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Applications of the oedometer, compaction, permeability and CBR tests to the study of sand with fly ash- lime

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***Abstract*— The study presents a series of experimental study using sand with fly ash- lime mixtures at various percentages. Increase in the amount of fly ash results in an environmental problem in many regions of the world. Fly ash is effectively used in engineering applications in some countries, and thereby reduces the potential impact on the environment. Lime is used to bind sand mixed with fly ash in this research. Fly ash used during the experimental works is identified as class F. Some engineering behaviour of sand mixed with fly ash- lime samples was characterized in oedometer, permeability, compaction, and CBR testing set ups. Significant modifications in compression index (Cc), void ratio (e), permeability (k), dry unit weight (γdry), optimum water contents (wopt), and CBR values were observed by a series of experimental results on the sand with 5% lime by various fly ash mix ratios (15%, 20% and 25% by weight).**

***Keywords*— Sand, fly ash, lime, oedometer, permeability, compaction, CBR testing**

I. Introduction

Fly ash is a solid waste material produced by the combustion of coal and consists of fine, powdery particles predominantly spherical in shape, either solid or hollow in nature. According to ASTM C618, there are two types of fly ash based on their chemical composition; (i) class F (low-lime, produced from burning bituminous coal or anthracite), (ii) class C (high-lime, produced from burning lignite coal or subbituminous) [1]. Since 1930's with the development of the industry using electrical energy, the fly ash has been started to use [2]. The current annual product of fly ash across the world is predicted around 600 million tonnes [3]. In recent years the amount of fly ash produced has been increasing throughout the world. The disposal of the large amount of fly ash has become a serious environmental problem. Hence, researches for the utilization of fly ash are necessary to reduce environmental problems, and economical loss. The laboratory and field investigations have indicated that geotechnical properties of fly ash (e.g., specific gravity, permeability, internal angular friction, and consolidation characteristics) make it suitable for use in various constructions. Fly ash has been used as bulk fill material in geotechnical fill, such as in construction of embankments, dikes, and road subgrade [4,5]. The advantages of using fly ash as a bulk fill material include low cost, low unit weight, and good strength. Significant efforts have been recently made in soil stabilization with fly ash, in particular for subgrade applications [6-18]. Arora and Aydilek (2005) evaluated the engineering properties of Class F fly ash amended soils as highway base materials. Camargo (2008) showed that addition of 10-15% by weight of Class C fly ash increases the CBR values.

Objective of the research presented here is to investigate the use of both fly ash and lime in stabilization of a sand. An extensive series of experiments have been carried out on the mixtures of sand with 5% lime and various ratios of fly ash (15%, 20% and 25% by weight) in oedometer, standard proctor, falling head permeability, and California Bearing Ratio testing set ups.

II. Materials and Method

Locally available river sand, collected from Adana region, (Narli) was used in this study. The sand has a specific gravity of 2.68, median grain diameter (D50) of 1.20 mm, coefficient of uniformity (Cu) of 6.87 and coefficient of curvature (Cc) of 1.04. The grain size distribution and the Scanning Electron Microscope pictures of the soil are shown in Figure 1 and Figure 2, respectively. The sand was classified as 'SW' according to the Unified Soil Classification System (USCS). The maximum and minimum dry unit weights of the sand were determined as 19.79 kN/m3 and 16.73 kN/m3 respectively. As it can be seen from the Figure 1, it is a well-graded sand, between the diameter of 0.075 mm and 4.75 mm. Table 1 presents some specifications of the sand.

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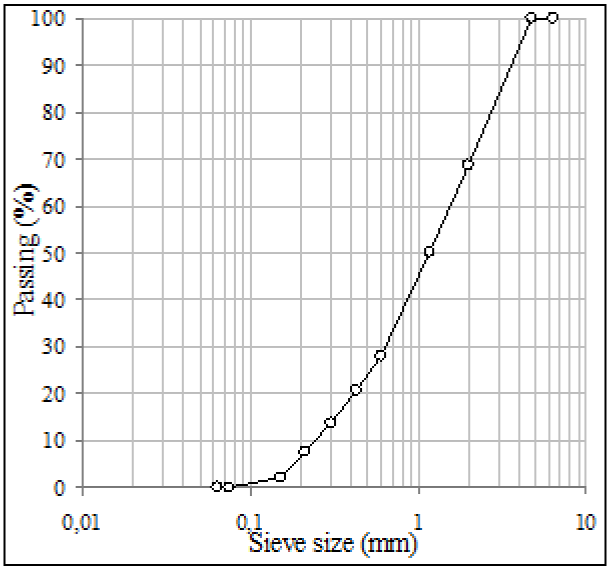

