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AN APPROACH FOR EVALUATION OF USE OF GEOCELLS IN FLEXIBLE PAVEMENTS

G. L. Sivakumar Babu, Professor, Indian Institute of Science, Bangalore. gls@civil.iisc.ernet.in
Pawan Kumar, Research Assistant, Indian Institute of Science, Bangalore. kpawan@civil.iisc.ernet.in

ABSTRACT: The design methodology for flexible pavements needs to address the mechanisms of pavement failure, loading intensities and also develop suitable approaches for evaluation of pavement performance. In the recent years, the use of geocells to improve pavement performance has been receiving considerable attention. This paper studies the influence of geocells on the required thickness of pavements by placing it below the granular layers (base and sub-base) and above the subgrade. The reduction in thickness here refers to the reduction in the thickness of the GSB (Granular Sub-base) layer, with a possibility of altogether getting rid of it. To facilitate the analysis, a simple linear elastic approach is used, considering six of the sections as given in the Indian Roads Congress (IRC) code. All the analysis was done using the pavement analysis package KENPAVE. The results show that the use of geocells enables a reduction in pavement thickness.

INTRODUCTION

With increased loading intensities on highways, flexible pavements need to be stable without excessive deformation under load in addition to satisfying the tolerable criteria in terms of load repetitions for fatigue and rutting mechanisms. Often the loads being excessive, there is possibility of plastic deformation due to the absence of confinement in the lateral direction when a vertical load is applied. The effects of confinement on pavement performance are significant. In the absence of proper confinement, pavement failures shown in Fig. 1 are likely.

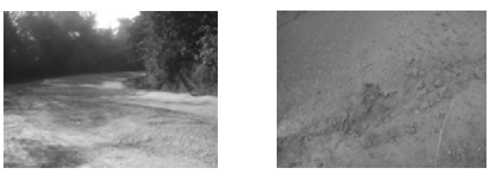

Fig. 1 Typical pavement failures due to lack of confinement

Considering that the distress is similar to bearing capacity failure, Geosynthetics in the form of geotextiles and geogrids made of polymeric materials are being used to improve bearing capacity of pavements. These materials provide confinement effect through friction. Geocells are three dimensional form of geosynthetic materials with interconnected cells filled with soil, which has many important advantages when used in pavements.

Huang (2004) explains that the mechanistic–empirical method of design is based on the mechanics of materials that relates an input, such as a wheel load, to an output or pavement response, such as stress or strain. The advantages of mechanistic methods are the improvement in the reliability of a design, the ability to predict the types of distress, and the feasibility to extrapolate from limited field and laboratory data. It must be noted that the Geocell material can be selected based on the field requirements. Even in the absence of the GSB layer, the drainage function can be effectively carried out by the geocell layer itself, since the membrane can be made semi-permeable.

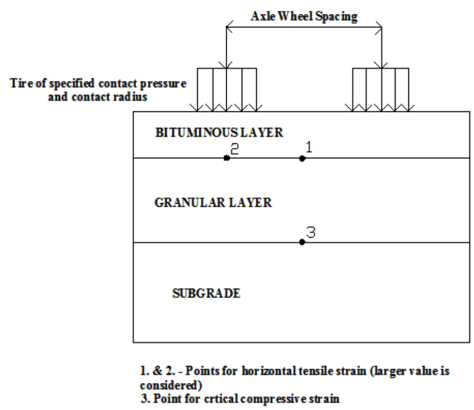

Fig. 2 Critical Analysis Locations in a Pavement Structure

The two failure criteria considered for flexible pavements are fatigue and rutting. The minimum of these two is taken as the design value for allowable load repetitions. The fatigue cracking of flexible pavements is based on the horizontal tensile strain at the bottom of the bituminous layer (Fig. 2). The failure criterion relates the allowable number of load repetitions to the tensile strain, through the laboratory fatigue test on bitumen specimens. The following equation is used:

$$N_F = FT1 \times (\epsilon_t)^{-FT2} \times E^{-FT3} \qquad (1)$$

Where N_F = allowable no. of load repetitions to produce 20% cracked surface, ϵ_t = Tensile strain at the bottom of bituminous layer, E = Elastic modulus of bitumen layer and FT1, FT2, FT3 are the fatigue coefficients.

