

Stabilization of Lateritic Soil Subgrade Using Cement, Coconut Coir and Aggregates

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Abstract: The subgrade soil and its properties are important in design of pavement structure as it has to give adequate support to the pavement, for which it has to possess sufficient strength and stability even under adverse traffic and climatic condition. Thus, the subgrade must be able to support loads transmitted from pavement structure without excessive deformation under adverse climatic and traffic conditions to increase the life of the pavement. It is a well known fact that, all soils do not possess all the desirable qualities for using it as a good quality pavement material. When such soils cannot be replaced, its subgrade performance should be increased by several modification techniques. In the present study an effort is made to obtain the optimum dosage of cement for stabilization of locally available lateritic soil and the investigations are conducted to study the behaviour on addition of fibres which is obtained naturally from the husk of coconut, and 10 mm down aggregates to the soil properties added in addition to the obtained optimum cement content to evaluate the extent of modification on MDD, OMC and CBR of the soil. The study incorporates investigations on basic properties of soil such as Atterberg's limits, grain-size distribution, specific gravity, maximum dry density (MDD), optimum moisture content (OMC), California Bearing Ratio (CBR), unconfined compressive strength (UCS). The optimum dosage of cement obtained as 6% by weight of soil mainly based on the UCS test. The experimental investigations shown that there is a tremendous increase in the CBR value of the soil treated with cement-aggregate modification. In addition, the field cost analysis is also made to compare the cost of construction for various modifications used.

Keywords: Lateritic soil, Soil modification, Cement, Coconut Coir, CBR, Unconfined Compressive Strength.

I. INTRODUCTION

Subgrade is the insitu material upon which pavement rests. It is the supporting ground beneath the pavement. It is considered to be one of the important parameters for design of pavement. The subgrade must be able to support loads transmitted from pavement structure with deformation being within allowable limits under the action of heavy traffic and adverse climatic conditions. For different moisture content it should not show volume changes as it may lead to uneven strength and uneven settlement. It should possess good drainage conditions so as to avoid excessive moisture retention and to reduce frost action in colder countries. Therefore it is necessary to evaluate the strength properties of soil subgrade. It helps to adopt suitable values of strength parameter for design purposes (Khanna and Justo 2011).

There are various types of soil available having different properties. Few are having good strength and stability while few having properties of high volume change due to change in moisture content. So it can be accepted that all soils do not possess all the desirable qualities of soil subgrade for pavement. Soil with poor subgrade qualities should be avoided as much as possible. But when it's unavoidable its subgrade performance should be increased.

In developing country like India due to limited finances construction of roads by conventional method is very difficult. Therefore there is need to use low cost road construction to meet the growing needs of traffic. Also when there is a lack of good quality granular materials needed, the load bearing capacity of soil can be improved by adopting various techniques like soil stabilization, adoption of reinforcement etc. The process of improving engineering properties of the soil and thus making it more stable is known as stabilization of soil. There are various methods for soil stabilization like mechanical stabilization, cement stabilization, thermal stabilization, lime stabilization, electrical stabilization; stabilization by grouting, chemical stabilization, bituminous stabilization, etc.

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The present study is carried out to compare the effect of addition of cement to laterite soil, laterite soil and coconut coir (two different proportions) and lateritic soil and aggregates (three different proportions). Thus pavement construction cost can be considerably reduced by stabilizing the soil.

II. OBJECTIVES AND SCOPE OF PRESENT INVESTIGATION

The investigation is carried out on Lateritic soil which is a major type of soil available in Mangalore region. Objectives of present investigations are:

1. To determine the optimum dosage of cement and coconut coir fibre for the locally available lateritic soil.
2. To study the engineering behaviour of lateritic soil stabilized with optimum dosage of cement and coir with the addition of 10 mm down aggregates.
3. To compare the chemical composition of treated and pure lateritic soil.
4. To check whether the cement treated soil and soil-aggregate mixture are economical to be used as soil-subgrade material.

