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Improvement in engineering properties of subgrade soil due to stabilization and its effect on pavement response

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Abstract. This paper presents laboratory investigation of stabilization of subgrade soil. One type of soil and three types of stabilizers i.e., hydrated lime, class F fly ash and polypropylene fibres are selected in the study. Atterberg limit, compaction, california bearing ratio (CBR), unconfined compressive strength and triaxial shear strength tests are conducted on unstabilized and stabilized soil for varying percentage of stabilizers to analyze the effect of stabilizers on the properties of soil. Vertical compressive strains at the top of unstabilized and stabilized subgrade soil were found out by elasto-plastic finite element analysis using commercial software ANSYS. Strategy for design of optimum pavement section was based on extension in service life (TBR) and reduction in layer thickness (LTR). Extension in service life of stabilized subgrade soil is 6.49, 4.37 and 3.26 times more due to lime, fly ash and fibre stabilization respectively. For a given service life of the pavement, there is considerable reduction in layer thicknesses due to stabilization. It helps in reduction in construction cost of pavement and saving in natural resources as well.

Keywords: California bearing ratio; stabilization; subgrade; layer thickness reduction; traffic benefit ratio

1. Introduction

Soil stabilization is one of the ground improvement techniques to improve certain properties of natural soils to meet the engineering purpose. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available stabilizers that may alter the gradation, texture or plasticity, or act as a binder for cementation of the soil. The long term performance of any construction project depends on the soundness of the under lying soils. Unstable soils can create significant problems for pavements. Lack of adequate road network to cater to the increased demand and increased distress in road leading to frequent maintenance has always been big problem in India.

Aggregate is generally expensive, Therefore it is important to minimize the aggregate layer thickness for a given service life. This can be achieved by incorporating stabilization technique. This stabilization technique can increase the service life for a given aggregate layer thickness. Effective utilization of local weak soils by imparting additional strength using stabilization materials enable reduction in construction cost and improved performance for roads.

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Exploring the feasibility of such materials for sub grade and embankment stabilization will help the road building sector to evolve a stronger, durable and economic design. A finite- element model of the pavement- layered structure provides the most modern technology and sophisticated characterization of materials that can be easily accommodated in the analysis. The primary objective of the present study is to evaluate the benefits in term of traffic benefit ratio (TBR) and layer thickness reduction (LTR) due to stabilization of subgrade soil.

2. Earlier work

Arbani and Viskarami (2007) observed that lime stabilization of geo-materials by producing cohesive materials in the soil increases the strength and decreases material plastic properties and hence these materials can be used for projects where high strength and high performance materials are desirable. The increase in strength of lime stabilized materials in compression as well as tension is attributed to the reactions between clay particles and lime. The clay lime compound provides the cemented material in soil. The optimum clay content to gain the maximum compressive strength and tensile strength of clayey sands is proposed to be between 25 to 30% for the investigated material. (Bagui 2012) reported that thickness 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 number of repetitions and CBR. (Moustafa *et al.* 2011) conducted a comparative study for optimization and quantification of the beneficial effects of stabilization of subgrade soils in flexible pavement system. Based on the investigated materials with the determined optimum amount of stabilizers, the service life of the simulated pavement section was increased by 67% to 231%. (Amu *et al.* 2005) conducted the tests on expansive clay soil to determine the optimum quantity of lime and the optimal percentage of lime- Eggshell Powder combination and reported that lime stabilization at 7% is better than the combination of 4% ESP+ 3% lime. Mishra and Rath (2011) studied the cost effectiveness of clayey soil & moorum, treated with fly-ash lime for construction of low volume roads and investigated that maximum saving was possible for 70% soil + 30% fly ash +2% lime. (Youssef *et al.* 2012) carried out soil investigation with lime stabilization on high plasticity clay and reported that the shear strength of soil increased as lime concentration increased up to 4%. CBR was improved when the soil was treated with lime. Nagrale and Srivastava (2009) concluded that dry density of soil decreases with lime content and C.B.R. value of soil increases from 1% to 2.74, 3.89 and 6.51% due to stabilization with 2.5, 5 and 7.5% lime content. There is considerable reduction in layer thicknesses and it is the function of percentage of lime and traffic for which pavement is designed. The thickness of sub-base reduces from 610 to 320 mm, where as the DBM thickness is reduced from 215 to 130 mm for 7.5 optimum lime percentages.

