



## Prediction Models for Estimation of California Bearing Ratio for Cohesive Soil

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### ABSTRACT

Cohesive soils are well known for their low strength properties. Thus, they are inappropriate for geotechnical works. Soils may be stabilized to increase strength and durability. Stabilization with cement is a common treatment technology. The present study examines the strength of cement stabilized soil. The laboratory tests were carried out in order to study the strength of California bearing ratio (CBR). Nine clayey soils with different properties were mixed with various amounts of cement content (3, 6, 9 and 12%) and compacted at the optimum moisture content and maximum dry density. Soaked or unsoaked condition of soil affects the CBR value. The test results show that unsoaked CBR before stabilization ranges between 2.78% and 10.22% which that of its corresponding soaked samples range between 1.01% and 9.5%. After stabilization, the values of unsoaked CBR range between 3.08% and 47%. The maximum values of unsoaked CBR are within 10.8% to 47%. So it can be used as sub-base condition. The conventional CBR testing method is expensive and time consuming. The laboratory test results were used for the development of regression based model to predict unsoaked and soaked CBR values for natural and cement stabilized soil.

**Keywords:** *cohesive soils, cement, CBR, regression model*

### I. INTRODUCTION

Construction of building and other civil engineering structures on weak or soft soil is highly risky on geotechnical grounds because such soil is susceptible

to differential settlements, poor shear strength and high compressibility. Improvement of load bearing capacity of the soil may be undertaken by a variety of ground improvement techniques like stabilization of soil, adoption of reinforced earth technique etc.

Soil improvement could either be by modification or stabilization or both. Soil modification is the addition of a modifier (cement, lime etc.) to a soil to change its index properties, while soil stabilization is the treatment of soils to enable their strength and durability to be improved such that they become totally suitable for construction beyond their original classification. Over the times, cement and lime are the two main materials used for stabilizing soils. The role of cement is to bind soil particles together, improve compaction and the engineering properties of available soil such as, unconfined compressive strength, workability, swelling potential and sensitivity to changes in moisture content. Soil stabilization with cement is widely used to improve foundations of structures, in basement improvement, in rigid and flexible highway, airfield pavements, waterproofing and reservoir and channel linings [7].

Cement is the oldest binding agent since the invention of soil stabilization technology in 1960's. It may be considered as primary stabilizing agent or hydraulic binder because it can be used alone to bring about the stabilizing action required [8]. The overall objective of this research is to study the compaction and strength of cement treated soils. The specific objectives of the study are investigation of the physical and mechanical properties of natural and

cement treated soils; investigation of the compaction characteristics of cement treated soils and interpretation of the effect of cement content on strength for various soils stabilized with cement.

The conventional CBR testing method is expensive and time consuming. To conduct CBR test on cement stabilized soil, a remoulded specimen is prepared and compacted at optimum moisture content. CBR test in laboratory requires a large soil sample and time consuming. To overcome this situation, it is better to predict CBR value of cement stabilized soil with easily determinable parameters.

## II. LITERATURE REVIEW

Underlying soils are an essential component of pavement structures, and inadequate strength performance is the cause of many premature pavement failures. Clayey soils in particular may provide inadequate support, particularly when saturated. Soils with significant plasticity may also shrink and swell substantially with changes in moisture conditions. These changes in volume can cause the pavement to shift or heave with changes in moisture content, and may cause a reduction in the density and strength of the subgrade, accelerating pavement deterioration. There is a substantial history of use of soil stabilization admixtures to improve poor soil performance by controlling volume change and increasing strength. Lime and cement have been used successfully for many decades [9].

Asma, U.H., Rafizul, I.M., Hasibul, M.H., Roy, S., Didarul, M. AND Shohel, M.R. 2013 conducted studies on “Engineering Behavior of Cement Stabilized Soil: New Statistical Model.” In this study soft soil was stabilized with cement at five contents and curing was done for 3, 7, 28 and 90 days. Result reveals that compressive strength increases with the increase of cement content and curing period. However, liquid limit has decreased with the increasing curing days but it has increased with the increasing cement content. Again, water content is decreasing with the increasing curing days and cement content. Based on SPSS analysis it is seen that regression model for 7 days is not acceptable to the desired confidence level with the obtained data. Regression model for 3 and 28 days is acceptable as it reached the desired confidence level. So, these obtained results from various tests and SPSS analysis on this cement stabilized soil can be used for further research and also for field application [10].

