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Evaluation of extension in service life and layer thickness reduction of stabilized flexible pavement

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Abstract. Decrease in availability of suitable subbase and base course materials for highway construction leads to a search for economic method of converting locally available troublesome soil to suitable one for highway construction. Present study insights on evaluation of benefits of stabilization of subgrade soils in term of extension in service life (TBR) and layer thickness reduction (LTR). Laboratory investigation consisting of Atterberg limit, Compaction, California Bearing Ratio, unconfined compressive strength and triaxial shear strength tests were carried out on two types of soil for varying percentages of stabilizers. Vertical compressive strains at the top of unstabilized and stabilized subgrade soils were found out by elasto-plastic finite element analysis using commercial software ANSYS. The values of vertical compressive strains at the top of unstabilized and stabilized subgrade, were further used to estimate layer thickness reduction or extension in service life of the pavement due to stabilization. Finite element modeling of the flexible pavement layered structure provides modern technology and sophisticated characterization of materials that can be accommodated in the analysis and enhances the reliability for the prediction of pavement response for improved design methodology. If the pavement section is kept same for unstabilized and stabilized subgrade soils, pavement resting on lime, fly ash and fiber stabilized subgrade soil B will have service life 2.84, 1.84 and 1.67 times than that of unstabilized pavement respectively. The flexible pavement resting on stabilized subgrade is beneficial in reducing the construction material. Actual savings would depend on the option exercised by the designer for reducing the thickness of an individual layer.

Keywords: stabilization; finite element analysis; layer thickness reduction; traffic benefit ratio; vertical compressive strain

1. Introduction

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. Evolving new construction materials to suit various traffic and site conditions for economic and safe design is a challenging task in road construction. Aggregate is generally expensive therefore it is often important to minimize the aggregate layer thickness for

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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. 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.

2. Earlier work

Long term pavement performance is related to the change of the material characteristics as a result of repeated loadings and environmental influence (Arraiganda *et al.* 2014). An advantage of stabilization technique is that adequate strength can be achieved in a short time. The effects of some influential factors (i.e., water content, cement content, curing time, and compaction energy) on the microstructure and engineering characteristics of cement-stabilized soils have been extensively researched (Suebsuk *et al.* 2010, 2011). (Olgun 2013) investigated the effect of polypropylene fiber inclusions on the geotechnical characteristics of a clayey soil that was chemically stabilized with cement and fly ash. The plastic strain of subgrade soil was modeled to quantify the amount of rut contributed from subgrade (Yesuf and Hoff 2015). Slag can be potentially used as stabilizer to improve the properties of organic soil (Zulkuf 2016). Engineering properties of laterite soil can be improved by using cactus mucilage, which has history of being used as earth material (Issac and Ikenna 2015). The additives and curing duration had a significant effect on the strength value of treated specimen. A rice husk powder content of 15% was found to be optimum (Hanifi *et al*. 2015). Sewage slush ash / lime mixture improves the property of subgrade soil. An addition of 2% nano SiO2 increases the unconfined compressive strength of soft subgrade soil treated with SSA / lime mixture by 7 KPa (Deng *et al*. 2016). UCS of optimized soil – fly ash is mixture reinforced with 0.75% of human fiber is 2.85 times higher than that of untreated soil (Abi *et al*. 2016). Rubber threads obtained from non usable tyre can be used as stabilizing material in road works (Moghaddas *et al*. 2015). Rice husk ash treatment is cost effective and sustainable alternate to deal with problematic local cohesive soil in agro based developing countries (Mubashir *et al.* 2015).

Shahu *et al.* (2013) carried out Finite-element analyses of a five-layer flexible pavement system; and the equivalent thickness, service life ratio, and cost-effectiveness of copper- fly ash – dolime mix in relation to the conventional water-bound macadam (WBM) layer were evaluated. Jie Gu (2011) based on the finite element analysis carried out by resorting to the mechanistic empirical approach demonstrated that the geogrid reinforcement can extend the service life of pavements. The first published finite element analysis of a pavement structure appeared in 1968 (Duncan *et al.* 1968), in which the authors used an axisymmetric formulation and specified the stiffness of each element in the granular layer as a function of the stresses in the element. Chen (2004) developed mechanistic-empirical model to predict rutting depth as a function of pavement responses, material properties and traffic characteristics. Several computer programs have been developed for nonlinear analysis of flexible pavements. Based on Bermister's layered theory, KENLAYER (Huang 2004) was developed to account for stress-dependent characteristics by assigning various moduli to different layers. ILLI-PAVE and MICH-PAVE are two well-known axisymmetry Finite-Element programs for pavement analysis taking nonlinear behaviors of materials into account. Efficiency in computer resources and computation time is the main advantage of the axisymmetrical finite element programs. Using general-purposed FE programs, such as ABAQUS and ANSYS, has become popular among researchers during recent years.

