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REINFORCED FLEXIBLE PAVEMENT DESIGN OVER EXPANSIVE CLAY SUBGRADE

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Key words

Geotextile, reinforcement, pavement, expansive soil, anchorage, safe bearing capacity

Abstract: Flexible pavement construction in expansive soils is expensive due to large pavement section resulting from low CBR values in wet condition. The volume instability of soil affects constructed pavements and demands frequent maintenance. Hence efforts are to be made for reducing large pavement section and also to suppress swelling of subgrade. Though the use of granular and CNS cushions in pavement construction helps in reducing volume changes affecting pavement layers, it cannot reduce required large pavement sections. Hence, in the present paper, a reinforced flexible pavement design methodology has been formulated for expansive subgrades with the objectives of pavement thickness reduction and swell control of subgrade. Test track studies have been done on unreinforced and reinforced flexible pavement sections laid over selected expansive subgrade. The surface levels have been observed for swell over a period of two years. The proposed design methodology has been validated from the Elastic layer theory.

Introduction

Expansive soils undergo alternate shrinkage and swelling due to moisture fluctuations and posses low strength in rainy season due to poor drainage conditions. As a result, flexible pavements constructed over such soils are not only expensive but also result in poor performance and premature failures. Various techniques such as usage of moisture barriers (Steinberg, 1992) to control swelling and cushions (Sand, Moorum, Cohesive Non-swelling Soil, Lime stabilized soil) to suppress swelling and serve as capillary cut-offs have been tried by various researchers (Katti, 1979; Natarajan and Shanmukha Rao, 1979) and have been observed to have met with limited success. Treatment of expansive soils using stabilizers has been tried to improve volume stability of soil. However, uniform mixing of soil is difficult and cannot be relied upon for large-scale usage.

So far none of the existing pavement design methodologies are aimed at reducing the design pavement thickness over expansive soils. Hence, in the present research work, it is proposed to use geotextiles for reinforcing flexible pavements. As there is no established design procedure for reinforced flexible pavements over soft clays, in the present paper, a design methodology ensuring safety against risks of shear and settlement failures in subgrade has been formulated. The design has provision for swell control of subgrade also. The reinforced and conventional unreinforced flexible pavement sections (Test Tracks) have been laid for performance appraisal against swelling of subgrade. The details of study are presented in subsequent sections.

Material Properties

Expansive Soil: The expansive soil used in the study was procured from Hanamkonda town, Andhra Pradesh.

Moorum: The moorum used as subbase material in the study was procured from a Quarry in Hanamkonda.

It may be seen from Table 1 that the expansive soil is High Compressible Clay with high swell potential as free swell index value is more than 50%. The moorum has CBR above 20% and plasticity index is less than 6%. So, it is suitable for use in sub base courses of unpaved roads

Geotextiles: Woven geotextile is used in this study. The properties of geotextile as determined from laboratory tests are presented in Table 2. The load-elongation response of the geotextile is presented in Figures 1 and 2 based on wide width tension tests.

Aggregate: Grade II aggregate has been used in Wet Bound Macadam (WBM) base of test tracks. The properties of the aggregate evaluated from laboratory tests are presented in Tables 3 and 4.

Stone Screening: Type A Stone Screenings satisfying MORTH specifications were used in forming WBM bases of Test tracks. The gradation characteristics of the material is presented in Table 5.

Binding Material: Moorum used in sub base course of test tracks with properties given in Table 1 was used to serve as binding material in forming WBM bases.

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Table 1 Engineering Properties of Expansive soil and Moorum

Engineering Property	Expansive Soil	Moorum
Specific Gravity	2.69	2.67
Grain Size Analysis		
a) Gravel (%)	4.0	24
b) Sand (%)	38	52
c) Fines (%)	58	24
Atterberg Limits		
a) Liquid Limit (%)	66	24.8
b) Plastic Limit (%)	28	19.6
c) Shrinkage Limit (%)	13.9	19.2
IS Classification Symbol	CH	SM-SC
Compaction Characteristics		
a) Optimum Moisture Content (%)	20	7.2
b) Maximum Dry Density (g/cc)	1.56	2.03
Soaked CBR Value (%)	2.1	21.2
Shear Parameters (Undrained)		
a) Cohesion (kN/m^2)	26	12
b) Angle of Internal Friction	12^0	38^0
Percent Swell (%)	8.7	--
Swell Pressure (kN/m^2)	70.0	--

