Design of Flexible Pavements by using Lime and Fly Ash Stabilizers

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Abstract :   Most of the time flexible pavements in India need to be constructed over problematic and poor subgrade. Such subgrades have low California Bearing Ratio (CBR), which leads to more thickness of the pavement. Decrease in availability of suitable granular sub-base and granular base course materials for highway construction leads to a search for economic method of converting locally available troublesome soil to suitable construction materials. Lime and Fly ash can be effectively utilized for improving the engineering properties of the weak soil. The present research was carried out to study the effect of lime and fly ash stabilization on Maximum Dry Density (MDD), Optimum Moisture Content (OMC) and California Bearing Ratio (CBR) of the subgrade soil. Also the pavement section has been designed as per Indian Practice Code IRC 37:2012 for different traffic intensity and construction cost estimated for 1 km pavement section resting on unstabilized and stabilized subgrade with different percentages of lime and fly ash. The study shows that 4.5 percent lime and 10 percent fly ash will be more effective in material and cost optimization.

IndexTerms - **stabilization, lime, flyash, california bearing ratio, economical analysis.**

I. INTRODUCTION

Soil Stabilization is the process of blending and mixing materials with a soil to improve certain properties of the soil. The process may include the blending of soils to achieve a desired gradation or the mixing of commercially available additives 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 laying soils. Unstable soils can create significant problems for pavements. Lack of adequate road network to cater to the increased demand and increase distress in road leading to frequent maintenance have always been big problem in our country. Evolving new construction materials to suit various traffic and site conditions for economic and safe design is a challenging task in road construction. Effective utilization of local weak soils by imparting additional strength using stabilization materials enable reduction in construction cost and improved performance for roads. 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. Desirable properties of subgrade are high compressive and shear strength, permanency of strength under all weather and loading conditions, ease and permanency of compaction, ease of drainage and low susceptibility to volume changes and frost action.

II. LITRATURE REVIEW

George vorobieff and Greg Murphy [1] suggested interim design approach for lime stabilization of subgrade material. The laboratory subgrade CBR is determined using AS 1289.6.1.1. It is noted that standard and not modified compaction is used in the preparation of sample. The design subgrade CBR may be calculated by either using the equivalent CBR approach or using the sub layering techniques. Field performance continually showed that lime stabilization worked well and shortcuts taken in the specification or by contractor should be avoided. Swapan Kumar Bangui [2] 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. Also aggregate consumption is less for the case of stabilized base compared to that of the conventional method. Moustafa Ahmed Kamel, Mohamed EL- Shabrawy Ali and Hamad M.EL- Ajmi [3] conducted a comparative study for optimization and quantification of the beneficial effects of stabilization of subgrade soils in flexible pavement system. They selected six different groups of stabilizers i.e. cement, lime, a mixture of cement and polystyrene fibers, cement and lime. 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%. Niroj Kumar Mishra, Sudhir Rath [4] 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 combination of 70 % soil + 30 % lime +2 % limes. Nafi Abdel Rahman Youssef, Omer Nawaf Maaitah & Khaldon Qdeshat [5] 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. Koteswara Rao. D. Anuaha, P.R.T. Pranav, G. V. Venkatesh [6] performed laboratory investigation on the stabilization of marine clay using saw dust and lime and observed that the CBR value of marine clay has been increased by 129.76% on addition of 15% sawdust and it has been further improved by 283.12% when 4% lime is added. Nagrale Prashant P. & P. Srivastava [7] 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. 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. O.O. Amu, O. Bamisaye and I. Komolafe [8] studied the stability and lime stabilization requirement of some selected lateritic soil samples using 2, 4, 6, 8 and 10 % of lime and reported that increase in dry density was as a result of the increasing lime particles that were ready to perform the exchange of cat ions with the soil particles, thus filling up the voids spaces and densely packing the soil particles together. However, the drop in density resulted from the excess water and lime

