrid and glasgrid in the development of load carrying capacity of a square foundation constructed over silty clay slope. The parameters considered in the study are slope geometry, the distance of the slope edge from the point of load application, first reinforcement depth (*u*), type of reinforcement, number of reinforcement layers (*N*), and influence depth of reinforcement (*d*). The major emphasis of the study is towards estimating the improved load carrying capacity of the footing being constructed on slopes, with the application of glasgrid and geogrid, tested under different working conditions. The tests have been carried out in a steel box, which has been modeled as per the footing width to prevent the boundary effect which could hamper the results of the study and the loading has been applied using a loading frame.

II. MATERIAL USED

A. Soil

A soil sample was collected from Gwalior, India. The latitude and longitude coordinates of the location are 26.2183 N, 78.1828 E. Soil was excavated up to a depth of 0.5 m. Then sample was procured in the laboratory. Initially, soil was oven dried for 24 hours in order to remove the natural moisture content there after it was used for experimental work.

The soil was classified as low plastic soil. The properties of foundation soil are tabulated in Table 1.

B. Geosynthetics

A 3D geogrid and a glasgrid was used as a reinforcing material. The material testing certificate of geosynthetics supplied by the dealer is tabulated in Table 2. The tensile strength and aperture size of the 3D geogrid is higher than the glasgrid. In the present study, the 3D geogrid and glasgrid have been represented as GGR1 and GGR2 respectively.

GGR1 was made of polypropylene while GGR2 was composed of high strength glass fibers. Geosynthetic samples are shown in Fig.1

III. EXPERIMENTAL WORK

A. Slope preparation

Small scale footing tests were conducted in a steel box of size 75 cm × 45 cm × 60 cm (L× B × H). Initially, the soil was air-dried and pulverized and then it was filled into the steel box at its maximum dry unit weight. Predetermined water content was mixed thoroughly with the soil to bring the soil upto its optimum moisture content i.e. 15 %. The slope foundation was compacted in the tank in two lifts for each test, each lift of up to 10 cm. For every layer, the quantity of soil is required to be filled was predetermined by using the volume of tank for each lift and multiplying it with the maximum dry unit weight. Each lift was compacted uniformly with the help of a light compaction rammer with a base diameter of 16.2 cm. At the end of compaction, a spirit level was used to check the horizontal surface of prepared slope.

B. Layout of geosynthetics

The geosynthetic configurations were decided according to the testing program described in the testing procedure i.e. at the respective *u/B*, *d/B* ratios, and number of reinforcement layers *N*. All the four dimensionless parameters (i.e. *N*, *d/B*, and *u/B*) were considered to ascertain the optimums in geosynthetic placements. A geometry of geosynthetics reinforced earth slope is shown in Fig.2.

C. Testing Setup

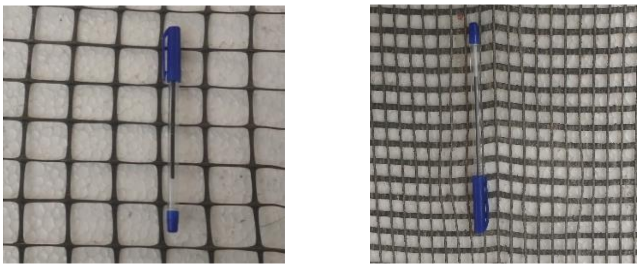
The experimental works were conducted on unreinforced and reinforced soil slope by using testing facilities developed in the laboratory. The dimensions of clay foundation are as follows: Length = 75 cm, width = 45 cm and height = 20 cm. A slope of height 30 cm was prepared at a slope angle 35˚, 40˚, and 45˚, in accordance with the geometry of slope shown previously. The back and sides of the tank were fabricated having 10 mm thickness of steel sheet, braced with structural steel member whereas front side of the tank consisted of a 20 mm thick acrylic sheet for visual observation. An angle was fixed on the face of acrylic sheet against the outward buckling during compaction and loading. Inner surface of the tank was greased to prevent the adverse effect of friction on the test results. A steel plate of size 75 mm × 75 mm was used as a footing prototype. The dimensioning of the tank was done in accordance with the footing width, to avert the boundary effect and hence dimensions of 10B, 6B and 8B were chosen as the length, width and height of the tank respectively, where B is the model footing width, i.e. 75 mm. The footing base was kept rough by gluing the sand with epoxy glue. The tank was tested in the load frame consisting of two rigid and circular steel columns of 15 cm in diameter, attached to the top head of the loading frame. A load cell of 25 kN capacity was placed at center between the footing plate and upper platen to avoid the eccentric loading. The output of the load cell was logged using a data logger in the form of pressure. Two dial gauges with an accuracy of 0.001mm were used at points diametrically opposite to the footing. Average reading obtained by both the dial gauges was considered as a footing settlement. The test bed was tested as per the provision of [10] up to a settlement of 20 mm. A low strain rate of 1mm/min was used to simulate undrained condition. Sitting load was applied initially on the footing to fix it over the clay base, to obtain planar strain conditions.