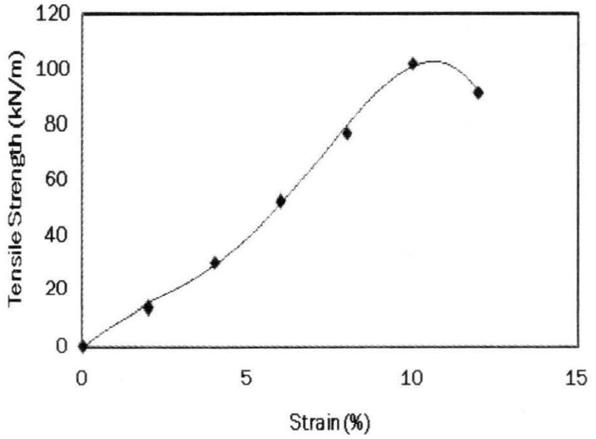

Fig. 1 Tensile test results for a woven geotextile in warp direction

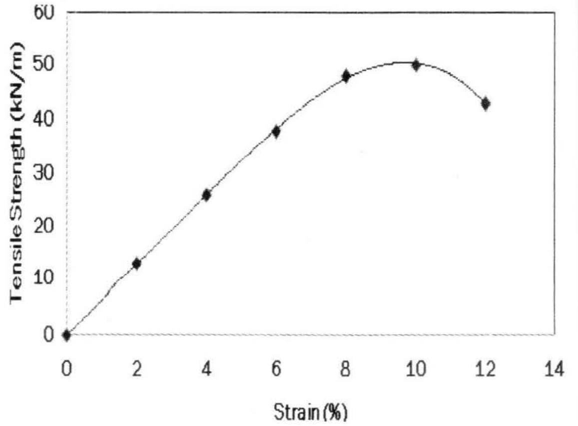

Fig. 2 Tensile test results for a woven geotextile in weft direction

Table 2 Properties of Woven Geotextile

Property	Value/Description
Base Polymer	High Tenacity Polymer
Mass per Unit Area (g/m^2)	295
Thickness (mm)	0.5
Tensile Strength	100kN/m in Warp and 50 kN/m in Weft
Elongation at Break (%)	9.8 & 8.7 in warp and weft
Apparent opening size	130 microns

Table 3 Gradation of Grade –II Aggregate

IS Sieve Designation (mm)	Percent by Weight Passing
90	100
63	94
53	66
45	8
22.4	2

Table 4 Engineering Properties of Aggregate

Property	Value
Specific Gravity	2.80
Crushing Value (%)	22.3
Impact Value (%)	20.7
Abrasion Value (%)	23.5

Table 5 Gradation of Stone Screenings

IS Sieve Designation (mm)	Percent by Weight Passing
13.2	100
11.2	96
5.6	23
0.18	6

Flexible Pavement Design Methodology

Unreinforced Case

The design methodology based on Safe Bearing Capacity (SBC) of subgrade developed by Satyanarayana Reddy and Ramamoorthy (2005) with the following considerations has been used in this study.

SBC Method of design

Considerations

1. The safe bearing capacity of subgrade soil is reduced by 20% to account for action of repetitive wheel loads.

2. Pavement thickness design based on consideration of 80% safe bearing capacity of subgrade soil is critical over the case of increasing static wheel loads by 15%.

3. The loading due to moving vehicles in saturated clayey subgrades is taken as equivalent to strip load since in saturated condition the excess pore water pressures do not get dissipated quickly.

4. The load bearing mechanism of pavement component layers is due to passive resistance offered by material of the layers under applied wheel loads and so 2:1 load dispersion (tan α =0.5, where α is dispersion angle with vertical)is valid for dispersion of wheel load through the flexible pavement layers.

5. The shape of contact area of tyre with pavement is considered as rectangular with two semi circular areas at the ends (Figure 3).

6. The pavement width equivalent to dispersed width of wheel at subgrade level acts as a surface strip footing over weak subgrade soils, particularly saturated clays.

