Stabilization of Clayey Soil with Lime and Waste Stone Powder

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Abstract. Clay soils are commonly stiff in dry state but lose their stiffness when saturated with water. Soft clays are characterized by low bearing capacity and high compressibility. In this research, waste stone sludge obtained from slab stone processing, from stone washing plants were recycled for Stabilization of clayey soil with lime. Thus, the effectiveness of using waste stone powder and lime in stabilizing fine-grained clayey soil (CL) was investigated in the laboratory. The soil samples in natural state and when mixed with varying percentages of lime and waste stone powder were used for the laboratory tests that included atterberg limits tests, grain size analysis, standard Proctor compaction tests, unconfined compression tests and California bearing ratio tests. The results show significant reduction in plasticity and changed the optimum moisture content and maximum dry density of clayey soil with increasing percentage content of waste stone powder and lime. The results of the unconfined compressive strength (UCS) and California bearing ratio (CBR) tests show that at the different curing times, the addition of waste stone powder and lime caused an increase in the value of UCS up to 6% waste stone powder content and 7% lime content, and increase in the value of CBR to 6% waste stone powder content and 9% lime content, thereafter, the values of UCS and CBR decreased.

Key words: Waste stone powder, Lime, Clayey soil, Stabilization of soil, Environmental pollution

1. INTRODUCTION

Soil stabilization is a technique introduced many years ago with the main aim of rendering deficient soils capable of meeting the requirements of specific engineering projects. Clay soil is a variable and complex material but because of its availability and low cost, it is frequently used for construction purposes. At a particular location, however, a clay soil may not be wholly suitable for the desired purpose. In such a case its properties may be altered by the addition of a small amount, by weight, of lime. The amenability of clay soil to such treatment depends not only on the type and amount of cementing material added but also on the chemical and mineralogical composition of the soil. Lime stabilization refers to the stabilization of soil by the addition of burned limestone products, either calcium oxide, CaO, or calcium hydroxide, Ca(OH)2. Quicklime is the most frequently used lime product for lime stabilization in Europe. On the other hand, hydrated lime is used more often than quicklime in the United States, although use of quicklime is increasing. Generally speaking quicklime seems to be a more effective stabilizer of soil than hydrated lime. Furthermore, when quicklime, in slurry form, is added to a soil a higher strength is developed than when lime is added in powder form. The addition of lime to clay soils produces an improved construction material. Hence soil stabilization with lime has been used in highway, railroad and airport construction to improve bases and sub-bases. It also has been used in the construction of embankments, in soil exchange in sliding slopes, as backfill for bridge abutments and retaining walls, for soil improvement beneath foundation slabs and for lime piles (Bell, 1988).

In recent years, environmental issues have driven interest to utilize industrial by-products as alternative construction materials. The well-established industrial by-products, such as fly ash, slag, Rice Husk Ash, mine tailing and waste stone powder have been obtained and mixed with lime and cement to improve the geotechnical properties of problematic soils and engineering properties of pozzolanic stabilized materials. Also over the thirty years, research has been carried-out to investigate the utilization of rice husk ash as stabilizing materials in soil improvement technique (Lazaro and Moh, 1970). Some researchers showed that rice husk ash is a promising material to improve lime or cement-stabilized soils (Rahman, 1987; Ali et al., 1992; Muntohar, 2009).
2. LITERATURE REVIEW OF USE OF WASTE STONE POWDER IN CONSTRUCTION AND BUILDING MATERIALS

Very little information has been published on the engineering properties of pozzolanic stabilized materials using Waste Stone Powder (WSP) as additive. Bilgın et al. (2012), investigated the usability of waste marble dust as an additive material in industrial brick. They concluded that addition of marble dust as additive had positive effect on the physical, chemical and mechanical strength of the produced industrial brick.

Karakus (2011) examined the use of Diyarbakir basalt waste in Stone Mastic Asphalt (SMA). Asphalt improved with Stone Mastic for road construction has been utilized in Europe and America for 40 years, although is a rather new process in Turkey. SMA basically consists of 93–94% aggregate and mineral fillers, 6–7% bitumen and additives. Karakus (2011) shows that test results indicate that properties of the basalt waste and the SMA produced were within the specified limits and that these waste materials can be used as aggregates and mineral filler in SMA. Studies on providing utilization of basalt dust and aggregate wastes are proposed to be undertaken also in the areas of concrete and construction chemicals.