III. LITERATURE REVIEW

The necessity of improving engineering properties of soil has been recognized as long as construction has existed. Many ancient cultures like Chinese, Romans, etc utilized various techniques to improve the soil stability. Modern era of soil stabilization began during 1960-70's when general shortage of aggregates and fuel resources forced engineers to consider alternatives to conventional techniques of replacing poor soil.

Portland cement is one of the most commonly used stabilizers. The reaction process taking place in cement stabilization doesn't depend upon soil minerals, but on reaction of water. Due to this reason nearly all types of soils can be stabilized by cement (Montgomery 1998). As the dosage of cement was increased properties like Maximum Dry Density (MDD), California Bearing Ratio (CBR) and Unconfined Compressive Strength (UCS) increased while there was reduction in Optimum Moisture Content (OMC) (Oyediran and Kalejaiye 2011). Soil-cement mix design using traditional mixing and compacting soil, laboratory methods proved to be reliable procedure to establish the optimum percentage for mix (Gomez and Anderson 2012). Triaxial is the most common and versatile test to determine stress-strain properties and shear strength properties of soil. Cement stabilized lateritic soil can be used as road base course (Jaritngam et al. 2012).

Coconut coir has highest strength among all natural fibres and high water absorption. Due to high lignin content rate of decomposition of coconut coir is less than compared to all other natural fibres. It retains 20% of its strength even after 1 year (Sivakumar et al. 2008). These qualities are responsible for use of coconut coir in soil stabilization. These can be used to reinforce soil that is poor in tension reducing the applied stress and hence preventing the rutting of subgrade (Sarma and Ravindranath 2005).

From the vast literature review conducted it was observed that cement acts as good stabilizer and coir alone cannot provide satisfactory results. Hence, combination of cement and coconut coir is investigated. Dosages for cement were selected as 3, 6, 9 and 12% as literature review showed that dosage of cement more than 10% of cement showed negative improvement (Oyediran and Kalejaiye 2011). UCS tests have been used in most of the experimental programme reported in literature in order to verify effectiveness of stabilization to access the importance of influencing factors like strength and durability of treated soil and to choose optimum percentage of cement. Also cost analysis was done to compare economics.

IV. EXPERIMENTAL INVESTIGATION AND RESULTS

4.1 Materials Used:

Lateritic soil used for the investigation is collected from the NITK, Surathkal campus 1 metre below the ground level. The collected sample is first air dried and then oven dried before using it for the tests. The index properties and

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compaction characteristics of the natural lateritic soil is tabulated in Table 1. The cement used in present investigation is ACC Cement grade-43. Its basic properties are also indicated in Table 1:

Geotechnical Engineering Properties of Lateritic Soil			Physical Properties of Cement	
Test	Results	IS Code	Physical Properties	Test Results
1. Specific Gravity	2.661	IS:2720 (Part III)-1990	Compressive Strength(28 days) N/mm ²	43
2. Grain Size Distribution (%)		IS:2720 (Part IV)-1985	Specific Gravity	3.12
a. Gravel	22		Fineness	
b. Sand	45		Minimum Specific Surface(m ² /kg)	301
c. Silt	31			
d. Clay	2		Initial Setting Time (min)	50
e. IS Soil Classification	Silty Sand (SM)		Final Setting Time (min)	240
3. Atterberg Limits (%)		IS:2720 (Part V)-1986	Soundness Expansion Le Chatelier's Test (mm)	10
a. Liquid Limit	36		Normal Consistency (%)	28
b. Plastic Limit	27			
c. Plasticity Index	9			
4. Standard Proctor Test		IS:2720 (Part VII)-1980		
a. MDD (g/cc)	1.965			
b. OMC (%)	12.05			
5. Modified Proctor Test		IS:2720 (Part VIII)-1983		
a. MDD (g/cc)	2.095			
b. OMC (%)	11.125			

Table 1 Properties of Lateritic Soil and Cement used in the investigations

In addition, coconut coir with the aspect ratio (length/diameter) of 20 i.e., the length of 20mm and the diameter of 1mm is used and the aggregates with 10 mm down size obtained from the nearby quarry are used for lateritic soil stabilization .