D. Testing Procedure

The tests were conducted in the load frame with the application of reinforcements at different positions in the soil slope. The aim of the study was to find out the influence of slope angle, angle edge and the optimum positions for placement of reinforcements in the structure to obtain maximum possible benefit from the reinforcements by mobilizing greatest tensile force within the reinforcement. To ascertain the optimums for geosynthetic placements, values of *u*, *d*, and *N* were varied for both the reinforcement. The optimum value of first reinforcement depth was determined by placing the reinforcement at *u/B* = 0.2, 0.4, 0.6, 0.8, and 1.0 respectively. Effect of reinforcement layers was estimated by fixing the top layer at optimum and increasing the reinforcement layers until the effect of the reinforcement becomes considerably insignificant for any further extensions in number of reinforcement layers. Distance between two reinforcements i.e. *h/B* was fixed at the optimum value of *u/B*. The tests for all the parameters, viz. via. *u/B*, *N* and *d/B* were carried out by fixing the slope angles at 45˚ and at an edge distance of 1. The tests were carried out for both the reinforcements, i.e. GGR1 and GGR2. The effect of slope geometry was analyzed for GGR1, varying the slope angles by 35˚, 40˚ and 45˚ respectively and fixing the value of *D/B* = 1. Similarly, the effect of edge distance (*D*) on bearing capacity of soil as ascertained by fixing the value of slope angle at 45˚ and varying the values of *D/B* at 0, 1, and 2.

Table. 1 Geotechnical properties of foundation soil

Properties	Values
Liquid limit (%)	34.0
Plastic limit (%)	21
Plasticity index (%)	13
Specific gravity	2.62
Optimum Moisture Content (%)	15
Maximum dry Unit Weight (kN/m^3)	17.6



(a) (b)

Fig.1 Photographs of (a) Geogrid (b) Glasgrid

Table.2 Material testing certificate of geosynthetics

Properties	Data
3D Geogrid	
Aperture Size (mm)	30 × 30 (MD × CMD)
Stiffness at 0.5% Strain (kN/m)	550 × 350 (MD × CMD)
Tensile Strength (kN/m)	115 × 115 (MD × CMD)
Glasgrid	
Opening Size (mm)	12.5 × 12.5 (MD × CMD)
Tensile Resistance @ 2% Strain (kN/m)	95 95

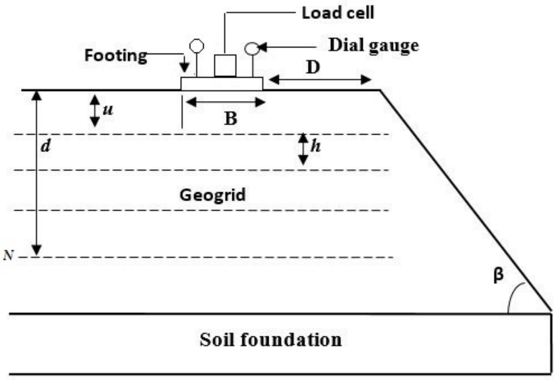
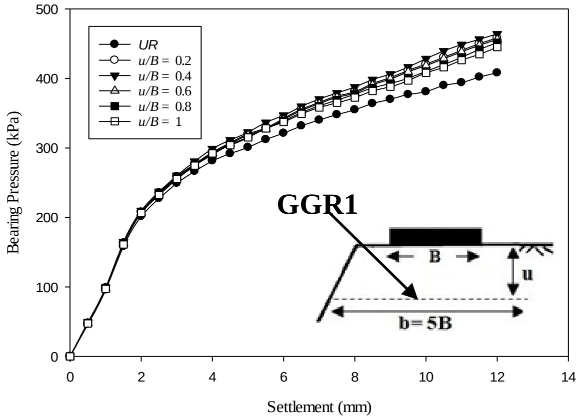


