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PERFORMANCE OF REINFORCED BASE COURSES OF FLEXIBLE PAVEMENTS OVERLYING SOFT SUBGRADES: INSIGHTS FROM LARGE-SCALE MODEL EXPERIMENTS

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ABSTRACT: In this study, large-scale model pavement experiments (LSMPEs) were performed to assess the performance of geosynthetic-reinforced bases of flexible pavements overlying soft subgrades (with California bearing ratio equal to 1% and 5%). Two configurations of reinforcement were considered – (1) base layers reinforced with geocell (GC) alone, and (2) base layers reinforced with geocell and geogrid (GG) combinations (GC+GG). Model pavements were constructed inside the test chamber measuring 1.5m (length) × 1.5m (width) × 1.0m (height). Wheel loads on the pavements were simulated by applying repetitive load equivalent to the tire contact pressure of 550 kPa through an actuator on a rigid circular plate (diameter equal to 300 mm). The reinforcement combination with GC+GG was found to perform better than GC alone due to additional support offered by geogrid when used as a base or basal reinforcement underneath the geocell mattress. The performance was evaluated in terms of cumulative permanent deformations and Traffic Benefit Ratio (TBR) over 100,000 repetitive load cycles. TBRs of the GC+GG combination showed values greater than 50 for test conditions considered. Furthermore, test results showed that the GC+GG combination reduced permanent deformation by up to 78%, while GC alone reduced it by about 52% compared to the unreinforced section. TBRs of geocell alone and geocell with basal geogrid combinations indicated extended service life of the pavement.

Keywords: Soft subgrade, Geocell, Geogrid, Permanent deformations, Traffic benefit ratio

1. INTRODUCTION

Pavements overlying soft subgrades cause excessive permanent deformation under repetitive loads. The subgrades associated with wetlands and heavy rainfall regions are a practical concern for improvement. Available conventional methods such as cement or lime stabilization or fiber reinforcement used to treat soft subgrades yield a good platform for the construction of pavement layers but consume enormous time and money. Alternatively, geosynthetics are highly preferred due to their cost-effectiveness and ease of construction. Geosynthetic reinforcement materials, viz., geogrid, and geocell offer various benefits in flexible pavements such as lateral restraint, load-carrying capacity, and membrane support [1-4]. Similarly, a three-dimensional honeycomb structure called geocell offers overall confinement and higher load carrying capacity [1, 5-7]. However, their benefit in terms of reduced deformations and improved pavement performance over soft subgrades is observed when reinforcement is placed near the loading region [8-11]. In most cases, when soft subgrades are encountered, single reinforcement such as geogrid or geocell placement in the base layers may not be adequate to control the pavement deformations. Hence, to overcome such problems generally, a geogrid reinforcement layer underlying a geocell mattress is placed to arrest downward deflections and provide extra support [8, 12, 13].

The geogrid basal reinforcement is used to increase the pavement's service life, decreasing base course thickness or arresting longitudinal cracks in the pavements [14]. The published studies suggest significant improvement in load-bearing capacity due to additional support with basal geogrid placed underneath geocell [8, 12]. The overall performance of the basal reinforcement accounts due to the tensile strength mobilization and membrane support [8, 13]. Previous researchers indicated the necessity of additional support with basal geogrid underneath the geocell mattress to increase the overall performance of the pavement [12, 13]. On the contrary, its benefit was reported to be marginal with an increase in the height of the geocell and was found to give superior performance when the limited size of geocell and appropriate geogrid is used [15]. The increase in height was reported to show buckling of geocell walls leading to a decrease in the load-bearing capacity [15].

The studies mentioned herewith have focused solely on evaluating the bearing capacity of reinforced foundations or pavements. However, studies have not focused on quantifying the overall pavement performance of geocell and geogrid basal reinforcement, such as improved service life, especially when soft subgrades are encountered. The improved service life of the flexible pavement is generally quantified in terms of *Traffic Benefit Ratio* (TBR) [1]. TBR is defined as the ratio of several load cycles sustained by base reinforced pavement at the defined permanent deformation to the number of load cycles sustained by the unreinforced pavement section at the same defined permanent deformation with the same material constitutions and thicknesses. Permanent deformation is also called cumulative permanent deformation or rutting. Thus, in this study, the influence of bases reinforced with geocell alone and combination of geocell and geogrid is evaluated in terms of cumulative permanent deformation and TBR of reinforced pavements overlying soft to relatively fair subgrades (with California bearing ratio (CBR) equal to 1% and 5%). The overall purpose of this study is to quantify the enhanced pavement performance in terms of increased service life by the inclusion of geosynthetics when soft subgrades with a CBR ≤ 5% are encountered.

