Effect of fly ash-limestone dust stabilization on volume change and strength of expansive soil

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Abstract. The expansive soils in semi-arid and arid regions are affected by swelling-shrinking due to climatic effects, causing damage to lightweight structures. Various methods and materials have been employed to improve the engineering properties of these soils. This paper includes the findings of experimental work conducted studying the effectiveness of use of fly ash (FA) and limestone dust (LS) in the enhancement of the engineering properties of expansive soil sampled from Haspolat, Nicosia. Limestone quarry dust is a by-product produced in quarries as a result of the process of crushing and grinding. Laboratory experiments were conducted on the expansive soil with additive proportions of 5% LS, 10% FA, and 5% LS+10% FA by dry mass of the soil at curing periods of 1, 14 and 28 days. The 5% limestone dust and 10% fly ash mixed samples have shown significant increment of up to 220% in CBR value, 82% in volumetric shrinkage, and 100% in swell potential. The study has concluded that the introduction of admixtures to expansive soil generally enhanced the geotechnical properties, exhibiting greater durability and stability compared to the untreated soil. Hence limestone dust and fly ash can be regarded as effective expansive soil stabilizers, also providing cheap solutions to the disposal issue.

1. Introduction
The sensitivity of expansive soils to water content alteration has made them quite difficult for civil engineers to manage in the construction of roads. These soils expand when water content increases and shrink when desiccate. The repetitive cycles of wetting and drying due to climatic and environmental factors cause swelling-shrinkage, hence damaging the foundations or roads built on them [1]-[3]. Therefore, to alleviate the problems with expansive soils, so as to ensure safe construction, environmental-friendly and cost-effective solutions are used, which include employment of materials to improve the engineering properties of problematic soils. Chemical stabilization and physical stabilization are the two forms of soil stabilization. The process of enhancing soil properties by redistributing soil particles to increase the density through compaction with vibration and/or mechanical weights can be categorized as physical (mechanical) stabilization. Physical stabilization is characterized by rewetting, removal and replacement processes [4]. The employment of chemical admixtures to stabilize soil is considered when physical stabilization methods are ineffective, insufficient, too costly and/or impossible to use. Some of the chemical admixtures used are lime, silica fume, marble powder quarry dust or microorganisms [5].

The utilization of industrial by-products and wastes as secondary additives in soil stabilization has been widely implemented. One example is limestone quarry dust, which is a by-product produced in quarries as a result of the crushing and grinding of stones. Limestone is classified as a sedimentary rock which is constituted mainly of dolomite and calcium carbonate. Calcium carbonate rocks are formed by the re-crystallization of existing lime deposits. As a result of its application potential and resilience, limestone has a broad scope of use. Quarry crushers generate about 15% to 20% waste daily from crushed stones and the accumulation causes environmental degradation as well as public and environmental health risks [6]. The assessed engineering properties of clay soils treated with lime and...
stone powder show that the admixtures are efficient in stabilizing soil [7]. The improvement of engineering properties was clearly observed in the soil when the maximum dry density and CBR increased and the optimum moisture content decreased with the introduction of stone dust [8]. Satyanarayana et al. [9] observed that the free swell value of an expansive soil reduced from 100% to 83% and the soaked CBR value increased from 1.2 to 6.7 with 10% quarry dust. Whereas, Naman and Kumar [10] observed an increment in CBR value of 50% with 30% quarry dust content. Optimum moisture content and water affinity reduce as quarry dust content increases. Sonthwal and Guray [11] observed that a decrease in maximum dry density occurred with quarry dust content beyond 25%. The maximum dry density of an expansive soil rose from 1.58 g / cm3 to 1.68 g / cm3 and the optimum moisture content reduced from 32% to 26% with 20% stone dust content CBR value decreases beyond 25% quarry dust content and this percentage is effective for stabilizing and upgrade the engineering features of black cotton soil. Koranne and Ali [12] carried out a probe of the effect of a combination of stone dust and fly ash at equal proportion with varying admixture percentages from 10% to 50% at 10% interval on the properties of expansive clay. The research found that the swelling potential was almost completely controlled at 20% - 30% admixture percentage and the strength and stability properties increased with rise in admixture percentage. The combination of fly ash and stone dust brings about better improvement of expansive clay than a single homogenous admixture (fly ash or stone dust).

