

Effect of Cement Deep Mixing Technique on Strength and Settlement Characteristics of Low Plastic Soils

Effet de la technique de mélange en profondeur du ciment sur les caractéristiques de résistance et de tassement des sols peu plastiques

M. V. Shah

L.D. College of Engineering, Ahmedabad, Gujarat, India

Parth Shah, A.R. Gandhi

L.D. College of Engineering, Ahmedabad, Gujarat, India

ABSTRACT: Low plastic soils with varying degree of saturation and low density are subjected to large settlement and needs more attention. This paper is an attempt to use cement deep mixing technique by forming soil-cement columns to strengthen low plastic soils having varying lengths such as 10cm, 20cm and 30cm and with varying degree of saturation as 60%, 80% and 100%. Soil was compacted at 90% of maximum dry density. Broder objective of this study is to evaluate unconfined compression strength, percentage reduction in settlement, modulus of subgrade reaction and elasticity of low plastic soil. Cement dosages were fixed on the basis of guidelines provided in FHWA 13-046 design manual. The results indicated appreciable increase in bearing capacity and settlement reduction of about 80% in treated soil as compared to untreated soil. Thus, this method can be feasible in low plastic soils subjected to varying degree of saturation.

RÉSUMÉ: Les sols peu plastiques, avec des degrés de saturation et des densités variables, sont soumis à des tassements importants et nécessitent plus d'attention. Ce papier est une tentative d'utilisation de la technique de mélange en profondeur du ciment en formant des colonnes sol-ciment pour renforcer les sols peu plastiques ayant des longueurs variables telles que 10 cm, 20 cm et 30 cm et avec un degré de saturation variable, 60%, 80% et 100%. Le sol été compacté à 90% de la densité sèche maximale. L'objectif de Broder de cette étude est d'évaluer la résistance à la compression non confinée, le pourcentage de réduction du tassement, le module de réaction du substrat et l'élasticité d'un sol peu plastique. Les dosages de ciment ont été fixés sur la base des directives fournies dans le manuel de conception FHWA 13-046. Les résultats ont indiqué une augmentation sensible de la capacité portante et une réduction du tassement d'environ 80% du sol traité, par rapport au sol non traité. Ainsi, cette méthode peut être réalisable dans des sols peu plastiques soumis à divers degrés de saturation

Keywords: CDM, UCS, modulus of subgrade reaction, cement column, degree of saturation

1 INTRODUCTION

Among various methods available for stabilizing the soil at certain depth such as compaction with columns of stone, ballast, vibro floatation technique, etc. deep soil mixing technique aims at strengthening the soil by mixing it with

various binders such as cement, lime, etc. As a result of the reaction between soil and binder, it's physical and chemical properties of soil changes which leads to substantial improvement in soil properties. Various deep soil mixing techniques include Cement Deep Mixing (CDM), Wet Deep Mixing Method (WDM),

Dry Deep Mixing Method (DDMM), etc. The present research emphasizes on studying the effectiveness of cement deep mixing (CDM) technique on soil compacted at different degrees of saturation. In the present study soil was compacted at 90% of maximum dry density and at varying degree of saturation as 60%, 80% and 100% of optimum moisture content, also the soil-cement column length were varied as 10cm, 20cm and 30cm and its unconfined compression strength as well as settlement facet were studied. For the purpose of evaluating the compression strength, unconfined compression strength test was carried out whereas for evaluating the settlement facet as well as the modulus of subgrade reaction and modulus of elasticity of soil, indigenously model plate load test was performed. The cement dosage for performing the unconfined compression strength test is fixed on basis of guidelines given in FHWA 13-046 Design Manual; on the other hand cement dosage for evaluating the settlement facet is done on the basis of CDM- LODIC method.

2 MATERIALS AND METHODOLOGY

2.1 Soil & Binder

All the experiments were carried out as per Indian Standards. Properties of low plastic soil investigated are tabulated in table 1 as follows:

Table 1 Physical Properties of Investigated Soil

Properties	Symbol	Results
Specific Gravity	G	2.7
Liquid Limit (%)	W _L	32
Plastic Limit (%)	W _P	21
Soil Classification (IS)	CL	Low Plastic Clay
Free Swell Index (%)	FSI	9.09
Cohesion (kg/cm ²)	C	0.5
Angle of internal friction (°)	φ	23
Optimum Moisture Content (%)	OMC	12.8

Maximum Dry Density (kN/m ³)	MDD	19.55
--	-----	-------

The soil was classified as low plastic clay as per Indian Standards with a clay content of 14.52%.

