Repeated Load Tests on Geocell Reinforced Sand Subgrades

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ABSTRACT

In this research, results from a series of large scale dynamic model tests on geocell reinforced and unreinforced homogeneous sand beds are presented. The placement density of sand in all the tests was maintained at 70%. The loading was applied through a circular steel plate which replicates the load application from a passenger car. A single axle wheel load of 40 kN was assumed on the pavement surface of which 7 kN was calculated to be applied on the subgrade layer. The influence of the width and height of the geocell reinforcement on the cyclic behavior of the loading system was studied and the performance improvement in terms of traffic benefit ratios and cumulative plastic deformations/rutting was determined. A traffic benefit ratio was observed to be as high as 45 for the case of geocell size h/D=1, b/D=4 at 10% plate settlement. The cumulative permanent deformations were reduced by 8 fold for the same case against the unreinforced case at 5% plate settlement.

1. INTRODUCTION

In India, a statistical survey by rural development of India shows that around 80% of road network is comprised of rural roads (Rural roads, 2012) whose performance is always inferior and questionable. Besides, engineers are often forced to seek alternative designs using inferior materials, commercial construction aids, and innovative practices for better performance of pavements. One such category of commercial construction aids is utilization of geosynthetics. Geosynthetics includes a large variety of products manufactured of different polymers are adopted in numerous geotechnical and transportation applications. Often, it is important to estimate the efficacy of such inclusions in natural ground to improve the design methodologies and construction practices prior to their utilization.

Research on geocell reinforcement for pavement applications started about five decades ago. This reinforcement technique was first adopted by the US Army Corps of Engineers for improving the bearing capacity of poorly graded sand by using it as a lateral confinement (Webster, 1979). Lateral confinement, increased bearing capacity, and tensioned membrane effects were identified as the important reinforcement mechanisms for geogrid and geocell reinforcement (Giroud and Noiray, 1981, Dash et al 2001, Han et al. 2008a). The geocell reinforced bases exhibit bending resistance, tensile strength, and shear strength, and intercept the failure planes from the subgrade (Zhou and Wen, 2008). Understanding these mechanisms originated from mostly static plate load tests, however, limited research has been focused on these mechanisms under cyclic loading. The following sections discuss the cyclic behavior of geosynthetic reinforcement and factors affecting the performance of the geosynthetics under repeated loading.

2. BACKGROUND

Ever since the reinforcement forms were used, many kinds of geosynthetics like geotextiles, geogrids and geocells have come into existence. Many researchers have studied these reinforcement forms (geogrids and geocells) under static loading for pavement applications, however, a very few studies are available on cyclic loading (Barksdale, 1989; Cancelli, 1999; Collin, 1996, Dash et al. 2001; Dash et al. 2003; Sitharam and Sireesh, 2005). Generally, geosynthetics are used as pavement base or subbase reinforcement. Base course lateral restraint is the main reinforcement mechanism of geosynthetics in paved roads as described by Bender and Barenberg (1980).Further, Kinney and Barenberg (1982) demonstrated that the geotextile-reinforcement can be used in unpaved roads. When the planar geosynthetic reinforcement is placed at the bottom of the asphalt concrete layer, it leads to the highest reduction in the vertical deflection (Hossein et al., 2009). Hossein et al. (2009) reported that the overall performance of the asphalt pavement was improved when an effective bonding was maintained between the asphalt concrete and the geogrid. The settlement over the loading area of reinforced pavement was also reduced when compared with unreinforced pavement under cyclic loadings.

To quantify the benefits with geosynthetic reinforcements in pavements under cyclic loading, a non-dimensional term called traffic benefit ratio (TBR) has been introduced. TBR is expressed in terms of extension of life or by savings in base course thickness. TBR is defined as the ratio of the number of cycles necessary to reach a given rut depth for a test section containing reinforcement, divided by the number of cycles necessary to reach the same rut depth for an unreinforced section with the same section thickness and subgrade properties. This is in consistent with the non-dimensional parameter called improvement factor defined in the case of static loading system on geosynthetic reinforced beds (Dash et al. 2001; Dash et al. 2003; Sitharam and Sireesh, 2005).