The fatigue cracking of flexible pavements is based on the horizontal tensile strain at the bottom of the bituminous layer (Fig. 2). The following equation is used

$$N_R = FT4 \times (\varepsilon_z)^{-FT5} \quad (2)$$

LITERATURE REVIEW

The term "geocell" refers to a synthetic, honeycomb like cellular material. A structure of these cells interconnected by joints to form a cellular network could be used for the confinement of soil (Fig. 3). Al-Qadi and Hughes (2000) evaluated the use of geocells in flexible pavements by conducting field studies. The case selected was the reconstruction of a road that showed excessive rutting. The use of geocells was chosen as the solution on an experimental basis, and the results showed that the pavement laid on the confined base showed no signs of rutting. However, the paper was unable to isolate effect of geocell alone, because of the presence of other geosynthetics. Emersleben and Meyer (2008) conducted large scale model tests and field tests which showed similar results which verified the fact that geocells reduce surface deflections and vertical pressure on the subgrade. The tests also studied the effect of aspect ratio and results showed that performance improved as the height to diameter ratio was increased. Geosynthetics firm Strata Geosystems (India) has been providing case histories for the use of its products. Their geocell product was used in the construction of an access road for Guwahati Solid Waste Landfill Site at West Boragaon, Guwahati. At the end of the study period it was found that the use of geocells not only reduced the material required, but also improved the speed of construction. Along with the field tests, Emersleben and Meyer (2008) also conducted large scale model tests in test boxes measuring 2m x 2m x 2m. The tests showed that the surface deflection is lesser in a geocell confined section and the results were verified by FWD measurements carried out in field studies. Rajagopal et al. (2001) proposed the following equation for the layer modulus of geocell-confined sand (Eg) in terms of the secant modulus of the geocell material and the modulus parameter of the unreinforced sand (K_u):

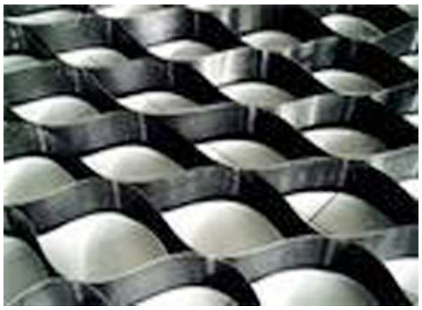

Fig. 3 Typical Geocell Mattress

$$E_g = P_a[K_u + 200M^{0.16}]\left(\frac{\sigma_3}{P_a}\right)^{0.7} \quad (3)$$

Here "Pa" is the atmospheric pressure, "Ku" is the modulus number for unreinforced soil (Duncan and Chang, 1970) and "M" is the secant modulus of geocell material in kN/m and σ_3 is the confining pressure. The additional confining pressure due to the membrane stresses can be calculated using the following equation (Henkel and Gilbert, 1952):

$$\Delta\sigma_3 = \frac{2M\varepsilon_c}{D}\frac{1}{(1-\varepsilon_a)} = \frac{2M}{D_0}\left[\frac{1-\sqrt{1-\varepsilon_a}}{1-\varepsilon_a}\right] \quad (4)$$

PROPOSED METHOD

The design traffic is considered in terms of the number of standard axles (in the lane carrying the maximum traffic) to be carried during the design life of the road. The total number of repetitions of the standard axle is usually expressed in terms of Million Standard Axles (msa). The California Bearing Ratio (CBR) is the soil strength parameter adopted by the IRC and thus it is also the parameter adopted in this paper. Temperature considered was 35oC and thus the composite modulus of the 60/70 grade bitumen layer (E_1) was taken as 1695MPa, as given in the codes. The Poisson's Ratio was taken as 0.5, 0.4 and 0.4 for the bituminous, GB + GSB and the subgrade layers, respectively (IRC-37-2001). The resilient moduli for the subgrade and granular layers were calculated using the following equation:

$$E_3 = 10 \times CBR \ \#$$
$$\#\#\#\# = 17.6 \times CBR^{0.64} \ (CBR > 5) \quad (5)$$

$$E_2 = E_3 \times 0.2 \times h^{0.45} \quad (6)$$

Where E_3 = Resilient modulus of the subgrade (MPa), E_2 = Composite elastic modulus of granular layers (MPa) and h = height of Granular layers (mm).

