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Stabilization of Silty Gravel Soil and Clayey Soil Using Combination of Lime and GGBS

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ABSTRACT
Soil Stabilization plays an important role in all Civil Engineering works. Mostly flexible pavements are required to be constructed over poor subgrade having soil stabilization issues which leads to more thickness of the pavement. This paper discussed the use of optimum percentage of lime, GGBS required for getting the maximum benefits. Two type of soil were used termed here as Soil A and Soil B and two types of stabilizers i.e. combination of hydrated lime and GGBS were selected in the present investigation. The Atterberg's limit, compaction, California bearing ratio (CBR) tests were conducted on un-stabilized and stabilized subgrade soil for (2%, 4%and 6%) of lime and (3%, 6% and 9%) of GGBS stabilizers. Based on the test results, 6 % lime and 6% GGBS were selected as optimum stabilizer content. The flexible pavement was design with respect to IRC 37:2012 with traffic intensity i.e., 50Msa, 100Msa, 150Msa. The comparative analysis were conducted which one will give maximum benefits and can be suitable for economical application in highway sub grade. Construction cost estimated for 1 km pavement section resting on un-stabilized and stabilized sub grade with different percentages of lime with GGBS. The study shows proportion percentage of the 2%, 4%, 6% lime and 3%, 6%, 9 percent GGBS respectively will be more effective in material and cost optimization.
Keyword: *Stabilization, Lime, GGBS, California Bearing Ratio, Economical Analysis.*

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I. Introduction

The methods of soil stabilization are greatly applied all over the world. The technique has been widely recommended for the construction of various layers of the pavements. The wide spread of different type soil has posed challenges and difficulties in the construction activities because of its different properties. The inadequate natural stability of soil can be reduced using various techniques; one of them is through admixtures or stabilizers. Soils may be stabilized to improved strength and durability or to stop erosion and dust formation. The main purpose for stabilization is the formation of a soil material or soil system that will remain in place under the design use conditions for the design life of the project. Purpose of the stabilization of flexible pavement resting on weak and troublesome soil is to acquire adorable properties of sub grade which are high compressive and shear strength, permanent strength under all climatic and loading conditions, ease and permanency of compaction, ease of drainage and low susceptibility to volume changes and frost action. Since sub grade soils vary considerably, the relationship of texture, density, moisture content and strength of sub grade materials is manifold.

Pavement design is based on the fact that minimum detailed structural quality will be obtained for individual layer of material in the pavement system. Individual layer must resist shearing, abstain excessive deflections that cause fag cracking within the layer or in overlying layers, and stop excessive permanent deformation through densification. As the genius of a soil layer is raised, the capability of that layer to convey the load over a greater area is generally raised so that a contraction in the required thickness of the soil and surface layers may be acceptable. In recent years, stabilization of flexible pavement has several applications like increase in ultimate strength in terms of California Bearing Ratio (CBR), ductility, toughness, energy absorption capacity of soil. Present study provides insight on comparative study of two stabilizers regarding their effect on improvement in characteristic strength of subgrade soils and its effect on pavement response.

Dr. D. D. Higgins (2005) summarized that UK research and practical experience relating to the use of ggbs+lime1 combinations for soil stabilization. It has been shown that ggbs + lime combinations are practical and effective options for soil stabilization, and provide technical benefits. Nadgouda, K.A. (2010) studied that Black cotton soil is one of the major soil deposits of India. Changes in various soil properties such as Liquid limit, Plastic Limit, Maximum Dry Density, Optimum Moisture Content, Differential Free Swell, Swelling

Pressure and California Bearing Ratio were studied. Pankaj R. Modak, Prakash B. Nangare (2012) studied stabilization of Black Cotton Soil (BC soil) is studied by using Lime and Fly ash. BC soils are highly clayey soils (Montmorillonite clay mineral). The result shows that the use of Lime and Fly ash increases the California Bearing Ratio values i.e. the strength of soil to a great extent. Anil Kumar (2013) represented that as study of the lime and fly ash as the admixtures or stabilizers in improving some engineering Properties of Black cotton (BC) soils. This experimental program evaluates the effect of the lime and fly ash on the some basic engineering properties of BC soil such as Liquid limit, plastic limit and compaction of BC soil and California bearing ratio (CBR) of BC Soil. Ankit Singh Negi (2013) studied that the complete analysis of the improvement of soil properties and its stabilization using lime. Laxmikant Yadu (2013) Evaluated that the potential of granulated blast furnace slag (GBS) with fly ash to stabilize a soft soil. This soil was classified as CI-MI as per Indian Standard Classification system (ISCS). Different amounts of GGBS, i.e. 3, 6, and 9% with different amount of fly ash i.e 3%, 6%, 9% and 12% were used to stabilize the soft soil. Oormila T. R. & T. V. Preethi (2014) investigated that the evaluation of soil properties like unconfined compressive strength test and California bearing ratio test, The soil sample was collected from Palur, Tamil Nadu and addition to that, different percentages of fly ash (5, 10%, 15% and 20%) and GGBS (15%, 20%, 25%) was added to find the variation in its original strength. B. Vishnuvardhan Kumar (2015) studied that a new Proprietary Cementitious Stabilizer (Road Building International Grade 81) and Ground granulated blast furnace slag(GGBS) is being used to study the improvement in engineering properties of Black Cotton (BC) soil. This type of Stabilization is referred to as Chemical Stabilization. Saurabh Gupta, Dr. Sanjay Sharma (2015) highlighted that the importance of alccofine as Supplementary cementitious materials in construction industries. There has scarce research on sub grade soil stabilization with alccofine; some researcher reported that importance of alccofine as supplementary cementitious materials in road projects. From the available literature review, present research work conducted the comparative analysis about which one will give maximum benefits and can be suitable for economical application in highway sub grade.

