The effect of reinforced soil type on the value of bearing ratio

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ABSTRACT

Generally; the most commonly used method to cover the required bearing ratio of soil is achieving up to 100% of its relative density. The use of appropriate soils and heavy dynamic rollers may not be possible in some situations. The effect of soil types and geosynthetic materials on the bearing ratio of reinforced soils was studied in a condition where the relative compaction of soil was 90%, because it can easily be attained. Three types of soil and two types of geosynthetic reinforcement have been evaluated. It was clarified that, if the geocell and geogrid were designed with an optimal shape, depending on soil's particles size, and placed in the appropriate depth, a significant effect will occur on the CBR value. Weaker soils, especially in the saturated condition, achieved more benefit from reinforcement; and the CBR increment of reinforced soils, decrease with increase in the depth of the geogrid position. However, the CBR increment due to use of geocell was greater than the geogrid affect. Also, it was found that the unreinforced soil resistance against the piston penetration was fixed approximately, while in reinforced cases; by piston penetration, tests show a growth in soil resistance. So, the CBR value of reinforced soil with a lower relative density would finally become equal or even more than the denser unreinforced soil.

Keywords: Reinforced pavement; Geogrid; Geocell; CBR

1 INTRODUCTION

Since, access to suitable materials is not always possible, and also, in some cases, the densification of the soil layers due to the sensitivity of project is impossible, it is necessary to find other solutions in order to achieve the required bearing ratio of the soil.

Soil has good compressive strength, relatively good shear strength, but without tensile strength. So, soil reinforcement is done by increasing tensile strength of soil to compensate the main weakness of the soil. The purpose of this study is investigating the effect of soil particle properties and geosynthetics reinforcement characteristics on the soil bearing ratio based on the California method while relative density of 100% cannot be gained.

Williams & Okine (2008), after studying on four geogrid-reinforced soils, found that the soil reinforcement improves the shear strength of interface and reduces the lateral propagation of forces; and would have more benefit on low CBR soils. In 2011, Mohamed M. Mekkawy et al., stated that the amount of CBR of the subgrade layer would always increase with increasing density. The result of test performed in 2013 by Kuity & Kumar Roy indicated that, saturated CBR increased significantly; unlike dry CBRs. In 2014, Abdi and Etefagh, in a study on various types of soil and geogrid, stated that, for each soil, there is an optimal size for the geogrid pockets, which it depends on the average particle size of soil. In 2014, Asha & Madhavi Latha, stated that he geocell has more positive effect in comparison with the geogrid. Also, in 2014, Manju and Madhavi Latha showed that, with the increase in the ratio of height to diameter of the geocell, the resistance properties of the reinforced soil were improved. The result of studies by Rajesh et al., in 2016, showed that the tensile strength and interaction of reinforcement would be governed on the resistance against piston penetration. In fact, Geocell effectively provides lateral confinement to infill material to increase the modulus and bearing capacity of base courses (Pokharel et al, 2018).

2 MATERIALS AND METHODS

2.1 Soil

The experiments are performed on three different gradations of soils. These gradations include types A, B, and F; provided in the AASHTO M 147. All test samples were prepared from the north of Semnan, Iran. In Fig. 1, the gradation of soil extracted from the mine and the specimens prepared therein are shown; and the physical and mechanical properties of the soils used in this study are summarized in Table 1.

2.2 Reinforcement material

Reinforcements are made from available polymeric materials; for this purpose, tests of determination of tensile strength, relative elongation and stiffness were carried out on several polymer specimen sheets, and two specimens with the properties of Table 2 are selected to make geogrid and geocell.

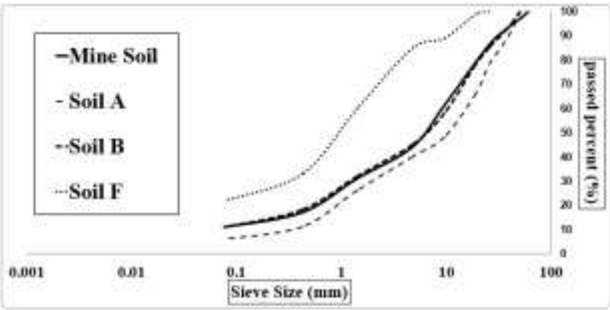

Fig. 1. Grain size distribution curves of mine soil and test specimens.

