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AN ANALYTICAL STUDY ON DESIGN AND ANALYSIS OF STABILISED RURAL ROADS

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Abstract: Cement and lime stabilised rural roads were modelled using CIRCLY program. Results indicate that at a particular modulus and CBR, thickness of soil-cement base and soil-lime sub-base increase with increasing allowable number of load repetitions to fatigue (N). Thickness of soil-cement base and soil-lime sub-base decrease as modulus of soil-cement and soil-lime increase. For each modulus of soil-cement base and soil-lime sub-base, as CBR is increased, thickness of soil-cement base and soil-lime sub-base decreased significantly. At a particular modulus, CBR and N, the thickness of soil-cement base for the paved road is less than that for unpaved road and that the thickness of soil-lime sub-base of paved road with granular base is considerably lower than those of soil-cement bases in both unpaved and paved roads. Finally, design curves were developed to estimate thickness of soil-cement base and soil-lime sub-base for different N-values and modulus of soil-cement and soil-lime mix.

Key Words: Stabilisation, CBR, Flexural modulus, Soil-cement base, Soil-lime sub-base

1. INTRODUCTION

The existing roads in the coastal areas of Bangladesh are mostly earthen roads and hardly water bound macadam roads not easily accessible for light traffic. Cyclone, storm surge, and floods affect almost all the coastal regions of Bangladesh every year. The roads are severely damaged due to flood, currents and wave action. This situation needs maintenance of these roads every year and due to financial constraint it is practically impossible. The usual practice of constructing the rural roads in the coastal regions is to dump the loose soil over the road formation and to render a nominal compaction of soil. These roads are subsequently exposed to rain, monsoon flood and wave actions. These adverse effects together with inadequate compaction significantly impair the durability of these roads. The ultimate effect is comparatively low subgrade strength and eventually higher pavement thickness if paved roads are to be constructed. On the basis of this context, some treatment of locally available materials has become necessary for satisfactory and economic construction of road in these regions. Cement stabilised bases or lime stabilised sub-bases may be provided for the construction of rural roads in the coastal areas for low volume, light traffic movement.

An increasing emphasis has been placed on the use of stabilised pavement materials in recent years. Through the use of stabilizing agents, low-quality materials can be economically upgraded to the extent that they may be effectively utilized in the pavement structure. Stabilised pavement materials are generally incorporated into the pavement structure as base courses and sub-bases. In a layered system of elastic materials, where the overlying layers have higher moduli of elasticity than underlying layers, tensile stresses are developed at the interfaces between the layered materials. This layered system analysis is commonly resumed to be applicable to a pavement where the stiffer materials are used in the upper layers. Since many stabilised materials are relatively weak in tension any type of rational design procedure must be taken into account their tensile strength.

The aim of pavement design is to provide the most economic support system for the traffic anticipated, considering the characteristics of the subgrade and the available construction materials. There are many different approaches to pavement design, relying to various degrees on empirical relationships, theoretical analysis, and field and laboratory testing. For analysing flexible pavements under wheel loads, the National Association of Australian State Road Authorities (NAASRA) has adopted a mechanistic design procedure based on linear elastic theory for anisotropic materials in a horizontally layered system. The response to vertical, horizontal, and rotational forces applied over circular contact areas on the surface of this system is calculated using the computer program CIRCLY developed at the Division of Geomechanics of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) of Australia. This paper presents results of analyses of cement and lime stabilised rural roads for low volume, light traffic movement modelled using CIRCLY program.

2. CIRCLY COMPUTER PROGRAM

Wardle (1976) developed the CIRCLY computer program. This program is capable of analysing multi-layered anisotropic medium subject to multiple circular loads. Provision has been made for a vertical loads with rough contact. In an investigation of a complex geomechanics system, program CIRCLY permits detailed loading conditions to be modelled economically and accurately for linear elastic material properties and simple geometry. In non-linear material properties or complex geometry are likely to be important, these effects can be estimated using a non-linear finite element program for a simplified loading system. Program CIRCLY is based on integral transform techniques and offers significant advantages over other linear elastic analysis techniques such as the finite element method. Input data for the program is much simpler than that required for most finite element programs. For most problems the program uses less computer time than a finite element program. The analytical solutions for single polynomial load types are found by integral transform methods. The integral are evaluated by Patterson's quadrature Solutions for multiple loads are obtained by superposition. The language of the program is Fortran IV.

In many soil and rock engineering problems loads are applied to the horizontal or near horizontal, surface of natural or man-made stratified deposits. Program CIRCLY calculates the stresses, strains and displacements that are developed in loaded deposits, permitting the rational assessment of the ultimate stability and the behaviour under working loads. In practice, loads may be applied to soil or rock pavement layers in the form of vertical wheel loads, horizontal wheel loads due to traction and braking, torsional wheel loads due to cornering, and the "gripping" load developed by pneumatic tyres on pavements. In addition, foundation loads on footings, piers and rafts may be applied as vertical forces, horizontal forces, moments about horizontal axes or contact stresses due to foundation roughness. The program allows all of these load types to be simulated for a circular loaded shape. As well as the usual isotropic properties, cross-anisotroic material properties have been considered. The cross-anisotropic material is assumed to have a vertical axis of symmetry. Anisotropics of this type have been observed in soil and rock deposits due to processes involved in their formation.

The input for the program is in the form of three data blocks, viz., geometry and magnitude of applied loads, thickness and elastic properties of layered system and co-ordinate points at which results are required. This input structure allows the solution of more than one problem in a single run and minimizes unnecessary duplication of input data. The output consists of all input parameters together with the results in the form of stresses, strains and displacements expressed in rectangular coordinate system at specified points. Optionally, stress and strain invariants such as principal strains and stresses can be calculated.

3. MECHANISTIC DESIGN PROCEDURE

In summary, the NAASRA procedure consists of the following (NAASRA, 1987):

(i) Selection of a trial pavement including the number of layers and thickness of all layers overlying the subgrade.

(ii) Selection of design loading (traffic) and determination of vertical stress (i.e., tyre contact pressure) and radius of the tyre contact area.

(iii) Determination of the elastic parameters of asphalt which includes flexural modulus and Poisson's ratio.

(iv) Determination of the following elastic parameters of the subgrade: vertical modulus, horizontal modulus, Poisson's ratio (vertical), Poisson's ratio (horizontal and cross) and shear modulus.

(v) Determination of the elastic parameters of the unbound granular sub-layer as mentioned in step (iv) and cemented materials (e.g. cement and lime stabilised layers) which includes flexural modulus and Poisson's ratio.

(vi) Adopting the fatigue criterion for the asphalt, cemented and subgrade layers.

(vii) Determination of the allowable number of load repetitions before unacceptable rutting or fatigue cracking occurs using the mathematical relationships for the fatigue criterion for the asphalt, cemented layer and subgrade.

(viii) The minimum allowable number of load repetitions before unacceptable rutting or fatigue cracking occurs using fatigue criterion for the asphalt, cemented layer and subgrade will be the allowable number of load repetitions to fatigue to be used for design.

The design procedure is based on the structural analysis of a multi-layered pavement subject to traffic loading. Salient features of the assumed model are as follows (NAASRA, 1987):

(i) Pavement materials are considered to be homogeneous, elastic and isotropic (except for unbound granular materials and subgrade)

(ii) Response to loading is calculated using linear elastic theory and specifically the computer program CIRCLY.

