Triaxial Compression Test Results on DMC Samples Prepared by Using Different Soil Types

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Abstract: In this study, the effects of cement, fly ash and super plasticizer, improver materials by adding into the grout, on soil-binder mixing columns called as deep mixing columns (DMC) are investigated. Fly ash is a waste product emerging from burning in the thermal power plant. By evaluating waste materials in this way, environmental pollution will be reduced directly and cement usage and carbon emissions caused by cement production will be reduced indirectly. By using super plasticizer into the grout, less porous and permeable elements with more structural strength will be manufactured. In order to achieve these goals, an experimental program was developed using statistical and experimental design methods. It is desired to determine the optimum grout quantity and consistency required to maximize the strength of the column manufactured with DMM in silty soils and silty sands. For this purpose, the amounts of fly ash (0-40%), cement (3-11%), super plasticizer additive (0.5-2%) and water/binder percentage (0.5-1.25%) were chosen as variables to form grouting material. Experimental studies have been carried out using Taguchi method, which is a powerful optimization technique, using 5-parameter and 4-level L16 design table. Undrained-unconsolidated triaxial test specimens were prepared in PVC tubes with diameter of 47 mm and length of 100 mm for each design for curing time of 28 days. As a result of the experiments, deviator stress of the soil-binder mixture was found for each design.

Keywords: Cement, deep mixing method, fly ash, super plasticizer, Taguchi method, silty soil.

1. INTRODUCTION

The deep mixing method (DMM) has been used frequently in the construction industry since 2000, especially in the soil improvement work. DMM is an in situ soil treatment technology whereby the soil is blended with cementitious and/or other materials. These materials are widely referred to as “binders” and can be introduced in dry or slurry form. They are injected through hollow, rotated mixing shafts tipped with some type of cutting tool. The shaft above the tool may be further equipped with discontinuous auger flights and/or mixing blades or paddles. These shafts are mounted vertically on a suitable carrier, usually crawler-mounted, and range in number from one to eight (typically two to four) per carrier, depending on the nature of the project, the particular variant of the method, and the contractor. Column diameters typically range from 0.6 to 1.5 m, and may extend to 40 m in depth. In some methods, the mixing action is enhanced by simultaneously injecting fluid grout at high pressure through nozzles in the mixing or cutting tools. The cemented soil material that is produced generally has a higher strength, lower permeability, and lower compressibility than the native soil, although total unit weight may be less. The exact properties obtained reflect the characteristics of the native soil, the construction variables, the operational parameters, and the binder characteristics.

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The most important point in soil remediation work using deep mixing method is to homogenously mix the binder with the ground as well as the one with suitable consistency. For this reason, many studies have been carried out in order to determine the optimum construction parameters (the amount and the consistency of binder and the system parameters). Farouk and Shahien (2013) [1] produced deep mixing column (DMC) in silty sand soils with a water/cement ratio of 0.8, 1, 1.25 and 1.5, with a cement dosage of 150-450 kg/m^3. Strength values range from 3-3.5 MPa with decreasing water/cement ratio. Pye *et al*. (2012) [2] have improved the high plasticity clayey soil under the railway with DMM. As the cement dosage is 275 kg/m^3, the mixing blade is manufactured with at least 200 turns in the meter within the soil. The soil strength before the improvement was between 15-50 kPa, while the strength of the improved soil was 300-500 kPa. Lorenzo and Bergado (2006) [3] mixed high plasticity clayey soil by adding 5-20% cement. In the study, the water/cement ratio is selected as 0.6. The researchers performed physical properties, free pressure resistance, consolidated-undrained triaxial shear and consolidation tests on the improved soil. Horpibulsuk *et al*. (2005) [4] conducted a soil improvement study on a high plasticized clayey slope with clay-water cement ratio of 7.5, 10 and 15. At the end of the study; it has been determined that the minimum amount of binder required to provide the necessary cementing at the end of a certain curing period varies with the microstructure of the clay. Deng *et al*. (2015) [5] have used metakaolin