Fig. 2 Reinforced soil slope

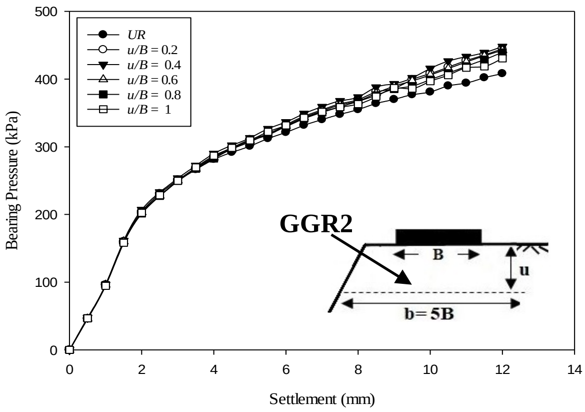
IV. RESULTS AND DISCUSSION

A. *Effect of first reinforcement depth (u)*

The settlement measured from the dial gauges is considered as footing settlement and denoted as (s). The settlement ratio (*s/B*) is explained as the ratio of settlement of footing (s) to the width of footing (*B*) and this settlement ratio was used to check the performance of reinforced soil foundation. A dimensionless parameter improvement factor (*IF*) was calculated at each settlement ratio to give an incisive account in the improvement of bearing capacity due to the inclusion of reinforcement in the foundation soil. The *IF* is explained as the ratio of the bearing pressure of a reinforced soil to that of an unreinforced soil, when evaluated at the same settlement ratio. In this study, the *IF* was calculated at four different settlement ratios i.e. *s/B* = 4%, 8%, 12% and 16%. It should be noted that the *IF* is synonym of bearing capacity factor (*BCR*) used by many researchers in their studies [11, 12]. Since the foundations are designed in accordance to the allowable bearing pressure of the soil, the computation of ultimate bearing capacity becomes substantial to correctly assess the increase in construction viability of the soil with applications of geosynthetics. [13] suggested a settlement ratio 10% to compute the ultimate nearing capacity of soil. In the present study, a double tangent method has been considered to compute the ultimate bearing capacity (*UBC*) of the soil in accordance with the IS code. To find out the optimum value of initial reinforcement depth, initially five tests were conducted on footing prototype supported by single layer of reinforcement. Fig. 3 (a-b) show the bearing pressure settlement curves for GGR1 and GGR2 respectively. As can be deciphered from the curves that bearing pressure of soil rises as *u/B* ratio increases. However, the increment in bearing pressure value is significant up to a value of *u/B* = 0.4 and beyond this value the bearing pressure rapidly decreases. The decrease in the bearing fastens, thus suggesting that any further rise in reinforcement depth would deteriorate the possible benefits of reinforcement.



(a)



(b)

Fig. 3 Pressure settlement curves for (a) GGR1 (b) GGR2

B. Effect of reinforcement layers (N) and influence depth of reinforcement (d)

A punching shear failure of the footing can be seen in Fig 4 (a) while Fig. 4 (b) shows the wedge formation above the last reinforcement layer, which confirms that the failure mechanism of reinforced silty clay is a punching shear failure in initial reinforcement zone followed by general shear failure in last reinforcement zone. Similar failure mechanism was observed by [14] when they tested the geogrid silty clay test bed. A chunk sample of reinforced soil was taken out from the tank after testing as shown in Fig. 4 (c), which indicates the supporting power of geosynthetics resulted in more load carrying capacity of foundation soil. For ascertaining the influence of increasing reinforcement layers in the improvement of load carrying capacity of soil, the top layer of reinforcement was fixed at 0.40B, i.e. the optimum top layer spacing, and the spacing between the reinforcements was varied at 0.40B, until the addition of additional layers of reinforcements does not have any significant benefit towards improving the bearing capacity or the optimum depth of reinforcement is achieved. The reinforcement depth ratio (d/B), which can be described as the ratio of the total effective reinforcement depth to the footing width (B) was ascertained for each reinforcement case. The depth of reinforcement (d) below the base of the footing is proposed by [1]

$$d = u + (N - 1) \times h \qquad (1)$$

Where u = first reinforcement depth below the base of footing, h = vertical spacing between two geosynthetic layers N = Number of geosynthetic layers. Effective depth of the reinforcement is the maximum depth beyond which any further addition of reinforcement does not have a significant development towards the bearing capacity. Initial test was carried out at D/B = 1.0 and β = 45˚. Fig. 5 (a-b) show the pressure settlement relationship for GGR1 and GGR2. As expected, the value of bearing pressure increases with increase in the number of reinforcement layers. Pressure settlement curves also show that effect of reinforcement becomes less substantial when fifth layer of reinforcement (i.e. d/B = 1.6) was added. Thus, signifying that beyond this depth, further addition of extra layers of reinforcement will not be viable towards any further settlement reduction. The probable reason of bearing pressure increment is increase in friction at the soil-reinforcement interface, which increases with the addition of reinforcement layers. [15] observed the similar behavior of geogrid and geotextile when they reinforced the earth slab.