2. RESEARCH SIGNIFICANCE

This article details the large-scale model pavement experiments (LSMPEs) conducted on geogrid, and a combination of geogrid and geocell (basal reinforcement application) reinforced flexible pavements overlying soft (CBR=1%) to relatively fair (CBR=5%) subgrades. The use of geocell and basal reinforcement application in base layers overlying soft subgrade is examined. The prepared test sections were subjected to repetitive load action by applying a typical tire contact pressure of 550 kPa through a double-acting linear dynamic actuator. The benefit of reinforcement in the base layers was quantified in terms of traffic benefit ratios (TBRs) for overlaying soft to relatively fair subgrade conditions. The input range of TBRs for the design of flexible pavements is recommended to extend the pavement's service life.

3. MATERIALS AND METHODOLOGY

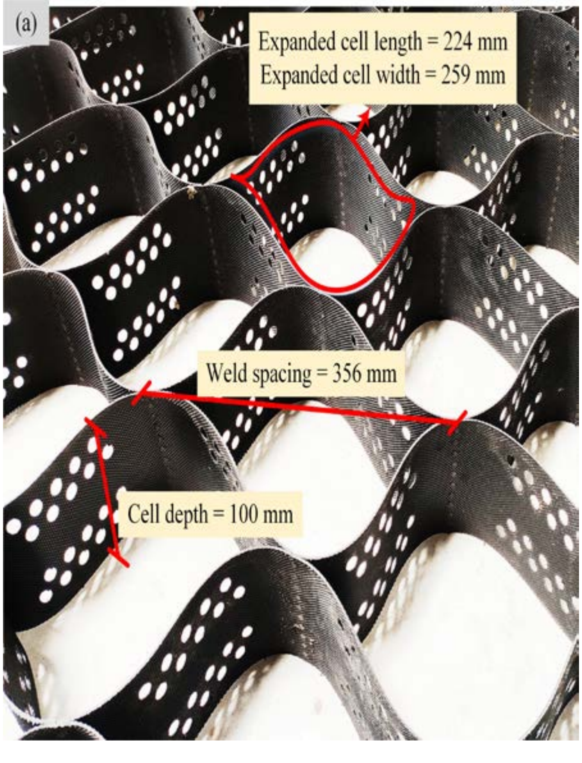
3.1 Subgrade Soil, Granular Base and Subbase, and Asphalt Layer

In this testing program, crushed aggregate, dense bituminous macadam, and clayey sand were used to prepare granular layers, asphalt layer, and subgrade, respectively. Similarly, geocell and geogrid made up of high-density polyethylene and polypropylene are selected for base reinforcement.

Locally available clayey sand was used as the subgrade material. The Standard Proctor test results showed a maximum dry unit weight of 19 kN/m^3 and an optimum water content of 14.5%. Soft and relatively fair subgrade conditions (CBR=1% and 5%) were simulated in the test chamber by varying water content and the compacted unit weight. Based on extensive calibration studies, targeted CBR =1% and 5% were achieved for the chosen subgrade when prepared at compacted dry unit weights and molding water contents of 16.55 kN/m^3 and 18.5%, and 17.40 kN/m^3 and 17.2%, respectively. The base and subbase layers were prepared following the gradation of wet-mix macadam with crushed stone aggregates, meeting the standard specifications mentioned in the American Society for Testing and Materials [16] and Ministry of Road Transportation and Highways [17], Government of India. Aggregates used for base and subbase layers had a maximum dry unit weight of 22.7 kN/m^3 and optimum water content of 5.5%. The asphalt material used in the study as a binder course had a compacted unit weight of 23.4 kN/m^3.

3.2 Geocell and Geogrid

High-density polyethylene (HDPE) geocell (GC) of height equal to 100 mm with weld spacing of 356 mm and a seam peel strength of 1420 N was used. The geocell used in the study had an expanded cell length of 224 mm and an expanded cell width of 259 mm. Geogrid (GG), made of polypropylene with peak tensile strength of 30 kN/m in biaxial directions and aperture size equal to 40 mm × 40 mm, was used as basal reinforcement placed right below the geocell mattress. The average rib and bar width of geogrid was 3.0 and 3.77 mm, respectively. The average node thickness of geogrid was 4.0 mm. The geogrid had a stiffness of 503 kN/m × 509 kN/m at 2% tensile strain in the biaxial directions. The geogrid and geocell used in the study are the typical ones used in the field for reinforcing base layers. Figures 1 (a) and (b) show the geocell and geogrid used in the study.