(Hjelmstad and Tacirglu 2000, Kim *et al*. 2009). Sukumaran (2004) presented a three-dimensional analysis model of airport flexible pavements using ABAQUS. To properly characterize the resilient response of coarse-grained unbound aggregates and fine-grained subgrade soils, Kim *et al*. (2009) developed a user-defined nonlinear material model using UMAT in the ABAQUS program.

Most of the modern multilayer elastic computer programs, such as BISAR and KENLAYER, can calculate the responses under various axle configurations (Huang 2003). Previous research by Webster (1992) and Haas *et al.* (1988) established a TBR value of 3.0 to 2.7 for geogrid stabilized subgrade. For flexible pavements constructed on subgrades with a CBR of 3 and with base course thicknesses between 175 and 300 mm, it can be conservatively estimated that the geogrids tested will increase the pavement life by approximately 2 to 4 times with respect to unreinforced pavements.

Quantified benefits of stabilization of flexible pavement are reported in term of traffic benefit ratio (TBR), which in turn defines the extension in service life of the stabilized flexible pavement as compared to equivalent unstabilized section (Perkins and Edens 2003, Webstar 1992, Hass *et al.* 1988, Thomas and Jeannette 1988).

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 % (Moustafa *et al.* 2011).

Most of the study is concerned with geotechnical aspect. Some of the researchers reported the benefits of these stabilizers in highway pavement application, but from the available literature it is observed that, comparative study on stabilizer which one will give maximum benefits is not carried out. Hence, considering this gap in research study, present investigation is carried out to evaluate the benefits of stabilization in term of improvement in characteristic strength of subgrade soils, layer thickness reduction, traffic benefit ratio.

3. Experimental investigations

3.1 Materials

Soils identified for the present investigation were procured from two sites of Maharashtra state of India, one from Ulwa (New Mumbai) and other from Taloja Phase I (New Mumbai), India and hereby they are referred to as the Soil A and Soil B, respectively. Primary engineering tests were conducted on both soils for its identification and classification. Physical properties and classification of the soils used in present study are shown in Table 1. As per AASHTO soil classification, soil A and soil B are referred to as A-7-5 and A-2-5 respectively.

3.2 Stabilizers

Three types of stabilizers i.e., hydrated lime; Class F fly ash and polypropylene fibers are used for the laboratory investigation. These stabilizers were mixed in the selected soils in different proportion by dry weight of soil as shown in Table.

3.3 Optimum quantity of stabilizers

Depending on the results of California Bearing Ratio (CBR) and UCS tests, 4.5% lime, 10% fly ash and 0.5% of fiber by dry weight of soil were considered as optimum content for stabilization of both subgrade soils. CBR values and UCS values obtained for these optimum percentages are shown in Table 3

4. Finite element modeling

4.1Mechanistic approach

This methodology has better capability to characterization of different material properties and loading conditions and has ability to evaluate different design alternatives on economic basis.

Fig. 1 shows system architecture for mechanistic approach.

Table 1 Physical properties of subgrade soils used in the present study

S.N	Property	Soil-A	Soil-B
1.	Liquid Limit (%)	96	42.8
2.	Plastic Limit (%)	35	33.19
3.	Plasticity Index (%)	61	9.61
4.	MDD (KN/m^3)	12.4	16.5
5.	OMC (%)	28	20
6.	CBR (%)	1.45	4.67
7.	Specific Gravity	2.36	2.32
8.	Moisture Content (%)	6.56	6.81
9.	Coefficient of Uniformity (C_u)	4.06	4.43
10.	Coefficient of Curvature (C_c)	1.21	1.19
11.	Soil Classification as per AASHTO	A 7-5	A 2-5
12.	Typical name	Clayey soil	Silty Gravel Sand

