1-1-2012

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Proceedings of Indian Geotechnical Conference
December 13-15,2012, Delhi (Paper NO B-214)

Improvement in CBR of the Expansive Soil Subgrades with a Single Reinforcement Layer

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ABSTRACT: The performance of a pavement is very sensitive to the characteristics of the soil subgrade, which provides a base for the whole pavement structure. It is therefore of utmost importance that the performance of such pavements is improved by adopting proper design and construction methodology. This paper presents the results of a series of California bearing ratio (CBR) and swell tests to evaluate the beneficial effects of placing a single layer of reinforcement horizontally at varying depths from the top surface of the subgrade soil. The position of the reinforcing layer is optimized for two different types of reinforcement namely, geogrid and jute geotextile. Results revealed that insertion of a single layer of horizontal reinforcement placed within the specimen at certain specified depth from the top of the compacted specimen not only controls the swell potential significantly but also improves the CBR value considerably.

INTRODUCTION

Problems associated with pavement construction become more critical when the subgrade consists of expansive soils. In India, expansive soils cover about 0.8×10^6 Km^2 area, approximately one fifth of its surface area [1]. It is therefore of utmost importance that the performance of such pavements is improved by adopting proper design and construction methodology. Reinforced earth technique is now being widely used for various geotechnical engineering applications. However, the application of reinforced earth in the construction of pavements especially over poor and problematic subgrades is limited. Several researchers have conducted investigations using different types of reinforcements and materials and reported that the provision of a geomembrane layer can effectively restrain the heave and swell pressure of underlying expansive soil [1]. Geosynthetics made from synthetic fibers are preferred over other reinforcing materials in case of important highway projects because of their strength and durability; however, these materials are expensive resulting in higher project cost and may not be environmental friendly in due course of time under adverse condition. On the other hand, geotextiles made from natural fibers such as jute, coir, sisal, and palm may provide an economical and ecofriendly substitute to geosynthetics for low cost road projects in rural areas, especially where they are easily available. This paper describes results of a series of CBR and swells tests to evaluate the beneficial effects of placing a single layer of horizontal reinforcement at varying depths from the top surface of the expansive subgrade soil. The aim of the paper is to optimize the position of the reinforcing layer for two different types of reinforcement used in the investigation, namely- geogrid and jute geotextile.

EXPERIMENTAL PROGRAMME

Materials Used

The soil used in the present investigation was collected from UCIL, Jadugoda mines area, Jamshedpur. The grain size distribution curve of the soil is shown in Figure 1. Table 1 and 2 show physical properties of the soil and the reinforcing elements used in the investigation.

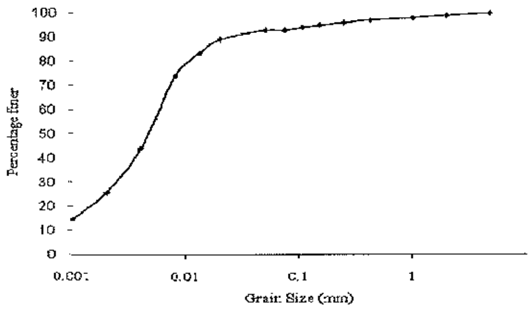

Fig. 1 Grain Size Distribution

Table 1 Properties of expansive soil

Parameter	Value	Parameter	Value
Specific gravity	2.72	FSI (%)	62.50
Grain size distribution:		MDD	17.10
Sand (%)	8.0	(kN/m^3)	
Silt (%)	66	OMC (%)	18.20
Clay (%)	26		
Liquid limit (%)	59		
Plastic limit (%)	34		
Plasticity index (%)	25		

Sample Preparation and Testing

CBR and Swell tests were conducted on the unreinforced and reinforced soil specimens. The specimens were compacted to

Table 2 Properties of reinforcing element

Parameter	Geogrid:	Jute Geotextile
Material composition	Polypropylene	Natural jute fiber (woven)
Aperture size (mm)	1.47	1.49
Thickness (mm)	0.27	3.2

Av. breaking strength (kN/m)	4.00	2.81

the maximum dry density (MDD) and optimum moisture content (OMC). For the reinforced soil specimen, a single layer of reinforcement was cut in the form of a circular disc of diameter 147 mm, i.e slightly less than the mould diameter 150mm. The embedment ratio (*z/d*) was defined as the ratio of depth of embedment (*z*) of the reinforcing layer from the top surface of the compacted soil specimen to the diameter of the loading plunger (*d*) and was varied as 0.25, 0.50, 1.0 and 1.50 as shown in Figure 2.