2.2 Binder

Microfine cement was employed as the binder material for strengthening of low plastic clay. In order to fill the gap of interaction between microfine cement and low plastic clay and also for properly strengthening of soil microfine cement is employed for the study.

2.3 Methodology

2.3.1 Deep mixing assembly

For fulfilling the purpose of deep mixing an assembly was fabricated which comprised of a solid shaft of 25mm diameter with perforations all around its circumference, a cutter blade with width of 50mm to facilitate drilling of 50mm diameter hole. Shaft was reduced to a diameter of 12.5mm at top in order to facilitate fixing of the assembly on the hand drill. Filling of the hole by cement slurry was commenced during the withdrawal of the assembly. The assembly consisted of an inlet at the top and perforations over the circumference of the solid pipe which proved to be advantageous in achieving the desired mixing between the soil and the cement slurry.

2.3.2 Sample preparation

Federal Highway Design Manual has provided with a standard curve between unconfined compression strength and total water to binder ratio. Using few of empirical relations as shown below in equations (1), (2) and (3) the cement dosage for required unconfined compression strength is obtained.

$$\gamma_{d,slurry} = \frac{G_b \times \gamma_w}{1 + (w:b)G_b} \quad (1)$$

$$VR = \frac{w \times \gamma_{d,soil}}{(wT:b) - (w:b) \gamma_{d,slurry}} \quad (2)$$

$$VR = \frac{\alpha}{\gamma_{d,slurry}} \quad (3)$$

In the above equations VR represents Volume Ratio; $\gamma_{d,slurry}$ is the unit weight of slurry; $\gamma_{d,soil}$ is the unit weight of soil; w:b presents water to binder ratio; wT:b is Total water to binder ratio; γ_w is the unit weight of water; α is cement factor giving the idea about the dosage of cement and G_b represents the specific gravity of binder.

The desired unconfined compression strength on field was taken to be 250kPa and as per guidelines provided by EuroSoilStab (2002) strength achieved by deep soil mixing technique on field is 50% to 80% of strength in laboratory, thus unconfined compression strength(UCS) of 400kPa was adopted for laboratory testing. The cement dosages obtained corresponding to the desired unconfined compressive strength for particular degree of saturation using equations (1), (2) and (3) as presented above are shown in Table 2.

Table 2 Cement dosages as per FHWA 13-046 guidelines

Degree of saturation (%)	$\gamma_{d,slurry}$ (kg/m ³)	VR	α (kg/m ³)
60	655.87	0.07	50.04
80	655.87	0.10	66.73
100	655.87	0.12	83.45

2.3.3 Preparation of soil bed and Installation

A tank of size 750mmX750mmX750mm was fabricated for the purpose of simulating the field condition in which the soil was filled as per the density corresponding to 90% of maximum dry density. The aluminum plate used as a foundation model can be concentrically loaded using the steel loading frame and mechanical jack, schematic diagram of the arrangement of

loading frame along with mechanical hydraulic jack and mechanical dial gauges is shown in Figure 1 below. Actual setup is presented in Figure 2 which shows the mechanical jack, proving ring with a capacity of 50kN, rod attached at the base of the proving ring which acts as a medium to transfer the load from mechanical jack to the aluminum footing model.

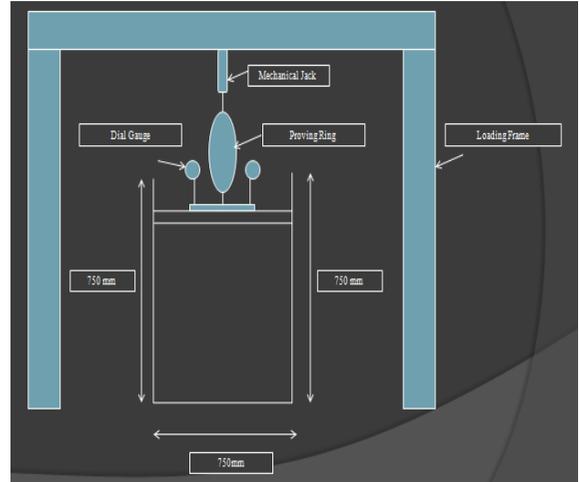


Figure 1. Schematic Diagram of Modeled Plate Load Test



Figure 2. Set-up of model plate load test.

2.3.4 Soil cement columns

Schematic plan of arrangement of soil-cement column is as shown in Figure 3. Figure 4 represents the drilled soil-cement columns in the fabricated tank. The cement dosages for a column length of 10cm, 20cm and 30cm on the basis of CDM-LODIC method are tabulated in Table 3.

