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PERFORMANCE STUDIES ON SUBGRADE FORMATION USING LIME AND CEMENT IN ROAD PROJECTS

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Abstract: Subgrades in selected project area may consist of wet, highly plastic clay soil. Weak subgrades can result in fatigue cracking and rutting in asphalt pavement systems. These problems can be prevented by using thick and expensive pavement sections. An alternative to thick pavement sections is to improve the subgrade support quality through soil stabilization. Soils may be improved through the addition of chemical or cementitious additives. These chemical additives range from waste products to manufactured materials and include lime and Portland cement. As a result, this study evolved to find the performance of subgrade formation using lime and cement specific to Jimma subgrade soils. Accordingly, two disturbed samples were collected from different parts of Jimma and the required laboratory tests have been conducted in order to achieve the intended performance. From the tests conducted on Atterberg limits, the addition of cement increased plasticity index for Sample-1 whereas, the addition of cement increased plasticity index initially, while higher percentage of cement led to reduction in plasticity index for Sample-2 and addition of lime increased plasticity index initially and higher percentages of cement led to reduction in plasticity index for both samples. Moreover, addition of cement increases MDD for both samples while OMC increases up to a certain limit for Sample-1 and decreases on further addition whereas the OMC value initially decrease and after that the value increases with further addition for Sample-2. And also in the case of lime stabilization, the MDD decreases up to a certain limit but after that the value increases on further addition for Sample-1 while it was reverse for Sample-2. And the OMC decreases initially for Sample-1and becomes almost constant while the OMC value first decreases up to a certain limit and after that the value increases with further addition for Sample-2. It was also found that with the addition of stabilizers, cement and lime, the CBR values increased which in turn more applicable for preliminary characterizing the strength of subgrade soils.
Keywords: subgrade soil, cement stabilization, lime stabilization, and strength of subgrade

1. INTRODUCTION

— Background

Increased costs associated with the use of high quality materials have led to the need for local soils to be used in geotechnical and highway construction. Often however, high water content and low workability of these soils pose difficulties for construction projects. Frequently, additives such as lime, cement, fly ash, lime-cement-fly ash admixture, cement kiln dust, emulsified asphalt, Geofiber, and polymer stabilizers are used to improve their engineering properties. The choice and effectiveness of an additive depends on the type of soil and its field conditions. Nevertheless knowledge of mechanistic behavior of treated soil is equally important as selecting the stabilizer [1] [2] [3] [4] [5].

High water content and low workability of local soils in the project sites have often caused difficulties for highway construction projects. The addition of a few percentages by weight of Portland cement has shown its effectiveness towards better control of workability during compaction in some projects. However, there is a need to systematically examine cement treatment effectiveness for a range of soils encountered and also study the mechanical properties of cement stabilized soils for highway embankment applications. Type and location of the soils that needed improvement prior to use were selected by Department Of Transportation officials [6].

Stabilization of soil by lime is also achieved through cation exchange, flocculation, agglomeration, lime carbonation and pozzolanic reaction. Cation exchange, flocculation and agglomeration reactions takes place rapidly and bring immediate changes in soil properties such as strength, plasticity and workability, whereas, pozzolanic reactions are time dependent [7] [8]. Many pavement subgrades in selected project area may consist of wet, highly plastic clay soil. Subgrade quality has a dramatic impact on both the initial cost of pavements and on the subsequent maintenance costs. Options for dealing with soft pavement subgrades include attempting to dry and compact the subgrade; reinforcing the subgrade with a geosynthetic material; applying a chemical stabilizer such as lime, cement, polymer, or other amendment; and/or designing a very thick and expensive pavement section. Traditional lime and cement treatment can be very effective, but many contractors are hesitant to use lime and cement due to issues with dust control and other handling problems in some country. Many other non-traditional amendments, including resins and polymers, are marketed, but their performance record is mixed and solid engineering data is lacking, preventing reliable design. Thus, it is the aim of the researcher to study the performance of subgrade formation using lime and cement.

