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Effect of Geogrid Reinforced Subgrade on Layer Thickness Design of Low Volume Bituminous Sealed Road Pavements

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Abstract:- Geogrid reinforcement is gaining acceptance as an effective way of improving on the properties of naturally occurring soils for road pavement construction. In many tropical countries, weak lateritic subgrades are common and often rejected after proof rolling during construction due to poor strength. The specific objectives of this research were to 1) Determine the effect of strength of geogrid reinforcement material on the California Bearing Ratio of a sample of relatively poor lateritic subgrade material under soaked and unsoaked conditions and 2) Establish the effect of geogrid reinforced subgrade on the design thickness of low volume paved roads. A natural lateritic subgrade soil was selected and tested without reinforcement. Then by placing a layer of a tri-axial geogrid above the third layer within the sample height, the effects of geogrid reinforcement on California Bearing Ratio values are investigated. This was undertaken for two strengths of geogrid in both soaked and unsoaked conditions. The California Bearing Ratios of the soil–geogrid subgrade was used to determine the pavement layer thicknesses for a low volume paved road using the Transport Research Laboratory Road Note 31 method of pavement design. The results indicate that base course layer thickness reduction as a result of geogrid reinforcement for a subgrade decreases with increasing traffic class. A minimum of 15% base course layer thickness reduction was observed for a surface dressed road with natural gravel base course.

Keywords:- Geogrid reinforcement, California Bearing Ratio, Lateritic subgrades, Pavement layer thicknesses

I. INTRODUCTION

Low volume paved and unpaved roads usually serve as access roads to rural areas, towns and districts. They play a very important role in rural economy, resource industries (forest, mining) and transportation to agricultural production areas. When low volume roads are built on poor subgrade soils, large deformations can occur, which increase maintenance cost and lead to interruption of traffic service. Leng (2002) states that in general, deterioration of unpaved and paved roads is faster than road replacement. The increasing material and construction costs, make it important to explore alternative construction methods with longer service life but at the same time cost efficient.

Geosynthetics have been found to be a cost effective alternative to improve poor sub-soils in adverse locations, especially in situations where there may be non-uniform quality and/or non-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 major use of a nonwoven fabric in a heavy duty yard in Haldia, it was found to decrease the pavement thickness by 30%.

Geogrid, a type of geosynthetic reinforcement is gaining acceptance as an effective way of improving on the properties of naturally occurring soils for road pavement construction. Venkatappa Rao and Banerjee (1997) reported that bi-oriented geogrids have been successfully utilised in Maharashtra in the State Highways for strengthening road pavements in black cotton soil. Gupta (2009) argues that the purpose of geosynthetic reinforcement in flexible pavements is to extend a pavement's lifespan or to enable the construction of a pavement with a reduced quantity of base course material without sacrificing pavement performance.

The Ghanaian engineering community is in the process of getting acquainted with geogrids through research work and conferences. In many tropical countries like Ghana, lateritic subgrades are common and often rejected after proof rolling during construction due to poor strength. Cost associated with poor subgrades include relatively larger sub-base and base thicknesses, right-of-way purchases as a result of relocation of road corridors and eventually longer construction periods with associated opportunity costs.

The purpose of this research was to determine the effect of tri-axial geogrids on road pavements. The specific objectives of the research were to 1) Determine the effect of strength of geogrid reinforcement material on the California Bearing Ratio (CBR) of a sample of relatively poor lateritic subgrade material under soaked and unsoaked conditions. 2) Establish the effect of geogrid reinforcement on the design thickness of low volume paved roads in the tropics.

II. LITERATURE REVIEW

Geosynthethics in Roadwork's

The ASTM D4439 (2001) define Geosynthetics as planar products manufactured from polymeric materials (the synthetic) used with soil, rock, earth, or other geotechnical engineering related material (the geo) as an integral part of a man-made project, structure or system. Venkatappa Rao and Banerjee (1997) states that geosynthetics improve or modify the behaviour of civil engineering works, facilitate construction, ensure better performance of the structure and reduce maintenance in the long run.

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).

