

# **Investigation on Fatigue and Durability Behaviour of Lateritic Soil Stabilized With Cement**

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**ABSTRACT:** The subgrade soil plays an important role in the design of pavement structure as it has to give adequate support to the pavement, for which it has to possess sufficient stability under adverse traffic and climatic condition. In the long term stability of structures durability of subgrade is required as to retain stability and integrity as these structures are exposed to the destructive forces of weathering where as the fatigue life is the number of traffic load cycles corresponding to the failure of the specimen under repeated loading or number of loading. Stabilised soil requires to be checked as this soil must be maintained for long term and may be susceptible for adverse climatic condition and repeated application of traffic loads. The present study carried to investigate the durability of the lateritic cement stabilized soil specimens by alternate wetting-drying test and freezing-thawing test, and also to investigate the fatigue behaviour of the same when exposed to the repeated traffic loading simulated in the laboratory as per BIS recommendations. From the durability test its been observed that that almost all samples withstood a minimum of 200000 cycles before failure showing the cement stabilized soil have high endurance limit. Thus the cement stabilization of lateritic soil is the best suited method for all weather and repeated traffic conditions.

**KEYWORDS:** Lateritic soil, Cement modification, Durability, Fatigue Life, Wet-Dry.

## **I. INTRODUCTION**

Subgrade is the supporting ground structure beneath the pavement. This sub-grade must be capable to withstanding loads transmitted from pavement structure with deformation being within allowable limits under the action of repeated application of heavy traffic and adverse action of changes in weather conditions throughout the life of the pavement. Varying water content adversely affects the stability of soil. Therefore it is necessary to evaluate the strength properties of soil subgrade under the adverse climatic conditions. The present study is carried out to compare the effect of addition of cement to naturally available lateritic soil.

The study also incorporates durability of the soil when it is stabilised. Stabilized soil has to be durable so that it can maintain strength under all adverse conditions. A good stabilizer should not only help in gaining strength, but should also retain its bonding with soil during the cyclic seasonal changes. Hence checking the durability is vital before recommending the stabilizer for practical applications. There are mainly two tests for durability- the wetting and drying test and freezing and thawing test, Based as per IS: 4332 (Part IV), 1968. Durability is defined as the ability of material to retain stability and integrity over years of exposure to the destructive forces of weathering.

Durability of the sub-grade is based on Fatigue life. Fatigue life is the number of load cycles corresponding to the failure of the specimen under repeated loading or number of loading (B.M. Lekha et al. 2013). To investigate fatigue behaviour of cement stabilized soils, specimens are exposed to the repeated loading in the laboratory. For this purpose the laboratory experiments are conducted in a fatigue testing apparatus and the specimens are subjected to number of repeated loads which simulate the effect of traffic movement on the pavement foundation soil. The number of loading cycles varied depending upon curing period, amount of load etc.

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## II. OBJECTIVES AND SCOPE OF PRESENT INVESTIGATION

The laboratory investigation is conducted on Lateritic soil which is a major type of soil available in Dakshina Kannada District of Karnataka State. The present investigations are carried to investigate:

1. To study the basic geotechnical engineering properties of locally available lateritic soil stabilized with various dosages of cement.
2. To determine the durability of the treated and untreated lateritic soil.
3. To study the behaviour of stabilized soil under repeated load condition.

## III. LITERATURE REVIEW

In the modern era soil stabilization has become a very important research topic in the field of Engineering. In soil stabilization, Portland cement is one of the most commonly used stabilizers for stabilizing various types of granular soils (B.M. Lekha et al. 2013). 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). In soil stabilization percentage of mix in mix design become a very important procedure (Gomez and Anderson 2012). 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). In the study on strength behavior Tri-axial is one of the most commonly and versatile test used in determination shear strength properties of soil. Cement stabilized lateritic soil can be used as road base course (Jaritngam et al. 2012).

The fatigue studies carried out on Lateritic soil treated with Zycosoil subjected to cyclic loading with constant amplitude of 1 Hz shown that, the fatigue life of the modified soil is higher than that of untreated soil cured for 6 weeks at laboratory conditions(B.M. Lekha et al. 2013).

From the vast literature review conducted it was observed that cement acts as good stabilizer and provide satisfactory investigation results. For the present study 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 and was uneconomical .

