Effect of Plasticity Index and Reinforcement on the CBR Value of Soft Clay

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Abstract: *In recent years, soil reinforcement is considered of great importance in many different civil projects. One of the most significant applications of soil reinforcement is in road construction. Sub grade soil and its properties are very important in the design of road pavement structure. Its main function is to give adequate support to the pavement from beneath. Therefore, it should have a sufficient load carrying capacity. The use of geosynthetics in road and airfield construction has shown the potential to increase the soil bearing capacity. One category of geosynthetics to particular, geogrid, has gained increasing acceptance in road construction. A geogrid is a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow strike-through of surrounding soil, stone, or other geotechnical material. Geogrid reinforcement of sub grade soil is achieved through the increase of frictional interaction between the soil and the reinforcement. Geogrid have been successfully used to provide a construction platform over subgrades. In this application, the geogrid improves the ability to obtain compaction in overlying aggregates, while reducing the amount of material required be removing and replacing. Relative agreement exists that substantial benefits can be achieved from the inclusion of geogrids within the pavement systems; however, the quantity of the improvement is in relative disagreement. This paper presents the effects of plasticity index and also reinforcing of soft clay on CBR values. Three samples of clay with different plasticity index (PI) values are selected and tested without reinforcement. Then by placing one and two layer of geogrid at certain depth within sample height, the effects of reinforcement and PI on CBR values are investigated in both soaked and unsoaked conditions. The results shows that as the PI increase the CBR value decreases and reinforcing clay with geogrid will increase the CBR value.*

Keywords: *Plasticity index, CBR value, reinforcement, geogrid, soft clay*

1. Introduction

Engineering are continually faced with maintaining and developing pavement infrastructure with limited financial resources. Traditional pavement design and construction practices require high-quality material for fulfillment of construction standards. In many areas of the world, quality material is unavailable or in short supply. Due to these constraints, engineers are often forced to seek alternative design using substandard materials, commercial construction aids, and innovation design practices. Concrete or asphalt pavement can not be constructed on weak soil, because in this case the pavement will be easily cracked. As sub grade soil function is to transfer applied loads from pavement to the layer beneath, it should have a sufficient load carrying capacity.

There are a lot of places all over the world where clayey soil can be found. Design and construction of pavement over this weak and expansible kind of soil is quit challengeable and problematic for geotechnical engineers. One category of commercial construction aids is geosynthetics. Geosynthetics include a large variety of products composed of polymers and are designed to enhance geotechnical and transportation projects. Geosynthetics, as applied to flexible pavement systems, have been widely used in recent years. Geosynthetic reinforcement is typically placed in the interface between the aggregate base course and the subgrade. Geosynthetics perform at least one of five functions: separation, reinforcement, filtration, drainage, and containment. One category of geosynthetics in particular, geogrids, has gained increasing acceptance in road construction. A geogrid is defined as a geosynthetic material consisting of connected parallel sets of tensile ribs with apertures of sufficient size to allow

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strike-through of surrounding soil, stone, or other geotechnical material. Existing commercial geogrid products include extruded geogrids, woven geogrids, welded geogrids, and geogrid composites. Extruded geogrids are formed using a polymer sheet that is punched and drawn in either one or two directions for improvement of engineering properties. Woven geogrids are manufactured by weaving polymer fibers, typically polypropylene or polyester, that can be coated for increased abrasion résistance. Welded geogrids are manufactured by welding the junctions of woven segments of extruded polymers. Geogrid composites are formed when geogrids are combined with other products to form a composite system capable of addressing a particular application. Extruded geogrids have shown good performance when compared to other types for pavement reinforcement applications.

The presence of high friction not only prevents the sliding between soil and geogrid element, but also helps the process of transferring stress from soil into the reinforcement element. Lack of integrity of geogrid in different levels causes some types of interlocking with soil particles. In addition, it's the little stiffness of geogrids that makes it possible to refer the increase in strength properties of soil to tensile strain created in geogrids. Using reinforcements in sub grades can increase safety coefficient of embankment stability and also decrease displacements. Furthermore, if the weak sub grade is stabilized or reinforced, the crust thickness required will be less, which results in less repairs and overall economy.

As it is known, in road construction, one of the most significant parameters for designing road sub grades is CBR value. In some projects, because of soft clay soils, CBR value is low, thus different methods such as reinforcing with geogrids are used to improve soil behavioral characteristics. The purpose of soft clay on CBR values.

