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INVESTIGATION ON GEOSYNTHETIC REINFORCED TWO LAYERED SOIL SYSTEM

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ABSTRACT

Use of geosynthetics for flexible pavements founded on expansive soil subgrade is one of feasible and economic solution to minimize the undulation and required pavement thickness. In this present investigation the effect of inclusion of the geosynthetic reinforcement on California Bearing Ratio (CBR) value of a two layered soil system with black cotton soil at bottom and granular soil at top as a buffer layer, with different thickness configuration and geotextiles of different physical and mechanical properties was studied by laboratory and field California bearing ratio tests. Thickness of flexible pavement over the two layer soil system of different thickness configurations was estimated for unreinforced and reinforced two layered soil system by the method suggested by United States Army Corps of Engineers and Indian Road Congress. The reduction (%) in the thickness of pavement due to inclusion of geotextiles has been observed in the investigation. The reduction in thickness of pavement can be achieved up to 53.53% depending upon the thickness configuration and the type of the geotextile used. The results have shown that the field CBR tests can yield the results in conformity with the values obtained in the laboratory test.

INTRODUCTION

The roads laid on bases formed of black cotton soil (BC soil) develop undulations at the surface due to loss of strength of the sub grade due to softening during monsoon. The black cotton soil (BC soil) has a high percentage of clay, which is predominantly montmorillonite in structure and black or blackish grey in colour. The physical properties of black cotton soil (BC soil) vary from place to place. At the liquid limit, the volume change is of the order of 200 to 300% and results in swelling pressure which is responsible for the failure of pavements. As such black cotton soil (BC soil) has very low bearing capacity and high swelling and shrinkage characteristics. Due to its peculiar characteristics, it forms a very poor foundation material for road construction. Due to very low California bearing ratio(CBR) values of black cotton soil (BC soil), excessive pavement thickness is required to keep the stresses induced in the soft soil subgrade within its carrying capacity to make the road surface durable.

Use of geosynthetic for flexible pavements founded on expansive soil subgrade is one of feasible and economic solution. Geosynthetics which are polymer made materials are non-biodegradable and durable when put in to the soil to perform desired function/s. These materials are gaining popularity as innovative construction material for various civil engineering structures. Geosynthetic in the form of geogrids or geotextiles when placed over an expansive soil subgrade like black cotton soil can perform function of reinforcement and separation imparting better strength to the subgrade. Geosynthetic layer inclusion in the form of a horizontal layer between soft subgrade soil and top granular layer prevents the ingress of soft subgrade soil into overlaying granular soil in the pavement, thus avoiding deformation to a considerable extent. Secondly, the combined effect of reinforcement and separation brings about increase in the strength of subgrade soil which will be beneficial in reducing the thickness of the pavement, as the strengthened subgrade can sustain higher stress values due to the surface load.

The objective of the present research work is to investigate effect of inclusion of the geosynthetic reinforcement on California bearing ratio (CBR) value of a two layered soil system with different thickness configuration and geotextiles of different physical and mechanical properties. Experimental investigation has been carried out on geosynthetic reinforced two layered soil system consisting of black cotton soil as subgrade and non-swelling coarse grained soil as buffer layer. The geosynthetic layer was incorporated at the interface of the two soil layers. Laboratory and field California bearing ratio (CBR) tests were carried out to investigate the effect of geosynthetic reinforcement layer on CBR of the two layered soil system. Thickness of granular soil layer components over the two layer soil system of different thickness configuration was estimated for unreinforced and reinforced two layered soil system using the design charts suggested by Indian Road Congress (IRC) and a design chart developed using the equation suggested by United.States Army Corps of Engineers.

LITERATURE REVIEW

The modern concept of soil reinforcement and the use of geosynthetics in civil engineering evolved about thirty years ago. Since then these materials have been put to a spectacular range of applications due to the simplicity of the design principles involving them and the ease of their applicability to construction practices. Geosynthetics have also gained widespread acceptance among civil engineering professionals as an economic and innovative alternative to conventional materials. The enhanced confidence in application of geosynthetics in civil engineering is due to the outcome of the research carried out by many investigators. Most of the investigators have carried out their research taking into account the various parameters like physical and mechanical properties of geosynthetics, their distribution, number of layers, depth of topmost layer with respect to the loaded base etc in the soil mass. The outcome of the research work carried out by many investigators on reinforced soil to study the beneficial effect of inclusion of geosythetic in different forms and configuration is presented below.

Reinforced soil

Henry Vidal(1969), a French architect and civil engineer observed that roughly formed mounds of dry sand, an inherently weak material, could be made to stand at a steeper angle after the addition of horizontal layer of fine needles of straw. He concluded that the composite construction material created by combining dry granular soil with a rough material having tensile strength is stronger than soil itself. From this observation emerged the idea of reinforced soil which is a composite construction material consisting of soil and reinforcement in the form of metal/geotextile strips, geogrids and geocells.

Giroud, et al (1984) presented a design method for geo-grid reinforced unpaved roads. They have stated that even for unpaved roads, where large displacement is acceptable, only a 10% reduction in thickness of a pavement (from its unreinforced thickness) can be made due to the membrane effect of the geogrid. The half of the thickness reduction resulting from geo-grid reinforcement is due to sub grade confinement (in case of clay sub-grade) and approximately half of the improvement is from improved load distribution resulting from interlocking of the geogrid and the base layer material.

Hoshiya and Mandal (1985), have studied effect of normal stress on coefficient of friction. They have concluded that in addition to surface characteristics of reinforcement, the value of coefficient of friction decreases with an increase in normal stress.

Chang et al (1988) evaluated the resistance of a geogrid reinforced asphalt-concrete beam to fatigue cracks. The number of cycles to failure for the reinforced beam was much greater than for the unreinforced one under different levels of loading. Such an increase in the number of cycles was dependent on the magnitude of the applied load. In addition the surface settlement was also reduced compared to the reference unreinforced system and such reduction in the number of cycles for reaching a specific settlement was also dependent on the magnitude of the applied force.

Chan et al (1989) conducted large scale experiments in order to investigate the aggregate base reinforcement potential of geogrid and geotextiles in surface placements. Their experimental tests included single and multiple track tests. Their results indicated that the inclusion of a geogrid despite its lower stiffness resulted in better performance of pavement than that of geotextile which is not desirable in paved roads, in order to produce the same effect as the geogrid.