Chandra *et al.* (2008) investigated two important aspects i.e., the optimum quantity of fibers for a subgrade soil which gives the maximum improvement in CBR and E value and benefits of fiber reinforced subgrade soil in flexible pavement. They reported that CBR values of three soils were increased to 4.33, 6.42, and 18.03% from 1.16, 1.95, and 6.20% respectively due to fiber reinforcement. For the constant thickness of base and DBM, the thickness of the sub base reduces by 38.52, 26.32 and 16.67% respectively for soils A, B and C. Actual savings would depend upon the option exercised by the designer for reducing the thickness of an individual layer. Rao and Jayalekshmi (2010) reported that the inclusion of fiber reinforcement in the soil subgrade enhances the CBR. The inclusion of 1% polyester fiber of aspect ratio 200 & 400 increases the CBR by 1.54 and 1.25 times respectively than the unreinforced soil samples.

Tingel *et al*. (2002) concluded from full- scale field tests that fiber stabilized sands were a viable alternative to traditional road constructions materials for temporary or low volume roads. They used a field mixing procedure more or less similar to that of Santoni and Webster (2001). Chegenizadeh *et al*. (2012) conducted series of CBR tests on stabilized clay composite using plastic and natural fibers. It was concluded that increasing in fiber content increased the CBR values for both natural and plastic fiber. The result proved that with increase in fiber length, the CBR values of composite clay were increased for both kind of fibers and short and randomly fiber inclusion showed to be reliable in industry projects as it helps to minimize the cost of project. (Yi *et al*. 2006) carried on pilot study on mechanical behavior of soil with inclusion of polypropylene fiber and lime and reported that when lime is added to soils, the reactions between lime and clayey particles change the properties of soils and hence cause increase in compression strength and shear strength of soils.

3. Experimental program

Soil for the present laboratory investigation was obtained from Ulwa region of Navi Mumbai, India. Primary engineering tests were conducted on the selected soil for its identification and are illustrated in Table 1.

Three types of stabilizers i.e., Hydrated lime, Class F fly ash and Polypropylene fibres are used for the investigation. Table 2 indicates different groups depending on the type of stabilizer and its percentage of mixing by dry weight of soil.

Stabilizers were mixed in the soil with varying percentages as per mentioned in Table 2 and

Table 1 Physical properties of soil used in the present study

Sr. No.	Property	Remark
1	Liquid limit (%)	96
2	Plastic limit (%)	35
3	Plasticity index (%)	61
4	MDD (KN/m^3)	1.24
5	OMC (%)	28
6	CBR (%)	1.45
7	Soil classification as per AASHTO	A 7-5
8	Typical name	Clayey soil

Table 2 Different percentages of stabilizers mixed with soil

Group No.	Stabilizer	Percentage of stabilizer by dry weight of soil			
1	Lime	1.5	3	4.5	6
2	Fly Ash	5	10	15	20
3	Fiber	0.25	0.5	0.75	1

Table 3 Effect of lime, fly ash and fibre stabilization on CBR values

Lime (%)	Max. CBR (%)	% increase	Fly ash (%)	Max. CBR (%)	% increase	Fibre (%)	Max. CBR (%)	% increase
0	1.45	-	0	1.450	-	0	1.45	-
1.5	2.04	40.68	5	2.825	94.82	0.25	3.94	171.72
3.0	6.86	373.10	10	3.680	153.79	0.50	4.23	191.72
4.5	7.70	431.03	15	2.606	79.72	0.75	3.13	115.86
6.0	7.60	424.14	20	1.633	12.62	1.00	2.84	95.86

