STUDIES ON GEOCELL REINFORCED ROAD PAVEMENT STRUCTURES

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ABSTRACT

Many of the pavement structures fail well before their design life owing to the poor quality of construction materials, inadequate compaction, inadequate preparation of the subgrade, overloading etc. Two options are considered during the design of a pavement structure in order to improve the longevity of the pavement. The first option is by increasing the thickness of different pavement layers and the other option is by increasing the rigidity of the layers within the system so as to reduce the stresses transferred to lower layers. Of these two methods it has been widely observed that increasing the strength and rigidity of the pavement layers is a more efficient method to lower stresses on the pavement layers thereby increasing the life of the pavement. In the present research work, the improvement in the strength and stiffness of the sub-base layer in a flexible pavement system through the use of geocell confinement was investigated by conducting field plate load tests and series of laboratory plate load tests. The improvement in the strength of the pavement is reflected by the increase in modulus of the section confined with geocells to the section without geocell confinement. This paper will describe the field and laboratory tests, interpretation of the data from these tests and the application of this data for design of flexible pavements.

Keywords: Geosynthetics, geocell reinforcement, flexible pavements, construction costs

INTRODUCTION

The performance of highway pavements is governed by the strength and stiffness of the pavement layers. The cost and duration of construction are dependent on the availability of aggregate for construction. Scarcity of natural resources often delays the projects or escalates the costs due to large lead distances from the borrow areas. Hence it is essential to look at alternatives to achieve improved quality of pavements using new materials and reduced natural material usage.

This paper reports on the studies of the performance of geocell reinforced flexible pavements. The geocells are three-dimensional honey comb geosynthetic products that provide all round confinement to the soils. The geocell confined soil acts like a semi-rigid mat in distributing the surface loads over a wide area of the foundation soil. A number of researchers have investigated the fundamental properties of the soil reinforced with geocells (Bathurst and Rajagopal 1993, Rajagopal et al. 1999) and the performance of the geocell reinforced foundation bases (Bush et al. 1990, Madhavi Latha et al. 2008, Krishnaswamy et al. 2000) and in flexible pavements (Emersleben and Meyer 2008, Han et al. 2008 and 2010, Rajagopal and Kief 2008, Pokharel 2010, Pokharel et al. 2010 and 2011).

Giroud and Han (2004) and Huang (2004) have discussed the design of flexible pavements with and without using the geosynthetic reinforcement layers. Empirical recommendations for the modulus of different layers in terms of the thickness of the layers and the CBR value were made by Huang (2004) and IRC-37 (2001).

The granular sub-base and the wet mix macadam materials were obtained from a highway construction site near Chennai. All the index tests were performed to characterize these materials. Field plate load tests were conducted and using the pressure-settlement data, the back calculation of elastic modulus of geocell reinforced layers in pavement were computed. This analysis was carried out by using linear elastic analysis software program.

Laboratory Plate load tests were carried out to determine the elastic modulus of the pavement layers under known load. Test box samples included geocell layer filled with granular sub base and fine aggregate over a given thickness of sub base layer. The obtained pressure-settlement values were used in the analysis using the software and to calculate elastic modulus and finally to obtain the improvement factor for reinforced layers. This improvement factor used for optimization of pavement layers, determine the cost and damage factors of the pavement systems incorporating the different sub-base alternatives. Following the analysis an optimum thickness was selected for the different alternatives for a knowing cost. The reduction in construction cost owing to reduction in materials and construction cycle times along with the increase in the strength of the sub grade. The results from the laboratory tests were substantiated by field tests.

FIELD STUDIES

The internal access roads at Govind Dairy Factory in Phaltan, Maharashtra are frequently in bad shape making it difficult for the milk vans to travel on the roads. The foundation soil is typically black cotton soil which undergoes severe swelling and shrinking. The properties of this soil are given in Table 1. The roads are typical unpaved roads with thick layers of Water Bound Macadem (WBM) and Granular Sub Base (GSB). 100 m long stretch of this road was treated with 150 mm thick geocell layer on an experimental basis to study the performance improvement. Similar studies were reported by Meyer (2005), Qadi and Hughes (2000).