This study analyses the effectiveness of adopting soil-stabilization technique to positively modify the geotechnical features of expansive soil. In this study, fly ash and lime stone dust were used as additives to modify the geotechnical features of a locally obtained expansive soil. An experimental program was conducted on both expansive soil (control sample) and stabilized soil to prove the combined influence on geotechnical properties with reference to introducing limestone dust and fly ash in different percentages to expansive soil. This study is to be done for the aim of probing the effectiveness Fly ash and limestone dust in the enhancement of the engineering properties of expansive soil sampled from Haspolat at the outskirts of Nicosia. Secondly, to probe the influence of the treatment age on swelling and shrinkage behavior of the expansive soil. These aims will be achieved through the objectives highlighted below.

2. Materials
The soil sample was obtained from the outskirts of Taşkent region, Nicosia. The physical properties are presented in Table 1. It was established that the untreated soil possesses moderate to high swell potential and therefore requires stabilization. The study involves exploration of the influence of limestone dust and fly ash on Atterberg limits, compaction characteristics, and swelling-shrinking behavior. The experimental study was carried out in accordance to ASTM Standards. The expansive soil has dark grey color and is in the form of claystone chunks. The samples were oven dried for 5 days at 50±1°C and pulverized to be able to study geotechnical properties. Class C fly ash is mainly generated through the burning of sub-bituminous or lignite coal but it may also be manufactured by burning bituminous or anthracite coal (made entirely of carbon). Class C type of fly ash. Its calcium oxide (CaO) content can be greater than 10%. The tests done on the limestone dust (LS) were conducted with reference to all the particles of the grinded limestone passed through the 0.425mm sieve as found by the investigation done. The geotechnical features of the limestone fine dust are presented in Table 1.
Table 1. Physical properties of the materials used

| Property          | Soil | Fly Ash | Limestone dust |
|-------------------|------|---------|----------------|
| Colour            | Dark gray | Light gray | White         |
| Sand size (%)     | 14   | 10      | 15             |
| Silt size (%)     | 50   | 90      | 73             |
| Clay size (%)     | 36   | --      | 12             |
| Liquid Limit (%)  | 62   | --      | 22             |
| Plastic limit (%) | 31   | --      | 16             |
| Plasticity Index (%) | 31 | NP      | 6              |
| Specific Gravity  | 2.58 | 2.34    | 2.76           |

3. Results and Discussions

3.1 Standard Proctor Compaction Test

This test was conducted with reference to ASTM 698 (Method A) for all samples used and the compaction test parameters are presented in Table 2. The maximum dry density increased to 1.71 g/cm³ from 1.69 g/cm³ of the untreated soil when 5% fine dust of the limestone was added. Whereas with 10% fly ash addition, the maximum dry density was reduced to 1.57 g/cm³ and the optimum water content increased to 24% compared to the optimum water content of the natural soil which was 19%. When 5% LS and 10% FA were added to the soil, the maximum dry density was decreased to 1.66 g/cm³, whereas there were no significant changes in the maximum moisture content.

Table 2. Standard Proctor Compaction test parameters

| Material         | Maximum dry density (g/cm³) | Optimum water content (%) |
|------------------|-----------------------------|----------------------------|
| Natural soil     | 1.69                        | 19                         |
| NS+10% FA        | 1.57                        | 24                         |
| NS+5% LS         | 1.71                        | 19.5                       |
| NS+10% FA+5%LS   | 1.66                        | 17.5                       |

3.2 One-dimensional swell test

This test is conducted to study the influence of admixtures and treatment age on swell potential according to ASTM D4546. Primary swell potential ($S_p$) and secondary swell rate ($C_{ss}$) were obtained from axial swell strain versus logarithm of time relationship, expressing the three stages of swell; initial, primary, and secondary. The swell potential is taken as the swell strain at the end of primary swell stage. All these parameters of untreated and treated soil with respect to treatment age are presented in Table 3.

Table 3. Swell parameters for untreated soil and its mixtures after different curing periods.

| Curing time | Swell parameters | NS  | 5% LS | 10% FA | 10% FA+5%LS |
|-------------|------------------|-----|-------|--------|-------------|
| 1 day       | $S_p$ (%)        | 5.6 | 1.32  | 0.668  | 0.360       |
|             | $C_{ss}$         | 0.877 | 0.34  | 0.112  | -           |
| 14 days     | $S_p$ (%)        | 2.846 | 0.0154 | 0.0508 |
|             | $C_{ss}$         | 0.772 | -     | -      |
| 28 days     | $S_p$ (%)        | 2.572 | 0.190  | 0.0231 |
|             | $C_{ss}$         | 0.91  | -     | -      |
The results indicate a decrease from 5.6% of the natural soil to 2.572% when 5% LS, 0.190% when 10% FA and 0.0231% when 10% FA+5%LS were added and aged for 28 days before testing. Therefore, the soil became a low swell potential soil after stabilization took place within 28-day curing period. The rate of secondary swell rate \((C_{ss})\) is observed to increase with 5% LS, whereas diminished completely when 10% FA and 10%FA+5%LS mixture are added.

