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Strengthening Low Plastic Soils Using Micro Fine Cement through Deep Mixing Methodology

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Abstract. Present research papers focuses to strength low plastic soil using deep cement mixing technique through model study. Soil column length of 10cm, 20 cm and 30cm was used with varying degree of saturation as 60%, 80% and 100% of OMC to determine settlement characteristics, unconfined compressive strength, modulus of subgrade reaction and modulus of elasticity of raw and treated soil. Cement dosage for UCS test and model plate load test was decided as per guidelines provided in FHWA 13-046 design manual and CDM-LODIC method respectively. Method of deep mixing the soil with cement was adopted from theory given by Filz et.al. (2005). The results depicted the cement deep mixing methodology based on soil particle-cement particle interaction with varying degree of saturation proved the efficacy for low plastic soils and maximum reduction in settlement was observed for 60% degree of saturation for column length of 20 cm. Modulus of elasticity was validated with provisions of FHWA whereas load carrying capacity of soil-cement column was validated with Broms empirical equation.

1 Introduction

Deep Soil Mixing technique was developed in 1970's in Japan and is now extensively used in countries like USA, France, etc. Deep soil mixing can be characterized into 23 different techniques like Cement Deep Mixing (CDM), Wet Deep Mixing Method (WDMM), Dry Deep Mixing Method (DDMM), etc. There is a difference between pressure grouting or jet grouting and wet deep mixing technique, in the former the binder is injected into the soil under a certain pressure head whereas in the latter the soil is filled under a certain static head and mixed under a particular rotational head depending on the degree of mixing as well as strength required as shown by Filz. [1].

The present research emphasizes on studying the effectiveness of cement deep mixing (CDM) technique on soil compacted at different degrees of saturation. The mechanical behaviour of strengthened soil varies considerably is greatly affected by method used for preparation of specimen [2]. CDM technique can further be classified into two different methods namely: CDM method and CDM- LODIC method, in the former the cement dosage is fixed as per strength requirement [3], whereas in the latter the cement dosage is fixed on the basis of weight of soil excavated from the hole drilled. 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 modelled plate load test was carried out. The cement dosage for performing the unconfined compression strength test was fixed on basis of guidelines given in FHWA 13-046 Design Manual [4]; on the other hand cement dosage for evaluating the settlement facet was on the basis of CDM- LODIC method.

2 Deep Mixing Technique & Materials

Topolnicki [5] classified the Deep Soil Mixing (DSM) technique in three levels taking into consideration dry and wet deep mixing method. These are mainly: (1) Mechanical, hydraulic or hybrid way of mixing; (2) position of mixing; (3) axis of rotation of the tool. The entire procedure of wet deep mixing mainly involves four stages; these can be summarized as follows:

(1) Insertion of temporary casing into the soil
(2) Introducing the tool into the installed casing
(3) Spreading of the tool and soil mixing
(4) Withdrawl of the assembly.

Commencement of the above four steps leads to the formation of a rigid soil-cement column which improvises the soil to a very great extent.

2.1 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

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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.

2.2 Soil and binder

Properties of low plastic soil investigated are tabulated in table 1 as follows:

Table 1. Physical properties of soil & binder

Properties	Results
Specific Gravity	2.7
Liquid Limit (%)	32
Plastic Limit (%)	21
Soil Classification (IS)	Low Plastic Clay
Free Swell Index (%)	9.09
Cohesion (kg/cm^2)	0.5
Angle of internal friction (°)	23
Optimum Moisture Content (%)	12.8
Maximum Dry Density (kN/m^3)	19.55
Microfine Cement	12000 SSA

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

2.3 Test set-up

Actual setup is presented in Figure 1 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 aluminium footing model.

Fig. 1. Model Test-setup and bores of soil-cement column

2.3.1 Preparation of soil-cement column

Water to cement ratio on the basis of trial and error was selected to be 1.2 since it provided a desired workable mix which can be easily poured into the inlet of the assembly. Five soil-cement columns were drilled and mixed among which four columns were spaced equally at 25cm centre to centre distance and one exactly under the footing. Soil-cement column had a fixed diameter of 5cm and length was varied as 10cm, 20cm and 30cm. Figure 5 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 2.

Table 2. Cement dosage as per CDM-LODIC method

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

2.3.2 Installation of soil-cement columns

The soil-cement columns were installed as per the theory suggested by Kitazume[1] and Tersahi[6], and the adopted theory behind fixing the arrangement of the column was also given by Kitazume [1].

2.3.3 Testing procedure

Testing was carried out on both treated and un-treated soil and results were compared. 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.

3 Results, Analysis and Discussion

3.1 Strength of Treated soil

Nine samples of unconfined compression strength were prepared and tested to study the effect of degree of saturation on effectiveness of Cement Deep Mixing (CDM) technique on unconfined compression strength of treated soil at a constant water cement ratio and varying cement dosages [8, 9]. The cement dosages varied along with the water content is obtained using empirical relations presented in FHWA 13-046 [4]. The unconfined compression strength of treated soil under varying degree of saturation at 28 days can be related to cement dosage by equation (1), however this relation between unconfined compression strength at 28 days and the cement dosage is applicable only when the cement dosages are fixed on basis of moisture content of soil corresponding to desired degree of saturation.

$$q_u = -2.342CD + 428.3 \quad (1)$$

As strength of 250kPa was fixed as desired strength and based on field efficiency criteria as suggested by Euro Soil Stab:2002 [7] the laboratory strength was fixed as 400kPa and cement dosages were evaluated on basis of guidelines provided in FHWA 13-046. The unconfined compression strength values of treated soil at various degree of saturation are shown in Table 3.

