Performance of Geosynthetic Reinforced Model Pavements under Repetitive Loading

K. H. Mamatha[1], S. V. Dinesh[2*] and B. C. Swamy[3]
[1]*Research Scholar, Department of Civil Engineering, Siddaganga Institute of Technology, Tumkur, Karnataka, India*
[2]*Professor, Department of Civil Engineering, Siddaganga Institute of Technology, Tumkur, Karnataka, India*
[3]*Associate Professor, Department of Civil Engineering, Central Connecticut State University, New Britain, Connecticut*
**E-mail*: dinesh@sit.ac.in, dineshsv2004@gmail.com

ABSTRACT: In this paper, the effectiveness of geosynthetic reinforcement materials such as geogrids and geocells in improving the pavement performance is investigated by carrying out a series of repeated load tests on unreinforced, geogrid and geocell reinforced model pavement sections. The effect of properties of geogrids and geocells on the improved performance is also studied. The provision of geogrid/geocell at the interface of subgrade and sub-base course is found to reduce the plastic settlement significantly with geocells being very effective when compared with geogrids. The reduced plastic settlement results in reduced rutting at the surface leading to increased service life of the pavements and also increased ride comfort to the road users. The geocells reinforcement results in higher TBR values when compared with that of geogrid.

KEYWORDS: Pavement, Geogrid, Geocell, Granular layer, Service life, Rutting

1. INTRODUCTION

Due to rapid growth in vehicular traffic, pavements are subjected to premature failure. In addition to this, pavements are also associated with problems like weak subgrades, inferior quality of aggregates, etc. Pavements built over weak subgrade show large deformation and ultimately result in pavement deterioration. Use of inferior construction materials results in reduced service life of the pavements and among various types of pavement failures rutting and fatigue are the predominant ones [Haung (2003)]. To overcome these failures, either the strength of subgrade needs to be improved by any suitable techniques viz., stabilization, reinforcement, etc. or the pavement thickness needs to be increased to withstand the traffic load. Among various ground improvement techniques, geosynthetic reinforcement is being widely used [Dash et al. (2001), Sitharam and Sireesh (2004), Dash (2012), Ravi et al. (2014), Hegde and Sitharam (2015), Arghadeep Biswas et al. (2016), Mamatha and Dinesh (2017)]. Among various forms of geosynthetic materials, geocells and geogrids are being used for reinforcing/stabilizing the structures with unbound materials such as roads, slopes, retaining walls and embankments. The use of geosynthetics in unpaved roads built over a weak subgrade is known to provide a reinforcing benefit to the roadway sections. Geosynthetics placed either on top of the subgrade or within the base course layer works with the soil and granular material to create a reinforced section through separation, confinement and/or reinforcement functions. Several studies have shown that geosynthetics can extend the service life of pavements [Webster and Watkins (1977), Giroud and Noiray (1981), Potter and Currer (1981), Haliburton and Baron (1983), Love (1984), Lawson (1992), Austin and Coleman (1993), Al-Qadi et al. (1994), Fannin and Sigurdsson (1996), Hufenus et al. (2006), Mamatha and Dinesh (2017)], reduce base course thickness for a given service life [Webster and Watkins (1977), Giroud and Noiray (1981), Love (1984), Bush et al. (1990), Sivakiumar Babu and Pawan Kumar (2012)] and delay rutting development [Potter and Currer (1981), Mamatha and Dinesh (2017)]. Among various forms of geosynthetic, geocells and geogrids are considered in the present work. Geocells completely encase the soil and provide all-round confinement, thus preventing the lateral spreading of the soil. Because of this, the soil-geocell layer acts as a stiff mat, distributing the load over a much larger area of the subgrade soil. This helps in reducing vertical and lateral deformations of the subgrade soil to a large extent besides increasing the overall load carrying capacity of the subgrade. Geogrid interlocks with aggregate through its apertures. The interlocking between geogrid and aggregate forms a confined zone below and above the geogrid if there is an appropriate relationship between the aperture size of the geogrid and the particle size of the aggregate [Love (1984)].