Barksdale et al (1989) found that for the stronger pavement the stiff geogrid at the bottom of the granular base did not produce any significant improvement. They concluded that placing the geogrid in the middle and bottom of the base, despite its lower stiffness, resulted in better performance of pavement against permanent deformation than the geotextile.

Miura et al (1990) investigated the mechanism by which a geogrid could suppress non-uniform settlement of a pavement constructed on a soft clay subgrade. They concluded that mechanism by which a reinforced pavement base improved performance was mainly due to interlocking effect rather than the membrane tension effect. To develop the membrane effect of a grid it was recommended that the geogrid be placed in a concave shape and long term effect of one-layer geogrid as a reinforcement in a pavement is comparable to that of base material about 10 cm thick.

Lawton and Fox (1992) stated that sand reinforced with multi oriented geosynthetics results into the highest ultimate strength in terms of California bearing ratio.

Dondi (1994) used the commercial finite element program ABAQUS to model a geosynthetic reinforced flexible pavement. There was reduction in the shear strain and stress transmitted to the top of sub grade and vertical displacement of the loaded area was reduced by 15-20% in the reinforced section. The fatigue life of a reinforced section is increased by 2-2.5 times as compared with unreinforced section.

Al Wahab and Al-Ourna (1995) observed that the fiber-reinforcement significantly improves the peak and post peak strength, ductility, toughness and energy absorption capacity of a soil.

Al-Wahab and Heckel (1995) from their study found that cohesive soil reinforced with just 1 % fiber content increases the unconfined compressive strength, ductility, toughness and the energy absorption capacity.

Ranjan et al (1996) examined the data of triaxial tests conducted on different types of sand reinforced with natural and synthetic fibers and observed that unreinforced sand attained the peak stress at about 10% of axial strain, whereas reinforced sand specimens did not fail even up to 20% of axial strain.

Fereidoon Moghaddas-Nejad, Hoh C. Small (1996) carried out experiments to investigate the influence of geogrid as reinforcement for the granular base layer of a flexible pavement constructed on sand. A decrease in vertical deformation of 40% was observed with geogrid at the bottom of the base layer and a decrease of 70% was observed with the geogrid at the middle of the base. Two different mechanisms associated with the geogrid reinforcement were recognized including interlocking with the base layer aggregate and reduction of the permanent lateral displacement of the granular material. There is improvement in load distribution on the sub grade layer due to the slab effect of the base layer and geogrid.

Nejad and Small (1996) investigated role of geogrid in a conventional pavement system and concluded that a remarkable reduction in the vertical surface deformation resulted from the interlocking function particularly in the vicinity of the reinforcement.

Consoli N. C, et,al, (1998) based on the triaxial tests on fiber reinforced cement treated soil, found that the triaxial peak strength increases due to fiber inclusion is more effective in uncemented soil. However, increase in residual strength is more when fiber is added to cement treated soil.

Berg et al (2000) showed in their review that geosynthetic membrane used to reinforce pavements system provides under certain conditions a substantial load carrying benefits to such systems. These conditions are controlled by subgrade strength, aggregate base characteristics, design requirements and geosynthtic characteristics.

Rosa L. S, et al (2001) performed unconfined compression tests on sand specimens reinforced with randomly oriented discrete fibers. Based on test results they concluded that inclusion of randomly oriented discrete fibers significantly improved the unconfined compressive strength of sand and the maximum performance achieved at a fiber dosage rate between 0.6 and 1.0% of dry weight.

Perkins (2001) tested three different locations of the geogrid by varying its stiffness, base thickness and the subgrade strength. For a weak sub grade the surface deflection was reduced by 50% with its position at the middle of the base. The geogrid with a higher stiffness gave a better traffic benefit ratio (TBR). In addition the increase in TBR when the geogrid was placed in the middle was higher than the value obtained when the same geogrid was placed at the base-subgrade interface. When the rut depth becomes more than 10 mm, the geogrid in the system with a thicker base produced higher TBR than the system with a thinner base.

Shenbaga R. Kaniraj and Vasant G. Havanagi (2001) studied combined effects of randomly oriented fiber inclusions and cement stabilization on the geotechnical characteristics of fly ash-soil mixtures. They observed that in direct shear tests, the randomly oriented fiber inclusions increase the failure displacement and the vertical displacement of the fly ash-soil specimens compacted at the MDD-OMC state. The trend in the change of the values of cohesion and angle of shearing resistance due to fiber inclusions is not very consistent. The brittle behaviour of fly ash stabilized and cement stabilized soil is considerably reduced when fibers are added to stabilized soils in both cases.

Hoe I. Ling and Zheng Liu (2001) studied the performance of geosynthetic-reinforced asphalt pavement under monotonic, cyclic and dynamic loading conditions. The study showed that geosynthetic reinforcement increased the stiffness and bearing capacity of the asphalt concrete pavement. Under dynamic loading, the life of the asphalt concrete layer was prolonged in the presence of geosynthetic reinforcement. The stiffness of the geogrid and its interlocking with the asphalt concrete contributed to the restraining effect.

Tingle et al (2002) observed that geo-fiber stabilization of medium sand improves the California bearing ratio by about six fold. This improvement was attributed to the confinement of sand particles by discrete fibers.

Murugesan (2004) examined the California bearing ratio(CBR) of subgrade soil reinforced with coconut, jute and nylon fibers at various percentages and reported an overall increase in CBR by 60% due to fiber reinforcement and that an optimum percentage of fiber content lies between 0.5 & 0.6.

Bassam Saad et al., (2006) carried out a series of finite element simulations to evaluate the benefits of integrating a high modulus geosynthtic into the pavement foundation. They concluded that when the geosynthetic reinforcement is placed at the bottom of the AC layer, it leads to the highest reduction of the fatigue strain criterion. Placing geosynthetic at the lower third of base leads to a tangible decrease in fatigue strain criterion. This decrease is more pronounced when using a stronger base. The decrease in fatigue strain obtained with geosynthetic reinforcement becomes more pronounced in the case of founding on clayey sub grade.

Madhavi L.G and Murthy V. S (2007) studied effects of reinforcement forms on the behavior of geosynthetic reinforced sand using triaxial test. They have concluded that soil samples reinforced with different forms of geosynthetics exhibit improved stress-strain response as compared to unreinforced sand at all confining pressures in terms of improved peak devioatric stress and increased failure strains.