II. Experimental Program

2.1 Material Selection

Two types of soil namely subgrade Soil A and subgrade Soil B available near Tala village Raigad district and Mulshi Tamhini ghat was collected for study purpose. The properties of both soils used in present study are given in Table 1. As per the AASHTO soil classification system, Soil A is A-2-5 (Silty Gravel Sand) and Soil B is A-6 (Clayey soil) , Similarly combination of hydrated lime, GGBS was used in the present investigation; these properties are listed in Table 2, Table 3,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. Combination of Hydrated Lime and GGBS was mixed with dry soil in different percentages varying from 2% , 4% and 6% and GGBS from 3%, 6% and 9 percent at the step of 2 percent lime by dry weight of soil and 3 percent GGBS by dry weight of soil.

Table 1: Physical Properties of Soils Used in Present Study

Sr. No.	Property	Soil-A	Soil-B
1.	Liquid Limit (%)	41.8	34.20
2.	Plastic Limit (%)	35.24	19.26
3.	Plasticity Index (%)	6.56	14.94
4.	MDD (kN/m3)	1.262	1.621
5.	OMC (%)	12	16
6.	CBR (%)	1.12	2.24
7.	Soil Classification as per AASHTO	A-2-5	A-6
8.	Typical name	Silty Gravel soil	Clayey soil

Table 2: Properties of Hydrated Lime Used in Present Study (Source: By Manufacturer)

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 in solubles	0.5±0.5 %

Table 2: Properties of Hydrated Lime Used in Present Study (Source: By Manufacturer)

Sr. No.	Particular	Hydrated Lime (90 % Purity)
	% Iron and Alumina	0.03±0.01 %
	% Magnesia	0.6±0.1 %
	% Silica	0.3±0.1 %
	% Chloride	0.002±0.001 %

Table 3: Properties of GGBS Used in The Present Study (Source- By Manufacturer)

Sr. No.	Particular/Parameter	GGBS
1.	Specific Gravity	2.825
2.	Grain size analysis	
	% of gravel	0
	% of sand particles	1.84
	% of silt size particles	98.16
	% of clay size particles	0
3.	Atterberg's limits	
	Liquid limit %	34.5
	Plastic limit%	NA
	Shrinkage limit %	34.0
4.	Plasticity index	NP
5.	Soil classification	ML
6.	Free swell	0
7.	Compaction Characteristics	
	Max.dry density (kN/m^3)	16.32
	Optimum Moisture content (OMC) in %	21.7

2.2 Determination of Optimum Quantity

2.2.1 Standard Proctor's Test

Standard Proctor Tests were carried out on both unstabilized and stabilized soils as per [IS 2720-Part (7)-1980]. Subgrade soil-A and soil-B mixed with various percentages of combination of lime varying from 2, 4, and 6 percent at the steps of 2 percent by dry weight of soil. Similarly with various percentages of GGBS varying from 3, 6 and 9 percent at the steps of 3 percent by dry weight of soil. The mixture was transferred in proctor mould in three equal layers and individual layer compacted by giving 25 numbers of blows consistently. The dry density-moisture content interrelations were outlined for individual test. Then optimum moisture content and maximum dry density at every percentage of lime and GGBS were estimated. Fig. 1 and Fig. 2 shows variation between dry density and moisture content for neat soil A and B and it give value of MDD as 1.262 at 12% OMD for unstabilized soil A and MDD as 1.621 at 16% OMD for unstabilized soil B. and Fig.3 and Fig.4 shows variation between dry density and moisture content for soil stabilized with combination of 2 percent lime with 3, 6 and 9 percent GGBS for both subgrade soil-A and soil-B respectively, it give value for MDD and OMC for respective combination. Similar graphs are made for other test conditions and variation between maximum dry density and optimum moisture content for lime and GGBS stabilized soil have been summarized in Table 4.

