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Layer Thickness Design of Low Volume Bituminous Sealed Road Pavements: Effect of Geo-Grid Reinforced Sub grade

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Abstract

Geo-grid reinforcement is gaining popularity as a “means to improve the qualities of naturally occurring soils for use in road pavement construction. Weak lateritic sub grades are found in many tropical nations, and they are frequently rejected after proof rolling during construction due to their low strength. The specific goals of this study were to: 1) determine the effect of geo-grid reinforcement material strength on the California Bearing Ratio of a sample of relatively poor lateritic sub grade material under wet and dry conditions, and 2) determine the effect of geo-grid reinforced sub grade on the design thickness of low volume paved roads. Without reinforcement, a natural lateritic sub grade soil was chosen and tested. Then, above the third layer within the geo-grid, add a layer of tri-axial geo-grid. This was done for two different geo-grid strengths in both damp and unsoaked conditions. Using the Transport Research Laboratory Road Note 31 technique of pavement design, the California Bearing Ratios of the soil–geo-grid sub grade were utilized to establish the pavement layer thicknesses for a low volume paved road. The findings show that the reduction in base course layer thickness caused by geo-grid reinforcement for a sub grade reduces with increasing traffic class. For a surface prepared road with natural gravel base course, a minimum of 15% base course layer thickness reduction was observed.

***Keywords**: Geo-grid reinforcement, California Bearing Ratio, Lateritic sub grades, Pavement layer thicknesses.*

Introduction

Access roads to rural areas, towns, and districts are mainly low-volume paved and unpaved roads. They are vital to the rural economy, resource industries (forestry, mining), and agricultural production areas transit. Large deformations can develop when low-volume roads are built on poor sub grade soils, increasing maintenance costs and causing traffic service interruptions. According to Leng (2002), the deterioration of both unpaved and paved roads is faster than road replacement. With rising material and building expenses, it's more necessary than ever to look at alternative construction methods that are both long-lasting and cost-effective.

Geo-synthetics have been found to be a cost-effective alternative for improving poor sub-soils in difficult locations, particularly where there is a lack of uniform quality and/or availability of desired soils, with applications in almost all geotechnical engineering projects, such as airport and highway pavements. In India, Ghosal and Som (1989) reported the first significant usage of a nonwoven fabric in a heavy-duty yard in Haldia, where it was discovered to reduce pavement thickness by 30%.

Geo-grid , a sort of geo-synthetic reinforcement, is gaining popularity as a technique to improve the qualities of naturally occurring soils for use in road pavement construction. Bi-oriented geo-grids have been successfully used in Maharashtra's State Highways for strengthening road pavements in black cotton soil, according to Venkatappa Rao and Banerjee (1997). According to Gupta (2009), the goal of geo-synthetic reinforcement in flexible pavements is to increase the lifespan of the pavement or to allow for the construction of a pavement with less base course material without sacrificing pavement performance.

Through research and conferences, the Ghanaian engineering community is becoming more familiar with geo-grid. Lateritic sub grades are abundant in many tropical nations, such as Ghana..

The goal of this study was to find out how tri-axial geo-grid affected road pavements. The study's specific goals were to: 1) determine the effect of geo-grid reinforcement material strength on the California Bearing Ratio (CBR) of a sample of relatively poor lateritic sub grade material under soaked and unsoaked conditions; and 2) determine the effect of geo-grid reinforcement material strength on the California Bearing Ratio (CBR) of a sample of relatively poor lateritic sub grade material under soaked and unsoaked conditions. 2) Determine the impact of geo-grid reinforcement on low-volume paved road design thickness in the tropics.

Literature Review

Geosynthethics in Roadwork’s

Geosynthetics are defined by ASTM D4439 (2001) as planar products composed of polymeric materials (the synthetic) that are utilised in conjunction with soil, rock, earth, or other geotechnical engineering-related materials (the geo) as an integral part of a man-made project, structure, or system. According to Venkatappa Rao and Banerjee (1997), geosynthetics improve or modify the behavior of civil engineering works, facilitate construction, provide better structure performance, and reduce long-term maintenance.