In the present paper, the results of a series of repeated load tests conducted on model pavement sections built in a steel tank to evaluate the effectiveness of geosynthetic and their properties on the improved performance in terms of rutting and fatigue compared to unreinforced sections are reported.

2. MATERIALS

In the present work, black cotton soil, aggregates and silty sand were used for the preparation of subgrade, sub-base and sacrificial layers respectively. The black cotton soil was collected from Bagalkot. Aggregates were collected from a nearby quarry located in Mydala, Tumkur District and silty sand was collected from a local site near Tumkur. The materials were tested for their properties and all the tests were carried out as per the relevant IS codes. The aggregates were sampled and tested to achieve the strength requirements of sub-base layer as specified by MoRT&H (2013). Grading II was considered for the sub-base course layer as per IRC: SP: 72 (2007). The engineering properties of soils are tabulated in Table 1. Figure 1 shows the grain size distribution curves of black cotton soil and silty sand.

Geocell and geogrid reinforcements made of high density polyethylene manufactured by STRATA Geosystems India Pvt. Ltd. were used for reinforcing the granular sub-base course layer. In order to study the effect of aspect ratio of geocells, three geocells of aspect ratio 0.45, 0.56 and 0.67 were considered and are designated as GC1, GC2 and GC3 respectively. For varying the aspect ratio, only the height of geocell was varied and diameter of geocell pocket was kept constant. To study the effect of strength of geogrid, two biaxial geogrids of tensile strength 30 and 40kN/m were considered and are designated as GG1 and GG2 respectively. Table 2 shows the properties of the geosynthetics considered.

3. CONSTRUCTION OF MODEL PAVEMENT

A steel tank of size 2m x 2m x 2m was used to build the model unpaved pavement sections. A steel plate of size 0.3m x 0.3m and 0.03m thick was used to transfer the load to the test sections. Stage construction was adopted to build the model unpaved pavement sections and is explained in detail in the following paragraphs. Figure 2 shows the pictorial view of stage construction of model pavement sections.

Table 1 Engineering properties of soils

Property	Silty sand	Black cotton soil
Specific Gravity	2.64	2.72
Grain Size Distribution (%)		
Gravel	4	0
Sand	88	10
Silt	8	36
Clay	-	54
Soil Classification		
I.S Soil classification	SW-SM	CH
H.R.B classification	A-2-4	A-7-C
Consistency limits		
Liquid Limit (%)	28	71
Plastic Limit (%)	NP	23
Plasticity Index (%)	-	48
Compaction Characteristics		
Modified Proctor Test		
OMC (%)	9	19
Maximum Dry Unit Weight (kN/m^3)	19.7	16.8
Standard Proctor Test		
OMC (%)	13	24
Maximum Dry Unit Weight (kN/m^3)	18.2	14.6
Unconfined Compressive Strength		
Unsoaked (kPa)	130	89
Soaked (kPa)	-	-
California Bearing Ratio Test (CBR)		
Unsoaked condition (%)	7	4
Soaked condition (%)	5	<2
Swelling Index (%)	-	34