Table 3. Cement dosage as per CDM-LODIC method

Soil-Cement Column Length (cm)	Cement Dosage (kg)
10	0.345
20	0.690
30	1.036

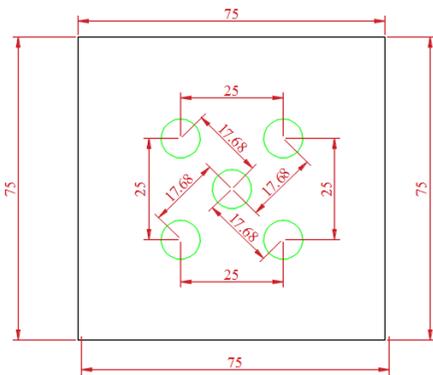


Figure 3. Schematic Plan for Soil-Cement Column arrangements.



Figure 4. Soil-Cement Column arrangements

2.3.5 Installation of columns

The soil-cement columns were installed as per the theory suggested by Kitazume and Tersahi, and the adopted theory behind fixing the arrangement of the column was also given by Kitazume (2002). Once the soil bed is prepared as explained in the above section, the centre of the column resting under the footing model is marked as corresponding to its position of rest of the four columns is fixed. These four columns are at an equal distance of 25cm centre to centre, whereas their distance from centre column is 17.68cm. After marking of the centre's of columns hand drill is fixed on the assembly in order to facilitate drilling of the hole of desired diameter and desired length, once the length is reached, soil mass from inside of the column is removed and weighed. A weight of cement equal to the weight of soil removed is mixed with desired amount of water as per the water to cement ratio which is fixed as 1.2 in the present study and the slurry so prepared is poured into the inlet provided at top of assembly.

2.4 Procedure

The load was applied on to the soil with the help of mechanical jack and the settlement readings were noted using mechanical dial gauges. In case of untreated soil, load was applied up to reaching the settlement of 25mm, whereas in case of untreated soil the loading was commenced up to the time when it becomes difficult to rotate the mechanical jack. In the end, results of both untreated as well as the soil treated at different degrees of saturation and with different soil-cement column lengths were compared for the purpose of studying the change in behavior of settlement as well as to evaluate and compare the modulus of subgrade reaction and modulus of elasticity of both treated as well as untreated soil. Further to The soil-cement columns were extracted post testing of the treated soil in order to study the changes in that have taken place in the soil-cement column under the application of load as well as to have an idea regarding its horizontal as well as vertical

zone of influence. While extracting soil-cement columns it was found that all the five columns were connected to each other although they were apart by a minimum distance of 17.68cm and a maximum distance of 25cm. On extracting individual columns with care such that there is no breakage in the column, it was found that a column of diameter 5cm while installing, had a diameter of 17.5cm at its base which is nearly 3.5 times its original diameter.

3 RESULTS, ANALYSIS AND DISCUSSION

3.1 Strength of Treated Soil

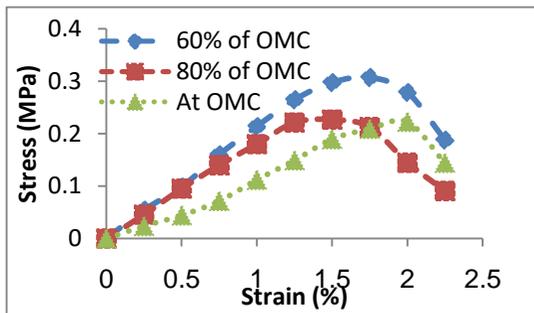


Figure 5. Stress-strain relationship for various Sr

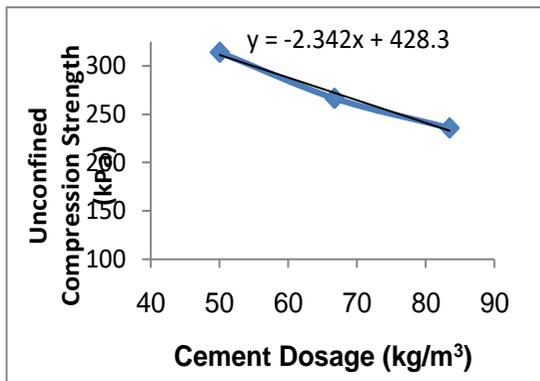


Figure 6. Relation between cement dosage and unconfined compression strength

Unconfined compression strength of treated soil under varying degree of saturation at 28 days can be related to cement dosage by equation (4). However this relation is applicable only when the cement dosages are fixed on basis of

moisture content of soil corresponding to desired degree of saturation.

$$q_u = -2.342CD + 428.3 \quad (4)$$

Table 4. Unconfined Compression Strength of treated soil for different Degree of Saturation