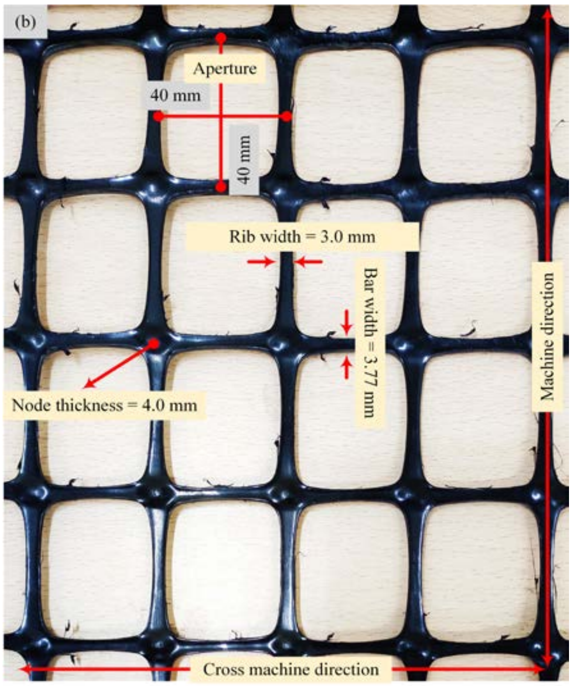


Fig.1 Photo snaps of geocell and geogrid used in the study (a) geocell and (b) basal geogrid used underneath the geocell mattress

4. EXPERIMENTAL PROGRAM

Pavement layers were prepared using a vibratory plate compactor inside the test chamber measuring 1.5 m × 1.5 m × 1.0 m [3]. The total thickness of granular layers (base plus subbase) and subgrade were maintained as 600 mm and 400 mm, respectively, overlying a soft subgrade of CBR=1%. In the case of pavements underlying relatively fair subgrade with CBR=5%, a total thickness of granular and subgrade layer was selected as 440 mm and 500 mm, respectively. These thicknesses were finalized based on Indian Road Congress guidelines for the design of flexible pavements [18]. The base layer thickness of 225 mm was maintained commonly for all the pavement sections. Over the prepared granular layer, a 50 mm thick asphalt layer was placed. Pavement layers were prepared to achieve 98% of their targeted densities. The expanded geocell mattress size equal to 1.45 m × 1.45 m in length and width was placed at 0.15*D* from the top of the base layer, where *D* is the diameter of the circular plate (i.e., 300 mm). In the case of basal reinforcement application, geogrid of size equal to 1.45 m × 1.45 m in length and width was placed right below the geocell mattress. Prepared testbed with complete instrumentation is shown in Fig. 2. In total, six large-scale model pavements were conducted. Two sections unreinforced, two test sections with geocell alone, and two test sections with geocell and geogrid as a basal reinforcement were tested. The prepared testbed was ensured for proper consistency in unit weight and water content for all the test cases; the maximum deviation in the measured properties was within 3%. As shown in Fig. 2, a repetitive load of haversine load pattern with 5 Hz frequency was simulated and applied over the prepared bed with a typical tire contact pressure of 550 kPa using 100 kN actuator on a 300 mm rigid circular plate placed on the center of the testbed [2, 3]. Figure 3 presents the typical load pattern applied on the prepared testbed. The permanent deformation data was measured using an inline displacement transducer inbuilt with the actuator system (refer to Fig. 2).