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to reduce hydraulic permeability to treated cement. The researchers have added 12-15% of cement and 1-5% of metakaolin in wet plastics with a 70% water content, and have developed relationships between permeability and void ratio. Pakbaz and Farzi (2015) [6] have improved both wet and dry mixing methods by adding lime and cement in 2, 4, 6, 8 and 10% ratios to bentonite-sand mixture. In the experiments made with cement, the wet method gave greater strength than the dry method but mixing with lime had the opposite effect. Kang *et al*. (2017) [7] had used high plasticity clayey soil extracted from the sea floor; mixed at water content of 1.5 and 2 times of liquid limit, and 10-30% cement added. As a result, they investigated how the strength (q_u) and stiffness (G) parameters change with curing time (5 hours - 90 days). They have improved their relationship for short-term cure periods and long-term cure periods. Madyannapu *et al*. (2010) [8] produced DMC on a high plasticity clayey ground. The design parameters are as follows: The binder (water/binder=1) containing 3% lime and 9% cement was injected into the soil with a volume of 0.078 m^3 per minute. The entrance speed of the mixing tool into the soil was 76 cm/min and the rotation speed was 40 rpm. The elastic modulus and strength values of the samples prepared in the laboratory were found to be 30-60% and 20-30% higher than the values in the field, respectively. Kitazume *et al*. (2015) [9] have prepared DMC samples with 12 different soils and 5 different moulding techniques (stump, rodding, dynamic and static compaction and uncompressed situation), and as a result they have examined how the strength and density values are affected by the moulding style. It has been observed that the moulding techniques, according to the type of binder, significantly influence the results.

Then the above studies are taken into consideration; the column performance is obtained with respect to the type of soil, the type of binder, the amount and the consistency of binder and the systematic parameters that are selected during the production of the column are variable.

2. MATERIALS AND METHODS

2.1. Materials

In the scope of this study, DMC samples were prepared using four soils which have different grain size distribution. Soil A, obtained from Doğanhisar in Konya, has 27% fine sand and 73% silt. The liquid and plastic limits of the soil A were obtained as 23 and 11, respectively, and it was classified as low plasticity silty soil (ML) according to USCS. Soil B, C and D were obtained by adding 5%, 30% and 50% sand in the silty soil. Soils B and C had 30.5% and 43.8% sand, respectively, and they are classified as ML. Soil D has 51.3% sand and it was classified as silty sand (SM). Consistency limits of soils B, C and D are same as with the soil A. Grain size distributions of soils are given in Figure **1**.

Cement and fly ash are used as binding material in DMC manufacturing. CEM-I cement was used in the study. The fly ash was obtained from Seydişehir Eti Aluminum Plant. Fly ash consists of 16% sand and 84% silt. Fly ash is not included in class C or F due to the chemical components it contains and the amount of CaO is very high (Table **1**). BASF master Rheobuild 1000 superplasticizer additive was used to increase the consistency of the binder material.