maximum dry density (MDD) and optimum moisture content (OMC) were obtained by performing Standard Proctor tests. Four days soaked CBR tests were conducted on unstabilized and stabilized soil with different percentages of lime, fly ash and fibre as per (IS 2720 (part 16)-1987). CBR values for different stabilizer content and percentage increase in CBR with respect to unstabilized soil are presented in Table 3. Unconfined compression tests were conducted on soil at OMC and MDD which were obtained through Proctor tests. The results of unconfined compression tests were plotted to study the stress-strain behavior for both unstabilized as well as stabilized soil for varying percentages of different stabilizers. Stress-strain curves were used for determining unconfined compressive strength and modulus of elasticity. These parameters are later used in pavement response model to analyze the induced strain at the top of the subgrade soil. Based on the maximum CBR value, unconfined compressive strength and E-value, 4.5% of lime, 10% of fly ash and 0.5% of fibre were selected as optimum stabilizer content.

4. Finite element modeling

Finite element method was used to analyze the pavement section resting on unstabilized and stabilized subgrade soil. The commercial software ANSYS was used for finite element modeling. The multilinear isotropic elasto-plastic hardening model defining the constitutive relationship of the materials involved was employed. The pavement section was modeled as a 2-D axisymmetric problem and 8-noded structural solid element was used for the analysis. The values of stresses and deformations within the pavement section and vertical compressive strain at the top of the subgrade were captured. Effect of the vertical compressive strain developed at the top of the subgrade due to change in the thickness of the subbase, granular base and dense bituminous

Table 4 Thickness of various layers of flexible pavement resting on unstabilized and stabilized sub grade soil

Subgrade soil	CBR	Subgrade (mm)	Subbase (mm)	Base (mm)	DBM (mm)	BC (mm)	Total (mm)
Unstabilized soil	1.45	500	610	250	175	40	1575
Stabilized with lime	7.70	500	200	250	100	40	1090
Stabilized with fly as	3.68	500	330	250	130	40	1250
Stabilized with fibre	4.23	500	330	250	130	40	1250

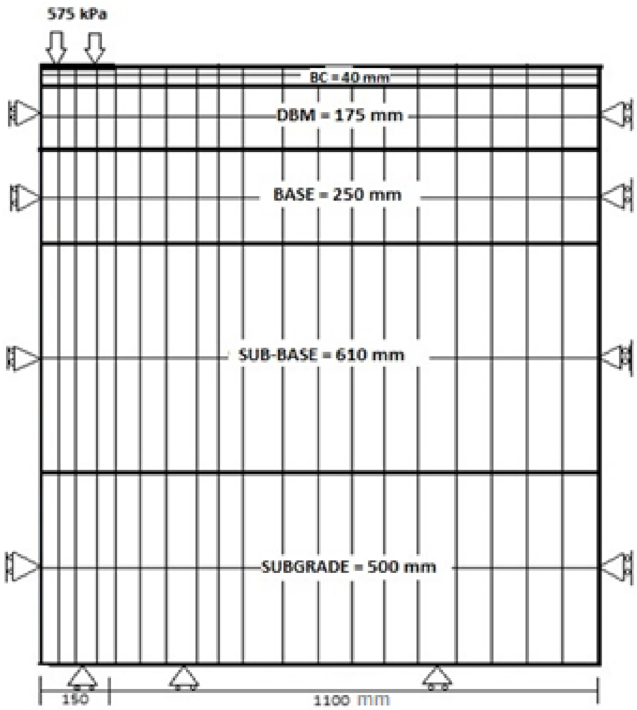


Fig.1 Finite-element discretization of pavement section

macadam (DBM) was investigated. These layer thicknesses above the unstabilized as well as stabilized subgrade soil were decided based on CBR of the subgrade soil for design traffic intensity of 50 million standard axles (msa) as per Indian code of practice, IRC 37-2001. Table 4 gives the values of thickness of various layers and total thickness of unstabilized and stabilized pavement.