7. Vesic's bearing capacity theory is valid for clayey subgrades.

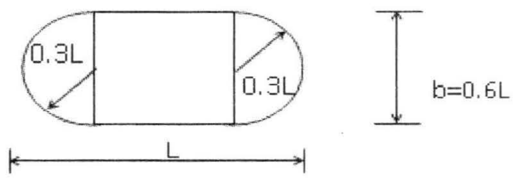

Fig. 3 Shape of tyre contact area

The pavement thickness (h) required for transmission of wheel loads without any risk of shear failure in subgrade has been worked out by equating vertical stress due to wheel load and overburden to safe bearing capacity of soil using the expression given below.

$$\frac{P}{(B+2h\tan\alpha)(L_e+2h\tan\alpha)}+\gamma_{av}.h=q_s \qquad (1)$$

where, P is equivalent single wheel load in kN.

B is width of load contact area = b+S

b is width of contact area of single tyre and S is center to center spacing of tyres.

L_e is length of contact area of equivalent rectangular section.

q_s is safe bearing capacity of subgrade

By considering a standard axle load of 10.2 t with tyre contact pressure of 5.62 kg/cm^2, the values of B and L_e have been worked out to be 47.7 cm and 25.68 cm respectively. The center to center spacing of tyres is taken as 0.3 m.

To account for moving vehicles on road, the safe bearing capacity has been reduced by 20% (Prakash, 1981). Keeping wheel load unchanged, for the expansive soil under study the required pavement thickness has been worked out to be 110 cm. Leonard et al. (1974) reported increase of wheel loads up to 15% in high speed vehicles. So, design pavement thickness required has been also worked out by increasing wheel load by 15% and maintaining safe bearing capacity of soil in static condition. The required design thickness has been found to be 91 cm. Hence, to evaluate risk of shear failure in subgrade, it is preferable to consider reduction in safe bearing capacity of soil rather than considering increase in wheel load.

CBR method of design

The required pavement thickness over the expansive soil under study has been calculated using US ARMY Corps of Engineers formula (1961) given below:

$$h = (0.447\log_{10}C + 0.305)\{ P/ (3.6045\, CBR) - A/(6.45\pi) \}^{0.5} \qquad (2)$$

Where,

h is the design pavement thickness in cm

C is anticipated number of vehicle passes in terms of standard axles.

P is Equivalent Single Wheel Load in kg.

A is Contact area in cm^2

For calculation of design pavement thickness values, 30 million standard axles were considered as vehicular traffic and a standard axle load of 10,200 kg with dual wheel configuration and a tyre contact pressure of 5.62 kg/cm^2 has been taken. The value of design pavement thickness has been worked to be 91.5 cm. (The value is less in comparison to the value obtained from SBC concept, which means that the pavement will have risk for undergoing shear failure if designed based on CBR method)

Reinforced Flexible Pavement

The design formulation for reinforced flexible pavement has been done after thorough study of Giroud and Noiray method of design as it is the only rational method of design available, others (Bender & Barenberg, 1978; Koerner, 1986) being empirical. Both shear and settlement failure criteria have been considered in design. The existing methods (Bender & Barenberg, 1978; Giroud & Noiray, 1981) do not cover the aspect of fabric placement condition at subgrade on performance of reinforced pavement. Apart from stressing the need for holding the fabric in position at subgrade, the design of fabric has been also done for swell control purpose. The considerations involved in design are given below.

Design considerations

1. The soil subgrade is subjected to vertical pressure equal to 80 percent of its safe bearing capacity due to membrane effect of geotextile fabric placed at subgrade level.

2. Initially due to wheel load transmission, the overlying pavement material gets punched into underlying soft subgrade and as a result geotextile gets strained and derives required tensile strength to support wheel loads.

3. The deformed shape of fabric will have right angle kinks along the boundaries of load dispersion followed by elliptical deformed shape on either side (Figure 4).