Krystyna, K. F (2007) studied the influence of geosynthetics reinforcement on the load – settlement characteristics of two-layer subgrade by loading test using a model footing resting at the surface of top layer. He concluded that inclusion of a geosynthetic layer, at the two-layer subgrade interface improves the load-settlement characteristics at greater footing settlements.

Satish Chandra et al (2008) carried out investigation on the benefits of reinforcing the subgrade soils with polypropylene fiber in flexible pavements. They observed that the CBR of reinforced soils continued to increase with both fiber content and aspect ratio. However they observed that mixing was extremely difficult beyond the fiber content of 1.5%. Hence 1.5% fiber was considered as optimum content. They also concluded that the pavement resting on reinforced subgrade soils is beneficial in reducing the construction materials.

Salah Sadek, et al (2010), based on the direct shear tests on fiber-reinforced sands, have concluded that the addition of nylon fibers with an aspect ratio ranging from 40 to 150 and a fiber content ranging from 0.5 to 1.5% to both fine and coarse sands prepared at a relative density of 55% increased the shear strength and the ductility of the sand-fiber composite.

I.M.C.R.G. Falorca and M.I.M.Pinto (2011) carried out experimental investigation to study the effect of short, randomly distributed polypropylene microfibers on shear strength behavior of soils. They have concluded that fibers increase the shear strength and significantly modify the shear stress displacement behavior of the soils. There is an increase in both the apparent cohesion and the angle of shearing resistance of soils owing to the short polypropylene microfibers. This also helps in increase of shear strength and hence the CBR value.

Above literature review indicates that the geosynthetic in their various forms are widely being used for reinforcement of soil to strengthen its properties and gain benefit out of it. However investigation on California bearing ratio (CBR) of a two layer soil system with weak black cotton soil at bottom and coarse grained soil at top as a buffer layer, reinforced with horizontal geotextile layer at their interface using both laboratory and field California bearing ratio tests is not found in the literature.

PRESENT INVESTIGATION

The present investigation was undertaken to study the beneficial effect of reinforcement at the interface of two dissimilar layers on California bearing ratio. California bearing ratio of subgrade with or without a buffer layer is an important factor which influences the overall thickness of pavements. This becomes more relevant when the road has to be constructed through the areas with black cotton soil, where its complete replacement may prove to be uneconomical. In the present investigation an effort was made to study the beneficial effect of inclusion of horizontal layer of geotextile at the interface of the two dissimilar layers of different thickness configuration. The investigation has been carried out by laboratory CBR test as well as field CBR test. Generally the flexible pavements are designed using laboratory CBR value. The laboratory CBR value is obtained on soil prepared in CBR mould which provides an unyielding confinement to the soil specimen being tested. This confinement will have some influence on the CBR value obtained. The CBR of soil in the field which is a measure of the strength of soil can be different owing to variation in the confinement. Hence in the present investigation field CBR test is also used to study the effect of horizontal layer of geotextile at the interface of a cohesive black cotton soil and non-cohesive coarse soil which acts as a buffer layer over the black cotton soil.

The investigation has been carried out with different thickness configuration of the two soils and three types of woven and non-woven geotextiles, having different physical and mechanical properties. The thickness of granular layer required over the unreinforced and reinforced two layered soil system has been worked out based on the CBR values obtained in the laboratory as well as in the field. The percentage saving in the thickness of granular layer required over the soil system investigated is also reported.

EXPERIMENTAL WORK

The experimental work carried out in present research work is intended to study the variation in California bearing ratio (CBR) of a geotextile reinforced two layered soil system consisting of black cotton soil at the bottom of the system and coarse grained soil at the top as a buffer layer. The main two variable parameters in the investigation are the configuration of thickness of two soil layers and the type of geotextile with different physical and mechanical properties.

MATERIAL USED

Soils Two types of soils namely coarse grained soil, hereinafter designated as P, with negligible swelling potential and black cotton soil, hereinafter designated as Q, with high swelling potential are used in present investigation. The black cotton soil which exhibited free swell index of 61.33% was selected for the investigation. The soils are used to form a two layered soil system with black cotton soil (soil Q) at the bottom and coarse grained soil with negligible swelling potential overlying it as a buffer layer.

Geotextiles Three woven and three non-woven geotextile, possessing different physical and mechanical properties were used in present investigation.

Woven geotextile (GTXw) Woven geotextiles designated as GTXw1, GTXw2 and GTXw3 were used in present investigation. These are woven multifilament polypropylene geotextiles resistant to chemicals and micro-organisms normally found in soils. These geotextiles are stable within pH range of 2 to 13 and are resistant to short-term to long-term ultraviolet radiation.

Non Woven geotextile(GTXnw): Non-woven geotextiles designated as GTXnw1, GTXnw2 and GTXnw3 were used in present investigation. These geotextiles are manufactured from high quality polypropylene staple fibres. The fibres are mechanically bonded through needle-punching to form a strong, flexible and dimensionally stable fabric structure, with optimum pore sizes and high permeability. The geotextile is resistant to chemicals and biological organisms normally found in soils and is stabilized against degradation due to short-term exposure to ultraviolet radiation. The test methods used to evaluate geotextile properties are given in table 1.

Table 1. Tests methods used to find properties of geotextile

Sr No	Property	Test method
1	Mass per Unit Area	IS 14716:1999,ASTM D 5261
2	Thickness	ASTM D 5199
3	Grab Tensile strength	IS 13162(Part 5)1992,ASTM D 4632
4	Trapezoidal tear strength	IS 14293, ASTM D 4533
5	Puncture Strength	IS 13162(Part -4), ASTM D 4833
6	Tensile Strength (MD)	IS 13162(Part 5)1992
7	Tensile Strength (CD)	IS 13162(Part 5)1992
8	Trapezoid Strength (MD)	IS 14293
9	Trapezoid Strength(CD)	IS 14293
10	Apparent Opening Size (mm)	ASTM D 4751

LABORATORY CBR TESTS ON TWO LAYERED SOIL SYSTEM

Laboratory CBR tests were performed without and with geotextiles at the interface of two layered soil system in accordance with IS 2720(Part 31) -1979. The configurations of soil layers in two layered soil system for laboratory CBR tests are given in table 2 and figure 1 shows thickness configurations of soil layers used in CBR mould.

