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Evaluation of Volume Compressibility Coefficient Variations Inlime-Cement Stabilized Bentonite Clay Using Wet and Dry Methods

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Abstract: According to the constituent materials of soil layers in the project area, different sites exhibit different behaviors towards compressibility. Mechanical and hydraulic behaviors of layers composed of coarse aggregates such as sand and gravel are very more predictable than those of layers composed of fine aggregates, especially clay. The settlement in such soils involves time parameters and it is possible to calculate and evaluate the parameters using the common tests in geotechnical engineering. The coefficient of volume compressibility is an important parameter for calculating the consolidation settlement of clay layers which can be calculated by means of the one-dimensional consolidation test device. In this study, 2, 4, 6, 8 and 10% of lime-cement at treatment times of 7, 14 and 28 days was used to stabilize the bentonite clay. All samples prepared by wet and dry method had the same moisture contents in the mentioned levels equal to the liquid limit moisture of the original soil. The studied soil falls in the group CH with the liquid limit of 132% based on the unified classification system. The results obtained in this study indicate that the changes in pressure applied on soil exhibit a significant impact on the performance of stabilizers and generally, the effects of wet and dry mixing methods on the coefficient of volume compressibility and consequently, on the settlement could be seen.

Key words: Stabilization, lime-cement, consolidation test, bentonite, coefficient of volume compressibility

INTRODUCTION

Soils are generally classified, according to different methods to fine-grained and coarse-grained ones. The major fine-grained soils are grouped into silts and clays that are mainly different in terms of cohesive and plastic properties of the clay. Clay is composed of a variety of minerals and different research has been done on the specific characteristics of the soil (Grabowska-Olszewska, 2003; Retnamony *et al*., 1998).

In terms of clay minerals in the soil, the values of exchangeable cations may change. The more the monovalent exchangeable cations in the clay soils, the higher the distribution of crystals and as a result, the particles become smaller and their Specific Surface Area (SSA) rises (Lan *et al*., 1995). Increase in the SSAand fineness of soil causes the changes in its hydraulic and mechanical properties including the plasticity ones such as liquid and plastic limits, coefficient of permeability and thickness of the double layer water around the clay particles (Mitchell and Kenichi, 2005).

Traditional additives such as cement, lime and some additives like bentonite (Kalkana and Akbulut, 2004) and silica (Ohtsubo *et al*., 2006) in research studies represent the effective role these additives play in reducing the permeability coefficient of clay and other mechanical and hydraulic parameters of soils stabilized with the stabilizing materials. Montmorillonite is one of clay minerals which due toits special properties such as the strong affinity to water absorption that increases its plasticity range is widely used in geo technical, environmental studies compared to another two commom clay minerals (Francisca and Glatstein, 2010). It is the main constituting part of bentonite.

Soil compaction and inflation does not change linearly or constantly and depends on the applied stress and current soil condition which by changing the stress, these parameters will also change (Atkinson, 2007). Another clay soil stabilization material is the rice husk ash which by increasing the level of this material, the decrease in the volume compressibility coefficientof these soils could be seen (Jain and Puri, 2013). Calculating the settlement is among the first phases in the design of structures. Calculating the settlement is further manifested when the soil needs to be modified. The coefficient of volume compressibility (m_v) can help to obtain the settlement:

$$\Delta H = mv.H_0.\,\Delta\sigma \quad (1)$$

According to Eq. 1, the consolidation settlement can be calculated using the volume compressibility coefficient. Given that in this study, the values of H_0 and $\Delta\sigma$ have been set as fixed in all samples, the consolidation settlement could be obtained by calculating m_v at any (wet and dry) mixing and a good comparison could be made on the effects of mixing methods. The following are some of the research that has been conducted in this context.

In a study on atype of peat having high settlement, moderate to low permeability and stabilized by cement, a consolidation test was done and the initial moisture content and void ratio was 668 and 9.33%, respectively. Comparing the results, the following can be noted: the coefficient of volume compressibility for the disturbed peatranges from 0.665-7.807 m^2/MN but after the stabilization, the range is reduced to 0.079-0.042 m^2/MN, representing the effect of stabilizing the peat with cement (Ali *et al.*, 2010).

In a study on the peat soil of Orumieh (Iran), it was observed that for a fixed vertical effective stress, the volume compressibility is increased by increasing the organic matter contents. On the other hand, the compressibility of the soil is reduced by increasing the vertical effective stress and the reduction level for soils with more organic matter content is higher.

In another study on a clay soil known as CL in the unified classification system, it was concluded that increasing the moisture content of samples from 27.20-51%, the coefficient of compressibility is also increased which it indicates the increased compressibility of the samples as a result of increasing the sample moistures but the rangeis declining by increasing the vertical stress.