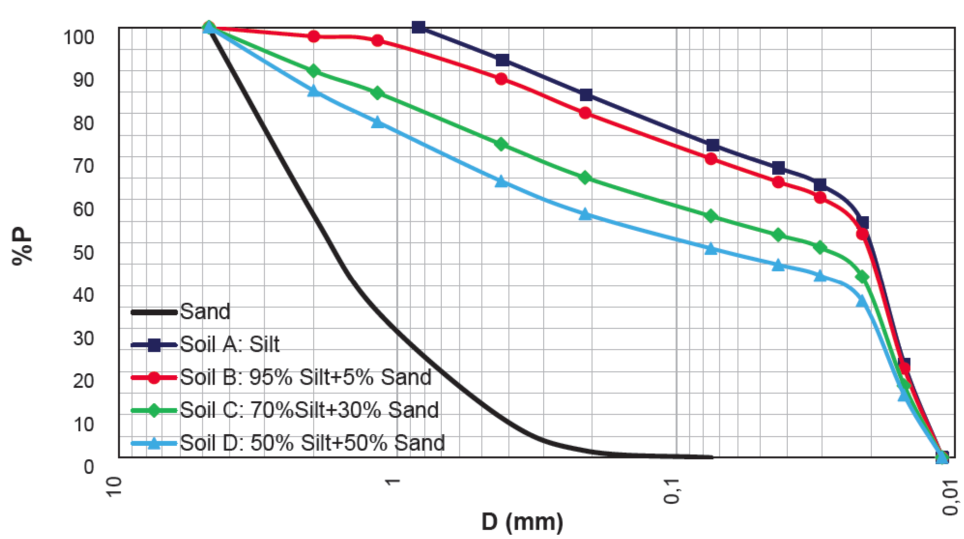

Figure 1: Grain size distributions of soils.

Table 1: Chemical Components of Fly Ash

Chemical component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Heat Loss	Free CaO
Fly ash (%)	19.8	8.1	6.0	28.3	1.0	18.2	0.4	0.1	1.8	16.3

2.2. Method

There are several approaches to designing any experiment and investigating the effects of the parameters on the results. In Taguchi method, this can be reached by using a suitable orthogonal array. In addition, maximum and minimum values can be estimated with other experimental results which have not been done, and the experimental cost can be kept to minimum with this method [10]. In this method, specially developed orthogonal array tables are used for designs. In this study, a 5-parameter and 4-level standard L16 orthogonal array table was used (Table **2**). In this study, parameters were chosen as the initial water content of soil (w_0), cement percentage, fly ash percentage, water/binder ratio and super plasticizer additive percentage. Parameters and their levels are given in Table **3**. Experimental results were evaluated by variance analysis (ANOVA) and optimization studies.

S/N ratio used in statistical analysis is determined by Eq. 1. The MSD value can be determined in cases where the target value is the largest, the smallest, and a specific value. Since the aim in the study is to obtain maximum strength, MSD value can be calculated by Eq. 2 so that the target value is the largest.

$$S/N = -10\log_{10}(MSD) \quad (1)$$

$$MSD = \left(\frac{1}{Y_1^2} + \frac{1}{Y_2^2} + \ldots + \frac{1}{Y_n^2}\right)/n \quad (2)$$

where, S/N is the signal to noise ratio, Y_1, …, Y_n values are the results of the experiment (analysis), n is the number of repetitions in an experiment.

When deep mixing samples were prepared, water corresponding to the initial water content of soil is first added to the soil and then mixed. Then injection material was prepared with mixture of cement, fly ash, super plasticizer additive and water. The injection material was again mixed with the previous mixture. The amount of cement and fly ash is calculated as the percentage of dry mass of the soil. The amounts of water and additives added to the injection are calculated on the basis of the amount of binder. Once a homogenous mixture has been obtained, the prepared mixtures are poured into PVC molds each of which has a diameter of 47mm and a height of 100mm. Deep mixing samples were cured in water bath at constant temperature for 28 days. At the end of the curing time, unconsolidated-undrained triaxial compression tests were carried out to determine the deviator stress (strength) of the deep mixing samples. During the tests, confining pressure (σ_3) was constant at 200 kPa for all designs.

3. TRIAXIAL COMPRESSION TEST RESULTS

Deviator stress (σ_1-σ_3) of DMC samples that were obtained from triaxial test results for all soil types at the end of 28 days curing time and the binder dosage for all designs are given in Table **4**. In the design of 4, strength is obtained maximum as 2814.3 kPa for soil A.