— Statement of the Problem

A tremendous amount of money is spent every year to construct new pavements and rehabilitate existing pavements. For new pavement construction, the life-cycle cost depends strongly on the support quality provided by the pavement subgrade. The increased costs associated with the use of high quality materials have led to the need for local soils to be used in geotechnical and highway construction. Road usually show excessive failures at an early stage of the pavement life. Subgrades in selected project area may consist of wet, highly plastic clay soil. Weak subgrades can result in fatigue cracking and rutting in asphalt pavement systems.

These problems can be prevented by using thick and expensive pavement sections, which distribute the vertical load from a vehicle wheel to reduce the pressure increment on the subgrade, and thereby limit tensile strain development in the pavement section. An alternative to thick pavement sections is to improve the subgrade support quality through soil stabilization. Subgrade stabilization can reduce pavement deflections, prevent fatigue cracking, and limit rutting. An investigation of the impact of subgrade stabilization on the life-cycle cost of pavements has the potential to produce substantial savings for roadway pavements.

Therefore, in order to prevent the problems, it is essential for engineers to stabilize the existing soils before commencing the construction activities. By stabilizing the soil, it is hoped that the soil will be more suitable as road subgrade and any road construction [9]. Thus, one method to ensure that existing soil is suitable for construction is by mixing it with cement and lime as a stabilizer.

— Objective of the Study

≡ General Objective

The overall objective of this research was to study the Performance studies on subgrade formation using lime and cement in road projects.

≡ The Specific Objectives

The specific objectives of the study are as follows:

a) To investigate the effects of lime and cement treatment on soil physical properties.
b) To identify the effects of lime and cement on soil Compaction and CBR values compared to untreated material.
c) To evaluate the effectiveness of the stabilizers on strength of samples.

2. RESEARCH METHODOLOGY

This section provides details about the experimental tests conducted during the study and a discussion of the results obtained. In order to have satisfactory data for studying the performance of subgrade formation by using lime and cement, laboratory tests were conducted by the researcher on samples collected from different localities of Jimma, so as to get records of test results. The tests done on the treated and untreated soil samples were; Particle size distribution, Atterberg limit (liquid limit and plastic limit), Proctor compaction test, California bearing ratio (CBR) and Specific gravity with mixed 2%, 4%, 6% and 8% cement and lime content. Then, discussions on sample collection and summary of laboratory test results were presented. Under the discussions of the obtained results, the effects of cement and lime were examined. Finally, a generalized conclusion and recommendation were made.

3. RESULTS AND DISCUSSION

The scope of this study is limited to the laboratory tests using two soil samples. The following section presents the results of laboratory tests performed for two Jimma Town soils to study the performance under two different additives i.e. cement and lime. Based on the samples retrieved from the sites, laboratory tests on the both samples were conducted in the geotechnical and highway laboratories of Jimma University Institute of Technology. A laboratory investigation program was carried out to evaluate the engineering properties of the untreated soil and the performance of soil stabilized with lime and cement.

— Tests Results – Untreated Soils

≡ Atterberg Limits Test Results

Table 1. Atterberg limit test results for untreated samples

Atterberg limits, %	Sample-1	Sample-2
LL, %	65.72	59.32
PL, %	54.11	45.29
PI, %	11.61	14.03

In this study, it is found important to carry out Atterberg limits as these are helpful as input index parameters to make the soil classification together with the particle size distribution results as applied in Table 2 below. The basic limits needed for this research are the liquid limit and the plastic limit. The liquid limit test is conducted as per AASHTO T 89 whereas the plastic limit test is conducted as per AASHTO T 90.

≡ Soil Classification

The soil classification result performed in Table 2 above explains that A-2-7 (Sample-1) is coarse grained soil whereas A-7-5 (Sample-2) is fine grained soil. Such kind of classification helps to provide information in which group symbol the soil lies. Besides this, these group symbols inform the quality of the soil which and where to use as a highway material.

Table 2. Classification of Selected Soil Samples.

Sample Number	Passing ASTM Sieve # 200%	Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Classification	
					USCS	AASHTO
S-1	3.040	65.72	54.11	11.61	SW	A-2-7
S-2	99. 60	59.32	45.29	14.03	MH	A-7-5

≡ Compaction Characteristics

Proctor compaction test were conducted for the soils under consideration to determine the maximum dry density and optimum moisture content of the soils.