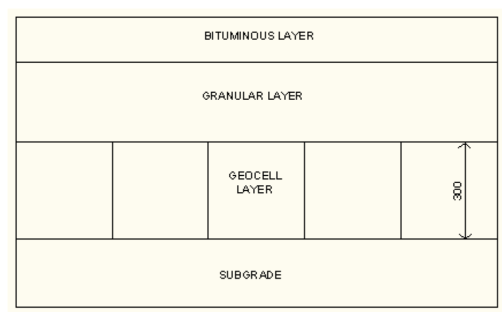

Fig. 4 Typical section with 300mm Geocell layer.

The geocell layer considered was of height 30 cm. Past literature suggests that the optimum aspect ratio for geocell performance is unity (Madhavi Latha and Rajagopal, 2007), thus the equivalent diameter of the geocell was also taken as 30cm. Furthermore, the following values were used for calculation: Equivalent diameter of the cell = 0.30 m, Secant modulus of geocell material = 4500kN/m, Assumed strain in geocells = 5% [Madhavi Latha et al (2009) found the average axial strain to be 4.8%] , Modulus number for sand Ku = 1000, Atmospheric pressure Pa = 100 kPa. Substituting the above values in equations (3) and (4), the value of the composite Geocell Layer Modulus was found to be 760MPa. Fig. 4 shows a schematic diagram of the pavement section with geocell confinement, where the geocell layer comes below the sub-base and above the subgrade. Since the above analysis is valid for sands, the infill material should preferably be chosen as sand, since the behaviour can be predicted by the above model.

Table 1 Sections considered for analysis

Section No.	CBR (%)	Design Traffic (msa)	Wearing Course (mm)	Granular Base (mm)	Granular Sub-base
I	2	10	140	250	460
II	5	10	110	250	300
III	10	10	90	250	200
IV	2	150	265	250	460
V	5	150	220	250	300
VI	10	150	200	250	200

Since all the analysis is intended to be restricted to the linear-elastic approach, a computer program known as KENPAVE, which is a pavement analysis and design package, was employed to analyse the sections, both unreinforced and reinforced. Madhavi Latha and Rajagopal (2007) showed that a composite layer of geocell encased with infill can be modelled as an equivalent single layer with equivalent elastic modulus as given by equation (3). Thus geocell layer is modelled as a single layer in KENPAVE with E = 760 MPa. The standard axle load considered in this analysis is 80kN, which corresponds to dual wheel load of 40kN, thus, assuming a contact pressure of circular loaded area to be 577kPa; the contact radius is calculated as 10.5cm. The distance between the load groups considered for the analysis is 31.5cm. For Damage Analysis, the fatigue coefficients for layer 1 are taken as FT1 = 0.0806, FT2 = 3.89 and FT3 = 0.854, and the rutting coefficients for layer 3 are taken as FT4 = 4.1656×10^{-8} and FT5 = 4.5337. The aim of the analysis is to determine to what extent the thickness of the GSB layer can be reduced, and hence for each of the six sections (table 1), different cases are analysed with decreasing GSB thickness. Sections with decreasing GSB thicknesses are tried till the allowable repetitions for the unreinforced and reinforced sections are comparable.