Table 1 Properties of Foundation Soil

CBR	4%
Swell index	150%
Liquid Limit	60%
Plastic Limit	25%
Shrinkage limit	8%

Based on the soil properties and the traffic data, the following designed section of pavement as shown in Fig. 1 was used for construction. The bottom most layer was treated with 4% lime (hydrated lime) in order to stabilize the expansive foundation soil.

The geocell used at the site is 150 mm high and made of a polymeric alloy. The c/c weld distance is 330 mm and the pocket opening dimensions are approximately 210 mm × 250 mm. The tensile strength of the 150 mm wide material is 3.7 kN (ASTM D638-2003) and the peel strength of the weld is 6 kN from ASTM D6392-99 standard tensile strength tests. There was no change of dimensions when pieces of the geocell were exposed to 100°C temperature in an oven for 1 hour duration (ASTM D1204).

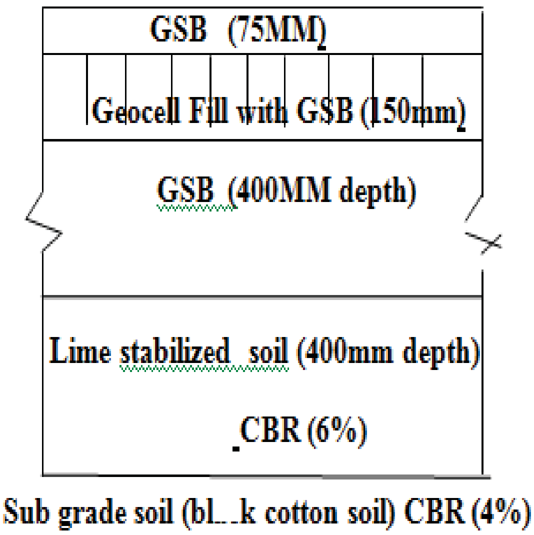

Fig. 1 Cross section of the pavement section at Govind Dairy Factory

Fig. 2 Mixing of the lime by a tractor

Fig. 3 Geocell layer spread over the road section

The construction of the pavement took place in March 2010. Unreinforced pavement sections were also constructed in the same manner without the geocell reinforcement at the sub-base level. The thickness of the GSB and the lime treated sections were the same as shown in Fig. 1.

The performance of the geocell reinforced pavement and the adjacent unreinforced sections were monitored for their performance. The year 2010 was characterized by unusually heavy rainfall in that region. The unreinforced pavement had undergone severe rutting and had to be reconstructed at least three times by dumping of aggregate and re-compaction during the period March to December 2010. The photographs of the unreinforced and the reinforced pavement sections are shown below for comparison purposes.

Fig. 4 Filling the geocell pockets

Fig. 5 Compaction by a vibro roller

The unreinforced pavement section had undergone severe surface depressions as indicated by the arrows shown in Fig. 6. On the other hand, the geocell reinforced road section had maintained a uniform surface, Fig. 7. The trucks had to negotiate the unreinforced sections at a slow speed while they could maintain their normal speed in the reinforced sections.

This difference in the performance clearly shows the improvement in the performance of the flexible pavements with geocell reinforcement.

The reasons for the superior performance of the geocell reinforced flexible pavement as compared to the unreinforced pavement need to be explored through careful laboratory tests on controlled sections. With this in view further laboratory tests were performed to examine the performance with different configurations.

Fig. 6 Unreinforced pavement

Fig. 7 Geocell reinforced pavement with uniform surface

LABORATORY TESTS

All the laboratory tests were performed using the standard Granular Sub Base (GSB) and Water Mixed Macadem (WMM) materials as defined in relevant IRC specifications. Both GSB and WMM are coarse granular materials. They were placed in the test tank in very loose condition to create a subgrade having a CBR value of 6%. The method of hand packing the materials to achieve this CBR value was developed by several repeated trials.

