Study on the Performance of Lime Column Technique for Treatment of a Na-Bentonite Clay

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Abstract. Lime column technique is one of the common methods which are used in order to treat swelling soils. The improvement mechanism of lime columns is based on reactions between lime and clay as a result of ion migration from the column. In this study, the performance of lime column technique on treatment of a Na-bentonite clay was investigated. For the purpose of the study, a laboratory model study was conducted. In the model, the column diameter was chosen 50 mm and a curing time of 60 days was considered. At the end of the curing time, free swelling tests were performed on the specimens extracted from different distances to the column in order to determine the changes on swelling behaviour of the bentonite. According to test results, a treatment distance of 50 mm was achieved and an improvement of 46.36% was obtained within the distance of treatment. The results of this study show that the most appropriate soils for lime column technique are the soils which have high permeability and contain a considerable amount of tree-layered clay minerals (such as Na-smectite).

1. Introduction

Swelling clays are problematic soils in terms of geotechnics and it is important to take appropriate precautions in order to minimize the problems they caused. Solutions like replacing swelling soil with a more suitable one or changing construction site may not be usually economical. Stabilization of soils some additives like lime, cement, fly ash is generally more economical. The best and more common stabilizing agent in literature is lime. In order to stabilize a soil with lime, lime is mixed with the soil or lime columns are built in the field. To building lime column, a hole is created in the ground and the hole is then filled with lime. The main improvement mechanism of lime column is based on migration of Ca$^{2+}$ and OH$^{-}$ ions from the column to the surrounding soil. As ions migrate into the soil, some reactions occur between lime and soil. The first reaction is cation exchange which takes place between Na$^{+}$ cations in the clay and Ca$^{2+}$ cation in the lime. Cation exchange reactions cause the soil to have a less swelling potential. Cation exchange reactions are followed by pozzolanic reactions which take place in a long period and cause the soil to have more strength [1]. The aim of this study is to investigate lime column performance on stabilization of a bentonite clay which has a very high swelling potential.

2. Materials and Methodology

In order to determine the properties of the bentonite, XRD (X-Ray Diffraction) analysis, grain size distribution analysis, Atterberg limits test, standard compaction test and free swelling test were performed on the bentonite. Lime column performance on the stabilization of the bentonite was determined by making a model in the laboratory. In order to determine the changes on the swelling...
behaviour of bentonite, free swelling test were performed on the samples extracted from different distances to the column by using a test apparatus which was created in this study.

2.1. Properties of used bentonite and lime
Bentonite used in the study was obtained from a clay pit located in Tokat (Turkey). The lime used is a slaked lime which was obtained from a lime pit located in Tokat (Turkey). X-Ray diffractograms of the bentonite were given in Figure 1. According to X-Ray diffractograms, present minerals in the bentonite are clay, quartz, calcite and felspar. Average semiquantitative Na-Smectite content of bentonite was detected as 89%. This value shows that the bentonite used has a very high swelling potential.

![Figure 1. X-ray diffractograms of bentonite: (a) bulk (whole) sample [2]; (b) clay fraction](image)

Physical properties of bentonite were given in Table 1. Bentonite used has a high plasticity index and its soil class was determined as CH (high plasticity inorganic clay) according to Unified Soil Classification System (USCS). Also, according to the classification proposed by Skempton [3], the bentonite falls into the class of active clay.

| Property          | Value   |
|-------------------|---------|
| Liquid limit (%)  | 269     |
| Plastic limit (%) | 34.72   |
| Plasticity index (%) | 234.28 |
| Soil class (USCS) | CH      |
| Specific weight   | 2.40    |
| Activity          | 2.34    |
| Maximum dry density (kN/m³) | 10.98 |
| Optimum water content (%) | 42     |
| Free swelling percent (%) | 25.18 |

Swelling potential of the bentonite was determined by using a test apparatus which was created in the scope of this study. The test apparatus created has the same properties of oedometer test apparatus, however a metal tube was used instead of a consolidation ring and the soil sample was not loaded with any pressure. Materials of the test apparatus were shown in Figure 2.
Figure 2. Materials of the test apparatus created for free swelling test

Swelling test were performed on the cylindrical sample extracted from the bentonite which was compacted in its optimum water content. The cylindrical sample was extracted by using a metal sampling tube which was 50 mm in diameter. After extruding the soil sample from the sampler, its height was adjusted to 20 mm by cutting it carefully. The soil sample was then placed into the metal tube. Porous stones were centered on the top and bottom surfaces of the sample and filter papers were placed between porous stone and the sample. The metal tube was then centered in a CBR mould and a strain meter was then placed on the top of the mould. A glass pipe was placed between the strain meter and the specimen to allow the strain meter to get the changes on the height of the specimen. A device with a hole on the its center was used to allow the glass pipe to stay vertically. A top and side view of the test apparatus created was shown in Figure 3. After creating the test apparatus for bentonite, the sample was cured for 2 weeks. At the end of the curing time, the change on the height of the sample was measured by using the stain meter and free swelling percent of the bentonite was calculated using following equation:

\[ FS = \frac{(V-V_0)}{V_0} \times 100 \]  

where FS is free swelling percent, \( V_0 \) is the first volume of the specimen, V is the final volume of the specimen.