Table 3. Proctor Compaction test results for untreated samples.

Sample Number	Maximum Dry Density (MDD), kN/m^3	Optimum Moisture Content (OMC), (%)
S-1	1318.00	36.00
S-2	1222.00	39.50

As here from Table 3, it can be generalized that the coarse gained (Sample-1) soil has higher MDD and lower OMC than the fine grained soil (Sample-2). The purpose of drawing the compaction curves shown below is to show the peak of the curve of moisture-density relationship and to extract MDD and OMC values from it.

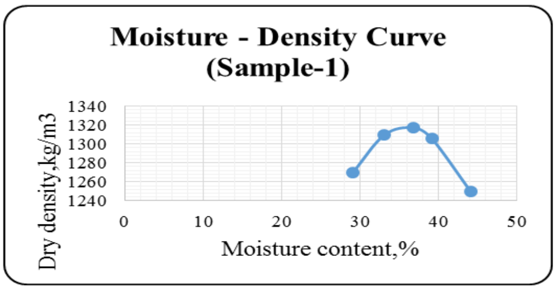

Figure 1. Typical Density-Moisture Content Relationship Graph (Sample-1)

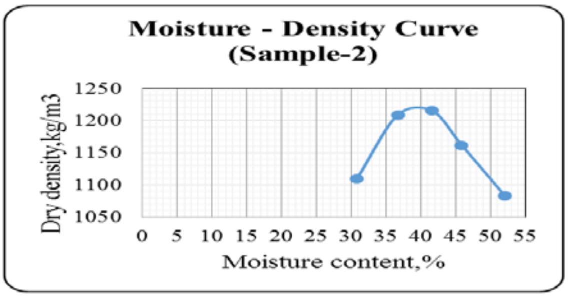

Figure 2. Typical Density-Moisture Content Relationship Graph (Sample-2)

≡ CBR Test Results

Here from Table 4, it can be seen that the coarse gained soil has higher CBR value than the fine grained soil sample.

Table 4. CBR test results for untreated samples.

Calculation of CBR, %				
Sample Number	Sample-1		Sample-2	
Penetration	2.5mm	5.0mm	2.5mm	5.0mm
Dial RDG	253.99	355.60	149.37	205.85
Load, (kN)	3.08	4.32	1.81	2.50
Standard Load, (kN)	13.20	20.00	13.20	20.00
CBR, %	23.36	21.58	13.74	12.49
CBR, %	23.36		13.74	

— Tests Results – Treated Soils

≡ Cement Stabilization

Variation of Atterberg Limits with Cement Content for Sample-1

The Atterberg Limit Test results and the updated soil classifications of Cement-stabilized Sample-1 is shown in Tables 5 below.

Table 5. Atterberg Limit Test Results of Cement and Sample-1 (A-2-7) Mix

	%age of Cement	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Classification of Mixed Soils
Sample-1	2	67.36	51.89	15.47	A-2-7
	4	63.77	47.72	16.05	
	6	62.92	46.77	16.15	
	8	62.04	45.81	16.22	

Despite the increase in cement contents for the Sample-1, the classification remained the same (A-2-7) as the untreated soil. Variation of liquid and plastic limits with different cement content for Sample-1 soil was shown in Figure 6 below.

From the Figure 6 shown above, it can be seen that liquid limit increased slightly (initially) and decreased with increasing in cement content, while plastic limit remained relatively decreased with increasing in cement content. Consequently the plasticity index increased followed with increase in cement content.

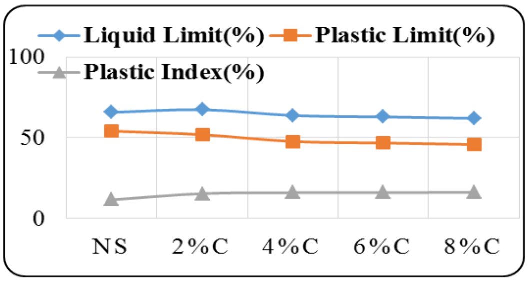

Figure 3. Variation of plastic behavior of Sample-1 soil for different cement content

Variation of Atterberg Limits with Cement Content for Sample-2

The Atterberg Limit Test results and the updated soil classifications of Cement-stabilized Sample-2 is shown in Tables 6 below.