Table 1. Engineering properties of prepared samples.

Soil type		Mine sample	Remolded sample type		
			A	B	F
Average size	D_{50}	6.47	11.0	6.70	0.95
Maximum nominal size	D_{90}	31	40	33	11
sand equivalent	S.E	22	37	22	22
Fine content	F.C.	11	6	11	22
Maximum dry density	$\gamma_{d,max}$	-	22.66	22.17	20.89
Optimum water content	$\omega_{opt.}$	-	4.8	5.1	7.1
CBR90 (unsaturated)	CBR	-	80	70	32
CBR90 (saturated)	CBR	-	66	15	9

Table 2. The features of selected reinforcement elements.

Sample No.	1	2
Application	Geogrid	Geocell
Symbolic name	GG	GC
Thickness (mm)	0.33	0.5
Weight per unit area (N/m2)	3.7	6.2
Yield strength (N/m)	736	1620
Ultimate strength (N/m)	1471	3165
Elongation at the yield strength (%)	8.2	10.9
Elongation at the ultimate strength (%)	95.7	95.1
Elasticity modulus per unit width (N/m)	3674	10270

2.3 Test equipment

An electric jack and one analog measurement displacement gadget with a precision of 0.25 mm is used in the tests to determine the California Bearing Ratio (CBR).

2.4 Reinforcement elements

2.4.1 Geogrid

Geogrid elements were made by cutting the square pockets from inside sample No. 1. Dimensions of these elements were considered 2 cm larger than CBR mold in order to reduce the boundary effects and preventing it from slipping during tests.

Based on Abdi & Etefagh (2014), the calculated optimum opening ratio of the pockets is presented in Table 3.

Table 3. Dimension of geogrid optimum opening size.

Soil type	D_{50}	Opening ratio	Optimal size (mm)	implemented size (mm)
F	0.95	15.15	14.4	15
B	6.7	4.80	32.1	30
A	11.0	3.58	39.4	40

2.4.2 Geocell

The geocell is a three-dimensional product of geosynthetics family, made of polymer materials, and these polymer bands are connected at certain intervals (Zhang et al, 2010).

Two points were considered in the geocell construction: 1) Geocell dimensions cannot be smaller than the maximum nominal size of soil's aggregates. 2) For an aspect ratio greater than one, 90% soil density cannot be achieved inside the cell. So in the experimental works of this study, the diameter of the geocell pockets considered as 1.5 times the nominal grain size of the soil (D90). The height of the pockets considered equal the diameter. The dimensions of the constructed geocell are summarized in Table 4.

Table 4. Dimensions of geocell based on the maximum nominal particle size of soil.

Soil type	D90 (mm)	Diameter & Height (mm)	Final Dimension (mm)
A	11	16.5	25
B	33	50	50
F	40	60	60

2.5 Test method

CBR experiments were carried out in dry and saturated conditions on unreinforced and reinforced soil specimens with a relative density of 90% of the maximum dry density of modified AASHTO. Geogrid reinforced specimens were tested with three positions of reinforcing element at 2.5, 5, and 7.5 cm depths from the soil surface, as well as the geocell, was also placed in a way that the distance between the upper edge of reinforcement and the soil surface is 2 centimeters.

3. RESULTS AND DISCUSSION

3.1 load-penetration curves

Investigation of the load-penetration curves for different soils in saturated and optimum moisture conditions indicates an increase in the strength of coarser aggregates against standard piston penetration. The results also show the positive effect of both types of reinforcements on soil bearing value. In the case of geogrids reinforced soils, the closer reinforcement elements to the soil surface, the more tangible effect on the bearing growth. For the reinforcement position of 7.5 cm (the height of the CBR mold is equal to 10 cm), the difference in the strength of reinforced soil in comparison with unreinforced soil is negligible. Figure 2 depicts the load-penetration changes, in the case of soil B, with the increase of the standard piston penetration as an example. As it is known, more increment in the standard piston penetration, result in more difference between the reinforced and unreinforced soils strength. Additionally, in larger penetration rates, the difference between the reinforced soil strength in the use of geocell and geogrid embedded in 2.5 cm, is considerable, while, up to the depth of 4 mm, their changes is almost the same.

