REINFORCED FLEXIBLE PAVEMENT DESIGN OVER CLAYEY SUBGRADES

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ABSTRACT
Prestressed concrete is a typical set up of cable and concrete which makes a prestressed concrete section considerably stiffer than reinforced concrete section .In prestressed concrete ,cable layout play an important role in reducing tension from concrete .Due to curvature ,cable exerts forces on the concrete to counterbalance the forces causing tension .In curved tendons ,upward force is imposed on the concrete which may reduce or eliminate the downward deflection as well ;which is almost always the governing factor in structural design .Cables are laid as a continuous curve ,but for analysis purpose they are modeled by some mathematical curve .The modeling of the prestressing cable in the finite element analysis is difficult and time consuming as concrete cable interaction involves various phenomena .The cable exists longitudinal and transverse forces on the concrete due to friction and curvature .Also cable stiffness should be considered in .In continuous structures the cable has been considered to consist of several parabolas. The reason is for parabolic profile, curvature becomes constant and cable force can be represented as equivalent uniformly distributed load acting in the opposite direction to the working loads. Although, parabolic assumption simplifies analysis, the cable profile becomes discontinuous at intermediate supports i.e. at the juncture of two parabolas. Due to this, there appears discontinuity at the juncture 0f two parabolas. Actual cable profile is smooth curve passing through all the spans.

Key words: Flexible Pavement, Clayey Subgrades, finite element analysis

1.0 INTRODUCTION

For rapid development of any country, accessibility and interconnectivity of different places through well connected transportation network with reasonable serviceability is essential. Road transportation is the most adaptable mode of transport under varied conditions of topography and hence top priority is given by the governments to improve road transportation facilities throughout world through allocation of huge capital investments[1]. In India Pradhan Mantry Gram Sadak Yojana (PMGSY) was launched on 25th December,2000, as a fully funded centrally sponsored scheme to provide all weather road connectivity in rural area of the country. The program envisages connecting all habitations with a population of 500 persons and above in the plain areas and 250 persons and above in hill sites, tribal and desert areas[2]. In the process of development of a country, governments continuously improve road networks by connecting different places in the shortest path. In this process the pavements have to pass through different subgrade soils. In India about 40% of total landarea is covered by clayey soils. So inevitably the roads have to pass through these weak clayey subgrade soils[3,4]. These soils swell and shrink with moisture fluctuations and pavements constructed on these weak subgrades suffer cracks and settlement of sub base in to subgrade. As it is unavoidable to lay pavement on these soils, there is necessity for a design methodology which ensures safety of pavements against these weak subgrades.

Failures in Flexible Pavements over Clay Subgrades

Premature failures are common in flexible pavements over clay subgrade. In rainy seasons, the subgrade soil gets softened and intrusion of subsoil into sub base will take place resulting in failure of the flexible pavement.

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The types of failures in clayey subgrades are:

Large pavement thickness

In wet condition expansive soils swell more and strength will decrease leading to large pavement thickness. Hence the construction cost will increase

Instability of Pavement

Due to moisture variation in different seasons, expansive subgrade is subjected to alternate swelling and shrinkage which leads to disturbance in different layers of pavement. This will cause instability in the pavement.

Shear failure in Shoulder Region

The shear failure of single lane roads in expansive soil subgrades is common due overtaking of vehicles in rainy season (Patel and Qureshi, 1979).

Undulated Pavement Surface

The soil gets softened in the edge portions in rainy season. The deformation will be more in edge portions due to wheel tracking on this softened edge portion leading to undulations in pavement surface.

Deterioration of Pavement

Sub soil intrusion into softened subgrade takes place in rainy season leading to intermixing of structural layers of pavement with subgrade. This will cause progressive reduction in the thickness of pavement over a period of time and failure under design traffic.

Stripping of Bitumen

In rainy season, moisture rise from subgrade to surface leads to stripping of bitumen.This stripping of bitumen causes raveling of aggregate.

Volume Instability

There will be volume instability, sub soil intrusion into overlying structural layers of pavements, softening of subgrade soil during rainy season and penetration of sub base course material into softened subgrade.

