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Rutting Behavior of Geocell Reinforced Base Layer Overlying Weak Sand Subgrades

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Abstract

In this study, a series of large scale repeated model load tests are performed on geocell reinforced and unreinforced base layers overlying weak sand subgrades. The weak sand subgrades are prepared at 30% relative density (R_D) through pluviation (sand raining) technique in a test tank of dimensions 1m × 1m × 1m (length × width × height). Two different base courses consisting of 75% R_D sand and a granular base material have been tested. The 75% R_D sand base course is also prepared by pluviation technique, while the granular base course is prepared in 5 layers, each of 50mm thick, by static compaction.
A repetitive load of 0.97kN and 9.7kN was applied on the prepared base layer through a 150mm diameter plate to replicate the traffic load equivalent to a contact pressure of 550kPa. Loading was applied through a graphical user interfaced multi-purpose test software along with the help of a hydraulic power unit, hydraulic service manifold and sophisticated double acting linear dynamic 100kN capacity actuator which is connected to a 3.5m high, 200kN capacity reaction frame. Four different tests are conducted on both the base courses (75% R_D sand and granular base) with and without reinforcement overlying the weak sand subgrade separately. There is a considerable amount of improvement observed for different number of cycles and plate settlements on quantification of traffic benefit ratios (TBR), cumulative plastic deformations (CPD) and rut depth reduction (RDR) for geocell reinforced base courses. However, geocell reinforced granular base course have shown a better improvement comparatively.

Keywords: Geocell, Sand subgrade, Traffic benefit ratio, Cumulative plastic deformation, Rut depth reduction

1 Introduction

The pavements are basically classified into flexible (asphalt) pavements and rigid (concrete) pavements. Majority of the pavements across the globe are flexible type. The flexible pavements predominantly fail due to two reasons: the bottom up fatigue cracking and the rutting. Unlike fatigue cracking, rutting is a very common mode of failure seen in the low-volume roads. The low-volume roads usually consist of a thin layer of bituminous or asphalt surfacing or unpaved in nature. Rutting can be

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described as a depression or an excessive settlement of the surface layer due to the traffic wheel loads or settlements of the pavement layers below. The excessive rutting can be due to the poor quality of the pavement materials used and this can be avoided by using superior quality road materials or by stabilizing the poor quality materials. The rutting behavior of the pavements can also be improved by inserting a geosynthetic material into the interface of subgrade and base or sub-base layers. Many researchers have found that the usage of geosynthetics as a reinforcement in the pavement layers has improved the performance of pavements against the rutting. Until, late 1970's the geosynthetic materials made up of various polymers and fabrics were used as reinforcement in the pavement layers. These reinforcements are planar in nature until recently, a new three dimensional geosynthetic reinforcement called as geocell are available with better load carrying capacity.

Geocell were first used as a reinforcement in the pavements by US Army Corps of Engineers to improve the bearing capacity of the soil. The geocell reinforcement in base layers of pavement alleviates the increase in the percentage of permanent deformations (Yang, et al., 2012). The other reinforcement mechanisms such as lateral confinement and increased bearing capacity effects were observed by (Dash, Krishnaswamy, & Rajagopal, 2001) and (Han, Yang, Leshchinsky, & Parsons, 2008) under static loading conditions.

2 Background

Several researchers have studied the use of geosynthetic reinforcements such as geogrids, geonets, geotextiles, composites and geocells in pavement layers to reduce the rutting phenomenon in low-volume roads (Giroud & Noiray, 1981; Barker, 1987; Haas, Wall, & Carroll, 1988; Al-Qadi, Brandon, Valentine, Lacina, & Smith, 1994). Generally, the improvement due to geosynthetic reinforcement is quantified in terms of TBR for repetitive loads and in terms of bearing capacity improvement for static loads. The TBR can be defined as a ratio of number of load repetitions applied on the reinforced beds to the number of load repetitions applied on the unreinforced bed for a given rut depth. The reinforcement of pavements using planar geosynthetics especially geogrids showed various reinforcement mechanisms such as lateral confinement, increased bearing capacity and tensioned membrane effect to provide higher TBR values (Giroud & Noiray, 1981). (Haas, Wall, & Carroll, 1988) used a laboratory test tank to study the effects of geosynthetics (geogrids and geotextiles) in a pavement model test under repeated loading conditions and found that the geosynthetic reinforcement increased the TBR by 0.8 to 3.3 times. Whereas, (Barker, 1987) made use of an outdoor test track to study the effects of geogrid reinforced airfield pavements and was successful in demonstrating beneficial effects of geogrids with the TBR value of 1.2. Studies on geocell reinforcement under static loading conditions were conducted by several researchers (Bush, Jenner, & Bassett, 1990; Mhaiskar & Mandal, 1994; Dash, Krishnaswamy, & Rajagopal, 2001; Saride S. , 2006; Hegde & Sitharam, 2013) and were capable of concluding that the geocell reinforcement increases the bearing capacity of footings, in terms of improvement factors, due to the lateral confinement of inter connected cell. The large scale triaxial test facility was used by (Mengelt, Edil, & Benson, 2006) to study the effect of geocell reinforcement under cyclic loads and observed an improvement in the resilient modulus of geocell reinforced specimens against unreinforced specimens.