## IV. EXPERIMENTAL INVESTIGATION

### 4.1 Materials:

Lateritic soil used for the investigation was collected from the NITK, Surathkal campus about 1 meter below the ground level. The collected sample is first air dried and then oven dried before using it for the tests. The geotechnical laboratory test result for the lateritic soil is shown in Table 1. The cement used for the 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
Specific Gravity	2.661	IS:2720 (Part III)-1990	Compressive Strength (28 days) N/mm <sup>2</sup>	43
Grain Size Distribution (%)			Specific Gravity	3.12
Gravel	22	IS:2720 (Part IV)-1985	Fineness Minimum Specific Surface(m <sup>2</sup> /kg)	301
Sand	45		Initial Setting Time (min)	50
Silt	31			
Clay	2			
IS Soil Classification	Silty Sand(SM)			
Atterberg Limits (%)				
Liquid Limit	36	IS:2720 (Part V)-1986		
Plastic Limit	27			
Plasticity Index	9			

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Standard Proctor Test			Final Setting Time (min)	240
MDD (g/cc)	1.965	IS:2720 (Part VII)-1980		
OMC (%)	12.05		Soundness Expansion Le Chatelier's Test (mm)	10
Modified Proctor Test				
MDD (g/cc)	2.095	IS:2720 (Part VIII)-1983		
OMC (%)	11.125		Normal Consistency (%)	28
UCS (kPa) @OMC	589.4	IS:2720 (Part X)-1991		
CBR (%)				
Soaked	18	IS:2720 (Part XVI)-1987		
Un-soaked	49			

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

### 4.2 Experimental Investigation:

Experimental investigation is carried on un-treated lateritic soil to study its basic properties by specific gravity test, Atterberg limits test, grain size analysis test, and heavy compaction test followed by the tests using un-Confined Compressive Strength (UCS) and California Bearing Ratio (CBR) as per BIS specifications (prepared to the proctor conditions) on untreated, and treated lateritic soil with cement dosages (3, 6, 9 and 12%) tested immediately after treating to know the engineering behavior of the soil before assessing its durability and fatigue behavior and the results are are tabulated in Table 2.

Soil Sample	Modified Proctor Test		UCS Test (kPa)	Soaked CBR Value
	OMC (%)	MDD(g/cc)		
Untreated Lateritic Soil	11.12	2.097	589.0	18.0%
Lateritic Soil+ 3% Cement	11.00	2.130	684.0	28.0%
Lateritic Soil+ 6% Cement	10.90	2.133	716.0	30.0%
Lateritic Soil+ 9% Cement	12.50	2.124	749.0	34.0%
Lateritic Soil+ 12% Cement	12.80	2.120	857.0	37.0%

Table 2 Results for Compaction, UCS and CBR test on lateritic soil immediately after mixing

### 4.3 Durability Test:

Test for Durability was carried on soil samples prepared by mixing lateritic soil with cement at 3, 6, 9 and 12 percentages. Three samples were prepared for each percentage of cement. Oven-dried soil was first dry mixed with various percentage of cement. A sufficient quantity of water was added to bring the moisture content of the mixture to the desired optimum moisture content as per I.S. Specifications for heavy compaction. The mixtures were remoulded into standard cylindrical mould of 3.8 cm diameter and 7.6 cm length by static compression in compaction frame to the desired maximum dry density as per I.S Specifications. The compacted specimens were cured for 7 days at 90-100% relative humidity in closed desiccators party filled with water at room temperature.

**Procedure for Wetting and Drying Test:** At the end of the storage in the desiccators, the specimens are submerged in potable water at room temperature for a period of 5 h and removed. Samples shall be weighed and their dimensions measured. All the specimens shall then be placed in an oven at 70°C for 42 hours and removed. Specimens are weighed again with their dimensions.

This procedures described above constitute one cycle (48 hour) of wetting and drying. The specimens shall again be submerged in water and the procedure continued for 12 cycles.

After 12 cycles of test, the specimens are dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens. The data collected will permit calculations of volume and moisture changes of specimens after the 12 cycles of test. The weight loss after each wetting and drying for each cycle is calculated separately. According to IS Specification, weight loss for cement stabilized soil should not exceed 14% of the weight of the soil (IS: 4332 (Part IV), 1968). The wetting and drying test results are illustrated in Table 3.

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No. of cycles	Percentage weight loss							
	3 % cement		6 % cement		9 % cement		12% cement	
	Wetting	Drying	Wetting	Drying	Wetting	Drying	Wetting	Drying
1	3.36	-8.29	2.11	-8.76	2.45	-8.98	2.95	-9.23
2	3.13	-8.74	0.97	-8.97	2.59	-9.22	3.01	-9.39
3	3.17	-8.44	2.36	-8.54	2.70	-8.78	3.24	-8.80
4	2.66	-8.74	1.98	-8.95	2.33	-9.06	2.91	-9.16
5	2.52	-9.14	1.90	-9.25	2.35	-9.41	2.89	-9.60
6	2.60	-8.93	1.95	-8.98	2.38	-9.16	3.00	-9.29
7	2.42	-9.16	0.28	-8.78	2.23	-8.98	2.82	-9.10
8	2.14	-9.34	-0.01	-8.58	2.31	-8.75	2.91	-8.76
9	2.00	-9.35	-0.14	-8.48	2.43	-8.64	3.02	-8.74
10	1.85	-9.46	-0.28	-9.07	2.15	-8.69	2.80	-9.12
11	1.75	-9.56	-0.30	-9.21	2.10	-8.80	2.74	-9.24
12	1.69	-9.57	-0.38	-9.30	2.10	-8.85	2.73	-9.34
UCS (kPa)	1266		5206		6319		6470	