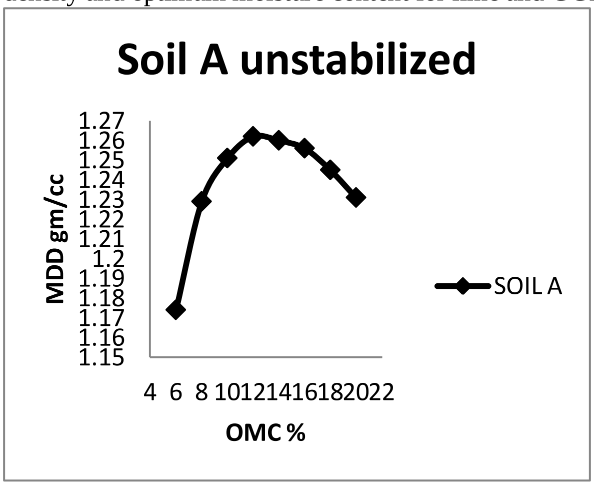

Figure 1: Typical graph shows variation between dry density and moisture content for neat soil A

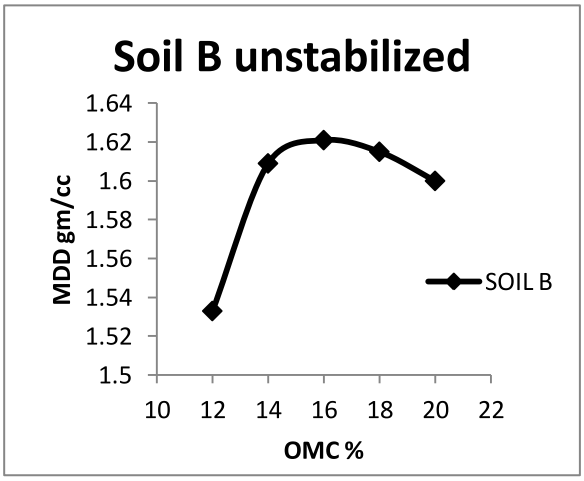

Figure 2: Typical graph shows variation between dry density and moisture content for neat soil B

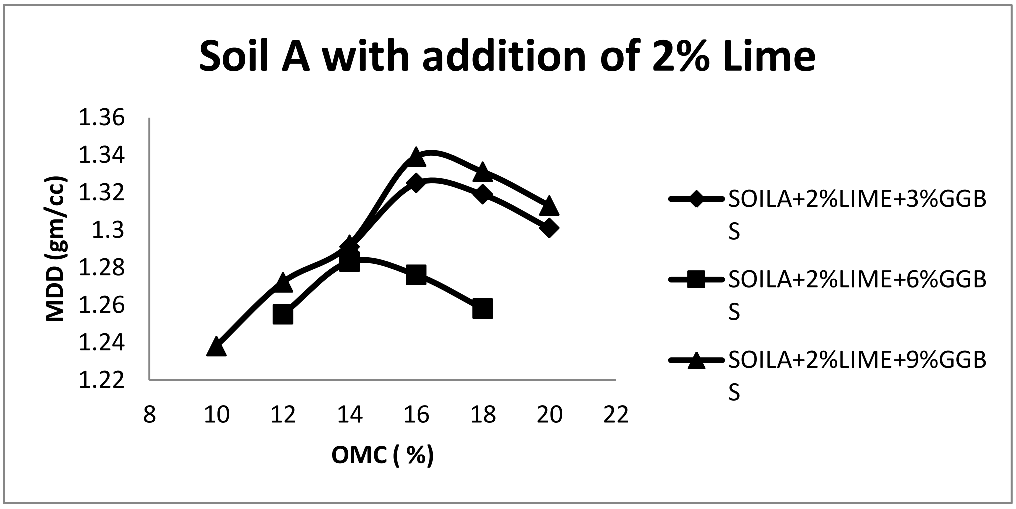

Figure 3: Typical graph shows variation between dry density and moisture content for soil stabilized with combination of 2% of lime with 3%, 6% and 9% of GGBS for soil A

