Prediction of Compaction Properties of Clayey Soils Stabilized With Calcium Carbide Residue

D.M.T.U. Sandamali
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
thulshiupeka@gmail.com

K.H.S.M. Sampath
Department of Civil Engineering
University of Moratuwa
Moratuwa, Sri Lanka
sampathkh@uom.lk

A. S. Ranathunga
School of Civil Engineering
University of Leeds
Leeds, UK
A.S.Ranathunga@leeds.ac.uk

Abstract — The use of Calcium Carbide Residue (CCR) for soil stabilization results in changes of the properties of natural soil. In terms of compaction properties, the addition of CCR reduces the maximum dry density (MDD) of clayey soils while increasing the optimum moisture content (OMC). This paper describes a multivariate linear regression model and a multivariate polynomial regression model which can predict the MDD, and OMC of clayey soils stabilized with CCR, respectively. In both models, the compaction properties of the natural soil and the CCR mix proportion are used as independent variables and the developed models can be used to study any clayey soil which can be classified as CH or CL according to the unified soil classification system (USCS). From the statistical analysis, it is found that the models are capable of accurately predicting the compaction properties (i.e., MDD and OMC) of clayey soils stabilized with different CCR dosages with a prediction accuracy of ±5%. Therefore, the developed correlations can be effectively used as an indirect approach to estimate the improved compaction properties of soil in the process of soft ground improvement using CCR.

Keywords — Calcium Carbide Residue; Compaction; Clayey soils; Regression analysis; Maximum dry density; Optimum moisture content

I. Introduction and Background

Clayey soils can be identified as one of the problematic soil types encountered during constructions due to their low strengths and high compressibility characteristics. In addition, clay is a water sensitive soil that exhibits extreme volumetric changes with the absorption and evaporation of moisture. Therefore, using a soil stabilizer for the clayey soils to improve its geotechnical properties is a common approach in the construction field.

Cement is generally used for soil stabilization in the field. Many recent studies have focused on calcium carbide residue (CCR) as a stabilizer to replace cement due to the high costs and negative environmental impacts involving cement usage. CCR is a by-product of acetylene gas production process and can be identified as a $Ca(OH)_2$-rich material. Cementitious products created as a result of pozzolanic reactions between $Ca(OH)_2$ from CCR and the natural pozzolanic materials such as alumina and silica in soil can stabilize the clay matrix [1].

Addition of CCR as a soil stabilizer changes the properties of soils such as strength and compaction characteristics. In fact, addition of CCR decreases the maximum dry density (MDD) of soil while increasing the optimum moisture content (OMC) [2]–[9].

Generally, the specific gravity of CCR is less than that of the clayey soils [2], [5]. Therefore, the addition of CCR reduces the net specific gravity of the treated soil. This reduced specific gravity and the aggregation of clay particles cause the decrement in maximum dry density of the CCR treated clayey soils [2], [5].

When the CCR is added to the clayey soil, the natural pozzolanic material in soil such as silica and alumina react with $Ca(OH)_2$ from the CCR. These pozzolanic reactions require water in which the requirement increases with the CCR dosage. Therefore, with the addition of CCR, the soil absorbs more water and hence the optimum moisture content of the CCR treated soils increases [2], [5].

Studying the compaction properties of a soil is essential for compaction works in field and laboratory applications. Also, it is important to know how the soil behaves after stabilizing with CCR, so that the CCR based soil stabilization can be utilized effectively.

Even though the experimental studies have shown the applicability of the CCR as a soil stabilizer, there are no studies with models predicting the change of behavior of CCR treated clayey soils in terms of compaction properties to be found in the literature.

Since the models developed in this research can predict the MDD and OMC values of the soil after the CCR is added, further compaction tests can be avoided and therefore the time and cost for such investigations can be minimized. Also, the results can be used for future research work that study the applicability of CCR as soil stabilizer for clayey soils. The proceeding chapters describe the developed regression models and validation of those models.

II. METHODOLOGY

The data required for training and validation of the models were collected through a systematic literature review. The experimental data that only use CCR as a stabilizer were extracted from the studies as mentioned in annex 1. The training and validation data used to develop the models are shown in Annex 1. Statistical tools in Excel and MATLAB were used for the data analysis and the generation of relevant graphs.