Table 6. Atterberg Limit Test Results of Cement and Sample-2 (A-7-5) Mix.

	Cement, %	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Classification of Mixed Soils
Sample-2	2	68.82	49.41	19.41	A-7-5
	4	59.98	45.91	14.07	
	6	59.69	45.64	14.05	
	8	59.32	45.29	14.03	

Similar to Sample-1, despite the increase in cement contents for the Sample-2, the classification remained the same (A-7-5) as the untreated soil.

Variation of liquid and plastic limits for different cement content for Sample-2 soil sample is shown in Figure 7 below.

As shown in Figure above, it can be seen that liquid limit and plastic limit increased slightly (initially) and decreased with increasing in cement content. Consequently the plasticity index increased initially followed by a decrease with increase in cement content.

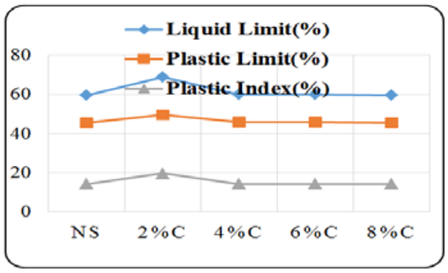

Figure 4. Variation of plastic behavior of Sample-2 soil for different cement content.

Variation of MDD and OMC with Cement Content for Sample-1

The effect of cement treatment on optimum water content and maximum dry unit weight of soils were determined from standard compaction tests and are as shown in Table 7 above. It can be observed, generally, as cement content increased, optimum water content decreased whereas maximum dry unit weight increased for Sample-1.

Table 7. Variation of MDD and OMC with cement content (Sample-1).

Type of Soil	Cement content, %	Optimum Moisture Content, OMC, (%)	Maximum Dry Density, kN/m^3
Sample-1	0	36.00	1318.00
	2	36.16	1345.90
	4	36.50	1334.00
	6	35.96	1347.53
	8	35.43	1361.05

Variation of MDD and OMC with Cement Content for Sample-2

Here from Table 8, it can be seen also that optimum water content decreased initially and increased gradually as cement content increased whereas Maximum Dry Density increased with increasing in cement content for Sample-2.

Table 8. Variation of MDD and OMC with cement content (Sample-2).

Type of Soil	Cement content, %	OMC, (%)	MDD, kN/m^3
Sample-2	0	39.50	1222.00
	2	35.50	1265.00
	4	38.50	1256.00
	6	39.92	1271.28
	8	41.34	1286.56

CBR Test Result for Sample-1 treated with cement additives

Here from the Table 9 shown above, as the cement contents increased the load corresponding to each penetration also increased and ranges from 5.98KN to 21.10KN at 12.7mm penetration.

Table 9. Summary of Load vs. Penetration of Untreated and Cement Treated for Sample-1.

Penetration (mm)	NS Load (KN)	2% Cement Load (KN)	4% Cement Load (KN)	6% Cement Load (KN)	8% Cement Load (KN)
0.00	0.00	0.00	0.00	0.00	0.00
0.64	0.79	2.97	0.61	1.88	3.58
1.27	1.76	4.55	2.55	4.99	6.86
1.96	2.49	5.52	5.40	7.41	9.83
2.54	3.11	5.89	6.94	8.56	11.51
3.18	3.57	6.32	7.57	9.66	12.81
3.81	3.93	6.67	8.38	10.55	13.93
4.45	4.19	6.97	9.07	11.31	14.85
5.08	4.35	7.23	9.67	11.96	15.64
7.62	5.07	8.02	11.48	13.94	18.06
10.16	5.58	8.57	12.77	15.35	19.77
12.7	5.98	9.00	13.77	16.44	21.10

Variation of CBR with Cement Content for Sample-1

Table 10. Summary of Variation of CBR Values with Cement Content for Sample-1 Soil.