Table 2.Thickness configurations of soil layers for laboratory CBR tests

Thickness of soil layer (mm)	Thickness Configurations	Notation for thickness configuration
$^{*}T_1 = {}^{**}T_2 = 62.5$	$T_1 = T_2 = 0.5T^{***}$	A
$T_1 = 93.75$ $T_2 = 31.25$	$T_1 = 0.75T$ $T_2 = 0.25T$	B
$T_1 = 31.25$ $T_2 = 93.75$	$T_1 = 0.25T$ $T_2 = 0.75T$	C

*Thickness of coarse grained soil (P)
**Thickness of black cotton soil (Q)
***Total thickness of two layered soil system

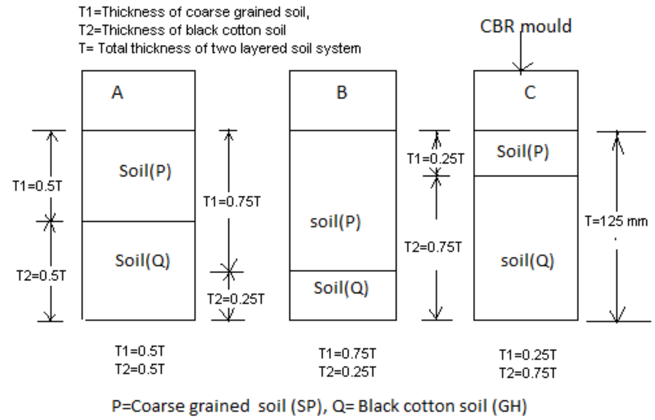

Fig 1. Thickness configurations of soil layers in CBR mould

Figures 2 shows schematic diagram for laboratory CBR test .

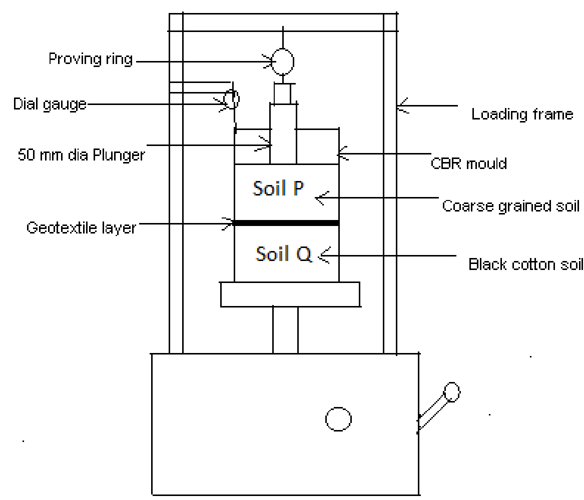

Fig 2 Schematic diagram of experimental set up for CBR test

FIELD CBR TESTS ON TWO LAYERED SOIL SYSTEM

Field CBR tests on two layered soil system without and with geosynthetics at the interface of the soil layers were conducted at the site of Padmashree Dr.Vithalrao Vikhe Patil College of Engineering, Ahmednagar, Maharashtra, India. All tests were conducted in accordance with IS 2720(Part 31). Three test tracks of 2 m wide and 5 m long consisting of two layered soil system with thickness configuration as given in table 3 were prepared. One strip of woven [GTXw1, GTXw2 and GTXw3] and nonwoven [GTXnw1 ,GTXnw2 and GTXnw3] geotextile of size 0.5 m and 2.5 m long were laid over compacted black cotton soil at spacing of 0.25 m. Then coarse grained soil was compacted over black cotton soil. Another three test tracks of same dimensions and thickness configuration were prepared without geotextiles.

Table 3. Configurations of soil layers used for field CBR tests

Test Track No	Thickness of soil layer	Configurations	Notation for thickness configuration
1	T_1= 150 mm T_2= 150 mm	T_1=0.5T T_2=0.5T	A
2	T_1=225 mm T_2=75 mm	T_1=0.75T T_2=0.25T	B
3	T_1=75 mm T_2=225 mm	T_1=0.25T T_2=0.75T	C

Where,
T_1 = thickness of coarse grained soil
T_2 = thickness of black cotton soil
T = total thickness of compacted two layers soil system

Figure 3 shows schematic diagram (plan) of test tracks with geotextile positions for field CBR tests.

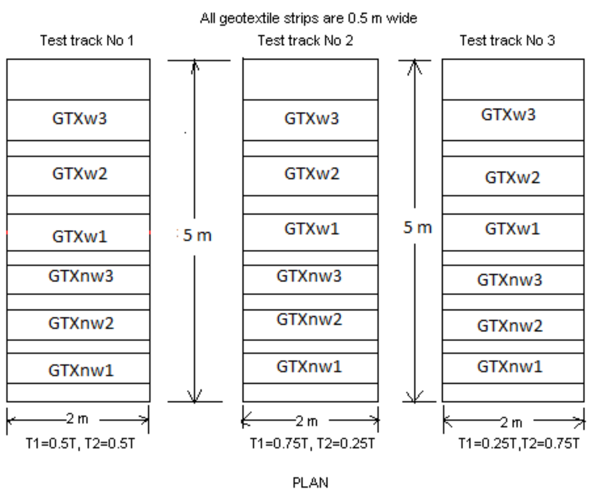

Fig 3. Test tracks and the geotextile strips positions

A loaded tractor was used to support the jack while applying load and load is applied through the inbuilt jack system. The load and the corresponding penetration of the plunger were measured using a proving ring and a dial gauge respectively. The CBR tests were carried out along the longitudinal centre line of the test tracks above the centre of the geotextile layer. CBR tests were performed on the test tracks without geotextile.

RESULTS AND DISCUSSION

Material properties

Properties of soils used in the present investigation are given in table 4.