Table 2 Different percentages of Stabilizers mixed with Soil

Stabilizer	**Percentage of Stabilizer by dry weight of soil**			
Lime	1.5	3	4.5	6
Fly Ash	5	10	15	20
Fiber	0.25	0.5	0.75	1

Table 3 Different percentages of Stabilizers mixed with Soil

Subgrade Soil A								
Lime (%)	Max. CBR	Max. UCS	Fly Ash (%)	Max. CBR	Max. UCS	Fiber (%)	Max. CBR	Max. UCS
4.5	7.70	334.1	10	3.68	331.5	0.5	4.23	319.5
Subgrade Soil B								
4.5	15.91	245.7	10	8.13	437	0.5	8.47	601.5

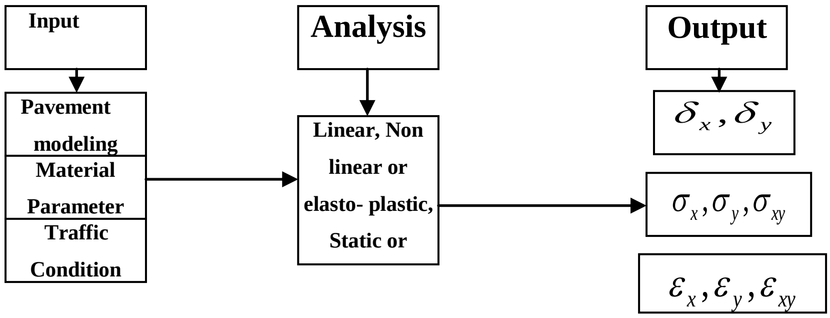

Fig. 1 System architecture for mechanistic approach

4.2 Modeling of pavement section

A 2- D axisymmetric , elasto – plastic finite element analysis of the mechanistic pavement model resting on unstabilized and stabilized subgrade was carried out by using commercial software ANSYS. In order to quantify the benefits of lime, fly ash and fiber stabilization, stresses, deformation and strain at the top of subgrade was captured from each computer run. Also, a parametric study was carried out to investigate the effect on deformation, strain and stress developed at top of unstabilized and stabilized subgrade due to change in thickness of subbase or base or DBM (from constant subbase and base as per standard section

4.3 Dimensions of model and loading

The dimensions of finite element model should be sufficiently large so that constraint imposed at boundary will have negligible influence on the stress distribution system. In present study right hand boundary had been placed at 110 cm from the outer edge of loaded area which was more than 7 times the radius of applied load of 150 mm. 8 noded structural solid elements were used for all the layers of flexible pavement. A uniform pressure of 5.75 kg/cm^2 was applied on circular contact area with a radius of 150 mm. This uniform pressure will be caused by single axle wheel load of 4080 kg. The elasto-plastic analysis was carried out to evaluate the primary response of the pavement resting on subgrade soil. While meshing, finer mesh was provided near loaded area where stress concentration was more, and subsequently it became coarser towards right boundary.

4.4 Boundary conditions

For the application of finite element method in pavement analysis, a five layered system of infinite extent was reduced to a system having finite dimensions. Fig. 2 shows typical 2 – D axisymmetric finite element models for pavement resting on subgrade soil B. Roller supports were provided along the axis of symmetry to achieve the condition that both the shear stress and radial displacement were equal to zero. The roller supports were provided along right hand boundary which was placed sufficient away from center of loading so as to have negligible deflection in radial direction. At the bottom boundary, roller supports were provided for permitting free movement in radial direction and any other movement restraint to vertical direction.