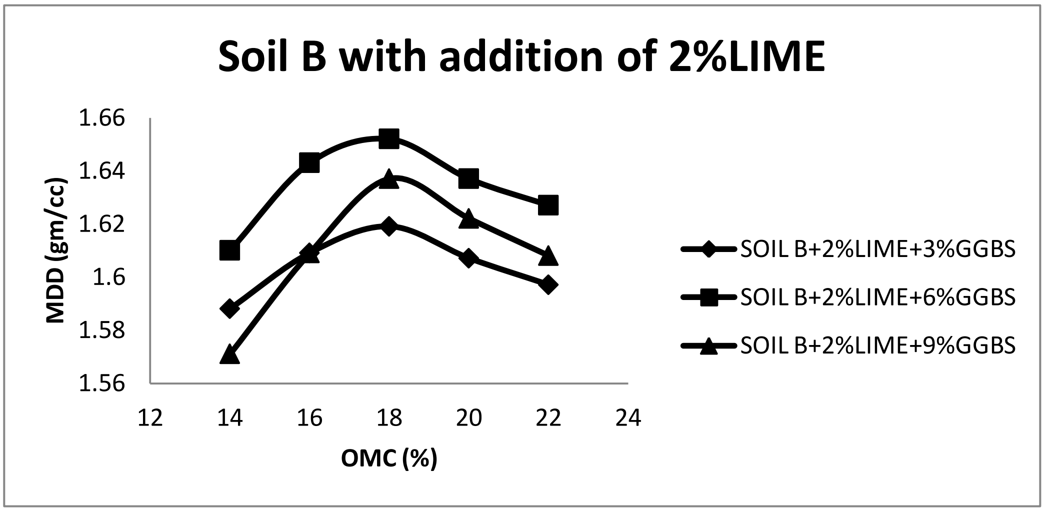

Figure 4: Typical graph shows variation between dry density and moisture content for soil stabilized with combination of 2% of lime with 3%, 6% and 9% of GGBS for soil B

The results show that, in case of subgrade soil-A, the value of maximum dry density and optimum moisture content raised with increase in lime and GGBS content, whereas in case of soil-B, the value of maximum dry density and moisture content also raised slightly with increase in lime and GGBS content. The value of maximum dry density of subgrade soil-A is 1.262gm/cm^3, it increases to 1.339 gm/cm^3 due to addition of combination of 2 % lime and 9% by weight of dry soil thereafter it start increase, whereas the value of maximum dry density of subgrade soil-B is 1.621gm/cm^3. It consistently increases with increase in percentage of lime and GGBS. Increase in density was as a result of the rising lime particles that were ready to achieve the interchange of cat ions with the soil particles, thus packing up the voids spaces and compact packing the soil particles together. However, the drop in density resulted from the excess water and lime remaining after the rising quantity has been utilized for stabilization process. The decrease in the MDD is due to light weight of the lime, it takes place of the soil particles and some of compacted applied energy takes up by the lime. The change in OMC was quite negligible. Table 4 shows the variation between maximum dry density and optimum moisture content for the subgrade soil-A and soil-B mixed with combination various percentage of lime and GGBS.

2.2.2 California Bearing Ratio Test

Four days soaked CBR tests were conducted on unstabilized and stabilized soils with combination of various percent of lime and GGBS as per [IS 2720 (part 16)-1987]. The maximum limit of lime content was 6%, and the maximum limit of GGBS was 6%. 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 calculated at 2.5 mm and

5.0 mm penetration levels and maximum of this is assumed as CBR value. CBR values at various combinations of lime and GGBS content and percentage increase in CBR with respect to unstabilized soil A-and soil-B are presented in Table 4. These value increases considerably due to lime and GGBS stabilization. The test result shows that, the soaked CBR value for 4 days soaked of subgrade soil-A is 1.12. This value increase to 14.54 % due to addition of combination of 6 % lime and 6 % GGBS by dry weight of soil thereafter it decreases. Similarly, the CBR value for 4 days soaked of subgrade soil-B is 2.24. It increases to 24.84 % due to addition of combination of 6% lime and 6% GGBS by dry weight of soil. Hence based on CBR test result, combination of 6 % lime and 6% GGBS by dry weight of subgrade soil-A and soil-B consider as optimum percentage of lime and GGBS for maximum benefits. The study shows that percentage increase in CBR value due to lime and GGBS stabilization in case of soil-A is more than that of subgrade soil-B. It shows that stabilization technique is supplemental benefit for weaker soil than stronger one. Results are presented in Table 4 and Figure 5 and Figure 6 shows typical graph for the CBR values of unstabilized soil-A and soil-B respectively. Figure 7 and Figure 8 shows typical graph for the effect of combination of 2% lime with 3% GGBS stabilization on CBR values of soil A and Soil B respectively.

Table 4: values for MDD and OMC and CBR value with combination of Lime and GGBS content for subgrade soil-A and soil-B

Sr. No.	Lime Content (%)	GGBS Content (%)	Subgrade Soil-A				Subgrade Soil-B			
			MDD kN/m3	OMC (%)	Max. CBR (%)	% increase	MDD kN/m3	OMC (%)	Max. CBR (%)	% increase
1.	2	3	1.283	14	2.46	119.64	1.619	18	4.47	99.55
2.	4		1.325	16	3.13	179.46	1.637	18	11.19	399.55
3.	6		1.339	16	3.80	239.64	1.652	18	11.95	433.48
4.	2	6	1.293	18	4.92	339.55	1.580	18	13.49	502.23
5.	4		1.322	16	5.37	379.46	1.639	18	14.77	559.37
6.	6		1.345	14	5.59	399.10	1.661	18	15.66	599.10
7.	2	9	1.301	14	11.86	958.92	1.552	18	16.56	639.28
8.	4		1.325	18	14.54	1198.21	1.556	18	18.91	744.196
9.	6		1.357	12	12.39	1006.25	1.661	18	14.84	561.16