Table 2: L16 Orthogonal Array Table for Taguchi Method

Test No	Parameters and their levels					Test No	Parameters and their levels				
	A	B	C	D	E		A	B	C	D	E
1	1	1	1	1	1	9	3	1	3	4	2
2	1	2	2	2	2	10	3	2	4	3	1
3	1	3	3	3	3	11	3	3	1	2	4
4	1	4	4	4	4	12	3	4	2	1	3
5	2	1	2	3	4	13	4	1	4	2	3
6	2	2	1	4	3	14	4	2	3	1	4
7	2	3	4	1	2	15	4	3	2	4	1
8	2	4	3	2	1	16	4	4	1	3	2

Table 3: Parameters and their Levels Used in the Experimental Studies

Level	Parameter				
	A	B	C	D	E
	Soil water content (%)	Cement (%)	Fly ash (%)	Water/binder ratio	Additive (%)
1	15	3	0	0.50	0.5
2	19	7	10	0.75	1.0
3	23	11	25	1.00	1.5
4	27	15	40	1.25	2.0

In this design, cement and fly ash amount in the grout was maximum. Besides, water/binder ratio and additive amount were also maximum and well-mixed column samples can be obtained. In this design, moreover, binder dosage is 400.6 kg/m^3. For soil B, C and D, maximum stress is obtained in the design of 8. Strength value changes between 3500 kPa and 4379.5 kPa according to the amount of sand that was added into the silty soil. In this design, DCM samples consisted of 15% cement, 25% fly ash and 0.5% super plasticizer. In this design, water/binder ratio and binder dosage are 0.75 and 406.6 kg/m^3, respectively. Minimum strength values for DMC samples that were prepared by using the soils A, B and C were obtained as 50 to 250 kPa in the design of 1. In this design, levels of all parameters in the grout was minimum. Moreover, binder dosage in this design is as minimum as 54.4 kg/m^3. DMC samples prepared by using soil D has minimum 467 kPa strength in the design of 9. Variance of strength values according to grout contents and DMC samples that were prepared by using soils have different gradation as can be seen in Figure **2**. It is concluded that, in the designs of 2, 8, 12 and 14, maximum strength is obtained for all soil types (Figure **2**). In these designs, there was 7-15% cement, 10-25% fly ash and adequate amount of water and super plasticizer in the grout.

One of the interesting results obtained from triaxial compression tests is that the excess of binder dosage does not mean that the strength will be too high. For example, binder dosage in soil-binder mixture was maximum in the design of 7. However, stress values of DMC samples were 40-60% of maximum strength for each soil type. In design 7, there was11% cement and 40% fly ash but water/binder ratio was 0.75 and 1% super plasticizer existed in grout, which is not adequate to form well mixed DMC samples.

4. STATISTICAL ANALYSIS RESULTS

Optimum levels of parameters can be determined by doing S/N analysis which has a special calculation in Taguchi method and it can be done with using Minitab.

The most effective levels of parameters on triaxial compression test results are determined as 19% initial water content of soil, 7% cement, 10% fly ash, 0.75 of water/binder ratio and 1% super plasticizer amount for

Table 4: Triaxial Compression Test Results and Binder Dosage of DMC Samples

Test No	σ_1-σ_3 (kPa)				Binder dosage (kg/m^3)	Test No	σ_1-σ_3 (kPa)				Binder dosage (kg/m^3)
	Soil A	Soil B	Soil C	Soil D			Soil A	Soil B	Soil C	Soil D	
1	166.8	251.5	54.4	904.7	54.4	9	296.9	273.1	473.1	467.0	270.2
2	2458.4	1767.3	4024.7	3270.0	241.3	10	1007.8	1356.3	1449.0	1552.4	388.3
3	2030.4	2276.2	3565.6	2050.6	363.2	11	795.0	1367.3	1232.6	871.5	151.9
4	2814.3	1618.7	2140.5	2138.9	400.6	12	1569.4	2975.6	3044.6	3284.2	309.8
5	643.0	421.2	526.9	545.0	177.0	13	410.7	873.1	1202.4	581.8	394.4
6	486.3	626.6	913.2	607.5	103.4	14	1456.2	1839.9	2653.9	1997.4	356.1
7	1632.5	2289.8	2014.4	2404.5	526.9	15	779.7	1051.4	937.2	905.3	216.0
8	835.4	3769.8	4379.5	3502.3	406.6	16	412.9	1169.7	1165.9	898.6	177.7