remaining after the increasing quantity has been used up for stabilization process. J. Trivedi, S. Nair and C. Iyyunni [9] carried out experimental studies to investigate optimum utilization of fly ash for stabilization of subgrade soil and concluded that OMC attains its highest value of 29.27 % for 10 % of fly ash as compare to 21.38 % for unstabilized soil whereas, CBR value increases from 5.64 % to 20.53 % for 20 % of fly ash. L. Yadu, R. Tripathi and D. Singh [10] conducted number of experiment for the comparison of fly ash and rice husk ash stabilized black cotton soil .Based on the CBR and UCS tests they reported the optimum amount of fly ash and rice husk ash was 12% and 9% respectively. Saving in the cost per km length of road has been estimated to be approximately 14% and 20% for RHA and FA respectively. B. Phanikumar and R. Sharma [11] studied the effect of fly ash on engineering properties of expansive soils and stated that optimum moisture content decreased and maximum dry unit weight increased with an increase in fly ash content. There is substantial history of use of soil stabilization admixture to improve poor subgrade soil performance by controlling volume change and increasing strength. V. Pasupuleti, S. Kolluru and T. Blessingstone [12] conducted experimental study on effect of fiber and fly ash stabilized subgrade and stated that optimum CBR value was obtained at 15% of fly ash with 1.5 % fiber content. E. Geliga and D. Ismail [13] investigated geotechnical properties of fly ash and its application on soil stabilization and reported that shear strength observed of sample mixture cured for 7 days were decreasing when amount of fly ash was 80% of the total weight of the mixture. R. Sharma [14] studied the sub grade characteristics of locally available expansive soil mixed with fly ash and randomly distributed fibers. As per the results of investigation, it was reported that proportion of 70 % soil and 30 % fly ash was the best proportion having maximum dry density and maximum CBR value.

Available literature shows that most of the research works on cement, fiber, saw dust, lime and fly ash stabilization is related to geotechnical aspects only. Very few attempts have been made on use of lime or fly ash in highway subgrade. Conflicting results have been reported in literature regarding optimum percentage of lime and fly ash required for soil stabilization. Actual benefits of stabilizing the subgrade soil with lime and fly ash also finding out its optimum dosage and which one (lime or fly ash) is most suitable in terms of economy and layer thickness reduction has not been reported anywhere in the previous literature.

III. EXPERIMENTAL PROGRAMME

A.   Material Selection

Two types of soil namely Soil A and Soil B available near Ulwa, Navi Mumbai and Taloja, Phase I, Navi Mumbai collected. The properties of both soils used in present study are given in Table I. As per the AASHTO soil classification system, Soil A is A-7-5 and Soil B is A-2-5. Similarly, hydrated lime and class F fly ash is used in the present investigation; its properties are listed in Table II and   Table III respectively. The index properties; liquid limit, Plastic limit and plasticity index were determined as per [IS 2720-Part (5)-1985]. The Standard Proctor's tests were conducted as per [IS 2720-Part (7)-1980] for deciding the Maximum Dry Density (MDD) and the Optimum Moisture Content (OMC) for soil. Hydrated Lime is mixed with dry soil in different percentages varying from 1.5, 3, 4.5, and 6 percent by dry weight of soil. Similarly, Fly Ash is mixed with dry soil in different percentages varying from 5, 10, 15 and 20 percent by dry weight of soil.

TABLE I.　　PHYSICAL PROPERTIES OF SOILS USED IN PRESENT STUDY

Sr. No.	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/m3)	1.24	1.65
5.	OMC (%)	28	20
6.	CBR (%)	1.45	4.67
7.	UCS (kg/cm2)	2.084	1.564
8.	Soil Classification as per AASHTO	A 7-5	A 2-5
9.	Typical name	Clayey soil	Silty Gravel Sand

TABLE II.　　Properties of Hydrated Lime Used in Present Study

Sr. No	Particular	Hydrated Lime (90 % Purity)
1.	**Physical Properties**	
	Colour	Snow white
	Residue on 62 μ	1±0.5 %
2.	**Chemical Properties**	
	% of available Lime	91±1 %
	% Activated CaO	70±0.5 %
	% Acid insolubles	0.5±0.5 %
	% Iron and Alumina	0.03±0.01 %
	% Magnesia	0.6±0.1 %
	% Silica	0.3±0.1 %
	% Chloride	0.002±0.001 %

TABLE III.　　Properties of Class F Fly Ash Used in The Present Study

Sr. No.	Characteristics	IS 3812 Grade Grade-1	Result Obtained
1.	Silicon Dioxide (Si02) + Aluminum Oxide (AI203) + Iron (Fe203) Min%	70.00	91.76
2.	Silicon Dioxide (Si02) By % Mass, Min	35.00	59.58
3.	Magnesium i.e. MgO Max %	5.00	3.30
4.	Sulphur Trioxide (SO3) Max %	2.75	0.22
5.	Moisture Content, Max %	-	0.08
6.	Loss on Ignition, Max%	6.00	0.50
7.	Available Alkalies as Sodium Oxide (Na2O), Max %	1.50	0.70
8.	Fineness % Retained On 45 micron sieve Max %	34	11.40