Table 3 Percentage weight loss during alternate cycles of wetting and drying for different percentages of Cement

**Procedure for Freezing and Thawing Test:** At the end of the storage in the desiccators, the specimens was submerged in freezer at temperature of minimum -10°C for a period of 24 hours and its weight and dimensions is measured. Then, the specimens were placed at room temperature for 23 hours and again its weight and dimensions been measured (IS: 4332 (Part IV), 1968).

The procedures described above constitute one cycle (48 h) of wetting and drying. The specimens shall again be submerged in water and the procedure continued for 12 cycles. After 12 cycles of test, the specimens was dried to constant weight at 110°C and weighed to determine the oven-dry weight of the specimens. The data collected will permit calculations of volume and moisture changes of specimens after the 12 cycles of test.

The weight loss after each freezing and thawing for each cycle is calculated separately. According to ASTM D 560-57 (1965) Specifications, the Standard weight loss for cement stabilized soil should not exceed 14% of the weight of the soil even in this case. The freezing and thawing test results are illustrated in Table 4.

No. of cycles	Percentage weight loss							
	3 % cement		6 % cement		9 % cement		12% cement	
	Freeze	Thaw	Freeze	Thaw	Freeze	Thaw	Freeze	Thaw
1	-0.48	-0.03	-0.50	0.11	-0.46	0.03	-0.32	0.18
2	-0.47	-0.21	-0.33	0.07	-0.28	0.15	-0.17	0.19
3	-0.22	-0.19	0.26	0.55	0.47	0.67	0.28	0.47
4	-0.10	0.37	0.35	1.03	0.37	0.71	0.14	0.59
5	0.07	0.45	0.65	1.09	0.49	0.72	0.34	0.68
6	-0.06	0.62	0.59	1.59	0.28	1.15	0.31	0.93
7	0.46	1.49	1.67	1.99	1.15	1.51	0.85	1.68

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8	1.04	2.39	1.64	2.24	1.14	1.76	1.28	2.19
9	1.40	1.88	1.64	1.97	1.44	1.64	1.93	2.20
10	0.90	1.40	1.17	1.70	1.20	1.57	1.78	1.78
11	0.28	1.37	1.45	1.57	1.08	1.48	1.67	1.74
12	0.01	1.18	1.18	1.20	1.06	1.29	1.62	1.73
<b>UCS (kPa)</b>	<b>258</b>		<b>2160</b>		<b>3365</b>		<b>4673</b>	

Table 4 Percentage weight loss during alternate cycles of freezing and thawing for different percentages of Cement



Fig.1. Durability Tests on soil (a) Durability Samples immersed in water (b) Durability samples after freezing

#### 4.4 Fatigue test:

The Fatigue test was conducted on the soil specimen similar to the specimen prepared in un-confined compression test and the samples were tested for 7days of curing. The Fatigue test equipment that is capable of applying the repeated loads at a frequency 0 to 12 Hz is used in the present investigation. The equipment is procured from SPANTROICS, Bangalore.

The main components of the test set-up are:

- Loading system including loading frame and load sensing device
- Control system including function generator
- Data Acquisition system

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Fig. 2. Experimental Setup for Fatigue Test

The cylindrical sample was mounted on the loading frame and the Deflection sensing transducers (LVDT) are set to read the deformation of the specimen. The load cell is brought in contact with the specimen surface. In the control unit through the dedicated software, the selected loading stress level, frequency of loading and the type of wave form are fed in to the loading device. The loading system and the data acquisition system is switched on simultaneously and the process of fatigue load application on the test specimen is initiated. The repeated loading, at the designated excitation level (i.e. at the selected stress level and frequency) is continued till the failure of the test specimen. The failure pattern of the test specimen is noted down manually.

Load given in fatigue test was 1/3, 1/2 and 2/3 of 7days UCS Strength. The Un-confined compressive strength (UCS) and Load Value and the fatigue test results for the lateritic soil treated with various dosages of cement are illustrated in Table 5.