C. Influence of slope angle (β) and edge distance (D)

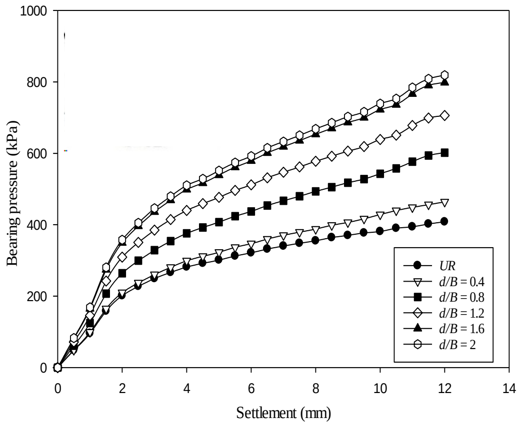
In the laboratory, different soil slope models were made and tested to check the influence of slope geometry on the load carrying capacity of reinforced soil slope. Fig. 6 (a-c) show the improvement factor vs u/B curves for different slope angles at D/B = 1. From the curves, the bearing capacity reduces as slope angle increases. Also, the change in the slope angles does not change or alter the position of the optimum depth of reinforcement with the depth remaining 0.4B for each of the cases, although the magnitude of improvement factor is the highest at β = 35˚. Three series of model footing tests were conducted to analyze the influence of D/B ratios on the bearing capacity of soil slope. The load carrying capacity increases as edge distance of the slope increases. The change in load carrying capacity with edge distance can be explained by the fact that as the distance from the slope increases, passive earth pressure increases. The effect of slope angle (β) is diminished when the load is located at an edge distance of two times of loading area. Fig.7 shows that highest improvement in load carrying capacity is obtained when the reinforcement is located at the slope crest without providing any slope edge distance in the case of a single layer reinforcement, located at u/B = 0.40. Although the improvement in load carrying capacity is more than that obtained for D/B = 1 and 2, the magnitude of bearing capacity is much greater in case of the latter. This observation can be attributed to the greater tensile force mobilized in the reinforcements at D/B = 0 due to greater settlement of foundation soil overlying the reinforcement layer, which prevents lateral deformation and facilitates better improvement in bearing capacity. However, the overall magnitude of the bearing capacity increases with increase D/B ratio.

(a)

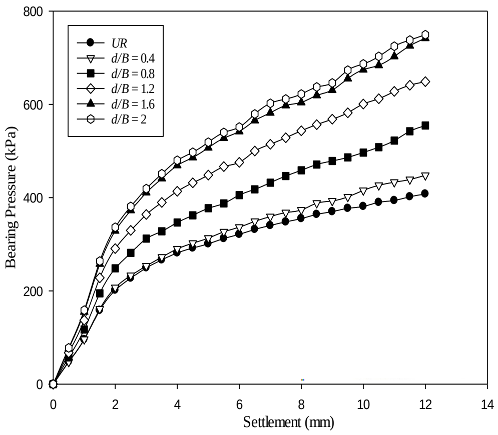
(b)

(c)

Fig. 4 (a) Punching failure of footing (b) soil wedge formation (c) soil wedge retained by geosynthetic

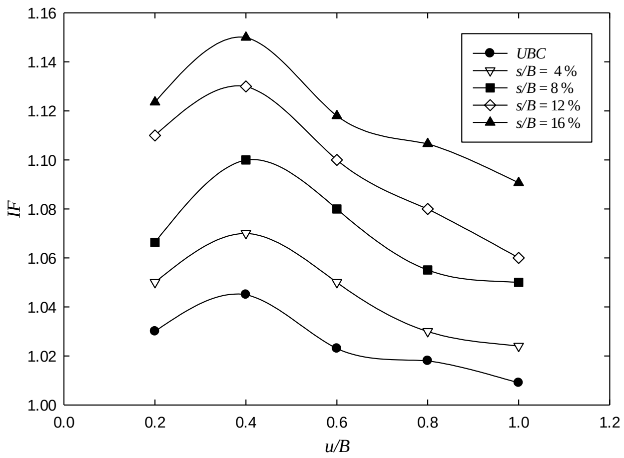


(a)