MDD and the OMC of the soil stabilized with CCR were selected as the dependent variables, whereas the independent variables were selected by conducting a step wise regression analysis as shown in Fig.1 and Fig.2. Since the aim is to study the variation of compaction properties with the CCR addition, the CCR mix proportion was also selected as an independent variable for the analysis. Specific gravity of CCR was not selected as an independent variable even though it could be identified as a promising independent variable according to the results of stepwise regression analysis, in order to maintain sufficient number of data sets for the analysis.

Clayey soils which can be classified as CH (high plasticity clay) or CL (low plasticity clay) according to the unified soil classification system (USCS) are considered for the analysis. Hence, the models are only valid for the CCR stabilized clayey soils with similar properties.

The best fit model was selected considering the adjusted R^2 value and standard error values of the regression analysis. This paper shows the models with highest R^2 values and the least standard error values. It is evident from Fig.1 and Fig.2, that the specific gravity ($Gs_{(Soil)}$) and the plasticity index ($PI_{(soil)}$) of un-treated soil do not have a strong correlation with selected dependent variables, thus, those variables are omitted from the statistical analysis. Hence, by following the results of the step wise regression analysis, the compaction properties of un-treated soil (i.e., $MDD_{(Soil)}$ and $OMC_{(Soil)}$) and the CCR mix proportion were selected as the independent variables. Hence the regression equations for MDD and OMC of treated soil can be expressed as shown in equations (1) and (2), respectively.

$$MDD_{(TS)} = f(MDD_{(Soil)}, CCR\%, OMC_{(Soil)}) \quad (1)$$

$$OMC_{(TS)} = f(MDD_{(Soil)}, CCR\%, OMC_{(Soil)}) \quad (2)$$

Where;

$MDD_{(TS)}$ = Maximum dry density of the CCR treated soil (kN/m^3)

$OMC_{(TS)}$ = Optimum moisture content of the CCR treated soil (%)

$MDD_{(Soil)}$ = Maximum dry density of the natural soil (kN/m^3)

$OMC_{(Soil)}$ = Optimum moisture content of the natural soil (%)

CCR% = CCR percentage mixed with natural soil

III. PREDICTION OF MDD

A. *Model development*

Using 30 data sets as shown in the annex 1, the following model (equation (3)) was developed using multivariate linear regression analysis (MLR).

Model 01:

$$MDD_{(TS)} = 0.91545 MDD_{(Soil)} - 0.06829 CCR\% + 1.022403 \quad (3)$$

Statistical details of the model are shown in table 1.

TABLE I. DETAILS OF MODEL 1

Multiple R	0.9501	
R Square	0.9027	
Adjusted R^2	0.8955	
Standard Error	0.6518	
Model F value	125.1973464	
Significance F	2.19576E-14	
Variables	$MDD_{(Soil)}$	CCR%
P-value	2.99E-14	0.002967

