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Effect of Geosynthetic Reinforcement on CBR Strength of Soft Soil-Aggregate System

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Abstract. In the last few decades, geosynthetics have gained major popularity in improving the design and maintenance of roads. The various physical properties of geosynthetics have significantly influenced the road qualities and their construction methods. This paper evaluates the impact of geosynthetic reinforcement on bearing strength of soft soil-aggregate system using California Bearing Ratio (CBR) tests. Different geosynthetic materials, viz. woven and nonwoven geotextile, geogrid, the combination of geogrid with woven and nonwoven geotextile (geocomposite) were used to reinforce the soil-aggregate system. The results showed that with the application of geosynthetics the soil-aggregate system can sustain higher applied loads. While the use of geotextile prevented the intermixing of aggregates into the soil layer and vice-versa, the reinforcement of woven geotextiles gave higher CBR values than nonwoven geotextiles. The better interlocking and lateral restrain of the aggregates in geogrid reinforcement yielded an increment of 43% in CBR strength. Improvement factor and Reinforcement ratio were defined to analyse the impact of geosynthetic reinforcement on the bearing strength of the soil-aggregate system. The combination of geogrid and woven geotextile had maximum load-bearing capacity among all the reinforcing arrangements with the Improvement factor of 1.85. The use of geosynthetic proved to be useful in limiting the pavement thickness which results in making road projects economical.

Keywords: Geosynthetic, geotextile, geogrid, bearing strength, reinforcement, CBR.

1 Introduction

A proper and well-established road network plays a vital role in socio-economic growth of a nation. Rural roads connect the villages and agricultural fields to the urban and developed city centres. The load coming on the pavement surface has to be transmitted finally to the subgrade. In unpaved roads during rainy season water percolates into the subgrade layer and reduces its bearing strength considerably. A weak subgrade cannot provide proper support to different pavement layers and will not be able to withstand heavy traffic loads. Therefore, a stable subgrade with optimum strength is the prime concern for the pavement design. Various chemical and mechanical methods are adopted to stabilise the soil subgrade (Amhadi et al., 2019; Afrin, 2017). Geosynthetics can be used to separate different pavement layers from intermixing and act as filter media and restrict the escape of soil particle with rainwater. They can facilitate the efficient drainage of rainwater and can improve the bearing strength of roads through reinforcement. With the use of geosynthetics, there is a reduction in plastic deformation and decrease in the depth of base course (Hufenus et al., 2006; Giroud and Noiray, 1981; Al-Qadi et al., 1994; Webster and Watkins, 1977; Moyaed and Nazari, 2011). The service life is increased and the construction and maintenance time of pavements is reduced with the inclusion of geosynthetics (Perkins, 1999, 2002; Cancelli and Montanelli, 1999; Chen et al. 2009; Goldfingle, 2009).

The improvement in the performance of geosynthetic reinforced pavements is depended on the factors such as type and material of geosynthetic, bearing strength of subgrade, grading of aggregates, location of placement of geosynthetic etc. (Ismail and Raymond, 1995; Broms, 1977; Kinney et al., 1998). In their study, Fannin and Sigurdsson (1996) found geosynthetics to be most effective for sections with a thin base layer. Under dynamic loading, Geotextile, when used in pavement, doesn't allow pore pressure to develop and restricts the movement of soil into the aggregate layer in the form of the slurry (Qurishee, 2017). Various tests have been done by many researchers to observe the effect of geosynthetics in pavement design. Plate load tests give more useful results as they better replicate the field conditions, but they are expensive to conduct. Extensive field tests (Miura et al, 1990; Bergado et al., 2001; Palmeria and Antunes, 2010) have been conducted to study the behaviour of unpaved road. CBR tests are easier and quick laboratory tests whose results can be used to correlate with the engineering properties of materials (Nair and Latha, 2010; Naieni and Mirzakhanlari, 2008; Yeole and Patil, 2013).

Hence, the main objective of this work is to observe the effect on geosynthetic reinforcement on the soft soil-aggregate system. Limited studies have been done on the use of a combination of geotextile and geogrid for pavement reinforcement. Therefore, in this work combination of geogrid and geotextile was used as geocomposite to study the cumulative impact of different geosynthetics when used together in the pavement.