4.2 Experimental Investigation:

The scope of this study is limited to the laboratory tests using lateritic soil. Basic tests such as specific gravity test, Atterberg limits test, grain size analysis test, and compaction test, are carried out on the un-treated lateritic soil. The CBR test, triaxial and UCS test are done to find out the properties of the soil stabilized with cement using dosages of 3, 6, 9 and 12 % of weight of untreated lateritic soil. From the compaction test, 6% dosage of cement was obtained to be the optimum. The test is conducted on untreated soil alone, soil with cement dosages (3, 6, 9 and 12%) and soil with optimum amount of cement (6%) and coir (0.5 and 1 %) and soil with aggregates (20, 25 and 30%). The compaction test is done immediately after treating it with the stabilizer which are illustrated in Table 2.

Soil Sample	Standard Proctor Test		Modified Proctor Test	
	OMC (%)	MDD(g/cc)	OMC (%)	MDD(g/cc)
Untreated Soil	12.05	1.965	11.125	2.0965
Soil+ 3% Cement	11.9	1.98	11	2.13
Soil+ 6% Cement	11.7	1.995	10.9	2.133
Soil+ 9% Cement	13.6	1.975	12.5	2.124
Soil+ 12% Cement	14.2	1.97	12.8	2.12
Soil+ 6% Cement +0.5% coir	12	1.96	11.12	2.13
Soil+ 6% Cement + 1% coir	11.8	1.982	10.83	2.125
Soil+ 6% Cement +20% aggregates	12.1	1.97	11.2	2.21

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Soil+ 6% Cement +25% aggregates	11.5	1.982	10.9	2.26
Soil+ 6% Cement +30% aggregates	11.1	1.991	10.9	2.33

Table 2 Results for Compaction test immediately after mixing

Also compaction test and CBR test are used to determine properties of soil stabilized with optimum cement and containing fibres (0.5 and 1%) and aggregates (20, 25 and 30%). Chemical composition of soil (treated and untreated) is determined by performing various laboratory chemical tests. From these results the optimum percentage of cement is selected to prepare the treated soil – aggregate mix with 10mm down aggregates. Cost analysis for cement treated soil with fibre and soil – aggregate mixes also carried out. The strength test results are illustrated in the Table 2.

Unconfined compressive strength (UCS) tests are performed using Standard test equipment and procedure available as per IS: 2720 (part 10)-1973 for untreated and treated soil samples compacted at modified proctor densities. The tests are conducted on treated soil specimens for 0, 7, 14, 28 and 60 days of moist curing, which is done inside the desiccators. Results are tabulated in Table 3.

Curing Period (days)	0	7	14	28	60
Soil Sample	Stress (kPa)				
Normal Soil	589	556	366	275	242
Soil +3% cement	684	934	1053	1124	795
Soil +6% cement	716	1858	2038	2230	2376
Soil +9% cement	749	2077	2354	2564	2668
Soil +12% cement	857	2164	2439	2675	2931

Table 3 Results for Unconfined compressive strength (UCS) tests

CBR test is conducted as per IS: 2720 (part 16)-1979 to determine the penetration resistance value of the soil. Untreated soil is tested for soaked and unsoaked condition for modified proctor compaction densities. Whereas, treated soil is tested only for modified proctor compaction density for soaked conditions only. The tests are conducted on treated soil samples for 0, 7, 14, and 28 days of moist curing. The curing was done by covering the CBR mould in polyethene covers which was then covered by wet gunny bags. Gunny bags were made wet twice a day and hence curing was done. The curing period for CBR was kept as 7, 14 and 28 days. The test is conducted on soil alone, soil with cement dosages (3, 6, 9 and 12%) and soil with optimum amount of cement (6%) and coconut coir (0.5 and 1 %) and soil with aggregates (20, 25 and 30%). Table 4 indicates the results of CBR test.