ISBN: 978-624-6150-05-1

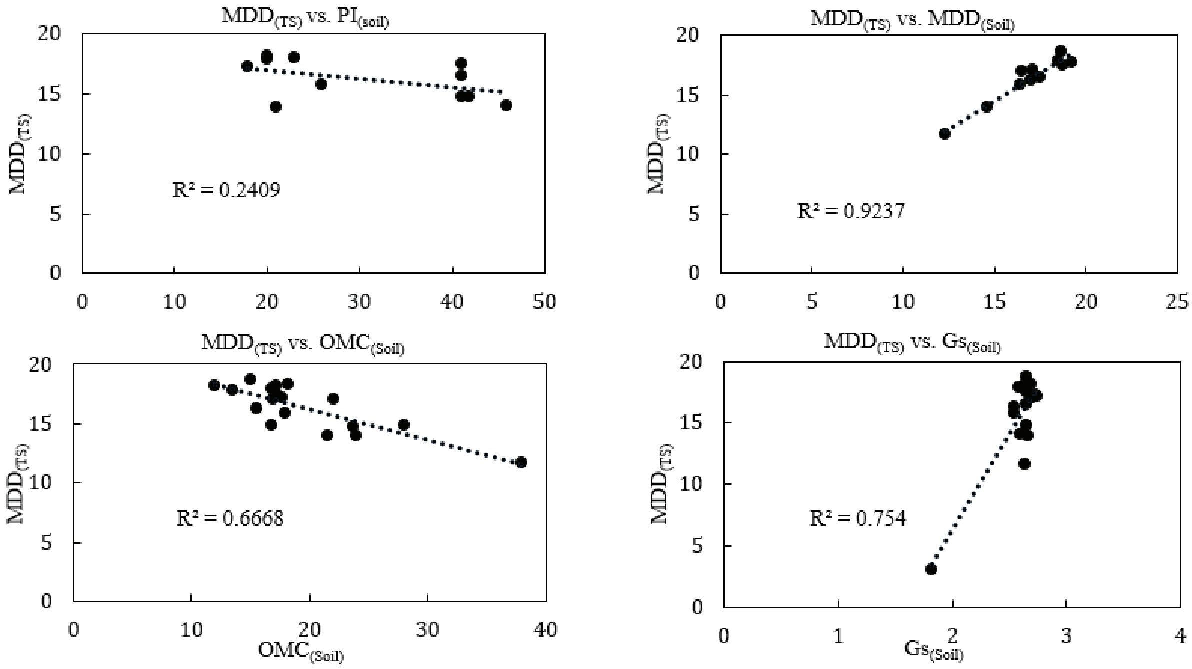

Fig. 1. STEP-WISE REGRESSION FOR MDD

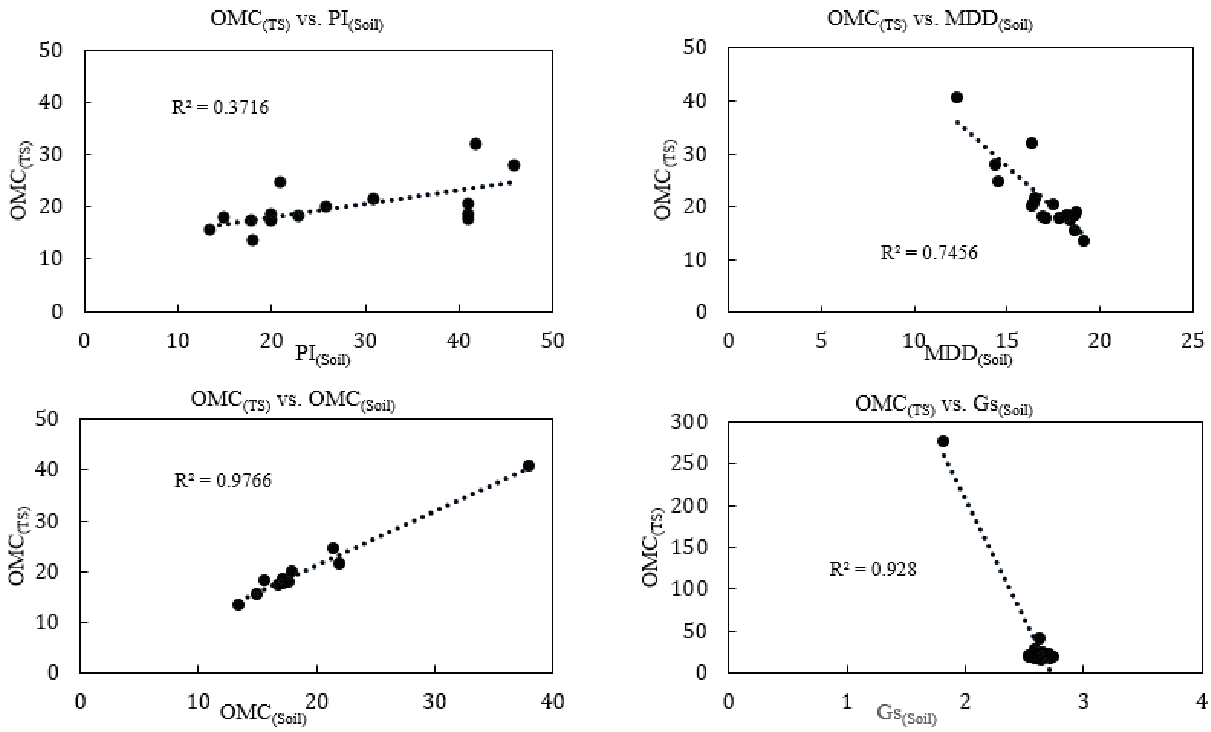

Fig. 2. STEP-WISE REGRESSION FOR OMC

Here the adjusted R^2 is close to 1 and the significance F is way below 0.05. Also, the P-values for both selected independent variables are less than 5%. Therefore, it can be seen that the developed model is an accurate and promising model. Also, the low p-values of independent variables show that the selected variables are suitable for the model.