Most geosynthetics are made from synthetic polymers such as polypropylene, polyester, polyethylene, polyamide, polyvinyl chloride, et cetera. These materials are highly resistant to biological and chemical degradation. Geosynthetics perform five to six essential or primary functions depending on the application. These are separation, drainage, filtration, reinforcement, protection and serving as fluid barriers. All these key functions have been applied in paved and unpaved roads as well as in parking areas. (Pilarczyk, 2000; Holtz, 2001).

Geotextiles, geo-grid , geomembranes, and geocomposites are all examples of geosynthetics. Geonets/geomeshes, as well as geomats/geowebs, are examples of others. Geo-grid are planar constructions made up of a regular network of tensile elements with large enough holes to interlock with the surrounding soil or aggregate. They're commonly employed for reinforcement (Holtz, 2001; Venkatappa Rao and Banerjee, 1997; ASTM D4439, 2001). The improved performance of road pavements as a result of geosynthetic reinforcement has been linked to three primary mechanisms: lateral restraint, greater bearing capacity, and the tensioned membrane effect produced by the geosynthetic when put within the base course or sub grade (Giroud et al., 1984; Perkins and Ismeik, 1997).

Anderson and Killeavy (1989) showed that within an access road and truck staging area, geotextile reinforced section with 350 mm base layer performed similar to unreinforced section with 450 mm thick base layer. Miura et al. (1990) constructed field test sections of road that contained 50 mm less of base course than the unreinforced section and were observed to perform better than the control sections for all the rut depths. Webster (1993) showed that for a sub grade with CBR of 8%, a section containing a geo-grid with 150 mm thick base had equivalent performance to an unreinforced section with 250 mm thick base. Gupta (2009) states that base course reductions in the range of 20% to 40% have been reported in literature after geosynthetic reinforcement with greater percentage reduction for the stronger sub grade materials.

Leng (2002) placed geosynthetic between base layer and sub grade in an unpaved structure. Results indicated that reinforcement improved stress distribution transferred to the sub grade, and decreased degradation of base course and surface deformation accumulation. Gosavi et al. (2004) investigated the strength behavior of soil reinforced with mixed geo-grid woven fabric and showed that the soaked CBR without the geo-grid was about 4.9% and after using the geo-grid , observed an improvement in the CBR value. Naeini and Moayed (2009) indicated that using a geo-grid at top of the third layer in a soil sample with different plasticity index causes a considerable increase in the CBR value compared with unreinforced soil in both soaked and unsoaked conditions.

Dhule et al. (2011) showed that the CBR value of an unsoaked soil increases with increasing percentage of geo-grid reinforcement. Rao et al. (1989); Shetty and Shetty (1989); Rao and Raju (1990); Ranjan and Charan (1998) presented results of series of laboratory CBR tests (soaked and unsoaked) on silty sand (SM) reinforced with randomly distributed polypropylene fibres. The results showed that the CBR value of the soil increased significantly with increase in fibre content. The increase in CBR was observed to be 175% and 125% under soaked and unsoaked conditions respectively with addition of 3% fibres by weight.

results for sub-base soil having CBR equal to 3% or lower. No major differences were found between different single layer integral geo-grid . The higher tensile modulus geo-grid showed better contribution at 3% CBR or lower. The percent reduction of rutting, between reinforced and unreinforced sections, increased with reducing sub grade CBR for all geosynthetics. The traffic improvement factor for road service life increases for deep allowed ruts, lower CBR values and lower pavement structural number.

When Montanelli et al. (1997) inserted geo-grid between the gravel base course and the sand sub grade, they found that the amount of vertical settlement under loading decreased as the CBR value of the sub grade increased. Furthermore, with CBR values less than 3%, the difference in settling between reinforced and unreinforced specimens is substantially bigger than in CBR values greater than 3%. Furthermore, settlement is smaller in reinforced specimens with 300 mm base courses than in unreinforced specimens with 400 mm base courses. Kumar et al. (1999) investigated the CBR value and ductility of silty sand and pond ash specimens augmented with randomly distributed polyester fibres.