Figure 1. Grain size distribution of the sand

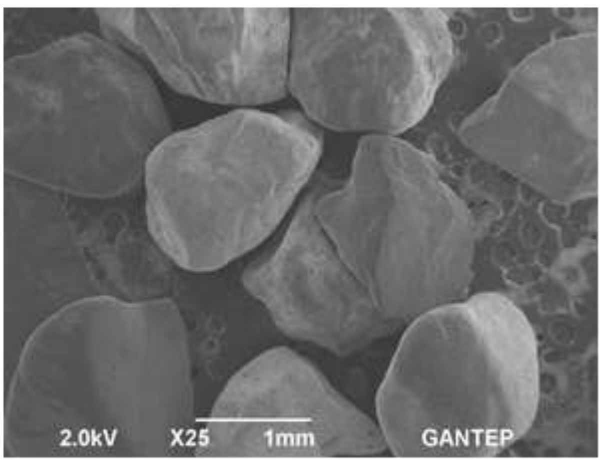

Figure 2. SEM picture of the sand

Table 1. Some specifications of the sand

Unified Soil Classification System (USCS)	SW
Specific Gravity, G_s	2.68
Maximum void ratio, e_{max}	0.615
Minimum void ratio, e_{min}	0.328
Angle of Friction, ϕ	44°
Coefficient of uniformity, C_u	6.87
Coefficient of curvature, C_c	1.04
Median Grain Size, D_{50}	1.20
Effective Grain Size, D_{10}	0.24

Fly ash used during the experimental works was obtained from Yumurtalik- Sugozu Thermal Power Station in Adana, Turkey. According to its chemical composition (4,24% of CaO), the fly ash used is identified as class F, and has a specific gravity (G_s) of 2,25. Scanning Electron Microscope picture of the fly ash is shown in Figure 3. Table 2 presents the composition of the fly ash used in the study. CL 80 S type hydrated lime was also used in this study. It is a product of AKAY Industry and Mining Company in Turkey and produced in accordance with TS EN 459-1.

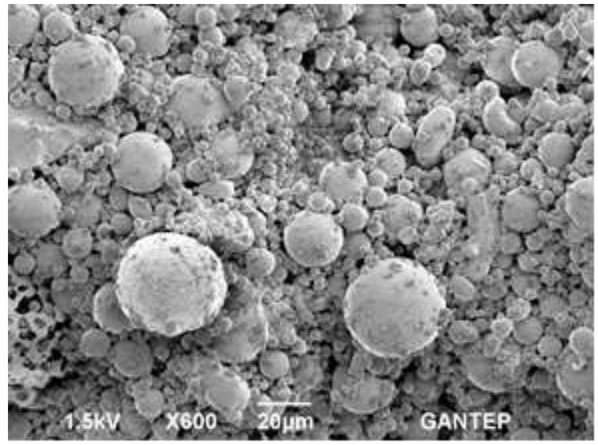

Figure 3. SEM picture of the fly ash used during the tests

Table 2. Composition of Yumurtalık- Sugözü fly ash

Composition (%)	**Fly ash**
CaO	4.24
SiO_2	56.2
Al_2O_3	20.17
Fe_2O_3	6.69
MgO	1.92
SO_3	0.49
K_2O	1.89
Na_2O	0.58
Loss on ignition	1.78
Specific gravity	2.25
Blaine fineness(m^2/kg)	287

ELE oedometer testing apparatus (ASTM D2435) was used to examine the consolidation characteristics of the sand with fly ash- lime mixtures. The maximum dry unit weight (γ_{drymax}) and optimum water content (w_{opt} %) for each test was determined using standard compaction test (ASTM 698). ELE falling head permeability testing equipment, a conventional laboratory testing method used to determine the permeability of fine grained soils with intermediate and low permeability, was employed (ASTM D5084). California Bearing Ratio (CBR) test was also performed (ASTM D1883- 99) to obtain CBR values.