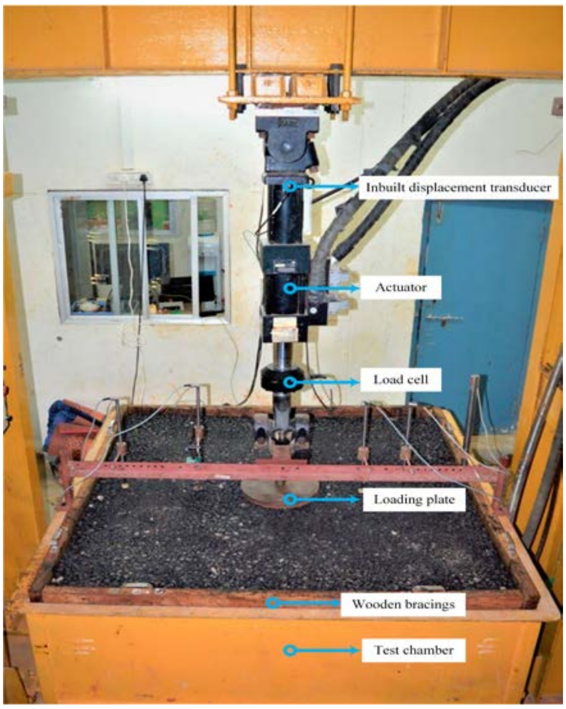


Fig. 2 Test setup showing prepared testbed system with actuator mounting

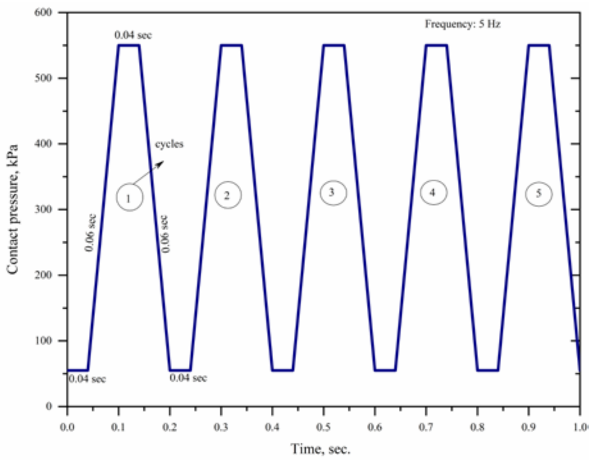


Fig. 3 Repetitive load pattern applied on the testbed

5. RESULTS AND DISCUSSION

5.1 Influence of Single Geocell and Combination of Geocell and Basal Geogrid On Permanent Deformations

Figures 4(a) and (b) present the permanent deformation *vs.* load cycles for geocell alone and geocell plus geogrid reinforced pavement bases overlying soft (CBR=1%) and relatively fair subgrade (CBR=5%), respectively. In all test cases, repetitive loads were applied up to 100,000 load cycles (N) due to test constraints related to the enormous amount of time it takes to apply repetitive loads. Figure 4(a) shows that the unreinforced section exhibits more than 20 mm of permanent deformation; thus exceeding the failure criterion in rutting. The relatively high permanent deformation of the unreinforced pavement section might have occurred to large vertical and lateral deformations of granular material overlying soft subgrade conditions under repetitive loads. During initial repetitive load cycles, reinforcement mobilization is low; however, as the load cycles increase further, deformations were drastically reduced for GC alone and GC+GG, as shown in Fig. 4(a). The superior benefit is witnessed for the GC+GG combination. For example, at 100,000 load cycles, unreinforced section, GC, and GC + GG showed deformations of 24 mm, 11 mm, and 5 mm, respectively. Compared to an unreinforced section, a reduction in measured deformations was found to be about 54% and 73% corresponding to GC and GC+GG at the end of load cycles, respectively. In the case of pavement section reinforced with geocell alone, reduced deformation might have resulted due to overall confinement. In the case of the GC+GG reinforcement combination, it is evident that due to the extra structural support offered through membrane and interlock action of basal geogrid, further reduction in permanent deformation was observed. Beyond the 30,000 load cycles, a near-constant permanent deformation was seen with the GC+GG reinforcement combination. Therefore, geocell with basal geogrid combination might be a viable solution to control deformation over very soft subgrades.

On the other hand, permanent deformations observed for pavements overlying relatively fair subgrade condition is presented in Fig. 4(b). In pavements underlying fair subgrade condition (CBR=5%), the resulting deformations were lower than those for a soft subgrade (CBR=1%) for a given applied load cycle. Between GC and GC+GG, the reinforcement benefit was found to be only marginal. Nevertheless, the GC+GG reinforcement combination performed better showing lower deformations than the geocell alone. Almost consistent deformations were observed beyond 30,000 load cycles for geocell alone and a combination of geocell and basal geogrid. Based on the permanent deformations presented in Fig. 4(b), it can be inferred that the reductions were in the order of 51% and 66% for GC and GC+GG, respectively, over 100,000 load cycles. In the case of pavements encountered with relatively fair subgrade conditions, geocell alone might be used to reinforce the base layers as no significant improvement in reducing the deformations was observed for GC+GG.