Table 3. Unconfined Compression Strength of treated soil for différent 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

3.2 Settlement of Treated soil

Changes in the settlement of treated soil as compared to that of untreated soil as well as to evaluate the modulus of subgrade reaction and modulus of elasticity of soil indigenously developed modelled plate load test was performed. An overall 80% of reduction in settlement was observed 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 4. Better results were obtained at a lower degree of saturation and for a soil-cement column length of 20 cm.

Table 4. Settlement values for untreated and treated soil under same loading condition

Degree of Saturation (%)	Soil-Cement Column length (cm)	Settlement (mm)	Percentage reduction in settlement
At OMC (Untreated)	None	29.52	None
60 (Treated)	10	4.915	83.35
	20	3.085	89.55
	30	6.5	77.98
80 (Treated)	10	5.42	81.64
	20	3.89	86.82
	30	6.702	77.29
At OMC (Treated)	10	6.03	79.57
	20	4.26	85.57
	30	7.31	75.23

It can be seen from the values tabulated above that for soil-cement column length of 30cm and diameter as 5cm which 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.

3.3 Effect of degree of saturation

The increase in degree of saturation for a particular length of soil-cement column the reduction in settlement decreases which confirms that soil compacted at dry side of optimum provides better result even for shorter length of soil-cement column. It should be however noted that no matter the settlement for soil-cement column length of 30 cm are higher than that of 10 cm and 20 cm but as degree of saturation was reduced from 80% to 60% the settlement for 30 cm column length also reduced.

3.4 Effect of soil column length

For a given degree of saturation with increase in soil-cement column length the reduction in settlement increases, however the results for soil-cement column length of 30cm were quite unexpected, at a given degree of saturation the settlement was no doubt much lesser than that of untreated soil but was greater than that of 10cm soil-cement column.

3.5 Evaluation of modulus of subgrade reaction and modulus of elasticity

After analyzing the reduction in settlement of soil under various conditions next parameters analyzed in this study are the modulus of subgrade reaction and modulus of elasticity of soil. Modulus of subgrade reaction was evaluated by taking in reference the methods provided in IS 9214:1979. For evaluating modulus of elasticity of soil two empirical relation on basis of elastic theory, this relation is represented in equations.

$$k = 4E/\pi d(1-\mu^2) \quad (2)$$

$$k = 0.65\ E/(B(1-\mu^2) * (B*E/EI)^{1/12} \quad (3)$$

The values of modulus of subgrade reaction and modulus of elasticity evaluated using above empirical relations are tabulated in Table 5 below.

Table 5. Modulus of subgrade reaction and modulus of elasticity of treated soil

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 (Treated)	10	7.38	83.46
	20	7.70	87.08
	30	5.63	63.67
80 (Treated)	10	7.40	79.33
	20	7.69	82.44
	30	5.33	60.28
At OMC (Treated)	10	5.03	53.92
	20	5.33	57.14
	30	5.00	56.55

4 Summary of findings

The following summary of findings has been summarized as under:

- 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 reduce, the main reason behind this being increase in cement dosage was totally dependent on moisture content pertaining to the required degree of saturation, and since with increase in degree of saturation strength reduced it followed the same trend with cement dosage as well.
- For a given degree of saturation of the soil, with the increase in the soil-cement column length about 30% to 35% more reduction in settlement was observed.
- For a given soil-cement column length, with the increase in the degree of saturation of soil, the percentage reduction in settlement was recorded to decline by 10% to 15%.
- At same degree of saturation, with the increase in the soil-cement column length modulus of subgrade reaction was found to increase by 5% to 7%
- For the same column length, with decrease in degree of saturation modulus of subgrade reaction was found to increase by 45% to 50%.
- For the same column length, with decrease in degree of saturation modulus of elasticity of soil was found to increase by 45% to 50%.
- At same degree of saturation, with the increase in the soil-cement column length modulus of elasticity of soil was found to increase by 4% to 6%.
- Soil-Cement column length of 30cm showed some unexpected results in which the settlement although was lesser than that of untreated soil but it showed about 20% more settlement than column length of 10cm at same degree of saturation
- Modulus of subgrade reaction and modulus of elasticity of soil treated using a soil-cement column length of 30cm also reduced by nearly 20% to 25%.
- 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.
- The difference in values of modulus of subgrade reaction of soil compacted with a moisture content corresponding to 60% and 80% saturation was negligible, however value of modulus of elasticity showed a little difference.
- 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.
- Validation for bearing capacity was carried out using the empirical relation as suggested by Broms [10] 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 0.885 kg/cm^2, 0.875 kg/cm^2 , 0.869 kg/cm^2 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/cm^2, 0.97 kg/cm^2, 0.92 kg/cm^2.

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 thus 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 particular Indian Codal guidelines on CDM technique, the assumptions made provided adequate results except that for soil-cement column length of 30cm, 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.

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