Visakhapatnam Chapter

Proceedings of Indian Geotechnical Conference 2020
December 17-19, 2020, Andhra University, Visakhapatnam

Cost Economics of Geocell Reinforced Flexible Pavements on Intermediate Compressible Clayey Subgrades

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Abstract. Accessibility and interconnectivity to distinctive places through well connected transportation network contribute for the socio-economic development of any country. About 40% of surface deposits in India are covered by clayey soils and inevitably the roads have to pass through such sub grades. In spite of adopting large pavement thickness to prevailing due low soaked CBR values, flexible pavements over clayey soils suffer from immoderate rutting, wavy surface, longitudinal cracking alongside wheel track and shear failure in subgrade in edge regions. Researchers are trying continuously to enhance the strength and stability of the clay subgrades through stabilization, reinforcing, moisture manipulation and soil replacement techniques. The advent of geosynthetics has drawn the interest of highway engineers to contemplate them for use in pavements to enhance performance. Particularly geogrids, geocells and geotextiles due to their multi-functional behaviour have been tried to control reflection cracking in overlays, as separator- filter - drain at clay sub grades, as reinforcing factor in soft-soils. The present study focuses upon geocell confinement of subbase and base layers of flexible pavements over clay subgrade of intermediate compressibility (CI) to reduce pavement thickness. The reduction of thickness of overlying layers of geocell strengthened layer is made by keeping vertical strain below the limiting vertical strain at subgrade level of unreinforced pavement as specified in IRC 37-2012. The designed pavement sections with geocell reinforced base and sub base layers indicated reduction in pavement thickness by about 12% and 24% respectively and the cost analysis revealed savings of about 12% and 8% for geocell reinforced base and sub base layer pavement sections for traffic of 50msa.

Keywords: Clay subgrade, Geocell, Reinforcement, Flexible Pavement.

1 Introduction

Inopportune and unanticipated failures of flexible pavements laid on clayey subgrades are frequent and familiar. Generally, clay subgrades soften due to wetting in rainy season and result in intermixing of subbase and subgrade material under traffic loads and as result pavement thickness decreases over a period of time. The use of geosynthetics as reinforcement in flexible pavement systems over clay subgrades has grown steadily over the last three decades. In spite of the evidence that geosynthetic reinforcements can lead to improved pavement performance, the specific conditions or mechanisms that enable and govern the reinforcement are unclear, largely remaining unidentified and unmeasured. The appropriate selection of design parameters for geosynthetics is complicated by the difficulty in associating their relevant properties to the improved pavement performance.

Das (2004) [3] reported that the first precaution of foundation construction on swelling clays as replacement of the soil with non expansive material. West (1995) [15] suggested improvement of bearing capacity of a subgrade soil through densification or compaction of the soil. Though the technique is effective in granular soils, it does not work well in clay as strength is governed by water content than compacted density. Petry and little (2002) [12] reported that lime and Portland cement are the most commonly used chemical stabilizers for clay subgrades. Chen (1988) [2] reported from laboratory studies that among various stabilizers including calcium lime, Portland cement and lime/cement mixtures, lime shows the greatest improvement to compressibility, CBR and swelling. He opined that field mixing of stabiliser with clay is difficult. Based on dynamic cone penetrometer (DCP) test results, Harrison (2005) [5] reported the effectiveness of ime stabilisation in improving the strength of black clay subgrades. Ramanujam and Jones (2007) [13] reported the disadvantage of cement stabilization of clay subgrade as the tendency of overlying pavement to crack due to increased stiffeness of subgrade. Satyanarayana Reddy and Rama Moorthy (2005) [14] reported that the flexible pavements receive failure due to shear failures of clay subgrades as the aspect of safety against shear failure is not considered in CBR method. A design methodology for flexible pavements based on safe bearing capacity (SBC) of subgrade soil has been developed evaluating the safety of pavements against shear failure risk.

Geosynthetics (geotextiles and geo composites) play a vital role in separation of materials, reinforcing, filtering, draining and moisture barrier (Koerner, 1986 [10], Das, 2006 [4], Choudhary et al., 2011 [1]). Placement of geotextile held in position at subgrade level helps in separation of clay subgrade and sub-base material, increases load bearing capacity, checking fine-grained soils from intruding into overlying layers and draining the undesirable water. Madhavi Latha (2011) [11] investigated the benefit of geocell reinforcement on the performance of earth embankments constructed over weak foundation soil from laboratory model studies. Geocell reinforcement was found to be beneficial in increasing the bearing capacity and reducing the deformation of the embankment. Zornberg and Gupta (2009) [16] stressed the need for geofabrics incorporation in design manuals as they lack understanding and actual testing inspite of their tremendius potential to improve pavement performance in weak sugrades.

2 Characterization of Clay Subgrade

The subgrade soil is collected from M.V.P. Colony, Visakhapatnam and its geotechnical characterization is done through laboratory tests carried out in accordance with relevant parts of IS 2720 [8]. Engineering properties of the clay subgrade under study determined from laboratory tests are presented in Table 1.