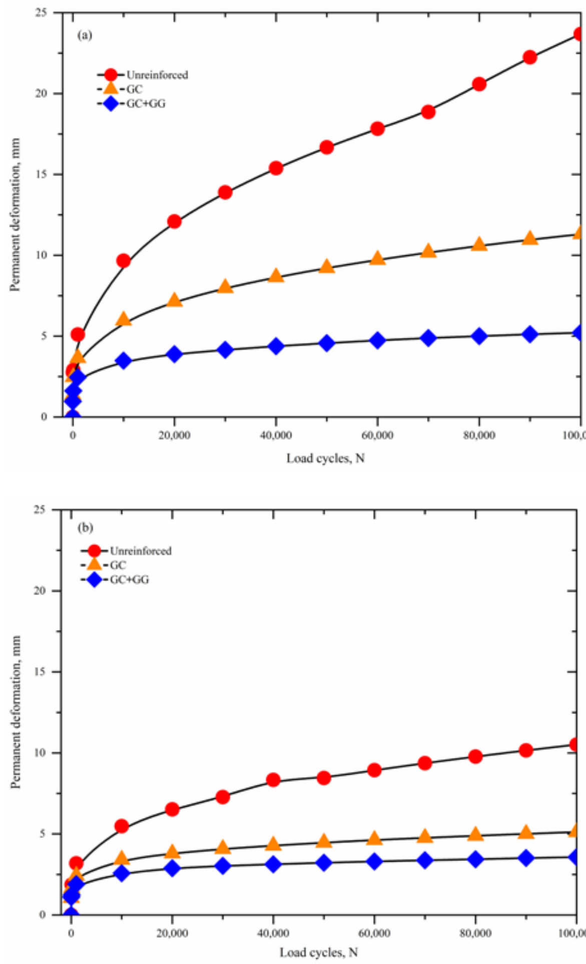


Fig. 4 Permanent deformation versus repetitive load cycles of unreinforced, GC reinforced base layer and GC+GG reinforced base layer for (a) pavement overlying CBR = 1%, and (b) pavement overlying CBR = 5%

5.2 Traffic Benefit Ratios (TBR) of Reinforced Base Layers

TBR is also called traffic improvement life, which indicates the extended life of the pavement. Figures 5(a) and (b) show the TBRs of reinforced pavements overlying soft and relatively fair subgrade conditions. In this study, about 11 mm maximum permanent deformations were observed for reinforced sections. Hence, the TBRs were calculated within specified permanent deformation; however, to witness TBRs at higher deformation, might require higher repetitive load cycles than those applied in the study. From Figs. 5(a) and (b), it can be noticed that pavements overlying soft and relatively fair subgrade conditions, GC reinforced base sections resulted in TBR as high as 12 and 8.3, respectively. Likewise, TBRs of bases reinforced with GC+GG combination was found to be as high as 150 and 38 over soft and relatively fair subgrade condition, respectively (refer to Fig. 5(b)). Initially, TBRs increase, and then with an increase in further permanent deformations, TBRs attenuates for GC reinforced section alone. However, this trend is expected as TBR is calculated as a ratio of reinforced cycles to unreinforced cycles at the same defined permanent deformation. In the case of the GC+GG reinforced section, resulting load-carrying cycles were more, thereby leading to higher TBR than the GC alone. Higher TBRs were observed in the case of pavement overlying soft subgrades, and lower values were observed for fair subgrades. In the available literature, TBRs ranged as high as 670 for geosynthetic reinforced pavement bases [1]. However, TBRs recommended for design at failure deformations were reported between 1 to 4 [1].