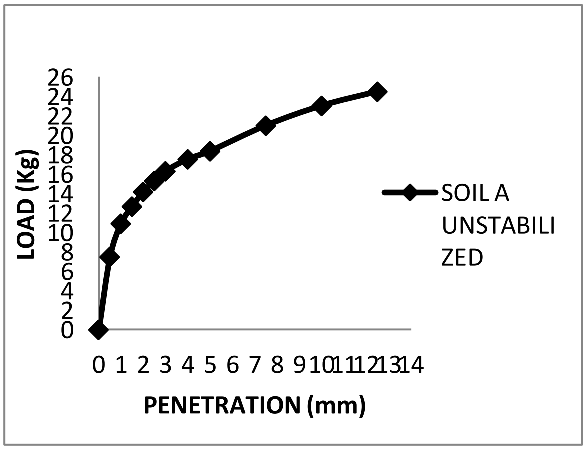

Figure 5: Typical graph shows the CBR values of unstabilized soil A

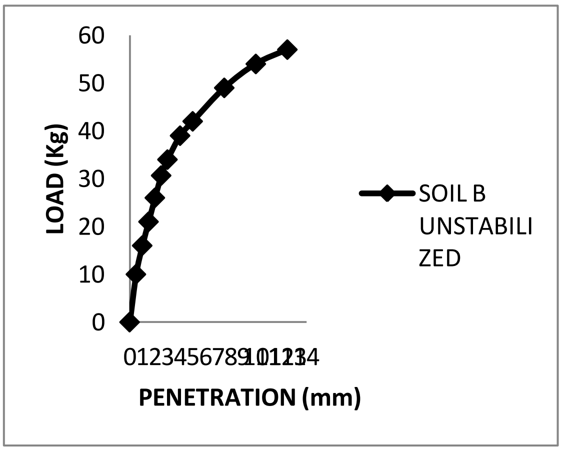

Figure 6: Typical graph shows the CBR values of unstabilized soil B

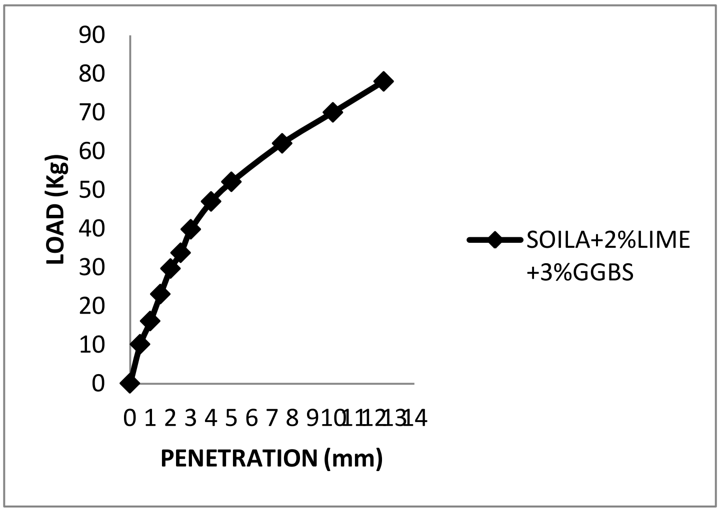

Figure 7: Typical graph shows the effect of combination of 2% lime with 3% GGBS stabilization on CBR values for soil-A

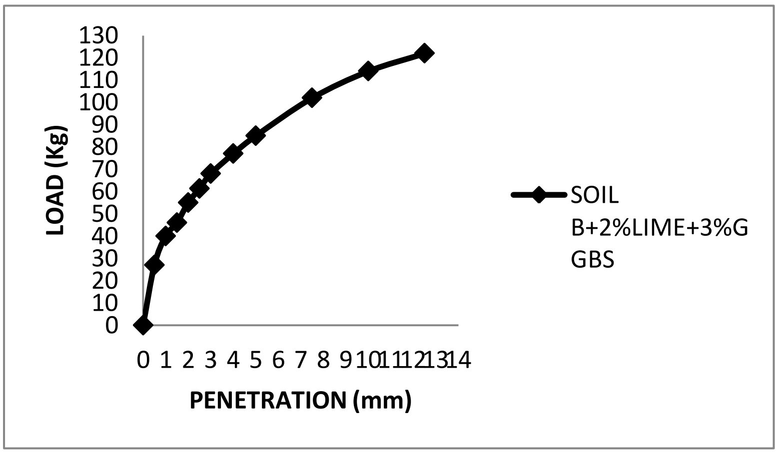

Figure 8: Typical graph shows the effect of combination of 2% lime with 3% GGBS stabilization on CBR values for soil-B