Table 1. Engineering Properties of the Subgrade soil

Engineering Properties	Subgrade Soil
Specific Gravity	2.70
Grain Size Analysis	
a) Gravel (%)	2
b) Sand (%)	32
c) Fines (%)	66
Atterberg Limits	
a) Liquid Limit (%)	40
b) Plastic Limit (%)	24
c) Shrinkage Limit (%)	16
IS Classification (as per IS1498:1970)	CI
Compaction Characteristics (IS Light Weight)	
a) Optimum moisture content (%)	15.8
b) Maximum Dry Density (g/cc)	1.78
Undrained Shear Parameters	
a) Cohesion (kN/m^2)	34
b) Angle of internal friction	13^o
Soaked C.B.R. Value (%)	3.2
Differential Free Swell (%)	20

3 Design of Unreinforced Flexible pavements over Clay Subgrade (CI)

The flexible pavement thickness design is done based on soaked CBR value of clay subgrade and for the anticipated traffic from the design plates of IRC: 37-2012 [6]. The number of commercial vehicles per day (CVPD) of 600 and 1200 with a traffic growth rate of 7.5% yielded design traffic of 25 msa and 50msa respectively for a design period of 20years. In estimation of Design traffic in terms of “msa”, vehicle damage factor of 3.5 and lane distribution factor of 0.75 (for double lane pavement) have been considered. The thickness design particulars of the unreinforced flexible pavement are presented in Table 2.

Table 2. Unreinforced pavement thickness as per IRC: 37-2012

Pavement Component	Design Traffic	
Layer thickness	25 msa	50 msa
Wearing Course (mm)	40	40

Pavement Component Layer thickness	Design Traffic 25 msa	50 msa
Dense Bituminous Macadam (mm)	130	160
Granular Base (mm)	250	250
Granular Subbase (mm)	380	380
Total	800	830

4 Design of Reinforced Flexible pavement over Clay Subgrade

In the present study, the base and subbase layers of the flexible pavement are proposed for reinforcing with geocells. Based on the information provided by M/s Tencate Geosynthetics, Modulus Improvement Factor (MIF) is taken as 2.2 for base and sub base layer confinement with geocell. Three-layer elastic approach is used for determination of tensile and compressive strains (Fig.1) for the unreinforced flexible pavement (as per IRC: 37-2012 [6]). Later, for base layer reinforced sections with geocell, the thickness of the layer above it and the reinforcing layer itself are gradually reduced until permissible strain criteria observed for unreinforced sections is not exceeded. The same approach is carried out for the design of sections with geocell reinforcement in subbase layer. The Modulus of elasticity (E) of subgrade, subbase and base layers are determined as per IRC: 37-2012 [6] and for the analysis, the modulus of elasticity values of base and subbase layer determined are utilised for determining the composite modulus of elasticity as base and subbase layers together are considered to be a single layer i.e. layer 2 in the three-layer elastic approach.

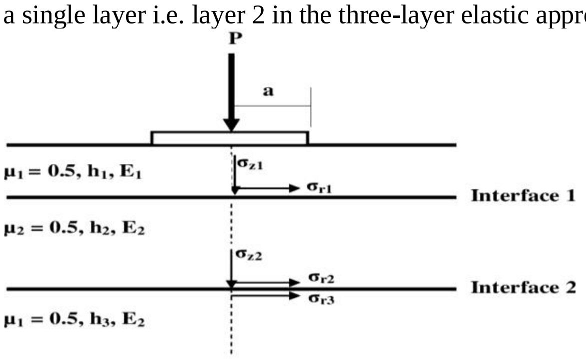

Fig. 1. Stresses at interfaces of a three-layer elastic system

The stresses in a three-layer system depend on the ratios k1, k2, A and H defined as

$$K_1 = \frac{E_1}{E_2};\ K_2 = \frac{E_2}{E_3};\ A = \frac{a}{h_2}\ and\ H = \frac{h_1}{h_2}$$

Jones (1962) presented tables for determining stress factors ZZ1-RR1 and ZZ2– RR3, Peattie's gave the equation to determine the radial strain (ϵ_{r1}) at the interface 1 and strain on the top of subgrade (ϵ_{Z3}) as,

$$\epsilon_{r1} = -\frac{1}{2E_1}(ZZ1 - RR1)p;\ \epsilon_{z3} = \frac{1}{E_3}(ZZ2 - RR3)p$$

where,

p = tyre pressure (7kg/cm^2 considered in the present study)

Thus, by determining the strains at the interface between the layers and checking for the fatigue and rutting failure criteria, the thickness of the pavement (h) is finalized.

Geocell Reinforced Base layer Flexible pavements

The data obtained from the three-layer theory analysis of unreinforced and geocell reinforced base layer pavement sections is presented in Table 3, 4, 5 and 6.