Need For the Study

In India about 40% of land area is covered by clay soils and about 30% of clay soils are expansive nature. Most of the pavements constructed on clay soil sub grade results large ruts, cracking of pavement surface and pot holes. Due to this the pavements on clay soil subgrade do not serve for long and offer poor riding surface. So, efforts are being made to improve subgrade strength by stabilizing the 1m thick top soil by lime stabilization or soil replacement or chemical stabilization or by placing geosynthetics.In the last two decades geosynthetics have attracted the attention of researchers. The majority of studies reviewed, indicate appreciable improvement in pavement performance can be achieved by proper placement of geosynthetic as a separator between base and subgrade material, which prevents the mixing of subgrade soil and granular base material and the resulting deterioration of base course. In the recent development, researchers are concentrating to improve performance of pavements by laying geotextiles and georgics over the compacted subgrade before spreading base course of aggregate, thus serving the purpose of separation and also reinforcing the pavement by sharing the load through its membrane action.

Aim and Objectives of the Study

The present work is aimed at formulating design methodologies for reinforced flexible pavement design over expansive and non-expansive clay subgrades. It is also intended to evaluate the performance of test tracks laid based on the developed design methodologies. To achieve the aim, the work has been planned with the following objectives.

- To critically study the available reinforced flexible design methodologies of reinforced flexible pavements.
- To understand the concepts of membrane action of geotextile fabric reinforcement and reinforced soil mattress over soft subgrade.
- To develop a design methodology for reinforced flexible pavement over expansive clay sub grade

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ensuring safety against swell, shear failure and settlement failurerisks.

- To develop reinforced flexible design methodology over non swelling clay subgrade with the objectives of reduced pavement thickness and safety against shear andsettlement failures.
- To lay unreinforced and reinforced test tracks over non expansive and expansive clay subgrades under the study.
- To evaluate the performance of laid test tracks under traffic and varied moisture conditions.

2.0 LITERATURE REVIEW

C.N.V. Satyanarayana Reddy (2011) 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.

Zornberg, J.G (2009) Basal reinforcement of pavement systems has been used for the purposes of: (i) increasing the lifespan of a pavement while maintaining the thickness of the base course, and (ii) decreasing the thickness of the base course while maintaining the lifespan of the pavement. This paper describes a third application of basal reinforcement of pavements, namely, the mitigation of longitudinal cracks induced in pavements constructed over highly plastic, expansive clay subgrades.

Regandla Devisaranya (2016) In the present work, the various failures occurring in clay subgrades are explained. The existing practices of unreinforced and reinforced pavement design and their limitations are reviewed. After evaluating the pavement thickness designs from „CBR" and „SBR" methods. Reinforced flexible pavement design has been developed based on the concept of reinforced foundation mattress. The sub base reinforced by geo grids has been considered to stiffen the layer and to spread wheel load over the subgrade over a large area. Detailed discussions are made on the work carried out and conclusions have been drawn.

3.0 METHODOLOGY

In this proposed methodology for design of reinforced flexible pavement over expansive and non-expansive subgrade has been explained with the help of flow charts. The performance studies of test tracks proposed to be laid based on formulated designs have been also explained.

The research work has been divided in to four stages and is explained through flow chart shown in Fig. The first stage of the work has been devoted to formulate a design methodology for reinforced flexible pavement over expansive clay subgrade. In thesecond stage, the work has been devoted to formulate a design methodology for reinforced flexible pavement over non expansive clay subgrade based on reinforced mattress approach. In the third stage, design thickness of pavement is finalized for layingtest tracks over expansive and non-expansive subgrades. The final stage study deals with the comparative study of performance of reinforced and unreinforced flexible pavement sections from test track studies