The test tank facility was used by (Pokharel, Han, Leshchinsky, Parsons, & Halahmi, 2009) and (Moghaddas & Dawson, 2010) to study the geocell reinforced pavement sections and determined that there was an increase in the stiffness of the base layer and reduction in the permanent deformations of the reinforced sections when compared to the unreinforced sections. Whereas, (Yang, et al., 2012) used accelerated pavement testing facility and concluded that there was a reduction in the permanent deformations of the geocell reinforced unpaved roads compared to the conventional unpaved roads. In addition to the traffic benefits or load carrying capacity, the performance improvement in terms of rutting benefits of geocell reinforced base layers are very crucial in pavement design. However, not much information is mentioned in the literature about the rutting benefits of the geosynthetics.

Based on the available literature, it can be summed up that very limited studies have reported the behavior of geocell reinforced pavement bases under repetitive traffic loading conditions. Hence, an attempt has been made to study the rutting behavior of geocell reinforced granular bases overlying weak sand bases under repetitive traffic loading.

3 Materials

3.1 Sand

Dry river sand was used to replicate a weak subgrade layer and also a dense base course layer. The particle size distribution was done by dry sieve analysis (ASTMD422, 2007) and the data is as presented in Figure 1. The specific gravity of the sand is 2.63 and has a coefficient of uniformity (C_u) of 2.4 and a coefficient of curvature (C_c) of 1.7. Based on the particle size distribution curve, the sand sample used in the study can be classified as poorly graded sand denoted by letter symbol SP according to the unified soil classification system (USCS). The maximum and minimum void ratios of the material is found to be 0.74 and 0.51 respectively, while the angle of internal friction is found to 41^0 and 34^0 for R_D 75% and R_D 30% respectively. The California bearing ratio (CBR) tests were conducted on the dry sand samples at 30% and 75% relative density (R_D) to check for the strength of the sand subgrade and sand base to be used in the study. The CBR values obtained are 3 and 21 respectively, for loose and dense conditions considered for this study. The sand subgrades were chosen over the clayey subgrades to maintain the uniformity in the sample preparation.

3.2 Aggregate

The base course materials used in the study are sand compacted at 75% R_D and granular materials (graded aggregates). The aggregates used in the study were obtained from a nearby quarry site and blended thoroughly in the laboratory. The sample after blending were tested for particle size distribution using dry sieve analysis and it was determined that the sample belongs to the grade-III of the base course materials as per MORTH (Ministry of road transport and highways) specifications. The particle size distribution curve can be seen in Figure 1.

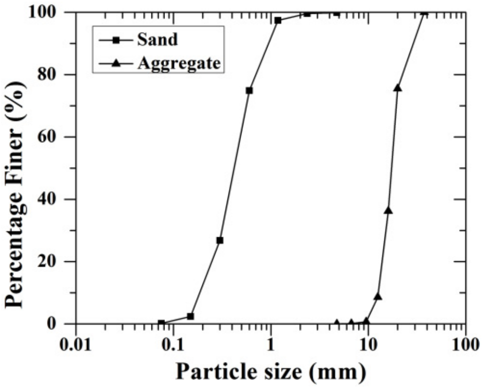

Figure 1: Particle size distribution curve for sand and aggregate

3.3 Geocell

Geocell is a three dimensional geosynthetic material made with ultrasonically welded high density polyethylene (HDPE) strips, expanded on site to form a honeycomb like structure. Geocell used in the current study is made up of a polymer of HDPE with a density ranging from 0.935 to 0.965g/cm^3 and a weld spacing of 356mm. The height or depth of the cell is maintained at 200mm with a minimum cell seam strength of 2100N throughout the test series.