A five layer flexible pavement system was modeled and analyzed for subgrade soils. Pressure equal to single axle wheel load has been assumed to be applied at the surface and distributed over a circular area of radius 15 cm. For application of FEM in the pavement analysis, the layered system of infinite extent is reduced to an approximate size with finite dimension. The right hand boundary is provided at 110 cm from outer edge of the loaded area, which is more than 7 times the loaded area. The elasto-plastic analysis was carried out to evaluate the primary response of the pavement resting on subgrade soil. The multilinear isotropic hardening model (MISO) available in ANSYS was used to evaluate the stresses, strains and deformations within pavement sections. While meshing, finer mesh was provided near loaded area where stress concentration is more, and subsequently it becomes coarser towards right boundary.

Fig. 1 shows a typical 2D axisymmetric finite- element model of the pavement resting on subgrade soil. Roller supports are provided along the axis of symmetry to achieve the condition that both shear stresses and radial displacements are equal to zero. Similarly, the rollers supports are provided along the right boundary which was placed sufficiently far away from the loaded area so as to have a negligible deflection in the radial direction. At the bottom boundary, roller supports were provided, permitting free movement in the radial direction and a restraint to any movement in the vertical direction.

Table 5 Values of Initial Tangent Modulii for pavement materials

Stabilizer	Lime		Fly ash		Fibre		Pavement layer			
Parameter	US*	S	US	S	US	S	Subbase	Base	DBM	BC
E (MPa)	9	15.8	9	14	9	12.8	70.12	99.20	269.67	403.33
Poisson ratio	0.35	0.35	0.35	0.35	0.35	0.35	0.30	0.30	0.25	0.25

5. Input data for finite-element modeling

Properties of the different layers required for carrying out FE analysis are the modulus of elasticity, poison ratio and the stress strain data. Initial tangent modulus is needed only to initialize the iterative procedure and actual cumulative stress strain data generated up to the end of particular load increment are used in the analysis for the subsequent load increment. The values of initial tangent modulus of all the pavement layers were estimated and presented in Table 5 along with values of Poisson ratio assumed for different layer materials (Chandra *et al*. 2008).

6. Benefits of stabilization

To evaluate the benefits of stabilization of soil in term of reduction in layer thickness and extension in service life of the pavement, a mechanistic – empirical design approach is used in the present study. The proposed methodology has a better capability of characterizing different material properties and loading conditions and has the ability to evaluate different design alternatives on an economical basis.

Two design alternatives considered in the present study are:

(1) Keeping the same service life of stabilized and unstabilized pavement section. This will result in reduction in layer thicknesses which is expressed in term of LTR.

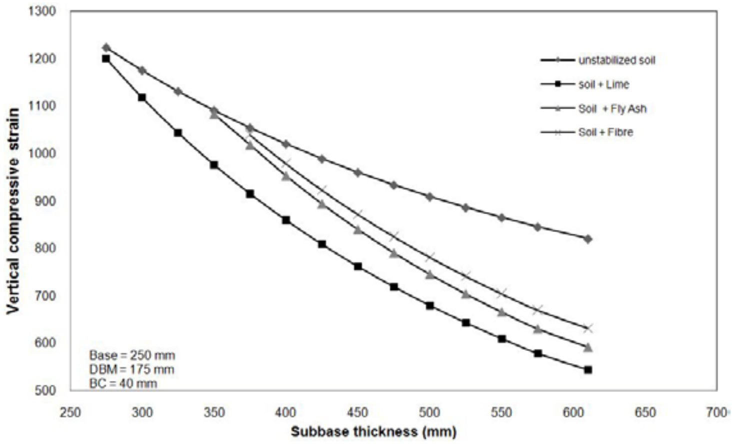
(2) Keeping the same pavement section for stabilized and unstabilized subgrade. This would result in to extension in service life of the pavement section and is expressed in term of TBR.