2 Materials

Soil and Aggregates

The clayey soil used in the study was collected from the NIT Silchar campus. The soil was oven-dried and all the lumps were broken using a wooden mallet. ASTM D 4318 and ASTM D 2487 were followed to find out the index properties of the soil as presented in Table 1. Aggregates of size 10 mm were used for the CBR test. The obtained values of different aggregate properties are shown in Table 2. and agreed with IS:2386 making it suitable for use in road construction.

Geosynthetic

The nonwoven geotextile used for the test was manufactured from high-quality UV stabilized polyester. The fibres were mechanically bonded through the needle-punching process to form a strong, flexible and dimensionally stable fabric structure. Woven geotextile used was made of staple polypropylene fibre durable in adverse chemical and biological soil condition. Biaxial geogrid, made of high-density poly-ethene, was used. Table 3 present the specification of geosynthetics.

Table 1. Properties of Soil

Particulars	Soil
Specific gravity	2.72
Soil classification (USCS)	CH
Liquid limit (%)	55
Plastic limit (%)	29
Maximum dry unit weight (kNm^{-3})	14.6
Optimum moisture content (%)	23

Table 2. Properties of aggregates

Particulars	Aggregates
Specific gravity	2.64
Water absorption (%)	2.8
Aggregate Impact Value (%)	28.41
Aggregate crushing strength (%)	27.34

Table 3. Properties of geosynthetics

Particulars	Nonwoven Geotextile	Woven Geotextile	Geogrid
Mass per unit area (gsm)	250	240	190
Thickness (mm)	1.5	1	1.5
Tensile strength (kN/mm)	15	45	27.2
Apparent opening size (micron)	80	75	-
Mesh size (mm x mm)	-	-	10 x 10

Table 4. Details of the tests carried

Designation	Test systems
S’	Soil alone (water content = 23%)
S	Soil alone (water content = 35%)
SA	Soil-aggregate system
SANWG	Soil aggregate system reinforced with nonwoven geotextile
SAWG	Soil aggregate system reinforced with woven geotextile
SAG	Soil aggregate system with geogrid
SAGNWG	Soil aggregate system reinforced with geogrid + nonwoven geotextile
SAGWG	Soil aggregate system reinforced with geogrid + woven geotextile

3 Experimental Studies

CBR test is the most widely accepted test to know the quality of pavement about the resistance offered by the material against the applied load. The current experimental work consists of several CBR tests on the unreinforced and reinforced soil-aggregate system. Every part of North-East India receives rainfall of more than 1000mm annually (Dikshit and Dikshit, 2014). Due to adverse topographical condition and tough terrain locations, the road infrastructure in the North-East is not adequately developed. Unsurfaced or unpaved roads have no asphaltic cover, the rainwater percolates into the subgrade and makes it very soft leading to a reduction in load-bearing strength of subgrade. According to IRC-SP 20 (2002), CBR test for the subgrade of rural roads should be done for the critical water content. A series of soil samples were collected daily at NIT Silchar campus during the monsoon season i.e. from June to August. The average moisture content found out in the soil for this period was around 35%. Therefore, 35% of water by weight of soil was considered for preparing the soil sample for the CBR test. The CBR value obtained for soil with 35% of moisture content is 2.08%, which indicates that at high moisture content soil became soft and possessed low strength. In the soil-aggregate system, subgrade soil was compacted in the CBR mould up to the height of 125 mm in three equal parts and aggregates were filled for 50 mm height in two parts. Geosynthetic when used alone for reinforcing was placed at the junction of soil and aggregate layer.