Several researchers investigated the cyclic behavior of different forms of geosynthetic reinforcements and provided TBRs. Haas (1985) reported a TBR of about 3.3 for geogrid reinforced beds in a large test tank. Similarly Barker (1987) used geogrid reinforcement under a moving single wheel system and observed a TBR of 1.2. Al-Qadi (1994) studied a combination of geogrid and geocell reinforcements in a test tank and observed TBR ranging from 1.7 to 3.0. Similar observations were made by many other researchers where the TBR was observed to be ranged from 1 to 4 under single axle wheel loads (Barksdale, 1989; Cancelli, 1999; Collin, 1996). Recently, Pokharel (2010) performed large-scale cyclic plate loading tests on geocells and observed that the NEOLOY polymeric alloy (NPA) geocell improved the strength and life of the unpaved road sections over weak subgrade. The reinforced sections had much higher percentage of elastic deformation (more than 90%) as compared with the unreinforced sections and also the NPA geocell.

The effect of the properties of infill material on the performance of unpaved and paved road sections subjected to cyclic loading shows that both the strength of the subgrade and the quality of infill material play a vital role in improving the performance of the geocell-reinforced road sections (Kazerani and Jamnejad, 1987). Higher performance was observed with geocell reinforcement with dense infill on a good subgrade. Similar observations were reported by Han et al., (2008a). Han et al (2008b) also reported that the placement of geocell from the surface of loading is very crucial. In static load tests, it was observed that the depth of placement of geocell should be maintained about 1 to 5% of the width of the loading area (Dash et al., 2001; Sitharam and Sireesh, 2005).

Literature study reveals, based on the limited information available on geocells, that the cyclic behavior of geocell reinforced beds are not yet understood completely. Hence, in this study, an attempt has been made to understand the cyclic/repeated load response of the geocell reinforced sand subgrades.

3. MATERIALS AND METHODS

3.1 Sand

The soil used in this investigation was dry sand. The particle size distribution of the sand was determined by dry sieve analysis as per ASTM D 422. The particle size distribution of the sand is shown in Figure 1.The sand is classified as poorly graded sand with letter symbol SP according to the Unified Classification of Soil (UCS). The physical properties such as specific gravity, maximum and minimum void ratios of sand were determined according to ASTM D 854-00, ASTM D 4253 and ASTM D 4254 respectively. The properties of sand are depicted in Table 1.

3.2 Geocell

Geocell is a strong, lightweight, three dimensional honeycomb-like cellular confinement systems, which is made of ultrasonically-welded HDPE strips that are expandable on-site to form a honeycomb-like structure. It acts as a foundation reinforcement mat for improvement of bearing capacity of weak soils. It is a polymer of High density polyethylene (HDPE) material with a density ranging between 0.935-0.965 g/cm^3 and with surface treatments of texturing which consists of a multiple of rhomboidal identifications over the entire strip area and material where the polyethylene strip shall be perforated with horizontal row of 10 mm diameter holes. The geocells used in this study are having weld at regular intervals of 400 mm and 75, 100 and 150 mm depths. A typical geocell mattress used in the present study can be seen in the Figure 2.

Table 1. Properties of sand used in investigation

Properties	Values
D 10 ,mm	0.20
D 30, mm	0.32
D 60, mm	0.48
C_u	2.40
C_c	1.07
Specific gravity	2.63
Emax	0.74
Emin	0.51