3. Design Charts and Economical Analysis

3.1 Response Model (as per IRC 37:2012)

The most important object of present research study is to evaluate the benefits of lime and GGBS stabilization in terms of Thickness Layer Reduction. The thicknesses of various layer of flexible pavement placed on unstabilised and stabilized subgrade for traffic intensity of 50 msa, 100 msa and 150 msa has been estimated using IRC 37:2012. The thickness of subgrade has been taken 500 mm. These model thicknesses are afterward used for evaluating the quantities and economics of stabilized flexible pavement. Table 5 shows the values of thicknesses of different 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 unstabilised subgrade soil-A is 1.12 % and subgrade soil-B is 2.24 %. 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 unstabilised subgrade soil-A as the CBR is less than 2 percent; to the sub-base thickness capping layer of 150 mm has been provide.

3.2 Thickness Layer Reduction

The laboratory CBR test conducted on subgrade soil-A and soil-B at combination of various percentages of lime and GGBS. The study has been extended to evaluate the thickness of various layers above the stabilized subgrade soils for a traffic intensity of 50msa, 100msa and 150 msa. Table 6 indicates the thickness of different layers and total thickness of the pavement resting on combination of 2,4 and 6 percent lime and 3,6 and 9 percent GGBS respectively, stabilized subgrade soil-A and soil-B for a traffic 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 and for traffic intensity of 50 msa, 100 msa and 150 msa, the thickness of sub-base is 610 mm respectively, for combination of 2%, 4%, 6% of lime and 9%, 9%, 6% GGBS stabilization, these thicknesses reduces to 330 mm, 260 mm and 200 mm. for soil-A Similarly, for soil-B it reduces to200mm respectively. 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, the thicknesses of DBM required for pavement placed in subgrade soil-A and soil-B is 175 mm, 195 mm and 215 mm respectively. It reduces to 140 mm,125 mm and 80 mm due to stabilization of subgrade Soil-A with combination of 2,4,6 percent lime and 9,9,6 percent GGBS respectively, and it reduces to 110 mm and 80 mm due to stabilization of subgrade soil-B with combination of 2,4,6 percent lime and 9,9,6 percent GGBS respectively. Table 6 shows the layer thickness reduction due to lime and GGBS stabilization for traffic intensity of 50 msa, 100 msa and 150 msa.

Table 5: Thickness of different Layers of Flexible Pavement placed 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	1.12	50	500	460 + 150	250	175	40	1575
2	1.12	100	500	460 + 150	250	195	50	1605
3	1.12	150	500	460 + 150	250	215	50	1625
Subgrade Soil – B								
4	2.24	50	500	460 + 150	250	175	40	1575
5	2.24	100	500	460 + 150	250	195	50	1605
6	2.24	150	500	460 + 150	250	215	50	1625

Table 6: Thickness of different Layers of Flexible Pavement placed on Unstabilized Sub grade for Soil - A and Soil – B

Sr. No.	Lime Content %	GGBS Content %	Traffic Intensity	CBR value	Subgrade (mm)	Granular Sub-base (mm)	Granular Base (mm)	DBM (mm)	BC (mm)	Total (mm)
Subgrade Soil – A										
1	2	9	50 msa	3.8	500	330	250	130	40	1250
2			100 msa		500	330	250	140	50	1270
3			150 msa		500	330	250	155	50	1285
Subgrade Soil – A										
4	4	9	50 msa	5.59	500	260	250	110	40	1160
5			100 msa		500	260	250	125	50	1185
6			150 msa		500	260	250	140	50	1200
Subgrade Soil – A										
7	6	6	50 msa	14.54	500	200	250	65	40	1055
8			100 msa		500	200	250	80	50	1080
9			150 msa		500	200	250	100	50	1100
Subgrade Soil – B										
10	2	9	50 msa	11.95	500	200	250	95	40	1085
11			100 msa		500	200	250	110	50	1110
12			150 msa		500	200	250	125	50	1125
Subgrade Soil – B										
13	4	9	50 msa	15.66	500	200	250	65	40	1055
14			100 msa		500	200	250	80	50	1080
15			150 msa		500	200	250	100	50	1100
Subgrade Soil – B										
16	6	6	50 msa	18.91	500	200	250	65	40	1055
17			100 msa		500	200	250	80	50	1080
18			150 msa		500	200	250	100	50	1100

3.2 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 (2014-15) (SoR) for Maharashtra state only (Kokan Region) 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 base course.
d) Dense Bituminous Macadam (DBM)
e) Bituminous Concrete (BC)

3.2.1 Estimation of Initial Construction Cost

The initial construction cost of every item was found out in details and afterward average unit cost of every item was estimated. Table 7 shows the thickness and volume of different layers, and corresponding cost of every layer of flexible pavement placed 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.10.5 /kg and cost of GGBS is assumed as Rs. 4/kg. Additional cost due to lime and GGBS has been worked out for stabilizing the subgrade soil-A and soil-B and it was included in the construction cost of the subgrade.