A combination of geogrid with nonwoven and woven geotextile was also used for reinforcing. A gap of 25 mm was maintained between geotextile and geogrid when used together because when geogrid is placed in direct contact with geotextile then the optimum interlocking of aggregates is not achieved and geogrid may slide over the geotextile (Hufenus, 2006). Therefore, when used as geocomposite, the geotextile was placed at the junction of soil-aggregate layer and geogrid was placed in the middle of the aggregate layer. The schematic set up of the soil-aggregate arrangement is presented in Fig. 1. The geosynthetic was cut into a circular shape and the diameter of the geosynthetic was kept 5mm less than that of the CBR mould to prevent any frictional resistance between the geosynthetic and wall of the mould. The number of blows given per layer of soil and aggregate by hammer is such that the compaction energy equals the standard proctor energy. Therefore, the number of blows given per layer of soil and aggregate was 55 and 33 blows respectively. The prepared arrangement was tested in a loading frame at a strain rate of 1.25 mm/min. Before that, a surcharge of 4 kg was placed over the system. The load-penetration data of the prepared systems was recorded for a displacement of 20 mm.

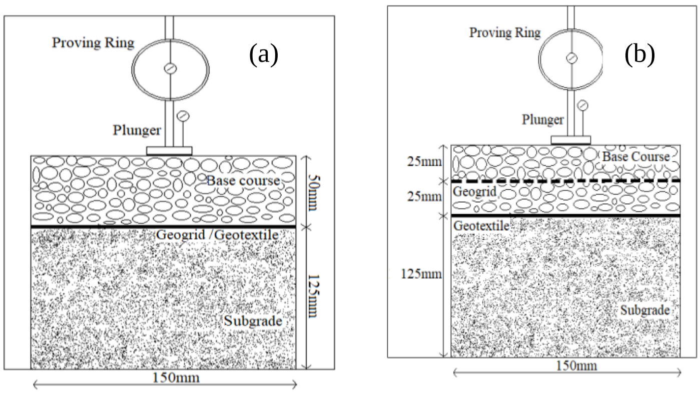

Fig. 1. Schematic set up of soil-aggregate system reinforced with (a) geogrid /geotextile (b) geogrid + geotextile

4 Results and Discussions

The CBR tests on different systems were performed and their load-penetration responses were studied. The various test combinations performed are mentioned in Table 4. The behaviour of the soil-alone, at a water content of 23% (OMC) and 35% under the applied load is presented in Fig. 2. The bearing capacity of the subgrade soil decreased with an increase in the moisture content. CBR value of soil reduced from 5.9% to 2.1% with the increase in moisture content from 23% to 35%. Therefore, unpaved roads become very critical in rainy season as rainwater percolating into the subgrade layer makes the soil soft and there is a reduction in strength of the roads. The remaining unreinforced and reinforced arrangements were prepared and tested with the soil having a moisture content of 35%. The addition of aggregate in soil-aggregate system improved the load resistance capacity as aggregates uniformly staggered the coming traffic load to a larger area of subgrade. The soil-aggregate system yielded a CBR value of 3.25%. For soil-aggregate system, there were undulations observed unlike the smooth load-penetration response of the soil alone. These undulations were observed due to the crushing and rearrangement of the aggregates under the applied load. Fig. 3 shows that there was intermixing of soil and aggregate during the test which is not desirable for the roads.

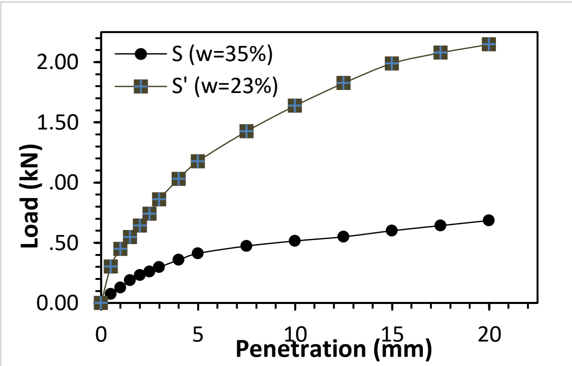

Fig. 2. Load-penetration response of the soil-alone system at water content 35% and 23%