In another study carried out on a clay with high plasticity and stabilized with the rice husk ash, the results show that in the samples with a fixed level of stabilizer, increasing the vertical effective stress reduces the coefficient of volume compressibility but by increasing the stabilizer, a clear trend in variations of this coefficient could not be seen, so that in some cases this coefficient is increased and in some other cases, it is reduced (Jain and Puri, 2013).

In another study on a peat stabilized with concrete columns, the result obtained from this study showed that by increasing the pressure and level of the stabilizer, the coefficient of compressibility is declined (Muntohar, 2004).

Furthermore, in a study on the impact of adding lime and rice husk ash on clay, it was found that increasing the stabilizer added to the clay may reduce the compressibility of the soil (Kazemian and Huat, 2009).

In the study conducted on the CL clay stabilized with rice husk ash in which the samples were prepared at three different moisture content (optimum moisture, 2% less than the optimum moisture and 2% higher than the optimum moisture content), the optimum moisture range of the study is from 16-24%. The stabilizers used in this study were first passed the sieve No. 200 then they added to the considered soil in different levels. The results obtained from this research showed that the variations in the coefficients of compressibility of samples were more regular than the increased pressure in the

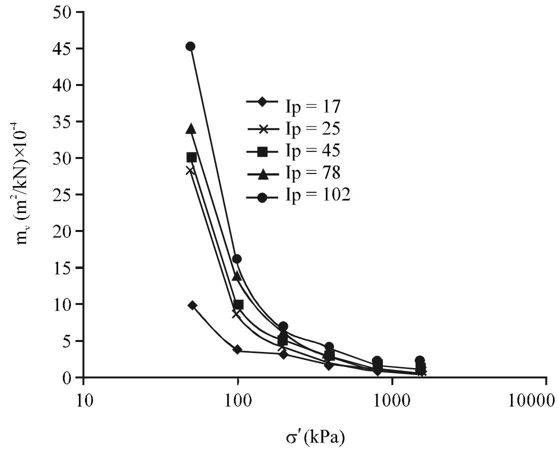

Fig. 1: Coefficient of volume compressibility versus effective stress for silty soil mixed with limestone bentonite

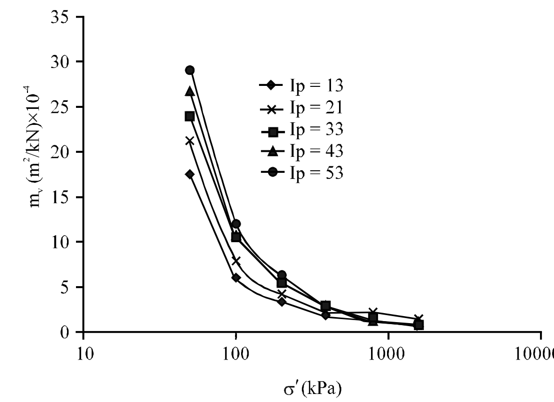

Fig. 2: Coefficient of volume compressibility versus effective stress for silty soil mixed with calcium bentonite

samples prepared in the optimum and less than optimum moisture contents, so that increasing the stabilizers can reduce the coefficient of volume compressibility but by increasing the moisture content and exceeding the optimum moisture, no regular trendin the coefficient changes can be seen in respect to the pressure (Eberemu, 2011).

In another study on the CL and ML soils stabilized with cement, some soil samples were mixed with different levels of cement and then, they were treated in 7, 14 and 21 days. It was concluded that as the stabilizers are increased, the coefficient of compressibility is dropped (Salman *et al.*, 2011).

In another study carried out on the sodium and calcium bentonite soils mixed with silt as part of the results is given in Fig. 1 and 2, the output emphasizes the highly dependent coefficient of volume compressibility to the applied load and the higher the value of plasticity index I_P, the more the coefficient of volume compressibility (Das, 2015).

MATERIALS AND METHODS

The soil that was used in this study consisted of a mixture of 60% commercial bentonite (wl = 255%, Ip = 122%) used in drilling and 40% local wind blown sand (D10 = 0.074 mm, D 60 = 0.2 mm, CU =2.4). The reason for using sand in the mixture was to reduce the time for primary consolidation of soil samples in the laboratory. The time for 90% consolidation (t 90) untreated mixture varied between 30 and 600 min depending on the stress level. The end of primary consolidation for untreated bentonite without sand was not measured. Liquid limit and plastic limit of the soil mixture were 132 and 70% respectively. All the samples prepared with initial water content equal to the base soil liquid limit. The reason for selecting initial water content of all samples as the liquid limit of the mixture was to have similar initial condition.