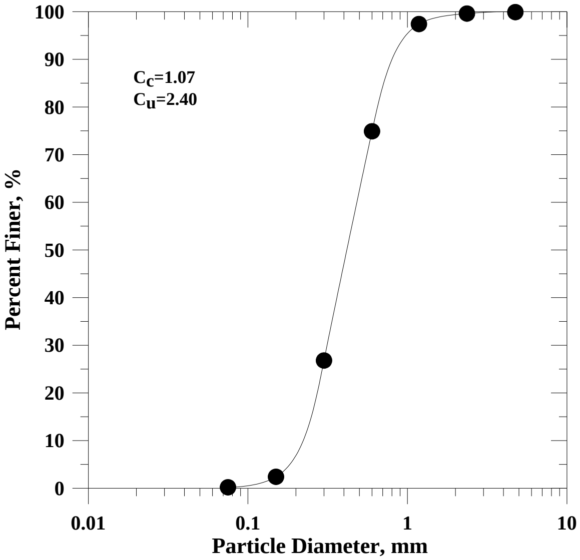

Figure 1. Particle size distribution curve for sand

Figure 2. Typical geocell used in the study

4. TEST SETUP

The sand beds with 70% relative density were prepared in a test tank measuring inner dimensions of 1m × 1 m x1 m (length x width x height). A rigid thin steel plate of 150 mm diameter (D) and 15 mm thickness was used to apply the repeated traffic loading. The size of the plate was chosen such a way that the area of the plate resembles the area of tire pressure. Loading was given by graphical user interfaced MTS MPT software with the help of hydraulic power unit (HPU), hydraulic service manifold (HSM) and sophisticated double acting linear dynamic 100 kN capacity actuator which is attached to a 3.5 m high, 20ton capacity reaction frame as shown in Figure 3.

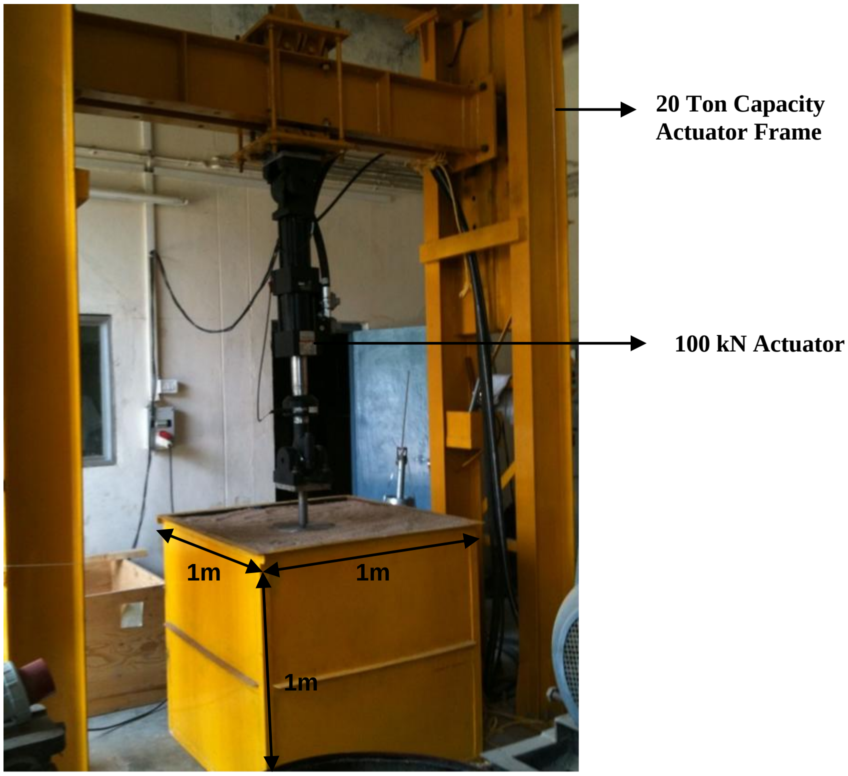

Figure 3. Test-cum-Loading system used in the present study

5. TESTING PROCEDURE

Test procedure can be explained under three sub topics:

1. Preparation of relative density calibration chart
2. Preparation of sand bed
3. Cyclic load tests

5.1 Preparation of Relative Density Calibration Chart

To determine the density with which sand is to be poured in the tank, a special technique called sand raining technique or sand pluviation technique was used. To achieve this, a special device is designed. This device has a hopper with a flexible pipe connected to its bottom. A 40 mm internal diameter and 300 mm long pipe with an inverted cone welded at its one end was intern attached to the bottom of the flexible pipe. The sand passes through the pluviator disperses at bottom by a 60^o inverted cone. This pipe is fitted with a movable scale to arrange different heights shown in Figure 4.