CALCULATION OF CBR, %								
Additive contents	2% Cement		4% Cement		6% Cement		8% Cement	
Penetration	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm
Dial RDG	482	593	535	790	699	978	941	1281
Load, (kN)	5.86	7.20	6.49	9.60	8.48	11.88	11.42	15.55
Standard Load, (kN)	13.2	20.0	13.2	20.0	13.2	20.0	13.2	20.0
CBR, %	44.39	36.00	49.17	48.00	64.24	59.40	86.52	77.75
CBR, %	44.39		49.17		64.24		86.52	

The effect of cement treatment on CBR values of soil sample-1 are shown in Table 10 above. It is observed that, CBR Values increased significantly as cement content increased. Thus, cement treated soils exhibited much more strengthen behavior compared with non-treated soils.

CBR Test Result for Sample-2 treated with cement additives

Here from Table 11 above, the load needed to penetrate increased as cement contents increased corresponds to each penetration depth.

Table 11. Summary of Load vs. Penetration of Untreated and Cement Treated for Sample-2.

Penetration (mm)	NS Load (KN)	2% Cement Load (KN)	4% Cement Load (KN)	6% Cement Load (KN)	8% Cement Load (KN)
0.00	0.00	0.00	0.00	0.00	0.00
0.64	0.46	0.57	1.50	1.58	2.00
1.27	1.03	1.32	3.20	3.52	4.35
1.96	1.63	1.93	5.06	5.22	7.28
2.54	1.94	2.30	6.01	6.13	8.68
3.18	2.10	2.62	6.88	6.96	9.54
3.81	2.28	2.87	7.41	7.62	10.64
4.45	2.38	3.09	8.00	8.19	11.47
5.08	2.51	3.28	8.50	8.68	12.17
7.62	2.92	3.85	10.05	10.17	14.34
10.16	3.20	4.26	11.15	11.23	15.87
12.7	3.42	4.58	12.00	12.05	17.06

Variation of CBR with Cement Content for Sample-2

Table 12. Summary of Variation of CBR Values with Cement Content for Sample-2

Calculation of CBR, %								
Additive contents	2% Cement		4% Cement		6% Cement		8% Cement	
Penetration	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm
Dial RDG	188	268	478	695	500	710	691	996
Load, (kN)	2.28	3.26	5.80	8.44	6.07	8.62	8.39	12.09
Standard Load, (kN)	13.2	20	13.2	20	13.2	20	13.2	20
CBR, %	17.26	16.29	43.92	42.21	46.02	43.11	63.55	60.44
CBR, %	17.26		43.92		46.02		63.55	

Similar to Sample-1 soil, the study reveals that the CBR value for subgrade soil Sample-2 increases with the increase in cement content. The effect of cement treatment on CBR values of soil Sample-2 was shown in Table 12 above. It is observed that, CBR Values increased significantly as cement content increased. Thus, cement treated soils exhibited much more strength compared with non-treated soils.

≡ Lime Stabilization

The tests mentioned and done in Section 3.2.1 were also repeated on each representative Soil-Lime mix similar to Soil-Cement mix above.

Variation of Atterberg Limits with Lime Content for Sample-1

Table 13. Atterberg Limit Test Results of Lime and Sample-1 (A-2-7) Mix.

	Percentage of Lime	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Classification of Mixed Soils
Sample-1	2	64.21	48.33	15.87	A-2-7
	4	58.93	45.33	13.6	
	6	57.91	44.61	13.3	
	8	56.39	43.52	12.87	

As in case of cement stabilizer, despite the increase in lime contents for the Sample-1, the classification remained the same (A-2-7) as the untreated soil.

Variation of liquid and plastic limits with different lime content for Sample-1 soil was shown in Figure 8 below.

Variation of liquid limit and plastic limit for Sample-1 for different lime content is shown in Figure 3.8. It can be seen that liquid limit and plastic limit decreased gradually as lime content increased. Therefore, plasticity index increased initially and decreased as lime content increased.