### 3.3. Volumetric shrinkage results

In order to evaluate the shrinkage behaviour of untreated and stabilized soils, volumetric shrinkage tests were conducted by drying saturated specimens after treatment times of 1, 14 and 28 days. Table 4 depicts the void ratios at full saturation and completely dried conditions, as well as the percent reduction and time taken for shrinkage to be completed. The outcome of the volumetric change test for the untreated soil and its mixtures after different curing periods revealed that the best improvement in volume change is observed for 10%FA+5%LS treated for 28 days, while the largest volume change was observed for untreated soil. Moreover, there were no cracks observed on the specimens when completely dried except in the untreated and 5% LS added ones.

| Materials          | Curing time (day) | Change in Void Ratio                  | Total Time of Shrinkage (min) |
|--------------------|-------------------|---------------------------------------|-------------------------------|
|                    |                   | Full Saturation Condition | Dried Condition | Reduction (%) |                         |
| NS                 | -                 | 0.640 | 0.312 | 51.25 | 1570 |
| 5% LS Mixture      | 1                 | 0.420 | 0.299 | 28.81 | 3182 |
|                    | 14                | 0.455 | 0.323 | 29.01 | 3094 |
|                    | 28                | 0.494 | 0.327 | 33.81 | 4340 |
| 10% FA Mixture     | 1                 | 0.756 | 0.611 | 19.18 | 1420 |
|                    | 14                | 0.673 | 0.569 | 15.45 | 3087 |
|                    | 28                | 0.658 | 0.545 | 17.17 | 2848 |
| 10% FA+5% LS Mixture | 1              | 0.581 | 0.452 | 22.20 | 4499 |
|                    | 14                | 0.519 | 0.468 | 9.83  | 2633 |
|                    | 28                | 0.613 | 0.556 | 9.30  | 1710 |

### 3.4. California bearing ratio test (CBR)

This test was done with reference to ASTM D 1883 through the employment of the standard Proctor method for unsaturated soil at 1, 14, and 28 days treatment periods. The 14.07% CBR value of the untreated soil increased to 16.26%, 15.27%, and 19.81% at 1, 14, 28 days treatment ages respectively when 5% fine limestone dust was introduced. Once 10% fly ash was introduced the CBR value rose to 15.69%, 26.92%, and 17.71% for the treatment ages 1, 14, and 28 days respectively. The variation in the rise of CBR value with 10% fly ash and 5% fine limestone dust was minimal. With the addition of a mixture of 5% LS + 10% FA, however, CBR increased with curing time up to 45.05% in 28-day treated specimens. Table 5 shows the CBR values of various mixtures at different treatment periods.
Table 5. California bearing ratio at various treatment periods.

| Material                  | 1 day  | 14 days | 28 days |
|---------------------------|--------|---------|---------|
| Natural soil              | 14.07  |         |         |
| Mix 5% LS                 | 16.26  | 15.27   | 19.81   |
| Mix 10% FA                | 15.69  | 26.92   | 17.71   |
| Mix 5% LS + 1% FA         | 45.79  | 31.77   | 45.05   |

4. Conclusions

This experimental study has investigated the effectiveness of employing limestone dust and fly ash in stabilizing expansive soil, and the following conclusions were derived:

- Addition of 5% LS to expansive clay samples led to a 76.43% reduction in swell potential. While adding a mixture of 10% FA and 10%FA+5% LS caused considerable reductions of 88.07%, 93.57% respectively in swell potential. Based on these observations addition of 10% FA, 10% FA +5% LS have given the best results in improving the expansive soil.
- The largest reduction in volumetric shrinkage percentage is 81.27% in 10% FA +5% LS added specimens with respect to untreated condition. There were no cracks seen when complete dehydation of the samples was achieved except in 5% LS and NS specimens.
- With the addition of 5% LS, and 10% FA, the value of CBR for unsoaked samples was improved by 40.8% and 25.9% respectively, while giving excellent value of 220%, when a mixture of 10% FA+5% LS added and 28-day cured specimens were used.

Finally, it may be concluded that limestone dust and fly ash are relatively effective as expansive soil stabilizers, enhancing the geotechnical properties. The use of these materials provides a cheap stabilizing method, subsequently encouraging its use which eliminates the disposal issue. 10%FA+5%LS can be employed to stabilize soil for road base and lightweight structures, as well as for cutting down the accumulation of waste which may pose health and environmental hazards.

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