Relative density calibration chart was obtained by conducting a series of tests with different heights of fall of sand pluviation. Natural densities were measured physically by collecting samples in small containers whose weights and volumes were known. With the known values of the minimum and maximum void ratios of sand used in the investigation, a calibration chart was prepared for the height of fall against the corresponding relative density. For any required relative density, the corresponding height of fall can be read directly from the calibration chart shown in Figure 5.

5.2 Sand Bed Preparation

The sand was placed in the test tank using pluviation technique as discussed above. In this study, the relative density of sand was maintained at 70 %. The test bed density was frequently monitored by taking samples at different depths during pluviation using flat cups. The densities were well within the range of 1% error. The modulus of the test beds were also examined with a 10 kg capacity Lightweight Deflectometer (LWD). From LWD tests, the average modulus of the test bed at 70% relative density was found to be 28.2 MPa. This modulus is compared with the pressure-settlement data obtained from an unreinforced bed which was found to be 27.8 MPa (average).

Figure 4. Devices used in the preparation of test beds

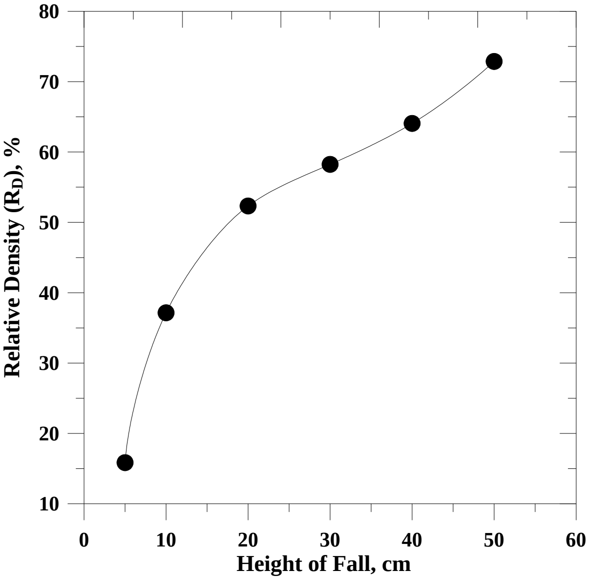

Figure 5. Calibration curve for the sand used in the study

5.3 Cyclic Load Tests

Upon filling the test tank up to the desired height, the fill surface was leveled and the loading plate was placed on a predetermined alignment such that the loads from the actuator applied would be transferred concentrically to the footing to avoid eccentricity. To facilitate this, a recess was made into the footing plate at its centre to accommodate a ball bearing through which vertical loads were applied to the plate. In the case of reinforced beds, upon ceasing the pluviation at predetermined depth, the geocell was stretched on the leveled subgrade and continued the sand pluviation to fill the geocell mattress.

The plate was located carefully at the centre of the actuator against the reaction frame to avoid eccentric loading. The cyclic load was applied to a loading plate using a computer-controlled servo hydraulic actuator, with a maximum load of 7 kN and a minimum on 0.7 kN using a continuous haversine loading pattern as shown in Figure 6. The load was estimated based on the field data using a strain type total pressure cells buried under subbase layer just above the subgrade. Similar loading pattern was also adopted by Edil et al (2007) for the case of geocell reinforced granular subbase layer. Since the intermediate layers have not been simulated in this model tests, the pressure exerted on to the subgrade was directly applied through a plate. A 10% of load (0.7 kN) was constantly applied on the plate to make the cycle a closed loop. The load form was applied at a frequency of 0.77 Hz. Multi-Purpose Test Ware (MPT) software was set up to control and acquire the applied load data as well as the deformation data.

A series of repeated load tests were conducted to verify the efficiency of the geocell layers in the subgrade. These tests include single geocell layers with different sizes with respect to the plate diameter. The width of geocell (b) was varied at 3 times the plate width (D) represented as geocell width ratio, b/D. Similarly the height of the geocell was varied as h/D=0.5, 0.67 and 1.0. The relative density of the sand was maintained at 70% in all tests. The depth of the reinforcement layer from the bottom of the plate was maintained at 0.1 times the diameter of the plate according to Sitharam and Sireesh (2005) and Dash et al (2001). All the tests were conducted until reaching the settlement about 20% of the plate diameter. The equivalent diameter of geocell pockets, d_c was maintained at about 1.6D in all the tests.

