LABORATORY STUDIES ON GEOTEXTILES REINFORCED SOIL FOR PAVEMENT

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ABSTRACT

The influence of introducing a three dimensional geo-synthetic material, called geocells in the base layer of flexible pavements is investigated in the current study. This study compares the reinforced and unreinforced pavement sections constructed on a subgrade having a moderate California bearing ratio (CBR) value of 5%. A series of model tests were carried out to understand the influence of geocell reinforcement on the load carrying mechanism of the pavement section under static and repeated loading conditions. The parameters studied were as follows: load-settlement response of the pavement sections, actual rut at the subgrade level, pressure transmitted to the subgrade soil underlying the geocell reinforced base layer and surface deformation profile of the test sections.

Different flexible pavement design methodologies proposed by Indian Roads Congress (IRC) and American Association of State Highways and Transportation Officials (AASHTO) were used for the design of pavement sections and were compared through experimental program conducted in the laboratory. Large scale repeated load tests were performed to replicate the actual field conditions. The test results indicate that the geocell reinforcement reduces the rutting in the pavement. The performance improvement was presented in terms of traffic benefit ratios (TBR), layer coefficient ratios (LCR), rut depth reductions (RDR) and rut benefit ratios (RBR). Besides, under the same load repetitions, the thickness of the reinforced pavement is considerably less than that of the unreinforced pavement section. In addition to the cost savings, this would conserve natural materials like aggregates used in the pavement construction. Overall, the inclusion of geocell in the base layer helps in improving the life, uniform distribution of load, reduction in rut depth and it also provides an economical and sustainable solution to the present practices.

1. INTRODUCTION

Constant increases in traffic frequency and axle loads place great demands on the existing road network. The stresses induced between layers soon result in crack formation, and any local differential settlements may lead to subsequent settlement of upper layers. These stresses results in crack formation in surface layer i.e. fatigue and the settlement by local differential settlement i.e. rutting. The nature of soil present around the world are of many varieties ranging from dense to very loose and stiff to very weak. Since the availability of good construction site is limited, in spite of how weak the soil is, there is need to improve such sites when it is not possible to avoid such sites. For the past few decades, use of geo-synthetics has been gaining advantages over the other improvement methods especially in pavement industry. Recently the application of geocells in pavement layers have been showing much performance improvement as it can provide an additional lateral confinement to the infill material over and above the reinforcement functions provided by conventional geo-synthetics. Several research studies have shown in the past that the geocell reinforcement is effective when a granular infill is used over weak subgrades under monotonic loading conditions. Studies were performed on the flexible pavements with and without geocell reinforced basal layer under static and repeated loading. However, not much information is reported in the literature on repeated load tests on pavement sections reinforced with geocells with extensive instrumentation. Hence, there is a need to understand the behavior of geocell reinforced granular aggregate bases over weak subgrades under repetitive traffic loading. Rutting is a common phenomenon encountered in flexible pavements supported by weak subgrades. Reinforcing the weak subgrades is one of the promising alternatives to counter the pavement surface rutting. Reduction in rut depth can be achieved using Geocell in the bases of flexible pavements. Studies have proved that inclusion of basal geocells can reduce rut depth to a greater extent.