4. Geotextiles fabrics are held in position by anchorage in longitudinal trenches made in shoulder regions of pavement.

Design for wheel load

The fabric-deformed shape at subgrade level considered in the proposed design methodology has been given in Figure 4. The deformed shape is more likely as geotextile gets punched into soft subgrade initially until reinforcing action of fabric starts and thereafter stops. Such a deformed shape with right angled kinks at boundaries of load dispersion has been proposed by Binquet and Lee (1975) in the theory of design of reinforced soil beds over soft soils. The displaced soil below load dispersion width results in heaving on either side which may be treated as elliptical. The other forms considered by researchers are parabolic, triangular and arc of circle (Giroud & Noiray, 1981; Natarajan, Mathur, Murthy, 1989) are appropriate in subgrades of moderate strength where local or punching shear does not occur. But in soft subgrades, the deformation will be due to punching of overlying material into it, resulting in uniform settlement at subgrade. The elliptical shape for heave is compatible with uniform deformation at subgrade under wheel loads.

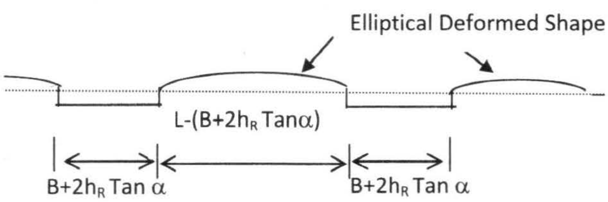

Fig. 4 Deformed fabric shape at sub grade adopted in design

From free body diagram (Figure 5) of deformed fabric below the load dispersion width, the tension developed in the fabric has been worked out by considering equilibrium of forces in vertical direction using the equation given below.

$$T = \frac{(q - 0.8q_s)(B + 2h_R \tan\alpha)}{2} \quad (3)$$

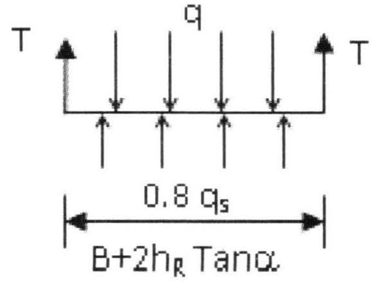

Fig. 5 Free body diagram of deformed fabric at sub grade below load dispersion width

The strain induced in fabric has been worked out using the equation 4 given below.

$$\in = \left(\frac{2s}{B + 2h_R \tan\alpha} \right) \times 100 \quad (4)$$

The design thickness of reinforced flexible pavement has been considered in excess of the value required to initiate shear movements in subgrade using the relation

$$\frac{P}{(B + 2h\tan\alpha)(L_e + 2h\tan\alpha)} + \gamma_{av}.h = 0.8q_u \quad (5)$$

The minimum value of h for reinforced flexible pavement has been worked out to be 45.5 cm

By adopting pavement thickness in reinforced case (hR) above 45.5 cm. the design requirement of fabric has been worked out for different permissible values of settlement at subgrade and data generated has been presented in Table 6.

Table 6 Design Requirement of Fabric

h_R (cm.)	q (kN/m²)	T (kN/m)	ϵ (%)			
			S 10mm	S 15mm	S 20mm	S 25mm
50	75.09	18.46	2.05	3.07	4.09	5.12
60	67.47	15.29	1.86	2.79	3.71	4.64
70	59.86	11.21	1.7	2.55	3.4	4.24
80	54.7	7.74	1.57	2.35	3.13	3.92

The values of rut against settlement have been obtained by equating half volume of rectangular portion to half the volume of elliptical portion. The axle length (L) has been taken as 2.44m. The values of rut so calculated have been given Table 7.

Table 7 Values of rut against subgrade settlement

Settlement (mm)	Rut (mm)
10	28.6
15	42.0
20	57
25	71.6

Design for swell

Considerations

1. Geotextile held in position due to anchorage in longitudinal trenches restrains underlying expansive soils and thus controls swell to some extent.

2. The lateral swell pressure generated in expansive subgrade due to swell controlled by Moorum sub base and geotextile mobilizes necessary frictional resistance in anchorage trenches counteracting tension induced in fabric as a result of swell control.

Considering a design pavement thickness of 70cm with 25cm thick WBM base layer, the thickness of Moorum sub base will be 45cm. From laboratory study, for a cushion to expansive soil ratio of 0.45, the percentage of swell controlled has been observed to be 62.5.

As geotextile is flexible and mobilizes its strength only upon straining, it is not possible to control swelling of subgrade completely. Hence, the requirement of tensile strength of fabric for permissible swells of 10mm, 15mm and 20mm has been worked out based on free body diagram of geotextile fabric in between anchorage trenches. To cut down the requirement on stiffness of fabric, in the present study it is proposed to anchor geotextile as shown in Figure 6 for a single lane pavement.