2. Literature survey

Rao et. al. [1], Shetty [2], Rao and Raju [3], Gopal Ranjan and Charan [4] presented the results of series of laboratory CBR tests (soaked and unsoaked) on silty sand (SM) reinforced with randomly distributed polypropylene fibers. The test results showed that the CBR value of the soil increase significantly with increase in fiber content. The increase in CBR was observed to be 175% and 125% under soaked and unsoaked conditions, respectively with addition of 3% fibers (by weight).

Benson and Khire [5] showed that there is an increase in CBR and secant modulus of sand when cut pieces of waste milk jugs is used for reinforcing. Cancelli et. al. [6]; Montanelli et. al. [7], Perkins and Ismeik [8] analyzed the results of a full scale pavement test conducted on several reinforced sections by use of geogrids in saturated silty clay soil having the CBR value of about 1% to 8%. The test results showed that the multi layer geogrids provide the best base reinforcement results for sub base soil having CBRs equal to 3% or lower. No major differences were found between different single layer integral geogrids. The higher tensile modulus geogrids have shown better contribution at CBRs 3% or lower. The percent reduction of rutting, between reinforced and unreinforced sections, increases with reducing the sub grade CBR, for all geosynthetics. The traffic improvement factor for road service life increases for deep allowed ruts, lower CBR values and lower pavement structural number.

Montanelli et. al.[7] , by placing geogrid between gravel base course and sand subgrade showed that with increase in CBR value of subgrade, the amount of vertical settlement under loading decreases. Another result of their study is that, the difference of settlement between reinforced and unreinforced specimen in CBR value less than 3 is much higher than the CBR value of more than 3. Besides, the amount of settlement in reinforced specimen with 300 mm base course is less than unrinforced specimen with 400 mm base course

Kumar et al. [9], based on their laboratory investigations conducted on silty sand and pond ash specimens reinforced with randomly distributed polyester fibers, concluded that the fibers increased the CBR value and ductility of the specimens. They also reported that the optimum fiber content for both silty sand and pond ash was approximately 0.3%-0.4% of dry unit weight.

Bergado, et. al. [10], performed CBR tests on soft and weathered clay overlain by compacted sand. The specimens were reinforced by geotextile with different stiffness between clay and sand. The results indicated that using geotextile in soil increase bearing capacity of soil. By increase in loading speed and geotextile stiffness, the load value increases in certain strain. (i.e. CBR value increases)

Gosavi, et. al. [11], Mittal and Shukla [12] investigated the strength behavior of locally available black cotton soil reinforced with randomly mixed geogrid woven fabric and fiberglass. CBR value of black cotton soil is 4.9% without geogrid. Soaked California Bearing Ratio test results show considerable increase in the CBR value for black cotton soil when reinforced. CBR value of black cotton soil increases 42% to 55% when 1% woven fabrics and fiberglass, respectively are added randomly. The rate of increase in CBR value with 2% addition of fibers is less and the absolute value of CBR still decrease with more addition of fibers. Increase in CBR value is more for higher aspect ratio of fibers. This may be because of higher tensile strength of the woven fabrics. For addition of 3% woven fabrics the rate of increase in CBR value decreases. Increase in the CBR value is due to the compaction characteristics of the fiber reinforced soil. It was resulted that for flexible pavement design, the higher value of CBR of sub grade soil gives lesser pavement thickness and which proves to be economical solution in the pavement construction.

Yetimoglu and Inanir [13] performed CBR tests to investigate the load–penetration behavior of sand fills reinforced with randomly distributed discrete fibers overlying soft clay. The test results indicated that adding fiber inclusions in sand fill resulted in an appreciable increase in the peak piston load. The reinforcement benefit increased with an increase in fiber content. However, the initial stiffness of load–penetration curves was not significantly affected by fiber reinforcement. The penetration value at which the piston load was the highest tended to increase with increasing fiber reinforcement content. In addition, the test results showed that increasing fiber reinforcement content could increase the brittleness of the fiber-reinforced sand fill–soft clay system providing higher loss of post-peak strength.