Sample	UCS Test Results (7 Days)		Fatigue test results of treated Lateritic soil					
			1/3 UCS		1/2 UCS		2/3 UCS	
	Stress (kPa)	Load (kg)	Load(kg)	Cycles	Load(kg)	Cycles	Load(kg)	Cycles
Soil +3%	9.344	105.961	35	200000	53	200000	71	200000
Soil +9%	18.577	210.663	70	200000	105	200000	140	200000
Soil +9%	20.765	235.475	78	200000	118	200000	157	200000
Soil +12%	21.638	245.375	82	200000	123	200000	164	200000

Table 5 UCS and the fatigue test results for the lateritic soil treated with various dosages of cement

## V. RESULTS AND DISCUSSIONS

The results of the durability test indicated that the lateritic soil gained strength when it is stabilized with cement. It was also observed that when the untreated samples were immersed in water for the first cycle of wetting, the samples

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couldn't withstand and samples got collapsed within a fraction of seconds and samples treated with cement didn't collapse even after 12 cycle for all dosages of cement. After the 12 cycles of wetting and drying,

From the UCS test it was noted that there was a remarkable increase in the strength and was 3times which was moist cured for 7days of curing. Therefore from the results it can be inferred that alternate wetting and drying cycles assisted in the development of strength of soil cement sample. Hence it should be recommended in places having alternate dry and wet weather.

Similar results were obtained after subjecting the standard soil specimen to the freezing-thawing test. After the 12 cycles of freezing and thawing, UCS test was conducted on the samples. It can be inferred from these results that alternate freezing and thawing also assisted in the development of strength of soil cement sample. Hence for the lateritic soil, the cement stabilization can be effectively used in the places where the subgrade is susceptible to the adverse action due to frost action.

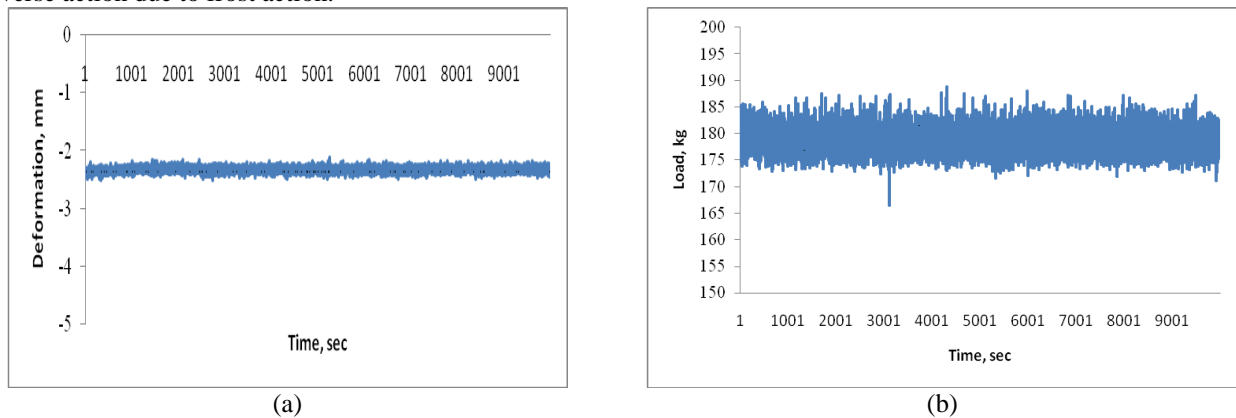


Fig 3 Fatigue Test Results (a) Deformation Vs time for initial 10000 sec (b) load and time for initial 10000 cycles

The figure 3a and 3b indicates the relation between Deformation Vs time for initial 10000 sec and, load Vs time for initial 10000 cycles from the Fatigue test. It can be also observed from the Fatigue test results that, almost all samples withstood a minimum of 200000 cycles for all three loadings so it can be revealed that these soil samples are strong enough to sustain the effect of repeated application of wheel load on the lateritic soil stabilized using cement. It shows soil mixed with all percentages of cement have high endurance limit.

### VI. CONCLUSION

The following conclusions were made on the basis of the basic geotechnical engineering tests; durability and fatigue test results on cement modified lateritic soil:

MDD values obtained from modified 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.

CBR value for untreated soil remained constant for most of the time, but for the soil treated with cement as the cement dosage increases CBR values also increases for all curing periods. The similar trends have been observed in the case of UCS results, indicating the gain of static strength by cement stabilization.

From Durability test it is concluded that the stabilized soil is durable as the percentage weight loss are within prescribed limits. The fatigue test results indicates that the lateritic soil stabilized with cement will have a good fatigue life, as the soil specimens successfully withstood more than 200000 cycles of simulated repeated traffic load when subjected to standard cyclic fatigue test conditions. Thus, the cement stabilization for the lateritic soil is the best suited one to be used as a effective subgrade support to withstand the adverse climatic and traffic loading.

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