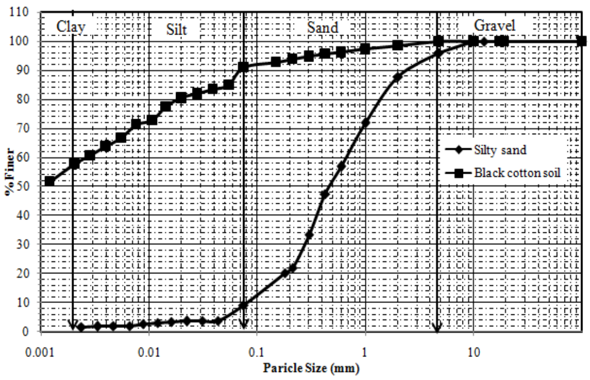


Figure 1 Grain size distribution curves of soils

3.1 Preparation of subgrade

The steel tank was initially filled with sand up to a depth of 1m corresponding to relative density greater than 85%. The pavement section of size 1m x 1m was constructed using a steel frame of size 1m x 1m and 0.3m height. On the sand deposit, a subgrade of 30cm thick was constructed using black cotton soil in three lifts of 10cm each. The soil and water required for the above mentioned dimension was determined based on its MDD and OMC corresponding to standard proctor condition as per MoRT&H (2013) guidelines for low volume roads. Soil was mixed thoroughly with the calculated amount of water and the whole mass was divided into three parts. The steel frame was placed on the sand deposit. Then, each part of the mixed soil was placed inside the frame and compacted by manual compaction. The compaction was done using a rammer of weight 20kg with a free fall of 50cm and 151 evenly distributed blows (equivalent proctor energy) to compact a volume of 0.5m x 0.5m x 0.1m to achieve a relative compaction of greater than 95%. Before placing the next layer, the top of the previously levelled surface was scratched for proper bonding. The procedure was repeated until the subgrade of desired thickness is prepared. Each layer was compacted for more than 95% relative compaction as specified by MoRT&H (2013) for clayey subgrade. The steel frame was raised to the top for further laying.

Table 2 Properties of geosynthetics

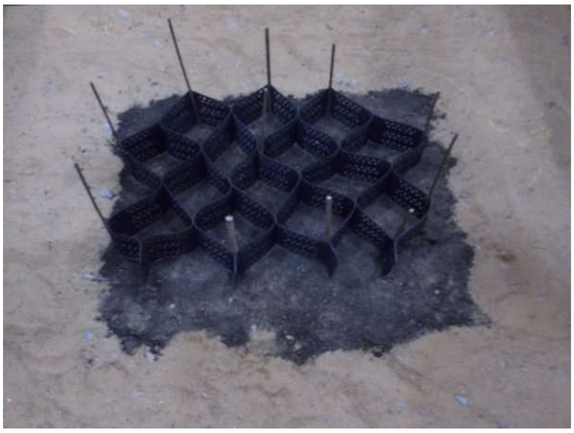
Geocell		Geogrid		
Property	**Value**	**Property**	**Value**	
Material	Polyethylene	Material	Polyester	
Polymer Density (gm/cm^3)	0.935 – 0.965	Creep reduction factor	1.51	
Expanded Cell Dimension Width (mm) Length (mm)	259 224	Tensile strength (kN/m)	MD	30, 40
			CMD	30, 40
Weld Spacing (mm)	356	Aperture size (mm)	MD	18
Sheet Thickness (mm)	1.52		CMD	18
Height (mm)	100, 125, 150	Creep limited strength (kN/m)	19.9, 26.4	

MD – Machine direction
CMD – Cross machine direction

3.2 Preparation of sub-base course

On the prepared subgrade, a sub-base course of 25cm thickness was constructed in three lifts. The required quantity of the sub-base material and amount of water to be mixed was determined based on its MDD and OMC under modified proctor condition as suggested by MoRT&H (2013). The calculated amount of sub-base material and water was mixed well and divided into number of equal parts. Each part was placed on the prepared subgrade one after the other and compacted using a vibratory plate compactor. The compactor consists of a base plate of 0.25m width, 0.25m length and 0.01m thick which operates at four different frequencies i.e., 20Hz, 40Hz, 60Hz and 80Hz. A series of trials were conducted to determine the time required to achieve the desired density. In each trial, the density of the compacted layer was determined. By knowing the time and density achieved, calibration charts were prepared for unreinforced sub-base for all the four frequencies. A separate calibration chart was developed for geocell reinforced sub-base due to the difficulty involved in the compaction of the sub-base material into the geocell pockets. In all the test sections, the granular sub-base was compacted at 80Hz frequency with the vibratory plate compactor with a compaction time of 15 minutes to compact an area of 0.25m x 0.25m. However, in case of geocell reinforced sub-base the compaction time required was 5 minutes more than that of the unreinforced sub-base to achieve the desired density. For the compaction of geogrid reinforced sub-base, the calibration chart developed for unreinforced sub-base was used. The time required to achieve the desired density was directly obtained from the respective calibration charts. A frequency of 80Hz was adopted for the construction of both unreinforced and geogrid/geocell reinforced sub-base layers. Before placing the next part of the material, the surface of the previously placed and compacted layer was scratched for proper bonding. The steel frame was further raised to the top to facilitate subsequent laying.