Triax Geo-grid

Certain elements affecting a geo-grid 's performance were determined through testing and research after reviewing all of the design parameters of a geo-grid . The rib section profile, rib thickness, connection efficiency, aperture size, and in-plane stiffness are all factors to consider. Extensive tests were carried out in accordance with the geo-grid 's rib directions. The junction strength was found to be approximately equivalent to rib strength in each direction tested, resulting in a junction efficiency of 100 percent. TriAx geo-grid , on the other hand, have three major directions of stiffness, which is further strengthened by their rigid triangular geometry. Biaxial geo-grid have tensile stiffness primarily in two dimensions. This creates a structure that is unlike any other geo-grid and delivers exceptional rigidity in all directions (Tensar, 2008).

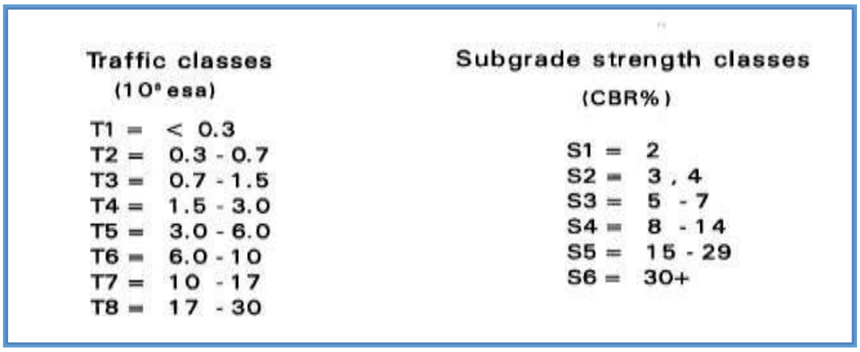
Aggregate particles interlock within the geo-grid and are restricted within the apertures in a mechanically stabilized layer, resulting in an upgraded composite material with improved performance characteristics. The magnitude and depth of the confined zones have an impact on the mechanically stabilized layer's structural characteristics. The degree of confinement and efficiency of the stabilized layer is directly influenced by the form and thickness of the geo-grid ribs, as well as the overall structure of TriAx. When compared to biaxial geo-grid , Triad geo-grid have a deeper rib depth. To compare the performance advantages of the two types of geo-grid with varying rib depths in a mechanically stabilized layer, trafficking experiments and analytical modeling were conducted. The findings were clear in demonstrating that better structural performance was attained.

Sub grade Strength and Pavement Thickness design for Low Volume Paved Roads in the Tropics

The Transport Research Laboratory (1993) Overseas Road Note 31 (ORN31) is the most popular design procedure for bitumen surfaced roads in tropical and sub-tropical countries. In situ CBR measurements of sub grade soils are not recommended in the design procedure because of the difficulty of ensuring that the moisture and density conditions at the time of test are representative of those expected under the completed pavement. Each sample or each test of the sub grade strength will usually give different results and these can sometimes cover a considerable range. For design purposes, it is important that the strength of the sub grade is not seriously underestimated for large areas of pavement or overestimated to such an extent that there is a risk oflocal failures. The best compromise is to use the lower ten percentile value, which is that value exceeded by 90 per cent of the readings. If the characteristics of the sub grade change significantly over sections of the route, different sub grade strength values for design should be calculated for each nominally uniform section (Transport Research Laboratory, 1993).

The structural catalogue of the Overseas Road Note 31 (ORN31) requires that the sub grade strength for design is assigned to one of six strength classes reflecting the sensitivity of thickness design to sub grade strength. The sub grade strength classes are defined in Table 1 in addition to the road traffic classes which are obtained after an estimate of the cumulative equivalent standard axle loading of the road. For sub grades with CBR less than 2%, special treatment is required. The design sub grade strength class together with the traffic class obtained are then used with the catalogue of structures to determine the pavement layer thicknesses (Transport Research Laboratory, 1993). Figure 3 in the appendix gives the structural catalogue for a surface dressed road with natural gravel sub-base and base course".