(iii) The design is based on the criteria that strains at three critical locations do not exceed certain values. These limiting strains are, shown in Fig. 1, are as follows:
- The horizontal tensile strain ε_1 at bottom of the asphalt layer
- The horizontal tensile strain ε_2 at bottom of the cemented layer
- Vertical compressive strain ε_3 at the top of the subgrade

(iv) For flexible pavements, the critical responses within the pavement will occur on the vertical axis directly under one wheel or on the vertical axis located symmetrically between a pair of dual wheels.

(v) The contact stress is related to the tyre pressure and is assumed to be in the range 550 kPa to 700 kPa.

(vi) The thickness and properties of granular layers are to be such that tensile stresses will not be generated in such materials.

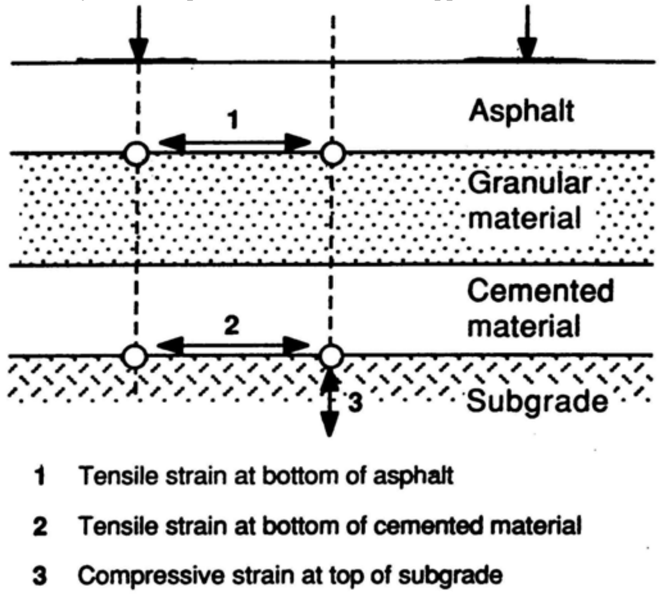

Figure 1. Pavement Model for the NAASRA Design Procedure (after NAASRA, 1997)

4. ANALYSIS AND DESIGN OF SOIL-CEMENTAND SOIL-LIME RURAL ROADS

Analyses were carried out for rural roads in the coastal areas having maximum width of 2.5 m. Following three types of pavement structures have been modelled using the computer program CIRCLY:

(i) Unpaved soil-cement roads, i.e., continuous soil-cement base directly supported over untreated natural sudgrade
(ii) Paved soil-cement roads, i.e., continuous soil-cement base overlying the untreated natural sudgrade and underlying an asphalt wearing surface
(iii) Paved soil-lime roads, i.e., continuous soil-lime sub-base overlying the untreated natural sudgrade and underlying an unbound granular base with an asphalt wearing surface at the top.

Schematic diagrams of the three different types of pavement structures modelled are shown in Fig. 2. Figs. 2(a), 2(b) and 2(c) show the structures of unpaved soil-cement road, paved soil-cement road with asphalt wearing surface and paved soil-lime road with unbound granular base and asphalt wearing surface respectively. Rajbongshi (1997) has reported details of analyses. The unpaved and paved roads have been assumed to subject design traffic loading of Light Cross County Vehicle (LCCV), i.e., jeep. LCCV is a single axle vehicle. The total axle load is 24 kN which is supported by two tyres of the axle. Therefore, the total load supported by each tyre of the axle is 12 kN. For LCCV, the tyre contact pressure in each tyre of the axle is 280 kPa. It has been assumed that the tyre contact pressure is uniform over the imprint area. Assuming circular tyre imprints, the radius of contact area of each tyre of the axle has been calculated from the following expression (NAASRA, 1987):

$$R_c = \sqrt{\frac{p_T}{\pi p_c}} \tag{1}$$

where, R_c = radius of contact area of tyre;
P_T = total load on each tyre of axle; and
p_c = tyre contact pressure

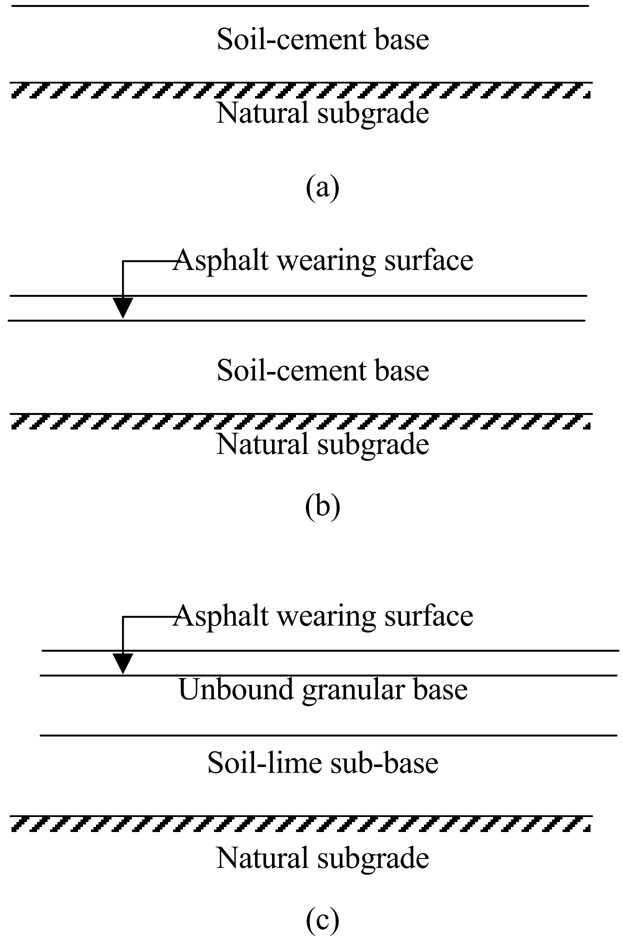

Figure 2. Schematic Diagram for Three Different Types of Road Structures (a) Unpaved Road with Soil-Cement Base (b) Paved Road with Soil-Cement Base and Asphalt Wearing Surface (c) Paved Road with Unbound Granular Base, Soil-Lime Sub-Base and Asphalt Wearing Surface

5. INPUT PARAMETERS FOR PAVEMENT LAYERS

All the pavement interface layers have been assumed to be rough. The asphalt wearing surface, soil-cement base and soil-lime sub-base have been assumed to be homogeneous, elastic and isotropic. In all the analyses of paved roads, the values of flexural modulus of asphalt and Poisson's ratio were set at 750 MPa (an average value for asphalt temperature between 30°C and 40°C) and 0.4 respectively. The thickness of the asphalt wearing surface have been kept constant in all paved road analyses with soil-cement base and soil-lime sub-base. The thickness of the asphalt wearing surface was taken as 38 mm (1.5 inch).