Degree of Saturation (%)	Cement Dosage (kg/m ³)	Unconfined Compression Strength (kPa)
60	50.04	314.03
80	66.73	266.36
100	83.45	235.76

As a strength of 250kPa was fixed as desired strength and based on field efficiency criteria as suggested by EuroSoilStab (2002) the laboratory strength was fixed as 400kPa and cement dosages were evaluated on basis of guidelines provided in FHWA 13-046 and are presented in Table 2, the unconfined compression strength values of treated soil at various degree of saturation are shown in Table 4 and it can be seen that strength reduces with increase in degree of saturation, but when soil is at its optimum moisture content the strength even reduces below the required strength on field. Thus, compacting and treating the soil on dry side of its optimum provides better results.

3.2 Settlement analysis

Results from plate load tests indicated a reduction of 80% in settlement in treated soil as compared to untreated soil. The final values of settlement at the same load for untreated and treated soil are tabulated in Table 5.

Table 5. Settlement values for untreated and treated soil under same loading condition

Degree of Saturation (%)	Soil-Cement Column length (cm)	Settlement (mm)	% reduction in settlement
At OMC	None	29.523	None
Untreated	60	4.915	83.35

(Treated)	20	3.085	89.55
	30	6.5	77.98
80	10	5.42	81.64
(Treated)	20	3.89	86.82
	30	6.702	77.29
At	10	6.03	79.57
OMC	20	4.26	85.57
(Treated)	30	7.31	75.23

It can be seen from table 5 that for soil-cement column length of 30cm and diameter as 5cm leads to length to diameter ratio of 6 the settlement values are higher as compared to that of rest of treated soil-cement column lengths. Better results were obtained at a lower degree of saturation and for a soil-cement column length of 20 cm.

3.3 Evaluation of modulus of subgrade reaction and modulus of elasticity

Modulus of subgrade reaction was evaluated by taking in reference the methods provided in IS 9214:1979. Two empirical relations shown in equation (5) and (6) were used for evaluating the modulus of subgrade reaction and least of the two values among them were adopted as final value.

$$k = \frac{P}{0.125} \quad (5)$$

$$k = \frac{0.7}{d} \quad (6)$$

For evaluating modulus of elasticity of soil two empirical relation on basis of elastic theory, this relation is represented in equations (7).

$$k = \frac{4E}{\pi D(1-\mu^2)} \quad (7)$$

The values of modulus of subgrade reaction and modulus of elasticity evaluated using above empirical relations are tabulated in Table 7 below. It can be seen from the tabulated values that at a lower degree of saturation modulus of subgrade reaction as well as modulus of

elasticity of treated soil have higher values for a given column length.

Table 7. Comparison of Modulus of Subgrade reaction and Modulus of Elasticity

Degree of Saturation (%)	Soil-Cement Column Length (cm)	Modulus of subgrade reaction k (kg/cm ² /cm)	Modulus of Elasticity E (kg/cm ²)
At OMC (Untreated)	None	4.44	47.59
60% of OMC (Treated)	10 20 30	7.38 7.70 5.63	83.46 87.08 63.67
80% of OMC (Treated)	10 20 30	7.40 7.69 5.33	79.33 82.44 60.28
At OMC (Treated)	10 20 30	5.03 5.33 5	53.92 57.14 56.55

4 VALIDATIONS

a) As per guidelines provided in FHWA HRT 13-046 the ratio of modulus of elasticity to unconfined compression strength of treated soil should lie in the range of 75 to 300. On evaluating the ratios of modulus of elasticity and unconfined compression strength of treated samples it worked out to be 77, 92 and 75 for 60%, 80% and 100% degree of saturation respectively.

b) Validation for bearing capacity was carried out using the empirical relation as suggested by Broms (2003) considering soil-cement columns as piles. Broms equation takes into account only the effect of degree of saturation and not of soil-cement column length. Bearing capacity of each soil-cement column obtained theoretically are 0.8847 kg/cm², 0.8750 kg/cm², 0.8688 kg/cm² for degree of saturation as 60%, 80% and 100% respectively, whereas the bearing capacity evaluated experimentally at same degrees of

saturation are 1.042 kg/cm², 0.968 kg/cm², 0.916 kg/cm². Figure 5.113 represents the comparison of experimentally evaluated and theoretically calculated bearing capacity at a particular degree of saturation. Experimental bearing capacity of a single column works out to be slightly higher than theoretical bearing capacity (Broms, 2003) for each degree of saturation.