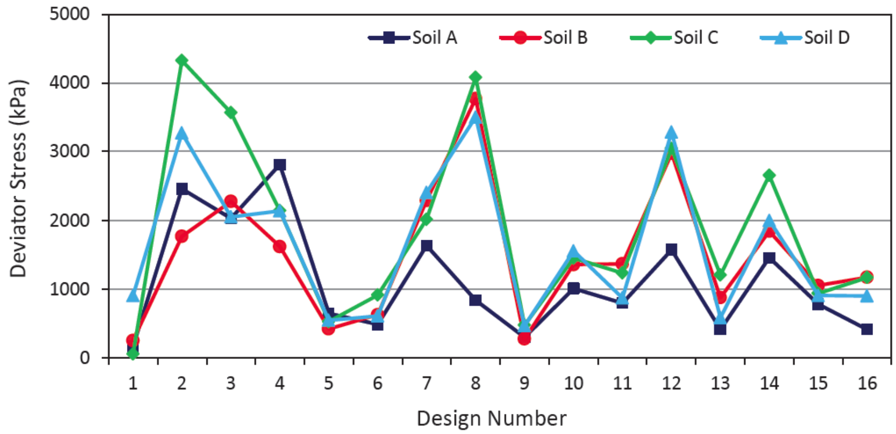

Figure 2: Variance of strength values according to grout contents and soil types.

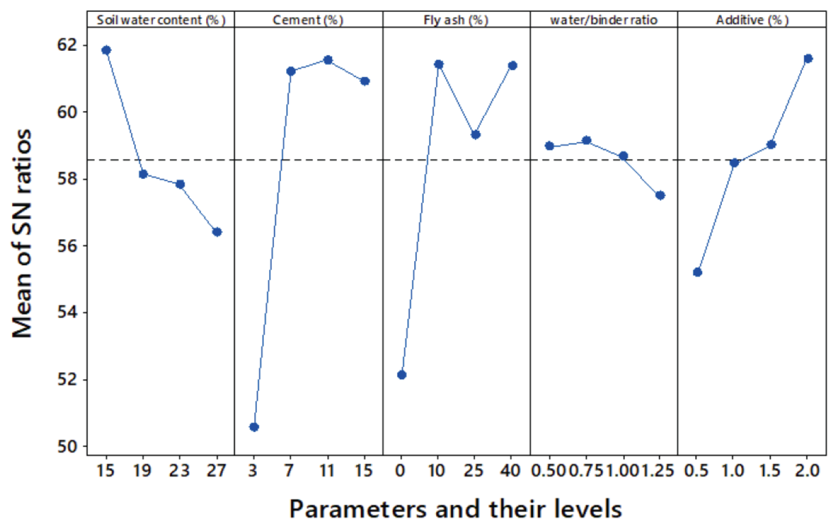

Figure 3: S/N analysis results for soil A.