2.2. Building of the laboratory model

In order to build the laboratory model, the bentonite was compacted in 15 cm by height, in a box with dimensions of 20 x 30 x 45 cm. The compaction was performed in optimum water content with standard compaction energy. In order to form lime column, a hole was created with diameter of 5 cm in the corner of the box using a sampler. The hole was then filled with slaked lime. A hollow polyvinyl chloride (PVC) pipe was installed on the top of the column and water was introduced into this pipe during the curing time in order to allow ion migration.
Previous studies on the lime column technique suggested that the curing time must be between 28 days and 2 years (Ruenkrairergsa and Pimsarn [4]; Rogers and Bruce [5]; Rogers and Glendinning [6]). In this study, considering the studies which were conducted by Rogers and Glendining [7] and Tonoz et al. [8], the curing time was chosen as 60 days. A section of the model created was shown in Figure 4.

3. Results and discussions
At the end of the curing time, specimens were extracted from different distances to the column by using sampling tubes with inner diameter of 50 mm. The sampling method was shown in Figure 5.
Figure 5. The sampling method

Free swelling tests were performed on the specimens extracted in order to determine the changes on swelling behaviour of the bentonite. The results obtained and the change on swelling values with distance to the column were given in Table 2 and Figure 6, respectively.

Table 2. Free swelling percent of the specimens extracted at different distances from lime column.

| Distance to lime column (mm) | Untreated bentonite | 0-50 | 25-75 | 50-100 | 75-125 | 100-150 | 125-175 | 150-200 | 175-225 | 200-250 |
|-----------------------------|--------------------|------|-------|--------|--------|---------|---------|---------|---------|---------|
| Free swelling percent (%)   | 25.18              | 14.01| 19    | 25.15  | 25.09  | 25      | 25      | 25.09   | 25.13   | 25.01   |

It can be seen from Table 2 and Figure 6 that free swelling percent of bentonite decreased until a distance of 50 mm from the column. After this distance, swelling values obtained were nearly the same with the swelling value of untreated bentonite. In other words, an improvement distance of 50 mm was obtained.

The decrement in swelling value of bentonite is derived from cation exchange reaction between clay and lime. Ca$^{2+}$ ion in lime was replaced with Na$^+$ ion in the clay. Na$^+$ ion causes more amount of water to enter interlayer of clay minerals than Ca$^{2+}$ ion does, and it causes the clay mineral to swell more. The improvement distance obtained represents distance Ca$^{2+}$ ion migration distance.

Decrement percentage in swelling potential of bentonite was calculated for all of sampling distances (Table 3). Change in swelling potential decrement percentage was given in Figure 7. It can be seen that an improvement of 44.36% was achieved in a distance of 50 mm from the column.
Figure 6. Change in free swelling percent of lime-treated specimens with distance to lime column.

Table 3. Decrement values in free swelling of the specimens extracted at different distances from lime column.

| Distance to lime column (mm) | 0-50  | 25-75 | 50-100 | 75-125 | 100-150 | 125-175 | 150-200 | 175-225 | 200-250 |
|-----------------------------|-------|-------|--------|--------|---------|---------|---------|---------|---------|
| Decrement in swelling potential (%) | 44.36 | 24.54 | 0.12   | 0.36   | 0.71    | 0.71    | 0.36    | 0.20    | 0.68    |

Figure 7. Change in free swelling decrement percent with distance to lime column.
4. Conclusions
In this study, lime column performance on stabilization of a bentonite clay which has a high amount of Na-smectite and a high swelling potential was investigated. For the purpose of the study, a laboratory scale model was built. At the end of a curing time of 60 days, free swelling tests were performed on the specimens extracted from different distances to lime column.

According to test results, a treatment distance of 50 mm was achieved. In other words, the most effective improvement distance was achieved at a distance of column diameter. This is not a desirable treatment distance in stabilization works. The reason of achieving such a low improvement distance is that bentonite used has a quite low permeability. High permeability is an essential factor for ion migration from the column. On the other hand, an improvement of 46.36% was obtained within the distance of treatment. This stabilization gain is desirable in stabilization works. The reason of obtaining such a stabilization gain is that three-layered clay minerals are quite reactive to lime. The results of this study show that the most appropriate soils for lime column technique are the soils which have high permeability and tree-layered clay minerals (such as Na-smectite) in a considerable amount.

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