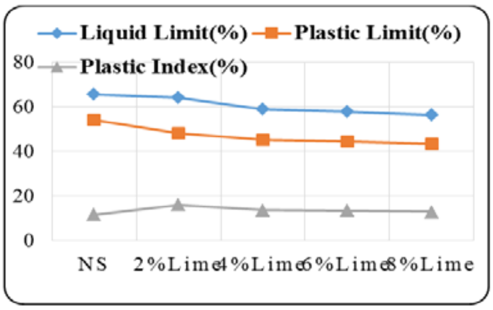

Figure 5. Variation of plastic behavior of Sample-1 soil for different Lime content

Variation of Atterberg Limits with Lime Content for Sample-2

As in case of Sample-1, despite the increase in lime contents for the Sample-2, the classification remained the same (A-7-5) as the untreated soil.

Table 14. Atterberg Limit Test Results of Lime and Sample-2 (A-7-5) Mix.

	Percentage of Lime	Liquid Limit, LL	Plastic Limit, PL	Plasticity Index, PI	Classification of Mixed Soils
Sample-2	2	56.89	40.33	16.56	A-7-5
	4	56.89	44.39	12.5	
	6	56.63	44.53	12.1	
	8	56.09	44.75	11.34	

Variation of liquid and plastic limits with different lime content for Sample-2 soil was shown in Figure 9 below.

Variation of liquid limit and plastic limit for Sample-2 for different lime content is shown in Figure 9. It can be seen that liquid limit decreased with increase in lime content while plastic limit and plasticity index increased initially and decreased gradually as lime content increased.

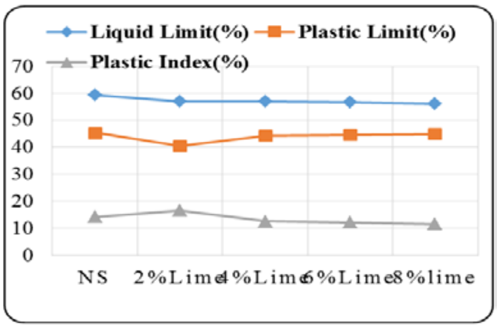

Figure 6. Variation of plastic behavior of Sample-2 soil for different Lime content

Variation of MDD and OMC with Lime Content for Sample-1

Variation of optimum moisture content and maximum dry density for different lime content is as shown in Table 15 above. And it can be seen that optimum moisture content decreased initially and became almost constant as lime content increased whereas Maximum Dry Density also decreased initially and increased as lime content increased for Sample-1.

Table 15. Variation of MDD and OMC with lime content (Sample-1).

Type of Soil	% of lime content	Optimum Moisture Content, OMC, (%)	Maximum Dry Density, MDD, kN/m^3
Sample-1	0	36.0	1318.0
	2	34.5	1310.0
	4	36.0	1307.0
	6	36.5	1302.0
	8	36.0	1314.0

Variation of MDD and OMC with Lime Content for Sample-2

As shown in the Table 16 above, it can be seen that optimum moisture content decreased initially and increased as lime content increased whereas Maximum Dry Density increased initially and decreased as lime content increased for Sample-2.

Table 16. Variation of MDD and OMC with lime content (Sample-2).

Type of Soil	% of lime content	Optimum Moisture Content, OMC, (%)	Maximum Dry Density, kN/m^3
Sample-2	0	39.50	1222.00
	2	36.77	1254.75
	4	35.11	1266.27
	6	36.00	1269.00
	8	40.00	1225.00

CBR Test Result for Sample-1 treated with lime additives

Table 17. Summary of Load vs Penetration of Untreated and Lime Treated for Sample-1.