All the laboratory tests were performed in a test tank having plan dimensions of 1.2 m ×1.2 m and height of 1.2 m. The diameter of the plate used for plate load tests was 150 mm. It was a plate having thickness of 30 mm. It was found to be rigid with uniform settlements during the laboratory tests.

Initially, 650 mm thick GSB layer was placed in the test tank in very loose condition to achieve a CBR value of 6%. Then the tests were performed with three different thicknesses of the geocell layers 50 mm, 100 mm and 150 mm. The following series of tests were performed in the test tank. Two different infill materials sand and WMM were used in the tests as noted below.

1. 650 mm thick GSB
2. 50 mm high geocell with GSB infill over 650 mm thick subgrade

3. 100 mm high geocell with GSB infill over 650 mm thick subgrade
4. 100 mm high geocell with SAND infill over 650 mm thick subgrade
5. 150 mm high geocell with GSB infill over 650 mm thick subgrade

Typical results from the laboratory plate load tests are shown in the following figures.

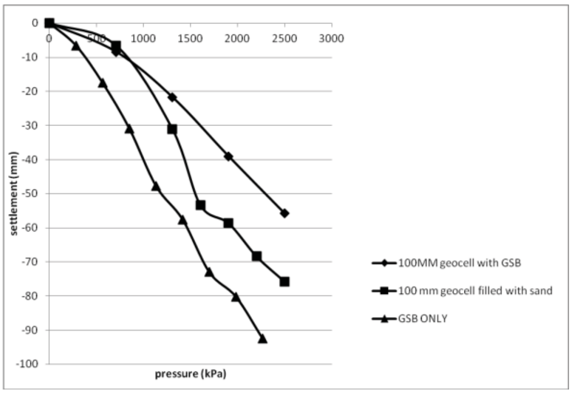

Fig. 8 Typical pressure-settlement data from laboratory plate load tests

Several tests were performed by varying the height of geocells, infill material and their combinations. Some repeat trails were performed to verify the consistency in the test data. Repeatable test data was obtained thus giving confidence for further interpretations.

ANALYSIS OF THE LABORATORY DATA

The pressure-settlement data was back-predicted by using the elastic-layer analysis software KENPAVE and the finite element software PLAXIS. The object of the analyses was to estimate the elastic modulus of the different geocell treated layers. The analyses were repeated several times until a good match was obtained between the measured settlement and the estimated settlement at a wheel load of 100 kN.

The Young's modulus values assumed for different layers are listed below. These were selected based on recommendations in IRC:37-2001 for Design of Flexible Pavements. The modulus values are given in terms of CBR value and the thickness of the respective layers.

E- Value for subgrade (CBR 4%) = 10*4 =40 MPa = 40000 kPa
E-Value for stabilized subgrade (CBR 6%) = 17.6*6^0.64 = 55.40 MPa = 55400 kPa
E-value for GSB (225 mm thick) =55400*0.2*225^0.45= 126771.577 kPa
E-value for GSB (75mm thick) = 55400*0.2*75^0.45 = 77324.53 kPa
E-value for GSB (150 mm thick) = 55400*0.2*150^0.45 = 105628.43 kPa
E- value for GSB (400mm thick) = 55400*0.2*400^0.45 = 164235.39 kPa

The improvement factor with geocell reinforcement is written as the ratio between the modulus of the geocell treated layer with that of the unreinforced layer (both having the same thickness). The improvement factors obtained for different cases are listed in Table 2. The pressure distribution below the geocell layer predicted by the analyses is shown in the following figure.