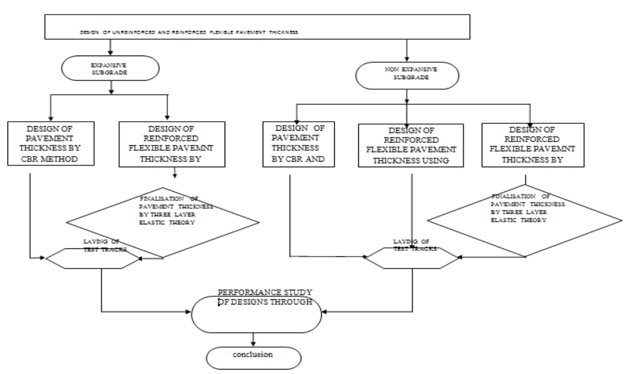

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Figure 1: Unreinforced Flexible Pavement Design Methodology

The conventional CBR method of design is based on soaked CBR value of subgrade, which is based on load penetration behavior of subgrade soil. So CBR method accounts only to settlement failure and does not account for shear failure. Clay subgrades are more susceptible to shear failure than settlement failure. Hence, it is preferable to check adequacy of the design pavement thickness in clay subgrades obtained from CBR method for safety against bearing capacity failure of subgrade. So, in the proposed study, it is proposed to determine design pavement thickness such that it does not exert pressure to subgrade in excess of its safe bearing capacity besides satisfying CBR method of design. The design methodologies based on Safe Bearing Capacity (SBC) of subgrade developed and CBR of subgrade given by US Army Corps of Engineers are used to finalise the design thickness of pavement.

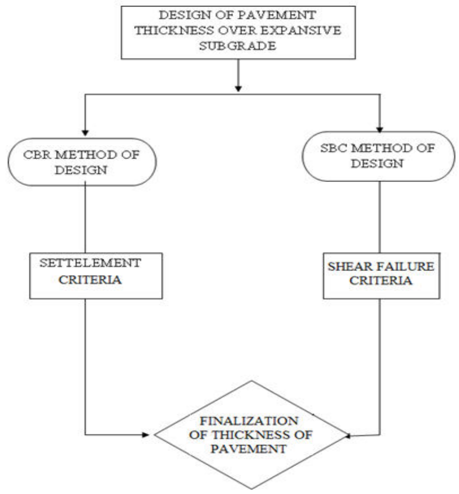

Figure 2: Flow chart showing methodology of design of flexible pavementthickness over clayey subgrade

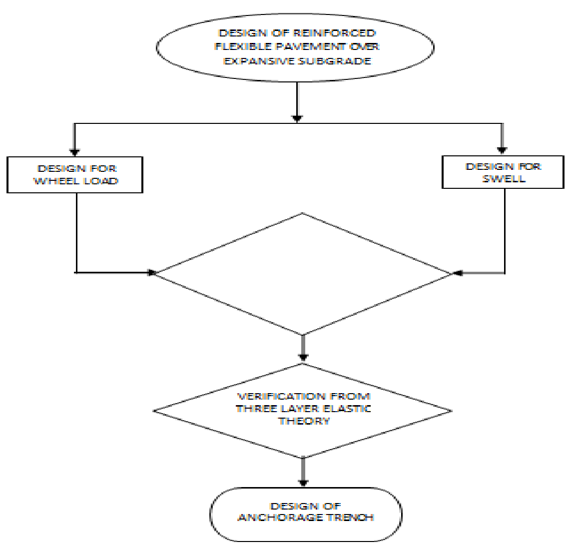

Figure 3: Approach used to finalize pavement thickness in reinforced flexible pavement over expansive subgrade

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Test Track Studies

Based on the proposed design methodologies of reinforced flexible pavements overexpansive and non-expansive clay subgrades, test tracks have been designed and laid for validation of the design methodologies. Unreinforced flexible pavement sections (Test Tracks) have been laid for performance appraisal of reinforced flexible pavements over unreinforced flexible pavements. The Reduced levels are taken on the laid test tracks in different seasons across the pavement surface (one each in edge region and one at the centre) at three locations. Based on the observations made from the test track studies, conclusions have been drawn in terms of effectiveness of the proposed pavement design methodologies in improving the performance and riding surface of pavement. Thedetails of test track studies are explained in flow chart presented in Fig.