Table 1 Sub grade and Traffic classes (TRL ORN 31)



Traffic classes
(10^6 esa)

T1 = < 0.3
T2 = 0.3 - 0.7
T3 = 0.7 - 1.5
T4 = 1.5 - 3.0
T5 = 3.0 - 6.0
T6 = 6.0 - 10
T7 = 10 - 17
T8 = 17 - 30

Subgrade strength classes
(CBR%)

S1 = 2
S2 = 3 , 4
S3 = 5 - 7
S4 = 8 - 14
S5 = 15 - 29
S6 = 30+

I. METHODOLOGY

"The sub grade sample was retrieved from a trial pit along a road in Kumasi, Ghana's Ashanti region, that was undergoing repair. According to the Ministry of Roads and Highways of Ghana criteria for road works and bridges, the material was air dried and tested for particle size distribution, consistency limitations, compaction, and CBR (2006). Compaction test was carried out in the laboratory to determine the optimum moisture content and maximum dry density of the soil sample using test method ASTM D1557 and BS 1377-4. Gradation test and consistency limits were done according to ASTM D422 and ASTM D4318, which are both in accordance with BS 1377-2. The CBR was tested according to the test procedure as per ASTM D1883 and BS 1377-4. In order to investigate the effect of geo-grid strength development in a typical sub grade material, two different samples of Tri-axial geo-grid were used, namely TriAx Tx 130s and TriAx Tx 170. These were obtained from Tensar, United Kingdom and used as the reinforcing material. The properties of the geo-grid samples are shown in Table 2. The choice of geo-grid was limited by availability of specimens supplied by the producer. The TriAx Tx 170 geo-grid has much higher structural integrity over the TriAx Tx 130s geo-grid , with higher load transfer ability and load bearing capacity".

Table 2 Properties of Geo-grid

Particulars	TriAx Tx 130s	TriAx Tx 170
Aperture Shape	Triangular	Triangular
Color	Black	Black
Rib Shape	Rectangular	Rectangular
Nodal Thickness	3 mm	4.1 mm
Aperture Stability	300 Nmm/deg	610 Nmm/deg
Radial Stiffness at Low strain	200 kN/m	500 kN/m
Junction Efficiency	93	90

CBR Experimental Study: The CBR test was conducted using three moulds holding compacted sub grade samples containing TriAx Tx 130s, TriAx Tx 170, and no-geo-grid, respectively. The CBR testing machine was used to test the reinforced and unreinforced soil samples under drenched and unsoaked conditions. The moulds were soaked for four (4) days in a drum of water with a surcharge applied to them in the wet condition. The geo-grid were put at the layer 3 level based on previous research findings (Naeini and Moayed, 2009) and our previous work, which revealed appropriate values. Figure 1 depicts the experimental set-up and schematic arrangement of the samples using geo-grid".