B.　Determination of Optimum Quantity of Lime and Fly Ash

1)　Standard Proctor's Test

Standard Proctor Tests were carried out on both unstabilized and stabilized soils as per [IS 2720-Part (7)-1980]. Both subgrade soil-A and soil-B mixed with different percentages of lime vary from 1.5 to 6 percent at the steps of 1.5 percent by dry weight of soil. Similarly, with different percentages of fly ash vary from 5 to 20 percent at the steps of 5 percent by dry weight of soil. The mixture was transferred in proctor mould in three equal layers and each layer compacted by giving 25 numbers of uniformly distributed blow. The dry density - moisture content relations were plotted for each test. Then optimum moisture content and maximum dry density at each percentage of lime and fly ash were evaluated. Fig. 1 and Fig. 2 give typical plot showing variation of dry density with moisture content for neat soil and soil stabilized with 1.5 percent lime for both subgrade soil-A and soil-B respectively. Similarly, Fig. 3 and Fig. 4 give typical plot showing variation of dry density with moisture content for neat soil and soil stabilized with 5 percent fly ash for both subgrade soil-A and soil-B respectively. Similar plots are made for other test conditions and variation of maximum dry density and optimum moisture content for stabilized soil at different lime content for soil-A and soil-B have been summarized in Table 4 whereas; similar plots are made for other test conditions and variation of maximum dry density and optimum moisture content for stabilized soil at different fly ash content for soil-A and soil-B have been summarized in Table 5.

The results show that, in lime, for subgrade soil-A, the value of both maximum dry density and optimum moisture content goes on increasing with increase in percentage of lime. The maximum dry density of unstabilized subgrade soil-A is found to be 12.164 kN/m^3. This value increases to 13.45 kN/m^3 at 3 % of lime content. Thereafter, these values drop down. Increase in density

was as a result of the increasing lime particles that were ready to perform the exchange of cat ions with the soil particles, thus filling up the voids spaces and densely packing the soil particles together. However, the drop in density resulted from the excess water and lime remaining after the increasing quantity has been used up for stabilization process. For soil-A, the optimum moisture content increase from 28 % at 0 % lime to 32 % at 3 % lime with corresponding increase in MDD from 12.164 kN/m^3 to 13.45 kN/m^3 thereafter it decreases to 12.75 kN/m^3 at 6 % lime content. For soil-B, value of maximum dry density goes on decreasing from 16.19 kN/m^3 at 0 % lime to 15.96 kN/m^3 at 6 % lime content. The decrease in the MDD is due to light weight of the lime replacing the soil particles and some of the applied energy of compaction absorbed by the lime. The change in OMC was quite marginal. Table 4 shows the variation of maximum dry density and optimum moisture content for the subgrade soil-A and soil-B mixed with different percentage of lime. In case of fly ash, the maximum dry density of subgrade soil-A and subgrade soil-B is found to be 12.164 kN/m^3 and 16.19 kN/m^3 respectively. These value increases to 14.46 kN/m^3 and 16.94 kN/m^3 respectively, thereafter, these values drop down. Increase in density may be due to heavy weight of fly ash replaced by soil and some of the compacting energy absorbed by fly ash.
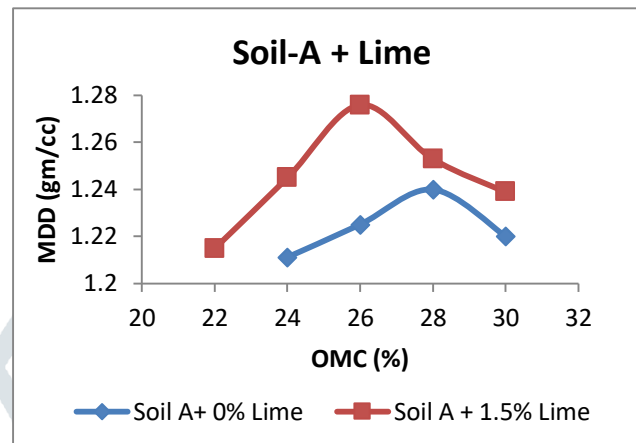

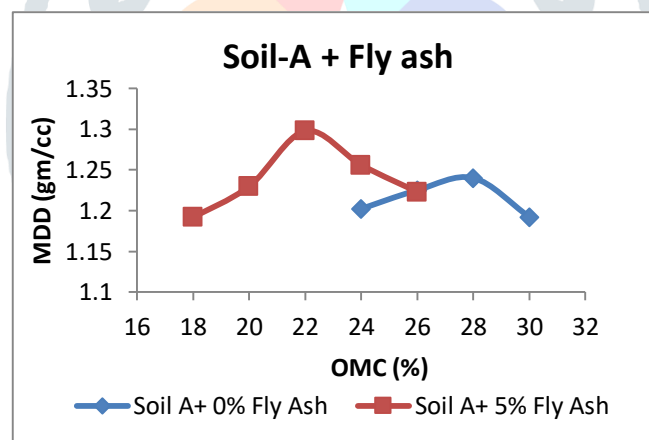*Fig.1* Variation of dry density with water content for Soil-A