Dr. Dilip Kumar Talukdar. conducted studies on “A Study of Correlation between California Bearing Ratio (CBR) Value with Other Properties of Soil”. From this study, the following conclusions can be made. CBR value of fine grained soil (ML and MI) bears significant correlation with PI, MDD and OMC. CBR value decreases with the increase in the plasticity index and optimum moisture content of soil but increases with the increase in the maximum dry density. There is a slight difference between the CBR value determined in the laboratory and computed by using multiple linear regression model involving LL, PL, PI, MDD and OMC [11].

Ramasubbarao, G.V. and Siva Sankar, G conducted studies on “Predicting Soaked CBR Value of Fine Grained Soils Using Index and Compaction Characteristics” The following conclusions can be drawn. The statistical parameters indicate that the model developed by Simple Linear Regression Analysis (SLRA) for correlating soaked CBR value with Maximum Dry Density (MDD) has shown better performance. The other models developed by SLRA for correlating soaked CBR value with P.L, %Fines (F), %Sand (S), L.L and OMC have shown relatively good performances. The statistical parameters indicate that better performance can be obtained from the model developed using Multiple Linear Regression Analysis (MLRA) by showing the highest R-value of 0.96 and R<sup>2</sup>- value of 0.92 and the lowest error of 0.97. It was observed that the use of index properties such as grain size analysis, plasticity characteristics and compaction characteristics appears to be reasonable in the estimation of soaked CBR value of fine grained soils [12].

Naveen B Shirur, Santosh G Hiremath conducted studies on “Establishing Relationship between CBR Value and Physical Properties of Soil”. The following conclusion can be drawn. Based on experimental results and SLRA, there is no significant relation exists to predict CBR value from liquid limit and plastic limit. Linear relation exists to predict CBR value from plasticity index, MDD and OMC. The empirical relation obtained from multiple linear regression analysis (MLRA) shows good relation to predict CBR value from MDD and OMC. From the correlation analysis it is clear that, large variation can be observed between experimental and predicted CBR value particularly in case of high compressible clays (CH) [13].

### III. MATERIAL AND METHOD

#### A. Speciation of Soils

In this study, clayey soils were collected locally from Yangon and Ayeyarwaddy Division. Nine clayey soil samples with different plasticity indices were used in this experimental study. Soil locations and notation for present study are shown in Table 1.

Soil samples were taken by using disturbed sampling method. The collected soils were hard and it was pulverized manually by hammer. Then the soils were screened through the sieve of 4.75 mm openings before preparing the specimens for testing. And then, physical properties of cohesive soil such as gravel, sand, silt and clay content, liquid limit (L.L), plastic limit (P.L), shrinkage limit (S.L), swelling potential, water content and specific gravity were tested.

**TABLE 1: SOIL LOCATIONS AND NOTATION**

No.	Location	Notation
1	South Oakkalapa	S-1A
2	Shan Su	S-1B
3	Yankin	S-2A
4	Lanmataw	S-2B
5	Dawpon	S-3A
6	Thar Kay Ta	S-3B
7	Kaukas	S-4A
8	North Oakkalapa	S-4B
9	Hinthada-Sone Aung	Kone-Myan S-4C

Atterberg limit test and sieve analyses of clayey soils were carried out according to ASTM D4318 and ASTM D422-63 respectively. Soil type and classification were performed based on USCS (ASTM D2487). The properties of the tested soils are given in Table 2a and Table 2b.