For both unpaved and paved roads with soil-cement base, analyses were carried out with flexural modulus equal to 300 MPa, 500 MPa and 750 MPa which were higher than the maximum value of laboratory measured flexural modulus of cement-treated sample obtained from flexural strength tests using simple beam with third point loading system. For the analyses of paved road with soil-lime sub-base and unbound granular base, flexural modulus of soil-lime sub-base have been set at equal 150 MPa, 300 MPa and 500 MPa which were also higher than the maximum value of laboratory measured flexural modulus of sample treated with lime, as obtained from flexural strength tests using simple beam with third point loading system. In each analysis unpaved and paved roads with soil-cement base and soil-lime sub-base, a typical value of Poisson's ratio of soil-cement and soil-lime has been taken as 0.2.

The natural subgrade materials and unbound granular materials have been assumed to be homogeneous, elastic and cross-anisotropic. The elastic parameters required for anisotropic layer are as follows:

- Three moduli, namely vertical modulus, horizontal modulus and shear modulus
- Two Poisson's ratio, namely, vertical Poisson's ratio and, horizontal and cross Poisson's ratio.

Three CBR-values of 5, 10 and 15 corresponding to 80%, 90% and 95% compaction of the subgrade soil have been taken for analysing each type of pavement structure. These values were estimated from the CBR - dry density relationships of the subgrade soil. The vertical moduli (E_v) of the subgrade was estimated from its respective CBR-value which is bases on the following empirical relationship:

$$E_v(\text{MPa}) = 10\,\text{CBR} \tag{2}$$

Equation 2 is at best an approximation and modulus has been found to vary in the range of 5 to 20 times CBR (Sparks and Potter, 1982). A maximum valued of 150 MPa is normally used for subgrade materials. For the unbound granular material (base-quality gravel), a typical value of vertical modulus of 400 MPa has been taken. A degree of anisotropy of 2 has been assumed for both the subgrade and unbound granular base and accordingly the horizontal modulus (E_h) of the subgrade and unbound granular base was estimated from the following equation:

$$E_h = \frac{1}{2}E_v \tag{3}$$

Both Poisson's ratios of the subgrade and unbound granular base were taken to be equal. Typical values of Poisson's ratios of 0.45 and 0.35 were set for the subgrade and unbound granular base. The shear modulus of the subgrade and unbound granular base was determined from the following equation:

$$\text{Shear Modulus} = \frac{E_v}{1+\nu} \tag{4}$$

In case of unpaved and paved roads with soil-cement base, for each CBR of subgrade and modulus of soil-cement base a number of analyses were carried out with varying thickness of the soil-cement base. Similarly, in case of paved roads with soil-lime sub-base, for each CBR of subgrade and modulus of soil-lime sub-base a number of analyses were carried out with varying thickness of the soil-lime sub-base. In each of these analyses, the thickness of the unbound granular base has been kept constant. The thickness of the granular base was 100 mm.

6. FATIGUE CRITERIA USED FOR PAVEMENT LAYERS

The limiting strains at the pavement interface layers are related to number of allowable load repetitions (N) before unacceptable rutting or fatigue cracking occurs. Critical responses, as mentioned earlier, are assessed for pavement and subgrade materials which are as follows:

Asphalt :	horizontal tensile strain at bottom of layer
Cemented layer :	horizontal tensile strain at bottom of layer
Subgrade :	vertical compressive strain at the top of the subgrade

In the unbound granular layer, no tensile stresses exist and compressive stresses do not create a problem either. This layer is not critical in terms of strain and therefore not considered in the model (NAASRA, 1987).

6.1 Asphalt Fatigue Criteria

The general relationship between the maximum tensile strain in asphalt produced by a specific load and the allowable number of repetitions of that load is given by the following expression (NAASRA, 1987):

$$N = \left[\frac{6918(0.856V_B + 1.08)}{E_{mix}^{0.36} \varepsilon_1} \right]^5 \tag{5}$$

where, N = allowable number of load repetitions to fatigue

ε_1 = the tensile strain (in microstrain) at the bottom of the asphalt layer

V_B = percentage by volume of bitumen in the asphalt

E_{mix} = Modulus (stiffness) of asphalt mix in MPa

For typical asphalt mixes containing 5 percent bitumen by mass (approximately 12 percent by volume) the fatigue criteria for a range of mix stiffness have been reported by NAASRA (1987). Substituting the values of asphalt modulus of 750 MPa (an average value for asphalt temperature between 30°C and 40°C) and V_B = 12%, as assumed in the present analyses, in equation 5, the fatigue criteria for the asphalt layer is given by the following expression:

$$N = \left[\frac{7245}{\varepsilon_1} \right]^5 \tag{6}$$

6.2 Fatigue Criteria for Cemented Materials

Fatigue relationships have been derived for cemented materials for various moduli and may be used to give an indication of fatigue life for cemented materials. NAASRA (1987) reported fatigue relationships for cemented materials. The relationship between the maximum tensile strain in cemented materials produced by a specific load and the allowable number of repetitions of that load is given by the following expression (NAASRA, 1987):

$$N = \left[\frac{K}{\varepsilon_2} \right]^{18} \tag{7}$$

where, N = allowable number of load repetitions to fatigue

ε_2 = the tensile strain (in microstrain) at the bottom of the soil-cement or soil-lime layer

K = fatigue constant depending on modulus of cemented materials

The values of K for the soil-cement and soil-lime layers have been determined by extrapolation of the relationship of fatigue of cemented materials reported by NAASRA (1987). The extrapolated values of K have been estimated as 385, 370, 360 and 340 for moduli of 150 MPa, 300 MPa, 500 MPa and 750 Mpa, respectively.

6.3 Subgrade Fatigue Criteria

The following equation for the limiting strain criterion for the subgrade has been used (NAASRA, 1987):

$$N = \left[\frac{8511}{\varepsilon_3}\right]^{7.14} \tag{8}$$

where, N = allowable number of load repetitions to fatigue
ε_3 = the vertical compressive strain (in microstrain) at the top of the subgrade

Equation 8 was derived by applying the mechanistic design procedure to a range of pavements and represents a "best fit" relationship. Use of the criteria shown in equation 8 in the mechanistic design procedure adopted produce designs that are generally consistent with observed performance of pavements.

7. RESULTS AND DISCUSSIONS

For a particular CBR of subgrade and modulus of soil-cement base and soil-lime sub-base, a number of analyses were performed with varying thickness (t) of soil-cement base and soil-lime sub-base. Using the fatigue criteria as shown in Equations 6, 7 and 8, the allowable number of load repetitions to fatigue (N) for each thickness of soil-cement base and soil-lime sub-base were determined for use in design.