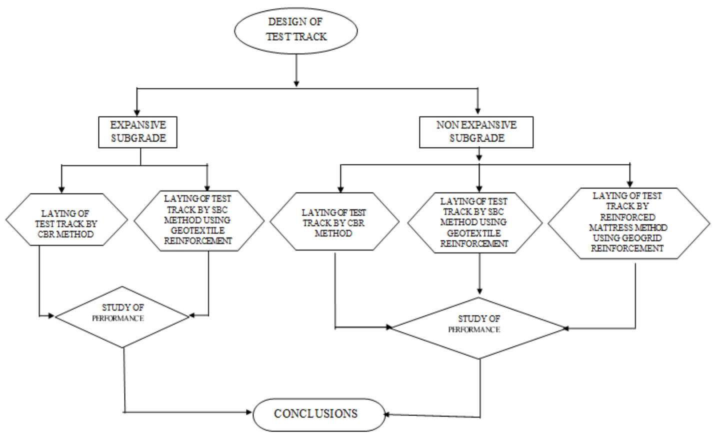

Figure 4: Flow chart showing study of test tracks

4.0 EXPERIMENTAL WORK

In the present chapter engineering properties of subgrade soils, moorum and aggregate used in the investigation are presented. The details of geotextiles and geogrids used are also been presented,

SUBGRADE SOILS

Two locations with different clay subgrades are selected for investigation in Kurnool city of Andhra Pradesh, India. The expansive clay (CH group) used in the investigation is procured from a site opposite to More Market, Near C Camp center, Kurnool. The non-expansive clay (CI group) is procured from a site opposite to Govt. General Hospital, Kurnool. Both the soils are collected at different depths ranging from 0.3 to 1m andmixed after pulverization. Laboratory investigation are carried out on the proposed clay surfaces to determination the engineering properties of the soils

Table 1: Engineering Properties of Expansive Clay Subgrade

S. No.	Engineering Property	Soil 1 (black clay)	Soil 2 (brown clay)
1.	Specific Gravity	2.7	2.69
2.	Grain Size Analysis a) Gravel (%) b) Sand (%) c) Fines (%)	 1 20 79	 3.0 43.0 54.0

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3.	Atterberg Limits a) Liquid limit (%) b) Plastic limit (%) c) Shrinkage limit (%)	68 33 12	42.0 22.0 16.0
4.	Compaction Characteristics (I.S. Light Compaction Test) a) Optimum Moisture content (%) b) Maximum Dry Density (g/cc)	23.2 1.55	15 1.80
5.	Undrained Shear Parameters a) Cohesion (kN/m^2) b) Angle of internal friction	26 9^o	31 15^o
6.	Soaked C.B.R. Value (%)	2	3.9
7.	Differential Free Swell (%)	100	20
8.	Swell Pressure (kN/m^2)	90	12

MOORUM

The moorum used as cushion material to suppress the swelling of expansive soil. The moorum used in the study is procured from a local quarry near Ulindakonda, Kurnool district. The various properties of moorum determined from the laboratory tests arepresented in the Table

Table 2: Engineering Properties of Moorum Soil

S. No.	Engineering Property	Moorum
1.	Specific Gravity	2.67
2.	Grain size Analysisa)Gravel (%) b) Sand (%) c) Fines (%)	23.0 54.0 23.0
3.	Atterberg Limits a) Liquid limit (%) b) Plastic limit (%) c) Shrinkage limit (%)	24.5 19 17
4.	I.S Classification Symbol	SC-SM
5.	Compaction Characteristics (I.S. Light Compaction Test) a) Optimum Moisture content (%) b) Maximum Dry Density (g/cc)	8.2 2.04
6.	Undrained Shear parameters a) Cohesion (kN/m^2) b) Angle of internal friction	1.2 35^o
7.	Soaked C.B.R. Value (%)	22.4

AGGREGATE

The aggregate used in the research study are procured from a quarry located at Thammarajupalli, Kurnool District, Andhra Pradesh, India. The gradation characteristics and engineering properties of aggregate are presented in the Table