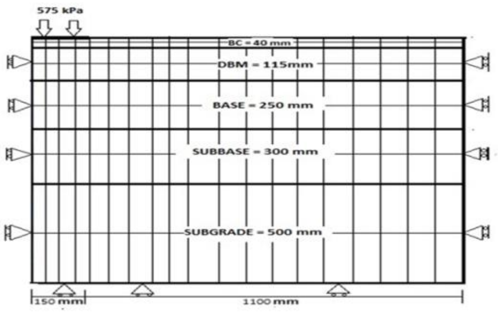

Fig. 2 Finite- element discretization of pavement section for unstabilized subgrade soil B

Table 4 Different percentages of stabilizers mixed with soil

Subgrade Soil A						
CBR	Subgrade	Subbase	Base	DBM	BC	Total
1.45	500	460+150	250	175	40	1575
Subgrade Soil B						
4.67	500	300	250	115	40	1205

The pavement section is modeled as an axisymmetric solid to mechanistically solve the layer pavement response due to traffic loading and to investigate the benefits of stabilizing the subgrade soil in flexible pavement design. The thickness of each layer above the subgrade soil is decided based on CBR value of subgrade soil for traffic intensity of 50 msa as per IRC 37:2001.The subgrade soil has infinite depth but finite element modeling requires consideration of finite depth for the subgrade soil. In the present study the thickness of subgrade is assumed to be 500 mm.

Table 4 gives the value of thicknesses of various layers and total thickness of pavements resting on subgrade soil A and soil B for traffic intensity of 50 msa. IRC recommends that if CBR value of subgrade soil is less than 2% design should be based on 2 percent CBR and capping layer of 150 mm should be provided in addition to subbase thickness. In present study, the CBR value of subgrade soil A is 1.45 percent hence a capping layer of 150 mm has been provided in addition to subbase thickness.

4.5 Input data for finite element modeling

The finite element analysis of the pavement system was carried out by employing the multilinear isotropic elasto - plastic hardening model (MISO) which uses von mises yield criterion. The properties of different layers required for carrying out the Finite Element analysis are the modulus of elasticity, poisson ratio and stress – strain data. Chandra and Mehendiratta (2002) reported that confinement in the pavement due to shoulder and surrounding soils is in the range of 26 to 40 KPa. Also, the subgrade soil has been assumed to be saturated and to have a low permeability. As the subgrade soil behaves in an undrained manner under traffic loading; unconsolidated, undrained triaxial tests were conducted on unstabilized and stabilized subgrade soils as well on other pavement layers at a confining pressure of 40 KPa. The modulus of elasticity is calculated by drawing tangent to initial portion of deviator stress – strain curve. Table 5 shows the value of modulus of elasticity of subgrade soil and other pavement layers used in Finite Element modeling.

5. Evaluation of stabilization benefits

To evaluate the benefits of stabilization of soils 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 would result in reduction in layer thicknesses which is expressed in term of LTR.

2. Keeping the same pavement section for stabilized and unstabilized pavement section. This would result in to extension in service life of the pavement due to stabilization and expressed in term of TBR.

The IRC 37 (2001) considers a rut depth of 20 mm to be a failure criterion for flexible pavement and provides rutting equation as

$$N_{20} = 4.1656 *10-8 (1/\varepsilon v) 4.5357 \quad (1)$$

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 Dense Bound Macadam (DBM). For soil A, 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 thickness was varied.

Table 5 Different percentages of stabilizers mixed with soil

Stabilizer	Lime		Fly Ash		Fibre		Pavement Layer			
Parameter	US*	S	US*	S	US	S	Subbase	Base	DBM	BC
Subgrade Soil A										
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
Subgrade Soil A										
E (MPa)	14.3	22.1	14.3	18.5	14.3	18.5	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