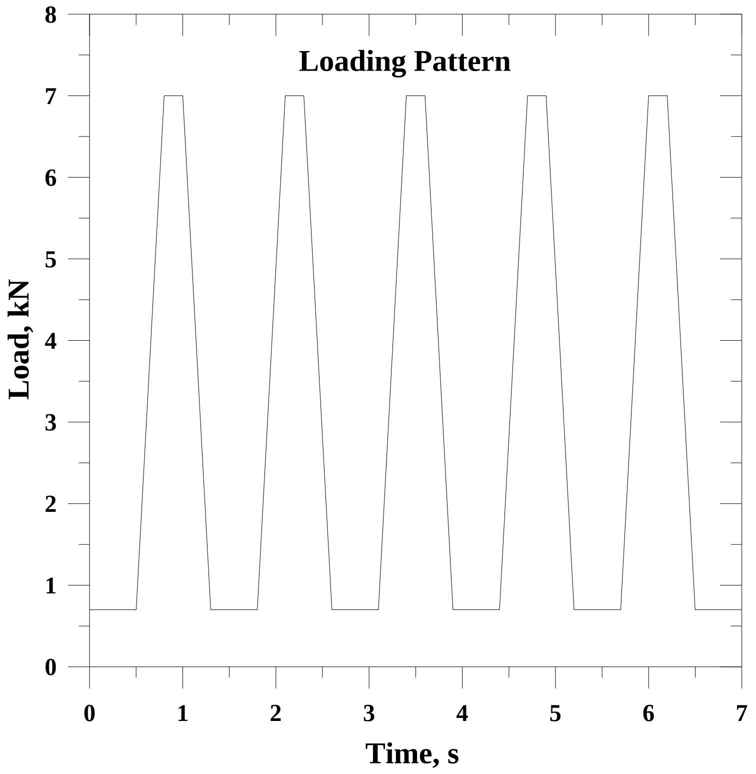

Figure 6. Loading pattern used in the study

6. RESULTS AND DISCUSSION

Figure 7 depicts the response of the geocell reinforced bed under cycling loading conditions. It can be observed that the total settlement ratios are large for the initial loading cycles, while their magnitude attenuates thereafter.

The settlement ratios are reduced as the amount of geocell reinforcement increases, hence, the unreinforced subgrade exhibits the highest settlement ratios.To quantify the reduction in settlement ratios and the efficacy of geocell, cumulative permanent deformations (CPDs) were calculated from a sequence of experiments. First, the permanent deformation was calculated for each loading cycle, by subtracting the elastic component of the settlement from the total settlement. The permanent deformations per loading cycle were then added cumulatively, to obtain the cumulative permanent deformations / settlements with increasing number of loading cycles. Figure 8 demonstrates the variation of cumulative permanent deformations with the number of loading cycles for all the cases considered in this study. The variation of the traffic benefit ratio, TBR, as defined earlier, for different geocell configurations is also presented in Figure 9.