**TABLE 2 a: PHYSICAL PROPERTIES OF NATURAL SOILS**

Location	S-1A	S-1B	S-2A	S-2B
Specific gravity	2.52	2.64	2.65	2.65
L.L	34.25	34.35	24.25	20.75
P.L	14.60	17.80	11.65	9.44
S.L	14.72	24.39	37.61	14.92
P.I	19.65	16.55	12.60	11.31
Gravel(%)	4.64	0.00	0.00	10.94
Sand (%)	20.38	17.32	48.73	27.34
Silt (%)	26.98	55.68	38.77	43.72
Clay (%)	48.00	27.00	12.50	18.00
R200	25.02	17.32	48.73	38.28
Group Symbol	CL	CL	CL	CL
Group Name	Lean Clay with sand	Lean Clay with Sand	Sandy Lean Clay	Sandy Lean Clay

**TABLE 2b: PHYSICAL PROPERTIES OF NATURAL SOILS**

Location	S-3A	S-3B	S-4A	S-4B	S-4C
Specific gravity	2.69	2.56	2.58	2.68	2.56
L.L	45.25	48.80	68.10	54.05	64.90
P.L	22.43	17.42	25.29	20.63	23.35
S.L	22.20	21.59	17.68	19.86	15.34
P.I	22.82	31.38	42.81	33.42	41.55
Gravel(%)	1.00	0.17	0.00	0.18	0.02
Sand (%)	7.48	11.26	1.18	8.00	0.66
Silt (%)	62.52	44.57	50.82	73.32	68.32
Clay (%)	29.00	44.00	48.00	18.50	31.00
R200	8.48	11.43	1.18	8.18	0.68
Group Symbol	CL	CL	CH	CH	CH
Group Name	Lean Clay	Lean Clay	Fat Clay	Fat Clay	Fat Clay

#### Testing Procedures

Laboratory tests were conducted to observe the basic index, unsoaked and soaked California Bearing Ratio (CBR) on unstabilized and stabilized soils according to ASTM standards. The unstabilized and stabilized with 3%, 6% , 9% and 12% cement content soil samples were prepared for compaction test. And then unsoaked and soaked CBR tests were conducted on each soil sample at the optimum moisture content. The laboratory test results were used for the development of regression based model to predict

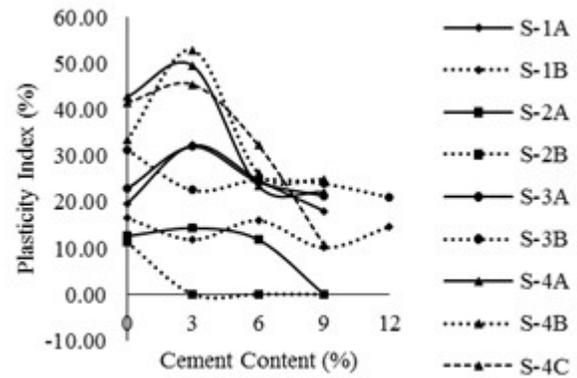
unsoaked and soaked CBR values for natural and cement stabilized soil.

	9	82.2	71.52	10.68
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**RESULTS AND DISCUSSIONS**

**A. Atterberg Limit Test of Soil Samples**

Atterberg limit test for clayey soils will be carried out according to ASTM D4318. The results of various soil samples are shown in Table 3 and Fig. 1. According to Fig. 1, plasticity index of cement stabilized soils decrease with the increase of cement content for S-1B, S-2B and S-3B. The P.I values for other soil types are the highest at 3% cement content and then decrease with the increase of cement content. A reduction in plasticity index causes a significant decrease in swell potential and removal of some water that can be absorbed by clay minerals.



**Fig. 1 Variation of Plasticity Index with Cement Content**

**TABLE 3: ATTERBERG LIMIT TEST RESULTS FOR STABILIZED SOIL SAMPLES**

Soil Type	Cement Content (%)	L.L (%)	P.L (%)	P.I (%)
S-1A	3	50.8	18.53	32.27
	6	45.7	20.94	24.76
	9	42	23.92	18.08
S-1B	3	36.8	24.98	11.82
	6	40.7	24.73	15.97
	9	36.5	26.43	10.07
S-2A	3	29.5	15.17	14.33
	6	24.7	12.87	11.83
	9	0	0	0
S-2B	3	0	0.00	0.00
	6	0	0.00	0.00
	9	0	0.00	0.00
S-3A	3	56	24.02	31.98
	6	53.2	28.87	24.33
	9	53.2	31.87	21.33
S-3B	3	48	25.44	22.56
	6	52	27.14	24.86
	9	47	23.07	23.93
S-4A	3	75	25.42	49.58
	6	52	28.58	23.42
	9	55.8	33.65	22.15
S-4B	3	81.8	28.79	53.01
	6	62	35.75	26.25
	9	59.5	34.60	24.90
S-4C	3	83.5	37.99	45.51
	6	74.2	41.85	32.35