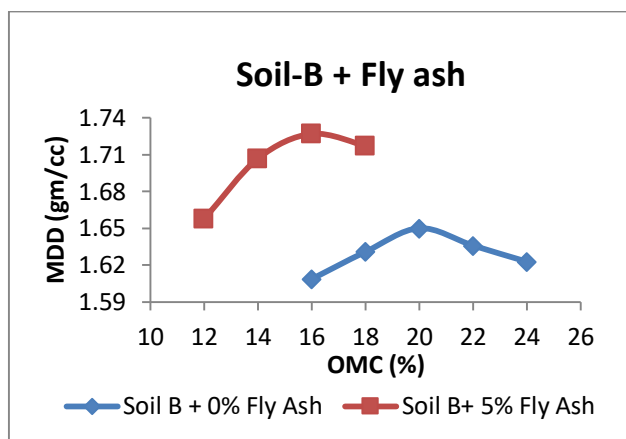*Fig.2* Variation of dry density with water content for Soil-A

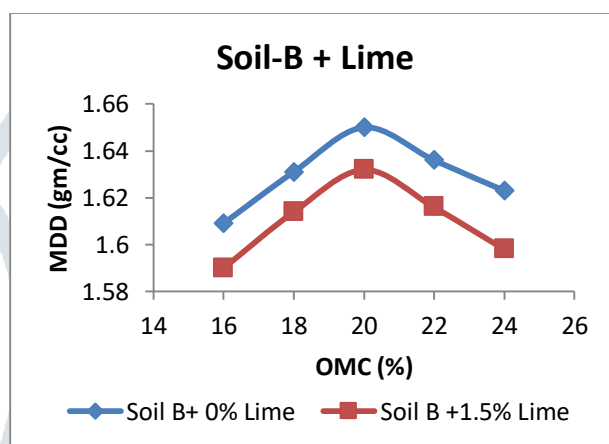*Fig.3* Variation of dry density with water content for Soil-B

Fig.4 Variation of dry density with water content for Soil-B

    2)   California Bearing Ratio Test

Four days soaked CBR tests were conducted on unstabilized and stabilized soils with different percent of lime and fly ash as per [IS 2720 (part 16)-1987]. The maximum limit of lime content was 6 percent, and the maximum limit of fly ash was 20 percent. The dry weight of soil required for filling CBR mould estimated from corresponding dry density and water content corresponding to optimum moisture content added to it. The mixture transferred to CBR mould and then compacted by static compaction.

The compacted CBR mould transfer to water tank for 4 days and that after it is tested in CBR testing machine. The CBR was determined at 2.5 mm and 5.0 mm penetration levels and maximum of this is adopted as CBR value. CBR values

TABLE IV.   Variation of MDD and OMC and CBR value with Lime content for soil-A and soil-B

Sr. No.	Lime Content (%)	Subgrade Soil-A				Subgrade Soil-B			
		MDD kN/m3	OMC (%)	Max. CBR (%)	% increase	MDD kN/m3	OMC (%)	Max. CBR (%)	% increase
1.	0	12.164	28	1.45	-	16.19	20	4.67	-
2.	1.5	12.52	26	2.04	40.68	16.01	20	8.17	74.95
3.	3	13.45	32	6.86	373.10	16.00	22	14.89	218.84
4.	4.5	12.87	32	7.70	431.03	15.990	22	15.91	240.68
5.	6	12.75	32	7.60	424.14	15.96	22	12.40	165.52

TABLE V.   Variation of MDD and OMC and CBR value with Fly Ash content for soil-A and soil-B

Sr. No.	Fly Ash Content (%)	Subgrade Soil-A				Subgrade Soil-B			
		MDD kN/m3	OMC (%)	Max. CBR (%)	% increase	MDD kN/m3	OMC (%)	Max. CBR (%)	% increase
1.	0	12.164	28	1.45	-	16.19	20	4.67	-
-2.	5	12.73	22	2.825	94.82	16.94	16	5.973	27.90
3.	10	14.46	18	3.68	153.79	16.63	18	8.13	74.09
4.	15	14.05	6	2.606	79.72	15.08	14	6.45	38.11
5.	20	14.02	6	1.633	12.62	15.48	14	5.68	21.63