(a) Prepared subgrade



(b) Geocell fixed with stakes

(c) Geogrid placed at the top of compacted subgrade

(d) Geocell layer filled with sub-base material

(e) Finished and levelled sub-base course

(f) Finished and levelled sacrificial layer

Figure 2 Stage construction for the construction of model pavement sections

In the geosynthetic reinforced sections, a geosynthetic layer (i.e., geocell and geogrid) was placed at the interface of subgrade and sub-base course layer and filled with the sub-base material and compacted. Each layer was compacted for more than 97% relative compaction as specified by MoRT&H (2013).

3.3 Preparation of sacrificial layer

Above the prepared sub-base, a sacrificial layer of 5cm thick as suggested by MORD (2014) and IRC: SP: 72 (2007) was laid in one lift. The quantity of soil and water required for the preparation of above mentioned dimension was determined based on its MDD and OMC corresponding to modified proctor condition. The soil and water were mixed thoroughly, placed on the prepared base and compacted using the vibratory plate compactor. Similar to the compaction of sub-base, calibration chart was developed for the compaction of sacrificial layer and the time required to achieve the desired density was directly obtained from the calibration chart. A relative compaction of more than 97% was maintained as specified by MoRT&H (2013). The surroundings of the model pavement was filled completely with sand to a relative density greater than 85% and this sand fill acts as shoulder in pavements.

4. TEST SETUP AND REPEATED LOAD TESTING

Repeated load tests were conducted on both unreinforced and geosynthetic reinforced model pavement sections. The haversine loading was adopted to simulate the repeated application of traffic loading and a peak load of 68kN was selected to simulate a tyre pressure of 700kPa exerted by a truck with single axle and single wheel on pavements. The displacement of the test plate and the deformation of the test section at the surface were recorded by means of dial gauges. Four dial gauges (i.e., D_1, D_2, D_3 and D_4) were mounted one at each corner of the test plate and surface profile was measured by using three dial gauges (i.e., D_5, D_6 and D_7) mounted at distances of 10cm, 20cm and 30cm respectively from the edge of the plate along machine direction on one side of the plate. For verification, three more dial gauges (i.e., D_8, D_9 and D_{10}) were mounted along cross machine direction at the same distances as mentioned above. The measured displacements on the loading plate (i.e., D_1, D_2, D_3 and D_4) are averaged and considered for the analysis. Figures 3 and 4 show the experimental set up and position of the dial gauges respectively. The test was terminated at 500 loading cycles.