7.1 Unpaved and Paved Soil-Cement Roads

Thickness of soil-cement base versus allowable number of load repetitions to fatigue (i.e., N) for CBR values of 5, 10 and 15 were plotted for unpaved and paved roads. Thickness of soil-cement base versus N plots for subgrade CBR-values of 5 and 15 for the unpaved cement stabilised road are shown in Figs. 3 and 4, respectively while Figs. 5 and 6 show the respective plots for paved road. It can be seen from Figs. 3 to 6 that for each modulus, thickness of soil-cement base increases with increasing allowable number of load repetitions to fatigue. At any particular value of N, the values of thickness of soil-cement base reduce as modulus of soil-cement base increases. Comparing the curves in Figs. 3 and 4, it can be seen that for each modulus, as CBR increased from 5 to 15, the thickness of soil-cement base reduced markedly for any particular value of N. For example, it has been found from the curves in Figs. 3 and 4 that for unpaved road at a modulus of 500 MPa and for N = 10^4 and 10^7 repetitions, as CBR is increased from 5 to 15, the thickness of soil-cement base reduced markedly from 230 mm to 165 mm (i.e. 28.3% reduction in thickness of soil-cement base) and 295 mm to 215 mm (i.e. 27.1% reduction in thickness of soil-cement base), respectively. For paved road, it has been was that at modulus of 500 MPa and for N = 10^4 and 10^7 repetitions, as CBR is increased from 5 to 15, the thickness of soil-cement base reduced markedly from 195 mm to 120 mm (i.e. 38.5% reduction in thickness of soil-cement base) and 260 mm to 180 mm (i.e. 30.8% reduction in thickness of soil-cement base), respectively. It, therefore, appears that for a particular modulus of soil-cement mix, the degree of reduction in the thickness of soil-cement base with the increase in CBR is higher in paved road than in unpaved road. Comparing Figs. 3 and 4 with Figs. 5 and 6, it is also evident that for all values of modulus, CBR and N, the thickness of soil-cement base for the paved road with asphalt wearing surface is less than that for unpaved road. For example, at modulus = 750

MPa, CBR = 15 and N = 10^7, the thickness of soil-cement base of unpaved road reduced from 200 mm to 165 mm for paved road (i.e. 17.5% reduction in thickness of soil-cement base). Using the data from the plots of thickness of soil-cement base versus N, design curves for unpaved road for CBR-values of 5, 10 and 15 were developed. Typical design curves for unpaved road (CBR = 5) for paved road (CBR = 15) are shown in Fig. 7 and Fig. 8, respectively. To develop design curves at any CBR and N, thickness of stabilised base were estimated for only three modulus values and these three data points were connected by straight line which resulted bilinear curves as shown in Figs. 7 and 8. If, however, thickness of stabilised base for a large number of modulus would have been evaluated, the resulting design curves could be linear in shape. It can be seen from Figs. 7 and 8 that at any CBR and N, the thickness of soil-cement base reduces as modulus increases. Using the design curves, thickness of soil-cement base for unpaved and paved roads with subgrade CBR values of 5, 10 and 15, and subjected to design traffic loading of LCCV could be estimated for different values of N and modulus of soil-cement mix.

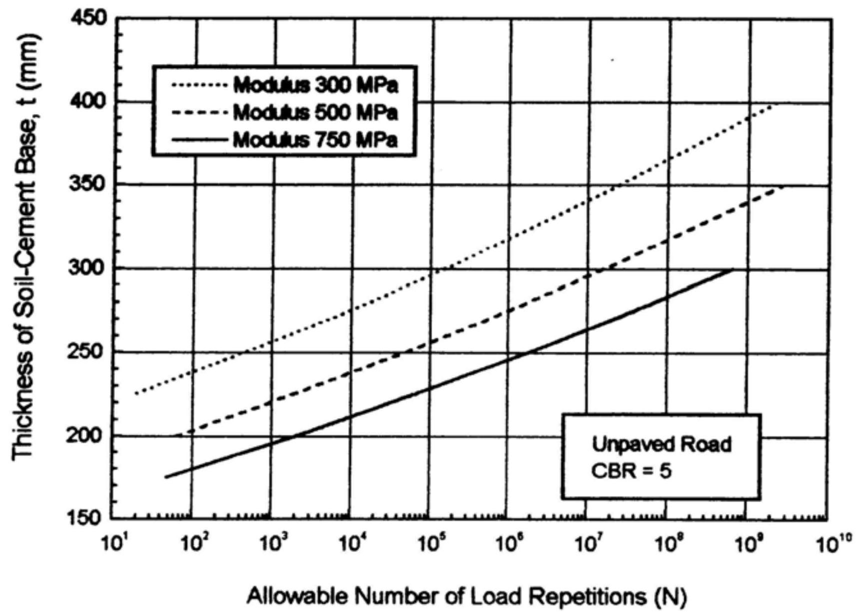

Figure 3. Effect of Soil-Cement Thickness on N for Unpaved Road (CBR = 5)

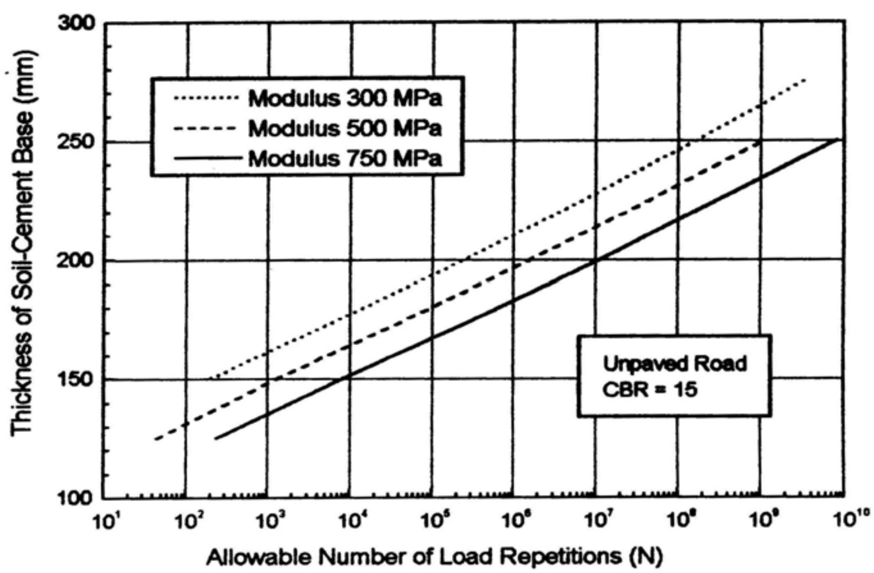

Figure 4. Effect of Soil-Cement Thickness on N for Unpaved Road (CBR = 15)

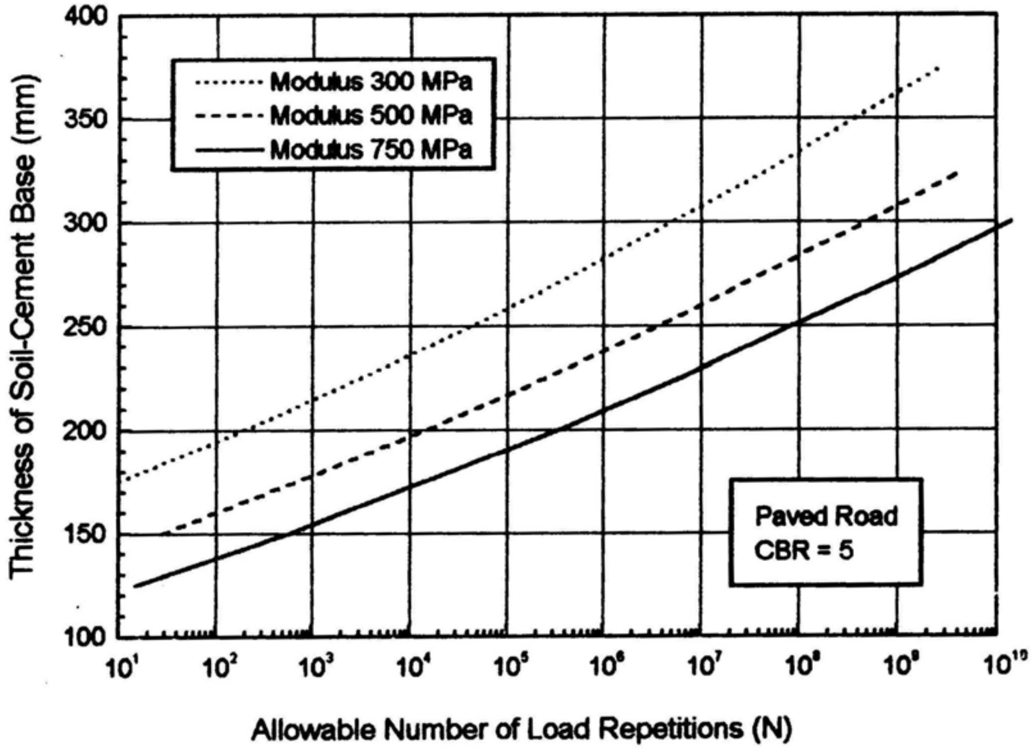

Figure 5. Effect of Soil-Cement Thickness on N for Paved Road (CBR = 5)