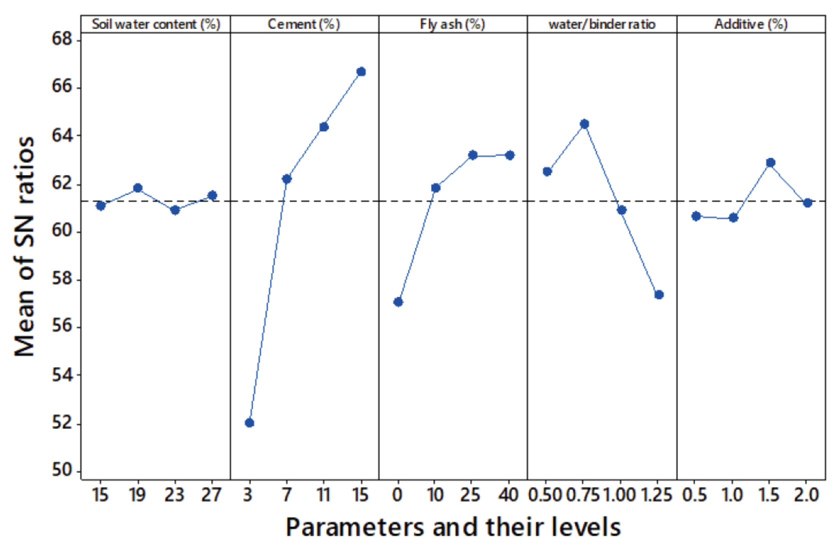

Figure 4: S/N analysis results for soil B.

at the end of 28 days curing time for soil A (Figure **3**) and soil B (Figure **4**). Degree of influence of parameters on strength values is same for soil A and soil B because grain size distributions of these soils are

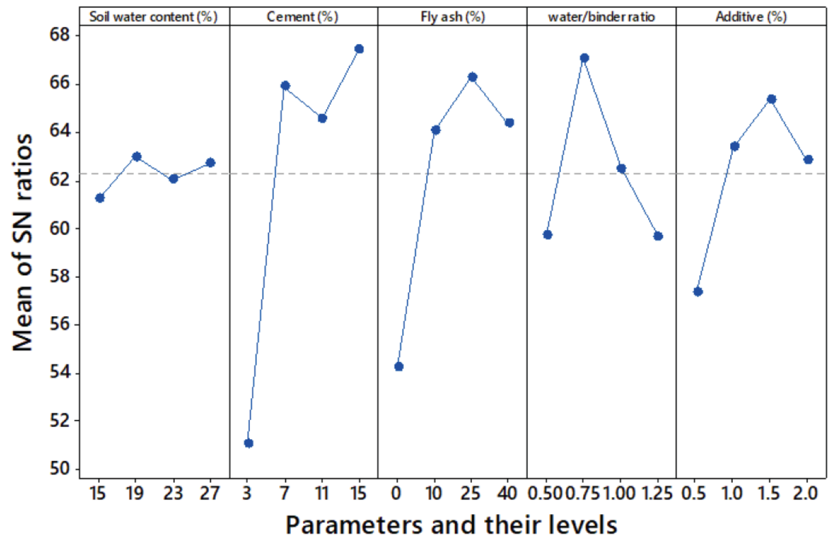

Figure 5: S/N analysis results for soil C.

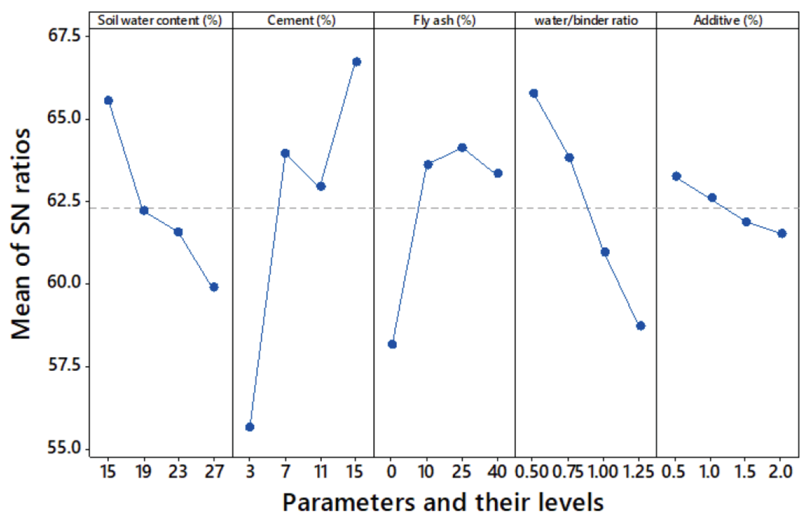

Figure 6: S/N analysis results for soil D.

close to each other. Moreover, it can be said that increasing the amount of cement and fly ash increases the strength of DMC samples and amount of super plasticizer while decreasing the initial soil moisture content and water/binder ratio. Above mentioned results are also valid for soil C (Figure **5**) and soil D (Figure **6**).