Dutta and Sarda [14] carried out an experimental study to investigate the CBR behavior of waste plastic strip reinforced stone

Table 1 Properties of the tested soil specimens

Soil Type	Color	Maximum Dry Density (MDD) (KN/m^3)	Optimum Moisture Content (OMC) (%)	Gs	LL (%)	PL (%)	PI (%)
CL	Brown	19.4	11.4	2.62	25.5	15.5	10
CL + 10% Bentonite	Light Brown	18.8	12.2	2.60	34.9	18.9	16
CL + 20% Bentonite	Gray	18.2	13.9	2.57	46	23	23

Table 2 Properties of the used geogrid

Type of Geogrid	Material	Color	Working Temp. (˚c)	Std.weight (g/m^2)	Tensile Strength (kN/m)	Mesh Aperture (mm)	Mesh Thickness (mm)
GS- 50	LDPE	Black	-50/+85	300	0.91	2	1

Table 3 CBR tests results

PI (%)	Moisture Content ω (%)		Degree of Saturation for soaked specimens (S) (%)	CBR (unsoaked) (%)			CBR (soaked) (%)		
	Unsoaked	Soaked		Without Geogrid	Geogrid in top of layer 3	Geogrid in top of layers 2 & 4	Without Geogrid	Geogrid in top of layer 3	Geogrid in top of layers 2 & 4
10	11.4	16	99	55.3	77.1	68.4	4.4	5.61	6.00
16	12.2	19	97	50.6	70.8	65.5	1.5	1.73	2.03
23	13.9	23	97	44.6	61.9	62.7	0.9	0.92	1.20

dusty ash overlying saturated clay. Test samples were reinforced by different plastic strip content (0.25% to 4%) and various lengths. The study reveals that addition of waste plastic strip in stone dusty ash overlying saturated clay resulted in an appreciable increase in the CBR value. Besides, adding more than 2% of reinforcement does not improve the CBR appreciably. Reinforced stone dust is more effective than reinforced fly ash.

3. Tested material

Soft clay soil specimens were collected locally from Khatoon Abad (Located in Semnan road). Different percentages (10 and 20%) by weight of Bentonite were used as a material for changing plasticity index of clay soil samples. The properties of the soil tested are shown in Table 1. Geogrid type GS-50 was used as the reinforcing material. Properties of the used geogrid are given in Table 2.

4. Experimental study

The experimental study involved performing a series of laboratory CBR tests on the unreinforced and geogrid reinforced clay specimens. Three samples of clay with different plasticity index values are selected and tested without reinforcement to determine the effect of plasticity index on CBR values. Then by placing one and two layers of geogrid at certain depth within sample height, the tests were carried out. All tests were performed inside a modified proctor mold at soaked and unsoaked condition according to ASTM-D 1883 [15]. The mold was a rigid metal cylinder with an inside diameter of 152 mm and a height of 178 mm. A manual loading machine equipped with a movable base that traveled at a uniform rate of 1.27 mm/min and a calibrated load indicating device were used to force the penetration piston with a diameter of 50 mm into the specimen. The test specimens were compacted in accordance with the procedures given in ASTM-D 1557 using modified effort. The clays at the optimum water content (OMC) were placed in 5 layers within CBR mold. Each of the layers were compacted by 56 blows of a 44.5 N rammer dropped from a distance of 457 mm.

The original soft clay with PI of 10% collected from Khaton Abad area. The soil samples are compacted in CBR mold at its optimum water content and then the CBR tests were carried out under soaked and unsoaked conditions. After that, the clay specimens were mixed with 10 and 20% (by weight) of Bentonite (PIs of 16 and 23% respectively) and completely blended until the specimen becomes homogeneous. The obtained samples are compacted at its optimum water content and tested under soaked and unsoaked conditions. In the next stage, the reinforced samples were prepared by inclusion of 1 layer (top of layer 3) and 2 layers (top of layer 2 and 4) of geogrid. The reinforced samples are also compacted and then the CBR tests were conducted under soaked and unsoaked conditions.

5. CBR test results

The results of soaked and unsoaked CBR tests on reinforced and unreinforced soil specimens with different plasticity indexes are presented in

Table 3 and Figures 1 to 6.

Figure 1 produce the soaked and unsoaked CBR values of unreinforced soil specimens with different plasticity indexes (10, 16 and 23%). As it is observed with increase in PI, the CBR value decreases for both soaked and unsoaked cases, because when the plasticity index of soil increases, the optimum moisture content (OMC) rises and the maximum dry density (MDD) decreases. Therefore, the soil strength decreases and its CBR value declines.

