Pavement Design for Rural Low Volume Roads Using Cement and Lime Treatment Base

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ABSTRACT

Quantity road aggregates have become rare and costly in many places in India due to massive construction activities required for the development of new infrastructure facilities. The pavement industry looks for ways of improving lower quality materials that are readily available for use in roadway construction. Cement/ lime treatment has become an accepted method for increasing the strength and durability of soils and marginal aggregates, reducing quantity of aggregates. Indian Roads Congress (IRC) developed a Special Publication (SP) for mix design of lime/cement treated base/subgrade. No pavement design guideline is presently available for cement/lime treated base. To overcome this problem, the objective of the present research work is to develop a pavement design chart using cement and lime stabilized base for rural roads with light to medium traffic (Traffic level up to 5 million standard axles). Based on this objective ,the scope of the present research work is limited to develop a pavement design chart varying California Bearing Ratio (CBR) of subgrade and thickness of stabilized material as well as axle load repetition up to 5 million standard axles (MSA).Charts have been developed using FPAVE software. Results indicated that at known particular resilient modulus of stabilized base and CBR of subgrade, thickness of soil-cement base and that of soil-lime sub-base increase with increasing the allowable number of load repetitions. Thickness of soil-cement base and that of soil-lime sub-base decrease as moduli of soil-cement base and soil-lime base increase. For each modulus of soil-cement base and soil-lime sub-base, as CBR is increased, thickness of soil-cement base and that of soil-lime sub-base decreased significantly. At a particular resilient modulus, CBR and N, the thickness of soil-cement base is less than that of granular base. Finally, design curves have been developed to estimate thickness of soil-cement base and that of soil-lime sub-base for different N-values and different values of modulus of soil-cement and soil-lime mix.

KEYWORDS: Stabilization, CBR, Flexural modulus, Soil-cement base, Soil-lime sub-base, Low volume road, Unpaved road.

INTRODUCTION

Some portions of the existing rural roads in India are unpaved/low volume roads. Heavy rainfall and floods affect almost all these roads frequently. The roads are severely damaged due to flood, currents and wave action. This situation needs maintenance of these roads every year/frequently. 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

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necessary for satisfactory and economic construction of roads in these regions. Cement stabilized bases or lime stabilized sub-bases may be provided for the construction of rural roads for low volume/ light traffic. An increasing emphasis has been placed on the use of stabilized pavement materials in recent years. Through the use of stabilizing agents, low-quality materials can be economically upgraded to the extent that these may be effectively utilized in the pavement structure. Stabilized 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 stabilized materials are relatively weak in tension, any type of rational design procedure must take their tensile strength into account.

Indian Roads Congress prepared a Special Publication (IRC: SP-89-2010): Guidelines for Soil, Material Stabilization Using Cement, Lime and Fly Ash. This publication is useful for selecting proper stabilized materials based on available local soil as stated below.

Some control over the grading can be achieved by limiting the coefficient of uniformity to a minimum value of 5; however, it should preferably be more than 10. If the coefficient of uniformity lies below 5, the cost of stabilization will be high, and the maintenance of cracks in the finished roads would be expensive. If the plasticity of soil is high, there are usually sufficient clay minerals which can be readily stabilized with lime. Cement is more difficult to mix intimately with plastic materials, but this problem can be alleviated by pre-treating the soil with approximately 2 percent lime. Table 1 to Table 4 are the guidelines for selection of stabilized materials for subgrade, sub-base and base course (IRC: SP: 89-2010).

LIMITATION OF IRC: SP: 89-2010

This document recommends the guidelines for mix design for Cement Treated Base (CTB)/Lime Treated Base (LTB)/Subgrade. Till date, there are no guidelines for thickness design for CTB/LTB base. Conventional pavement design is carried out using IRC: 37-2001.

Table 1. Selection of Stabilizer for Soil

Stabilized Material	Soil Properties					
	75 Micron Passing > 25 %			75 Micron Passing < 25 %		
	PI<10	10<PI<20	PI>20	PI<10	10<PI<20	PI>20
Cement	Yes	Yes	-	Yes	Yes	Yes
Lime	-	Yes	Yes	No	-	Yes
Lime Pozzolana	Yes	-	No	Yes	Yes	-

Note: PI refers to Plasticity Index.