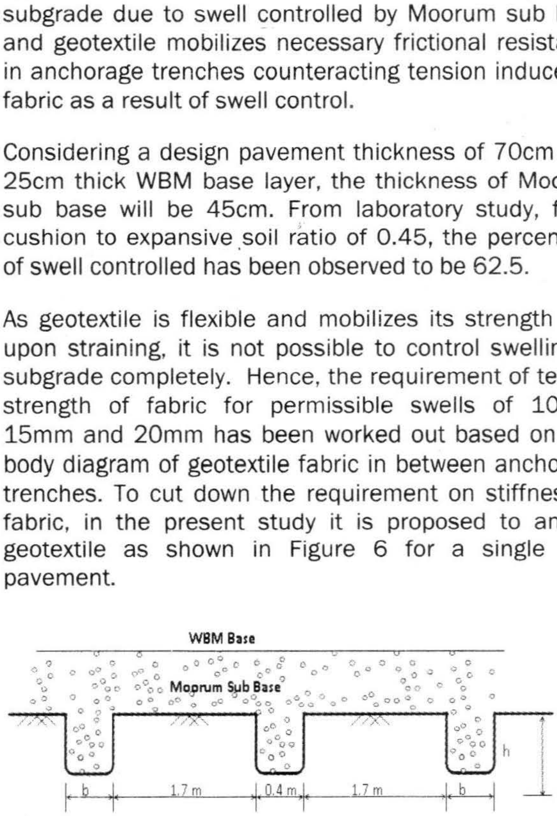

Fig. 6 Proposed reinforced flexible pavement over expansive soil with woven geotextile

The tension (T) developed in the fabric as a result of swell control has been worked out using the equation 6 as

$$T = 0.5p \times B' \tag{6}$$

Where p is pressure exerted by expansive soil on geotextile due to swell controlled by it.

B' is clear spacing of anchorage trenches.

The strain (ϵ) induced in the fabric against different allowable swell (S_a) values has been calculated using the equation

$$\epsilon = (2S_a / B') \times 10 \tag{7}$$

The requirement of geotextile fabric for swell control against different permissible swell values has been given in Table 8.

Table 8 Fabric requirement for swell control

Permissible Swell (mm)	Swell controlled by Geotextile (%)	Upward pressure exerted by subgrade on fabric (p)	T (kN/m)	ϵ (%)
10	26	18.2	15.5	1.2
15	20.3	14.1	12.1	1.8
20	14.5	10.2	8.6	2.4

Design of anchorage trench

Unless geotextile fabrics are held in position by proper anchorage, the required tensile strength to support wheel loads or control swelling is not mobilised. Hence, it is proposed to anchor geotextile fabrics in longitudinal trenches as shown in Figure 6. Normal pressures applied on geotextile surfaces are shown in Figure 7.

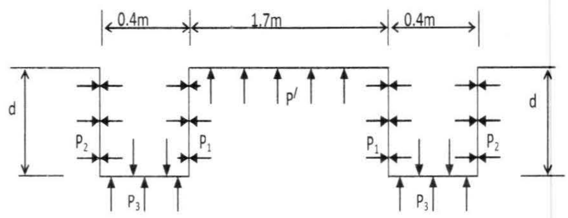

Fig. 7 Normal pressures applied on Geotextile surfaces

The shearing resistance on geotextile surfaces at anchorage trench has been calculated using normal pressures as indicated in Figure 7 as

$$F = d\left[\begin{array}{l}\{C_{a_e} + p_1 \tan\phi_{\mu_e}\} + \\ \{C_{a_m} + p_1 \tan\phi_{\mu_m}\} + \{C_{a_m} + p_2 \tan\phi_{\mu_m}\} \\ + \{C_{a_e} + p_2 \tan\phi_{\mu_e}\}\end{array}\right] + b\left[\{C_{a_e} + p_3 \tan\phi_{\mu_e}\} + \{C_{a_m} + p_3 \tan\phi_{\mu_m}\}\right] \tag{8}$$

Where,

p_1 = percentage swell controlled in central portion x swell pressure (p_s)

p_2 = percentage swell controlled in edge region x p_s

p_3 = effective overburden pressure at geotextile fabric in anchored trench b, d are the width and depth of trench for anchoring geotextile fabrics

C_{a_e}, ϕ_{μ_e} are the adhesion and interfacial friction angle of expansive soil with geotextile fabric

C_{a_m}, ϕ_{μ_m} are the adhesion and interfacial friction angle of moorum with Geotextile

The frictional characteristics of expansive soil and Moorum with the geotextile have been determined by conducting pull out tests. The results of tests have been given in Table 9.