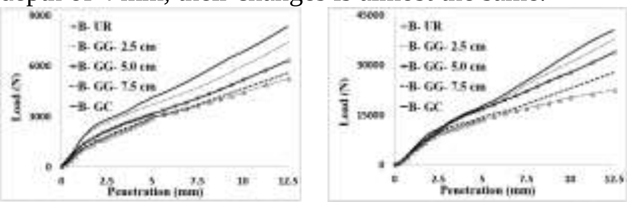

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Figure 2. Load-Penetration curves for; a. Soil B (saturated), b. Soil B (unsaturated)

In 12.5 mm penetration of the standard piston, the increment in the value of load imposed on the geogrid reinforced samples placed at a depth of 2.5 cm was 62% while in the case of reinforcing with geocell was 76%. These growth rates were 68 and 80% for soil B, and 80 and 102% for the soil F, respectively, using geogrid and geocell. In the saturated samples, resistance increment was obtained 76% for both reinforcement elements in the soil A; for the geogrid reinforced soils B and F, the growths were 41 and 118% and for geocell ones, 59 and 150 % in the applied load values were observed. The results indicate that the amount of applied load for 12.5 mm penetration of the piston in unreinforced soil A, is 20% higher than that of B, in optimum moisture content; while, in the reinforced cases, the increase of 16 and 17% have been found, in the use of geogrid and geocell, respectively. As a comparison, in the saturated state, it is measurable that the load value for 12.5 mm penetration of the piston for soil A was 3.2 times of that for soil B in unreinforced condition and 4.3 and 4 times in reinforced condition with geogrid and geocell, respectively. The ratio of the forces value in Soil A obtained, was 7.5, 5.8, and 5.3 times of those for saturated Soil F in unreinforced and reinforced with Geogrid and Geocell respectively.

3.2 Effect of water existence on CBR

The results have been shown that the negative effect of saturation on the soil compression strength against penetration, in the case of fine-grained soils (soils B and F) is more in comparison with granular soils with the higher sand equivalent (soil A). Figure 11 presents the decrease of compressive bearing after saturation for different types of reinforced and unreinforced soils in percentage. Additionally, the results indicate that, although the CBR value of reinforced soils containing fine grains (soils B and F) shows a substantial increment in the saturated state compared to unreinforced soil, but there is not a significant difference between the rates of CBR reduction of soils due to saturation. The point is that, in dry condition, there are coarse aggregates in the soil that perform the governor role to increase the CBR value. As can be seen in Fig. 3, the amount of CBR loss in effect of saturation is about 80% in soil B and 70% in soil F, and there is not a difference between the reinforced and the unreinforced conditions; while this reduction rate for clean soil A in the unreinforced state is only 18%, which is limited to 11 and 13%, by reinforcing with geogrid and geocell, respectively.

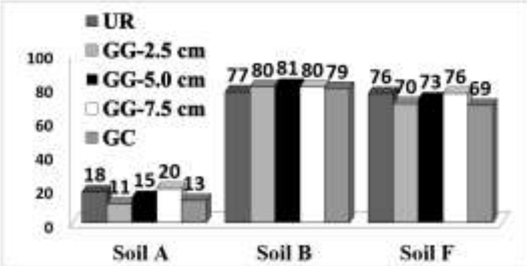
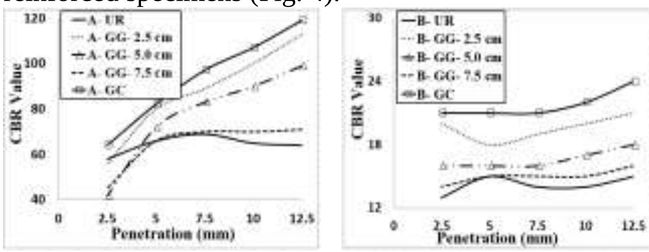


Figure 3. Effect of saturation on CBR reduction rates

3.3 Changes in CBR vs. increasing depth of penetration

In AASHTO T 193, the maximum CBR values were reported for 2.5 and 5.1 mm of penetrations; but, this idea is not confirmed in the case of reinforced soils, due to the more mobilization of forces in large settlements. It is observed that the curve slope of CBR vs. penetration is great for the clean soil of A; but for the soils B and F, the slope is mild for the geogrid reinforced specimens (Fig. 4).



a b

Figure 4. CBR changes vs. piston penetration for a. Soil A (saturated), b. Soil B (saturated)

3.3 Road designing CBR

The amount of CBR used in the roads designing is the larger value of the corresponding values of 2.5 or 5.1 mm. The positive effect of geogrid reinforcement, embedded at various depths, on the CBR increment for different soils, in comparison with geocell effect is shown in figure 5.