Ahmed and Ugai (2011) investigated the use of Recycled gypsum, which is derived from gypsum waste Plasterboard, is one of the wastes that have recently been used in Japan for ground improvement in different projects such as embankments and highways (Kamei et al., 2007; Ugai and Ahmed, 2009; Ahmed et al., 2010, 2011). But the use of recycled gypsum in ground improvement has a serious problem, which is related to the solubility of gypsum.

Demirel (2010) studied the effect of using Waste Marble Dust (WMD) as fine sand on the mechanical properties of concrete. It was observed that addition of WMD such that would replace the fine material passing through a 0.25 mm sieve at particular proportions displayed an enhancing effect on compressive strength. Marble dust is a by-product of marble production facilities and also creates large scale environmental pollution. Therefore, it could be possible to prevent the environmental pollution especially in the regions with excessive marble production and to consume fewer natural resources as well through its utilization in normal strength concretes as a substitute for fine aggregate.

In general, the use of waste and recycled materials in ground improvement has many environmental benefits, apart from reducing the cost of ground improvement. Utilization of waste and recycled materials in earthwork projects has many challenges, such as environmental aspects and durability. Durability is a vital function to evaluate the use of waste and recycled materials in ground improvement applications. It has been stated that the durability of soil stabilized with wastes, induced by environmental conditions in cold and rainfall regions can have a chief effect on their performance. For that reason, the effect of environmental conditions should be considered when evaluating the performance of soil stabilized with wastes. Environmental features, soaking and un-soaking state are considered to be one of the most destructive actions that can help to damage the structure of stabilized soil, such as pavement or embankment structures (Khoury and Zaman, 2007). Furthermore, seasonal changes in environment have a potential to change the engineering properties of soils, stabilized with waste stone powder. However, little has been known on the use of waste stone powder and lime for soil stabilization. Thus, in this research, waste stone sludge obtained from slab stone, processed from stone washing plants were recycled using preliminary laboratory tests for Stabilization of clayey soil with lime.

3. MATERIALS AND METHOD

The experimental program consisted of the following phases: (1) preliminary laboratory tests that included Plasticity limits, grain size analysis, and standard Proctor compaction tests to establish the moisture-density relationships of the un-stabilized soil; (2) unconfined compression tests and California bearing ratio on soils mixed with various amounts of lime and waste stone powder.

3.1. MATERIALS USED

Three different materials were used in this research: clayey soil, lime and Waste stone powder.

3.1.1. CLAYEY SOIL

The clay soil used in this study has a wide range of mineralogical composition. This consists of various proportions of different types of clay minerals, notably kaolinite, illite, mixed-layer clays and montmorillonite, of non-clay minerals, notably quartz, and/or organic matter and colloidal matter. Very small amounts of certain clay minerals may exert a large influence on the physical properties of a clay deposit. In addition, the degree of crystallinity is important; clay minerals with poorly-ordered crystallinity have different properties from those with well-ordered crystallinity. The different properties of the various
families of clay minerals can be explained partly by the different levels of activity on the surface of the clay particles.

In this research the mineralogy of the clay soil was of kaolinite. The chemical compositions of the kaolinite and lime that were used in this study are given in Table 1. Also the clay soil used in this study is classified as Clay of Low Plasticity (CL) by Unified Soil Classification System (USCS). The grain size distribution of the tested soil, in accordance with ASTM D422 Standard Test Method is shown in Figure 1.

Table 1: Average mineralogical composition of the lime and clayey soil that are of interest for the stabilization

<table>
<thead>
<tr>
<th>Chemical composition</th>
<th>Kaolinite (%)</th>
<th>Lime (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SiO₂</td>
<td>55.7</td>
<td>2.23</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>26.6</td>
<td>0.71</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>0.54</td>
<td>0.26</td>
</tr>
<tr>
<td>Alkaline(K₂O, Na₂O)</td>
<td>0.75</td>
<td>0.08</td>
</tr>
<tr>
<td>CaO</td>
<td>0.5</td>
<td>79.8</td>
</tr>
<tr>
<td>TiO₂</td>
<td>0.09</td>
<td>-</td>
</tr>
<tr>
<td>MgO</td>
<td>-</td>
<td>0.66</td>
</tr>
<tr>
<td>etc.</td>
<td>15.82</td>
<td>16.26</td>
</tr>
</tbody>
</table>