Fig. 3. Intermixing of soil and aggregate layer in the unreinforced system

Fig. 4. Exhausted geogrid after the test

4.1. Effect of geotextile reinforcement

Both nonwoven and woven geotextile were tested as reinforcing material placed between soil and aggregate layers. From Fig. 5, it is clear that nonwoven geotextile didn't have any profound impact on the bearing strength due to its low tensile strength. The nonwoven geotextile failed to withstand high loads and was ruptured. Both nonwoven and woven geotextiles served the purpose as separator and prevented the movement of aggregates into the soil layer and vice-versa. Geotextile can be preferred for its function of separation, stabilisation, filtration (Giroud J.P., 1981). Since the permeability of nonwoven geotextile is more it can very efficiently facilitate the drainage of rainwater from the unpaved roads while retaining the soil particles. Woven geotextile proved to be more effective in the reinforcement because of its high tensile strength. There CBR value obtained with the inclusion of nonwoven geotextile was 3.67% which had a nominal increment from the unreinforced soil-aggregate system whereas the CBR value for the woven geotextile reinforced system was 4.27%. The woven geotextile can be used in pavements for its better performance as separator and reinforcement as well. Improvement factor (*IF*) was defined as the ratio of CBR value of the reinforced system to that of the unreinforced soil-aggregate system to evaluate the benefits of different reinforcing materials. Table 5 summaries the CBR values, Improvement factor and secant modulus of different systems.

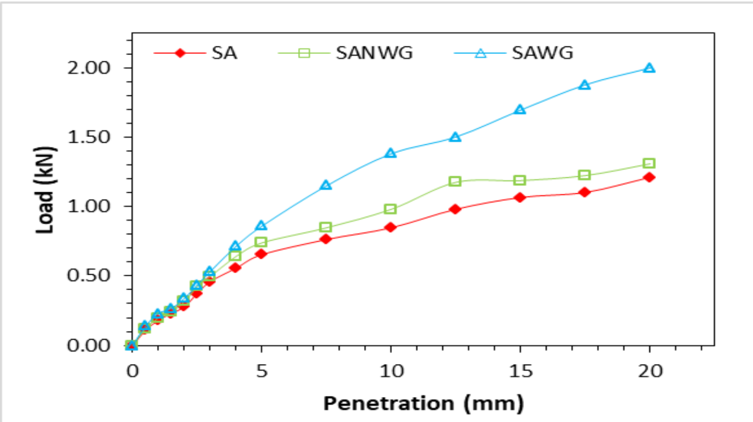

Fig. 5. Load-penetration graph of unreinforced and geotextile reinforced soil-aggregate system

4.2. Effect of geogrid reinforcement

The mesh of geogrid helped in confining and interlocking of aggregates. The confinement provided was dependent upon the grading of aggregate and aperture size of geogrid. The CBR value achieved with geogrid reinforcement was 4.64% with an improvement factor of 1.43. The lateral restraint of aggregates provided better distribution of load over soil subgrade (Perkins, 1999). With better lateral restrains the stiffness of the base layer improves which causes a reduction in shear stresses. In the unreinforced system, the mode of failure was punching whereas with the use of geogrid it was a general failure (Binquet & Lee, 1975). A certain level of penetration is required to introduce the membrane effect in geosynthetic after which it applies an upward component of tensile force (Göbel, Weisemann, & Kirschner, 1994). Fig. 4 shows the exhausted geogrid after the test. The combination of geogrid with nonwoven and woven geotextile was also tried to study the effect of geocomposite where different geosynthetic materials perform different functions to collectively improve the pavement characteristics. The combination of woven geotextile and geogrid reinforcement yielded the best results with a CBR value of 6.02% and the improvement factor of 1.85. With the use of geocomposite the functions of separation, confinement, lateral restrain, filtration, and reinforcement can be achieved. The ribs of geogrid facilitated the interlocking and friction at the interface which enhanced the lateral restraint in the aggregate layer, whereas for lateral restrain geotextile depends on interface friction only (Steward et al. 1977).