Soaked CBR Values (%)				
Curing Period (days)	0	7	14	28
Untreated Soil	18	18	17	15
Soil +3% cement	28	33	38	41
Soil +6% cement	30	73	98	107
Soil +9% cement	34	89	101	117
Soil +12% cement	37	96	106	125
Soil +6% cement + 0.5% fibre	34	75	88	109
Soil +6% cement + 1% fibre	40	78	101	117
Soil +6% cement + 20% aggregates	51	81	104	145
Soil +6% cement + 25% aggregates	58	99	125	168
Soil +6% cement + 30% aggregates	60	112	137	184

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Table 4 Results for California Bearing Ratio (CBR) tests

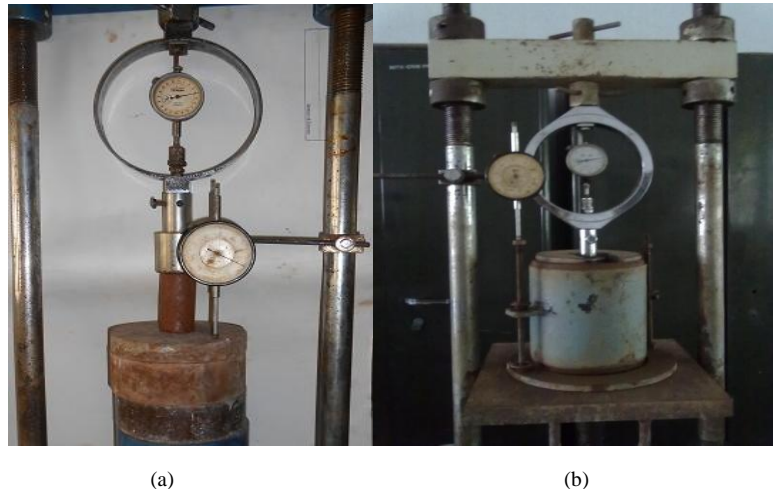


Fig. 1. Tests on soil (a) Unconfined Compressive Strength Test (b) California Bearing Ratio Test

4.3 Chemical Analysis:

Chemical analysis was performed in the laboratory for both untreated and treated soil sample as per the relevant Indian standard codes and the results are given in Table 5.

Property	Laterite Soil	Laterite Soil + Cement (6%) (% by mass)
pH	10.13	10.7
Conductivity	1.2mS	1.95mS
Silica(SiO ₂)	65.8%	69%
R ₂ O ₃ (Al ₂ O ₃ + Fe ₂ O ₃)	20.30%	17.40%
Al ₂ O ₃	1.95%	5.54%
Fe ₂ O ₃	18.35%	11.86%
Chlorides	5.6%	8.2%
Sulphate	0.32%	0.085%
Calcium Oxide (CaO)	5.05%	8.22%
Magnesium Oxide(MgO)	2.20%	3.65%

Table 5 Chemical Composition of Treated and Untreated Soil

V. RESULTS AND DISCUSSIONS

The UCS test results showed that there was decrease in UCS strength of soil sample as the curing period increases. As the cement is added to soil sample UCS strength increases. More is the cement content higher is the UCS strength. This can be explained as the time progresses formation of dicalcium silicates takes place due to hydration of cement. The presence of dicalcium silicates is responsible for strength at the later stages. It can also be seen as the time progresses UCS values for untreated soil declined. Since there is no binding agent and as the time passes due to curing soil samples weathers slightly and it becomes too weak. Similar trend can be seen for soil with 3% of cement. It can be attributed to the fact that quantity of binder is too less. The variation of UCS with curing period is indicated in Fig 2 a.