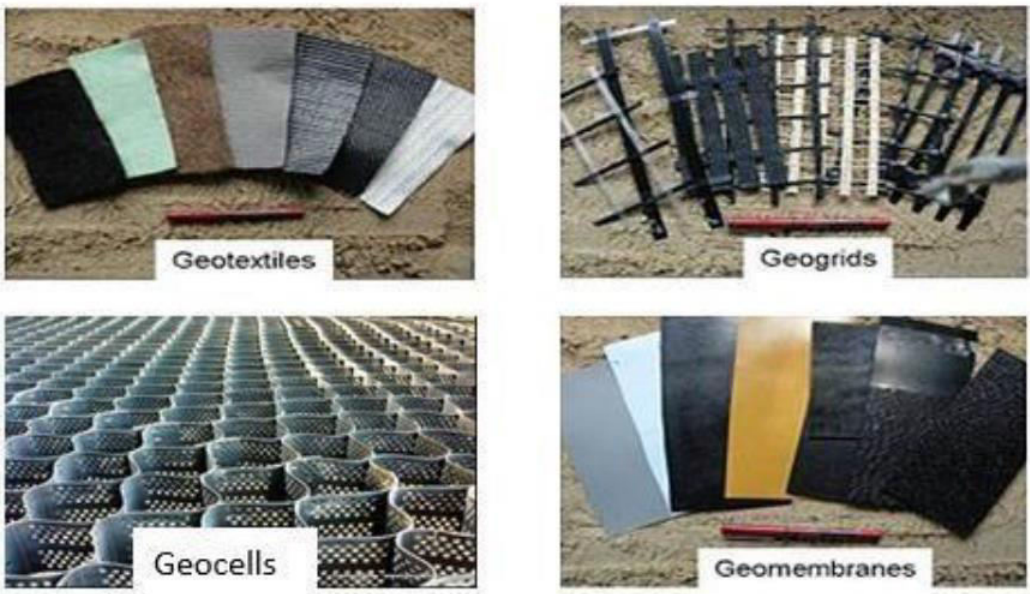
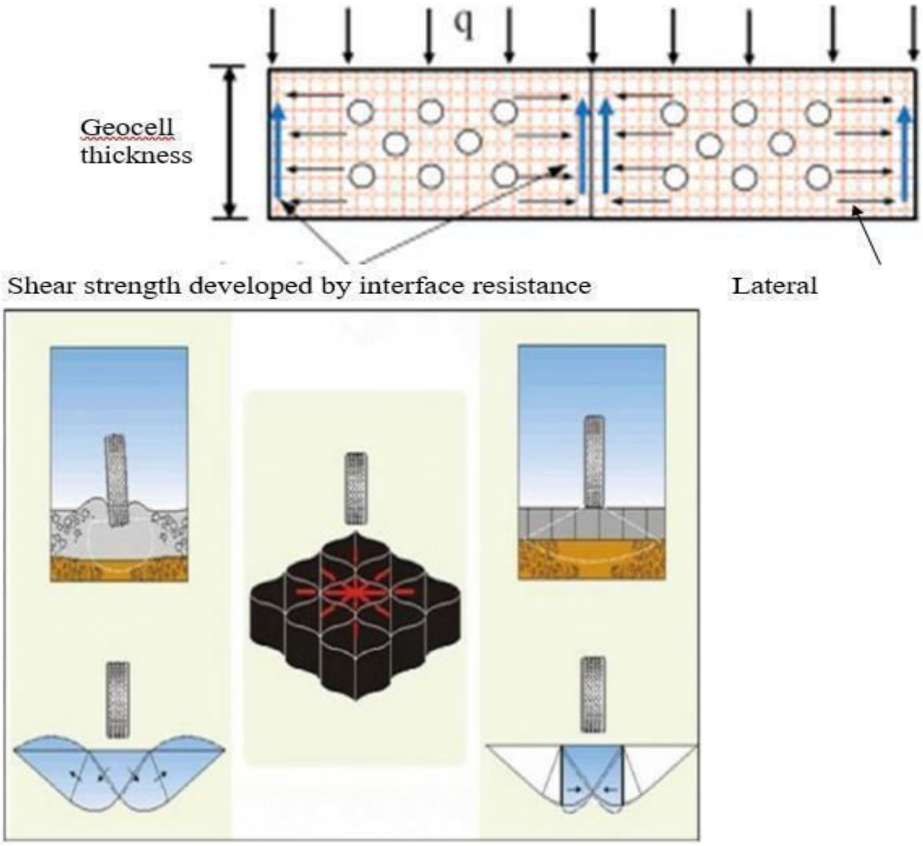


Figure 1.1 Varieties of geo-synthetics used in pavements [1]

Geocell reinforced Granular Bases

The geocell reinforcement provides a confinement to the infill material. The typical section consists of a moderate subgrade, a geocell-reinforced granular base, and a surface layer. The replication of traffic load from the axles is done with the help of repeated load test in which a load equivalent to a contact pressure of 550kPa is applied. The study is done to analyze the rutting behavior of geocell reinforced pavements with reduced thickness and analyzing the pressure distribution through it. Properties of geocell reinforced bases, and the interaction of geocell with the material contributing to the vertical and horizontal confinement characterize the overall behavior of the reinforced composite section. The inclusion of three dimensional geocell structure as basal reinforcement has been found to be effective in lateral confinement. Past research showed that geocell reinforcement at the base course of an unpaved road improves the engineering behavior of the reinforced composite section, such as stiffness and bearing capacity