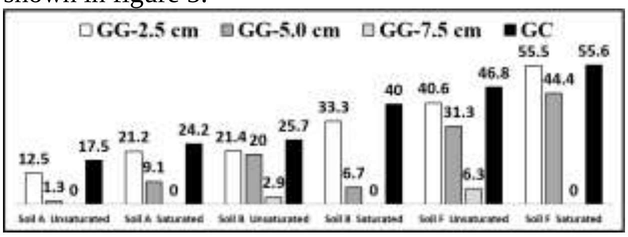


Figure 5. Effect of reinforcing on designing CBR

3.4 Comparison of CBR of reinforced and denser unreinforced soils

CBR value for soils with 100% relative density is significantly more than that for reinforced soils with 90% but by increasing the amount of penetration, these values would be matched together and even for geocell reinforced sample could be more than the denser unreinforced sample (see figure 6).

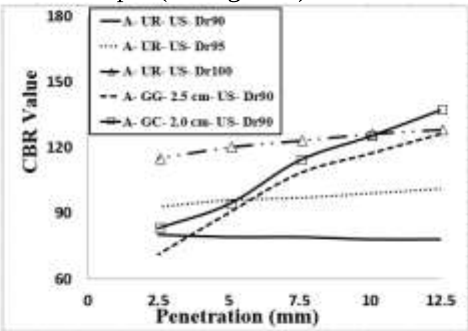


Figure 6. CBR of denser soil vs. reinforced samples

4. CONCLUSION

Three types of soil in various conditions of unreinforced, geogrid, and geocell reinforced were examined in the CBR tests in order to evaluate the reinforcement effects on bearing ratio of the soil types. After studying about the results of the experiments, it was observed that the amount of CBR of reinforced soils is greater than unreinforced specimens due to decreasing the lateral movement under the standard piston as a result of confinement effect of reinforcement; in other words, reinforcement increases the shear strength of the soil. The decrement of saturated CBR relative to unsaturated condition depends on the drainage properties and the cleanliness of fine aggregates, rather than reinforcement function. Unlike the unreinforced state, in the case of reinforced soils, the CBR rate increases during piston penetration because more resisting forces are mobilized below the standard piston in larger displacements. The most important results could be stated as follows:

The bearing ratio of geogrid reinforced soil increases with decreasing depth of the geogrid. At the depth of 2.5 cm, the average increment for different types of soil in optimum moisture and saturated condition is 30% and, at 7.5 cm, the reinforcement does not have an effect on the CBR.

Geocell has a more positive effect on the CBR in comparison with geogrid. The increment of CBR in geogrid-reinforced soils is 12.5%, 21.4% and 40.6% in optimum moisture of A, B and F soils, respectively. While in geocell reinforced samples, these values were 17.5%, 25.7% and 46.8% in optimum moisture content for A, B, and F soils, respectively.

In cleaner sandy materials, not only a decrease in the amount of CBR, due to saturation, is much less than that of soils which contain silt and clay, even this less effect can also be reduced by the reinforcement. This reduction for clean soil A is only 17%, which is even reduced by 30%, using reinforcement. But the decrease in the amount of CBR, due to the saturation, reaches up to around 70-80% for soils B and F, which the reinforcement did not have any effect on this amount.

Also, the results indicate that the effect of reinforcement is more, in the poor soils especially in saturated conditions. In F soil, as a loose one, both geogrid and geocell reinforcements increased the saturated CBR by 56 percent, while The CBR value of soil A, in the optimum moisture condition, increases by 12 percent and 17 percent by using geogrid and geocell respectively.

Increasing the density of unreinforced soil increases its CBR, but in larger amounts of penetration, the bearing ratio of reinforced soil with less density will be equivalent to it, or it may be more.

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