**B. Compaction Test**

Compaction test (ASTM D1557) was performed on the unstabilized and stabilized soil samples to determine their engineering properties under laboratory conditions. The results of compaction test for various soil types are shown in Table 4, Fig. 2 and Fig.3. Fig 2 shows the relationship between cement content and optimum moisture content (OMC). From this figure, OMC values are not the same with the addition of cement content. According to comparison of OMC with PL, OMC is smaller than PL. Fig. 3 shows the relationship between cement content and maximum dry density (MDD). MDD values are decreased with the addition of cement content except fat clay (S-4A, S-4B and S-4C). MDD values for fat clay are the highest in 9% cement content.

**TABLE 4: COMPACTION TEST RESULTS FOR UNSTABILIZED AND STABILIZED SOIL SAMPLES**

Soil Type	Cement Content (%)	OMC (%)	MDD (lb/ft <sup>3</sup> )
S-1A	0	16.8	110.47
	3	13.3	103.4
	6	17.4	108.06
	9	14.5	108.5
S-1B	0	17.5	100.3
	3	20.5	100
	6	21	99.7
	9	18	98.4
	12	17.8	97.5

S-2A	0	10.8	118.4
	3	13	111.3
	6	11	112.8
	9	13.7	114.08
S-2B	0	12	118.5
	3	12	113
	6	12	116
	9	12.9	116.5
S-3A	0	23.7	96.05
	3	23	93.1
	6	20	94
	9	20	94.97
S-3B	0	19	102.3
	3	18.5	102
	6	17	102.2
	9	17.5	101.83
	12	17	100.5
S-4A	0	26.5	83.79
	3	24.2	88.4
	6	23	93.51
	9	12.6	93.9
S-4B	0	24.8	94.2
	3	20.50	94.9
	6	16.11	93.84
	9	18.58	95.8
S-4C	0	24.5	93
	3	7.6	90.91
	6	12	90.5
	9	8.2	94.57

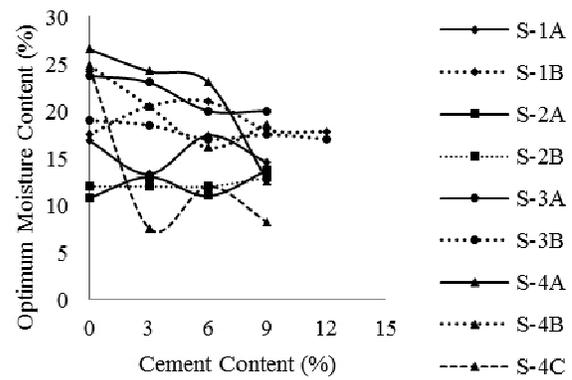


Fig. 2 Relationship between Cement Content and Optimum Moisture Content

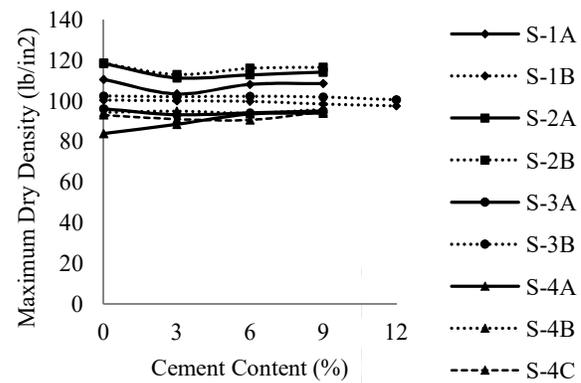


Fig. 3 Relationship between Cement Content and Maximum Dry Density

### C. California Bearing Ratio Test (CBR)

The California Bearing Ratio (CBR) test is commonly used to determine the suitability of a soil as a subgrade or subbase for highway and runway design and construction. From Fig 4, natural soil is too small in unsoaked CBR values except S-2A. So, soils are stabilized with cement to increase strength and to be able to use road construction instead of conventional material by reducing road thickness. These stabilized soils compacted with optimum moisture content are tested for CBR. Table 5, Fig 4 and Fig 5 show the results of unsoaked and soaked CBR values for various soil types with different cement contents.