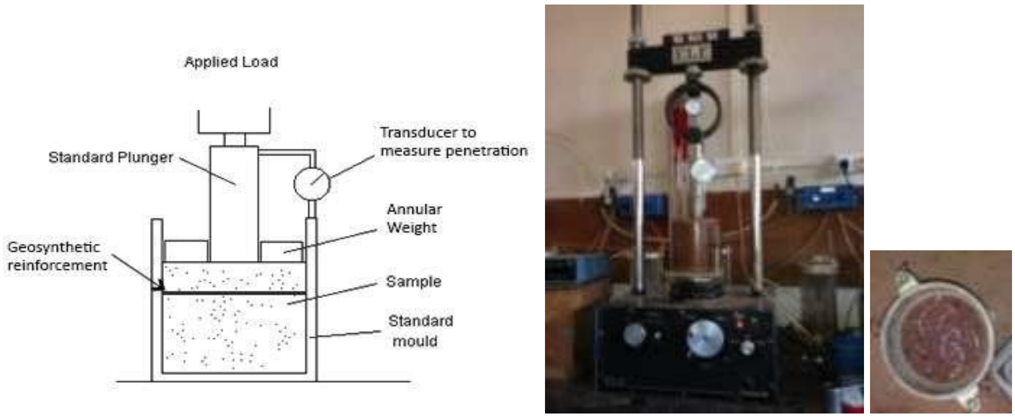


Figure 1 CBR set-up of experiment and schematic arrangement

II. RESULTS AND DISCUSSION

Characteristics of Sub grade Material

"The soil sample was obtained locally and used for the study. The properties of the tested soil specimen are as shown in Table 3. The grain size distribution curve showed that the percentage passing the 4.75 mm sieve was 96.8%, with 17.6% passing the 0.075 mm sieve. Using the Unified Soil Classification system the material isclassified as a sandy silt material with a group symbol of SM".

Table 3 Properties of Sub grade Material

Color	Brown	Particle size less than 2 mm	91%
Specific Gravity	2.65	Particle size less than 1 mm	30%
Liquid Limit	67%	Maximum Dry Density (MDD)	2150 kg/m^3
Plastic Limit	36%	Optimum Moisture Content (OMC)	17.90%
Plasticity Index	31%	California Bearing Ratio (Soaked)	11.60%

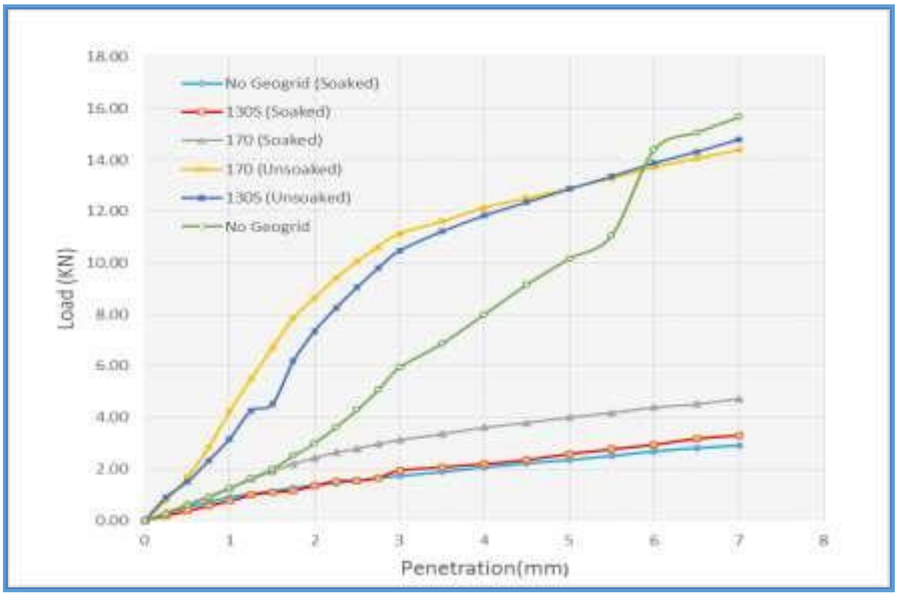
CBR Strength Development

"Table 4 demonstrates how the CBR value and dry density of the soil sample, as well as the sample interfaced with the geo-grid , changed under soaked and unsoaked conditions. The TriAx Tx 130s increased the CBR of the drenched soil sample by 11 percent and the CBR of the unsoaked soil sample by 112 percent. On the other hand, the TriAx Tx 170 enhanced the CBR value of the drenched sample by 72% and the unsoaked sample by 135%. As a result, we can conclude that the TriAx Tx 170 had a substantially stronger effect on raising the bearing strengths of soil samples, particularly in the soaked state, where its effect was almost 60% greater than the TriAx Tx 130s".