The predictive curve of model 01 which was generated with MATLAB, is shown in Fig.3 and can be used for easy reference when the MDD of the natural soil and CCR dosages are available.

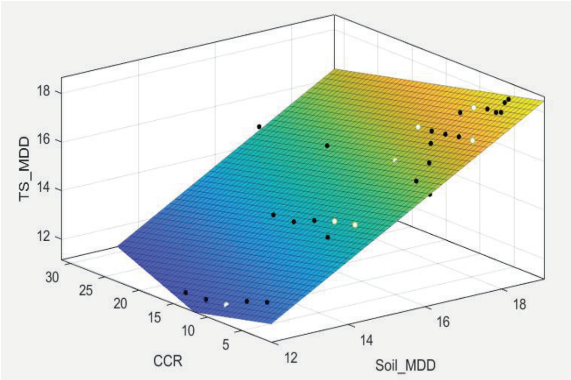

Fig. 3. PREDICTIVE CURVE FOR MODEL 1

B. *Model validation*

Total of 9 data sets which were not used for training the model were used for the validation. Validation shows that the developed model can predict the MDD of treated soil within a predictive accuracy of ±5%.

Fig.4 shows the MDD predicted by model 01 with respect to the actual MDD values found in literature. The trendline generated for the validation results is very close to the equity line. And the trendline have a R^2 value close to 1, which shows that the predicted MDD values can represent the experimented MDD values successfully. Also, the predicted values are within the ±5% error bars indicating the accuracy of the model.

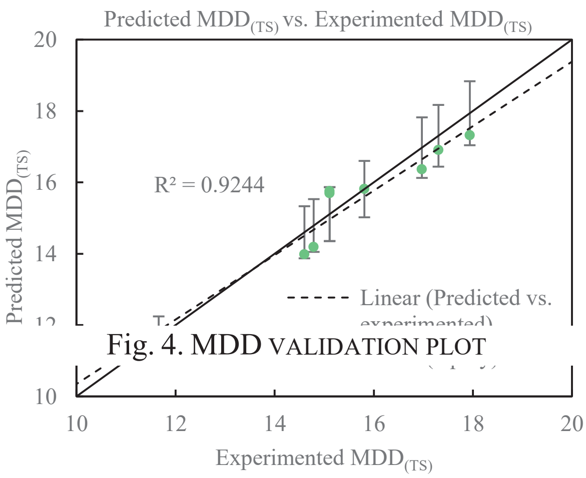

Fig. 4. MDD VALIDATION PLOT

As shown in table 2, the goodness of fit data generated by MATLAB shows approximately similar RMSE values for the model and validation which also indicates the accuracy of model 01. Therefore, it can be concluded that model 01 is an accurate and promising model that can predict the MDD of the clayey soils stabilized with CCR.

TABLE II. ADDITIONAL VALIDATION DATA OF MODEL 1

Goodness of fit for the model:	
SSE	11.47
RMSE	0.6518
Goodness of validation:	
SSE	2.41354
RMSE	0.517852

IV. PREDICTION OF OMC

A. *Model development*

Since a successful predictive model for OMC could not be developed using multivariate linear regression analysis, a polynomial regression equation was developed.

Using 30 data sets as shown in annex 1, the following model (equation (4)) was developed using multivariate polynomial regression analysis tool of MATLAB.

Model 02:

$$OMC_{(TS)} = 46.13 - OMC_{(Soil)}\, CCR\% \left(0.03566 - 0.0007532\, OMC_{(Soil)} + \frac{4.946 - 0.2521\, OMC_{(Soil)} + 0.003365\, OMC^2_{(Soil)}}{CCR\%} - \frac{0.535}{OMC_{(Soil)}}\right) \quad (4)$$

This model has a R^2 value of 0.9862 and an adjusted R^2 value of 0.9826 which are very close to 1. Which shows model 02 is a promising model to predict OMC of clayey soils.