Load transfer mechanism of geocell mattress

2. **LITERATURE REVIEW**

The studies on a 3-dimensional reinforcing structure named geocell was introduced considering the additional function of confinement along with the various functions provided by planar geo-synthetics like geo-grids and geo-textiles. Bush et al. [10] carried work on the design and construction of geocell foundation mattress supporting embankments over soft grounds. They concluded that the differential and total settlements were reduced due to load distribution through geocell mattress. The study also reported that the cost saving up to 30% can be achieved by constructing geocell reinforced embankment over soft soil as compared to conventional methods. Several researchers (Barksdale [11]; Cowland and Wong [12]; Cancelli, [13]; Collin [14], Dash et al. [15]; Sitharam and Sireesh, [16]) have done extensive study on the geocell reinforced beds under static loading conditions to understand the behavior of geocell mattress and have successfully quantified the improvements mainly in terms of increased bearing capacity of footing. Saride et al. [17] and Han et al. [18] reported that the geocell reinforcement proved effective in increasing the bearing capacity of footings because of the lateral confinement of the cell in case of a geocell under static loadings. It was performance of reinforced beds. Studies performed by Dash et al [19] and Sitharam and Sireesh [16] suggested that the placement depth of geocell should be maintained about 1 to 5% of the width of the loading area in static load tests. Dash et al. [19] performed model studies on circular footing of the test beds can be improved drastically by employing geocells in a dense sand layers. They also observed about 80% reduction in footing settlements when an optimum size of geocell (width ratio, b/D = 5 and height ratio, h/D = 2.1) was used. From their study they concluded that the geocell with smaller opening size is found to be an appropriate reinforcement for paved roads with very less permissible settlements, whereas in the case of unpaved roads, large size geocells are observed to be effective.

The studies on the geo-synthetic reinforcement were started about five decades ago. Different reinforcement forms are being used for a long time viz. geo-textiles, geo-grids, geonets, geocomposites and geocells. Extensive literature is available on these materials as reinforcement (geo- grids and geocells) under static loading for pavement applications however, a very few studies are available on cyclic loading. Understanding of these mechanisms originated from static plate load tests, but later research have been focused on these mechanisms under cyclic loading.

It was noticed that the ultimate bearing capacity increases with increasing number of reinforcement layers under dynamic loading. Depth of placement of initial reinforcement and spacing between consecutive layers were kept constant (u/D = h/D = 0.33) for all tests. Also, width of geo-synthetic reinforcement was maintained four times width of model footing. It was observed that increase in reinforcement layer (beyond N = 4) does not enhance the improvement in bearing capacity. Dynamic load tests were conducted based on the optimum configuration obtained from static load test. Dynamic load was applied using a 16 rectangular shaped waveform and frequency of 1 Hz. Tests were conducted in a rigid stee1 tank measuring 760 mm from all sides and a square shaped rigid footing of side 76.2 mm (Halliday and potter [24].

The design methods presently available for use of geo-grids in road base stabilization provide no or insufficient information about the required number of layers and the mechanical characteristics of geo-grids. Hence, a new design method has been developed which includes the design of geo-grids for road base stabilization, based on a four layer model: asphalt (binder and wearing course), base, subbase and subgrade. The base and/or subbase thickness has to be defined with one of the available methods such as AASHTO method [29], Giroud–Han method [6], Leng – Gabr method [30], etc. The proposed design methods can be used to calculate the tensile forces in the geo-grids generated by self- weight of the different layers; wheel load of heavy vehicles; membrane effect at the base (or subbase) subgrade interface. It is then possible to set the number and the mechanical characteristics of geo-grid layers required for absorbing the horizontal forces generated by these three mechanisms.

In recent years, many designers and leading geo-grid manufacturers favor the use of a parameter called layer coefficient ratio (LCR) to quantify the benefits of geo-grid reinforcement into pavement design. This approach is sensible and more technically correct. The LCR approach applies and limits the geo-synthetic benefit derived from trials to the specific layer improved by inclusion of reinforcement (granular base course layer) whereas the TBR approach applies to the whole pavement section.