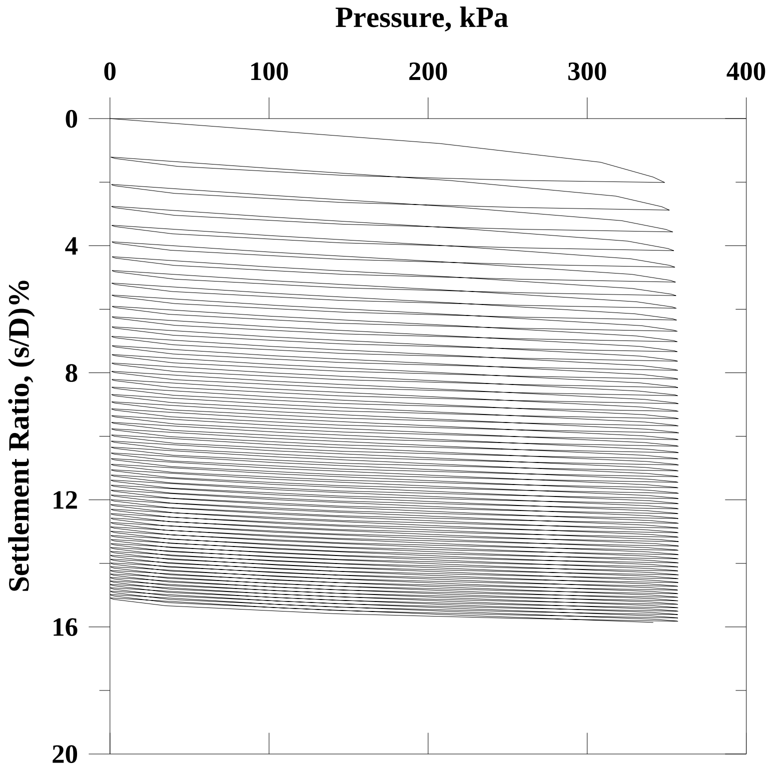

Figure. 7 Typical pressure-settlement pattern from repeated loading for the case of geocell reinforced bed (h/D=1, b/D=4)

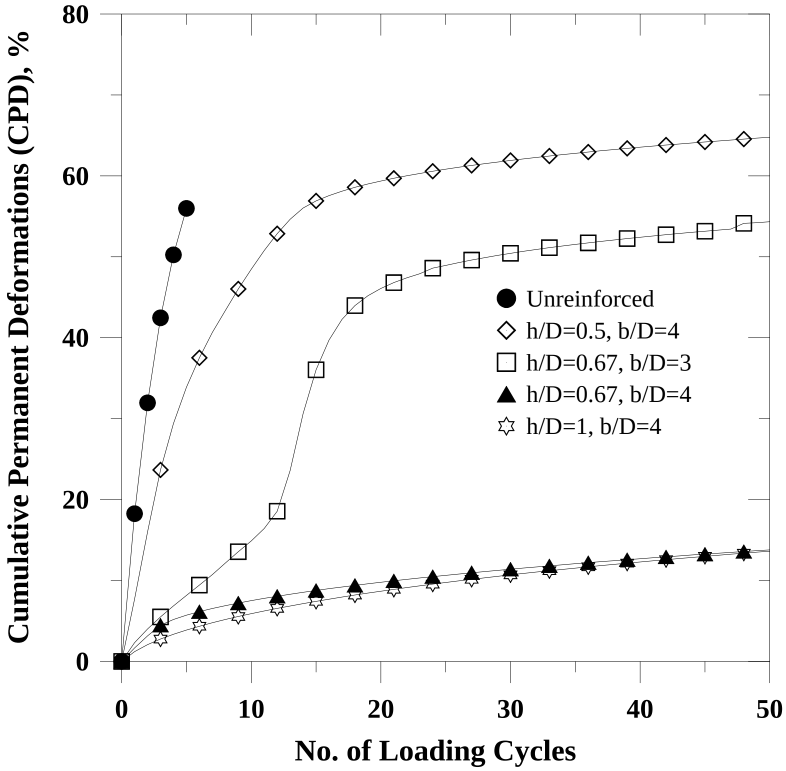

Figure 8. Variation of cumulative permanent deformations with number of loading cycles for various cases