A. Oedometer Test

Compressibility characteristics of fly ash depend on its initial density, degree of saturation, self-hardening characteristics and pozzolanic activity. Partially saturated ashes are less compressible compared to fully saturated samples [19,20]. The

1-D consolidation test method carried out during the investigation is the standard method of measuring consolidation properties, which involves the incremental loading of soil specimens. Incremental loading is to apply daily increments of vertical load to a submerged container in a rigid ring, with drainage permitted through porous stones at the bottom and top. The load is doubled each day, that is, the ratio of load increment to existing load is usually 1. To study the mechanical properties of specimens tested, it is crucial to maintain consistency between the specimens prepared for the testing. Therefore, great care was taken to have reasonable repeatability during the preparing of the specimens to be tested. The sample preparation technique was the same for all specimens. The mixtures were prepared on dry weight basis by using oven dried materials. The required amount of materials were weighed, and mixed manually in a dry case, until the mixtures are observed to be visually homogeneous. Then, the mixtures were spooned, without vibration, into the mould with thin layers. When the mould was completely filled, the top cap was placed, then the desired amount of water was added to the cell for making the specimen saturated. After a soaking period of 24 h elapsed at room temperature in a controlled environment, the loading process was started. Figure 4, Figure 5 and Figure 6 presents typical oedometer curves for the sand with fly ash at different contents.

B. Falling Head Permeability

Permeability is a significant parameter in the design of leachate to predict the loss of water. During the experimental study described, each sample was first compacted at optimum water content according to the ASTM 698 standards, then kept in a water tank for 48 hours to get fully saturated, and tested. It can be seen from the test results that an increase in fly ash decreases the permeability (Figure 8).

C. Compaction Test

The density of fly ash is an important parameter since it controls the strength, compressibility and permeability. Densification of fly ash improves the engineering properties. The compacted unit weight of the material depends on the amount, and the method of energy application, grain size distribution, plasticity characteristics and moisture content at compaction. The maximum dry unit weight (γ_{drymax}) and optimum water content (w_{opt} %) for each test were determined according to ASTM 698. Figure 7 presents typical maximum dry unit weight- optimum water content relation.

D. California Bearing Ratio Test

One of the major applications for fly ash utilization is as a sub-base material in pavement constructions. Sridharan *et al.* (1998) and Pandian *et al.* (2001) reported the use of fly ash to improve the CBR of soils. The CBR tests were conducted in accordance with ASTM D 1883. The specimens were soaked and tested according to the ASTM. Sand- lime- fly ash mixtures were prepared at the optimum water content that had been determined previously in a series of compaction test. Following the compaction of the specimens at five layers with 56 blows per layer, a surcharge plate of 2.44 kPa was placed on the specimen prior to testing. The loads were carefully recorded as a function of penetration up to a total penetration of 6.0 mm. CBR value is used as an index of soil strength and bearing capacity [23]. This value is widely used and applied in design of the base and the sub-base material highway and roads. Figure 9 shows fly ash content vs CBR values for the fly ash tested under soaked conditions. The CBR values obtained at 5.0 mm penetration for some of the fly ash are shown in Table 3.

III. Results and Discussions

Sands with 5% lime were tested using different fly ash contents, which are 15%, (FA15) 20% (FA20), and 25% (FA25) by dry weight. Testing program and the results obtained are presented in Table 3.

Table 3. Summary of specimen data

		FA15	FA20	FA25
Maximum dry unit weight (γ_{drymax}) (kN/m^3)		21,5	21,2	20,3
Optimum water content (w_{opt}) (%)		7,3	8,5	9,1
CBR value (%)		25,3	27,8	38,2
Permeability (k) (m/sec) (x10^{-4})		8,15	6,22	4,23
Void ratio (e)	e_0	0,675	0,689	0,717
	e_f	0,465	0,473	0,490
Intergranular void ratio (e_s)	e_{s0}	1,162	1,345	1,578
	e_{sf}	0,892	1,047	1,238