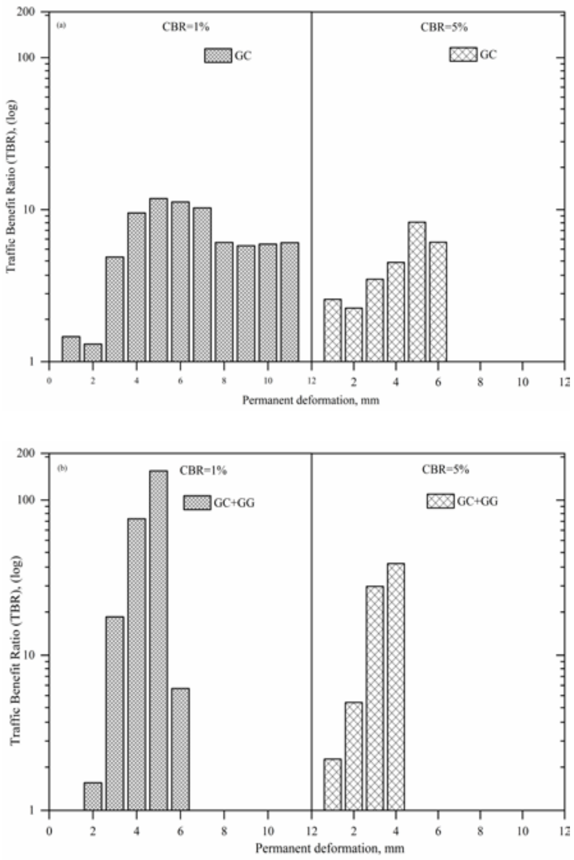


Fig. 5 TBR versus permanent deformations for (a) geocell alone for pavement overlying subgrades with CBR=1% and 5%, (b) combination of geocell plus basal geogrid for pavement overlying subgrades with CBR = 1% and 5%

6. RECOMMENDATIONS

The combination of geocell and geogrid placed below the geocell was found to be a viable solution over soft subgrades. The reinforcement benefit can be observed majorly in two ways. Firstly, the reduced cost due to a decrease in thickness of a granular layer, and secondly, increased service life and reduced maintenance cost if the same thickness of the pavement is maintained. On the contrary, the unreinforced pavement section frequently requires rehabilitation and asphalt overlays leading to huge cost incurrences; this activity might be minimal in the case of reinforced pavements. Over relatively fair subgrade conditions, geocell alone might help in improving pavement performance.

It can be noted that in the present study, reported TBR values ranged as high as 150 corresponding to low permanent deformation values (i.e., below 10 mm). However, this value may decrease further at higher permanent deformations (rutting) or designated rutting failure criteria. For example, at a standard rutting criterion of 20 mm [18] of the pavement overlying subgrade with CBR=1%, the computed load cycles of unreinforced pavement and extrapolated load cycles at the same rut depth for GC [refer to Fig. 4(a)] alone resulted in about 76,593 and 1,014,862 cycles, respectively. Thus, the corresponding TBR is 13.25. Hence, it is recommended to adopt the TBR values about the rutting failure criterion. The design-related aspects that involve reducing base course and improving the pavement's service life can be found in Berg et al. [1] and Holtz et al. [19] studies.

7. CONCLUSIONS

In this study, essential insights obtained from large-scale model pavement experiments were discussed. The flexible pavement bases overlying soft (CBR=1%) to relatively fair subgrade (CBR=5%) conditions were reinforced with geocell alone (GC) and a combination of geocell plus geogrid (GC+GG) to witness the overall pavement performance. The repetitive load tests were conducted to evaluate the load-response of geosynthetic reinforced flexible pavements. The permanent deformation behavior versus the applied repetitive load cycles was evaluated for geocell alone, and geocell plus geogrid combination placed in the base layer of the flexible pavement overlying soft and relatively fair subgrades.

Further, the extended life of the pavement due to reinforcement is quantified in terms of traffic benefit ratio (TBR) by considering permanent deformation observed over 100,000 load cycles. The main conclusions obtained from the present study are discussed below.

- The reduction in pavement deformation due to geocell (GC) alone and geocell plus basal geogrid (GC+GG) ranged as high as 54% and 73%, respectively, over soft subgrades (CBR=1%). Likewise, the corresponding reductions were 51% and 66% for pavements over relatively fair subgrades (CBR=5%).

- Geogrid placed right underneath the geocell was found to arrest lateral movement of granular material effectively leading to higher reductions in deformations. In other words, the additional basal reinforcement right underneath the geocell mattress leads to sustain higher load cycles than the pavement base system supported with geocell alone for the same rut deformation.
- GC+GG combination was more effective than GC alone for pavements overlying soft subgrades (CBR=1%). However, no significant improvement of GC+GG compared to GC alone was observed for pavements overlying fair subgrades (CBR=5%).
- Higher TBRs were witnessed for a GC+GG due to extra support offered by geogrid underneath the geocell.
- Traffic Benefit Ratio (TBR) of GC alone ranged as high as 12 and 8.3, respectively, for pavements overlying soft and relatively fair subgrades.
- TBRs of geogrid placed underneath a geocell mattress (GC+GG) showed as high as 150 and 38 for pavement overlying soft and relatively fair subgrades, respectively. However, it may be noted that the reported TBR values correspond to relatively low permanent deformation values (i.e., within 12 mm).

8. ACKNOWLEDGEMENT

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