IV. DESIGN CHARTS AND ECONOMICAL ANALYSIS

A. Response Model (as per IRC 37:2012)

The main object of this research is to evaluate the benefits in terms of Layer Thickness Reduction (LTR) due to stabilizing the sub grade soils with lime and fly ash. The thicknesses of different layer of flexible pavement resting on unstabilised and stabilized subgrade for traffic intensity of 50 msa, 100 msa and 150 msa has been evaluated using IRC 37:2012. The thickness of subgrade has been taken 500 mm. These model thicknesses are subsequently used for estimating the quantities and economics of stabilized flexible pavement. Table 6 gives the values of thicknesses of various layers and the total thickness of the pavement for design traffic intensity of 50 msa, 100 msa and 150 msa. In present study, the CBR value of unstabilized subgrade soil-A and soil-B is 1.45 % and 4.67 % respectively. There is no provision in IRC 37:2012, for soil whose CBR is less than 2 percent. Hence the design approach assume as per IRC 37:2001 for unstabilized subgrade soil-A as the CBR is less than 2 percent; capping layer of 150 mm has been provided in addition to the sub-base thickness.

B. Layer Thickness Reduction

The laboratory CBR test conducted on subgrade soil-A and soil-B at different percentages of lime and fly ash. The study has been extended to evaluate the thickness of various layers above the stabilized subgrade soils at different lime and fly ash contents and for a traffic intensity of 50 msa, 100msa and 150 msa. For lime stabilized subgrade, Table 7 for soil-A and soil-B indicates the thickness of various layers and total thickness of the pavement resting on 4.5 percent lime stabilized subgrade soil-A and soil-B for a trafiic intensity of 50 msa, 100 msa and 150 msa. The result show that for a pavement resting on unstabilized subgrade soil-A and soil-B for traffic intensity of 50 msa, 100 msa and 150 msa, the thickness of sub-base is 610 mm and 300 mm respectively, by lime stabilization it reduces to 200 mm for both subgrade soils for a lime content of 4.5 percent. Similarly by fly ash stabilization it reduces to 330 mm and 200 mm for soil-A soil-B respectively for a fly ash content of 10 percent. It indicates that there is considerable saving in natural aggregates. Also, DBM may be the important layer responsible for total cost of construction of pavement. The study shows that, In case of lime, for traffic intensity of 100 msa, in soil-A, thickness of DBM 195 mm; it reduces to 115 mm and for soil-B, thickness of DBM 130 mm; it reduces to 80 mm due to stabilization of subgrade with 4.5 percent lime. Also, in case of Fly Ash, for traffic intensity of 100 msa, in soil-A, thickness of DBM 195 mm; it reduces to 140 mm and for soil-B, thickness of DBM 130 mm; it reduces to 115 mm due to stabilization of subgrade with 10 percent fly ash.

TABLE VI.   THICKNESS OF VARIOUS LAYERS OF FLEXIBLE PAVEMENT RESTING ON UNSTABILIZED SUB GRADE FOR SOIL – A AND SOIL-B

Sr. No.	CBR Value	Traffic Intensity in msa	Sub grade (mm)	Granular Sub-base (mm)	Granular Base (mm)	DBM (mm)	BC (mm)	Total (mm)
Subgrade Soil-A								
1	1.45	50	500	460+150	250	175	40	1575
2	1.45	100	500	460+150	250	195	50	1605
3	1.45	150	500	460+150	250	215	50	1625
Subgrade Soil-B								
4	4.67	50	500	300	250	115	40	1205
5	4.67	100	500	300	250	130	50	1230
6	4.67	150	500	300	250	145	50	1245

TABLE VII. THICKNESSES OF VARIOUS LAYERS AND TOTAL THICKNESS OF PAVEMENT RESTING ON LIME STABILIZED SUB GRADE FOR SOIL – A AND SOIL-B

Sr. No.	Lime Content	Traffic Intensity	CBR value	Subgrade (mm)	Granular Sub-base (mm)	Granular Base (mm)	DBM (mm)	BC (mm)	Total (mm)

Subgrade Soil-A									
1	4.5 %	50 msa	7.70	500	200	250	100	40	1090
2	4.5 %	100 msa	7.70	500	200	250	115	50	1115
3	4.5 %	150 msa	7.70	500	200	250	135	50	1135
Subgrade Soil-B									
4	4.5 %	50 msa	15.91	500	200	250	65	40	1055
5	4.5 %	100 msa	15.91	500	200	250	80	50	1080
6	4.5 %	150 msa	15.91	500	200	250	100	50	1100

TABLE VIII.   THICKNESSES OF VARIOUS LAYERS AND TOTAL THICKNESS OF PAVEMENT RESTING ON FLY ASH STABILIZED SUB GRADE FOR SOIL – A   AND SOIL-B