CBR value for untreated soil remained constant for most of the time but after 14 days its value started decreasing. For soil treated with cement as the cement dosage was increased CBR values also increased for all curing periods. It

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can be explained like curing aids development of strength of cement because it reduces heat of hydration and development of tricalcium silicates and dicalcium silicates takes place and are responsible for strength of cement. In untreated soil there is no cementitious material so therefore there wasn't any development of strength. In turn due to curing it experienced alternate wetting and drying and hence it weathered a bit and CBR values started reducing. The variation of soaked-CBR with curing period is shown in Fig 2 b.

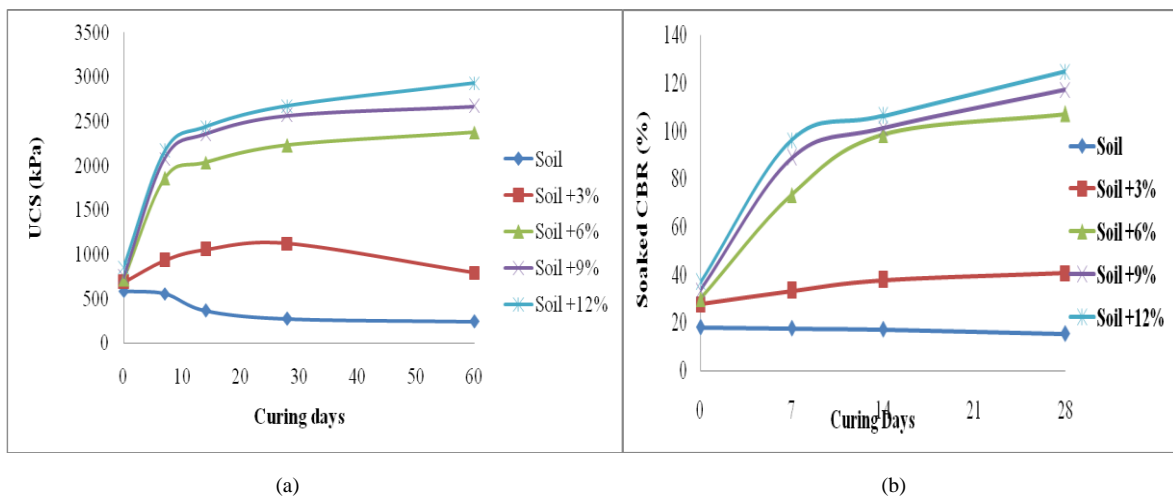


Fig. 2. (a) Variation of UCS according to curing periods (b) Variation of Soaked CBR for Curing Periods

The cement content corresponding to 7 day UCS strength of 1750 kPa is taken as design cement content (6%) and is considered quite adequate when soil-cement is to be used for base course of highway pavements with light to medium traffic (Khanna and Justo 2011). By maintaining this optimum dosage of 6% the further investigation was carried out. Firstly weight of soil needed for a particular test was determined, and then 6% of that weight was replaced by cement. Then coconut coir of length 20mm was used. Coconut coir was used at dosage of 0.5 % and 1% of weight of soil. In this phase only compaction tests and CBR tests were carried out since UCS samples couldn't be moulded as the soil couldn't reach moulding water content at OMC conditions.

It can be observed from Figure 3 (a) that CBR values for both the percentages of fibres increased tremendously as the curing period increased and it can be seen that values are very high compared to that of untreated soil. It can be observed from Figure 3 (b) that CBR values for all three percentages of aggregates increased manifold as the curing period increased and it can be seen that values are very high compared to that of untreated soil. These values were higher compared to that of soil and cement and even soil, cement and fibres mix.

Before recommending cement for practical purpose for stabilizing weak subgrade soils, a cost comparison was to be done to ascertain whether it proves cost effective on the longer run. Any new material or method will be accepted only if it is cost effective. Manufacturers of cement claims that sub base and base layers usually provided in pavement can be replaced by a layer of cement treated layer which requires much lesser thickness since the CBR value of cement treated subgrade and granular sub-base will be high.