The results of the oedometer tests conducted in various specimens prepared in a loose state are shown in Figures 4, 5 and 6 present the variation of void ratio (e), intergranular void ratio (e_s) with different oedometer pressures (σ_v). Figure 5 presents intergranular void ratio (e_s) vs. fly ash content (%) under different oedometer pressure values. It is seen that the initial void ratio values (e_o) of the mixtures increase with the increasing fly as content. The compressibility of the sand-lime- fly ash mixture increases with the increasing fly ash content. Similarly, e_s values increases as the fly ash content increases at all oedometer pressure values. The readers are referred to the study by Monkul and Ozden (2005) for more details in estimating the e_s values. The tests were carried out immediately after the specimens had been prepared in the testing equipment. Therefore, it should be kept in the mind

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that it could be expected to have different results at different curing times.

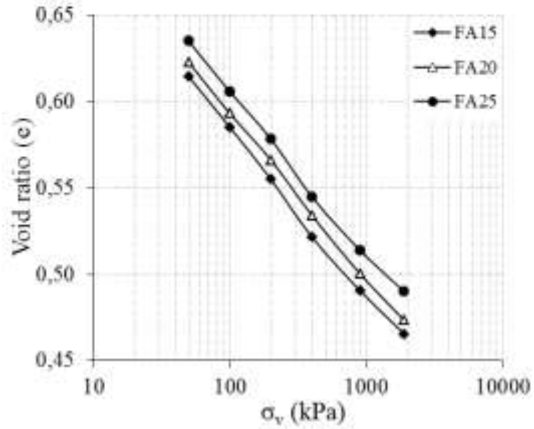

Figure 4. Variation of void ratio with different oedometer pressures

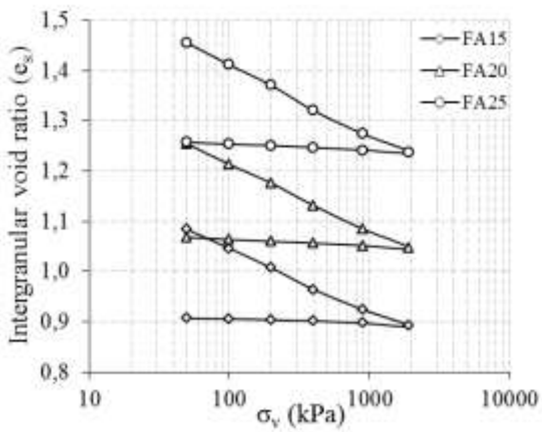

Figure 5. Variation of intergranular void ratio with different oedometer pressures