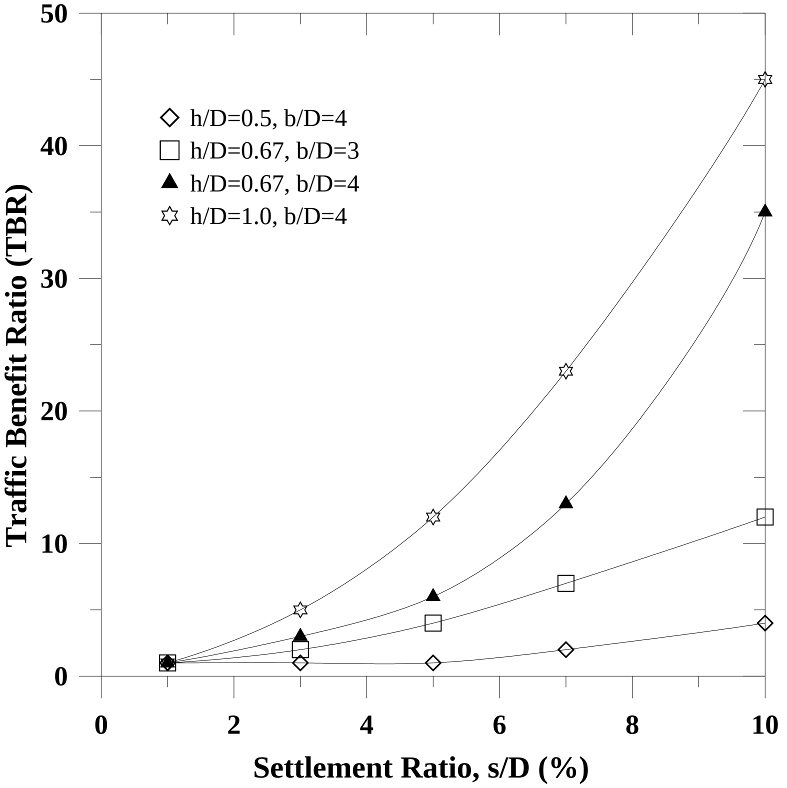

Figure 9. Variation of traffic benefit ratios with settlement ratios for different geocell sizes

The unreinforced subgrade was tested for only few loading cycles as the prescribed maximum amount of settlement (s/D> 50%) was reached at this stage. It is clear from Figure 9 that the permanent deformations of geocell reinforced beds are much less when compared to the unreinforced subgrades. This reduction is as high as 8 fold between unreinforced case and geocell reinforced case (h/D=1, b/D=4). It is to be noted here that the permanent deformations are higher for the case of h/D=0.5 with b/D=4. The higher permanent deformations, in this case, can be attributed to the least flexural stiffness of the geocell mattress available compared to the other cases. It can also be inferred from this figure that for obtaining higher structural support for the pavement layers, the geocell height should be adequate enough to provide resilient behavior. The geocell with h/D=1 is providing highest resilient behavior during the repeated traffic loading in this study.

From Figure 9, the traffic benefit ratio (TBR) at 10% settlement ratio are observed to be as high as 45 for h/D=1; b/D=4 case; 35 for h/D=0.67; b/D=4 case, 12 for h/D=0.67; b/D=3 case and 8 for h/D=0.5; b/D=4 case of geocell reinforced sections. Hence, it can be summarized that the geocell of sufficient size (b) and thickness (h) will provide a higher traffic benefit ratio for a given level of traffic loading conditions.

Further study is required to understand the optimal benefits from the critical geocell geometry. It is also important to determine the depth of this kind of reinforcement and number of layers of reinforcement for optimum performance.

7. CONCLUSIONS

From a large scale cyclic model tests on unreinforced and geocell reinforced beds, following conclusions can be drawn:

1. Geocell can be used as reinforcement in pavement subgrade layers to increase the stiffness of the subgrade.

2. Geocell reinforcement reduces the plastic settlements, referred as rutting on the pavement surface by providing lateral confinement to the infill soil. The reduction in permanent deformation is observed to be as high as 8 fold for the case of geocell size h/D=1, b/D=4 versus the unreinforced bed at 5% plate settlement.

3. The traffic benefit ratio, TRB was observed to be as high as 45 for the case of geocell size h/D=1, b/D=4 versus 8 for the case of geocell size h/D=0.5, b/D=4 at 10% plate settlement. The lower TRB for the thin geocell layer is attributed to the flexural stiffness of the geocell mattress offered to support the cyclic loading. Hence, it is important to choose an optimum size geocell for higher structural support for a given traffic loading system.

4. Further systematic study is required to completely understand the geocell material in pavement layers such as base and subbase layers with aggregate infill.

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