3. MATERIALS AND METHODS

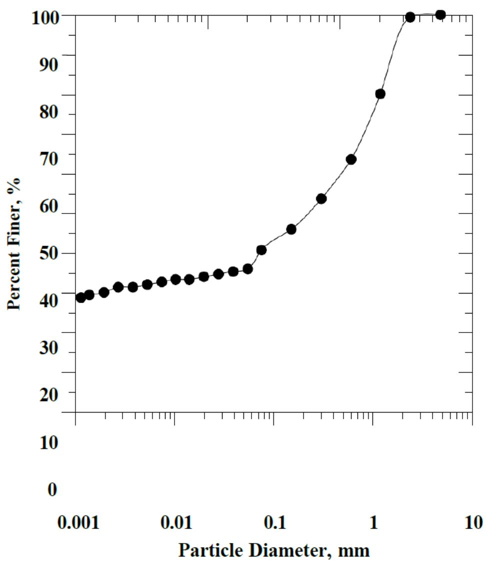
3.1 Introduction

In this Chapter, the properties of different materials used and sample preparation techniques adopted in the present study are presented. The material properties are stated first and then the sample preparation procedures are elaborately discussed. The following materials are used in the study:

- Clayey sand to prepare a subgrade.
- Wet mix macadam (WMM) as a base course.
- Bituminous macadam as a surface layer.
- Geocell mattress as a base layer reinforcement

Sieve analysis

A dry sieve analysis as per IS-2720 (Part4-1985) [32] was performed to determine the particle size distribution of the soil. Fig. 3.1 shows the particle size distribution of clayey soil, which consists of about 40%, fines (i.e. particles smaller than 75µ sieve size). For further classification of the soil, Atterberg's limits tests were performed



Atterberg's limits

Atterberg's limits including liquid limit (LL) and plastic limit (PL) were conducted as per IS- 2720 (Part4-1972) [33]. The images of apparatus used during this test can be seen in Fig.3.2a. Fig.

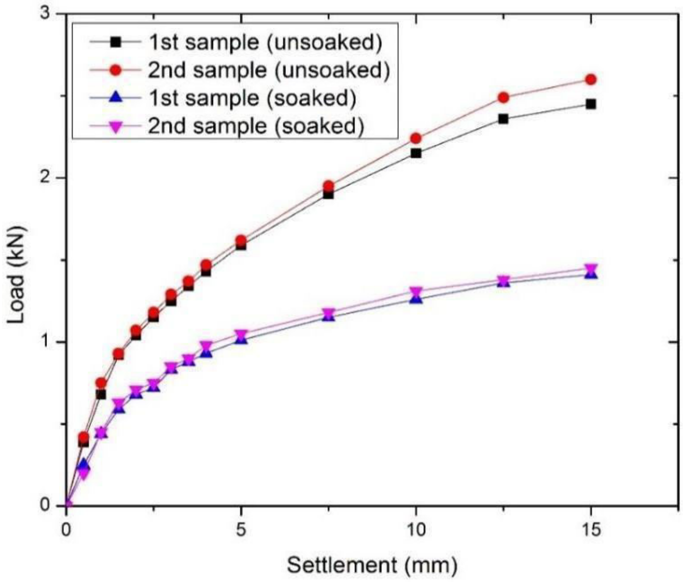
3.2b shows the flow curve of the soil. The liquid limit and plastic limit of the soil are found out to be 47% and 21% respectively. The Plasticity Index of the soil, which is the difference between LL and PL is found out to be 26%. As per the Indian standard soil classification system, the soil is found out to be well graded sand with clay (SC).