Sr. No.	Fly Ash Content	Traffic Intensity	CBR value	Subgrade (mm)	Granular Sub-base (mm)	Granular Base (mm)	DBM (mm)	BC (mm)	Total (mm)
Subgrade Soil-A									
1	10 %	50 msa	3.68	500	330	250	130	40	1250
2	10 %	100 msa	3.68	500	330	250	140	50	1270
3	10 %	150 msa	3.68	500	330	250	155	50	1285
Subgrade Soil-B									
4	10 %	50 msa	8.13	500	200	250	100	40	1090
5	10 %	100 msa	8.13	500	200	250	115	50	1115
6	10 %	150 msa	8.13	500	200	250	135	50	1135

Whereas, for lime, in case of soil-A, for a traffic intensity of 150 msa, thickness of DBM is 215 mm; it reduces to 135 mm and in soil-B, thickness of DBM 145 mm; it reduces to 100 mm due to stabilization of subgrade with 4.5 percent lime. Also, in case of fly ash for traffic intensity of 150 msa, in soil-A, thickness of DBM 215 mm; it reduces to 155 mm and in soil-B, thickness of DBM 145 mm; it reduces to 135 mm. due to stabilization of subgrade with 10 percent fly ash. Decrease in thickness of DBM due to lime and fly ash stabilization indicates that there may be considerable saving in cost of the pavement.

C. Economic Analysis

The construction costs of flexible pavements resting on unstabilized and stabilized sub grade soils for different strategies and alternatives have been estimated in order to find out the most optimal design section based on the economic aspect. The routine maintenance cost has not been included as the long term data of stabilized flexible pavements is not available. The initial construction cost has been worked out for one km long 7.0 m wide pavement. The Schedule of Rate (2017-18) (SoR) for Maharashtra state only (Pune, Nashik, Aurangabad, Amravati, Nagpur and Kokan Regions) of India was followed to carry out this economic analysis. Various layers included in each design section are as follows:

a) The sub grade of 500 mm
b) Granular Sub-Base (GSB) of River Bed Material (RBM)
c) Water Bound Macadam (WBM) for sub-base course
d) Dense Bituminous Macadam (DBM)
e) Bituminous Concrete (BC)
f) Cost of Lime per kilogram
g) Cost of Fly Ash per kilogram

I.Estimation of Initial Constrcution Cost

The initial construction cost of each item was worked out in details and subsequently average unit cost of each item was estimated. Table 9 present the thickness and volume of various layers, and corresponding cost of each layer of flexible pavement resting on unstabilized subgrade soil-A and soil B for a designed traffic intensity of 50 msa, 100 msa and 150 msa. Cost of lime is assumed as Rs.4 /kg and cost of fly ash is assumed as Rs. 1.5/kg. Additional cost due to lime and fly ash has been worked out for stabilizing the subgrade soil-A and soil-B and it was added in the construction cost of the subgrade. Table 10 show the additional cost of subgrade due to stabilization with 4.5 percent lime and 10 percent fly ash. The total cost of the flexible pavement resting on stabilized subgrade soil-A and soil-B has been worked out for different alternatives and presented in Table 9 to Table 16.

TABLE IX.   THICKNESSES OF VARIOUS LAYERS AND LAYER WISE COST OF CONSTRUCTION FOR SUBGRADE SOIL – A AND SOIL-B

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵
for traffic intensity of 50 msa					for traffic intensity of 50 msa			
Subgrade	500	3500	250.70	8.77	500	3500	250.70	8.77
GSB	610	4270	535	22.84	300	2100	535	11.24
GB	250	1750	614	10.75	250	1750	614	10.75
DBM	175	1225	5779.50	70.80	115	805	5779.50	46.52
BC	40	280	7960	22.29	40	280	7960	22.29
Total cost required for flexible pavement resting on soil - A			135.45 *10⁵	Total cost required for flexible pavement resting on soil - B				99.57 *10⁵
for traffic intensity of 100 msa					for traffic intensity of 100 msa			
Subgrade	500	3500	250.70	8.77	500	3500	250.70	8.77
GSB	610	4270	535	22.84	300	2100	535	11.24
GB	250	1750	614	10.75	250	1750	614	10.75
DBM	195	1365	5779.50	78.90	130	910	5779.50	52.60
BC	50	350	7960	27.86	50	350	7960	27.86
Total cost required for flexible pavement resting on soil - A			149.12 *10⁵	Total cost required for flexible pavement resting on soil - B				111.22 *10⁵
for traffic intensity of 150 msa					for traffic intensity of 150 msa			
Subgrade	500	3500	250.70	8.77	500	3500	250.70	8.77
GSB	610	4270	535	22.84	300	2100	535	11.24
GB	250	1750	614	10.75	250	1750	614	10.75
DBM	215	1505	5779.50	86.98	145	1015	5779.50	58.66
BC	50	350	7960	27.86	50	350	7960	27.86
Total cost required for flexible pavement resting on soil - A			157.20 *10⁵	Total cost required for flexible pavement resting on soil - B				117.28 *10⁵