OBJECTIVE AND SCOPE

Based on the limitation of present codal provisions in India, the objective of the present study is to develop comprehensive guidelines for pavement design for rural roads using CTB/LTB.

Based on the present needs, the scope of the study has been limited to develop pavement design charts for rural roads for design axle load repetition up to 5 Million Standard Axles (MSA) with CBR 3,5,7 and 10.

Charts have been developed using FPAVE software and checked by other software. Detail pavement design methodology is reported herein.

Table 2. Material Characteristics for Cement Modified Granular Materials

Property	Specified Value
Liquid Limit	<45%
Plasticity Index	<20%
Organic Content	2%
SO_4 Content	0.2%
Water Absorption	<2%
Ten Percent Fine Value	≥ 50 kN

Table 3. Gradation Requirement for Stabilized Materials

Sieve Size	Passing (%)			
	Grading I	Grading II	Grading III	Grading IV
75 mm		100		
53 mm	100	80-100	100	
45 mm	95-100			
37.5 mm				95-100
26.5 mm		55-90	70-100	55-75
22.4 mm	60-80			
11.2 mm	40-60			
9.5 mm		35-65	50-80	
4.75 mm	25-40	25-55	40-65	10-30
2.36 mm	15-30	20-40	30-50	
0.6 micron				
0.425 micron	8-22	10-35	15-25	
0.3 micron				
0.075 micron	0-8	3-10	3-10	0-10
7 Days Unconfined Compressive Strength (MPa)	6	4.5	1.5	0.75

APPROACH AND METHODOLOGY

The basic design procedures for developing charts are stated below (IRC: 37-2001):

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

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

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

(iv) Determination of the following elastic parameters of the subgrade: elastic modulus and Poisson's ratio.

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

(vi) The minimum allowable number of load repetitions before unacceptable rutting/ cracking occurs.

The design procedures are based on the structural analysis of a multi-layered pavement subject to traffic loading. The design is based on the criteria that strains at three critical locations do not exceed certain values. These limiting strains, shown in Fig. 1, are as follows:

- The horizontal tensile strain ε_1 at the bottom of the asphalt layer.
- The horizontal tensile strain ε_2 at the bottom of the cemented layer.
- Vertical compressive strain ε_3 at the top of the subgrade.

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. The contact stress is related to the tire pressure and is assumed to be in the range 560 kPa. The thickness and properties of granular layers are to be such that tensile stresses will not be generated in such materials. Wheel load is taken as 20400 N.

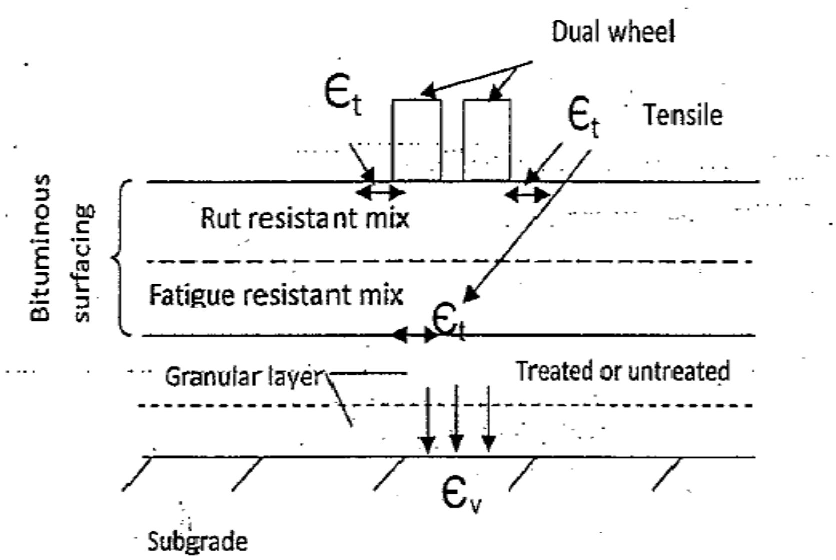

Figure 1: Different Layers of Pavement

Analysis and Design of Soil-Cement and Soil-Lime Rural Roads

Analyses were carried out for low volume /rural roads with light traffic. Then the following types of pavement structures have been modeled.