Table 3: (a) Gradation of Aggregate used in WMM

IS Sieve Designation (mm)	Percent by Weight Passing
53	100
45	95
22.4	70
11.2	45
4.75	30
2.36	21
0.6	15
0.075	5

Table 3: (b) Engineering Properties of Aggregate

S. No.	Property	Value
1.	Specific Gravity	2.80
2.	Crushing Value (%)	23.2
3.	Impact Value (%)	20.9
4.	Abrasion Value (%)	23.5
5.	Flakiness & ElongationIndex	22.0
6.	OMC (%)	7.0
7.	MDD (g/cc)	2.28

Reinforcing Materials

In the present study woven geotextile and geogrid are used as reinforcing material in flexible pavement design. The details of reinforcing material used are given below

Geotextiles

In the present work two woven polypropylene geotextiles of different tensile strengths as stiffness are used as reinforcing material in the swell studies. The geotextiles are procuredfrom Garware Wall Ropes, Pune.

5.0 REINFORCED FLEXIBLE PAVEMENT DESIGN OVEREXPANSIVE AND NON EXPANSIVE SUBRADES

In the present chapter, the reinforced flexible pavement designs are done for expansive and non-expansive clay subgrades based on the proposed design methodologies presented in chapter 3. The reinforced flexible pavement design over expansive clay subgrade is done based on SBC approach considering membrane action of geotextile fabric, accounting for traffic and swell control of subgrade. The reinforced flexible pavement design over non expansive clay subgrade is done based on reinforced soil mattress approach and SBC method of design. The unreinforced pavement thickness design isdone based on conventional CBR method of design.

SBC method of design

The design pavement thickness based on the consideration of risk of shear failure hasbeen evaluated for the clay subgrade under the study using the SBC method of design presented in research methodology For tyre contact pressure of 5.62 $kg/cm^{2,}$ the contact area has been evaluated and thewidth and length of the contact area

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have been obtained as 177 mm and 295 mm. maintaining the width constant, the length of equivalent rectangular area is determined as
256.3 mm. The center to center distance of the tyres has been taken as 300 mm. The design thickness is obtained as 1100 mm from the SBC method of design. The design pavement thickness values obtained from CBR and SBC methodologies are 920mm and 1100 mm respectively. Hence to avoid shear failure of subgrade soils, increased pavementthickness based on SBC approach shall be adopted for clay subgrades

Finalisation of thickness of pavement by Three Layer Elastic Theory

The stability of designed reinforced pavement is evaluated using Peattie's three layer elastic theory as explained in section The values of Elastic modulus of subgrade, Sub base and base courses have been estimated based on CBR values given in Table

Table 4: Elastic Modulus Values of Pavement layers considered in Analysis

Pavement Component	Field CBR(%)	Elastic Modulus(MPa)
Subgrade	2.0	20.0
Sub Base	20	120
WMM Base	90	310

The vertical and shear stresses at subgrade level (where geotextile is being placed) for different pavement thicknesses obtained from Peattie's theory are given in Table. The table also presents ultimate bearing capacity of subgrade and the shear resistance available at geotextile fabric surface. The shear resistance is calculated using the interfacial shear parameters of moorum with geotextile presented in Table. The pavement section is considered to have base layer of 250 mm and the rest sub base layer.

Table 5: Vertical and Shear Stresses at Subgrade Level fromThree Layer Elastic Theory

PavementThickness (mm)	Radial Shear Stress, σ_r(kN/m^2)	VerticalStress (kN/m^2)	Shear Resistance (kN/m^2)	UltimateBearing Capacityq_u (kN/m^2)
500	45	153.8	64	93.8
600	42	136.7	58	94.4
700	37	109.7	48	95
<u>800</u>	<u>25</u>	<u>71</u>	<u>34</u>	<u>96</u>

The pavement thickness of 800 mm, the induced vertical stress is below bearing capacity of soil and also the shear stress induced is less than shear resistance available at the geotextile fabric. Hence, a thickness of 800 mm is essential to avoid large shear displacements in subgrade and also to prevent lateral slipping of sub base material on geotextile under the loads.