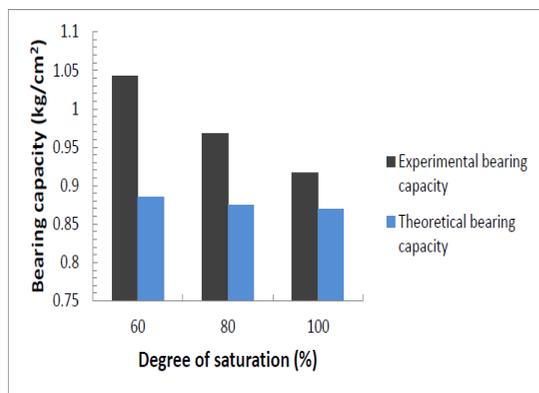


Figure 7. Experimental and theoretical Load carrying capacity v/s degree of saturation

5 CONCLUSIONS

Few of the important conclusions that can be derived from this study are summarized as follows:

- As the moisture content of the soil approaches the optimum moisture content, strength of the treated soil reduces.
- With increase in cement dosage, unconfined compression strength was found to be decrease, because quantity of cement dosage was totally dependent on moisture content pertaining to the required degree of saturation. As cement dosage increases, degree of saturation increases and thus strength reduces.
- For a given degree of saturation, with the increase in soil-cement column length, settlement decreases upto 30% to 35% and modulus of subgrade reaction increased by 5%

to 7% and modulus of elasticity increased by 4 to 6%.

- For a given soil-cement column length, with the increase in the degree of saturation of soil, the percentage reduction in settlement was 10% to 15% and modulus of subgrade reaction and modulus of elasticity was found to decrease by 45% to 50%.
- Soil-Cement column length of 30cm showed some unexpected results in which the settlement was less than that of untreated soil but 20% more settlement than column length of 10cm at same degree of saturation. Modulus of subgrade reaction and modulus of elasticity also reduced by nearly 20% to 25%. Thus, length to diameter ratio of 6 can be considered to be ineffective; however the study of length to diameter ratio post testing is also important.
- Thus, compacting the soil on dry side of optimum with length of soil-cement column such that length to diameter ratio of nearly 4 was found to be optimum.

It can be concluded that Cement Deep Mixing (CDM) technique when applied on low plastic soils subjected to variation in degree of saturation gives satisfactory results. Use of microfine cement as a binder for low plastic soils was found to be adequate for a suitable water to cement ratio selected. Various assumptions regarding the length of soil-cement column were made in the study due to lack of ample amount of Indian Codal guidelines on CDM technique. Thus indicating the feasibility of CDM technique as a modern ground improvement technique for low plastic soil especially when soil is compacted on dry side of optimum.

5 ACKNOWLEDGEMENTS

The authors are thankful to Dr. G. P. Vadodaria, Principal, L.D. College of Engineering, Ahmedabad for providing all the

research facilities required for the successful accomplishment of this project work.

for quality control and assurance of the deep mixing method

OanaCarasca (2016), Soil Improvement by mixing: techniques and performances, Energy Procedia, 85, pp. 85-92

6 REFERENCES

Bruce D. A. (2001), Practitioner's guide to deep mixing, Ground Improvement, 5(3), pp. 95-100.

Bergado D. et.al. (1996), "Lime/cement deep mixing method", Proceeding of soft ground improvement in Lowland and Environments, Rotterdam.

EuroSoilStab (2002), Design guide soft soil stabilization, CT97-0351

Mostafa A. Ismail et.al (2002), Effect of cement type on shear behavior of cemented calcareous soil, ASCE, 128(6), pp.520-529

Tersahi M. (2003) , The State of Practice in Deep Mixing Methods, Grouting and Ground Treatment (GSP 120) , 3rd International Specialty Conference on Ground Improvement and Treatment New Orleans. Louisiana, USA, pp. 25-49

Filz G. M. et.al. (2005), Standardized definitions and laboratory procedures for soil-cement specimens applicable to wet method of deep mixing, Geo-Frontiers Congress, ASCE, 162(1), pp. 1-13

Topolnicki, M.et.al, (2012), Novel Application of Wet Deep Soil Mixing for Foundation of Modern Wind Turbines. Grouting and Deep Mixing,ASCE, 228, Vol. 1, pp. 533-542.

Ahmed Farouk & Marawan M. Shahein (2013), Ground improvement using soil-cement columns: experimental investigation, Alexandria Engineering Journal. Elsevier, 52, pp. 733-740

Federal Highway Administration Design Manual: Deep Mixing for Embankment and Foundation Support (2013), FHWA-HRT-13-046

Masaki Kitazume et.al. (2015), Applicability of Molding procedures in laboratory mix tests