Another advantage of this combination is having a soil which in the Unified Classification System (USCS) is named CH and the reason to use wind blown sand in this combination is decreasing the liquid limit of bentonite and bringing the liquid limit of the soil to the desired level, another reason to use wind blown sand is the availability of this wind blown sand and the fact that it is very cheap. It is realized that in practice during wet method application higher initial water content than during dry method application before setting time may be achieved. The cement that was used was Type 2 cement manufactured in Karoon factory in Khuzestan. The lime that was used was of non-hydrated type and had chemical composition as shown in Table 1 (Das, 2015).

Table 1: Chemical composition of lime

Compositions	Composition content (%)
SiO_2	0.7
Al_2O_3+Fe_2O_3	1.3
L.O.I	26.4
CaO	71.1
MgO	0.5

Sample preparation: All specimens were prepared in the pvc molds of 5 cm in diameter and 16 cm in height. After curing of samples, specimens for consolidation tests were cut and prepared from original cured samples using wire saw (diameter = 5 cm, height = 3 cm). In order to eliminate any sample disturbance during the removal of the samples from the molds, the molds were cut longitudinally into two halves and the two halves were then taped back together stiffly before placing the soil samples into them. Before placing the soil samples into the molds, the bottom of the molds were sealed tightly with a thick plastic. In order to prevent the soil from sticking to the molds a plastic lining was placed inside the molds.

The soil samples after proper mixing were placed in to the molds with spatula in four stages. In each stage, after placing the soil in to the mold to a height of about 4 cm, the mold was tapped 40 times against the surface of the table from a height of about 10 cm. This was done in order to ensure removal of any air bubble trapped within the samples. The samples were then sealed and wrapped with a thick plastic and placed into a water tab for curing. After the curing period, each consolidation test specimen was cut and prepared from the original sample using awire saw.

Dry mixing method: In dry mixing method 2, 4, 6, 8 and 10% by drymass of lime-cement (in equal amount) were added dry to the soil samples prepared at the water content of 132% equal to the liquid limit of the soil and mixed thoroughly with spatula for 10 min before the soil mixture was placed into the mold. The samples were then cured for 7, 14 and 28 days before testing. For each group one consolidation test on the soil sample without admixture was also performed for comparison purposes.

Wet mixing method: In wet mixing method lime-cement (equal amount) in slurry form were added to the already wet soil in percentages of 2,4,6,8 and 10 by dry mass. The initial water content of mixtures was 132% the same as those for dry method. The samples for this series were also cured for periods of 7, 14 and 28 days before testing.

In the wet method, the ratio of 1-3 of water-cement-lime is used, a small amount of the primary water which must be added to the sample in order to make it reach the desired moisture is deducted and added to the cement-lime in order to make the cement-lime slurry.

RESULTS AND DISCUSSION

After doing the consolidation test and calculating the coefficient of volume compressibility for 1 and 2 kg/cm^2 pressure, the values of volume compressibility coefficient were plotted versus the different treatment time steps of 7, 14 and 28 days for this study to better control and evaluate the changes in the behavior of stabilizers and the mixture method and the results are shown in Fig. 3 and 4. The coefficient of volume compressibility for the initial soil is shown in Table 2.

According to the results shown in Fig. 3, it can be stated that in the pressure of 1 kg/cm^2 for 7days treatment period, the significant difference in the coefficient of volume compressibility was not seen but by increasing the treatment time at 14 and 28 days, the effect of mixing