However from swell control consideration, it is proposed to maintain sub base of 450 mm to have cushion to expansive soil ratio as 0.45 so as to have control of subgrade swell by 15%. As per IRC 37-2000, for traffic of 30 msa, the minimum sub layer thickness is 250mm and the surface layer recommended are 120 mm dense bituminous macadam (DBM) and 40 mm bituminous concrete. So the design reinforced flexible pavement thickness is fixed as 860 mm.

6.0 TEST TRACK STUDIES

The chapter presents reinforced and unreinforced flexible pavement test tracks laid over expansive and non expansive clay subgrades under the study for performance appraisal. The designed test tracks are laid in October 2022 and are monitored under traffic and varied seasonaleffects. The surface levels are recorded

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every month across the width of the test tracks. The design thickness of test tracks is determined by considering an average daily traffic of 1500 cvd with a growth factor of 8% 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 15 years (estimated traffic volume of 30msa).

DETAILS OF TEST TRACKS OVER NON EXPANSIVE SUBGRADE

Unreinforced and reinforced test tracks are laid over non expansive clay subgrade located at Govt. Hospital, Kurnool, Andhra Pradesh, India. Reinforced test tracks are laid based on SBC method of design using woven geotextile fabric reinforcement at subgrade and geogrid reinforced foundation mattress approach whereas unreinforced test track sections is laid based on CBR method of Design. The details of test tracks laid over non expansive clay subgrade are presented in Fig.

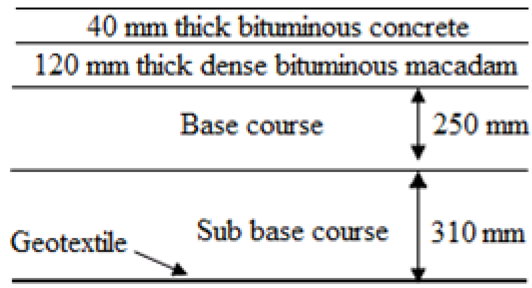

Figure 5: Design section of flexible pavement with geotextile

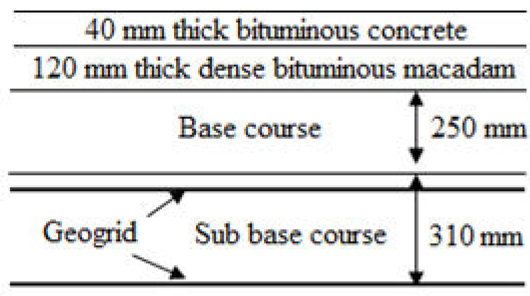

Figure 6: Design section of flexible pavement with geogrid sub base mattress

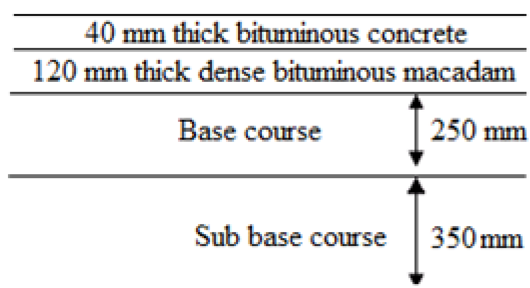

Figure 7: Design details of unreinforced pavement section

Some of the photographs taken during laying of the test tracks are shown in the Appendix –II.

Performance Studies On Test Tracks

The reduced levels of unreinforced and reinforced test tracks laid over expansive and non-expansive clay subgrades are presented in Tables.

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Table 6: Reduced levels of surface of unreinforced and reinforced test tracks ofexpansive clay subgrade

Period	Location	Unreinforced Test track	Geotextile Reinforcedtest track
Nov’11	L	99.879	99.680
	C	99.952	99.754
	R	99.821	99.613
April’12	L	99.809	99.664
	C	99.891	99.741
	R	99.759	99.596
Nov’12	L	99.886	99.684
	C	99.956	99.757
	R	99.824	99.615

From Table it can be seen that the average swell in unreinforced and reinforced sections are 69mm and 18mm respectively. The reinforced test track has controlled volume changes in subgrade significantly as compared to unreinforced test track.

