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Laboratory Investigation of the Effect of Deep Soil Mixing Method on Engineering Properties of Soft Clay Stabilized by Slag and Lime

P. Rabbani, S. H. Lajevardi*
Department of Civil Engineering, Arak Branch, Islamic Azad University, Arak, Iran

ABSTRACT: Soft clayey soil generally has high compressibility and low strength. Presence of this soil type in the site of civil projects can always be a challenge. Soil stabilization is one of the useful ways to improve problematic soils. Cutter Soil Mixing (CSM) is almost a new method for deep stabilization. This laboratory study, investigate the effect of various depths of stabilization on the engineering properties of soft clay treated by CSM method. To prepare samples, simulate different depths and related overburden pressures new devices were designed, modified and made. Moreover, mixture of blast furnace slag and hydrated lime slurry was used in this method for the first time. Prepared samples were cured for 28, 56 days under saturated conditions, and various overburden pressures to investigate the effect of this stabilization method on physical and mechanical properties of them. The obtained results revealed that increasing the depth of stabilization decreases the moisture content of the samples, increases their saturated/dry densities and improves the strength parameters of them. Moreover, mechanical properties of the samples showed fewer changes by passing the specific depth.

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1. INTRODUCTION

Some soils types are not strong enough in terms of engineering characteristics to tolerate the overburden pressures apply from above construction. One of these soils type is soft clay. The most important minerals of clay are kaolinite, Illite and montmorillonite [1]. Using soil stabilization methods can be useful and very effective to improve the engineering properties of problematic soils. The Cutter Soil Mixing (CSM) method is a new and efficient way for deep stabilization of non-cohesive and cohesive soils. In this method, the process of treatment is completely different with other similar ones. This research investigates the effect of increasing the depth of soil stabilization on the engineering properties of soft clay treated by CSM method.

2. LITERATURE REVIEW

The CSM method involves mixing of cementitious self-hardening slurry with native soil, which finally leads to the construction of rectangular walls with up to 60 meters length inside the ground. The stages of construction CSM walls are as follow [2, 3]:

- Initial preparations and proper situation of the digging machine along with wall axis
- Conducting the cutter soil mixing tools into the ground with constant speed to reach the desired depth
- Lifting the mixing tools from the desired depth while pumping the self-hardening slurry to the soil until the whole tools are out of ground
- Placing the reinforcement elements into the wall if it is necessary

Chemical stabilization process starts immediately after constructing the CSM walls. Investigations show that pozzolanic additive like iron and steel slag can be used as stabilizer agent for soil improvement [4-6]. However, the chemical reactions of slag and soil are usually very slow. Therefore, use of lime as an activator can be a proper strategy to active the slag and speed soil-slag chemical reactions up [7-9].

3. METHODOLOGY

Materials used in this study are soft clay, air-cooled blast furnace slag (ACBFS) and industrial hydrated lime (IHL). The main characteristics of native soil are illustrated in Table 1.

Table 1. Native soil properties

Soil Properties	Value
Soil classification (USCS)	CL
Plastic limit (LL)	24.1%
Liquid limit (LL)	41%
Saturated density	1.76 gr/cm^3
Dry density	1.27 gr/cm^3
Unconfined compressive strength	1.17 Kg/cm^2
Compressibility index (Cc)	0.3