The bearing strength achieved with the combination of woven geotextile and geogrid was more than that of the geocomposite of nonwoven geotextile and geogrid as shown in Fig.6. The addition of nonwoven geotextile to the geogrid had benefits as nonwoven geotextile separated the soil and aggregate layer and stabilised the system, therefore, the penetration resistance achieved was more than that of the geogrid alone reinforced system which can also be observed from the secant subgrade modulus as shown in Table 5. Further to quantify the impact of geosynthetic reinforcement on the soil-aggregate system *Reinforcement ratio* was analysed. Koerner (2005) defined reinforcement ratio at a particular penetration as, the ratio of load resistance offered by the geosynthetic reinforced system to that of load resisted by the unreinforced system. The membrane effect of geosynthetic became evident after a certain penetration level was achieved. For small penetration values, the role of geosynthetic reinforcement was not profound. Therefore, reinforcement ratio was calculated from the penetration of 5mm and henceforth. The reinforcement ratio versus penetration curves for the different reinforcing combinations is presented in Fig. 7. It was observed from the curve that with the addition of geosynthetic the soil-aggregate system could sustain higher loads as reinforcement ratio obtained was more than one.

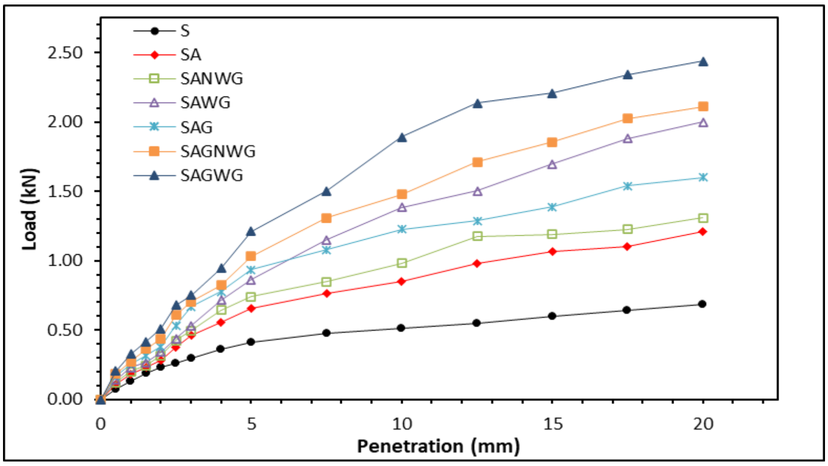

Fig. 6. Load-penetration graph for soil, unreinforced and geosynthetic reinforced soil-aggregate system

Table 5. CBR values, Improvement factor (IF) and Secant modulus of different test systems

Test Systems	S	SA	SANWG	SAWG	SAG	SAGNWG	SAGWG
CBR (%)	2.1	3.25	3.67	4.27	4.64	5.12	6.02

IF	-	-	1.13	1.31	1.43	1.57	1.85
Secant modulus (kPa/mm)	-	56.85	75.41	87.77	95.00	105.07	123.62