- Unpaved soil-cement roads; i.e., continuous soil-cement base supported over untreated granular sub-base of 150 mm thickness for subgrade CBR of 5 % and above; and 200 mm granular sub-base for subgrade CBR < 5%.

- A 20 mm thin surface in the form of premixed carpet as asphalt wearing surface at the top for protection of layers from environmental and climatic condition.

Table 4. Material Characteristics for Lime/Modified Soils

Property	**Specified Value**
Passing 75 mm sieve	100%
Passing 26.5 mm sieve	95-100%
Passing 75 micron sieve	15-100%
Plasticity Index	>10 %
Organic Content	2%
SO_4 Content	0.2%
Minimum Lime	2.5 %
Degree of Pulverization	>60%
UCS	As per contract specification

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, the values of flexural modulus of asphalt and Poisson's ratio were set at 500 MPa at 35 ^{0} C and 0.4, respectively. The thickness of the asphalt wearing surface has been kept constant at 20 mm in all analyses with soil-cement base and soil-lime base. Soil-cement base analyses were carried out with elastic modulus values equal to 300 MPa, 400 MPa, 500 MPa, 600 MPa and 700 MPa. For the analyses with soil-lime base, elastic modulus values of soil-lime base have been set equal to 150 MPa, 300 MPa,400 MPa and 500 MPa.

The natural subgrade materials and unbound granular materials have been assumed to be homogeneous, elastic and cross-anisotropic.

The vertical modulus (E_v) of the subgrade was estimated from its respective CBR-value which is based on the following empirical relationship:

The relation between resilient modulus and CBR is given as:

$$\left.\begin{aligned} E\ (\text{MPa}) &= 10{*}\text{CBR} && \text{for CBR} < 5 \text{ and} \ldots \\ &= 176{*}(\text{CBR})^{0.64} && \text{for CBR} > 5 \end{aligned}\right\} \quad (1)$$

E = Resilient modulus of subgrade soil.

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.

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. Austroad (2004) 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:

$$Nf = RF\{\frac{(11300/E^{0.804}+191)^{12}}{\mu z^{12}}\} \qquad (2)$$

where,

Nf = Fatigue life of the cemented material.

RF = Reliability factor for cemented materials for failure against fatigue.

= 1 for expressways, national highways and other heavy volume roads;

= 2 for other roads carrying less than 1000 trucks per day.

E = Elastic modulus of CTB.

μz = Tensile strain of CTB.

Many researchers reported that the equation overestimates fatigue life. Hence, fatigue life is not considered in-designed .Only E-values of cement treated base amounting to 10% of the initial value have been considered for the design to develop the pavement design charts.