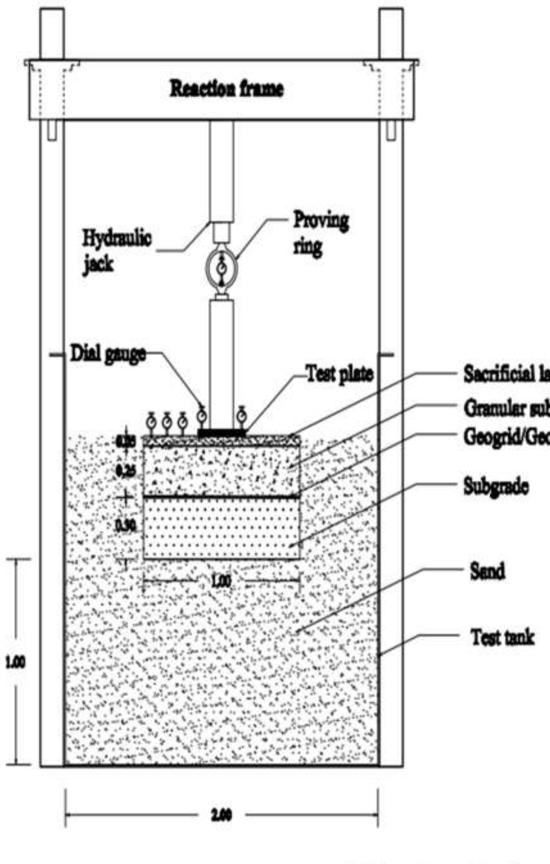


Figure 3 Experimental setup

5. RESULTS AND DISCUSSIONS

A series of repeated load tests were conducted on unreinforced and geosynthetic (i.e., geocell and geogrid) reinforced model pavement sections and the test results are discussed in the following paragraphs. The unreinforced model pavement section is designated as UR.

Figures 4 to 6 show the variation of total, plastic and elastic settlements with number of load cycles of unreinforced and geosynthetic reinforced model pavement sections respectively. In both unreinforced and geogrid/geocell reinforced pavement sections, plastic settlement accounts for 90% of the total settlement and elastic settlement is only 10% of the total settlement. This clearly indicates the predominant rutting behaviour in pavements. It is observed that the total and plastic settlements increased significantly with increase in the number of load cycles in unreinforced model pavement section. The total and plastic settlements of geogrid/geocell reinforced test sections follow the same trend as in case of unreinforced test section with the reduced magnitude. The geogrid/geocell reinforcement does not show any significant influence on the elastic behaviour of the model pavement sections and the elastic settlement remains almost same irrespective of the test condition. The accumulation of total and plastic settlements is significant in unreinforced and geogrid reinforced model pavement sections with geogrid reinforced sections having lesser settlements. The reduced settlement in geogrid reinforced test sections is attributed to the partial particle interlocking offered by the geogrid apertures and the tension membrane mechanism. In case geocell reinforced test sections, maximum settlement of about 50% to 70% of the total and plastic settlements occurred at the end of 50 loading cycles when compared with the settlements at the end of 500 loading cycles and beyond 50 loading cycles, the increase in settlement is marginal. This is attributed to the confinement offered by the geocell walls to the unbound granular materials offering resistance to the displacement of aggregates. The geocell beam acts as a wide beam and transfers the applied load over a wider area thereby increases the life of the pavement structure. Among geocells and geogrids considered, geocells were found to be very effective in reducing the plastic settlement of the model pavement section.

Provision of geogrid/geocell at the interface of subgrade and sub-base shows significant reduction in total and plastic settlement and the reduction further increased with increase in tensile strength of geogrid and aspect ratio of geocells. Among GG1 and GG2, GG1 performed better and among GC1, GC2 and GC3, GC3 gave the maximum improvement in the pavement performance. The strength mobilization began at 50 load cycles in pavement reinforced with geogrid/geocell and beyond 50 load cycles, a significant reduction in settlement was observed when compared with that of unreinforced pavement section. The geosynthetic offer confinement and friction effect at the interface and the friction effect mobilizes when the granular layer on the top of geosynthetic tends to undergo significant lateral deformation. Under these conditions, the friction force mobilizes preventing the lateral flow provides confinement and hard layer effect at the bottom. This is likely to result in dilation effect, thereby enhances the load carrying capacity under significant reduction in total settlement. At the end of 50 load cycles, the reduction in plastic settlement is in the order of 17%, 24%, 13%, 43% and 56% respectively for GG1, GG2, GC1, GC2 and GC3 when compared with the unreinforced pavement section. At the end of 500 load cycles, the reduction in plastic settlement reduces to 11% (from 17%) and 15% (from 24%) in case of GG1 and GG2 respectively. On the contrary, in case of GC1 the reduction in plastic settlement increases to 24% and in case of GC2 and GC3 it remains almost constant (at 43% and 56% respectively) indicating complete strength mobilization.