The various types of geosynthetics comprise of geotextiles, geogrids, geomembranes and geocomposites. Others include geonets/geomeshes as well as geomats/geowebs. Geogrids are planar structures formed by a regular network of tensile elements with apertures of sufficient size to interlock with surrounding soil or aggregate, they are mostly used for reinforcements (Holtz, 2001; Venkatappa Rao and Banerjee, 1997; ASTM D4439, 2001). The improved performance of road pavements due to geosynthetic reinforcement has been attributed to three main mechanisms namely, lateral restraint; increased bearing capacity; and the tensioned membrane effect produced by the geosynthetic when it is placed within base course or subgrade (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 subgrade with CBR of 8%, a section containing a geogrid 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 subgrade materials.

Leng (2002) placed geosynthetic between base layer and subgrade in an unpaved structure. Results indicated that reinforcement improved stress distribution transferred to the subgrade, and decreased degradation of base course and surface deformation accumulation. Gosavi et al. (2004) investigated the strength behavior of soil reinforced with mixed geogrid woven fabric and showed that the soaked CBR without the geogrid was about 4.9% and after using the geogrid, observed an improvement in the CBR value. Naeini and Moayed (2009) indicated that using a geogrid 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 geogrid 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.

Cancelli et al. (1996); Perkins and Ismeik (1997); Montanelli et al. (1997) analysed the results of a pavement test conducted on several reinforced sections by use of geogrids in saturated silty clay having CBR values of about 1% to 8%. The results showed that multi-layer geogrids provide the best base reinforcement results for sub-base soil having CBR equal to 3% or lower. No major differences were found between different single layer integral geogrids. The higher tensile modulus geogrids showed better contribution at 3% CBR or lower. The percent reduction of rutting, between reinforced and unreinforced sections, increased with reducing subgrade 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.

Montanelli et al. (1997) placed geogrid between gravel base course and sand subgrade, they showed that with increase in CBR value of subgrade, the amount of vertical settlement under loading decreases. Furthermore, the difference of settlement between reinforced and unreinforced specimen in CBR value less than 3% is much higher than the CBR value of more than 3%. Additionally the amount of settlement in reinforced specimen with 300 mm base course is less than unreinforced specimen with 400 mm base course. Kumar et al. (1999) conducted investigations on silty sand and pond ash specimens reinforced with randomly distributed polyester fibres, they concluded that the fibres increased the CBR value and ductility of the specimens.

Triax Geogrid

By examining all the design characteristics of a geogrid, through testing and research, certain factors were identified to affect its performance. These are the profile of the rib section, rib thickness, junction efficiency, aperture size and in-plane stiffness. Rigorous tests have been conducted in line with the rib directions of the geogrid. In each direction tested, the junction strength was found to be essentially equal to rib strength giving a junction efficiency of 100%. Biaxial geogrids have tensile stiffness predominantly in two directions, TriAx geogrids on the other hand have three principal directions of stiffness, which is further enhanced by their rigid triangular geometry. This produces a significantly different structure than any other geogrid and provides high stiffness through 360 degrees (Tensar, 2008).

In a mechanically stabilised layer, aggregate particles interlock within the geogrid and are confined within the apertures, creating an enhanced composite material with improved performance characteristics. The structural properties of the mechanically stabilised layer are influenced by the magnitude and depth of the confined zones. The shape and thickness of the geogrid ribs and the overall structure of TriAx have a direct influence on the degree of confinement and efficiency of the stabilised layer. TriAx geogrids have greater rib depth compared with conventional biaxial geogrids. Trafficking tests and analytical modelling were undertaken to compare performance advantages between the two forms of geogrid with various rib depths in a mechanically stabilised layer. The results were conclusive in confirming that an improved structural performance was achieved with the TriAx geogrid and its deeper rib depth and unique profile. Numerical modeling techniques confirm the importance of geogrid rib thickness on aggregate confinement and load dissipation. Determination of the suitability of Triax for any specific project however is to be made by local engineers (Tensar, 2008).