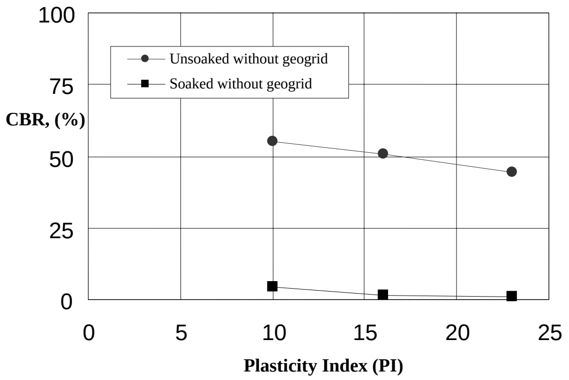

Fig. 1 CBR values for various PIs

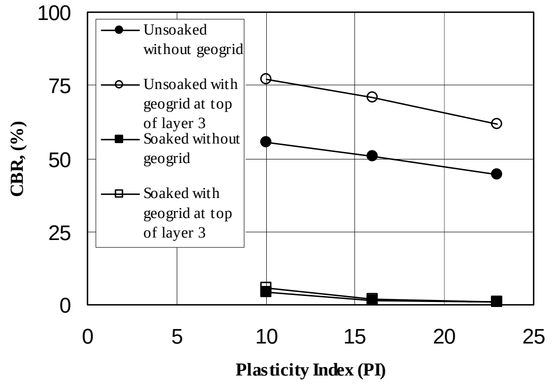

Fig. 2 CBR values for various PIs with geogrid in layer

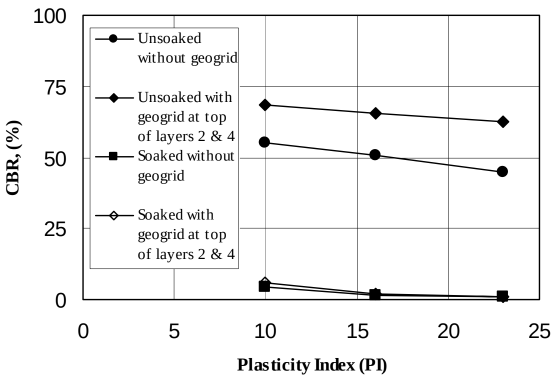

Fig 3. CBR values for various PIs with geogrid in 2 layers

Figure 2 shows the results of CBR tests for one layered reinforced soil. The CBR value increases in both soaked and unsoaked conditions compared with unreinforced case. As it is expected, the unsoaked CBR value is more than soaked one in various plasticity indexes. For example, for PI= 16, the soaked CBR value decreases 97.6% as compared with unsoaked one.

Figure 3 presents the CBR test results for two layered reinforced soil samples (at top of layer 2 and 4). As it is expected unsoaked CBR is more than soaked CBR. In this case, soaked and unsoaked CBR is also increased compared with the state of unreinforced specimens. For example, for PI=23, by placing geogrid at top of layer 2 and 4, the CBR value increases about 40.6% and 33.3% respectively.

The unsoaked CBR values of different reinforced conditions of soil samples are compared in Figure 4. The CBR value of unreinforced soil with PI=10 is 55.3 which in case of adding geogrid in one layer it increased by 39.42%. If geogrid is placed in top of layer 2 and 4, the CBR value becomes 23.69%. Similarly, for soil specimens with plasticity indexes of 16% and 23%, the CBR value without geogrid is 50.6 and 44.6 which in case of being reinforced in one layer, it increased by 39.92% and 38.79% respectively. If geogrid is placed in 2 layer, the CBR value increases by 29.45% and 40.58% in comparison with the initial state.

In Figure 5, the CBR values in different reinforced soaked conditions are evaluated. It can be inferred that for PI=10%, geogrid inclusion at the top of layer 3, causes 27.5% increase in comparison with the state of having no geogrid. In two layered reinforced samples, the CBR value increases by 36.36% compared with the case of no geogrid. It should be pointed out that mostly similar results were obtained for PIs of 16 and 23%. Based on obtained results, the soaked CBR values increase in both one and two layer reinforced samples.

The proportion of CBR value of reinforced specimen to CBR value of unreinforced specimen is considered by CBR ratio. It can be found that by placing geogrid at one layer in unsoaked condition, the CBR ratio in various PIs grows considerably as compared with the state of placing geogrid at 2 layers (Figure 6). By placing geogrid at one layer, more braced forces are produced in geogrid compared with two layered condition and interlocking between soil and geogrid increases. However, in the soaked condition, the samples with 2 layer geogrid shows upper CBR ratio in comparison with geogrid at one layer.