TABLE 5. UNSOAKED AND SOAKED CBR RESULTS FOR UNSTABILIZED AND STABILIZED SOIL SAMPLES

Soil Type	Cement Content (%)	Unsoaked CBR (%)	Soaked CBR (%)
S-1A	0	2.83	3.33
	3	21	42.00
	6	35.33	105.22
	9	16.29	48.87
S-1B	0	3.30	2.01
	3	3.08	4.56
	6	6.4	17.4
	9	10.8	49.55
	12	4.97	29.73
S-2A	0	10.22	9.5
	3	26.33	94.33
	6	47.00	105.00
	9	27.38	82.14
S-2B	0	2.78	2.22
	3	32.5	66.2
	6	11.82	85.26
	9	13.53	127.83
S-3A	0	3.33	2.67
	3	12.67	19.33
	6	21.11	40.83
	9	14.84	32.79
S-3B	0	4.19	3.71
	3	10.27	27.79
	6	11.00	43.65
	9	12.4	93.4
	12	8.68	74.72
S-4A	0	3.50	2.00
	3	10.00	11.83
	6	18.00	32.00
	9	16.29	42.27
S-4B	0	2.83	3.00
	3	13.56	12.63
	6	9.73	12.15
	9	11.45	54.05
S-4C	0	2.81	1.01
	3	16.25	5.19
	6	12.81	12.45
	9	15.81	30.75

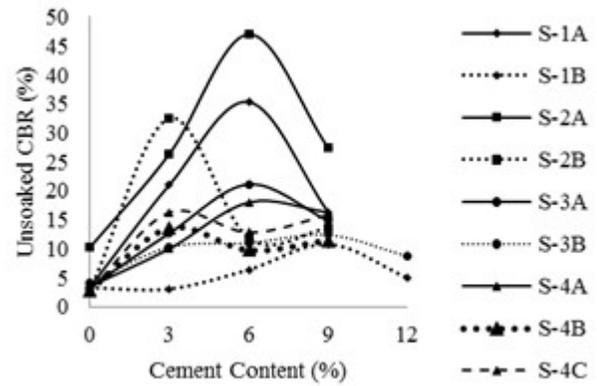


Fig. 4 Effect of Cement content on Unsoaked CBR

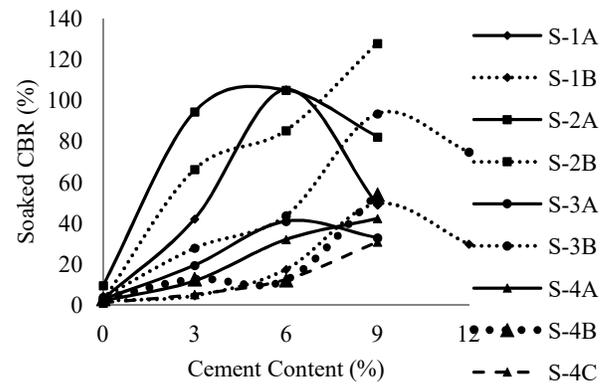


Fig. 5 Effect of Cement content on Soaked CBR

**D. Proposed Model for Estimating CBR Values**

In this study, multiple liner regression analysis (MLRA) was developed for estimating unsoaked and soaked CBR values in terms of cement content (CC), liquid limit (LL) and optimum moisture content (OMC). MLRA has been carried out by considering unsoaked and soaked CBR values as the independent variable and the rest of soil properties as dependent variables. MLRA can be carried out using standard statistical software like SPSS. Table 6 and Table 7 shows the summary of the computation of linear regression equations for different condition of test results.