5. CONCLUSION

Experimental and statistical studies were carried out to investigate the strength parameters of deep mixing columns that were manufactured on silty soils. Experiments were carried out using a 5-parameter, 4-level Taguchi orthogonal array table with initial water content, fly ash and cement content, water / binder and superplasticizer additive percentage being variables in the study. As a result of the statistical analysis, the optimal value of DMC performance was obtained with 7% cement, 10% fly ash, 1% super plasticizer additive and injection material formed at 0.75% water/binder ratio. When a deep mixing column is manufactured, fly ash by that is a waste material can be used by keeping the amount of cement at 7%. Thus, an appropriate design is made for both column performance and economy aspects.

REFERENCES

[1] Farouk A, Shahien MM. Ground improvement using soil–cement columns: Experimental investigation. Alexandria Engineering Journal 2013; 52: 733-740. https://doi.org/10.1016/j.aej.2013.08.009

[2] Pye N, O'Brien A, Essler R, Adams D. Deep dry soil mixing to stabilize a live railway embankment across thrandeston bog. Grouting and Deep Mixing 2012; 2012: 543-553. https://doi.org/10.1061/9780784412350.0040

[3] Lorenzo GA, Bergado DT. Fundamental characteristics of cement-admixed clay in deep mixing. J Mater Civ Eng 2006; 18(2): 161-174. https://doi.org/10.1061/(ASCE)0899-1561(2006)18:2(161)

[4] Horpibulsuk S, Miura N, Nagaraj TS. Clay–water/cement ratio ıdentity for cement admixed soft clays. J Geotech Geoenviron Eng 2005; 131(2): 187-192. https://doi.org/10.1061/(ASCE)1090-0241(2005)131:2(187)

[5] Deng Y, Yue X, Liu S, Chen Y, Zhang D. Hydraulic conductivity of cement-stabilized marine clay with metakaolin and its correlation with pore size distribution. Engineering Geology 2015; 193: 146-152. https://doi.org/10.1016/j.enggeo.2015.04.018

[6] Pakbaz MS, Farzi M. Comparison of the effect of mixing methods (dry vs. wet) on mechanical and hydraulic properties of treated soil with cement or lime. Applied Clay Science 2015; 105-106: 156-169. https://doi.org/10.1016/j.clay.2014.11.040

[7] Kang G, Tsuchida T, Kim Y. Strength and stiffness of cement-treated marine dredged clay at various curing stages. Construction and Building Materials 2017; 132: 71-84. https://doi.org/10.1016/j.conbuildmat.2016.11.124

[8] Madhyannapu RS, Puppala AJ, Nazarian S, Yuan D. Quality assessment and quality control of deep soil mixing construction for stabilizing expansive subsoils. J Geotech Geoenviron Eng 2010; 136(1): 119-128. https://doi.org/10.1061/(ASCE)GT.1943-5606.0000188

[9] Kitazume M, Grisolia M, Leder E, Marzano IP, Correia AAS, Oliveira PJV, Åhnberg H, Andersson M. Applicability of molding procedures in laboratory mix tests for quality control and assurance of the deep mixing method. Soils and Foundations 2015; 55(4): 761-777. https://doi.org/10.1016/j.sandf.2015.06.009

[10] Shrestha R. Soil Mixing: A Study on 'Brusselian Sand' Mixed with Slag Cement Binder, Master Dissertation, University of Ghent 2008.

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