*Corresponding author's email: Sh-lajevardi@Iau-arak.ac.ir

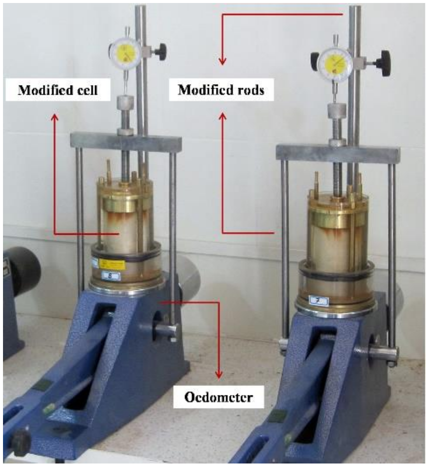

Fig. 1. Soil overburden pressure simulator

Table 2. Applied pressures and equivalent depths

Applied pressure (kg/cm^2)	Equivalent depth (m)
0	0
1	5.8
2	11.6
3	17.3
4	23.1

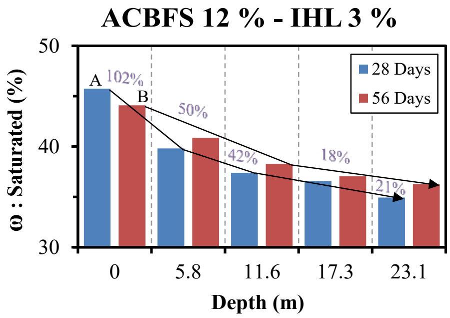

Fig. 2. Moisture content of treated samples

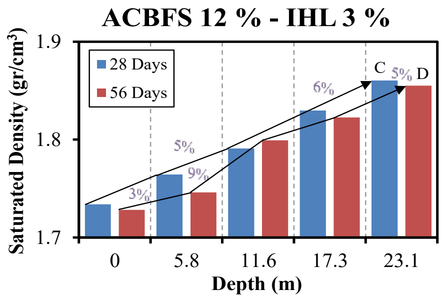

Fig. 3. Saturated densities of treated samples

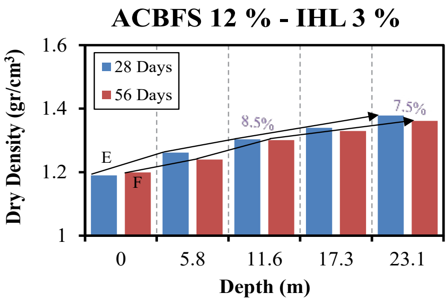

Fig. 4. Dry densities of treated samples

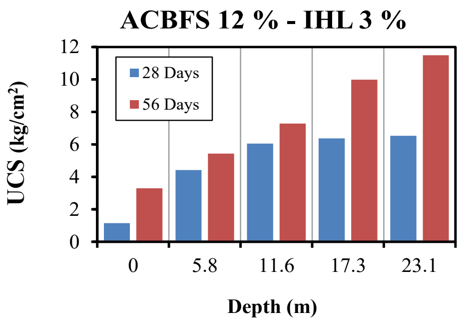

Fig. 5. UCS of treated samples

The chemical components of native soil and additives were determined as well. Main chemical compositions of soft clay are 65% of SiO_2 and 22% of Al_2O_3, while used slag mostly contains of 51% SiO_2 and 19% of Fe_2O_3 and hydrated lime consists of more than 90% of $CaOH_2$.

In order to simulate the effect of the depth of CSM method during stabilization process, new devices were designed and made as shown in Fig. 1.

To simulate soil saturation condition, moisture was added to the soil equal to 39% of soil dry weight. Then 12% of slag and 3% of lime were added to saturated soil in form of slurry. To prevent from the blockage of injection devices, water/additive ratio was considered equal to one [3]. At next step the mixture of soil and additives were poured into several layers in the mold. The saturated density of all prepared samples before loading were very close to each other and equal to 1.73 gr/cm^3. Finally, various vertical pressures were applied to the samples to simulate different depths (see Table. 2). All samples cured for 28 and 56 days.

4. RESULTS AND DISCUSSION

The effect of the depths and curing time on the moisture contents of treated samples are shown in Fig. 2.

Chemical and pozzolanic reactions between soft clay, slag, and lime as well as increasing overburden pressures has led to lower moisture content of the samples. The samples also showed a smooth surface with less obvious cavities by the end of curing time, which has effect on lower moisture content.

The effect of the depths and curing time on the saturated and dry densities of treated samples are illustrated in Figs. 3 and 4 respectively. It can be seen that the saturated and dry density of samples has increased in the depth. Presence of slag and applying overburden pressures increase the dry density of the samples while lime and water decrease the mixtures densities due to their low density. However, the effect of the first two agents was slightly more in this study.

The effect of the depths and curing time on unconfined compressive strength (UCS) of treated samples are shown in Fig. 5. The maximum observed UCS was related to the 56 days cured sample consists of 15% additives and located in the depth of 23.1 meters.

5. CONCLUSIONS

To investigate the effect of deep soil mixing method on the engineering properties of soft clay stabilized by slag and lime several experimental tests were conducted and the following conclusions were drawn from the results:

The moisture content of CSM walls is not constant in the depth and its change has significant effect on other engineering properties of the samples. For the treated samples consist of 12% slag and 3% lime, the depth of 11.6 meter has found and introduced as a critical depth in which the highest rate of moisture content changes occurs from surface to that depth.

The saturated and dry density of cured samples has increased in the depth at almost a constant rate. Therefore, the density of a CSM wall is not fixed in the depth. The results also showed that increasing curing time from 28 to 56 days does not have significant effect on changing the saturated and dry densities.

Using deep soil mixing method has significant effect on increasing the unconfined compression strength of the treated samples.

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