Figure 7 shows the surface profiles of unreinforced and geosynthetic reinforced model pavement sections at the end of 500 load cycles. The unreinforced pavement section shows increased heaving at the edge of the loading plate. Whereas provision of geogrid/geocell reinforced test sections showed reduced heaving. Provision of geocells significantly reduced the surface heaving and the heaving further reduced with increase in the aspect ratio of geocells. The pavement section reinforced with GC3 showed minimum heave at the surface when compared with the other aspect ratios considered. The reduced heaving ultimately results in reduced rut depth thereby geosynthetic reinforcement increases the level of service of the pavement and ride comfort to the road users. Among the two forms of geosynthetic considered, it is observed that the geocells are very effective in reducing the rutting behaviour to a large extent. This qualitatively indicates that geocell reinforced sections have a very large resilient modulus values than unreinforced sections which results in sustainable, durable, long lasting and maintenance free pavement sections.

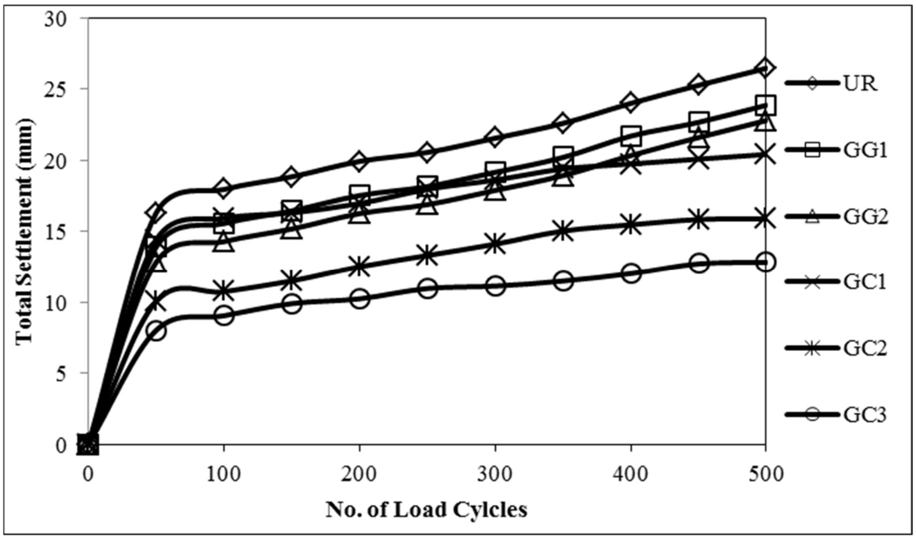


Figure 4 Variation of total settlement with number of load cycles in unreinforced and geosynthetic reinforced test sections