RESULTS & DISCUSSION

The resulting damage analysis values for the 6 sections are provided in Tables 2-7. These are the values calculated using the KENLAYER feature of KENPAVE considering a 30cm geocell layer below granular layer. The last two columns (in bold) compare the capacity (allowable repetitions, i.e. minimum of N_F and N_R) of the unreinforced and reinforced sections, which are calculated using the strain values (ϵ_t and ϵ_z). In general, the N_R value for the sections with geocells is much higher than the corresponding N_F value and thus it is not mentioned in the any of the tables. We can see from Table 2 that the capacity of a confined section in which 260 mm of the GSB is removed is 7.7 msa, which is greater than the 7.6 msa obtained for the unconfined section with GSB of 460mm. Thus, it is possible to reduce the GSB layer by 260 mm by using a 30cm geocell layer for this particular section.

Table 2 Results for Section I (CBR 2%, 10 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	**Allowable Repetitions (msa)**	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+460	7.6	9.1	36.8	**7.6**	**9.1**
2	250+450	7.5	9.0	33.7	**7.5**	**9.0**
3	250+400	7.0	8.7	21.5	**7.0**	**8.7**
4	250+350	6.5	8.4	13.6	**6.5**	**8.4**
5	250+300	6.0	8.1	8.6	**6.0**	**8.1**
6	250+250	5.5	7.9	5.3	**5.3**	**7.9**
7	250+200	4.9	7.7	3.3	**3.3**	**7.7**

*Note: [1]Unreinforced, [2]Reinforced, *N_R for reinforced sections is very high and is not indicated (applies to tables 2-7)*

Table 3 Results for Section II (CBR 5%, 10 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	**Allowable Repetitions (msa)**	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+300	11.2	12.2	131	**11.2**	**12.2**
2	250+250	10.1	11.4	72	**10.1**	**11.4**
3	250+200	9.1	10.7	38	**9.1**	**10.7**

Table 4 Results for Section III (CBR 10%, 10 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	**Allowable Repetitions (msa)**	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+200	12.8	13.5	136	**12.8**	**13.5**
2	250+150	11.1	12.2	66	**11.1**	**12.2**

For section II, it is observed that the value for the original section is comparable to that of a geocell-confined section with GSB thickness 200mm. Thus, it is possible to reduce 100 mm of GSB layer when 30cm geocell layer is incorporated. For section IV, the confinement completely eliminates the need for a GSB layer, whereas for sections V and VI, the GSB thickness can be reduced by 200mm and 150mm, respectively. For section III, because of the high modulus of the soil, the geocell-confined sections' capacity isn't enhanced to any significant degree.

Table 5 Results for Section IV (CBR 2%, 150 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	Allowable Repetitions (msa)	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+460	149	199	448	**149**	**199**
2	250+450	147	198	422	**147**	**198**
3	250+400	139	193	310	**139**	**193**
4	250+350	131	189	228	**131**	**189**
5	250+300	122	184	167	**122**	**184**
6	250+250	114	180	123	**114**	**180**
7	250+0	77	163	30	**30**	**163**

Table 6 Results for Section V (CBR 5%, 150 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	Allowable Repetitions (msa)	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+300	162	204	1172	**162**	**204**
2	250+250	148	194	749	**148**	**194**
3	250+200	134	185	475	**134**	**185**
4	250+150	120	176	300	**120**	**176**
5	250+100	106	168	189	**106**	**168**

Table 7 Results for Section V (CBR 10%, 150 msa)

Sl. No	GB + GSB (mm)	N_F (msa)		N_R* (msa)	Allowable Repetitions (msa)	
		UR[1]	RE[2]	UR[1]	**UR[1]**	**RE[2]**
1	250+200	180	225	1327	**180**	**225**
2	250+150	159	210	776	**159**	**210**
3	250+100	138	196	449	**138**	**196**
4	250+50	118	182	259	**118**	**182**

CONCLUSIONS

The analysis carried out for the typical sections of IRC-37 suggests that it is possible to reduce the thickness of GSB layer using geocells. The general conclusion that can be drawn from the results is that the potential for reduction is pronounced in the case of soils with lower CBR, and also the sections designed for higher loads. The 2% CBR section for 150 msa showed a possibility of completely removing the GSB layer, and even other sections displayed potential reduction in GSB to varied extents. These results need to be validated by field and laboratory trials, but do serve as a starting point. This analysis could also be extended considering appropriate constitutive models for soils under repeated loadings.

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