Table 8 shows the additional cost of subgrade due to stabilization with combination of 2%, 4%, 6% lime and 9%, 9%, 6% GGBS. The total cost of the flexible pavement placed on stabilized subgrade soil-A and soil-B has been found out for different combinations and presented in Table 9.

Table 7: Thicknesses of Different 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 (m^3)**	**Cost per m^3 (Rs.)**	**Layer wise Cost (Rs.) x10^5**	**Thicknesses of various layers (mm)**	**Volume (m^3)**	**Cost per m^3 (Rs.)**	**Layer wise Cost (Rs.) x10^5**
Design traffic intensity of 50 msa								
Subgrade	500	3500	285.3	9.98	500	3500	285.3	9.98
GSB	610	4270	897.20	38.31	610	4270	897.20	38.31
GB	250	1750	934.50	16.3	250	1750	934.50	16.3
DBM	175	1225	5059	61.9	175	1225	5059	61.9
BC	40	280	7960	22.2	40	280	7960	22.2
Total	**Total cost required for flexible pavement resting on soil A**			**148.69*10^5**	**Total cost required for flexible pavement resting on soil B**			**148.69*10^5**
Design traffic intensity of 100 msa								
Subgrade	500	3500	285.3	9.98	500	3500	285.3	9.98
GSB	610	4270	897.20	38.31	610	4270	897.20	38.31
GB	250	1750	934.50	16.3	250	1750	934.50	16.3
DBM	195	1365	5059	69.05	195	1365	5059	69.05
BC	50	350	7960	27.8	50	350	7960	27.8
Total	**Total cost required for flexible pavement resting on soil A**			**161.44*10^5**	**Total cost required for flexible pavement resting on soil B**			**161.44*10^5**
Design traffic intensity of 150 msa								
Subgrade	500	3500	285.3	9.98	500	3500	285.3	9.98
GSB	610	4270	897.20	38.31	610	4270	897.20	38.31
GB	250	1750	934.50	16.3	250	1750	934.50	16.3
DBM	215	1505	5059	76.1	215	1505	5059	76.1
BC	50	350	7960	27.8	50	350	7960	27.8
Total	**Total cost required for flexible pavement resting on soil A**			**168.49*10^5**	**Total cost required for flexible pavement resting on soil B**			**168.49*10^5**

Table 8: Additional Cost due to Stabilization with Combination of Different % of Lime and GGBS Content in Soils A and B

Subgrade Soil	Lime Content (%)	GGBS Content (%)	Dry Density for Soil (gm/cm^3)	Weight of dry Soil (kg)	Weight of Lime (kg)	Weight of GGBS(kg)	Additional Cost (x10^5)
Soil-A	2	9	1.339	4.686*10^6	93.7*10^3	421.74*10^3	9.98+16.86

Table 8: Additional Cost due to Stabilization with Combination of Different % of Lime and GGBS Content in Soils A and B

Subgrade Soil	Lime Content (%)	GGBS Content (%)	Dry Density for Soil (gm/cm³)	Weight of dry Soil (kg)	Weight of Lime (kg)	Weight of GGBS(kg)	Additional Cost (x10⁵)
	4	9	1.345	$4.707*10^6$	$188.28*10^3$	$423.63*10^3$	19.76+16.94
	6	6	1.325	$4.637*10^6$	$278.22*10^3$	$278.22*10^3$	29.21+11.28
Soil-B	2	9	1.652	$5.782*10^6$	$115.6*10^3$	$520.38*10^3$	12.13+20.81
	4	9	1.661	$5.813*10^6$	$232.5*10^3$	$523.17*10^3$	24.41+20.92
	6	6	1.556	$5.446*10^6$	$326.7*10^3$	$326.7*10^3$	34.30+13.06

Table 9: Thicknesses of different Layers and Layer wise Cost of Construction for Pavement placed on combination of 2 % Lime and 9 % GGBS stabilized sub grade for Soils for Design traffic of 50 msa, 100 msa and 150msa