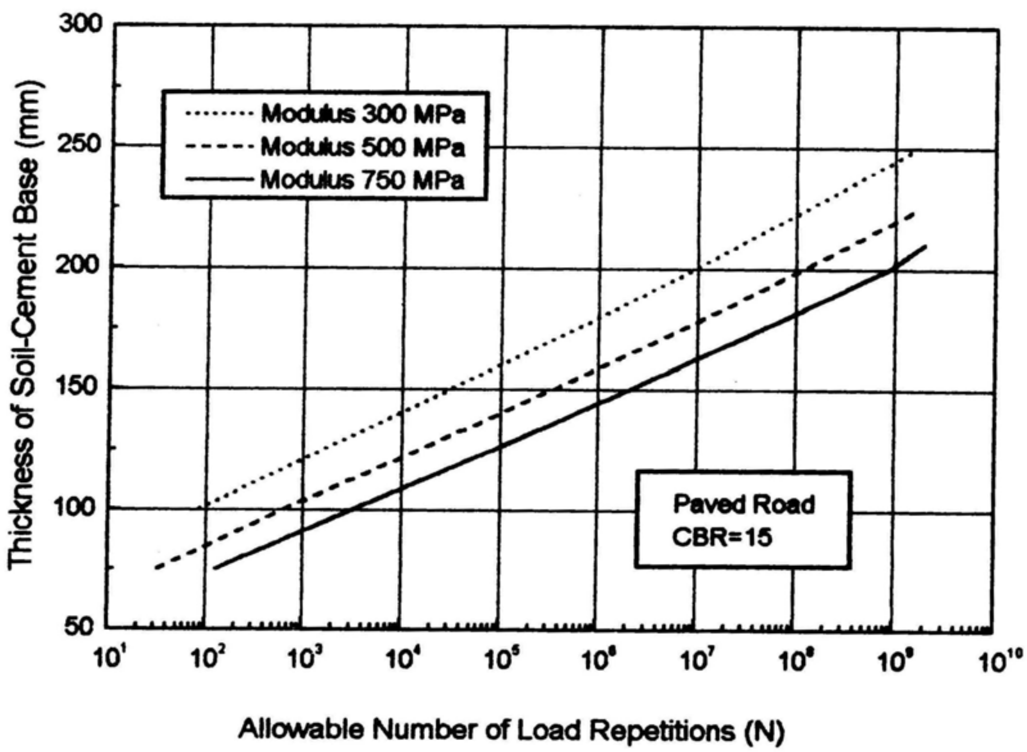

Figure 6. Effect of Soil-Cement Thickness on N for Paved Road (CBR = 15)

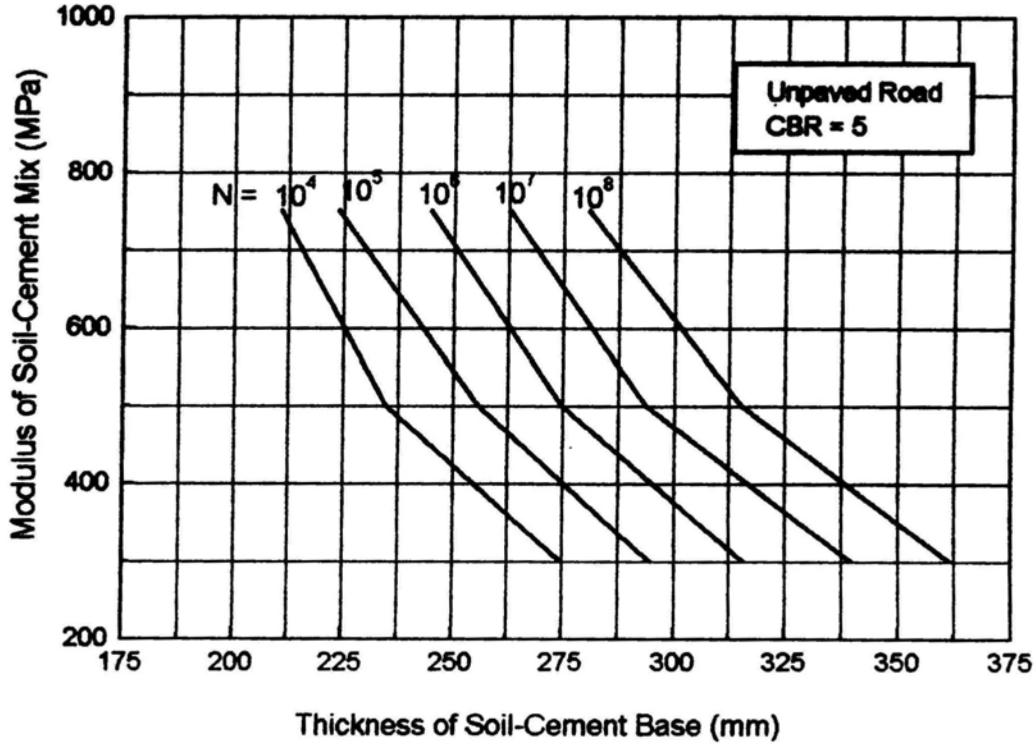

Figure 7. Design Curves for Unpaved Soil-Cement Road (CBR = 5)