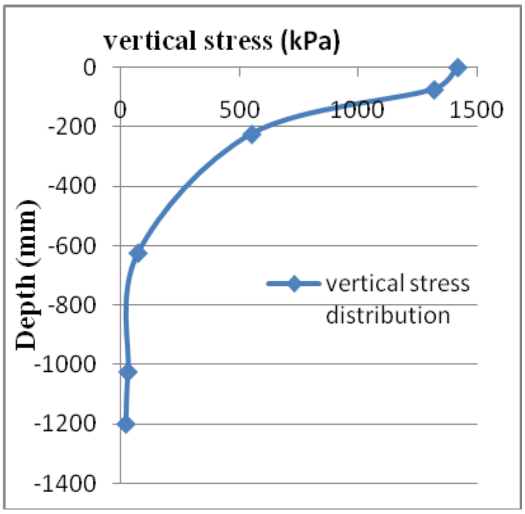

Fig. 9 Pressure distribution below the footing in geocell reinforced case

Table 2 Modulus Improvement Factors (MIF)

Type of study	MIF
Field tests	2.75 (150 mm geocell)
Laboratory tests	2.92 (150 mm geocell)
	2.84 (50 & 100 mm geocell)

The analyses by the finite element software also gave similar modulus improvement factors (MIF). Similar MIF values were also reported by Rajagopal and Kief (2008).

The geocell layer in the pavement section significantly reduced the vertical pressures transmitted to the subgrade layers as shown in Fig. 9. The influence of this pressure reduction means that the service life of the pavement increases or for achieving the same service life of the pavement section, the thickness of the GSB layers could be reduced.

The optimized thickness of the different layers for achieving a 20-year service life with 10 and 100 million standard axle loads was performed using the program KENLAYER for two different subgrade CBR values of 2% and 10%. For extremely soft subgrades, the use of two geocell layers one at subgrade level and another at the top surface have given the best performance in terms of low damage factor and low thicknesses of different layers.

The thickness of different layers obtained for the case with 150 million standard axle loads and 2% subgrade CBR value obtained by different methods is presented in the following table. The design section shown in the second column is as per IRC 37 (2001). In the following, "BC" is the bitumen concrete, WMM is the water mix macadam, DBM is the dense bound macadem.

Table 3 Pavement layer thickness layers

Combinations	IRC-unreinforced	Geocell at Subgrade	Geocell in base and subgrade
BC	50 mm	50mm	50 mm
DBM	215 mm	185 mm	170 mm
WMM	250 mm	0	Geocell with GSB-200 mm
GSB	460 mm	500 mm	100 mm
sub-grade	500 mm	200mm Geocell with soil infill on 300mm subgrade layer	200mm Geocell with soil infill on 300mm subgrade layer
Total cost (Rs.)/m^2	2634.6	2488.6	2451.5
Total thickness	975 mm	735 mm	520 mm
Design Life	16 years	20 years	20 years

Table 4 Unit costs of various materials

S. No.	Layer	Cost (Rs.)/m^3
1	BC	7840
2	DBM	6468
3	WMM	1200
4	GSB	1200
5	SUBGRADE	165

It is seen from the above that the use of geocell layer at subgrade level or at two different depths within the pavement section reduces the overall thickness of the pavement. The reduced thickness of layers results in the reduction of the total cost of the pavement. The relative cost estimates for different sections is given in Indian rupees. These are only tentative and do not include the maintenance costs, etc. The actual cost comparison should be based on life-cycle costs including the maintenance costs, etc. The reduction in thickness of imported granular materials leads to lesser Green House Gas emissions leading to environmentally friendly solutions.

CONCLUSIONS

Based on the results obtained from this investigation, the following conclusions can be drawn:

- The use of geocell layer in the flexible pavements increases the structural stiffness of the pavement system.
- The use of geocell layer is found to reduce the thickness of granular layers by as much as 50%.
- The total cost of the pavement system per unit area was found to be lower even with the use of expensive geocell layer.
- The increase in stiffness improves the performance of the pavement and increases the service life of the pavement.
- It is best to provide a geocell layer as close to the surface loads as possible for maximum influence. If a second layer is to be provided, the second layer could be provided at the subgrade level.
- The reduction in thickness of the base layers leads to faster construction because of lesser material requirements. This in turn will also lead to lower carbon foot print due to transportation of lesser quantities of materials from far off quarries.

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