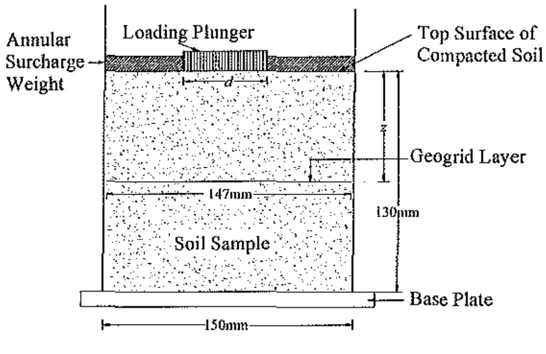

Fig.2 Test model with geogrid layer

The required quantity of dry soil and water for filling the mould was calculated based on the maximum dry density and optimum moisture content obtained from the standard Proctor test. The soil was mixed thoroughly after adding required amount of water corresponding to the optimum moisture content. The soil was filled in the mould up to the mark where reinforcing layer was to be placed and then compacted up to the desired level to get the required dry density. After compaction of the soil, reinforcement was placed inside the mould at the specified position. Finally the remaining soil was filled and compacted. The top soil surface of the mould was levelled. A filter paper and a perforated metallic disc with adjustable stem along with an annular surcharge weight (weight 25 N) were then placed on the top of the compacted soil specimen. The whole mould assembly was transferred to a soaking tank filled with water. After that the swell measuring device was placed on the top edge of the mould. It consists of a tripod and a dial gauge. The spindle of the dial gauge was allowed to rest over the adjustable stem of the perforated metallic plate. The initial dial gauge reading was recorded. The mould assembly was left undisturbed for 96 hours in the soaking tank to allow soaking of water in the specimen. After 96 hours of soaking, the final dial gauge reading was recorded in order to measure the expansion or swelling of the specimen due to soaking of water. Now the whole mould assembly was transferred to a motorized loading frame to conduct the CBR test. Initially a seating load of 40 N was applied through the penetration plunger at the centre of the specimen. The dial gauge of the proving ring and penetration dial gauge were set to zero prior to application of any further load. The load was then applied through the penetration plunger at a constant rate of strain (1.20 mm/minute) and the loads were carefully recorded up to a total penetration of 12.50 mm. Finally load- penetration curves were drawn for each case and corrections were applied to the load-penetration curves wherever required using the standard procedure. This process was followed for all the specimens considered in the investigation.

RESULTS AND DISCUSSION

CBR tests were conducted for both unreinforced as well as reinforced case under soaked condition. For the reinforced case, a single layer of reinforcement (geogrid) was placed at varying depths from top soil surface. In order to ascertain the influence of the position of the reinforcing layer on the swelling characteristics and load- displacement response of the specimen, the embedment ratio of the reinforcement was varied from 0.25 to 1.50 (0.25, 0.50, 1.0 and 1.50). Initial dial gauge reading prior to soaking of the specimen was recorded and then final dial gauge reading after the completion of soaking was also noted to determine the expansion ratio. Expansion ratio is defined as the ratio of change in height of the specimen to the original height of the specimen expressed in percentage. To know the effect of type of reinforcement on expansion ratio, the process was repeated by changing the reinforcement type from geogrid to jute geotextile. Figure 3 shows the variation of expansion ratio with embedment ratio (*z/d*) for both the type of reinforcements used in the investigation.

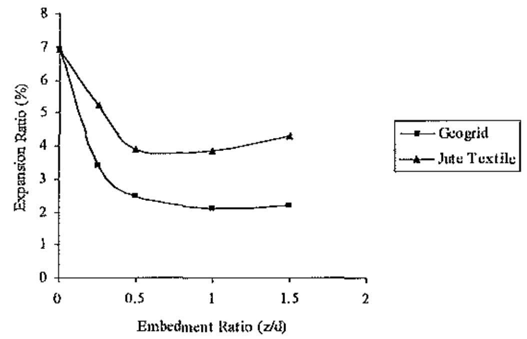

Fig. 3 Variation of Expansion ratio with Embedment ratio

From Figure 3 it can be observed that, in general, the placement of a horizontal layer of reinforcement within the soil specimen reduces the swelling. It is also noticed that there is an optimum depth of embedment at which the expansion ratio is minimum for a particular type of reinforcement. In the present case, the value of embedment ratio is 1.0 (one) for both type of reinforcement. From the Figure 3 it can be observed that the expansion ratio for the unreinforced case is 6.90% which decreased to 2.12% when the reinforcement is geogrid. But when the reinforcement is changed to jute geotextile, the expansion ratio decreased up to 3.88%. Based on these observations it can be concluded that the placement of a horizontal layer of reinforcement can effectively control the swelling and can be explained as follows: swelling pressure in a soil develops in all directions and would mobilize the interfacial frictional force between soil and reinforcement due to its normal component on the reinforcement. This frictional force tends to counteract the swelling pressure in a direction parallel to the reinforcement and consequently reduces the heave. In Figure 3, it is clear that the expansion ratio is less for the geogrid reinforcement as compared to that of jute geotextile at any given embedment ratio.