Table 4. Soil properties

Property	Property value	
	Soil (P) (SP)	Soil (Q) (CH)
Specific gravity	2.67	2.45
Free swell index. (%)	5.20	61.33
Maximum dry density (kg/ m^3)	1790	1465
Optimum moisture content (%)	13.50	24.00
Liquid Limit (%)	---	72.50
Plastic Limit (%)	---	14.90

The properties of woven and non-woven geotextiles are given in table 5 (a) and 5 (b) respectively

Table 5(a). Properties of woven geotextiles

Property	**GTXw1**	**GTXw2**	**GTXw3**
Mass per Unit Area (g/m²)	142	224	241
Thickness (mm)	1.6	1.7	1.9
Puncture Strength (N)	323	862	1058
Tensile Strength (MD)*(kN/m)	34.88	61.52	72.5
Tensile Strength (CD)** (kN/m)	33.32	40.18	64.484
Elongation (MD) %	23.6	33.5	46.648
Elongation (CD) %	23.107	23.10	34.65
Trapezoid Strength (MD) N	630	525	742.0
Trapezoid Strength (CD) N	500	690	1200
Apparent Opening Size(mm)	1.62	0.678	0.69
Cone drop test (mm)	10	6.0	18.86

*Machine direction **Cross machine direction

Table 5 (b). Properties of non-woven geotextiles

Property	GTXnw1	GTXnw2	GTXnw3
Mass per Unit Area (g/m²)	179.5	200	250
Thickness (mm)	1.8	1.6	1.9
Grab Tensile strength (N)	557	720	865
Elongation @ Break (%)	77	60	60
Trapezoidal tear strength (N)	238	333	375
Puncture Strength (N)	383	400	535
Apparent Opening Size (µm)	180	150	150
Cone drop test (mm)	10	7.5	5.5
CBR puncture strength (N)	1650	2200	2750

CALIFORNIA BEARING RATIO TESTS

Laboratory CBR Test

Laboratory CBR test involves vertical load application to push a standard plunger of 50 mm diameter into the soil prepared at controlled density and moisture condition. Bearing pressure vs. penetration curves are plotted. From these plots bearing pressure corresponding to 2.5 mm and 5.0 mm penetration are obtained. The CBR value at these defined penetrations is obtained from the following relation.

$$CBR = \frac{P_s}{P_f} \times 100 \qquad (1)$$

Where P_s = Unit load carried by soil at defined penetration of standard plunger.

P_f = Unit load carried by standard crushed stones at same defined penetration.

Laboratory CBR test curves

Figure 4-6 show CBR curves for unreinforced and reinforced two layered soil system for different thickness configuration of soil layers with woven and non-woven geotextiles from which CBR values are obtained from the relation mentioned above. The CBR values so obtained are presented in table 6 and 7.

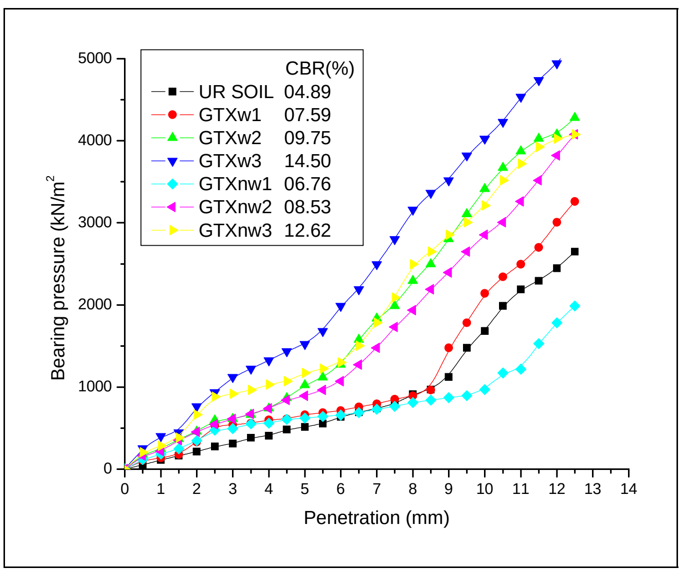

Fig 4. CBR curves for thickness configuration (A)

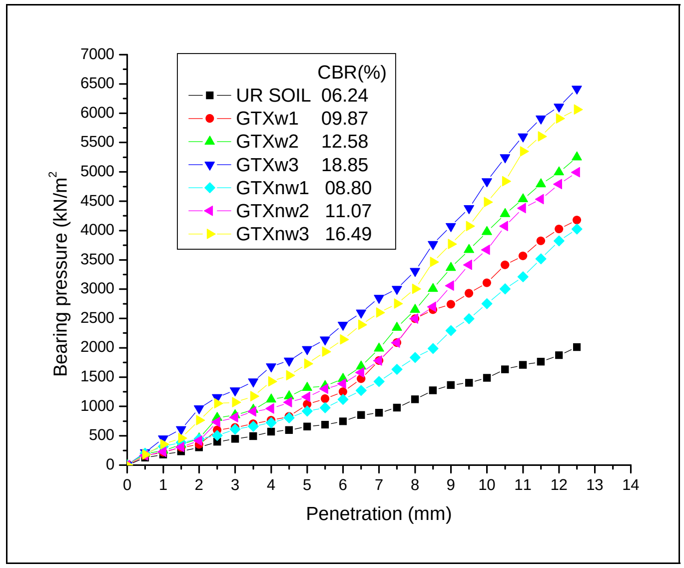

Fig 5. CBR curves for thickness configuration (B)

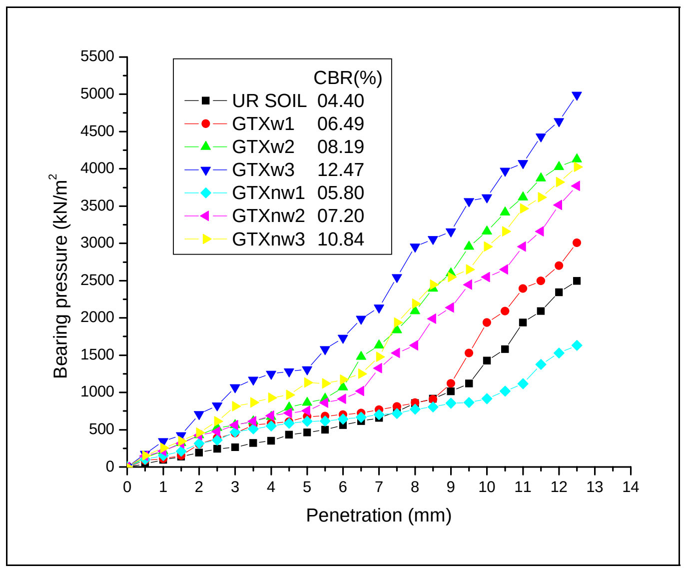

Fig 6. CBR curves for thickness configuration (C)

Table 6. Laboratory California Bearing Ratio of two layered soil system without geotextile

Thickness Configurations of soil layers	Thickness of soil layer	CBR value (%)
A	T_1 = 62.5mm T_2 = 62.5mm	4.89
B	T_1 =93.75mm T_2 =31.25mm	6.24
C	T_1 =31.25mm T_2 =93.75mm	4.40

Table 7. Laboratory California bearing ratio of two layered soil system with geosynthetics

Soil system	CBR value (%) of reinforced soil layer system					
	GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	7.59	9.75	14.5	6.76	8.53	12.62
B	9.87	12.58	18.85	8.80	11.07	16.49
C	6.49	8.19	12.47	5.80	7.2	10.84

From table 6 and 7 it can be observed that for unreinforced and reinforced soil system CBR is highest for thickness configuration (B) due to combined effect of the buffer layer and the membrane effect of the geotextile layer at the interface of the two soils. It is least for configuration C due to lesser thickness of buffer layer. In Table 8 the ratio of California bearing ratio of reinforced soil to that of unreinforced soil $[(CBR)_R/(CBR)_{UR}]$ for different soil layer thickness configuration and geotextiles is presented.