Table 4 CBR tests results (Soaked and Unsoaked)

	Soaked			**Unsoaked**		
“Sample	**Dry Density (kg/m^3)**	**CBR Value**	**Percentage increase in CBR**	**Dry Density (kg/m^3)**	**CBR Value**	**Percentage Increase in CBR**
With No Geo-grid	**1678**	**11.6%**	**-**	**1670**	**32.1%**	**-**
With TriAx Tx 130s	**1710**	**12.9%**	**11%**	**1640**	**67.9%**	**112%**
With TriAx Tx 170	**1715**	**20.0%**	**72%**	**1699**	**75.4%**	**135%”**

Figure 2 “benevolences the variations of load-penetration curves for the soil sample without geo-grid reinforcement in both soaked and unsoaked conditions as well as the load-penetration curves for the soil – geo-grid samples with TriAx Tx 170 and TriAx Tx 130s geo-grid respectively in both soaked and unsoaked conditions. Figure 2 shows that when the sample is soaked, the TriAx Tx 130s does not offer much resistance to penetration when used as reinforcement”.



“Figure 2 Penetration resistance comparison between soil-aggregate and soil-geo-grid -aggregate

Effect of Geo-grid Reinforced Sub grade on Pavement Thickness Design

In order to assess the effect of the geo-grid reinforcements on pavement layer thickness design, the Transport Research Laboratory (1993), Overseas Road Note (ORN) 31 was used. The layer thicknesses for the sub grade sample without geo-grid , as well as the sub grade sample with TriAx Tx 130s and TriAx Tx 170, were selected from the ORN 31 for a granular road base road with surface dressing, for traffic levels T4 (1.5 - 3.0 x10^6esa), T5 (3.0 - 6.0 x10^6 esa) and T6 (6.0 -10.0 x10^6 esa) respectively as shown in Table 5”.

Table 5 Thickness selection of Natural Gravel Pavement layers based on TRL ORN 31

	Description	No Geo-grid		TriAx Tx 130s		TriAx Tx 170	
		Soaked	Unsoaked	Soaked	Unsoaked	Soaked	Unsoaked
	CBR Value	11.6%	32.1%	12.9%	67.9%	20.0%	75.4%
	Sub grade class	S4	S6	S4	S6	S5	S6
Traffic level/ Layer Thickness							

T4	“Base course	200 mm	200 mm	200 mm	200 mm	200 mm	200 mm
	Sub-base course	200 mm	0.00	200 mm	0.00	125 mm	0.00
T5	Base course	200 mm	225 mm	200 mm	225 mm	225 mm	225 mm
	Sub-base course	250 mm	0.00	250 mm	0.00	150 mm	0.00
T6	Base course	225 mm	250 mm	225 mm	250 mm	250 mm	250 mm
	Sub-base course	275 mm	0.00	275 mm	0.00	175 mm	0.00”

“From the TRL ORN 31 requirements for sub grade class, when the sub grade soaked CBR is 11.6% or 12.9%, as we had for the sample without geo-grid and the sample with TriAx Tx 130s respectively, the sub grade class is S4. For traffic load T4 (1.5 - 3.0 x10^6 esa), T5 (3.0 - 6.0 x10^6 esa) and T6 (6.0 - 10.0 x10^6 esa), the pavement thickness (base course and sub-base) will be 400 mm, 450 mm and 500 mm respectively. For all three (3) traffic loadings, each pavement will have a base course of natural gravel with thicknesses between 200 - 225 mm overlying a sub-base thickness of 200 – 275 mm. It can be seen from Table 5 that the pavement thicknesses would be same for the sample with no geo-grid as the sample with the TriAx Tx 130s for the soaked CBR condition. Thus there would be no reduction in terms of pavement thicknesses in using the TriAx Tx 130s with the sub grade sample under soaked conditions.