*US- Unstabilized pavement section, S- Stabilized pavement section0

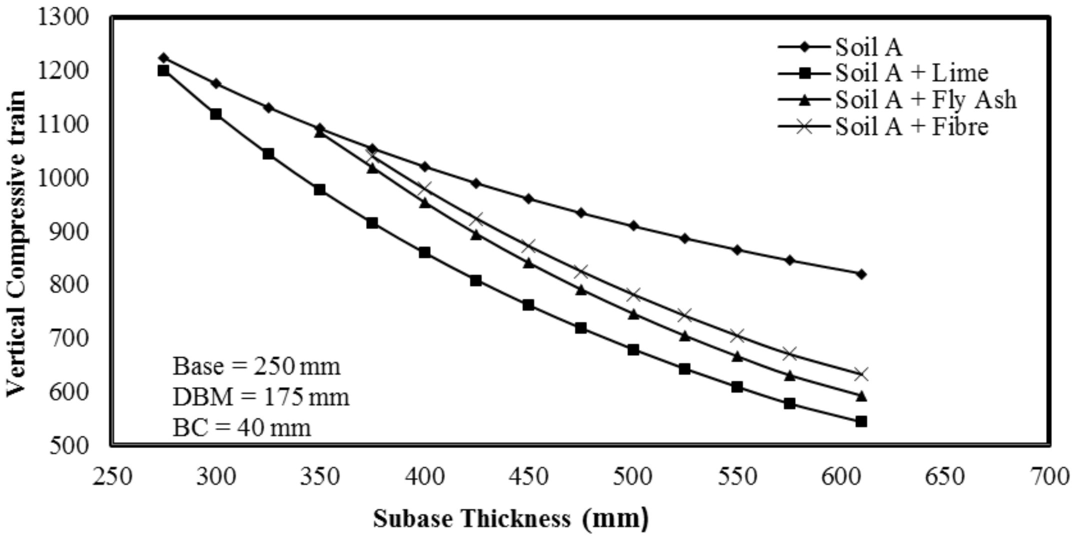

Fig. 3 Variation of vertical compressive strain at top of subgrade soil a with subbase thickness for pavement resting on unstabilized and stabilized subgrade

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 captured for all these alternatives from finite element analysis and variation in vertical compressive strain with varying subbase thickness is plotted as shown in Fig. 3. Similar exercise was carried out for soil B.

The values of vertical compressive strain the top of unstabilized and stabilized subgrade soil A and soil B are further used for estimation of benefits of stabilization in term of LTR and TBR. The TBR gives the extension in the service life of pavement due to stabilization and can be expressed as (Berg *et al.* 2000)

$$TBR = N_S / N_U \quad (2)$$

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

$$LTR = [(D_U - D_S) / D_U] * 100 \quad (3)$$

D_U and D_S are layer thicknesses of unstabilized and stabilized pavement sections respectively.
Using Eqs. (1)-(3), the benefit of subgrade soil stabilization in term of extension in service can be given as (Berg *et al.* 2000)

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

Where ε_{VS} and ε_{VU} are vertical compressive strain at the top of stabilized and unstabilized subgrade respectively. The vertical compressive strain, ε_V at the top of subgrade is obtained through commercial software ANSYS and B = 4.5337 (IRC 2001).

Table 6 Stabilization benefits in subbase, base and DBM thickness (Soil B)

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	300	-	1.25	2.84	250	-	1.25	2.84	115	-	1.25	2.84
	275	8.33	1.20	2.34	225	10	1.17	2.11	100	13.04	1.18	2.12
	250	16.66	1.15	1.92	200	20	1.09	1.53	80	30.43	1.10	1.54
	225	25	1.10	1.56	175	30	1.01	1.08	60	47.82	1.02	1.09
	200	33.33	1.05	1.26								
Fly ash	300	-	1.14	1.84	250	-	1.14	1.84	115	-	1.14	1.84
	275	8.33	1.10	1.54	225	10	1.08	1.44	100	13.04	1.08	1.44
	250	16.66	1.05	1.29	200	20	1.02	1.11	80	30.43	1.02	1.11
	225	25	1.01	1.07								
Fibre	300	-	1.12	1.67	250	-	1.12	1.67	115	-	1.12	1.67
	275	8.33	1.10	1.54	225	10	1.07	1.37	100	13.04	1.07	1.37
	250	16.66	1.08	1.46	200	20	1.02	1.11	90	21.73	1.01	1.08

Table 7 Stabilization benefits in subbase, base and DBM thickness (Soil A)