Compaction characteristics

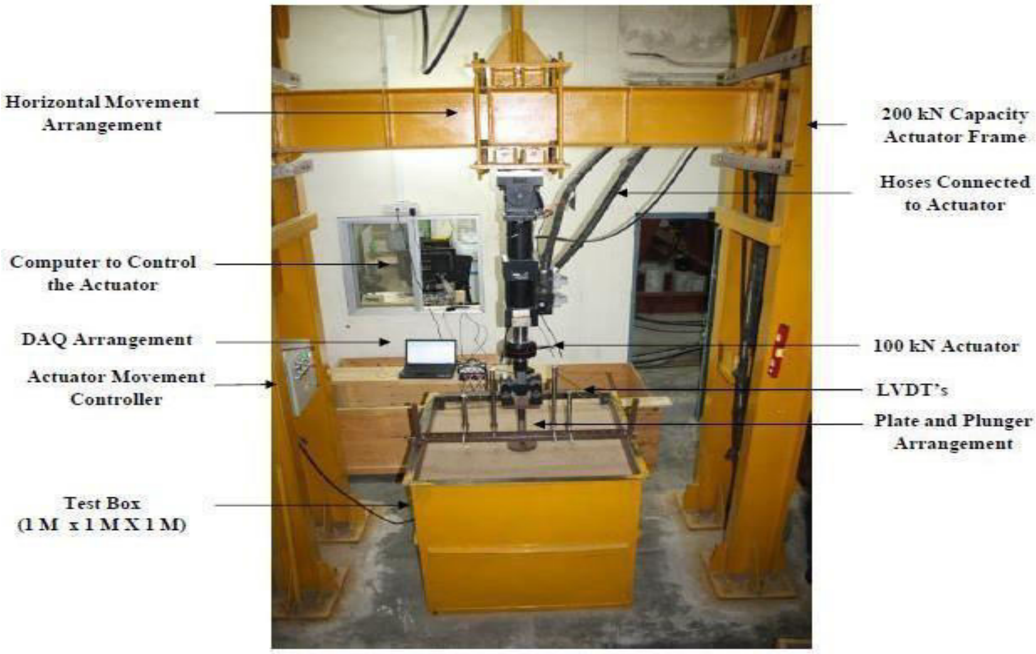
The Standard Proctor compaction test is a laboratory method of finding the optimum moisture content (OMC) and maximum dry unit weight (MDU) which is conducted as per IS-2720 (Part7-1980) [35]. According to the procedure, the soil is compacted in three layers in compaction mold of volume 948 cc and each layer is given 25 blows from a standard hammer of weight 2.6 kg and falling height of 310 mm.

California Bearing Ratio

The California bearing ratio (CBR) test is used to determine the bearing resistance of subgrade soils. According to Indian roads congress (IRC) guidelines, the flexible pavement design is dependent on this value. This test was conducted as per IS-2720 (Part16-1987) [36] on the subgrade clayey soil. The values of the CBR in soaked and unsoaked conditions are 4.9% and 7.8%, respectively. For further analysis and the design of pavement section, CBR of about 5% was considered.



Load-settlement curve for CBR test



Test methodology

The subgrade soil was prepared and compacted at their required density and placement water content in a test tank measuring inner dimensions of 1m × 1m x 1m (length x width x height). On top of the subgrade soil a granular base layer i.e. WMM with and without geocell mattress were prepared. On the top of the base course layer a 50 mm thick layer of bituminous course was laid and compacted up to the required density. The test bed configuration and densities maintained will be discussed in the subsequent sections below. Once the final grade was prepared, a rigid thin steel plate of 150 mm diameter (D) and 15 mm thickness was concentrically placed to apply the appropriate static or repeated traffic loading. The size of the plate was chosen based on the previous experimental studies conducted in a similar testing by Edil et al. [39].

Preparation of test beds

Following are the stages adopted for the preparation of entire pavement section.

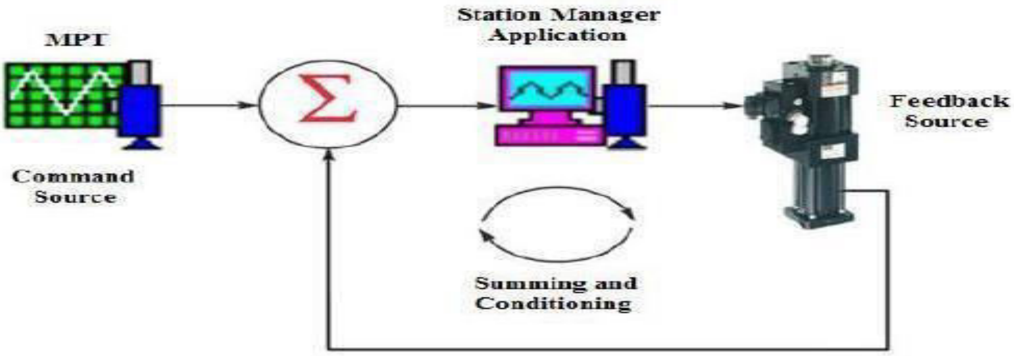
- Preparation of calibration charts.
- Preparation of subgrade.
- Preparation of base course layer.
- Preparation of bitumen course layer.