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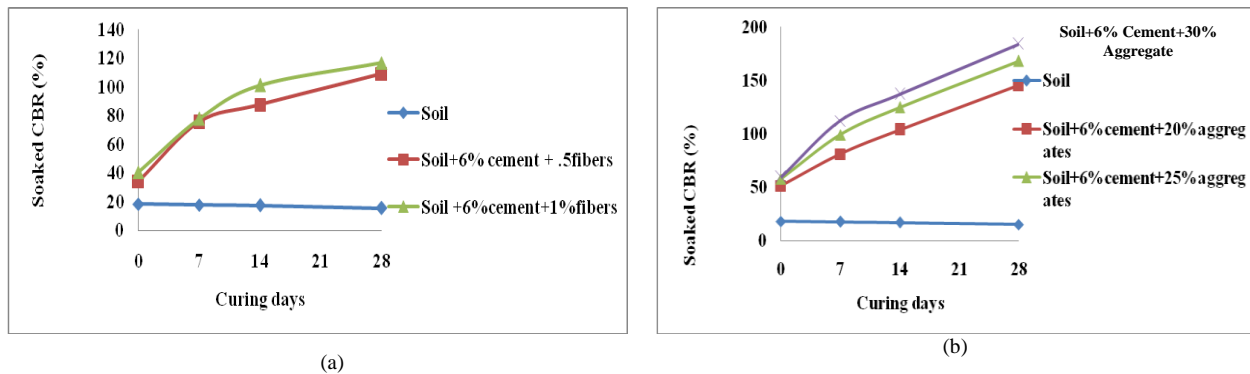


Fig. 3. (a) Soaked CBR values for various curing periods (b) Variation of Soaked CBR for Curing Periods

Finally the field cost analysis is carried out by incorporating the local unit cost of all the materials necessary for the soil modification. From this cost analysis carried out with all types of treated soil, it is clear that the soil treated with cement and coir fiber is not economical and shall not be preferred. It has been observed that, with the optimum cement content as the percentage of aggregates increases, the cost of soil per unit volume also decreases. Hence, soil treated with 30% of aggregates in addition to optimum cement content is preferred. The final cost analysis results were tabulated in Table 6.

Cost Analysis of the Treated Lateritic Soil		
Property	28 day CBR (%)	Cost the soil per m ³
Natural Soil	15	Rs.600
Soil+6% Cement	107	Rs.1544
Soil+6% Cement+1% Coir Fiber	117	Rs.1944
Soil+6% Cement+20% Aggregates	145	Rs.1468
Soil+6% Cement+25% Aggregates	168	Rs.1453
Soil+6% Cement+30% Aggregates	184	Rs.1437

Table 6 CBR values and Cost of different combination of treated soil

VI. CONCLUSION

The following conclusions were made on the basis of the laboratory tests and analysis of results:

- MDD values obtained for the lateritic soil treated with cement, from both modified and standard proctor compactions, immediately after mixing, showed increase till 6% of cement and then it decreased.
- Similarly, OMC values obtained for the various percentages of cement (0, 3, 6, 9 and 12%) with lateritic soil immediately after mixing decreased till 6% of cement and then increased gradually.
- For both standard and modified proctor tests for the lateritic soil treated with cement and coir, MDD was higher in both the cases compared to that of untreated soil while OMC was lower than that of untreated soil when it was mixed with coir and 6% cement.
- It is observed that CBR values for both the percentages of fibres increased tremendously as the curing period increased and the values are very high compared to that of untreated soil.
- From the unconfined compression test results showed that the strength of untreated soil sample reduced as curing period increased, and the UCS strength increased as the cement was added. Similar trend was observed in the penetration resistance test (CBR), where it showed a great penetration resistance as the cement was added.
- From the overall experimentation results and the cost analysis which was carried out, it can be observed that with the optimum cement content as the percentage of aggregates increased the cost of the soil per unit volume decreased and hence soil treated with 30% of aggregate with optimum cement content is preferred in the lateritic soil stabilization.

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