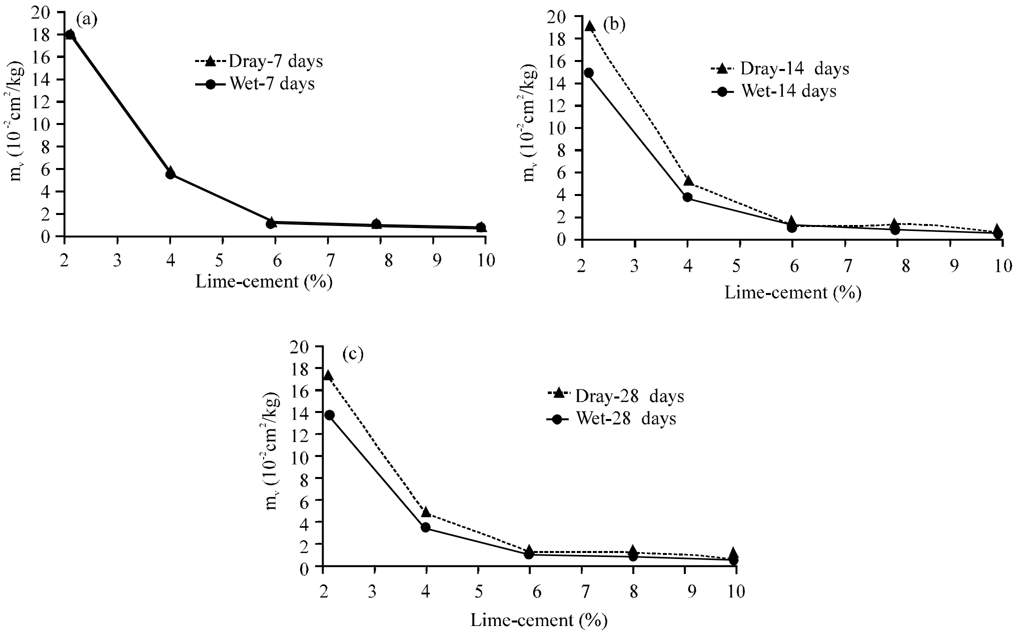

Fig. 3: Coefficient of volume compressibility for 7, 14 and 28 days treatments versus additive levels for 1 kg/cm^2 pressure; a) p = 1 (kg/cm^2)-7 days; b) p = 1 (kg/cm^2)-14 days; c) p = 1 (kg/cm^2)-28 days

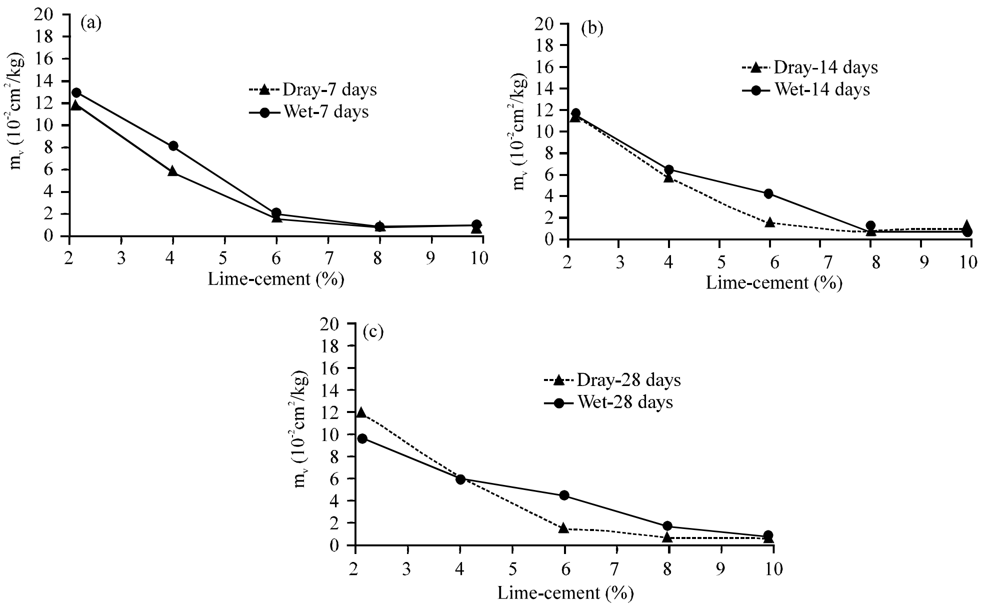

Fig. 4: Variations of volume compressibility coefficient for 7, 14 and 28 day treatments versus additive levels for 2 kg/cm^2 pressure; a) p = 2 (kg/cm^2) -7 days; b) p = 2 (kg/cm^2) 14 days; c) p = 2 (kg/cm^2) -28 days

Table 2: Specifications of compressibility coefficient of initial soil

P (kg/cm^2)	m_v (10^{-2} cm^2/kg)
1	21
2	15

method was visible so that the samples prepared by the wet method showed less volume compressibility coefficient than those prepared by the dry method. Another notable point seen from the results in the pressure of 1 kg/cm^2 is that for 14 days sample with 2% additives, there is 25% difference between the coefficients of volume compressibility in wet and dry samples (Fig. 4). However, by increasing the stabilizer, the sample results will show more convergence. According to the results shown in the Fig. 4, it can be said that in the pressure of 2 kg/cm^2, the sample behavior is quite different from 1 kg/cm^2 pressure, so that in this pressure, it is the dry samples that show less volume compressibility coefficient than the wet samples. Another result obtained from the 2 kg/cm^2 pressure is the similarity to the case with the pressure of 1 kg/cm^2 related to converging the results of mixing method to the increased stabilizers.

CONCLUSION

In general, according to the obtained results, it can be stated that: The mixing methodhas a direct effect on the coefficient of volume compressibility. The applied pressure affects on the performance of stabilizers in such a way that in the pressure of 1 kg/cm^2, the wet samples exhibit better results in reducing the coefficient of compressibility while as the load increases, the performance of stabilizing materials would change and the dry samples have less compression coefficient than the wet samples. By increasing the stabilizer level, the behaviors of both mixing types are similar to each other but in lower levels such as 2%, a 25% difference between the coefficients of volume compressibility can be seen.

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