Figure 4 shows load-penetration curves at different embedment ratio for both unreinforced and reinforced specimens obtained from the CBR tests when the reinforcement is geogrid. Figure 5 shows the load-penetration curve when type of reinforcement is jute geotextile.

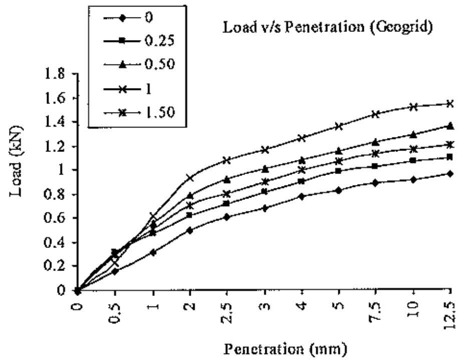

Fig. 4 Load versus penetration at different embedment ratio

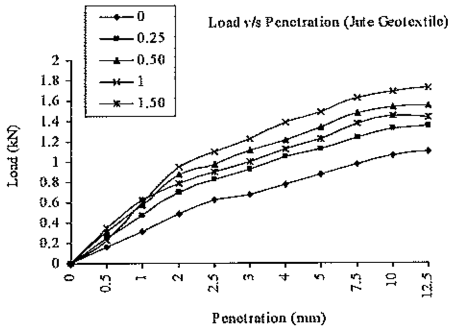

Fig. 5 Load versus penetration at different embedment ratio

It can be observed from these figures that there is a marked influence of a reinforcement layer within the specimen as depicted from load-displacement response. It is noticed that the piston load at a given penetration is higher for all cases of reinforced specimen as compared to that of an unreinforced specimen. The amount of increase in the piston load depends on the embedment ratio (*z/d*) and type of reinforcement. From the load- penetration curves, the CBR values for all cases were calculated at 2.5 mm and 5.0 mm penetrations, respectively. It was observed from CBR calculation that for all the cases considered in the present investigation, the CBR value corresponding to 2.5 mm penetration was always higher than that of 5.0 mm penetration. Therefore CBR values reported in the present investigation are those of 2.5 mm penetration. Figure 6 presents the variation of CBR with embedment ratio for both the types of reinforcements used in the investigation. The CBR value of the unreinforced soil corresponding to 2.5 mm and 5.0 mm penetration were found to be 4.52% and 4.09% respectively.

At optimum embedment ratio (z/d =1.0) the value of CBR increased to 7.53% at 2.5 mm penetration and 6.42% at 5.0 mm penetration, respectively when geogrid was used as reinforcement. But when the reinforcement was changed to jute geotextile, the CBR value increased from 4.52% to 8.03% at 2.5 mm penetration where as at 5.0 mm penetration, the CBR value increased from 4.09% to 7.28%.

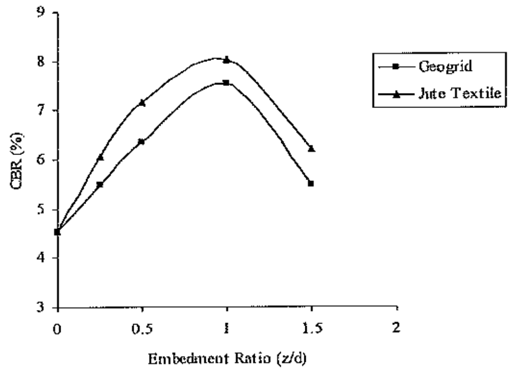

Fig. 6 Variation of CBR (%) with embedment ratio

Improvement in CBR values due to presence of reinforcement has been expressed by a dimensionless term known as California bearing ratio index (CBRI). It is defined in literature [2] as the ratio of CBR value of reinforced soil (CBR_r) to the CBR value of unreinforced soil (CBR_u)[$CBRI = CBR_r/CBR_u$]. Fig. 7 shows the variation of CBRI with embedment ratio (*z/d*) for both the types of reinforcement used in the investigation. It is observed that the maximum improvement in CBRI also occurs when embedment ratio is equal to 1.0 for both types of reinforcement. At z/d = 1.0, improvement in CBRI value is 78% when the reinforcement is jute geotextile, but in case of geogrid the extent of improvement was lower and found to be equal to 66%. Therefore contrary to the swelling behavior, the jute geotextile was found to be more effective than the geogrid in improving the strength characteristics for all the cases of the embedment ratios considered in the investigation. Further it can be observed that there is an optimum depth of embedment ($z=d$) where the CBRI value is maximum. At optimum depth, the reinforcement is able to do much better load distribution below the reinforced zone and a more adequate anchorage resistance can be mobilized under higher overburden pressure. At any depth other than embedment depth, the improvement in the CBRI value is not significant because of the fact that vertical stress intensity reduces either