Subgrade 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 subgrade 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 subgrade 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 subgrade is not seriously underestimated for large areas of pavement or overestimated to such an extent that there is a risk of local 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 subgrade change significantly over sections of the route, different subgrade 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 subgrade strength for design is assigned to one of six strength classes reflecting the sensitivity of thickness design to subgrade strength. The subgrade 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 subgrades with CBR less than 2%, special treatment is required. The design subgrade 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 Subgrade and Traffic classes (TRL ORN 31)

Traffic classes (10^6 esa)	Subgrade strength classes (CBR%)
T1 = < 0.3	S1 = 2
T2 = 0.3 - 0.7	S2 = 3 , 4
T3 = 0.7 - 1.5	S3 = 5 - 7
T4 = 1.5 - 3.0	S4 = 8 - 14
T5 = 3.0 - 6.0	S5 = 15 - 29
T6 = 6.0 - 10	S6 = 30+
T7 = 10 - 17	
T8 = 17 - 30	

III. METHODOLOGY

Data collection

The subgrade sample was taken from a trial pit along a road under rehabilitation in Kumasi, in the Ashanti region of Ghana. The material was air dried and tested for particle size distribution, consistency limits, compaction and CBR according to the requirement set out in the Ministry of Roads and Highway, Ghana specifications for Road works and Bridges (2006). Gradation test and consistency limits were done as per ASTM D422 and ASTM D4318 respectively which are both in accordance with BS 1377-2, compaction test was carried out in the laboratory to determine the optimum moisture content and the maximum dry density of the soil sample using test method ASTM D1557 and BS 1377-4. The CBR was tested according to the test procedure as per ASTM D1883 and BS 1377-4. In order to investigate the effect of geogrid strength development in a typical subgrade material, two different samples of Tri-axial geogrids 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 geogrid samples are shown in Table 2. The choice of geogrid was limited by availability of specimens supplied by the producer. The TriAx Tx 170 geogrid has much higher structural integrity over the TriAx Tx 130s geogrid, with higher load transfer ability and load bearing capacity.

Table 2 Properties of Geogrid

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

Three moulds with compacted subgrade samples containing TriAx Tx 130s, TriAx Tx 170 and no-geogrid respectively were used for the CBR test according to ASTM D1883. The reinforced and unreinforced soil samples were tested for CBR under soaked and unsoaked conditions, using the CBR testing machine. In the soaked condition, the moulds were soaked in a drum of water with a surcharge placed on them for four (4) days. The geogrids were placed at the layer 3 level based on result reported by previous research (Naeini and Moayed, 2009) and our earlier work which showed optimal values. The experimental set-up and schematic arrangement of the samples with geogrid is shown in Figure 1.

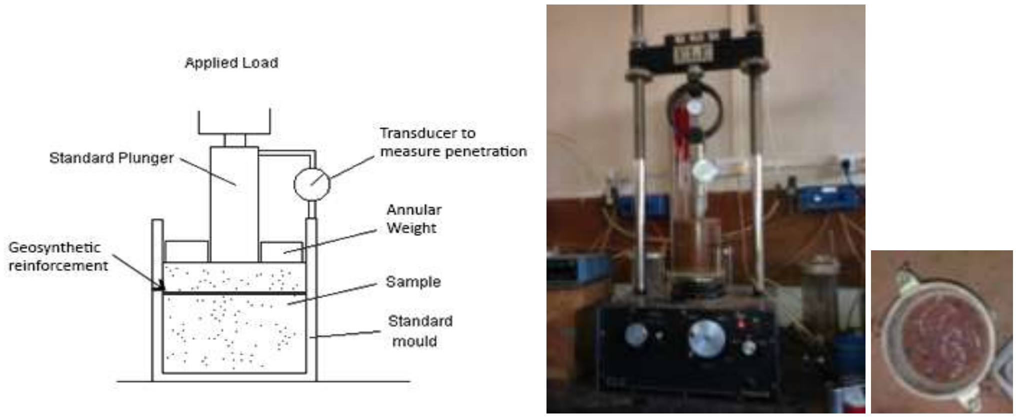

Figure 1 CBR set-up of experiment and schematic arrangement

IV. RESULTS AND DISCUSSION

Characteristics of Subgrade 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 is classified as a sandy silt material with a group symbol of SM.

Table 3 Properties of Subgrade 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 shows the variations in the CBR value and dry density of the soil sample and the sample interfaced with the geogrids under soaked and unsoaked conditions. The TriAx Tx 130s caused a 11% increase in the CBR of the soaked soil sample and 112% increase in the CBR of the unsoaked sample. The TriAx Tx 170 on the other hand increased the CBR value of the soaked sample by 72% and the unsoaked sample by 135%. We can therefore conclude that the TriAx Tx 170 has a much more pronounced effect in increasing the bearing strengths of the soil samples especially in the soaked condition where its effect was about 60% more than that of 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 Geogrid	**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 presents the variations of load-penetration curves for the soil sample without geogrid reinforcement in both soaked and unsoaked conditions as well as the load-penetration curves for the soil – geogrid samples with TriAx Tx 170 and TriAx Tx 130s geogrids 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.