4 Testing Program

4.1 Pavement Test Section

Four test sections were prepared in a test tank with inner dimensions of 1m × 1m × 1m (length, width and height) and the repeated load was applied through a rigid steel circular plate of 150mm diameter and 15mm thickness. The test tank and the loading plate dimensions were decided based on the observations made from previous studies (Edil, Fratta, & Shuettpelz, 2009; Saride, Rayabharapu, & Vedpathak, 2014). In addition, the boundary effects on the test data were verified with four earth pressure cells attached to the test tank walls, have recorded negligible lateral earth pressures. The schematic of the test setup used in the study is shown in Figure 2.

The subgrade for all the test sections were maintained same and prepared with 30% R_D sand to replicate a weak subgrade with a CBR value of 3 up to a thickness of 0.65m. The sand subgrade was prepared by using a sand raining or a pluviation technique. There were four pavement test sections prepared to study the rutting behavior of the geocell reinforced and unreinforced test sections; the test section-1 consisted of a 0.25m thick 75% R_D sand base layer overlying the weak 30% R_D sand subgrade. Similarly, section 3 comprised of a 0.25m thick graded aggregate base layer having a density of 2.3gm/cc. Sections 2 and 4 were the geocell reinforced version of sections 1 and 3 respectively, i.e. the base layer is reinforced with a geocell mattress of height 200mm (i.e. height to plate width ratio, h/D = 1.33 and 650mm wide (i.e. width of geocell to plate width ratio, b/D = 4.33). The size of geocell was fixed based on the previous studies done by (Saride, Rayabharapu, & Vedpathak, 2014). The summary of the configuration of each test section is shown in Figure 3.

4.2 Sample Preparation

The weak sand subgrades and the dense sand bases with corresponding uniform relative densities were prepared in the test tank using a sand raining or pluviation technique. A pluviator consisted of a 300mm long stand pipe having an internal diameter of 40mm and also having an inverted cone with an angle of 60^0 attached at one end of the pipe. The pluviator is attached to a hopper bottom container. The sand is poured from the hopper through the pluviator, which is movable such that the sand is filled into the test tank from the hopper uniformly. The uniform density of the sample is maintained based on the relative density calibration chart prepared. The densities were examined by placing several cups of known dimension at different levels in the test bed. It was noted that a fairly uniform densities were maintained with an acceptable error of 3%.

The graded aggregate base layers were prepared by static compaction. The compaction process was done with the help of a static weight compactor of 5kg having a square shaped base plate of 100mm size and a height of fall of 50cm. The number of blows required to achieve the desired density is calculated and a calibration chart similar to the sand calibration was prepared. Unlike, the normal granular base layers, compacted at maximum dry density and optimum moisture content; the base layers in the current study were compacted at completely dry state so as to avoid the water from entering into the dry sand subgrades. This scenario replicates the severe subgrade and base layer conditions.