Surface cracking and rutting are two types of structural failures in a flexible pavement. Cracking is due to fatigue caused by repeated application of load in the bounded layer generated by traffic where as rutting is due to accumulation of pavement deformation in various layers along the wheel path. As the scope of the present study is limited to stabilizing the subgrade soil only, rutting has been considered as a failure criterion. The IRC 37 (IRC 2001) considers a rut depth of 20 mm to be a failure criterion for flexible pavement and gives rutting Eq. (1) as

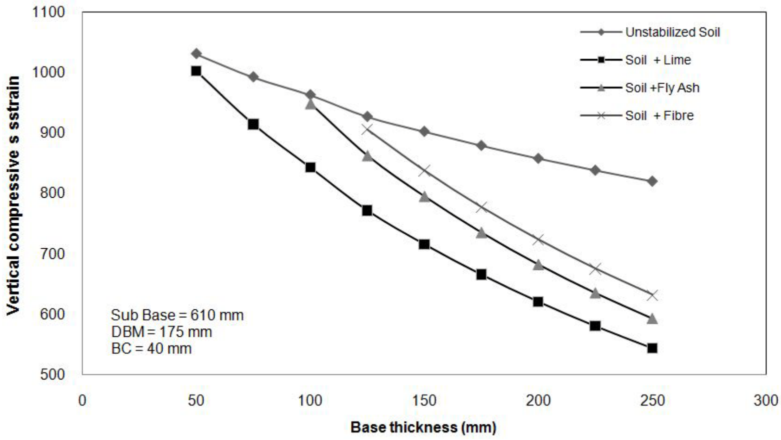
$$N_{20} = 4.1656 \times 10^{-8} (1/\varepsilon_v)^{4.5337} \tag{1}$$

Where N_{20} = number of cumulative standard axles to produce a rutting of 20 mm
ε_v = vertical compressive strain at top of subgrade.

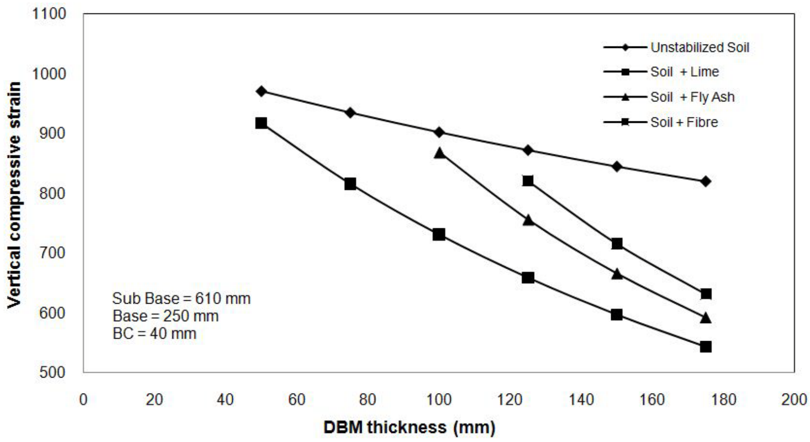
Vertical compressive strain developed at the top of unstabilized and stabilized subgrade was obtained for varying thicknesses of subbase, base and DBM. The thickness of the base course of 250 mm and DBM thickness of 175 mm were maintained constant and subbase thickness was varied. Again keeping the subbase thickness of 610 mm and DBM thickness of 175 mm, the base



(a)



(b)



(c)

Fig. 2 (a) Variation of vertical compressive strain at top of subgrade with subbase thickness; (b) variation of vertical compressive strain at top of subgrade with base thickness; (c) variation of vertical compressive strain at top of subgrade with DBM thickness

thickness was varied. Similarly, DBM thickness was varied for a constant subbase of 610 mm and base thickness of 250 mm. The vertical compressive strains developed at the top of the subgrade in unstabilized and stabilized pavement sections were evaluated for all these alternatives from elasto-plastic finite element analysis. Figs. 2(a)-(c) illustrate the variation of vertical compressive strain at the top of the subgrade with subbase, base and DBM respectively.These plots were used to study the benefits of stabilization of the subgrade soils in term of reduction in layer thickness (LTR) and extension in service life (TBR).