3.1.2. LIME AND WASTE STONE POWDER

In this research, quick lime was used as the stabilizing agent. The major chemical constituent of the lime is calcium oxide [CaO]. The other stabilizing material is Waste stone powder (WSP). For this research, Waste stone powder, derived from waste slab marble was used as sludge. Waste stone powder cause great amount of environmental pollution that By reusing and recycling these waste materials as an additive in the improvement of geotechnical properties of soils will greatly contribute to the economy and to the environment by minimizing polluting effects coming from stone quarries and stone plants. Recycled stone powder used in this research was produced in slab stone processing plant in Broujerd city in Iran.

3.2. SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURES

The clayey soils were initially mixed with the predetermined quantities of lime and WSP in a dry state and subsequently mixed with the water so that the mixes acquire the intended moisture content. Initial mixings were carried out in a laboratory with hand for at least 2 min for each mix and the mixtures were quickly stored in large plastic bags to prevent losing of moisture. The mixing was continued by shaking and overturning the bag for additional 2 min. Finally, air was squeezed out by hand from the bags as shown on figure 2. The mixed samples were sealed and stored in a room for 24 hours. Before tests the samples were remixed again in the plastic bag by hand shaking, overturning and squeezing the bags. The quantities of lime and WSP used were 3, 6, 9 and 11% by weight of the dry soil. Atterberg limits and standard Proctor compaction test were carried out on the natural (0% WSP and 0% lime content) and treated soil samples.

4.1. ATTERBERG LIMITS

Atterberg limits test was performed in accordance with ASTM D4318-93. The results of the Atterberg limits test on the soil samples in natural state and when mixed with varying percentages of lime and WSP are shown graphically in Figs.3 and 4. From the results, there is a decrease in liquid limit and increase in plastic limit with increasing WSP and lime contents. The plasticity index also show decreasing trends. The reduction of each of these properties is obviously a change in water content due to increase in WSP content. The implication of these reductions in
the plasticity properties of the soil with increasing amount of WSP and lime is that the soil becomes friable and workability is improved.

4.2. STANDARD PROCTOR COMPACTION TEST

Standard Procter compaction tests were conducted to determine the optimum moisture content and maximum dry density for soil stabilized with different contents of lime and WSP. The clay soil was mixed with lime and WSP. Waste stone powder was added in varying proportions of 3, 6 and 9% and Lime was added in varying proportions of 3, 6, 9 and 11%. The treatment of the samples with lime and WSP content changed the optimum moisture content and maximum dry density of the samples. The optimum moisture content increased with increasing lime and WSP contents for all the samples. Also the maximum dry density decreased with increasing lime but increased with increasing WSP content. The procedures used in carrying out these tests were as described in ASTM D698-78 Standard Test Method for compaction of Soils. The results of the compaction test are given in figures 5 and 6.

It was observed that by increasing lime content, maximum dry density decreases and optimum moisture content increases. Also, when lime was added to soil, instantaneous reaction with cation exchange occurs, and clay particles flocculate together. This process led to formation of air voids within inter-particles spaces and makes creation of a porous medium with lower maximum dry density. Furthermore, more water is necessary for filling the created voids, so optimum moisture content increased (Jafari and Esna-ashari, 2012). These mentioned effects are combined in lime–waste stone powder–soil mixtures as shown in figure 7.
Fig. 6: dry density versus water content for mixtures

Fig. 7: Variation of maximum dry density and optimum moisture content with varying percentages of lime and WSP.
4.3. UNCONFINED COMPRESSIVE STRENGTH:

The unconfined compressive strength tests were conducted on clayey soil; clayey soil + lime mixes; clayey soil + lime + waste stone powder mixture. All the samples were prepared by static compaction plastic tube mold at their respective optimum moisture contents and maximum dry densities. The test was conducted under a constant strain rate of 1.5mm/min. For each test loading was continued until 3 (or) more readings are decreasing or constant. The properties and characteristics of lime treated clayey soils vary significantly, depending on the types of soil and amount and type of additives, and curing conditions including time and moisture. In this study, the samples of clayey soil and additive mixes, were cured for 7 and 28 days under 2 conditions: 1- soaked, that is after compaction, all samples were wrapped in cellophane to keep their water content constant, and left to cure for 7 and 28 days as shown on figure 8, and 2 - unsoaked samples. Saturation of soil specimens with water before testing for unconfined compressive strength simulates some of the worst conditions to which a stabilized soil may be subjected to. All the tests were carried out in accordance to ASTM D2166 standard.