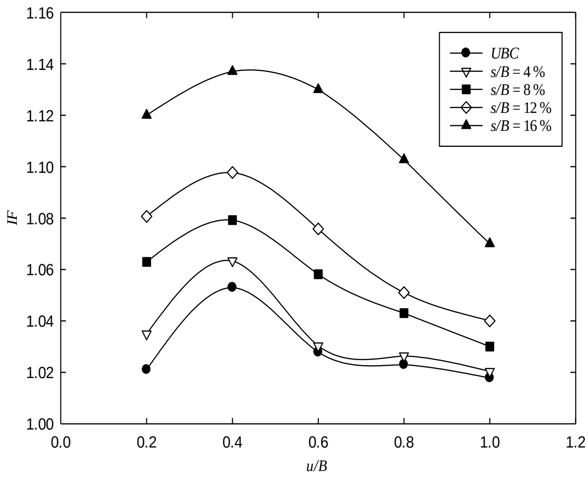


(b)

Fig. 5 Pressure settlement curve for (a) GGR1 (b) GGR2 for *d/B*



(a)



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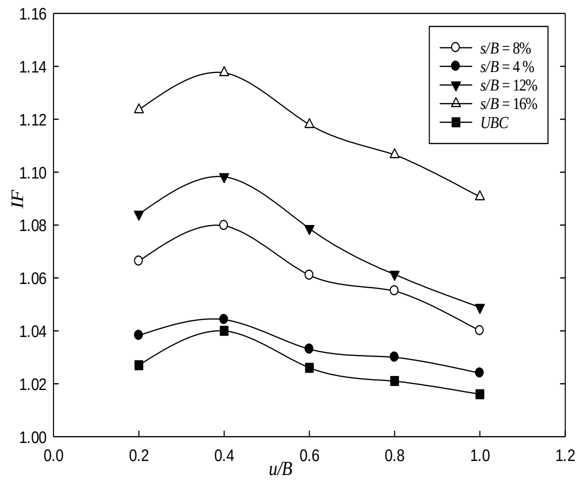

(c)

Fig. 6. Improvement factor curves for (a) β=35˚ (b) 40˚ (c) 45˚

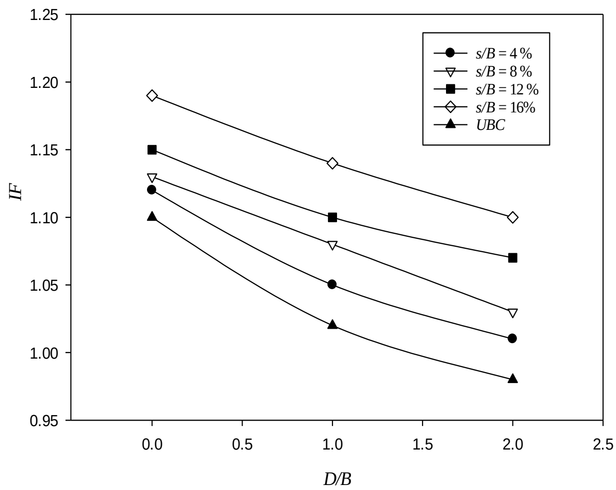

Fig. 7. Improvement factor versus *D/B* curve

V. CONCLUSION

The study demonstrates that the both geosynthetics i.e. 3D geogrid and glasgrid can be significantly utilized as a reinforcing material in an optimum way to assure a win-win condition. Based on the experimental work following conclusions were drawn from the study.

1. The maximum benefit of reinforcement in case of single layer of reinforcement was availed when the reinforcement layer was placed at u/B = 0.4. This signifies that the reinforcement requires a cover to mobilize the tensile strength.
2. The maximum number of reinforcement layers were obtained at N= 4 for both the reinforcements. After testing for reinforcement at a deeper point, the increase in bearing capacity was not substantial. Thus, signifying the presence of an optimum number of reinforcement layer beyond which inclusion of a geosynthetic is not viable.
3. Maximum bearing capacity was achieved at $\beta = 35^\circ$, with respect to β=40˚ and 45˚.
4. A substantial improvement in bearing capacity was found at D/B = 0. However, the highest magnitude of bearing capacity was obtained as the distance between the loading area and the slope edge increased.
5. GGR1 performed better than GGR2 at every settlement ratio, viz. via. s/B =4%, 8%, 12% and 16%. Thus, signifying that mechanical properties of the geosynthetics such as aperture size, tensile strength and tensile modulus have a significant role in reinforcement efficiency of the geosynthetic.

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