Pavement layer	Subgrade Soil-A				Subgrade Soil-B			
	Thicknesses of various layers (mm)	Volume (m^3)	Cost per m^3 (Rs.)	Layer wise Cost (Rs.) $x10^5$	Thicknesses of various layers (mm)	Volume (m^3)	Cost per m^3 (Rs.)	Layer wise Cost (Rs.) $x10^5$
Design traffic intensity of 50 msa								
Subgrade	500	3500	285.3	9.98+9.83+16.86	500	3500	285.3	9.98+12.13+20.81
GSB	330	2310	897.20	20.72	200	1400	897.20	12.56
GB	250	1750	934.50	16.35	250	1750	934.50	16.35
DBM	130	910	5059	46.03	95	665	5059	33.64
BC	40	280	7960	22.28	40	280	7960	22.28
Total	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil A**			**$142.05*10^5$**	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil B**			**$127.75*10^5$**
Design traffic intensity of 100 msa								
Subgrade	500	3500	285.3	9.89+9.83+16.86	500	3500	285.3	9.98+12.13+20.81
GSB	330	2310	897.20	20.72	200	1400	897.20	12.56
GB	250	1750	934.50	16.35	250	1750	934.50	16.35
DBM	140	980	5059	49.57	110	770	5059	38.95
BC	50	350	7960	27.86	50	350	7960	27.86
Total	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil A**			**$151.17*10^5$**	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil B**			**$138.64*10^5$**
Design traffic intensity of 150 msa								
Subgrade	500	3500	285.3	9.98+10.3+89.1	500	3500	285.3	9.98+12.13+20.81
GSB	330	2310	897.20	20.72	200	1400	897.20	12.56
GB	250	1750	934.50	16.35	250	1750	934.50	16.35
DBM	155	1085	5059	54.89	125	875	5059	44.26
BC	50	350	7960	27.86	50	350	7960	27.86
Total	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil A**			**$156.49*10^5$**	**Total cost of pavement resting on 2% lime & 9% GGBS stabilized subgrade for soil B**			**$143.95*10^5$**

Similarly thickness of different layer and layer wise cost of construction for pavement placed on combinations of 4% ,6% lime and 9% ,6% GGBS stabilized subgrade soils for design traffic intensity 50msa, 100msa and 150msa are calculated . The economic analysis shows that, in case of combination of lime and GGBS for design traffic intensity of 50 msa, 100 msa and 150 msa the construction cost of flexible pavement resting on unstabilised subgrade soil-A is 148.69 lakh, 161.44 lakh and 168.49 lakh respectively (Table 7), it reduces to 142.05 lakh,151.17 lakh, 156.49 lakh respectively due to stabilization with combination of 2% lime and 9% GGBS content, and due to stabilization with combination of 4% lime and 9% GGBS content it reduces to 140.58 lakh, 151.47 lakh, 156.78 lakh. And it reduces to 124.67 lakh, 135.57 lakh and 142.65 lakh respectively due to stabilization with combination of 6% lime and 6% GGBS content.

Also, for design traffic intensity of 50 msa, 100 msa and 150 msa the construction cost of flexible pavement placed on unstabilised subgrade soil-B is 148.69 lakh, 161.44 lakh and 168.49 lakh respectively (Table 7), it reduces to 127.75 lakh,138.64lakh,143.95lakh respectively due to stabilization with combination of 2 % lime and 9% GGBS content, and due to stabilization with combination of 4% lime and 9% GGBS content it reduces to 129.51lakh, 140.41lakh, 147.29lakh.And 131.54 lakh, 142.44 lakh and 149.52 lakh respectively due to stabilization with combination of 6 % lime and 6% GGBS content.

The percentage reduced in cost has been found out for different design traffic intensity. It shows that, combination of 2% lime and 9% GGBS, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-A decreases by, 4.46, 6.36 and 7.12 respectively, for combination of 4% lime and 9% GGBS, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-A reduced by, 5.45, 6.175, 6.94 respectively and for combination of 6% lime and 6% GGBS, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-A decreases by,16.154, 16.04, 15.33 respectively. In soil-B, the total cost of pavement decreases by, 14.08, 14.12, 14.56 respectively for combination of 2% lime and 9% GGBS, for a design traffic intensity of 50 msa, 100 msa and 150 msa. for combination of 4% lime and 9% GGBS, for a design traffic intensity of 50 msa, 100 msa and 150 msa, the total cost of pavement in soil-B decreases by, 12.89, 13.02 and 12.58respectively. The total cost of pavement in soil-B decreases by, 11.53, 11.76 and 11.25 respectively for a design traffic intensity of 50 msa, 100 msa and 150 msa. it is observed that combination of 6% lime and 6% GGBS are more economical among other combination for soil A and combination of 2% lime and 9% GGBS are more economical among other combination for soil B.

III. Conclusions

Analysis of stabilized flexible pavement shows that there is a considerable decrease in thicknesses layer and at percentage combinations of lime and GGBS for which pavement is designed. Percentage decrease in cost indicates that, the design of flexible pavement resting on combination of 6% lime and 6% GGBS stabilized subgrade soil-A with traffic intensity of 50 msa and combination of 2% lime and 9% GGBS stabilized subgrade soil-B 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 and GGBS is the best stabilizer. GGBS material is one of the waste material which can easily available from nearby steel plants and it is typically cheaper so waste management of the industrial waste can be done economically.

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