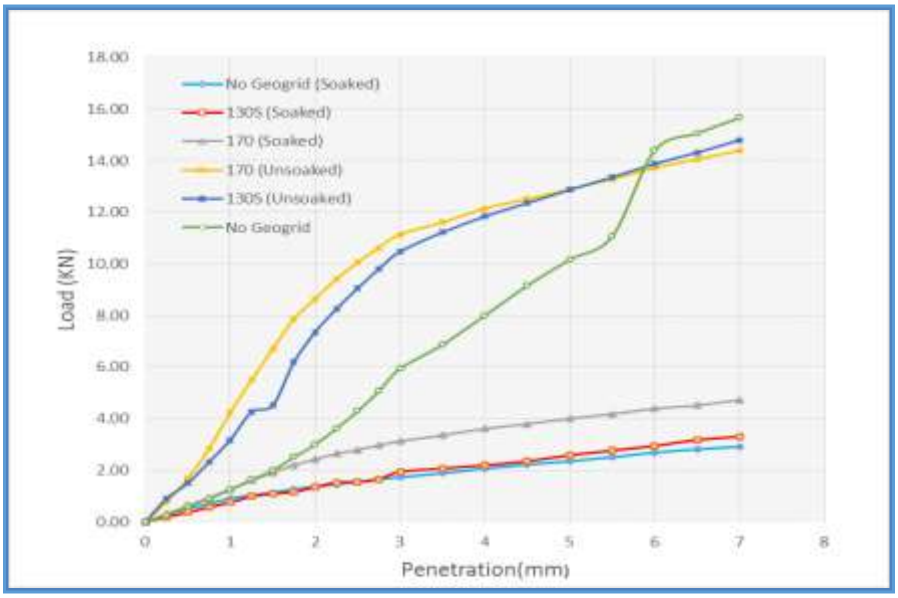

Figure 2 Penetration resistance comparison between soil-aggregate and soil-geogrid-aggregate

Effect of Geogrid Reinforced Subgrade on Pavement Thickness Design

In order to assess the effect of the geogrid reinforcements on pavement layer thickness design, the Transport Research Laboratory (1993), Overseas Road Note (ORN) 31 was used. The layer thicknesses for the subgrade sample without geogrid, as well as the subgrade sample with TriAx Tx 130s and TriAx Tx 170, were selected from the ORN 31 for a granular roadbase road with surface dressing, for traffic levels 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) respectively as shown in Table 5.

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

	Description	No Geogrid		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%
	Subgrade 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 subgrade class, when the subgrade soaked CBR is 11.6% or 12.9%, as we had for the sample without geogrid and the sample with TriAx Tx 130s respectively, the subgrade 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 geogrid 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 subgrade sample under soaked conditions.

When the subgrade was reinforced with the TriAx Tx 170 geogrid, the soaked CBR was 20% which belongs to the class S5 subgrade. 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 subgrade sample with TriAx Tx 170 geogrid 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) subgrade 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 geogrid reinforcement for a subgrade soil tends to decrease with increasing traffic volume. Base course reduction benefits accruing from the use of geogrid 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 may be pervious or in high rainfall areas.

Considering the unsoaked CBR, in all cases the unsoaked CBR including the no-geogrid option was more than 30% (subgrade class S6). This results in pavement layer (base) thicknesses of 200 mm, 225 mm and 250 mm for T4, T5 and T6 respectively. In this case, there is no need for a sub-base course for all traffic loadings. This implies that increasing strength in geogrid reinforcement used in a subgrade soil results in increasing strength of the soil in both soaked and dry conditions. Strength gain with geogrids are higher in dry or unsoaked conditions than in wet or soaked conditions, however, benefits in terms of structural gains in strength such as savings in pavement layer thicknesses with increasing geogrid 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 subgrade in dry and arid areas may not necessary result in savings in pavement thicknesses, in such areas, reinforcement with geogrid improves the subgrade 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 geogrids with different strength properties. This generally informs us that geogrid reinforcement would be very helpful in dealing with relatively poor lateritic subgrade materials by improving the strength.