Penetration, (mm)	NS	2% Lime	4% Lime	6% Lime	8% Lime
	Load (KN)	Load (KN)	Load (KN)	Load (KN)	Load (KN)
0.00	0.00	0.00	0.00	0.00	0.00
0.64	0.79	1.74	0.83	2.43	2.03
1.27	1.76	2.88	3.39	6.13	7.40
1.96	2.49	3.61	5.01	9.11	10.80
2.54	3.11	4.04	5.98	10.80	12.84
3.18	3.57	4.41	6.82	11.76	14.60
3.81	3.93	4.72	7.49	12.82	16.02
4.45	4.19	4.97	8.07	13.73	17.23
5.08	4.35	5.20	8.57	14.51	18.27
7.62	5.07	5.87	10.08	16.88	21.45
10.16	5.58	6.35	11.15	18.56	
12.7	5.98	6.72	11.99	19.87	

Variation of CBR with Lime Content for Sample-1

Table 18. Summary of Variation of CBR Values with Lime Content for Sample-1.

Calculation of CBR, %								
Additive contents	2% Lime		4% Lime		6% Lime		8% Lime	
Penetration	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm
Dial RDG	330	426	487	701	853	1187	1047	1495
Load, (kN)	4.01	5.17	5.92	8.51	10.36	14.41	12.71	18.15
Standard Load, (kN)	13.2	20.0	13.2	20.0	13.2	20.0	13.2	20.0
CBR, %	30.38	25.85	44.85	42.55	78.48	72.05	96.29	90.75
CBR, %	30.38		44.85		78.48		96.29	

As in case of cement treatment, the effects of lime treatment on CBR values are directly proportional with the percentage of additives. The summary of variation of CBR Values of soil Sample-1 under different lime contents are as shown in Table 18 above. And it is observed that, CBR Values increased as lime contents increased. Thus, lime treated soils also exhibited much more improvement in strength compared with non-treated soils.

CBR Test Result for Sample-2 treated with lime additives

Here from Table 19 above, the load required for penetration at each depth initially decreased with 2% lime addition and then increased on further addition.

Table 19. Summary of Load vs Penetration of Untreated and Lime Treated for Sample-2.

Penetration, (mm)	NS Load (KN)	2% Lime Load (KN)	4% Lime Load (KN)	6% Lime Load (KN)	8% Lime Load (KN)
0.00	0.00	0.00	0.00	0.00	0.00
0.64	0.79	0.55	1.40	1.40	1.58
1.27	1.76	0.97	3.07	3.78	4.29
1.96	2.49	1.27	4.61	5.04	6.01
2.54	3.11	1.52	5.46	6.07	7.03
3.18	3.57	1.70	6.13	6.82	7.92
3.81	3.93	1.82	6.62	7.42	8.64
4.45	4.19	1.88	7.08	7.93	9.25
5.08	4.35	1.97	7.48	8.37	9.78
7.62	5.07	2.25	8.70	9.71	
10.16	5.58	2.45	9.56	10.67	
12.7	5.98	2.60	10.23	11.40	

Variation of CBR with Lime Content for Sample-2

The study on subgrade soil Sample-2 reveals that the CBR value increases with the increase in lime content. And this shows that the thickness of the pavement layers reduction as lime content increases. The summary of the variation of CBR values with lime content for Sample-2 soil is as shown in Table 20 above.

Table 20. Summary of Variation of CBR Values with Lime Content for Sample-2

Calculation of CBR, %								
Additive contents	2% Lime		4% Lime		6% Lime		8% Lime	
Penetration	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm	2.5mm	5.0mm
Dial RDG	122	161	441	612	496	685	574	800
Load, (kN)	1.48	1.96	5.35	7.43	6.02	8.32	6.97	9.71
Standard Load, (kN)	13.2	20	13.2	20	13.2	20	13.2	20
CBR, %	11.19	9.78	40.54	37.16	45.61	41.58	52.82	48.56
CBR, %	11.19		40.54		45.61		52.82	

4. CONCLUSIONS

Based on the above observations the following conclusions can be drawn:

— Cement Stabilization

Despite the increase in cement contents, the soil classification remained the same for both Sample-1(A-2-7) and Sample-2(A-7-5) as the untreated soil. The addition of cement increased plasticity index from 11.61% to 16.22% for Sample-1. Whereas, the addition of cement increased plasticity index initially from 14.03% to 19.41%, while higher percentage of cement led to reduction in plasticity index to 14.03% for Sample-2. Thus, cement added soils have better workability. In general, reduce in the plasticity index indicate an improvement.