Data acquisition system (DAQ)

Data acquisition system (DAQ) from Hottinger Baldwin Messtechnique (HBM), Germany make is used to acquire the data from all the instrumentations used in the testing. There are two types of HBM‟s Quantum X data acquisition systems used namely MX 840 and MX 1615. The MX840A is an 8-channel universal amplifier which supports all current transducer technologies and MX1615 B which is the 16-channel universal amplifier used mostly in specific to strain gauges. The DAQ‟s are connected together using a fire wire cable which comes from the manufacturer.

Multi-purpose test ware

Multi-Purpose Test ware (MPT) allows user to create complex test designs with discrete processes. Each process thus represents an individual test activity. A set of processes is grouped together in a closed loop to generate a have sine loading pattern. The tests can be done into two ways viz. Force controlled method and Displacement controlled method. The tests done in the study were based on forced controlled method in which the configuration of devices provides a means of comparing a command signal (programmer output) to generate a signal with a feedback (transducer output) signal to generate a signal that controls a servo valve. The servo valve controls hydraulic flow of the actuator which moves the actuator piston rod. The actuator piston rod applies the force required to displace the component to be tested.



Traffic benefit ratio

To quantify the benefits from the geo-synthetics especially in pavement applications, a non- dimensional term has been introduced and is expressed in terms of extension of life or by savings in base course thickness. Extension of life is defined in terms of a Traffic Benefit Ratio (TBR).

$$\text{TBR} = \frac{N_r}{N_u}$$

where, Nr = No. of cycles required to reach given amount of rut depth

Nu= No. of cycles required to reach same amountof rut depth

Rut depth reduction

$$(\text{RDR})\text{N} = (1 - \frac{CPD_{reinf}}{CPD_{unreinf}}) \times 100$$

Equivalent modulus improvement factor

$$\text{EMIF} = \frac{E_{reinf}}{E_{unreinf}}$$

Rut benefit ratio

$$(\text{RBR})\text{N} = (1 - \frac{\text{CPD}_{\text{reinf}}}{CPD_{unreinf}}) \times 100$$

Layer coefficient ratio

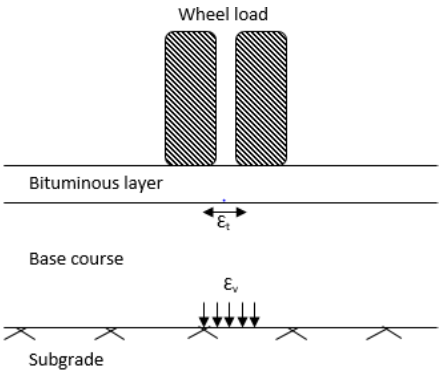
$$\text{LCR} = \frac{0.249\ log_{10}(EMIF.M_{r2}/0.0069) - 0.977}{0.249\ log_{10}(M_{r2}/0.0069) - 0.977}$$

RESULTS AND DISCUSSION

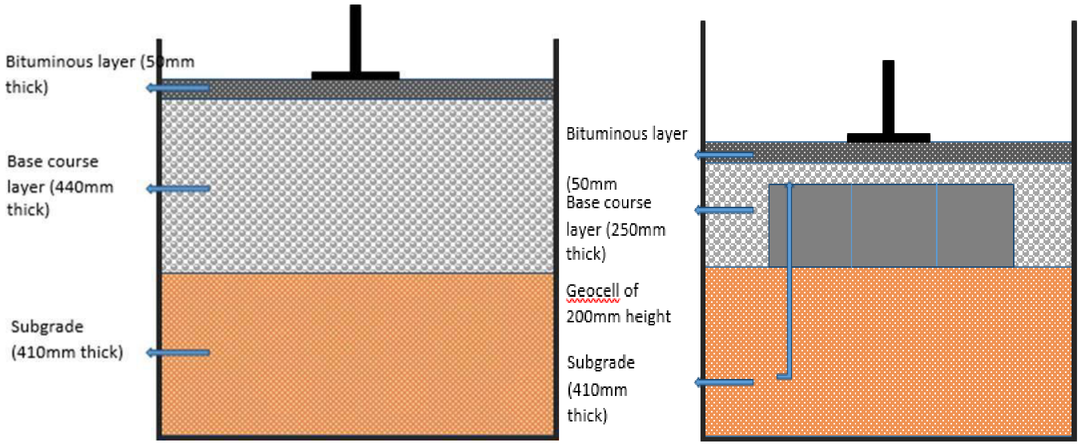
The flexible pavements are designed as a layered system in which the wheel loads are transferred to the lower layers by distributing the loads to a wider area. The stresses and strains at critical locations are computed using linear elastic models. The pavements should be designed such that they should perform efficiently throughout their design life. The failure of flexible pavements is generally due to fatigue cracking and the formation of ruts, which can be visualized on the pavement surface.