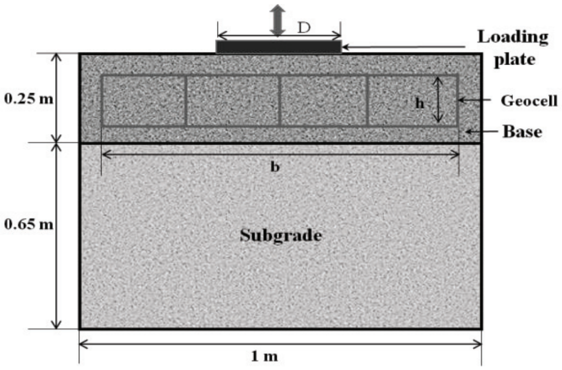

Figure 2: Schematic of test setup

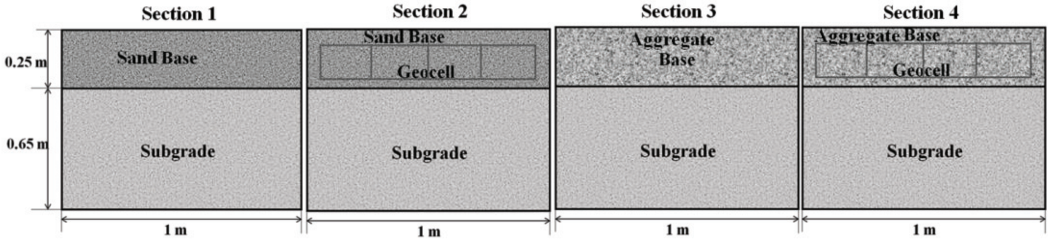

Figure 3: Summary of pavement test sections

4.3 Repetitive Loading

A 100kN double acting linear dynamic actuator attached to a 3.5m high, 200kN reaction frame as shown in Figure 4a was used to apply the repeated load on the prepared test sections. A graphical user interfaced multipurpose test software with the help of hydraulic power unit and hydraulic servo manifolds are attached to create user defined load patterns and to control the testing. A maximum load of 9.7kN equivalent to a single axle wheel load (550kPa contact pressure) and a minimum load of 0.97kN (10% of maximum load) was applied to replicate a live traffic single axle wheel load. The load pattern of a continuous haversine type with a frequency of 1 Hz was applied as shown in Figure 4b to replicate the live moving traffic. The seating load of 0.97kN was applied for a span of 0.2 seconds and a time span of 0.3 seconds was required to ramp the load from 0.97kN to maximum load of 9.7kN and the maximum load was applied for 0.2 seconds and the load was released from 9.7kN to 0.97kN in 0.3 seconds. The repeated loads were applied on the prepared test sections until a prescribed rut depth or the plate settlement was achieved, i.e. the tests were stopped once a loading plate settlement ratio of 20% was reached.

5 Results and Discussions

The typical data from repeated load tests is obtained in the form of a pressure-settlement variation (test section-2) as shown in Figure 5 and it can be observed that the settlement ratio decreases with number of load repetitions. The total settlement ratio can be defined as the ratio of the plate settlement to the diameter of the loading plate. To analyze the permanent deformations of the unpaved road surface, the total deformations are separated into plastic and elastic deformations and the summation of the plastic (permanent) deformations will result in the CPD which is expressed in terms of percentage of loading plate diameter. Figure 6a shows the variation of CPD with the number of loading cycles for different sections studied and it is observed that the test section-2 has taken 300 number of load cycles approximately for a CPD of 20%, which is test termination criterion. While, both sections 3 and 4 have a CPD of 6% and 5% respectively for the same 300 number of load cycles and section-4 performed well completing more than 10,000 number of load repetitions before failure and section-3 was strong enough to complete 8900 number of load repetitions before reaching a CPD of 20%. Overall, the section-4 (geocell reinforced graded base layer case) performed well when compared to all the other sections under application of repetitive loads.

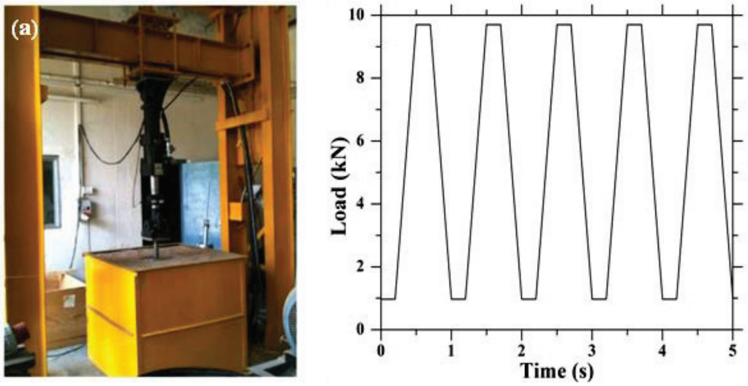

Figure 4: (a) Test setup and loading system used in the study; (b) Typical loading pattern used in the study

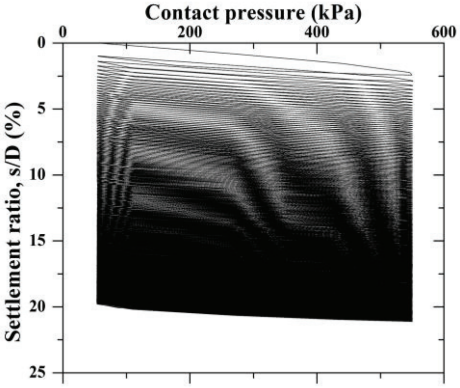

Figure 5: Typical pressure-settlement curve for repeated load

The rutting behavior of the geocell reinforced base courses overlying weak sand subgrades were studied in terms of the parameters, namely: RDR expressed in percentage and TBR also expressed in percentage as explained in the earlier section. RDR is defined as the ratio of difference between CPDs of unreinforced test section and geocell reinforced test section to the CPD of unreinforced section for a particular number of load cycle. RDR is expressed as shown in Equation 1. The results from different sections are presented in Table 1.