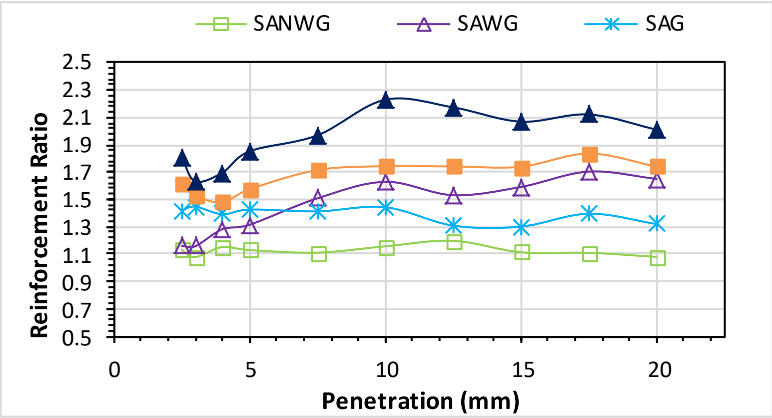

Fig. 7. Reinforcement ratio of reinforced soil-aggregate systems

Impact of reinforcement on the base layer thickness

The role of the base course is to disperse the coming load to a bigger area of subgrade and facilitate the structural support to the unpaved layer. It is prepared with hard and durable aggregates. The thickness of the base course is selected so as it can reduce the traffic load intensity through the depth to a level where it can be handled by the underlying subgrade. Generally, aggregates are acquired from the quarry near the construction site. In cases where there is no local quarry available or there are terrain restrictions in procuring aggregates then it becomes a difficult and costly task to arrange the amount of aggregates required for the construction of the base course. Geosynthetics help in restricting the depth of base course leading to a reduction in the use of construction materials. The use of geosynthetic not only improves the pavement parameters but also reduces the cost and time of construction. IRC: SP 20 (2002) relates the CBR value with the thickness of pavement. From Fig. 8, it can be established that by improving the CBR value the thickness of pavement required for a particular traffic load reduces.

Design example

Considering the design for an unpaved road with a total number of commercial vehicles passing daily to be around 400. The difference between CBR value of unreinforced and geogrid reinforced soil aggregate system was of 1.39%. From Fig. 8, the reduction obtained in the thickness of pavement by placing geogrid between subgrade and base course layer is of 100mm. Similarly, if the combination of geogrid and woven geotextile is used for reinforcing the pavement then the thickness of pavement can be reduced by around 200mm. The depth of the base course can be associated with the construction cost of the road. Lesser the thickness of pavement layers, lesser would be the construction cost. Reduction in the amount of aggregates required for the construction of base course will reduce the construction cost and time.

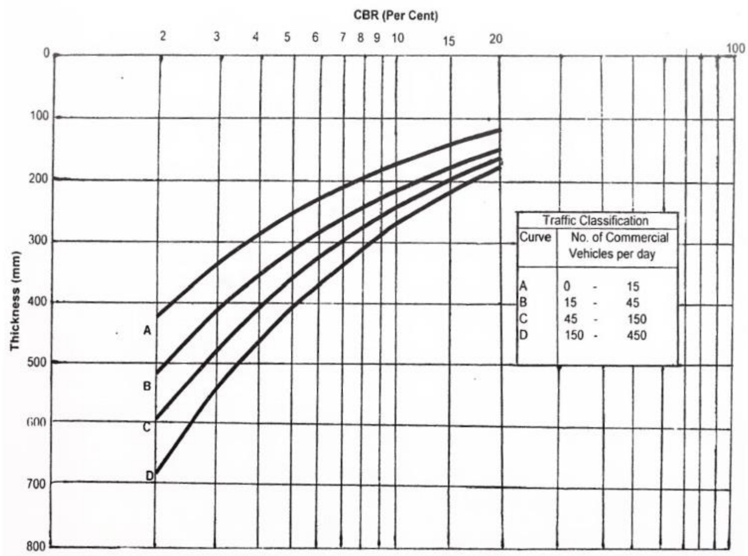

Fig. 8. CBR curves for flexible pavement design (IRC: SP:20-2002)

5 Conclusions

A set of CBR tests were performed to understand the impact of geosynthetic reinforcement on unreinforced soil-aggregate systems. Different geosynthetics viz. nonwoven and woven geotextile and geogrid were employed for the reinforcement. Based on these studies the conclusions that are derived are as follows:

1. The inclusion of geosynthetic reinforcement increases the bearing resistance of the soil-aggregate system with an increment of 85% in CBR values for geocomposite consisting of geogrid and woven geotextile.
2. The load-bearing capacity became profound at higher penetration values due to the introduction of the membrane effect in geosynthetic.
3. The nonwoven geotextile prevented the movement of aggregate from the base layer into the subgrade layer and vice versa but because of very low tensile strength, its impact on bearing strength was nominal. The woven geotextile was not only very effective as separator but also significantly im-

proved the CBR value because of its high tensile strength. At higher penetration values, the woven geotextile reinforced system performed better than geogrid.

4. The geogrid restrains the aggregates with the proper interlocking of aggregates, but this is mainly dependent upon the gradation of aggregates and mesh size of geogrid.
5. The geosynthetic can significantly decrease the pavement thickness. There is a reduction in the requirement of aggregates hence making the construction of pavement quicker, more economical and ecofriendly

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