Table 8. Ratio of laboratory California bearing ratio of reinforced soil to that of unreinforced soil

Soil system	**$(CBR)_R$ / $(CBR)_{UR}$**					
	GTXw1	**GTXw2**	**GTXw3**	**GRTnw1**	**GRTnw2**	**GTXnw3**
A	1.55	1.99	2.97	1.3	1.74	2.58
B	1.58	2.02	3.02	1.41	1.77	2.64
C	1.48	1.86	2.83	1.32	1.64	2.46

Figure 7 shows graphical representation of ratio of laboratory California bearing ratio of reinforced soil to that of unreinforced soil for woven (GTXw1, GTXw2 and GTXw3) and non-woven (GTXnw1, GTXnw2 and GTXnw3) geotextiles with respect to three thickness configurations.

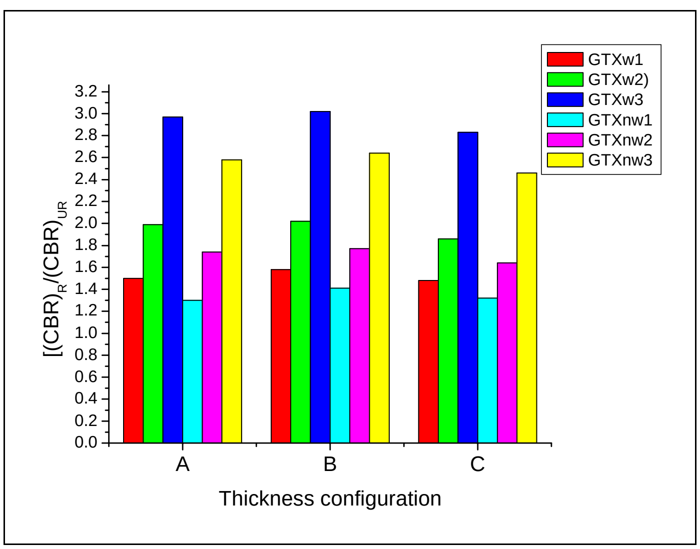

Fig 7. Ratio of laboratory California bearing ratio of reinforced soil to that of unreinforced soil

FIELD CALIFORNIA BEARING RATIO TEST

Field CBR curves

Figure 8-10 show field CBR curves for unreinforced and reinforced two layered soil system for different thickness configuration of soil layers(i.e., for test track 1-3 respectively) from which California bearing ratio of two layered soil system without and with geosynthetics are worked out as per the equation (1) and presented in table 9 and 10 respectively.

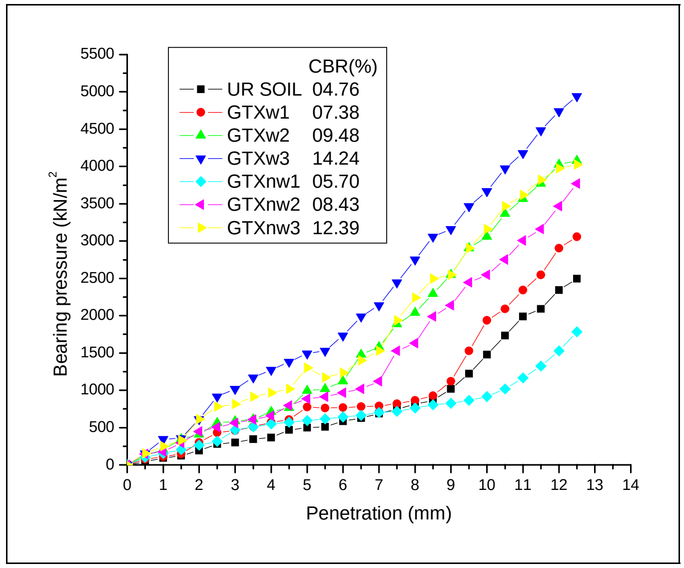

Fig 8. Field CBR curves for test track No 1 [Thickness configuration A]

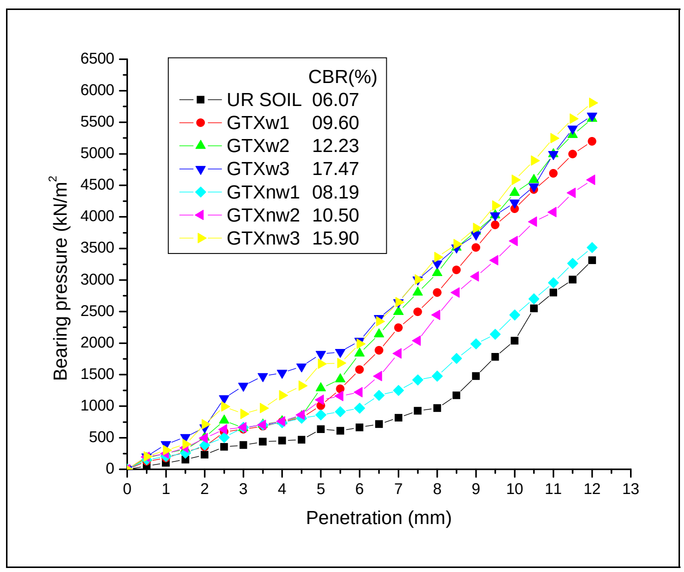

Fig 9. Field CBR curves for test track No 2 [Thickness configuration B]