V. CONCLUSION AND RECOMMENDATION

Conclusions

Based on the results of this study the following conclusions may be drawn:

- Interfacing soil with a geogrid material increases the penetration resistance and hence the CBR strength in both soaked and unsoaked conditions. Therefore the performance of a subgrade material in a pavement system is better with the inclusion of a geogrid.
- The addition of a single layer of TriAx Tx 130s geogrid 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 geogrid 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 geogrid at top of layer 3 has more effective performance in penetration resistance in unsoaked condition than soaked conditions for both geogrids.
- The introduction of TriAx Tx 130s geogrid in both soaked and unsoaked condition did not change the subgrade 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 subgrade 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) subgrade 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 geogrid reinforcement for a subgrade soil tends to decrease with increasing traffic volume.
- Base course reduction benefits accruing from the use of geogrids 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 may be pervious or in high rainfall areas.

Recommendations

Geogrids have a good potential to reduce the cost of pavement layers if weak subgrades are encountered on the alignment. On low volume paved roads, designers should consider the installation of geogrids to improve the California Bearing Ratio, reduce layer thicknesses and increase structural number of pavements.

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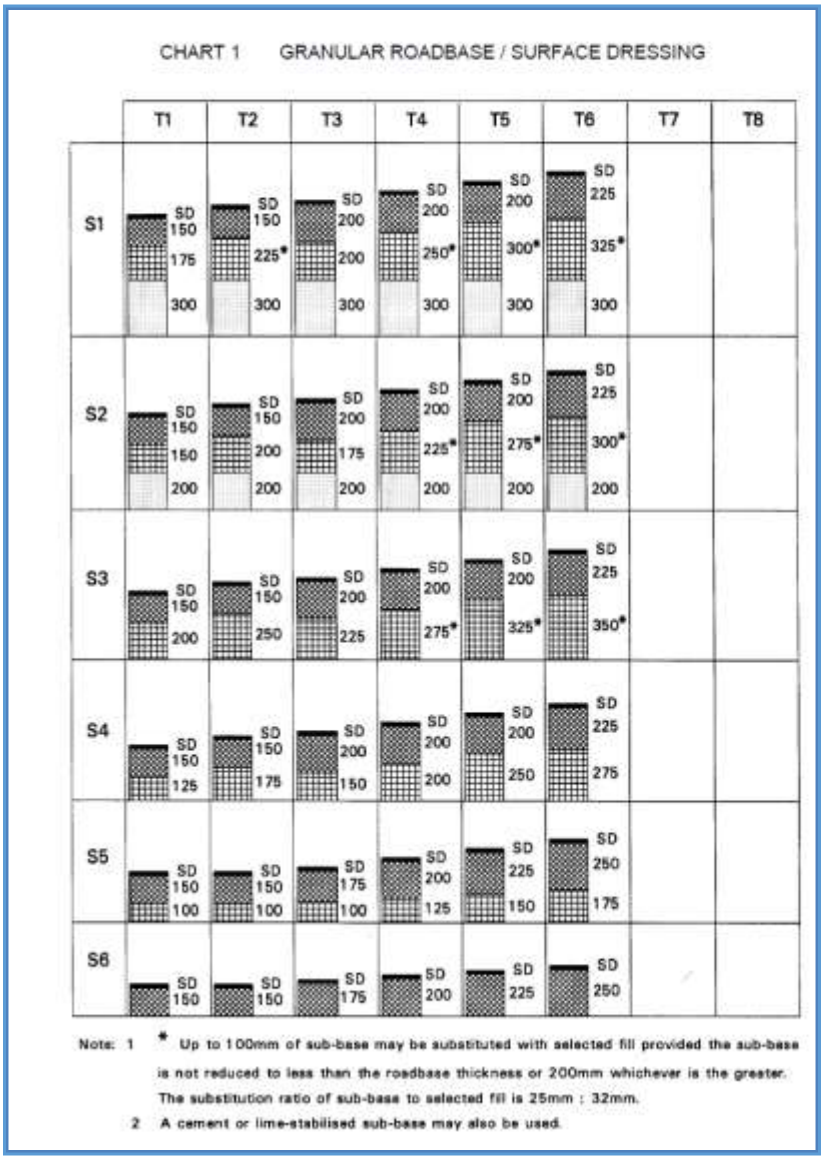

Figure 3 Structural catalogue for natural gravel sub-base and base course with surface dressing pavements (TRL Overseas Road Note 31)