Table 7: Reduced levels of surface of unreinforced and reinforced test tracks ofnon-expansive clay (CI) subgrade.

Period	Location	Unreinforced Test track	Geogrid Reinforcedtest track	Geotextile Reinforcedtest track
Nov’11	L	99.713	99.573	93.623
	C	99.729	99.609	99.641
	R	99.749	99.649	99.661
April’12	L	99.674	99.559	99.602
	C	99.691	99.560	99.621
	R	99.706	99.556	99.639
Nov’12	L	99.711	99.568	99.619
	C	99.726	99.570	99.635
	R	99.744	99.572	99.655

From Table, it can be seen that the average settlement in unreinforced, geogrid reinforced and geotextile reinforced sections are 40mm, 15mm and 21mm respectively. The geogrid reinforced test track is observed to exhibit improved performance overunreinforced test track. This can be attributed to the stiffening action of the geogrid. The geotextile reinforced pavement also indicated control of settlement compared to unreinforced test track, but its performance is less compared to geogrid reinforced test track..

Reinforced Flexible Pavements over Expansive Clay Subgrade

Swell is significant influencing factor of performance of pavements over expansive soils. Hence it is desirable to have design methodology over expansive soil subgrade ensuring safety against ‘swell’, besides designing it for wheel loads. The reinforced flexible pavement design methodology is aimed at reducing design pavement thickness and satisfying the above said criteria.

The design of reinforced flexible pavement for wheel load is done by considering uniform deformation below wheel load spread width at subgrade accompanied by elliptical heave in between wheel loaded area. The tension induced in reinforcing fabric is determined by considering the free body diagram of deformed fabric at sub grade for different considered pavement thickness values. The design tensile strength required is specified in terms of strains against different permissible settlements at subgrade. The rut values are determined by equating the area of deformation under the wheel load at subgrade to the neighboring elliptical heaved area.

As simple placement of geotextile at subgrade does not mobilize required tensile strength to support wheel loads and to control swell of subgrade, it is necessary to anchor the geotextiles in longitudinal trenches. The depth of anchorage trench is determined by equating the frictional resistance mobilized on geotextile fabric in anchorage trench to higher value of tensile strength requirements of fabric from wheel load and swell control considerations. The depth of trench is fixed as 400mm from calculations. The finalized design thickness for reinforced flexible pavement for supporting traffic volume of 30msa is given Table.

Table 8: Design details of finalized reinforced flexible pavement over expansive clay

Design Thickness(mm)	Sub-base Thickness(mm)	Base Thickness (mm)	Surfacing(mm)	
			DBM	BC
860	450	250	120	40

Reinforced Flexible Pavements over Non-expansive Clay Subgrade

In case of clay of intermediate compressibility under the study as swelling is of less concern, the design of reinforced flexible pavement is done only for wheel load using geotextile reinforcement at sub grade. To mobilize the required tensile strength, anchorage is proposed in trenches spaced at 1.7 m with a trench width of 0.4 m the required tensile strength of reinforcing fabric is worked out for different pavement thickness values and the corresponding strains are also determined against different permissible settlements. The deformed fabric shape at subgrade is taken as presented in Fig. Among the different design options developed, the design thickness is finalized from three layer stress analysis The finalized design thickness is 720 mm. The width of anchorage trench is obtained as 0.12 m. However for practical convenience, width of trench is finalized as 0.3 m. The cross section details of finalized design of reinforced flexible pavement are given in Table.

Table 9: Design details of finalized reinforced flexible pavement over non expansiveclay

Design Thickness(mm)	Sub-base Thickness(mm)	Base Thickness (mm)	Surfacing(mm)	
			DBM	BC
720	310	250	120	40

The required tensile strengths of reinforced fabric are 16.5kN/m @ 1.7 percent strain and 4.5kN/m @ 2.55 percent strain for wheel load and swell control considerations respectively. Based on tension test results presented in Table 4.5 woven geotextile 2 is satisfying the requirement for expansive clay subgrade and woven geotextile 1 is satisfying the requirement for non expansive clay subgrade. Hence they are considered as reinforcement required in respective clay subgrades.