When the sub grade was reinforced with the TriAx Tx 170 geo-grid , the soaked CBR was 20% which belongs to the class S5 sub grade. This results in pavement thicknesses of 325 mm for traffic loads of T4, 375 mm for traffic of T5 and 425 mm for traffic of T6. Thus improving the sub grade sample with TriAx Tx 170 geo-grid resulted in overall thickness reduction of 75 mm for each traffic load class (T4, T5, T6) under the soaked CBR condition. When compared with the unreinforced thickness of the flexible pavement, the Base Course Reduction due to the TriAx Tx 170 in a sandy silt (SM) sub grade soil with unreinforced soaked CBR of 11.6% was 19% for traffic class T4, 17% for traffic class T5 and 15% for traffic class T6 which is the highest traffic class in the design category, thus base course thickness reduction as a result of geo-grid reinforcement for a sub grade soil tends to decrease with increasing traffic volume. Base course reduction benefits accruing from the use of geo-grid may be felt most in lower volume roads especially in areas where water may drain into the lower layers of pavements as may occur with unsealed shoulders and under conditions of poor surface maintenance where the road base may be pervious or in high rainfall areas.

In all situations, including the no-geo-grid option, the unsoaked CBR was greater than 30%. (sub grade class S6). T4, T5, and T6 have pavement layer (base) thicknesses of 200 mm, 225 mm, and 250 mm, respectively. There is no requirement for a sub-base course for all traffic loadings in this situation. This means that increasing the strength of geo-grid reinforcement in a sub grade soil increases the soil's strength in both wet and dry situations. In dry or unsoaked situations, geo-grid gain more strength than in wet or soaked conditions, however, benefits in terms of structural gains in strength such as savings in pavement layer thicknesses with increasing geo-grid strength are much more significant or pronounced in wet or soaked conditions than in the dry or unsoaked conditions. The increase in strength in the sub grade in dry and arid areas may not necessary result in savings in pavement thicknesses, in such areas, reinforcement with geo-grid improves the sub grade such that when the normal pavement structure of sub-base and base course are placed, the entire structure will have a very high structural number or strength. The findings are consistent with the study made by Barksdale et al. (1989) when they compared the performance of geo-grid with different strength properties. This generally informs us that geo-grid reinforcement would be very helpful in dealing with relatively poor lateritic sub grade materials by improving the strength.

III. CONCLUSION AND RECOMMENDATION based on the results of this study the following conclusions may be drawn:

- Interfacing soil with a geo-grid material increases the penetration resistance and hence the CBR strength in both soaked and unsoaked conditions. Therefore the performance of a sub grade material in a pavement system is better with the inclusion of a geo-grid .
- The addition of a single layer of TriAx Tx 130s geo-grid at the top of the third layer in a sandy silt soil increases the CBR value of the sample for soaked and unsoaked conditions by 11% and 112%respectively.
- TriAx Tx 170 geo-grid placed at top of the third layer in a sandy silt soil causes an increase in soaked and unsoaked CBR by 72% and 135% respectively.
- Placing one layer of geo-grid at top of layer 3 has more effective performance in penetration resistance in unsoaked condition than soaked conditions for both geo-grid .
- The introduction of TriAx Tx 130s geo-grid in both soaked and unsoaked condition did not change the sub grade strength class for an SM soil and therefore did not result in base course thickness reduction.
- The interfacing of TriAx Tx 170 in soaked condition increased the sub grade strength class and resulted in significant pavement thickness reduction for all traffic levels.
- Base course thickness reduction due to the TriAx Tx 170 in a sandy silt (SM) sub grade soil with unreinforced soaked CBR of 11.6% was 19% for traffic class T4, 17% for traffic class T5 and 15% for traffic class T6 which is the highest traffic class in the design category.
- Base course thickness reduction as a result of geo-grid reinforcement for a sub grade soil tends to decrease with increasing traffic volume.
- Base course reduction benefits accruing from the use of geo-grid may be felt most in lower volume roads especially in areas where water may drain into the lower layers of pavements as may occur with unsealed shoulders and under conditions of poor surface maintenance”, where the roadbase possibly will be impervious or in high rainfall ranges.

Recommendations

Geo-grid does have a strong potential of reducing the price of pavement layers if weak sub grades are found all along alignment. For raise the structural number of pavements, reduce layer thicknesses, and boost the California Bearing Ratio, geo-grid should be used on low-volume paved roads.

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