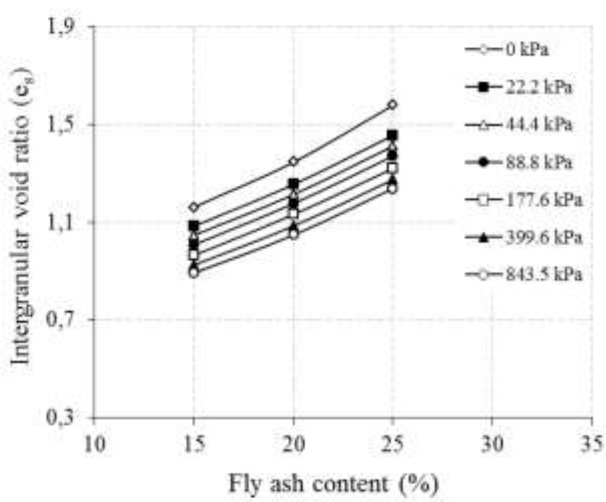

Figure 6. Intergranular void ratio vs. fly ash content under different stresses

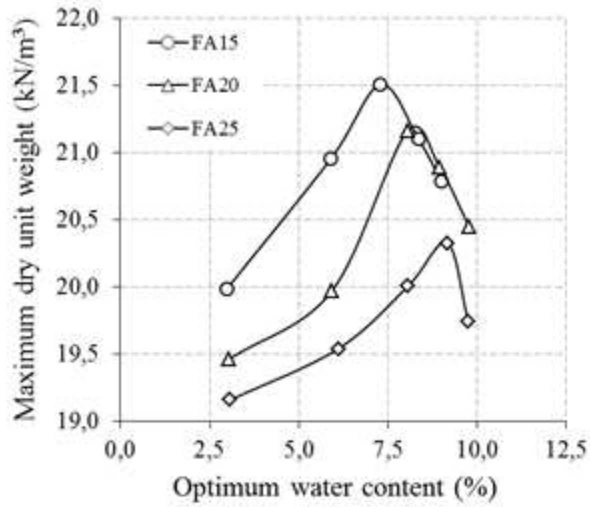

Figure 7. Effect of fly ash on the sand with lime in compaction tests

From the standard proctor test results (Figure 7) it is seen that addition of fly ash increases the optimum water content (w_{opt}) and decreases the maximum dry unit weight (γ_{drymax}). Also, a less variation of dry unit weight over a much wider range of water contents is observed, as the fly ash content increases. This could be because of the presence of lower specific gravity fly ash.

Based on the tests employed in the falling head permeability testing equipment, a sharp decrease in permeability (k) values with an increase in fly ash content is observed (Figure 8). This could be because of the filling of voids, and possible cementations taken place between the sand grains.

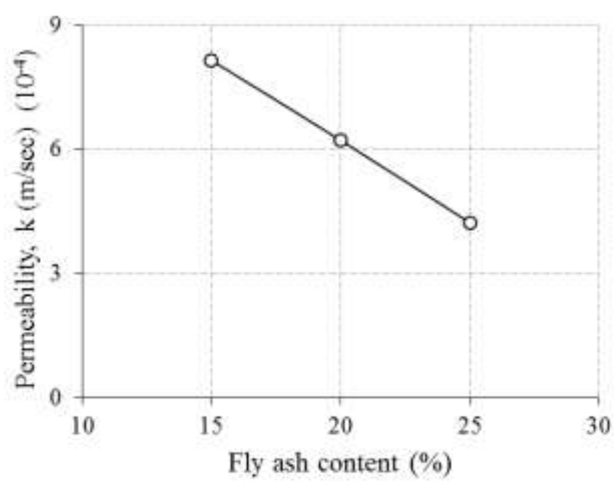

Figure 8. Effect fly ash on the sand with lime in coefficient of permeability (k)

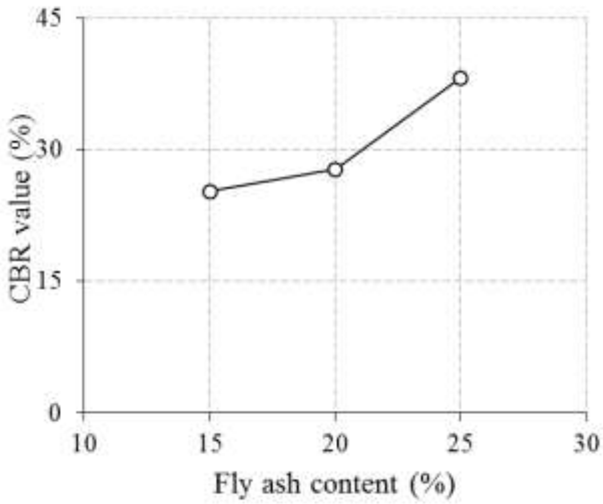

Figure 9.. Effects of the fly as content on the CBR value of the sand with 5% lime

CBR values increases with increasing fly ash content. CBR testing results on the sand- lime- fly ash mixtures are shown in Figure 9.

IV. Conclusions

The test results given in this paper show five facets of the behavior sand- lime mixtures with various fly ash (Class F) contents.

(i) Some improvements are presented to be interrelated with an increase in fly ash content in the specimens of sand with 5% lime.
(ii) Initial void ratio (e_o), and intergranular void ratio values of the mixtures increase with the increasing fly ash content at all oedometer pressure values employed in the experimental studies.
(iii) Addition of fly ash increases the optimum water content (w_{opt}) and decreases the maximum dry unit weight (γ_{drymax}).
(iv) A decrease in permeability (k) values with an increase in fly ash content is observed.
(v) CBR values increases as the fly ash content increases.

The tests were carried out immediately after the specimens had been prepared in the testing equipment. Therefore, it should be kept in the mind that it could be expected to have different results at different curing times.

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