The TBR gives the extension in service life of the pavement due to stabilization. It is defined as the ratio between the number of load cycles on a stabilized section (N_S) to reach a defined failure state (a given rutting depth) and the number of load cycles on an unstabilized section (N_U) with the same geometry and material constituents that reaches the same defined failure state (Berg *et al.* 2000) and given as

$$TBR = N_S/N_U \tag{2}$$

Where N = number of traffic passes required for producing a rutting of 20 mm and S and U denotes stabilized and unstabilized pavement sections. According to (Perkins and Edens 2002), layer thickness reduction due to stabilization for the equivalent service life of pavement can be expressed as

$$LTR = [(D_U - D_S)/D_U] \times 100 \tag{3}$$

D_U and D_S are base course thicknesses of unstabilized and stabilized pavement sections respectively. As no separate equation is available in the literature to relate the vertical compressive strain at the top of the stabilized subgrade to the number of load repetitions necessary to produce the allowable rutting, Eq. (3) was used for both unstabilized and stabilized subgrade.

Using Eqs. (2)-(3), the benefit of subgrade soil stabilization in term of extension in service can be given as

$$TBR = N_S/N_U = (\varepsilon_{VS}/\varepsilon_{VU})^{-B} \tag{4}$$

The vertical compressive strain, ε_V at the top of subgrade is obtained through commercial software ANSYS and B = constant equal to 4.5337 (IRC 2001).

The results of elasto-plastic finite element analysis presented in Figs. 2(a)-(c) indicate that the vertical compressive strain at the top of the unstabilized subgrade soil is 820.24 microstrain. For constant thicknesses of base and DBM, this strain value was obtained for subbase thickness of 420 mm, 462.5 mm and 480 mm in case of lime, fly ash and fibre stabilization respectively. Also, for constant thicknesses of subbase and DBM, the base thickness can be reduced to 107.5 mm, 140 mm and 157.5 mm due to lime, fly ash and fibre stabilization of soil. Similarly for constant value of subbase and base thickness, the DBM thickness gets reduced to 75 mm, 112.5 mm and 125 mm due to lime, fly ash and fibre stabilization respectively. The designer can consider different options of partly reducing the thickness of each layer and also finally choose the most economical section for the same service life of stabilized pavement to that of unstabilized pavement.

If pavement section is kept same for unstabilized and stabilized subgrade soils, the vertical compressive strain for unstabilized soil reduces from 820.24 microstrain to 542.92, 592.19 and 631.89 microstrains for lime, fly ash and fibre stabilized pavements respectively. The corresponding values of TBR are found to be 6.49, 4.37 and 3.26 respectively.

Results obtained from such a study are summarized in Table 6. These results show that for a constant thickness of base and DBM, the thickness of subbase reduces by 54.91, 42.62 and 38.52%

Table 6 Stabilization benefits in subbase, base and DBM thickness of subgrade soil