TABLE X.   ADDITIONAL COST DUE TO STABILIZATION WITH DIFFERENT % OF LIME AND FLY ASH CONTENT IN SOILS

4.5 % Lime Content					10 % Fly Ash Content				
Subgrade Soil	Dry Density for Soil (kN/m3)	Wt. of dry Soil (kN)	Wt .of Lime (kN)	Additional Cost *10⁵	Subgrade Soil	Dry Density for Soil (kN/m3)	Wt. of dry Soil (kN)	Wt .of Fly Ash (kN)	Additional Cost *10⁵
Soil-A	12.87	45045	2027.03	8.27	Soil-A	14.46	50610	5061	7.74
Soil-B	16.00	56000	2520	10.28	Soil-B	16.63	58205	5820.5	8.90

TABLE XI. THICKNESSES OF VARIOUS LAYERS AND LAYER WISE COST OF CONSTRUCTION FOR PAVEMENT RESTING ON LIME STABILIZED SUB GRADE FOR SOIL – A AND SOIL-B (50 MSA)

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵
4.5 % Lime					4.5 % Lime			
Sub grade	500	3500	250.70	8.77 + 8.27	500	3500	250.70	8.77 + 10.28
GSB	200	1400	535	7.49	200	1400	535	7.49
GB	250	1750	614	10.745	250	1750	614	10.745
DBM	100	700	5779.50	40.46	65	455	5779.50	26.30
BC	40	280	7960	22.29	40	280	7960	22.29
Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - A			98.025 *10⁵	Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - B				85.875 *10⁵

TABLE XII. THICKNESSES OF VARIOUS LAYERS AND LAYER WISE COST OF CONSTRUCTION FOR PAVEMENT RESTING ON LIME STABILIZED SUB GRADE FOR SOIL – A AND SOIL-B (100 MSA)

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵
4.5 % Lime					4.5 % Lime			
Sub grade	500	3500	250.70	8.77 + 8.27	500	3500	250.70	8.77 + 10.28
GSB	200	1400	535	7.49	200	1400	535	7.49
GB	250	1750	614	10.745	250	1750	614	10.745
DBM	115	805	5779.50	46.52	80	560	5779.50	32.37
BC	50	350	7960	27.86	50	350	7960	27.86
Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - A			109.655 *10⁵	Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - B				97.515 *10⁵

TABLE XIII. THICKNESSES OF VARIOUS LAYERS AND LAYER WISE COST OF CONSTRUCTION FOR PAVEMENT RESTING ON LIME STABILIZED SUB GRADE `FOR SOIL – A AND SOIL-B (150 MSA)

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵
4.5 % Lime					4.5 % Lime			
Sub grade	500	3500	250.70	8.77 + 8.27	500	3500	250.70	8.77 + 10.28
GSB	200	1400	535	7.49	200	1400	535	7.49
GB	250	1750	614	10.745	250	1750	614	10.745
DBM	135	945	5779.50	54.62	100	700	5779.50	40.46
BC	50	350	7960	27.86	50	350	7960	27.86
Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - A			117.755 *10⁵	Total Cost of Pavement Resting on 4.5 % Lime Stabilized subgrade for Soil - B				105.605 *10⁵

TABLE XIV.   THICKNESSES OF VARIOUS LAYERS AND LAYER WISE COST OF CONSTRUCTION FOR PAVEMENT RESTING ON FLY ASH STABILIZED SUB GRADE FOR SOIL – A AND SOIL-B (50 MSA)

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵	Thicknesses of various layers (mm)	Volume (m³)	Cost per m³ (Rs.)	Layer wise Cost (Rs.) *10⁵
10 % Fly ash					10 % Fly ash			
Sub grade	500	3500	250.70	8.77 + 7.74	500	3500	250.70	8.77 + 8.90
GSB	330	2310	535	12.36	200	1400	535	7.49
GB	250	1750	614	10.745	250	1750	614	10.745
DBM	130	910	5779.50	52.60	100	700	5779.50	40.46
BC	40	280	7960	22.29	40	280	7960	22.29
Total Cost of Pavement Resting on 10 % Fly Ash Stabilized subgrade for Soil - A			114.5 *10⁵	Total Cost of Pavement Resting on 10 % Fly Ash Stabilized subgrade for Soil - B			98.655 *10⁵	

The economical analysis shows that, in case of lime, for design traffic intensity of 50 msa, 100 msa and 150 msa the construction cost of flexible pavement resting on unstabilized subgrade soil-A is 135.45 lakh, 149.12 lakh and 157.20 lakh respectively (Table 9), it reduces to 98.025 lakh, 109.655 lakh and 117.755 lakh respectively due to stabilization with 4.5 % lime content. Also, for design traffic intensity of 50 msa, 100 msa and 150 msa the construction cost of flexible pavement resting on unstabilized subgrade soil-B is 99.57 lakh, 111.22 lakh and 117.28 lakh respectively (Table 9), it reduces to 85.875 lakh, 97.515 lakh and 105.605 lakh respectively due to stabilization with 4.5 % lime content.