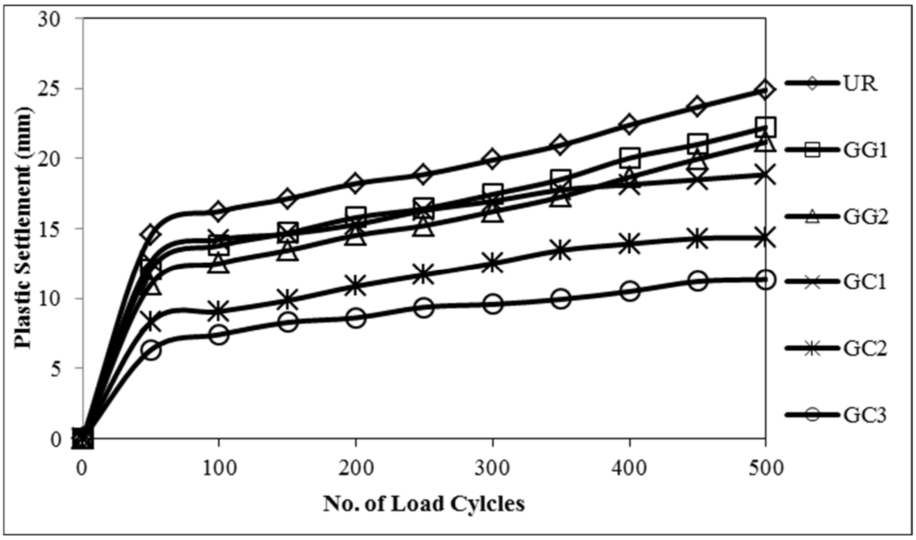


Figure 5 Variation of plastic settlement with number of load cycles in unreinforced and geosynthetic reinforced test sections

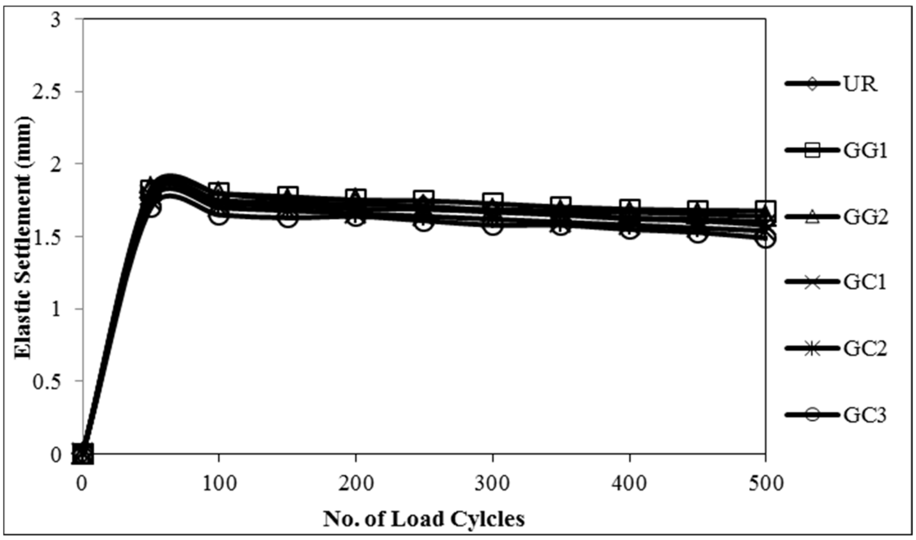


Figure 6 Variation of elastic settlement with number of load cycles in unreinforced and geosynthetic reinforced test sections

The benefit derived from the geosynthetic reinforcement is expressed in terms of a non-dimensional factor called traffic benefit ratio (TBR) and it is defined as ratio of number of load cycles in geosynthetic reinforced model pavement section to the number of load cycles in unreinforced model pavement section to reach a constant permanent deformation. Figure 8 shows the variation of traffic benefit ratio (TBR) with the form and properties of geosynthetic. Geogrids were found to yield a lower TBR values when compared with that of geocells and is in the order of 1.22 and 1.33 respectively for GG1 and GG2. On the other hand, among GC1, GC2 and GC3, GC1 yielded a lower TBR value and GC3 yielded a higher TBR value and the values are in the order of 1.25, 1.67 and 2.22 respectively for GC1, GC2 and GC3.