The failures arising from subgrade can be minimized and performance of pavement can be improved by spreading the wheel loads over a larger area in a clay subgrade. So, the design of reinforced flexible pavements over brown clay (non swelling clay) is proposed by stiffening the sub base by reinforcing with high tensile strength geogrid so as to spreadthe wheel loads over a larger area at subgrade level. The proposed methodology is based on reinforced soil mattress concept.

The contact pressure at subgrade is determined by considering the stiffening action of subbase. The reinforcement is designed in sub base for maximum bending moment by taking cover to geogrid reinforcement as 50mm on either side. The required tensile strength (T) of reinforcement is calculated using the relation.

$$\boldsymbol{T = \frac{Max, BM}{d}}$$

Where, d is effective depth of sub base layer

The design details of reinforced flexible pavement over non expansive clay from reinforced soil mattress approach are presented in Table

Table 10: Design details of finalized reinforced flexible pavement over non expansiveclay using reinforced soil mattress approach

Design Thickness(mm)	Sub-base Thickness(mm)	Base Thickness (mm)	Surfacing(mm)	
			DBM	BC
720	310	250	120	40

TEST TRACK STUDIES

The reinforced and conventional unreinforced (based on CBR method) flexible pavement test tracks are laid for performance appraisal against swelling of expansive subgrade(CH). In non expansive subgrade, both geotextile reinforced and geogrid reinforced test tracks are laid along with conventional unreinforced flexible pavement test track (based on CBR method). The reduced levels of surface of test tracks at left, centre and right locations of test track sections are determined in different seasons and average values of reduced levels are determined. It is observed from reduced levels of test track data on expansive subgrade that the average settlement in unreinforced and reinforced sectionsare 65 mm and 15 mm.The reinforced test track of expansive soil exhibited control volume changes with the average swell of 18 mm where as in unreinforced test track it is 69 mm

The reduced levels observed on non-expansive clay subgrade revealed that the average settlement in unreinforced, geotextile reinforced and geogrid reinforced sections is 40 mm, 15 mm and 21 mm respectively.

CONCLUSIONS

Based on the design formulations for reinforced flexible pavements over expansive and non-expansive clay subgrades and observations of associated test track studies, the following conclusions are made

The design thickness from CBR method of design is less compared to SBCmethod of design for clay subgrades under the study. Hence, pavement design thickness determined from SBC method of design should be adopted for ensuring the risk against risk of shear failure in subgrade.

The design methodology for reinforced flexible pavements with uniformsettlement below wheel loads associated with elliptical heaving on either side at subgrade yields reasonable stiffness for reinforcing fabric over soft clay subgradesas it is validated from test track studies.

Use of anchored geotextile as reinforcement at expansive subgrade under study reduced design pavement thickness by about 24 percent and 7 percent in comparison to SBC and CBR methods of design respectively.

The geotextile held in position by anchorage in longitudinal trenches results in control of additional swell (20 percent in the present study) provided sub base moorum controls some swell (65% in the study) initially due to its cushion action.

Shear failures in edge regions of pavements can be avoided due to strengthened shoulder portion by the suggested method of anchoring geotextiles in longitudinal trenches on either side of pavement.

Transforming the sub base layer in non-expansive clay subgrade as Reinforced mattress helps in spreading the loads over a larger area and avoids the problems of shear failure, penetration of sub base layer material into subgrade. As a result pavement offers good riding surface and better performance

Granular sub bases are to be used in flexible pavements over clay subgrades sothat they can be transformed as foundation mattress for safe and uniform transfer of stress to subgrade.

The sub base should be provided by two layers of reinforcement at top and bottomlevels of the layer as developed bending moments change sign across the mattress width

Sub base foundation mattress extending into shoulder portion strengthens theshoulder region and avoids failures during overtaking of vehicles

Test track with geogrid reinforced sub base mattress performs better compared to geotextile reinforced test track

Use of geogrid reinforced sub base mattress and geotextile reinforced test tracks reduced settlement by about 60 percent and 45 percent respectively compared to unreinforced test track section

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