Similarly, in case of fly ash, for design traffic intensity of 50 msa, 100 msa and 150 msa the construction cost of flexible pavement resting on unstabilized subgrade soil-A is 135.45 lakh, 149.12 lakh and 157.20 lakh respectively (Table 9), it reduces to 114.5 lakh, 124.115 lakh and 130.185 lakh respectively due to stabilization with 10 % fly ash content. Also, for design traffic intensity of 50 msa, and 100 msa the construction cost of flexible pavement resting on unstabilized subgrade soil-B is 99.57 lakh and 111.22 lakh respectively (Table 9), it reduces to 98.655 and 110.29 lakh respectively due to stabilization with 10 % fly ash content.

The percentage decrease in cost has been worked out for different design traffic intensity. It shows that, in lime, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-A decreases by, 27.63, 26.465 and 25.09 respectively and in soil-B, the total cost of pavement decreases by, 13.75, 12.322 and 9.95 respectively. Similarly, in fly ash, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of of pavement in soil-A decreases by 15.47, 16.77 and 17.18 respectively and in soil-B, for a design traffic intensity of 50 msa, and 100 msa the total cost of pavement decreases by, 0.92 and 0.84 respectively and for 150 msa, it is observed that uneconomical.

V. CONCLUSION

- In case of lime, for subgrade soil-A, with an increase in lime content up to 3 % the maximum dry density increases and thereafter it drops down whereas; the optimum moisture content decreases at 1.5 % lime content and thereafter the increase in OMC is constant up to 6 % of lime content. For soil-B, maximum dry density decreases and OMC increases as the percentage of lime content increases.

- In case of fly ash, for subgrade soil-A, with an increase in fly ash content up to 10 %, the maximum dry density increases and thereafter it drop down whereas; the optimum moisture content consistently decreases for subgrade Soil-A. For soil-B, with an increase in fly ash content up to 5 %, the maximum dry density increases and thereafter it drop down whereas; the optimum moisture content consistently decreases for subgrade Soil-B.

- In case of lime, the percentage increase in CBR for soil-A is 40.68, 373.10, 431.03 and 424.14 % for the lime percentage of 1.5, 3, 4.5 and 6 % respectively. Percentage increase in CBR for soil-B is 74.95, 218.84, 240.68 and 165.52 % for the lime percentage of 1.5, 3, 4.5 and 6 % respectively.

- In case of fly ash, the percentage increase in CBR for subgrade soil A is 94.82, 153.79, 79.72 and 12.62 for the fly ash percentage of 5, 10, 15 and 20 respectively whereas the percentage increase in CBR for subgrade soil B is 27.90, 74.08, 38.11 and 21.63 for the fly ash percentage of 5, 10, 15 and 20 respectively.

- From CBR test, in case of lime, the maximum improvement in terms of CBR is observed at 4.5 % lime for both subgrade soil-A and soil-B. Similarly, in case of fly ash, the maximum improvement in terms of CBR is observed 10 % fly ash for both subgrade soil-A and soil-B. Hence it can be considered as optimum percentage of 4.5 percent lime and 10 percent fly ash required for design the flexible pavement.

- Analysis of stabilized flexible pavement shows that there is a considerable reduction in layer thicknesses and it is the function of percentage of lime and fly ash also traffic for which pavement is designed.

- The percentage decrease in cost shows that, in lime, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-A decreases by, 27.63, 26.465 and 25.09 respectively and in soil-B, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement decreases by, 13.75, 12.322 and 9.95 respectively.

- The percentage decrease in cost shows that, in fly ash, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of of pavement in soil-A decreases by, 15.47, 16.77 and 17.18 respectively and in soil-B, for a design traffic intensity of 50 msa and 100 msa, the total cost of pavement decreases by, 0.92 and 0.84 respectively. For 150 msa, it is observed that uneconomical.

- Percentage decrease in cost indicates that, the design of flexible pavement resting on 4.5 % lime stabilized subgrade soil-A with traffic intensity of 50 msa and 10 % fly ash stabilized subgrade soil-A with traffic intensity of 150 msa will be more economical in terms of saving natural resources as well as initial construction cost of the pavement.

- From the percentage increase in CBR and economical analysis for flexible pavement, it can be concluded that lime is the best stabilizer than fly ash.

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