$$\boldsymbol{RDR = (1 - (CPD_r/CPD_u)) \times 100} \quad \mathbf{(1)}$$

From the results presented in Figure 6a, it can be noted that the load carrying capacity of the weak subgrade cannot be improved by a dense sand layer, which has shown premature failure (reached 20% settlement ratio) within the first cycle. Whereas, all the other sections were strong enough to complete a minimum number of load cycles before reaching the failure condition. The results of the various test sections are summarized in Table 1.

Both the performance factors RDR and TBR could be able to determine only for the case of geocell reinforced aggregate base layers. The performance factors for sand bases could not be obtained as the unreinforced dense sand base layers were unable to sustain any number of load cycles. Hence, the TBR and RDR details of the geocell reinforced aggregate base layers alone are calculated and presented. The TBRs are calculated with respect to the settlement ratio or corresponding rut depth and are tabulated along with the ESALs in Table 1. While, the RDR is calculated for a particular number of load cycle and the variation of RDR for different number of load cycles is as shown in Figure 6b. From Figure 6b, it can be seen that the RDR is increasing with the increase in number of load cycles and a clear improvement can be seen in the performance of geocell reinforced section against the unreinforced section reducing the rutting of unsurfaced pavement test sections such as rural roads and low-volume roads. As high as 22% RDR was achieved with aggregate base layers reinforced with geocells. It can also be noted from Figure 6b that the RDR has attenuated after about 100 load cycles representing that the bed has reached its ultimate permanent deformation (rut) under the load and thereafter, the behavior of geocell reinforced bed can be considered as resilient (elastic).

Test sections	s/D =1		s/D =5		s/D =10		s/D =15	
	ESALs	TBR	ESALs	TBR	ESALs	TBR	ESALs	TBR
Section 1	-	-	-	-	-	-	-	-
Section 2	1	-	10	-	52	-	130	-
Section 3	1	-	106	-	1020	-	3540	-
Section 4	1	1	199	1.14	1168	1.34	4755	1.87

Table 1: Summary of repeated plate load test

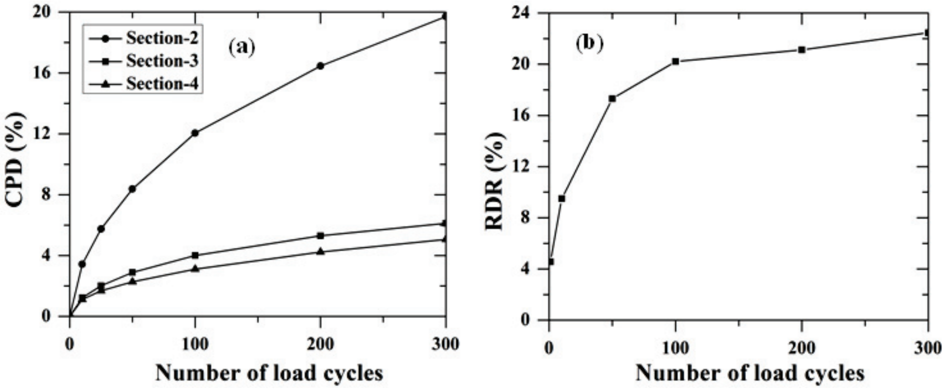

Figure 6: (a) Variation of CPD with number of load cycles; (b) Variation of RDR with number of load cycles

6 Conclusions

A series of repeated load tests were conducted on the unsurfaced pavement test sections with and without geocell reinforcement and the following conclusions can be drawn:

Geocell reinforcement can be used effectively to improve the performance of the unsurfaced rural pavements by reducing the rutting. The improvement against rutting in unpaved roads is shown in terms of performance factors namely TBR and RDR. The TBR and RDR for the granular aggregate base shows a good improvement with the increase in settlement ratio and number of load repetitions respectively with a TBR value of 1.87 at a settlement ratio of 15%. As high as 22% RDR was achieved with aggregate base layers reinforced with geocell mattress and has reached its ultimate permanent deformation (rut) under the load. Thereafter, the behavior of the geocell reinforced bed can be considered as resilient (elastic).

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