Also, a predictive curve for model 02 was generated using MATLAB, which was shown in Fig.5 and can be used for easy reference when the OMC of the natural soil and CCR dosages are available.

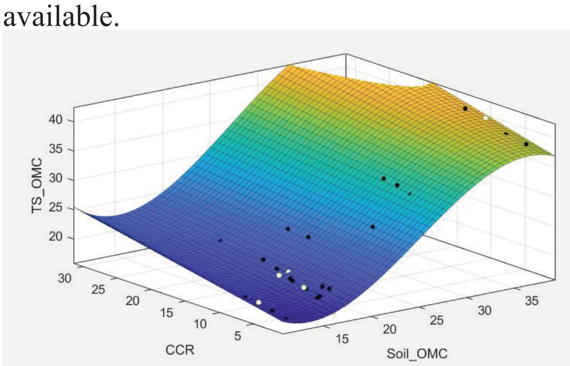

Fig. 5. PREDICTIVE CURVE FOR OMC

ISBN: 978-624-6150-05-1

B. Model validation

Total of 9 data sets that were not used for training the model were used for the validation. Validation shows that the developed models can predict the OMC of treated soil within an accuracy range of ±5%.

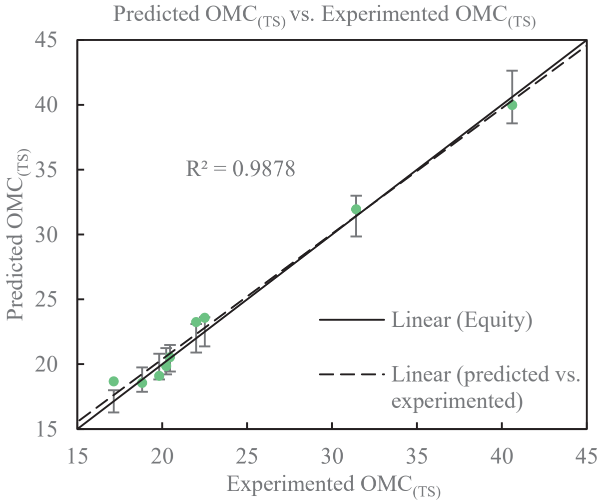

Fig. 6. OMC VALIDATION PLOT

Fig.6 shows the OMC values predicted by model 02 with respect to the actual OMC values. The trendline for the predicted OMC values is very close to the equity line and has a R^2 value of 0.9878. also, all the predicted OMC are within the ±5% accuracy range except one value which can be identified as an outlier.

Also, according to table 3, the RMSE values for the model and the validation are approximately similar. Considering all these facts, it can be concluded that model 02 is a sufficiently accurate and promising model that can be used to predict the OMC of clayey soils stabilized with CCR.

TABLE III. VALIDATION DATA OF MODEL 2

Goodness of fit for the model:	
SSE	23.36
RMSE	1.008
Goodness of validation:	
SSE	6.31428
RMSE	0.837607

V. CONCLUSION

With the addition of CCR, the MDDs of clayey soils are decreasing while the OMCs are increasing. According to the step wise regression analysis, it was identified that PI and Gs of natural soil do not have a significant effect on the CCR stabilized clayey soils, but in contrast, MDD and OMC of natural soil have a significant impact on the treated soil. Hence, it is evident that the compaction characteristics of natural soil and CCR dosage affect the compaction characteristics of CCR stabilized soil mainly, and therefore, current study attempted to develop correlations between compaction characteristics of natural and treated soil, incorporating the CCR% used for the treatment.

The developed linear and non-linear regression models confirm that MDD and OMC of treated soil can be estimated with an accuracy range of ±5% using the defined independent variables. Hence, the developed correlations can be effectively used to estimate the compaction characteristics of CCR-stabilized clayey soil, which will assist in minimizing the associated time and cost for additional testing.

REFERENCES

[1] N. Latifi, F. Vahedifard, E. Ghazanfari, and A. S. A. Rashid, “Sustainable Usage of Calcium Carbide Residue for Stabilization of Clays,” *J. Mater. Civ. Eng.*, vol. 30, no. 6, Art. no. 6, Jun. 2018.