1. Vertical compressive strain at the top of the sub-grade which can cause sub-grade deformation resulting in permanent deformation at the pavement surface.

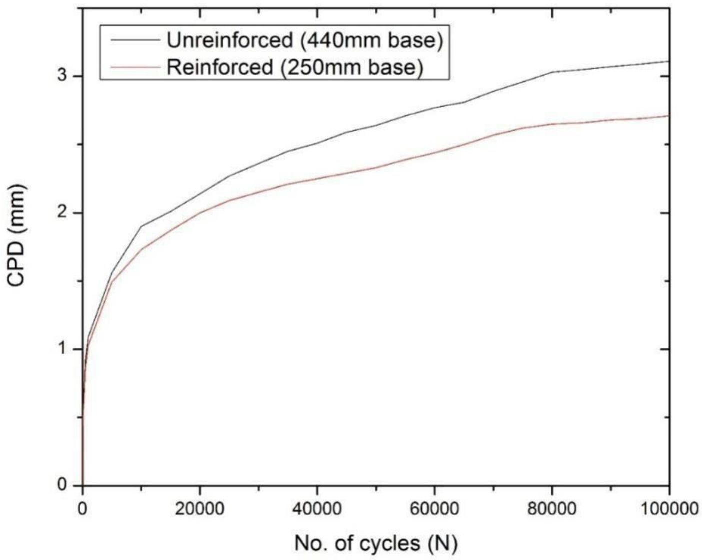
2. Horizontal tensile strain or stress at the bottom of the bituminous layer which can cause fracture of the bituminous layer.



Static load test results



Repetitive load test results



CONCLUSION

For any civil engineering construction, the first and foremost thing to be kept in mind is cost. After comparing the cost analysis discussed in previous chapter, it clearly shows that reinforced pavement is 10.15% cheaper than the unreinforced pavement for every km single lane road construction. The inclusion of geocell in base layer results in reducing the base thickness to 43% to that of the unreinforced one, which ultimately reduces the usage of the virgin material which is very scarce in nature. The geocell also helps in reducing the permanent deformations of the pavement by inducing additional elasticity to the respective layers. The reduction in cumulative permanent deformation observed is 13% in reinforced case. Rut depth reduction (RDR) and rut benefit ratio (RBR) observed is 13% and 19% respectively, it indicates that the geocell helps in transferring the load to a larger area which ultimately induces less rut at subgrade. The equivalent modulus improvement factor observed is 1.3 times of the unreinforced pavement section which indicates that the reinforced pavement section is stiffer than the unreinforced one and that too with the reduced thickness. A TBR of 1.7 is achieved at only 50% of permissible settlement (5 mm) after applying 5% of designed traffic, it means that for the same settlement the reinforced pavement can sustain for a longer duration as compared to unreinforced one. A layer coefficient ratio of 1.82 is observed. This study finally concludes that the geocell reinforced pavement section of reduced thickness (250 mm base thickness) performs better than the unreinforced pavement section of base thickness 440 mm in all respects.

According to AASHTO, the thickness of unreinforced pavement section is 553 mm in place of 440 mm from IRC for the same traffic repetitions. The Indian roads are designed based upon IRC guidelines, which may result in premature failures due to the reason, that the correlations to calculate the resilient modulus of base layer, mentioned in IRC depends only on CBR of subgrade and does not consider resilient modulus of the layer itself. Whereas, in the case of AASHTO, the resilient modulus of individual layers are determined and designed as per the actual values obtained, unlike IRC method.

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