Stablizer	Subbase Thicknes (mm)	Constant base and DBM			Base Thickness	Constant subbase and DBM			DBM Thickness	Constant subbase and base		
		LTR (%)	$\varepsilon_{VU}/\varepsilon_{VS}$	TBR		LTR (%)	$\varepsilon_{VU}/\varepsilon_{VS}$	TBR		LTR (%)	$\varepsilon_{VU}/\varepsilon_{VS}$	TBR
Lime	610	-	1.510	6.49	250	-	1.510	6.49	175	-	1.510	6.49
	575	6.08	1.463	5.61	225	10	1.446	5.32	150	14.28	1.416	4.84
	550	9.83	1.420	4.91	200	20	1.383	4.35	125	28.57	1.324	3.57
	525	13.93	1.379	4.29	175	30	1.321	3.54	100	42.85	1.234	2.59
	500	18.03	1.338	3.75	150	40	1.261	2.86	75	57.14	1.146	1.85
	475	22.13	1.299	3.27	125	50	1.201	2.30	50	71.42	1.058	1.29
	450	26.22	1.260	2.86	100	60	1.142	1.83	-		-	
	425	30.32	1.223	2.49	75	70	1.085	1.44	-		-	
	400	34.42	1.187	2.17	50	80	1.028	1.13	-		-	
Fly ash	610	-	1.385	4.37	250	-	1.385	4.37	175	-	1.385	4.37
	575	6.08	1.339	3.76	225	10	1.321	3.53	150	14.28	1.269	2.94
	550	9.83	1.298	3.26	200	20	1.258	2.83	125	28.57	1.154	1.91
	525	13.94	1.258	2.83	175	30	1.196	2.25	100	42.85	1.038	1.18
	500	18.03	1.218	2.45	150	40	1.135	1.77	-		-	
	475	22.13	1.180	2.11	125	50	1.074	1.38	-		-	
	450	26.22	1.142	1.82	100	60	1.014	1.06	-		-	
Fibre	610	-	1.298	3.26	250	-	1.298	3.26	175	-	1.298	3.26
	575	6.08	1.261	2.86	225	10	1.241	2.66	150	14.28	1.180	2.12
	550	9.83	1.227	2.53	200	20	1.185	2.16	125	28.57	1.063	1.31
	525	13.93	1.195	2.24	175	30	1.13	1.74	-		-	
	500	18.03	1.162	1.98	150	40	1.076	1.39	-		-	
	475	22.13	1.131	1.75	125	50	1.022	1.10	-		-	

The vertical compressive strain for unstabilized soil A is found to reduce from 820.24 microstrains to 542.92, 592.19 and 631.89 microstrains for lime, fly ash and fiber stabilized pavements respectively. The corresponding values of TBR are found to be 6.49, 4.37 and 3.26 respectively. Similar exercises have been done for subgrade Soil B. Results obtained from such studies is summarized in Tables 6 and 7.

The results depicted in Tables 6 and 7 show that for a constant thickness of base and DBM, the thickness of subbase reduces by 34.42, 26.22 and 22.13% due to lime, fly ash and fiber stabilization of subgrade soil A respectively. Similar options can be exercised for soil B. 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 fiber stabilized subgrade soil A, the thickness of subbase can be reduced by 34.42, 26.22 and 22.13% respectively. But if it is desired to opt for 18.03% reduction in subbase thickness, it is possible to gain additional benefit in term of TBR of 3.75, 2.45 and 1.98 for lime, fly ash and fiber stabilized pavement resting on subgrade soil A respectively.

6. Conclusions

Following important conclusions are drawn from this investigation.

• The maximum improvement in terms of CBR is observed when both the subgrade soils A and soil B are stabilized with 4.5% lime, 10% fly ash and 0.5% fiber

• The decrease in the value of vertical compressive strain at top of stabilized subgrade indicates that there is

(i) Reduction in layer thicknesses if service life is considered to be same for unstabilized and stabilized pavement.

(ii) Extension in service life for same layer thicknesses of unstabilized and stabilized pavement.

• For a constant thickness of base and DBM (as for the standard section), the thickness of the subbase reduces by 34.42, 26.22 and 22.23 % due to lime, fly ash and fiber stabilization of subgrade soil A respectively.

• For 18.03% layer thickness reduction in subbase thickness, it is possible to gain additional benefit in term of TBR of 3.75, 2.45 and 1.98 for lime, fly ash and fiber stabilized pavement resting on subgrade soil A respectively.

• Lime, fly ash and fiber stabilization of subgrade soil B revealed the decrease of 33.33, 25 and 16.66% in thickness of the subbase for constant thickness of base and DBM.

• The suggested mechanistic design approach provides different alternatives to the designer to quantify the subgrade stabilization benefits in term of traffic benefit ratio (TBR) and layer thickness reduction (LTR). The proposed procedure includes cost effective analysis including the saving of natural resources as an integral part of design of stabilized flexible pavement.

• Actual saving in the construction cost of the flexible pavement would depend upon the option exercised by the designer for reducing the thickness of an individual layer.

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