Table 3. Strains for the Conventional (IRC Approach) Pavement Section for 25 msa

Conventional Pavement Section (Unreinforced Section) (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40 DBM – 130 Base – 250 Subbase – 380 Total Thickness – 800	0.000205	0.000319

Table 4. Strains for the Conventional (IRC Approach) Pavement Section for 50 msa

Conventional Pavement Section (Unreinforced Section) (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40 DBM – 160 Base – 250 Subbase – 380 Total Thickness – 830	0.000177	0.000290

Table 5. Strains for the Geocell Reinforced Base Pavement Section for 25 msa

Base Reinforced Section (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40		
DBM – 100		
Base – 200	0.000210	0.000373
Subbase – 380		
Total Thickness – 720		

Table 6. Strains for the Geocell Reinforced Base Pavement Section for 50 msa

Base Reinforced Section (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40		
DBM – 110		
Base – 200	0.000194	0.000359
Subbase – 380		
Total Thickness – 730		

Even though there is a decrease in the thickness of the reinforced pavement sections of about 80mm (for 25msa) and 100mm (for 50msa) with the introduction of geocell reinforcement, the strains are observed to be higher compared to unreinforced sections. However, the designs are done keeping the strains in permissible limits with regard to fatigue and rut for the considered traffic.

Geocell Reinforced Subbase layer pavement design

The data obtained from the three-layer theory analysis of geocell reinforced subbase layer pavement sections is presented in Table 7 and Table 8 below.

Table 7. Strains for the Geocell Reinforced Subbase Pavement Section for a Traffic of 25 msa

Subbase Reinforced Section (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40		
DBM – 130	0.000170	0.000516
Base – 150		
Subbase – 280		

Subbase Reinforced Section (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
Total Thickness – 600		

Table 8. Strains for the Geocell Reinforced Subbase Pavement Section for a Traffic of 50 msa

Subbase Reinforced Section (mm)	Tensile Strain at the top of Interface 1	Compressive Strain at the bottom of Interface 2
BC – 40		
DBM – 160		
Base – 150	0.000132	0.000446
Subbase – 280		
Total Thickness – 630		

The limiting values of strains for satisfying fatigue and rutting failure criteria for traffic of 25msa and 50msa and the tensile and compressive strains of geocell reinforced pavement sections are presented in the Tables 9 and 10.

Table 9. Limiting strain values and strains of unreinforced and geocell reinforced pavement sections for a traffic of 25 msa

Failure Criteria	Limiting Strain	Unreinforced Section	Geocell Reinforced Base Section	Geocell Reinforced Subbase Section
N_F	0.000283	0.000205	0.000210	0.000170
N_R	0.000549	0.000319	0.000373	0.000516

Table 10. Limiting strain values and strains of unreinforced and geocell reinforced pavement sections for a traffic of 50 msa

Failure Criteria	Limiting Strain	Unreinforced Section	Geocell Reinforced Base Section	Geocell Reinforced Subbase Section
N_F	0.000237	0.000177	0.000194	0.000132
N_R	0.000472	0.000290	0.000359	0.000446

5 Cost Economics

The cost analysis of the designed unreinforced and geocell reinforced flexible pavement sections under study is carried out by estimating the quantities of items of work required for 1km stretch of dual carriage way dual lane pavement by adopting rates from SSR 2018 -19 of Government of Andhra Pradesh, India and Geocell rate has been adopted from its manufacturer at INR 225/- per sq.m. The abstract estimates for various designed pavement sections are presented in Table 11.

Table 11. Abstract Estimate of the various designed pavement sections

S.No.	Type of Pavement Section	For Traffic of 25msa Amount (INR)	For Traffic of 50msa Amount (INR)
1	Unreinforced	3,82,36,000 3.824 Crores	4,16,99,500 4.17 Crores
2	Geocell Reinforced Base	3,52,72,000 3.528 Crores	3,64,26,500 3.645 Crores
3	Geocell Reinforced Subbase	3,47,53,000 3.476 Crores	3,82,16,500 3.822 Crores

6 Conclusions

Based on the experimental and analytical study, the following conclusions are drawn.

1. The clay subgrade of intermediate compressibility under the study has a low soaked CBR value (3.2%) and demands large pavement thickness (800mm thickness for 25msa and 830mm thickness for 50msa).
2. Geocell reinforced base flexible pavement section has resulted in reduction of pavement construction cost by about 7.75% for 25msa and 12.5% for 50msa traffic and reduction in design pavement thickness by about 10% for 25msa and 12% for 50msa traffic.
3. Geocell reinforced subbase flexible pavement has resulted in reduction of pavement construction cost by about 9% for 25msa and 8.5% for 50msa and reduction in design thickness by about 25% for 25msa and 24% for 50msa.
4. Geocell reinforced subbase flexible pavement sections result in higher reduction in thickness of the subbase and base layers compared to geocell reinforced base layer pavement sections and thereby help in reducing the demand on conventional road aggregates and also, lower the carbon foot print impacting the environment.

The geocell reinforced pavements cost can be further reduced by using industrial waste materials such as Pond Ash, GGBS, crusher dust as a subbase layer in place of the conventional GSB material.

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