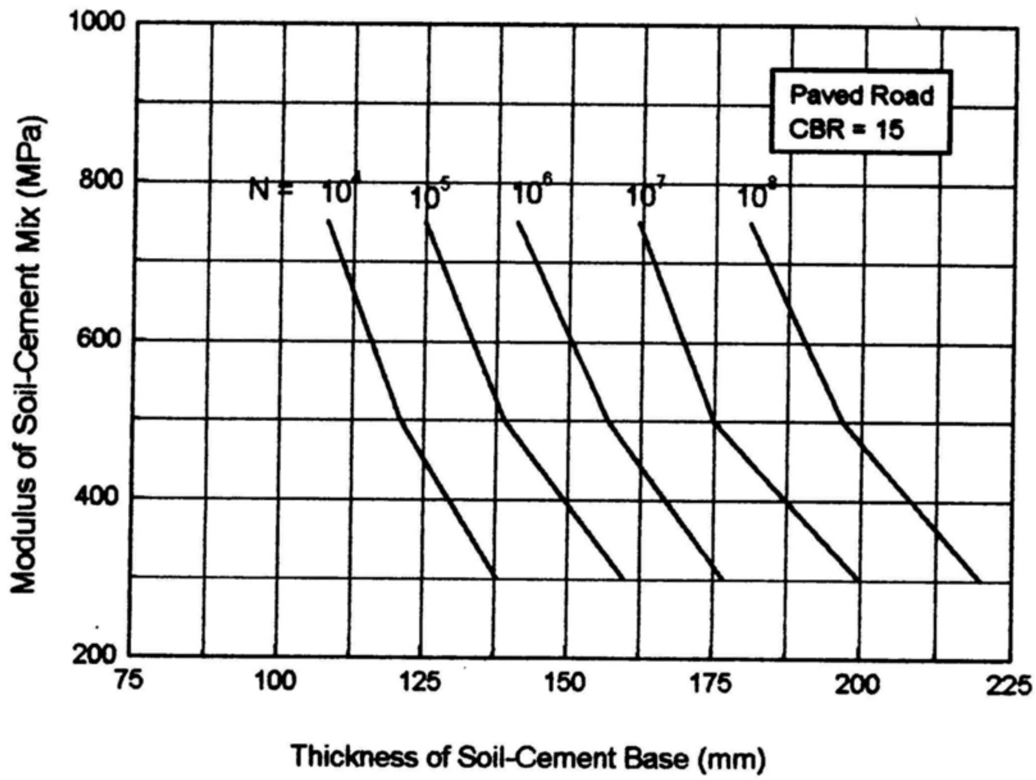

Figure 8. Design Curves for Paved Soil-Cement Road (CBR = 15)

7.2 Paved Soil-Lime Roads

Thickness of soil-lime sub-base versus allowable number of load repetitions to fatigue (i.e., N) for CBR values of 5, 10 and 15 were plotted. The thickness of soil-lime base versus N plots for subgrade CBR-values of 5 and 15 for the paved soil-lime road with granular base are shown in Fig. 9 and Fig. 10, respectively. It can be seen from Figs. 9 and 10 that for each modulus, thickness of soil-lime sub-base increases with increasing N and that for any particular value of N, the values of thickness of soil-lime sub-base reduces as modulus of soil-lime sub-base increases. Comparing the plots in Figs. 9 and 10, it can be seen that for each modulus, as CBR increased from 5 to 15, the thickness of soil-lime sub-base reduced for any particular value of N. For example, it has been found that at N = 10^4 and 10^7 repetitions and at a modulus of 300 MPa of the soil-lime sub-base, as CBR is increased from 5 to 15, the thickness of soil-lime sub-base reduced significantly from 240 mm to 45 mm (i.e., 81.3% reduction thickness of soil-lime sub-base) and 295 mm to 100 mm (i.e., 66.1% reduction thickness of soil-lime sub-base), respectively. Using the data from the plots of thickness of soil-lime sub-base versus N, design curves for unpaved roads for CBR-values of 5, 10 and 15 were developed for different values of N which are shown in Figs. 11, 12 and 13, respectively. Again because of considering few data points (only three) for each values of N and are connected by straight lines, the resulting design curves are bilinear in shape. If, however, thickness of stabilised sub-base for large number of modulus would have been evaluated, the resulting design curves could be linear in shape. The design curves in Figs. 11 to 13 show that at any CBR and N, the thickness of soil-lime sub-base reduces as modulus increases. The thickness of soil-lime sub-base for paved roads with subgrade CBR-values of 5, 10 and 15, and subjected to design traffic loading of LCCV could be estimated by using the design curves shown in Figs. 13 to 15 for different values of N and modulus of soil-lime mix.

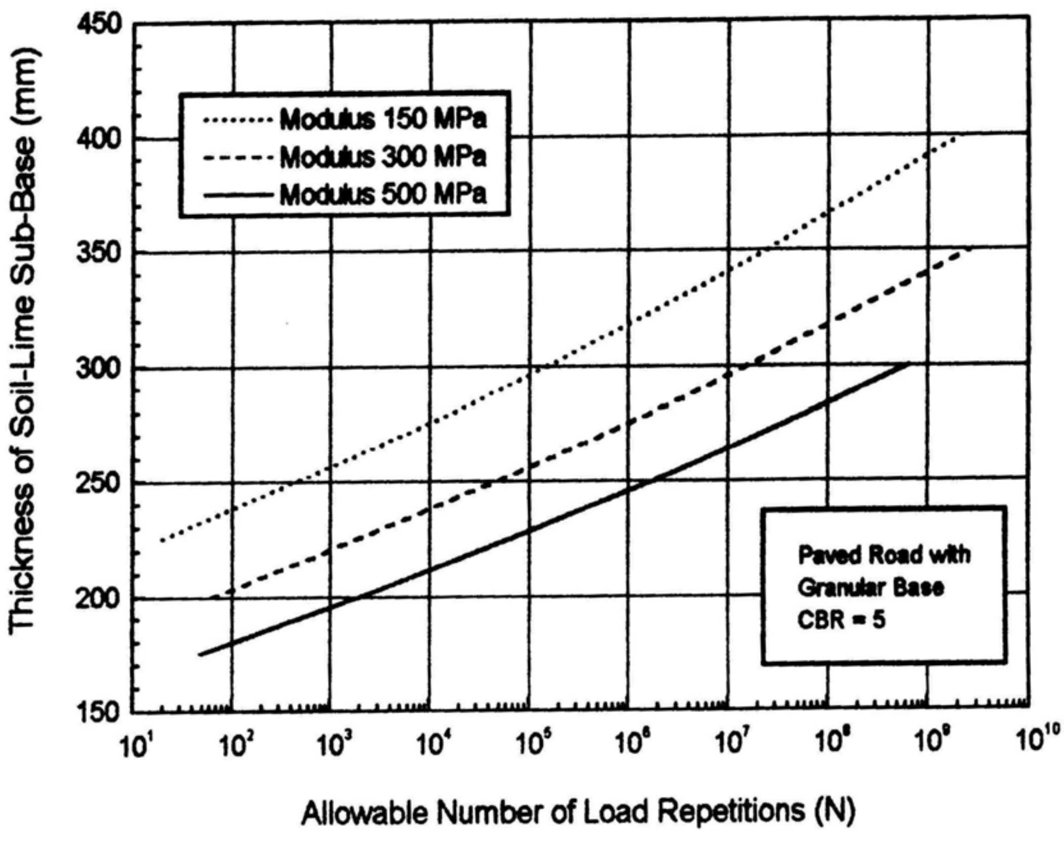

Figure 9. Effect of Thickness of Soil-Lime Sub-Base on N (CBR = 5)