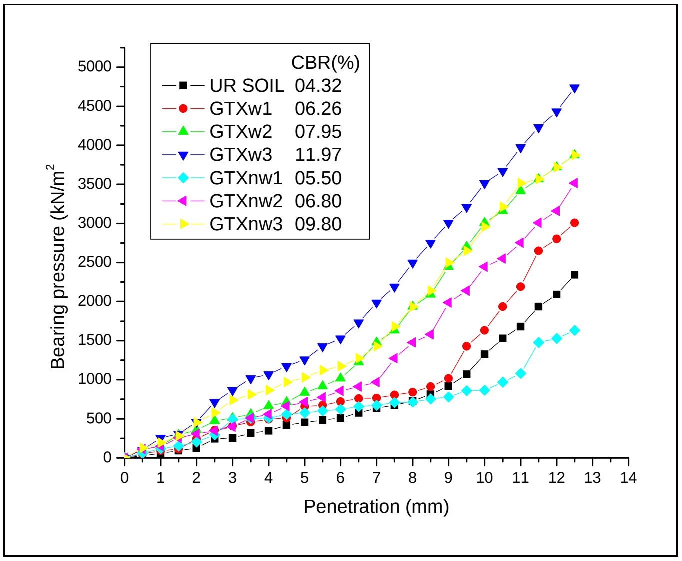

Fig 10. Field CBR curves for test track no 3

[Thickness configuration C]

Table 9. Field California Bearing Ratio of two layered soil system without geotextile

Test Track No	Thickness Configurations of layers	Thickness of soil layer	CBR value (%)
1.	A	T_1 = 150mm T_2 = 150mm	04.76
2.	B	T_1 =225 mm T_2 =75 mm	06.07
3.	C	T_1 =75 mm T_2 =225 mm	04.32

Table 10. Field California bearing ratio of two layered soil system with geosynthetics

Track No	Soil system	CBR value (%) of soil layer system for different geotextiles					
		GTX w1	GTX w2	GTX w3	GTX nw1	GTX nw2	GTX nw3
1.	A	07.4	09.5	14.2	05.70	08.43	12.39
2.	B	09.6	12.2	17.4	08.19	10.50	15.90
3.	C	06.3	07.9	11.9	05.50	06.80	09.80

In Table 11 the ratio of California bearing ratio of reinforced soil to that of unreinforced soil $[(CBR)_R/(CBR)_{UR}]$ for different soil layer thickness configuration and geotextiles is presented.

Table 11.Ratio of field California bearing ratio of reinforced soil to that of unreinforced soil

Two layered soil system	**$(CBR)_R$ / $(CBR)_{UR}$**					
	GTXw1	**GTXw2**	**GTXw3**	**GTXnw1**	**GTXw2**	**GTXw3**
A	1.55	1.99	2.81	1.20	1.77	2.60
B	1.58	2.00	2.88	1.35	1.75	2.62
C	1.44	1.84	2.77	1.27	1.57	2.27

Figure 11 shows graphical representation of ratio of field California bearing ratio of reinforced soil to that of unreinforced soil for GTXw and GTXnw for thickness configurations A, B and C.

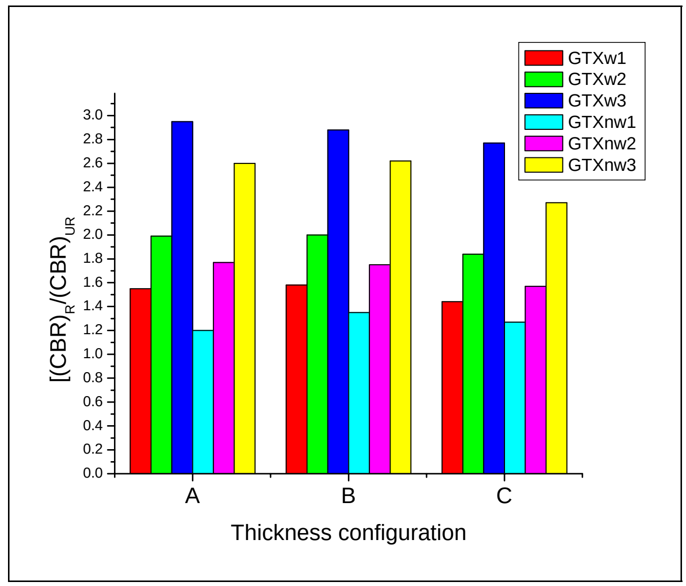

Fig 11. Ratio of field California bearing ratio of reinforced soil to that of unreinforced soil

EVALUATION OF THICKNESS OF FLEXIBLE PAVEMENT OVER TWO LAYER SOIL SYSTEM

United States Army Corps of Engineer's modified CBR design method and Indian Road Congress method for design of flexible pavements are used to evaluate the thickness of pavement layer over the two layered soil system based on the laboratory and field CBR results. Pavement thickness is worked out for both unreinforced and reinforced soil system and the percentage reduction in pavement thickness is evaluated.

U.S. Army Corps of Engineer's modified CBR design method for design of flexible pavements

In this method the thickness of pavement layer over unreinforced and reinforced two layered soil system is calculated using equation 2.

$$h = (3.24 \log N + 2.21)\left(\frac{P}{56 \times CBR} - \frac{A}{2030}\right) \ldots\ldots (2)$$

Where
h = design thickness of the pavement in millimeters
N= Anticipated number of vehicle passes
P= The single or equivalent single wheel loads in N
A= tyre contact area in mm^2
A design chart as shown in figure 5.14 is developed for N=10, 100, 1000, 10000
P=80 x 10^3 N and A=300mm x 450 mm

The design chart shown in figure 12 is used to obtain thickness of the pavement over the two layered soil system for N=10000.

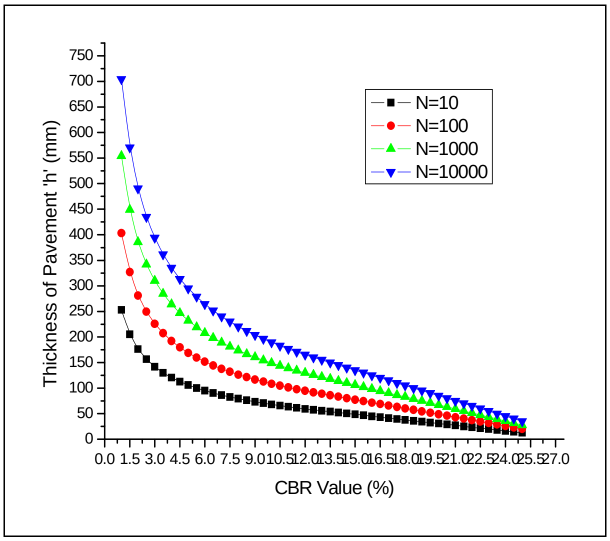

Fig 12. Design chart based on U.S. Army corps of engineers modified CBR design equation

The thickness of flexible pavement required over the unreinforced and reinforced two layered soil system for CBR values obtained by laboratory and field CBR test are tabulated in table 12 and 13 respectively.