Table 9 Frictional Characteristics of Soils with Geotextile

Soil	Adhesion (kN/m^2)	Angle of internal friction
Expansive Soil	17.4	15^0
Moorum	8	20^0

P_1= 0.745 x 70 = 52.15 kN/m^2 ; P_2 = 0.6 x 70 = 42 kN/m^2 ; P_3 = 17.5 kN/m^2

By taking depth of anchorage trench as 0.4m, the width of trench required has been calculated by equating mobilized frictional resistance on anchored portion of geotextile to tension induced in fabric due to swell control. The mobilized frictional resistance has been calculated by dividing the shearing resistance by a factor of safety of 3. The required width of trench has been worked out to be 0.4m.

Details of Test Track Studies

Unreinforced and reinforced flexible pavement test tracks have laid for studying their swell control ability on subgrade. The test tracks have been laid adjacent to Sri Kodanda Ramalayam at Balasamudram, Hanamkonda. For test track studies, the design pavement thickness has been determined by considering an average daily traffic of 50 cvd with a growth factor of 7.5% and adopting a standard axle load of 10.2 tons with dual wheel configuration with a contact pressure of 5.62 kg / cm^2 for a design period of 10 years. It is proposed to have a shoulder of 1 m on either side of test tracks. Unreinforced test track section has been designed in line with IRC 37-2001 and reinforced section has been designed based on proposed method of design in the study. The details of unreinforced and reinforced test track sections follow.

A. Unreinforced Flexible Pavement (For a traffic of 1 msa)

Total Thickness : 75.1 cm

Moorum Sub base : 52.6 cm

WBM base: 22.5 cm

B. Reinforced Flexible Pavement section with stiff geotextile held in position at subgrade (by anchoring into longitudinal Trenches)

Total Thickness : 70 cm

Moorum Sub base : 47.5 cm

WBM base: 22.5 cm

Fabric Requirement:

- Should have a tensile strength of 11.2 kN/m @ strain of 2.6% for wheel load supporting
- Should have a tensile strength of 12 kN/m @ strain of 1.8% for control of swell (i.e. against a permissible swell of 15mm)

Stiffness of Woven Geotextile with properties presented in Table 2 has been found to meet the above requirements based on wide width tension test and hence it is used as reinforcement in test track study.

C. Reinforced Flexible Pavement section with stiff geotextile simply placed at subgrade

Total Thickness : 60 cm

Moorum Sub base : 47.5 cm

WBM base : 22.5 cm

Fabric requirement is same as previous case except that the fabric is simply placed at subgrade.

Tractor dozer has been used to remove all debris and vegetation and to level off the existing ground surface. The subgrade is then compacted using 10t roller. Moorum sub base has been compacted using the roller. The compacted material at respective OMC and MDD was tested for Field CBR to assess the quality. At random, degree of compaction has been determined and compaction was continued until degree of compaction achieved was above 97 percent. WBM layer has been formed using Grade II aggregate; Type A stone screenings conforming to MORTH 2001 and Moorum as binding material. The sub base moorum was used as binding material also. After compaction of base layer, Field CBR test was performed to ensure CBR above 85%.

For test tracks, open graded Premix Carpet (PC) of 20 mm thick has been laid across each test track at centre in the form of a 0.3m strip to serve as wearing course to enable recording of levels in different seasons. The reduced levels of surface at left (L), centre (C) and right (R) locations of test track sections have been determined in different seasons using dumpy level and average values of Reduced Levels have been presented in Table 10. The reduced levels have been determined by taking R.L of Floor level of Ramalayam as 250.000m.