TABLE 6. LINEAR REGRESSION EQUATIONS FOR UNSOAKED AND SOAKED CBR VALUES (NATURAL SOIL)

No	Linear Regression Equations	R	R <sup>2</sup>	Sig.
1	$CBR_{unso} = 13.793 + 0.291LL - 1.114OMC$	0.72	0.52	0.05
2	$CBR_{so} = 9.103 - 0.286OMC$	0.65	0.43	0.03

TABLE 7. LINEAR REGRESSION EQUATIONS FOR UNSOAKED AND SOAKED CBR VALUES (CEMENT STABILIZED SOIL)

No.	Linear Regression Equations	R	R <sup>2</sup>	Sig.
1	$CBR_{unso} = 18.839 + 1.16CC - 0.634OMC$	0.70	0.49	0.01
2	$CBR_{so} = 30.665 + 4.102CC - 1.148OMC$	0.72	0.51	0.012

**E. Validity of the Proposed Model**

The validity of the proposed model for prediction of unsoaked and soaked CBR values was verified by the results of few researchers. The results of the predicted and observed unsoaked and soaked CBR values for natural soil are shown in Table 8 and that for cement stabilized soil are presented in Table 9. The results of the analysis indicate that there is a close relationship between CBR values, Compaction and index properties. There is a slight difference between the observed and predicted CBR value by using multiple linear regression model involving CC, LL and OMC. Regression analysis provides a sound background for preliminary assessment of CBR values.

**CONCLUSIONS**

This study presented the effect of cement content on geotechnical properties and proposed models for untreated and treated soil samples. The results of the study are presented in the following.

(1) Soils with liquid limit less than 50% are considered to be CL and those with liquid limit greater than 50% exhibit CH according to USCS. Plasticity index of cement

TABLE 8. VALIDITY OF PROPOSED MODEL FOR UNSOAKED AND SOAKED CBR VALUES (NATURAL SOIL)

Researcher	Lel Myat Thu	Saw Kaythi Maung
LL (%)	41	59.2
OMC (%)	16.3	21.5
Predicted value	Unsoak	7.57
	Soak	4.44
Observed value	Unsoak	10.7
	Soak	3.1
Ratio of Predicted to Observed	Unsoak	0.71
	Soak	1.4

TABLE 9. VALIDITY OF PROPOSED MODEL FOR UNSOAKED AND SOAKED CBR VALUES (CEMENT STABILIZED SOIL)

Researcher	Lel Myat Thu			
CC (%)	4	6	8	10
OMC (%)	26.7	27	26.5	29
Predicted Value	Unsoak	6.55	8.68	11.31
	Soak	16.42	24.28	33.06
Observed Value	Unsoak	10.8	12.2	14.3
	Soak	15.2	27.6	52.3
Ratio of Predicted to Observed	Unsoak	0.61	0.71	0.79
	Soak	1.08	0.88	0.63

stabilized soils decrease with the increase of cement content for S-1B, S-2B and S-3B. The P.I values for other soil types are the highest at 3% cement content and then decrease with the increase of cement content.

(2) The values of MDD decrease with the increase of cement content except S-4 group. The values of OMC decrease with the increase of cement content for S-3 group and S-4 group. For S-1 and S-2 group, these values are the highest at 6% and 9% cement content respectively and then gradually decrease with the increase of cement content.

(3) CBR (unsoaked) values are the highest at 3% cement content for S-2B, S-4B, S-4C, at 6% cement content for S-1A, S-2A, S-3A, S-4A and at 9% cement content for S-1B, S-3B. The maximum values of unsoaked CBR are within 10.8% to 47%. So it can be used as sub-base condition. CBR (soaked) values are the highest at 6% cement content for S-1A, S-2A, S-3A, S-4A and at 9% cement content for other soil types.

(4) The results of the analysis indicate that there is a close relationship between CBR values, Compaction and index properties. There is a slight difference between the CBR value determined in the laboratory and computed by using multiple linear regression model involving LL and OMC. Regression analysis provides a sound background for preliminary assessment of CBR values.

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