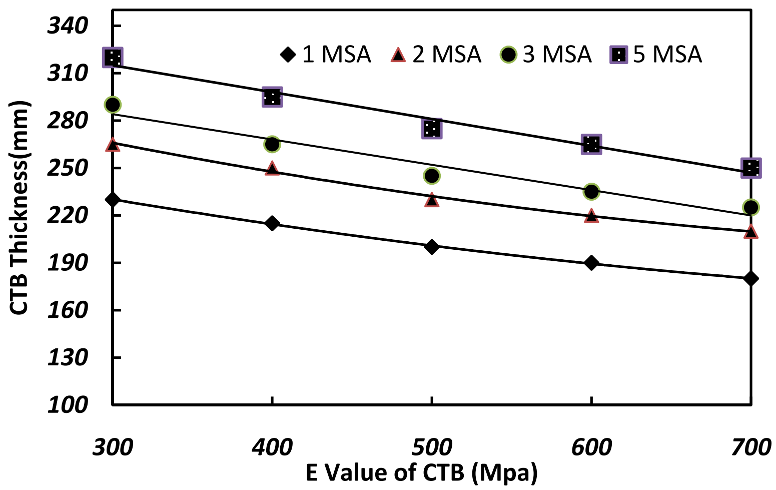

Figure 2: Design Curves for CBR = 3%

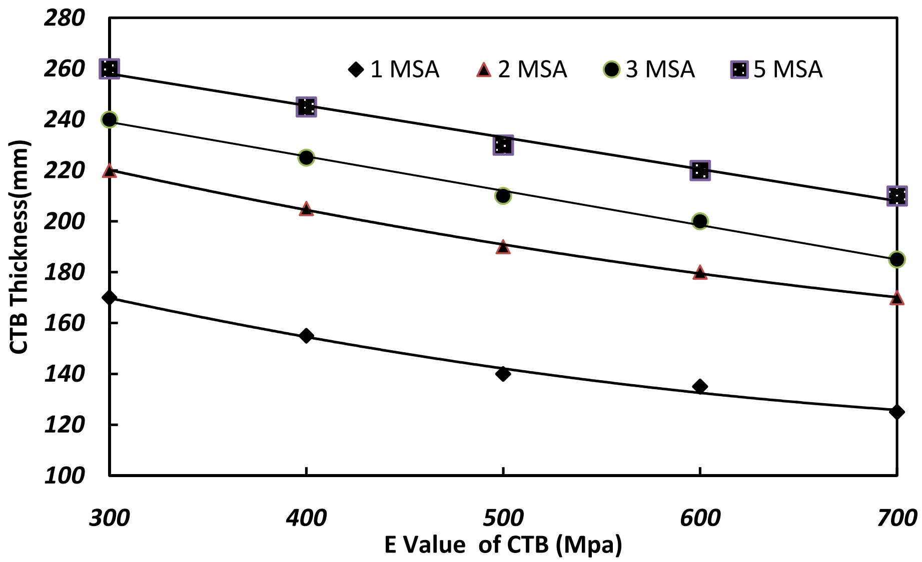

Figure 3: Design Curves for CBR = 5%

Subgrade Rutting Criteria

Large amount of field data for rutting in asphalt pavements was collected and analyzed during several research projects of the Ministry of Surface Transport

(MOST), and the vertical elastic subgrade strain was developed for different repetitions of standard axle loads and subsequently adopted in IRC-37:2001. A similar approach was used by Asphalt Institute, Austroads and Shell for the design of flexible pavements. The bituminous layers were not very thick in India in the eighties and nineties of the past century when rutting data were collected and most of the rutting took place in the subgrade and the granular layers only. The equation for rutting is given as (MOST 2000):