Stabilizer	Subbase thickness (mm)	Constant base and DBM			Base thickness (mm)	Constant subbase and DBM			DBM thickness (mm)	Constant subbase and base		
		LTR (%)	$\varepsilon_{VU} / \varepsilon_{VS}$	TBR		LTR (%)	$\varepsilon_{VU} / \varepsilon_{VS}$	TBR		LTR	$\varepsilon_{VU} / \varepsilon_{VS}$	TBR
LIME	610	-	1.51	6.49	250	-	1.51	6.49	175	-	1.51	6.49
	575	6.08	1.46	5.61	225	10	1.44	5.32	150	14.28	1.41	4.84
	550	9.83	1.42	4.91	200	20	1.38	4.35	125	28.57	1.32	3.57
	525	13.93	1.37	4.29	175	30	1.32	3.54	100	42.85	1.23	2.59
	500	18.03	1.33	3.75	150	40	1.26	2.86	75	57.14	1.14	1.85
	475	22.13	1.29	3.27	125	50	1.20	2.30	50	71.42	1.05	1.29
	450	26.22	1.26	2.86	100	60	1.14	1.83				
	425	30.32	1.22	2.49	75	70	1.08	1.44				
	400	34.42	1.18	2.17	50	80	1.02	1.13				
	375	38.52	1.15	1.89								
	350	42.62	1.11	1.65								
	325	46.72	1.08	1.43								
	300	50.81	1.05	1.25								
	275	54.91	1.01	1.08								
FLY ASH	610	-	1.38	4.37	250	-	1.38	4.37	175	-	1.38	4.37
	575	6.08	1.33	3.76	225	10	1.32	3.53	150	14.28	1.26	2.94
	550	9.83	1.29	3.26	200	20	1.25	2.83	125	28.57	1.15	1.91
	525	13.93	1.25	2.83	175	30	1.19	2.25	100	42.85	1.03	1.18
	500	18.03	1.21	2.45	150	40	1.13	1.77				
	475	22.13	1.18	2.11	125	50	1.07	1.38				
	450	26.22	1.14	1.82	100	60	1.01	1.06				
	425	30.32	1.10	1.57								
	400	34.42	1.06	1.35								
	375	38.52	1.03	1.16								
	350	42.62	1.00	1.03								
FIBRE	610	-	1.29	3.26	250	-	1.29	3.26	175	-	1.29	3.26
	575	6.08	1.26	2.86	225	10	1.24	2.66	150	14.28	1.18	2.12
	550	9.83	1.22	2.53	200	20	1.18	2.16	125	28.57	1.06	1.31
	525	13.93	1.19	2.24	175	30	1.13	1.74				
	500	18.03	1.16	1.98	150	40	1.07	1.39				
	475	22.13	1.13	1.75	125	50	1.02	1.10				
	450	26.22	1.10	1.54								
	425	30.32	1.07	1.36								
	400	34.42	1.04	1.20								
	375	38.52	1.01	1.06								

due to lime, fly ash and fibre stabilization of subgrade soil for almost same service life of unstabilized and stabilized pavement. Similar options can be exercised for base and DBM. The flexible pavement can be designed by adopting any of these alternatives.

Reduction in the thicknesses of the layer as well as additional gain in term of extension in service life of the pavement can be achieved by designing the pavement at any intermediate layer. For example, in the case of lime, fly ash and fibre stabilized subgrade soil; the thickness of subbase can be reduced by 54.91, 42.62 and 38.52% respectively. But if it is desired to opt for 22.13% reduction in subbase layer thickness only, it is possible to have additional benefit in term of TBR of 3.27, 2.11and1.75 for lime, fly ash and fibre stabilized pavements.

7. Conclusions

Two important aspects have been analyzed in present laboratory investigation namely, (1) to find the optimum quantity of lime, fly ash and fibre which will lead to maximum improvement in CBR and *E* value. (2) To evaluate the benefits of stabilization of subgrade soils in flexible pavement.

The following conclusions are drawn from the present study.

- C.B.R value of soil was increased from 1.45 to 7.70, 3.68 and 4.23% due to lime, fly ash and fibre stabilization respectively.
- If the pavement section is kept same for unstabilized and stabilized subgrade soil, pavement resting on stabilized subgrade soil gives TBR values of 6.49, 4.37 and 3.26 due to lime, fly ash and fibre stabilization respectively.
- For constant thickness of base and DBM, the thickness of base reduces by 54.91, 42.62 and 38.52% for subgrade soil due to lime, fly ash and fibre stabilization respectively.
- The pavement resting on stabilized subgrade soils is beneficial in term of reduction in layer thickness and saving in consumption of construction materials. However actual savings would depend upon the option exercised by the designer for reducing the thickness of an individual layer.
- Comparing the effect of these three stabilizers on layer thickness reduction and traffic benefit ratio, lime is preferred than fly ash and fibre.
- Fly ash which is not only an industrial waste but also hazardous to the environment can be beneficially used as a stabilizer.

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