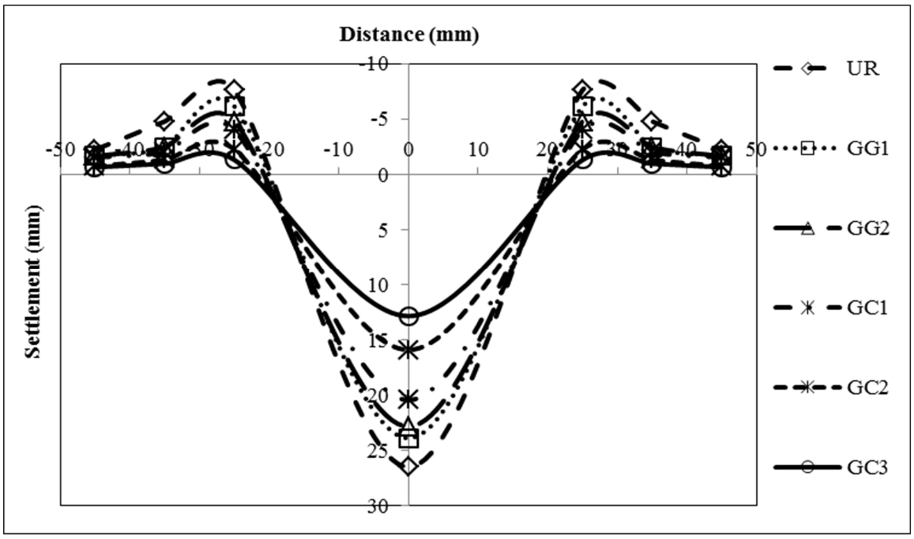


Figure 7 Surface profiles of unreinforced and geosynthetic reinforced model pavement sections at the end of 500 load cycles

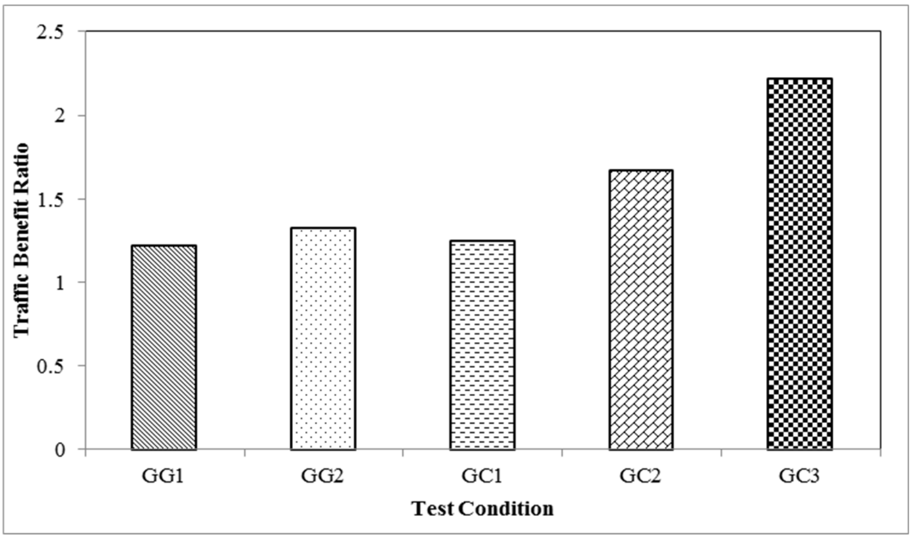


Figure 8 Variation of traffic benefit ratio with the geosynthetic reinforcement

6. CONCLUSIONS

A laboratory based experimental investigation consisting of repeated load tests on unreinforced, geogrids and geocells reinforced model pavement sections was carried out to study the effect of provision of geosynthetic at the interface of subgrade and sub-base course layer and their properties on the performance of flexible pavements. Based on the test results, the following conclusions are drawn.

- The provision of geosynthetic at the interface of subgrade and sub-base course results in significant reduction in plastic settlement leading to reduced rut depth at the surface and increased service life of the pavement structure.
- The introduction of geosynthetic at the interface of subgrade and sub-base course did not show significant improvement in terms of fatigue performance of the pavement structure.
- Among geogrids and geocells, geocells are found to be beneficial in improving the pavement performance and this is attributed to its cellular structure offering all-around confinement.
- Provision of geosynthetic reduces the surface heaving and minimum heave is found with higher aspect ratio geocell.
- The planar form of geosynthetic (geogrid) yields lower TBR values and cellular form of reinforcement (geocell) yields higher TBR values, higher aspect ratio geocell provides maximum benefit.

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