Table 12. Thickness of flexible pavement required based on laboratory CBR values

Thickness configuration	Thickness of granular layer required over two layered soil system(mm)						
	UR soil	GTXw			GTXnw		
		GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	295	231	197	145	256	210	156
B	259	198	163	125	209	181	131
C	325	250	219	169	278	238	185

Table 13.Thickness of flexible pavement required based on field CBR values

Thickness configuration	Thickness of granular layer required over two layered soil system(mm)						
	UR soil	GTXw			GTXnw		
		GTX w1	GTXw2	GTXw3	GTXnw 1	GTXn w2	GTXn w3
A	356	206	188	231	284	234	240
B	253	184	219	194	188	234	238
C	338	231	228	216	222	219	244

The percentage reduction in thickness of flexible pavement for laboratory CBR values and field CBR values is tabulated in table 14 and 15 respectively.

Table 14. Percentage Reduction in thickness of flexible pavement for laboratory CBR values

Thickness configuration	Reduction (%) in the thickness of pavement					
	GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	23.00	34.24	50.84	13.20	28.80	47.11
B	23.55	37.10	51.74	19.30	30.12	49.40
C	23.08	32.61	48.00	13.20	26.76	43.10

Table 15. Percentage Reduction in thickness of flexible pavement for field CBR values

Thickness configuration	Reduction (%) in the thickness of pavement					
	GTX w1	GTX w2	GTX w3	GTXn w1	GTXn w2	GTXn w3
A	23.10	33.99	48.84	13.22	27.72	46.20
B	27.50	34.94	53.53	18.58	28.99	48.69
C	24.30	33.43	45.85	12.90	27.81	42.60

From table 14 and 15 it can be observed that the reduction in thickness of pavement is highest in case of configuration B and it is least in case of thickness configuration C. The highest reduction in thickness is 51.74% for GTXw3 in thickness configuration B for laboratory CBR value. The highest reduction in thickness is 53.53% for GTXw3 in thickness configuration B for field CBR value.

INDIAN ROAD CONGRESS (IRC) DESIGN METHOD FOR FLEXIBLE PAVEMENT

The CBR method which considers traffic in terms of commercial vehicles per day recommended by (IRC) is used here to estimate the thickness of pavement over unreinforced and reinforced two layered system for laboratory and field

CBR values. The CBR curves updated for 10.2 tonnes single axle legal limit presently in force is used here for estimation of pavement thickness.

The thickness of pavement required over the unreinforced and reinforced two layered soil system is worked out for laboratory and field CBR values considering 450-1500 commercial vehicles per day exceeding 3 tonnes and presented in table 16 and 17 respectively.

Table 16. Thickness of pavement for laboratory CBR values by IRC method

Thickness configuration	Thickness of granular layer required over two layered soil system(mm)						
	UR soil	GTXw			GTXnw		
		GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	460	350	315	260	390	340	275
B	410	315	270	209	330	295	232
C	500	415	328	280	430	365	295

Table 17. Thickness of pavement for field CBR values by IRC method

Thickness configuration	Thickness of pavement required over two layered soil system(mm)						
	UR* soil	GTXw			GTXnw		
		GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	475	370	320	250	420	340	265
B	420	320	271	225	330	298	230
C	530	415	350	290	445	385	315

*Unreinforced two layered soil system

The percentage reduction in thickness of flexible pavement for laboratory and field CBR values based on Indian Roads Congress method is tabulated in table 18 and 19 respectively.

Table 18. Reduction in thickness of pavement for laboratory CBR values based on IRC method

Thickness configuration	Reduction (%) in the thickness of pavement					
	GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	22.90	32.98	44.68	16.33	27.66	41.49
B	23.17	34.15	49.50	19.51	28.05	43.41
C	17.00	39.80	44.00	14.00	27.00	41.00

Table 19. Reduction in thickness of pavement for field CBR values based on IRC method

Thickness configuration	Reduction (%) in the thickness of pavement					
	GTXw1	GTXw2	GTXw3	GTXnw1	GTXnw2	GTXnw3
A	22.1	32.63	46.43	11.57	28.42	44.2
B	23.81	35.48	47.37	21.43	29.05	45.23
C	21.70	31.90	45.11	16.00	27.36	40.56

From table 18 and 19 it can be observed that the reduction in thickness of pavement is highest for configuration B and it is least in case of thickness configuration C. The highest reduction in thickness is 49.5% for GTXw3 in thickness configuration B for laboratory CBR value. The highest reduction in thickness is 47.37% for GTXw3 in thickness configuration B for field CBR value.

CONCLUSIONS

Based on the test results and their analysis the following conclusions are drawn.

[1] California bearing ratio of two layered soil of two layered soil is substantially improved due to inclusion of horizontal layer of geotextile at the interface of the soil layers. The improvement in CBR is function of thickness configurations of soil layers and the tensile strength of the geotextile.

[2] Inclusion of geosynthetic in the flexible pavement have shown beneficial effect in reducing overall thickness of pavement over a soft clay subgrade overlain by a coarse grained soil as buffer layer. This beneficial effect is function of the tensile properties of geotextiles used in the investigation.

[3] Based on the U.S. Army Corps of engineers design method the reduction in thickness of pavement is highest for configuration B and it is least in case of thickness configuration C. The highest reduction in thickness is 51.74% for GTXw3 in thickness configuration B for laboratory CBR value. The highest reduction in thickness is 53.53% for GTXw3 in thickness configuration B for field CBR value.

[4] Based on the Indian Roads Congress method of design for flexible pavements the reduction in thickness of pavement is also highest for configuration B and it is least in case of thickness configuration C. The highest reduction in thickness is 49.5% for GTXw3 in thickness configuration B for laboratory CBR value. The highest reduction in thickness is 47.37% for GTXw3 in thickness configuration B for field CBR value.

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