The results of the unconfined compressive strength tests performed in this study for the natural and mixed states of the clay samples are given in figures 9-12. The figures show that at the different curing times, the addition of waste stone powder and lime caused an increase in the value of UCS up to 6% waste stone powder content and 7% lime content, thereafter, the value decreased.

Whereas curing is one of the major variables affecting the strength of lime stabilized soil. Its effect on strength is a function of time and relative humidity according as shown on figure 13 and 14. In every series of tests, the unconfined compressive strength increased with increase in curing time for unsoaked samples and decreased with increasing curing time for soaked samples.

4.4. CALIFORNIA BEARING RATIO TEST

The California Bearing Ratio tests are conducted on clayey soil, clayey soil + lime mixes, clayey soil + lime + waste stone powder mixture. The samples were tested in both soaked and un-soaked conditions using ASTM D1557 standard at various percentages of lime and waste stone powder mixtures. The tests were conducted at curing time intervals of 7 days, and 28 days and at optimum moisture contents. The different curing time are presented in Figs. 15, 16 and 17. The CBR increases with addition of lime and continues to increase with time if there is lime available in excess of the lime fixation point. In this study the fixation point for lime was 9% and for waste stone powder was 6%.
Fig. 10: Values of unconfined compressive strength of Soil, treated with different amounts of lime and waste stone powder after 7 days curing and soaked.

Fig. 11: Values of unconfined compressive strength of Soil, treated with different amounts of lime and waste stone powder after 28 days curing and unsoaked.

Fig. 12: Values of unconfined compressive strength of Soil, treated with different amounts of lime and waste stone powder after 28 days curing and soaked.

Fig. 13: Influence of curing time on the unconfined compressive strength of un-soaked sample that treated with different amounts of waste stone powder and 3% lime.

Fig. 14: Influence of curing time on the unconfined compressive strength of soaked sample that treated with different amounts of waste stone powder and 3% lime.

Fig. 15: CBR values of stabilized specimens versus lime content after 96 hours curing and soaking.
From Figures 15, 16 and 17 it can be seen that the CBR values increase with increase the lime and waste stone powder content. Inclusion of waste stone powder increases the CBR until 6 %, and decreases beyond this point. Also, lime content increases the CBR up to 9 % lime content, and thereafter decreases. Excessive contents of waste stone powder and lime increases probability of their agglomerating which means reduction of effective interfacial contact area between consuming materials and clayey soil.

5. CONCLUSION

The results of this experimental investigation have shown that beneficial effects are obtained by the addition of lime and WSP to clayey soil. Therefore, the resulted geotechnical properties of lime-waste stone- powder treated soil have led to the following conclusions:

1. There is a decrease in liquid limit and increase in plastic limit with increasing waste stone powder and lime content.
2. The plasticity index show decreasing trends with increasing waste stone powder and lime content.
3. The treatment of the samples with lime and waste stone powder changed the optimum moisture and maximum dry density.
4. The optimum moisture content increased with increasing lime and waste stone powder contents.
5. The maximum dry density decreased with increasing lime content.
6. The maximum dry density increased with increasing waste stone powder content.
7. The unconfined compressive strength of treated soil specimen with lime and waste stone powder was affected mostly by the amount of lime and waste stone powder mixed in soil mixtures. The unconfined compressive strength increased in association with increasing lime and waste stone powder content.
8. It was observed that the CBR value of the clayey soil increased by 244 % with addition of 9 % Lime + 6 % WSP at 28 days curing.
9. It was observed that there is remarkable influence on strength and CBR values of clayey soil at 9 % Lime + 6 % WSP for CBR, and 7 % Lime + 6 % WSP for UCS which are optimum percentages.
10. Waste stone powder caused great amount of environmental pollution. Reusing and recycling these waste materials as additive in the improvement of geotechnical properties of soils, greatly will contribute to the economy and to the environment by minimizing polluting effects coming from stone quarries and stone plants.

REFERENCES


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