$$N = 4.1656 \times 10^{-08} [1/\varepsilon_v]^{4.5337}. \quad (3)$$

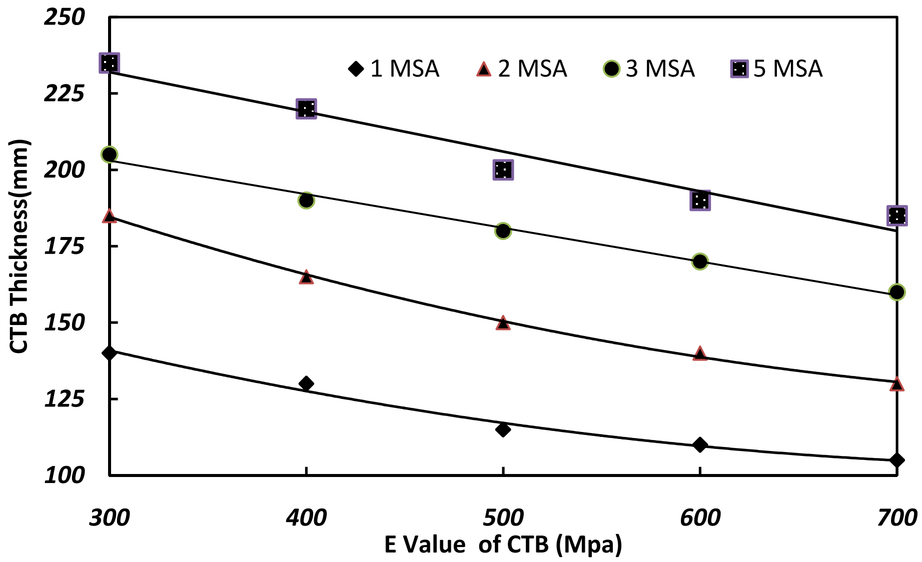

Figure 4: Design Curves for CBR = 7%

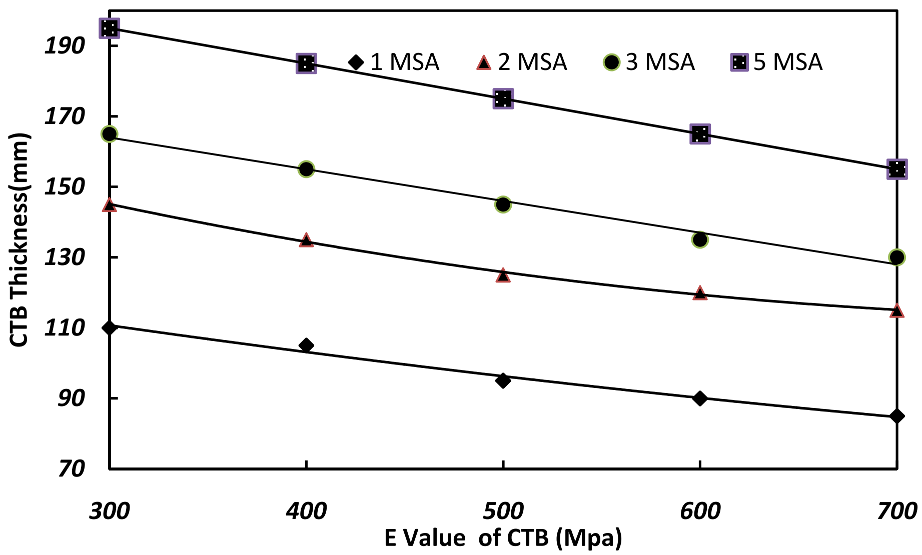

Figure 5: Design Curves for CBR = 10%

Table 5. Thickness Comparison

CBR(%)	Cement Treated Base		Conventional Design(IRC:37-2001)	
	CTB*	Granular Sub-base	Granular Base	Granular Sub-base
3	200	200	225	435
5	140	150	225	205
7	115	150	225	150
10	95	150	225	150

* E-value of CTB is taken 500 MPa; Design MSA = 1.