Reinforced pavement section with simple placement of fabric exhibited a swell of 45mm whereas reinforced section with anchored geotextile fabric exhibited a swell of 16mm only. The test track studies confirmed the need for holding geotextile fabric at subgrade by anchorage in longitudinal trenches.

In Table 10, the anchored geotextile fabric reinforced pavement section indicated control of swell as per design (observed average swell was 16mm against design permissible swell of 15mm) and confirmed the proposed concept.

Verification from Three Layer Elastic Theory

Reinforced Flexible pavement will be stable only if sub base material does not slip over reinforcing material and subgrade is not overstressed. Three layer elastic theory (Peattie, 1962) has been used to evaluate the stability of proposed reinforced pavement design options with different thickness and design thickness is finalized.

The vertical and shear stresses induced at the level of subgrade under varying thicknesses have been evaluated using stress-strain factors of Peattie (1962) for three layer systems using the modulus of elasticity (E) values of WBM base, Sub base and subgrade materials (calculated based on measured Field CBR values from test tracks laid using Relations suggested by IRC 37-2001 as given below.

$E = 10 \times CBR$ ...... if $CBR < 10\%$ (9)

$E = 17.6\,(CBR)^{0.64}$....... For $CBR > 10\%$ (10)

The values of Field CBR values and elastic modulus of the pavement components are tabulated in Table 11.

The vertical and shear stresses at subgrade level (where geotextile is being placed) for different pavement obtained from Peattie theory are given in Table 12. The Table also presents ultimate bearing capacity of subgrade (under dynamic action of vehicles) and frictional resistance available at geotextile fabric surface. The pavement section is considered to have base layer of 225mm and the rest sub base layer.

Table 10 Reduced levels of surface of unreinforced and reinforced test tracks

Period	Location	Unreinforced Test track	Reinforced test track with anchored geotextile	Reinforced test track with woven geotextile simply placed
May' 06	L	249.870	249.855	249.870
	C	249.890	249.880	249.890
	R	249.865	249.860	249.865
Nov' 06	L	249.925	249.875	249.915
	C	249.945	249.895	249.930
	R	249.920	249.880	249.920
May' 07	L	249.880	249.860	249.875
	C	249.895	249.885	249.895
	R	249.870	249.865	249.880
Nov' 07	L	249.930	249.885	249.920
	C	249.945	249.900	249.935
	R	249.925	249.885	249.920

* The Reduced levels reported in the table are in meters

Table 11 Parameters of Pavement Component layers

Pavement Component	Field CBR (%)	Elastic Modulus (MPa)
Subgrade	2.1	21.0
Sub Base	23.2	131.6
WBM Base	88.5	310.1

The data presented in Table 12 infers that for a pavement thickness of 70cm, the induced vertical stress is below dynamic bearing capacity of soil and also the shear stress induced is less than frictional resistance available at the geotextile fabric. Hence, a thickness of 70 cm is essential to avoid large shear displacements in subgrade and also to prevent lateral slipping of sub base material on geotextile under the loads.

Table 12 Vertical and shear stresses at subgrade level from three layer elastic theory

Pavement Thickness	Vertical stress (kN/m^2)	Shear Stress (kN/m^2)	0.8q_u (kN/m^2)	Frictional resistance at geotextile surface (kN/m^2)
50	117.7	79.2	109.4	50.8
60	107.9	49.7	109.8	47.2
70	98.1	10.3	110.1	43.7

Conclusions

- Flexible pavement thickness should be taken as greater of the two values obtained from CBR and SBC methods to avoid shear and settlement failures in clay subgrades.
- Proposed Method of design for reinforced flexible pavements with uniform deformation of fabric at subgrade level with elliptical heaving on either sides yields reasonable stiffness for reinforcing fabric over soft clay subgrades.
- The design thickness finalized from the present research ensures safety against overstressing of subgrade as it is validated from Peattie's three layer Elastic theory.
- Use of geotextile as reinforcement at expansive subgrade under study reduced design pavement thickness by about 40 percent.
- The geotextile held in position by anchorage in longitudinal trenches results in control of additional swell (20 percent in the present study) provided subbase moorum controls some swell (65% in the study) initially due to its cushion action.
- Simple placement of geotextile fabric at subgrade does not control the swell of the subgrade as it does not restrain the subgrade.

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