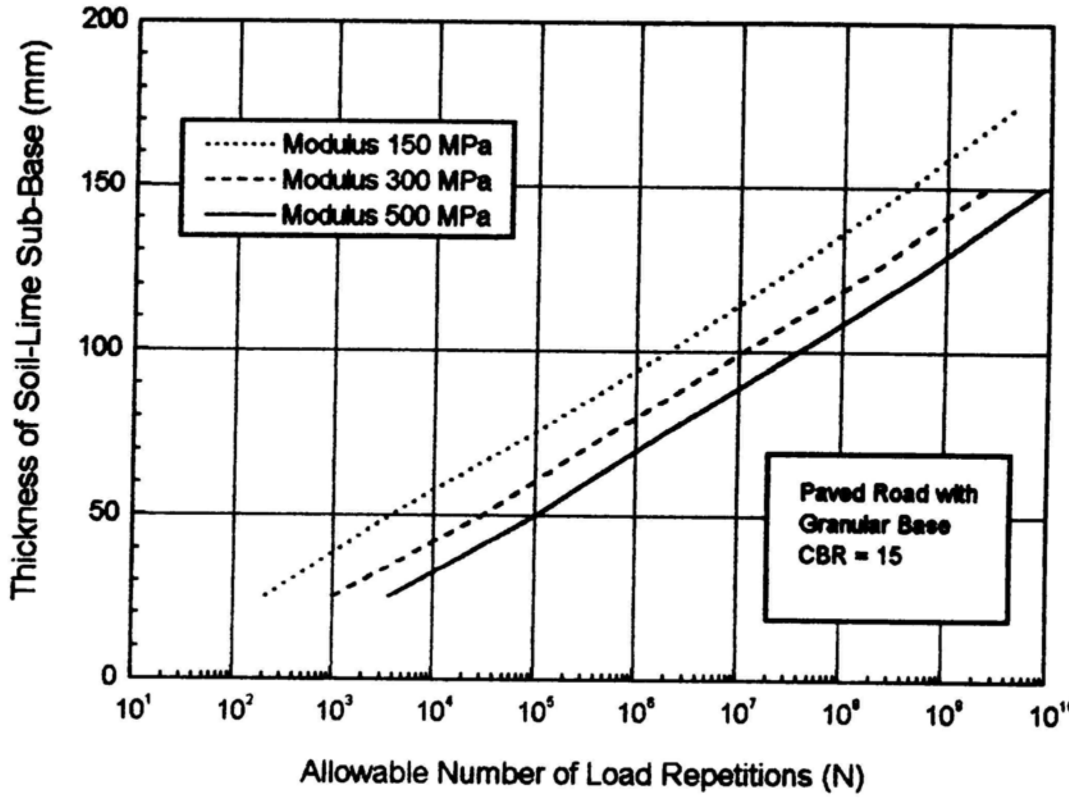

Figure 10. Effect of Thickness of Soil-Lime Sub-Base on N (CBR = 15)

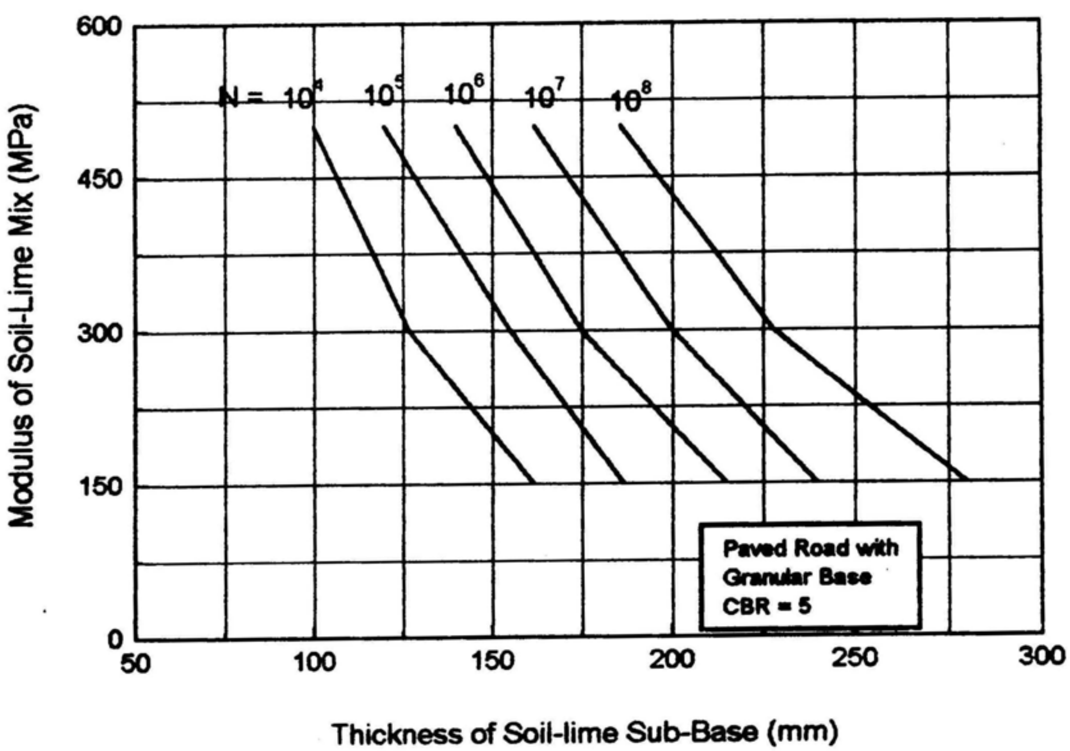

Figure 11. Design Curves for Soil-Lime Paved Road with Granular Base (CBR =5)

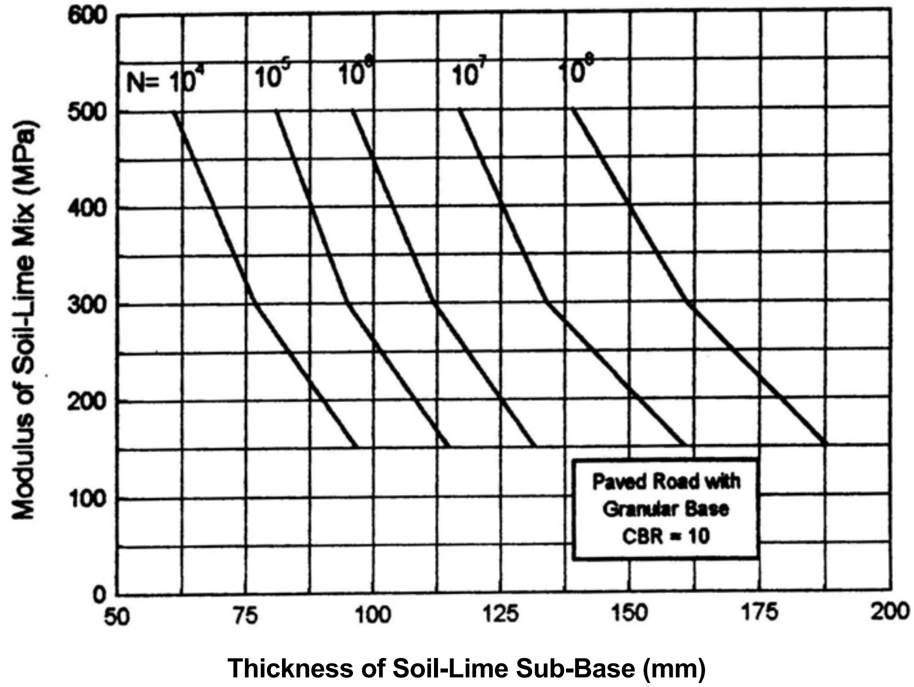

Figure 12. Design Curves for Soil-Lime Paved Road with Granular Base (CBR = 10)