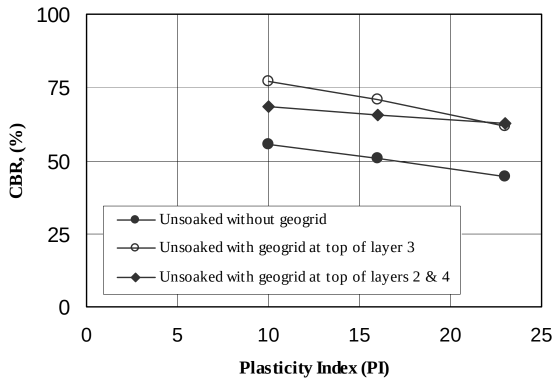

Fig. 4 Comparison of different kinds of reinforcement in CBR tests for various PIs

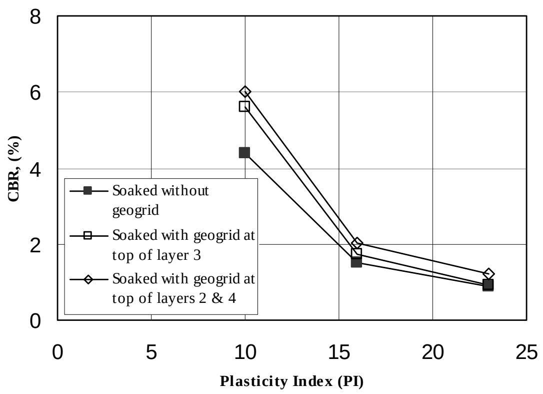

Fig. 5 Comparison of different kinds of reinforcement in CBR tests for various PIs

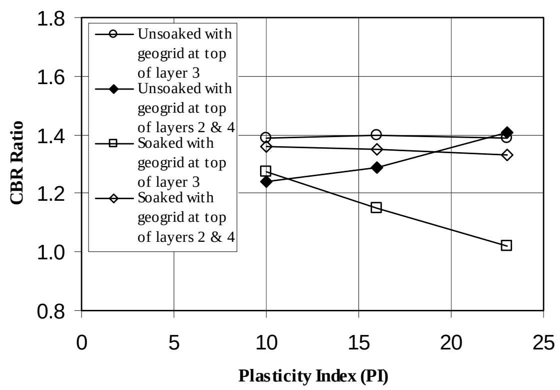

Fig. 6 CBR ratio in soaked and unsoaked tests with different kinds of reinforcement

6. Conclusions

In this study three types of soil with various plasticity indexes of 10, 16 and 23 that it is achieved by adding different percents of bentonite (10 and 20%) to original clay soil are used. The samples were initially tested without geogrid in soaked and unsoaked conditions. Then by placing a single layer of geogrid at the second layer of the sample, CBR tests were performed on the reinforced soil. Consequently, geogrid was placed at the first and the third layer and CBR tests were repeated. The testing results obtained from this research program present the fallowing conclusions:

1- With increase of PI in all reinforced and unreinforced specimens the CBR value of soaked and unsoaked soil samples decreases. As the plasticity index of soil increases, the optimum moisture content (OMC) rises and the maximum dry density (MDD decreases. Therefore, the soil strength decreases and its CBR value declines.

2- Using single layer of geogrid at top of layer 3 in different PIs causes a considerable increase in CBR value compared with unreinforced soil in both soaked and unsoaked conditions.

3- Using two layers of geogrid at top of layers 2 and 4 causes an increase in unsoaked CBR value compared with unreinforced soil but this increase is less than the case in which geogrid is placed at top of layer 3. However, in this case, the soaked CBR value is more than both unreinforced and one-layered geogrid specimen.

4- Inclusion of one layer geogrid (at top of layer 3) in unsoaked soil samples with different PI values causes 40% increase in CBR results compared to unreinforced soil samples. While, for two layered geogrid inclusion (at top of layers 2 and 4) the CBR values increases 24, 29 and 40% for PI values of 10, 16 and 23% respectively. Thus, placing one layer of geogrid at top of layer 3 (near the surface) has more effective performance in unsoaked condition. However, in soaked conditions the CBR values for two layered geogrid inclusion (at top of layers 2 and 4) increase about 35% at different PI values, which is more than one layered geogrid inclusion (at top of layer 3). Therefore, in soaked condition, placing 2 layers of geogrid (at top of layers 2 and 4) is more effective in the CBR values.

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