With addition of cement on both samples, the MDD of the samples under consideration increases from 1318 kN/m^3 to 1361.05 kN/m^3 for Sample-1 and 1222 kN/m^3 to 1286.56 kN/m^3 for Sample-2. In the case of OMC, the value increases up with addition of cement content for Sample-1 up to a certain limit (from 36% to 36.50%)and decreases on further addition of cement to 35.43% whereas the OMC value initially decrease from 39.50% to 35.50% and after that the value increases with further addition of cement for Sample-2 to 41.34%.

The increase cement content corresponds to the increase in CBR values. By adding cement into soil, the CBR values increase multiply for both Samples and the maximum CBR, as much as 86.52% and 63.55% was found at 8% cement additives for Sample-1 and Sample-2 respectively.

Generally, cement treatments are beneficial in term of increasing pavement capacity and service life.

— Lime Stabilization

Similar to cement treatment, despite the increase in lime contents, the soil classification remained the same for both Sample-1(A-2-7) and Sample-2(A-7-5) as the untreated soil. For both sample soil, addition of lime increased plasticity index initially (from 11.61% to 15.87% for Sample-1 and 14.03% to 16.56% for Sample-2), while higher percentages of cement led to reduction in plasticity index to 12.87% and 11.34% respectively.

In the case of lime stabilization, the MDD decreases up to a certain limit (from 1318 to 1302kN/m^3) but after that the value increases on further addition of lime to 1314kN/m^3 for Sample-1 while it's reverse for Sample-2 since the value first increases up to a certain limit (from 1222 to 1269kN/m^3) and then decreases with further addition of lime contents to 1225kN/m^3. As in the case of OMC, the value decreases initially (from 36 to 34.5%) for Sample-1and becomes almost constant with addition of lime content while the OMC value first decreases up to a certain limit (from 39.50 to 35.11%) and after that the value increases with further addition of lime for the Sample-2 to 40%.

The CBR Values increases from 23.36 to 96.29% with increase in lime contents for Sample-1 while the value initially decreased from 13.74 to 11.19% and increased to 52.82% on further addition of lime content for Sample-2.

Generally, the laboratory study found that the initial strength of cement stabilized soils was higher than lime stabilized soils. This shows that cement stabilization is more effective to attain higher strength than lime stabilization. However, the laboratory mixing and curing may allow the specimens to achieve much higher strength than what may be attained in the field. The CBR Values of stabilized soils was higher, in some cases many times higher, than non-stabilized natural soils.

The thickness of pavement layers varies with the change in the value of CBR. With the higher value of CBR, the crust thickness is less and vice versa. From the CBR Test Results, the values becomes higher and higher for both subgrade soil samples as outlined in these document under both additives, cement and lime. Therefore, this implies that the thickness of the pavement must be reduced with corresponding to the percentage of stabilizers, cement and lime content.

5. RECOMMENDATIONS

Recommendations made based on the findings of this study

- Lime or cement stabilization of roadbed soils should be used more systematically and be considered as a part of the pavement structure during design and construction of flexible pavements. Planned soil stabilization can reduce the need costly soil replacement (undercutting) during construction. Stabilized roadbed makes construction easier and provides stronger support to pavement structure above it.
- Structural benefit of soil stabilization should be incorporated during flexible pavement thickness design, which would result in reduced pavement thickness. Therefore, one can use procedures developed in this research study to calculate the thickness reduction, which can then be compared with the cost of stabilization.
- Since soil characteristics vary from one location to the next, the benefit of soil stabilization to achieve higher uniformity is inferred, but not quantified, in this study. Further studies to investigate the effect of roadbed support uniformity on pavement performance and to quantify the benefits of more uniform support are recommended.
- Performance studies of subgrade formation soils with cement and lime should be monitored and evaluated. Currently, few pavement sections with stabilized roadbed soils have had sufficient amount pavement condition data in order to compare their long term performance with pavements without stabilization. The conclusions of this study is based on a limited amount of data, therefore, additional data should be collected in the future to continue validation of the findings.

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