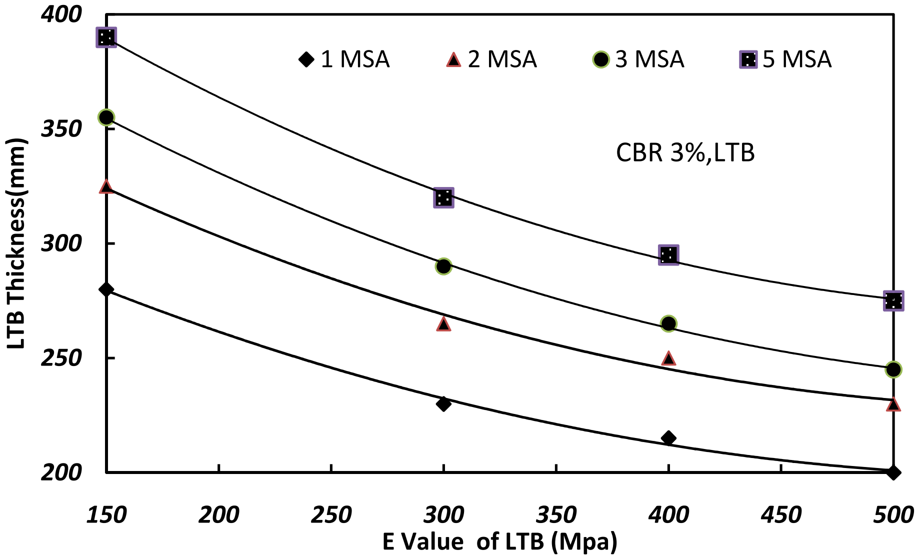

Figure 6: Design Curves for CBR = 3%

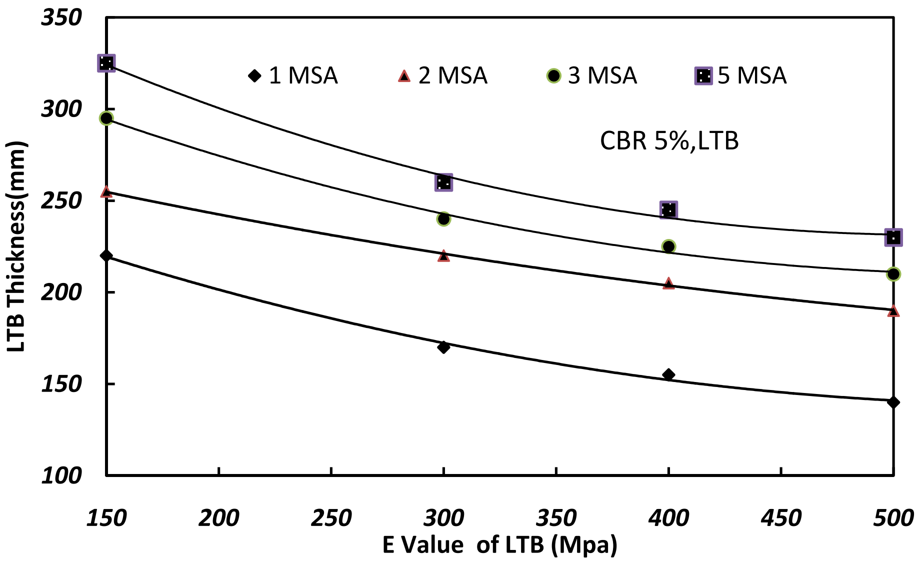

Figure 7: Design Curves for CBR = 5%

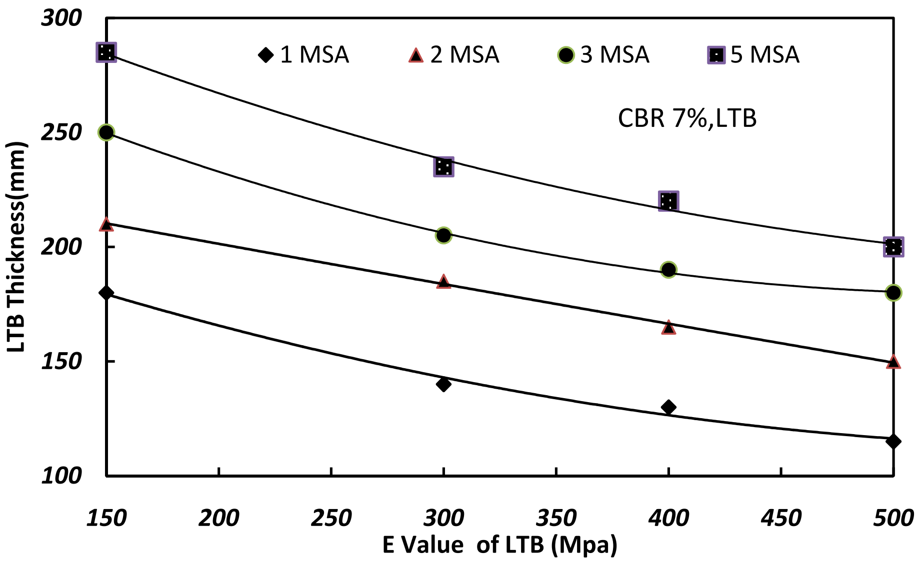

Figure 8: Design Curves for CBR = 7%

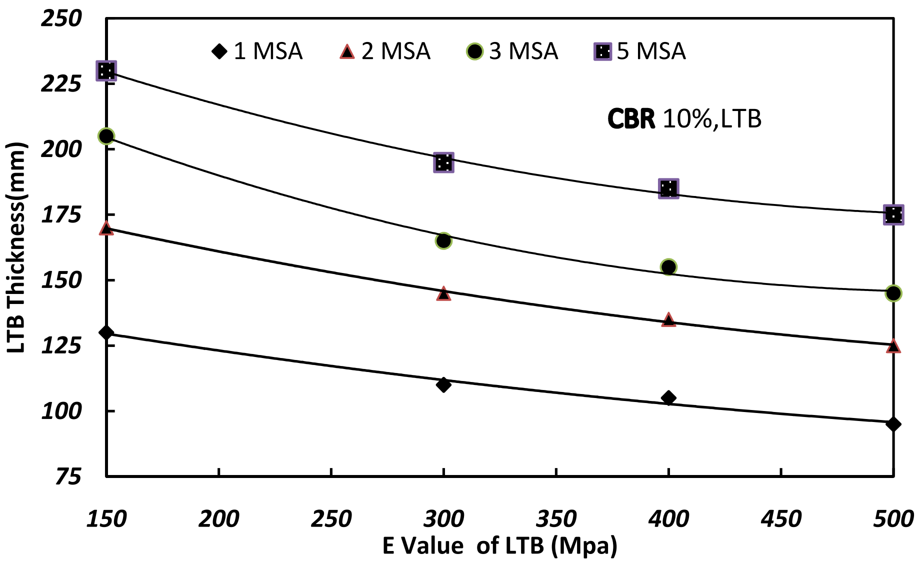

Figure 9: Design Curves for CBR = 10%

RESULTS AND DISCUSSION

Using FPAVE software, strain at the top of sub-grade level has been determined and pavement life has been determined using equation 2. Finally, pavement design charts have been developed for design purposes.

For a particular CBR of subgrade and resilient 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 rutting criteria as shown in Equation 3, the allowable number of load repetitions, N for each thickness of soil-cement base and soil-lime base was determined to develop the pavement design charts.

The relationships showing thickness of soil-cement base *versus* allowable number of load repetitions, N for CBR-values of 3, 5,7 and 10 are plotted and shown in Figs. 2,3,4 and 5. The relationships showing thickness of lime treated base *versus* N for subgrade CBR-values of 3, 5, 7 and 10 are plotted in Figs. 6, 7, 8 and 9.

It is found from Figs. (2 to 5) that for each resilient modulus, the thickness of soil-cement base increases with increasing the allowable number of load repetitions. At any particular value of N, the value of thickness of soil-cement base reduces as the modulus of soil-cement base increases. Comparing the curves in Figs. 2 and 5, it is found that for each resilient modulus, as CBR increased from 3 to 10, 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. 2 and 5 that for an unpaved road with an elastic modulus of 500 MPa and for N = 1 MSA and 5 MSA repetitions, as CBR is increased from 3 to 10,the thickness of soil-cement base reduced markedly from 200 mm to 95 mm and from 280 mm to 185 mm, respectively. Similar results are also obtained from lime base for various CBR values.