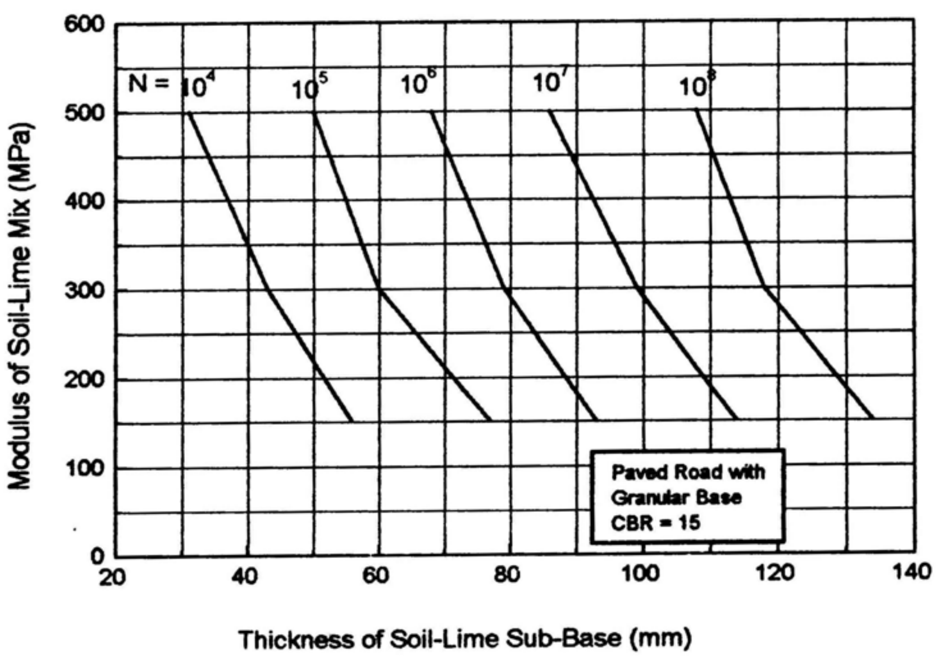

Figure 13. Design Curves for Soil-Lime Paved Road with Granular Base (CBR = 15)

7.3 Comparisons of Thickness of Cemented Layers for Unpaved and Paved Roads

Table 1 shows a comparison of the thickness of cemented layers (i.e., soil-cement base and soil-lime sub-base) of unpaved road, paved road with asphalt wearing surface and paved road with granular base and asphalt wearing surface for a particular allowable load repetitions value of 10^6 and modulus of cemented materials of 300 MPa and 500 MPa and for different CBR values (5, 10 and 15). The thickness of the cemented material was estimated from the design curves of the unpaved and paved roads presented earlier. The figures in the parentheses in Table 1 indicate the total thickness of the road. It can be observed from Table 1 that the thickness of soil-lime sub-base of paved road with granular base are considerably lower than those of soil-cement bases in both unpaved and paved roads. For example, it has been found that at allowable load repetitions of 10^6, CBR value of 10 and for modulus values of 300 MPa and 500 MPa of the cemented materials, the thickness of lime-stabilised layer of soil-lime paved road with granular base are respectively about 45% and 48% less than those for the paved road with soil-cement base. Table 1 also shows that, as mentioned earlier, the thickness of soil-cement base of unpaved road are lower than those of the thickness of soil-cement base of paved road with asphalt wearing surface.

It can be seen from Table 1 that at a particular modulus of cemented material and CBR of subgrade, the total thickness of unpaved road with soil-cement base and paved road with soil-cement base is about the same which indicates that the thickness of soil-cement layer of the paved road is reduced by an amount equal to the thickness of the asphalt wearing surface provided. Although, the total thickness of the unpaved and paved road with soil-cement base are approximately the same, it could be mentioned that the paved road would offer more resistance to deformation and would be more durable under existing traffic loading and weather conditions. However, the unpaved road would definitely be more cost-effective compared with the paved road. Table 1 also shows that at a particular modulus of cemented material and CBR of subgrade the total thickness of the paved road with soil-cement base and the paved road with soil-lime sub-base and unbound granular base is approximately the same. This observation indicates that compared with the thickness of the soil-cement base, the thickness of the soil-lime sub-base has been reduced by an amount equivalent to the thickness of the unbound granular base. Although, it is rather difficult to predict the relative durability of these two types of roads but it seems that the paved road with soil-cement base would be more economical than the paved road with soil-lime sub-base and granular base.

Table 1 Comparisons of Thickness of Cemented Layers for Different Types of Roads At Allowable Load Repetitions of 10^6

Modulus of Cemented Material (MPa)	CBR of Natural Subgrade	Thickness of Cemented Layer (mm)		
		Unpaved Road	Paved[1] Road	Paved[2] Road
300	5	315 (315)	280 (318)	175 (313)
	10	254 (254)	218 (256)	120 (258)
	15	211 (211)	177 (215)	78 (216)
500	5	275 (275)	236 (274)	144 (282)
	10	226 (226)	190 (228)	98 (236)
	15	196 (196)	158 (196)	70 (208)

1 Paved road with soil-cement base and asphalt wearing surface
2 Paved road with soil-lime sub-base, granular base and asphalt wearing surface.

8. CONCLUSIONS

Analyses were carried out on unpaved road with soil-cement base, paved road with soil-cement base and paved road with soil-lime sub-base and unbound granular base. All these road structures, having maximum width of 2.5 m and subjected to design traffic loading of Light Cross County Vehicle (LCCV) were modelled using the computer program CIRCLY. The major findings and conclusions obtained from the analyses can be summarised as follows:

- At a particular modulus and CBR, the thicknesses of soil-cement base (for both unpaved and paved road) and soil-lime sub-base increase with increasing allowable number of load repetitions to fatigue.
- At any particular value of allowable number of load repetitions to fatigue (N), the values of thicknesses of soil-cement base (for both unpaved and paved road) and soil-lime sub-base reduce as modulus of soil-cement base and soil-lime sub-base increase.
- For each modulus of soil-cement base and soil-lime sub-base, as CBR increased from 5 to 15, the thickness of soil-cement base (for both unpaved and paved road) and soil-lime sub-base reduced significantly for any particular value of N.
- Design curves have been developed for the three types of roads and it has been found that, in general, at any CBR and N, the thickness of cemented layer reduced as modulus of the cemented layer increased. Using these design curves, the thickness of soil-cement base (for unpaved and paved roads) and the thickness of soil-lime sub-base for paved road with subgrade CBR = 5, 10 and 15, and subjected to design traffic loading of LCCV could be estimated for different values of allowable load repetitions and modulus of soil-cement and soil-lime mix.
- At any particular values of modulus, CBR and N, the thickness of soil-cement base for the paved road with asphalt wearing surface are less than that for unpaved road and that the thickness of soil-lime sub-base of paved road with granular base is considerably lower than those of soil-cement bases in both unpaved and paved roads. It has been found that at a particular modulus of cemented material and CBR of subgrade, the total thickness of unpaved road with soil-cement base, paved road with soil-cement base and paved road with soil-lime sub-base and unbound granular base is approximately the same.
- The thickness of different types of rural roads (i.e., unpaved road with soil-cement base, soil-cement paved road and soil-lime paved road with granular base) have been predicted on basis of the results obtained by modelling the different types of roads using CIRCLY computer program. It deserves mentioning that the applicability of these results could only be verified by constructing similar trial roads and subsequently monitoring their performance under imposed loading and prevailing environmental conditions.

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