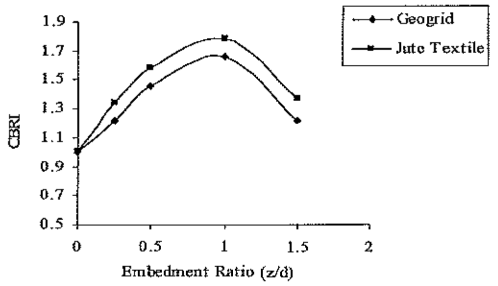

Fig. 7 Variation of CBRI with embedment ratio

due to smaller overburden of the soil mass above the reinforcement layer ($z < d$) or due to the applied load at the surface as per the Boussinesque equation of distribution of stress ($z > d$) and thereby interface frictional resistance is not fully mobilized which results in a decrease of CBRI value.

The increase in strength of soil due to inclusion of reinforcement within the specimen can also be expressed in terms of piston load ratio (PLR). It is defined as the ratio of maximum piston load at 12.5 mm penetration for reinforced specimen (L_r) to the maximum piston load at the same penetration for unreinforced specimen (L_u) [PLR = L_r / L_u]. The variation of PLR with respect to embedment ratio (z/d) for both the types of reinforcement has been shown in Figure 8. As expected it can be observed from the Figure 8 that the value of PLR is higher for the reinforced specimen. The extent of increase in PLR however depends on z/d ratio for a particular type of reinforcement and vice versa. Again it can be observed that for a given embedment ratio, the jute geotextile yields higher PLR as compared to that of the geogrid and the maximum improvement in PLR for jute geotextile is 1.56 whereas the same in case of geogrid is 1.39.

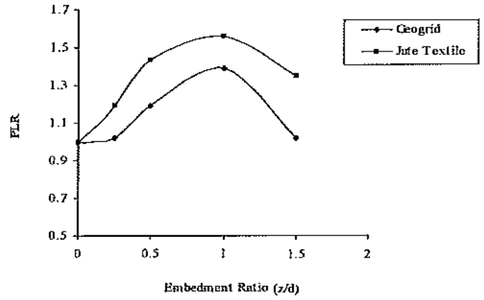

Fig. 8 Variation of PLR with embedment ratio

The modulus of elasticity is usually calculated from the straight portion of the stress-strain curve but for most of the soils the stress-strain curve is not linear for appreciable distance and rather it is non-linear. Therefore in the present investigation secant modulus [Ratio of load (in kPa at a penetration of 2.5 mm) to the penetration of 2.5 mm] was determined from the load – penetration curve. Figure 9 shows the variation of secant modulus with embedment ratio for both the types of reinforcement. As expected, the secant modulus for the reinforced case is higher than that for unreinforced case for all the embedment ratio considered in the investigation. For example, the secant modulus for the unreinforced soil is 124.16 MPa which increased to 206.56 MPa when the soil is reinforced with geogrid. But when reinforcement was jute geotextile, the value of secant modulus became 220.57 MPa. In both the cases, the maximum value of secant modulus was obtained at an embedment ratio equal to 1.0.

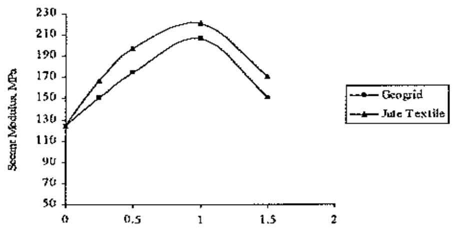

Fig. 9 Variation of secant modulus with embedment ratio.

CONCLUSIONS

Following conclusions can be drawn from the present investigation:

1. The insertion of a single layer of reinforcement within the expansive soil subgrade controls the swelling significantly. The percentage reduction in swell potential however depends on its depth of embedment and the type of reinforcement used.
2. The CBR value of the soil increases substantially when a single layer of reinforcement is placed horizontally within the soil. The extent of improvement depends on the type of reinforcement and the embedment ratio.
3. The stress-strain behavior of expansive soil subgrade improves considerably when the reinforcement is provided at optimum embedment depth under static load condition as evident from the secant modulus values obtained for different cases.
4. The jute geotextile offers a better reinforcing efficiency as compared to the geogrid and can be used for low cost road projects in rural areas. But durability study is required for long term application of the jute geotextile.

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