Comparisons of Thickness of Cemented Layers for Unpaved and Paved Roads

Table 5 shows a comparison of the thickness of cemented layers and the conventional thickness for a particular allowable load repetition value of 10^6 and resilient modulus of cemented materials of 500 MPa for different CBR-values of 3, 5, 7 and 10.

It is observed from Table 5 that the thickness of cement lime base with granular sub-base is considerably lower than that of the conventional design. There is a shortage of aggregates and many stone quarry areas are banned by the Government. To solve the shortage of aggregates, stabilized materials/marginal materials with CTB/LTB shall be used, and charts developed are useful for thickness design.

CONCLUSIONS

Analyses were carried out with soil-cement base and soil-lime base. The major findings and conclusions obtained from the present study may be summarized as follows:

- Thicknesses of soil-cement base / soil-lime base increase with increasing the allowable number of load repetitions for known resilient modulus of stabilized material and known CBR.
- Thicknesses of soil-cement base / soil-lime base reduce as modulus of soil-cement base /soil-lime base increases for a particular number of repetition and CBR.
- When CBR increases from 3 to 5/7/10, the thickness of soil-cement base / soil-lime base reduces significantly for any particular value of repetitions.
- Design curves have been developed for the roads, and it has been found that, in general, at any CBR and N, the thickness of cemented layer reduces with increasing the elastic modulus for known CBR and number of axle load application .
- Aggregate consumption is less for the case of stabilized base compared to that of the conventional method.

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