[2] W. I. Balarabe and S. M. R. Sharmila, “Soil Stabilization Using Calcium Carbide Residue and Coconut Shell Ash,” *J. Basic Appl. Eng. Res.*, 2018,

[3] M. S. Kumari, B. V. S. Kavya, and G. J. Vincent, “A study on replacement of additives with CCR+FA to improve bearing capacity of soil,” *Proc. Natl. Conf. Recent Innov. Civ. Eng.*, 2017.

[4] I. K. Mohammed, M. Alhassan, and M. M. Alhaji, “Improvement of Deficient Laterite Soil using Cement and Calcium Carbide Residue,” *2 Nd Int. Civ. Eng. Conf.*, 2020.

[5] S. Mohammed, M. Alhassan, and M. M. Alhaji, “Stabilisation of Tropical Black Clay Using Calcium Carbide Residue and Cocunut Shell Ash,” *Niger. Inst. Civ. Eng.*, 2020.

[6] B. J. S. Varaprasad, J. R. Joga, and S. R. Joga, “Remediation of expansive soils using mango kernel ash and calcium carbide residue,” *Int J Environ. Waste Manag.*, vol. 25, no. 2, 2020.

[7] N. Venkatesh, P. Yewanth, V. P. C. Rama, B. S. K. Reddy, and S. T. Chaitanya, “Evaluation of a Clayey Soil Stabilized by Calcium Carbide Residue as Pavement Subgrade,” *Transp. Infrastruct. Geotechnol.*, 2021

[8] N. Venkatesh, L. M. Heera, and J. P. Rakesh, “Multi-scale laboratory investigation on black cotton soils stabilized with calcium carbide residue and fly ash,” *J. Eng Res.*, vol. 6, 2018.

[9] N. Venkatesh, L. M. Heera, and J. P. Rakesh, “Resilient modulus of clayey subgrade soils treated

with calcium carbide residue," *Int. J. Geotech. Eng.*, 2018.

[10] S. Horpibulsuk, P. Chayakrit, and C. Avirut, "Soil Stabilization by calcium carbide residue and fly ash," *J. Mater. Civ. Eng.*, vol. 24, no. 2, Art. no. 2, Feb. 2012.

ANNEX 01:

	Reference	Soil type (USCS)	MDD(Soil) kN/m³	OMC(Soil) %	CCR %	MDD(TS) kN/m³	OMC(TS) %
Training Data	[10]	CH	16.9	18	5	16.27	19.98
					20	15.31	21.78
					30	14.98	22.02
	[1]	CH	12.3	38	3	12.44	38.5
					6	12.15	39
					12	11.56	41
					15	11.51	41.2
	[1]	CL	14.6	21.5	9	14.3	23.2
					12	13.91	24.5
					15	13.86	24.7
	[8]	CH	16.468	16.7618	4	15.4956	18.8307
					8	14.8046	20.5705
					10	14.216	21.4639
					12	13.9217	22.2163
	[4]	CL	18.2466	12	2	18.1926	17.5185
					4	18.1026	18.1481
					8	17.5158	18.8519
	[5]	CH	17.501	17	4	17.2324	19.0242
					6	17.1219	19.5072
					8	17.0224	20.0868
	[9]	CH	17.4772	17.2041	8	16.5227	17.5612
		CL	18.4724	16.7619	4	17.8834	17.3061
	[2]	CL	16.3827	18	4	15.8235	20
		CH	14.4207	24	6	14.0087	27.8
	[7]	CL	18.7	17.2	4	18.2	18.3
	[6]	CH	18.8	18.21	4	18.3034	18.81
	[3]	CH	16.3827	28	2	15.4998	30.6
					6	14.8131	32
					8	14.2245	32.8
					10	13.9302	33.14
Validation Data	[10]	CH	16.9	18	10	15.81	20.46
	[1]	CH	12.3	38	9	11.66	40.6
		CL	14.6	21.5	3	14.79	22
		CL	14.6	21.5	6	14.6	22.5
	[8]	CH	16.468	16.7618	6	15.1116	19.8182
	[4]	CL	18.2466	12	6	17.937	18.8148
	[5]	CH	17.501	17	2	17.3043	17.1397
		CH	17.501	17	10	16.9727	20.2317
	[3]	CH	16.3827	28	4	15.1074	31.42

ISBN: 978-624-6150-05-1