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Effect of Soil-Particle and Pore Orientations on Uniaxial Compressive Strength

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ABSTRACT
The main objective in the compaction of earth dams, highway embankments, bridge abutments and fills behind retaining walls is to increase the strength of the soils. Compressive strength value of the samples is controlled by the fabric of the compacted soil. The fabric of the compacted soil is not isotropic in all directions. In this study, it has been shown the other two horizontally oriented soil fabrics perpendicular to the compaction direction were, on the contrary to popular belief, not isotropic. It has been shown that the soil fabric tends to become isotropic with the addition of more than 20% spherical fly ash and the compressive strength values depending on perpendicular directions are about equalized to each other.
Keywords – Soil fabric, strength, orientation.

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I. INTRODUCTION

The arrangement of the particles in the soil, geometrical arrangements of pores between particle groups and particles and the interaction force between these particles are called “soil fabric" [1,2,3]. The distribution of soil particles and pores that form the soil fabric, their orientation in a certain order and the magnitude and grade of this orientation can be explained in terms of the nature and magnitude of the stress on the soil alone [4,5,6,7,8,9,10,11,12,13]. The micromorphological structures of the soil, including particles, pores orientations and several other properties, can be investigated using optical and electron microscopy with the help of thin sections and polished blocks [3,5,14] (Fig. 1).

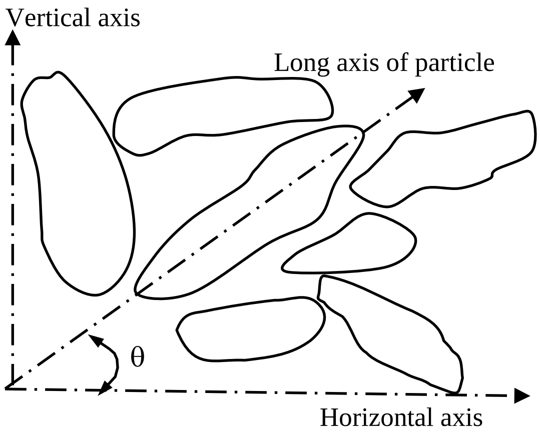


Fig.1. Two dimensional orientation of a sand particle. [3]

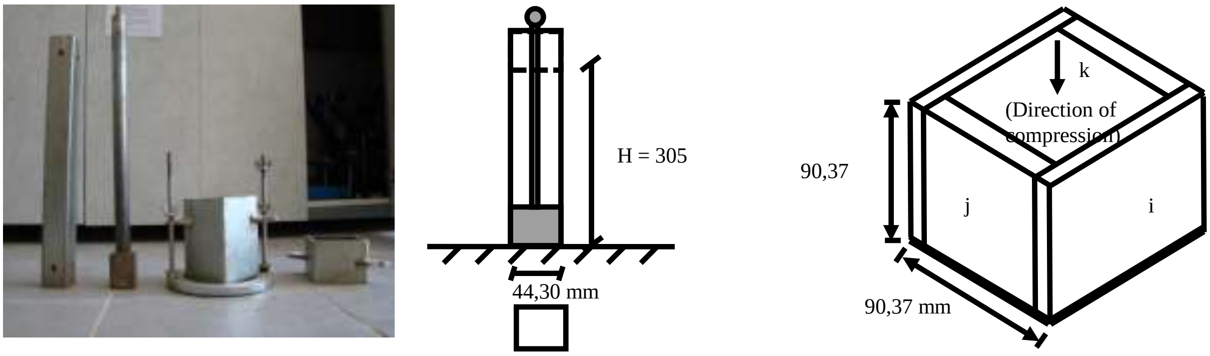
The particles, pores and other constituents of the soils may not preserve their initial fabric and can be reoriented under any stress. These soil constituents are oriented parallel to the shear stress when they are subjected to shear stress and perpendicular to these shear stress when subjected to the compaction and consolidation pressure [12,16,13].

However, in these studies, all of the experimental studies on the changes in the compressive strength values are based on the soil and rock types, fractures, strength properties etc., not on the orientations of the particles, pores and other constituents of the soil. Any available published material on the relations between the orientations of particles and pores in soils and compressive strength measured in the laboratory could not be found. Therefore, they could not make a healthy explanation for the compressive strength values of the horizontal and vertical directions of the soil fabric. In this study, it was explained that the changes in the compressive strength values are related to the orientation positions of the soil constituents. The main purpose of this study is to investigate soil particles and pores orientation during compaction of a clayey soil were correlated with the compressive strength values measured.

II. EXPERIMENTAL PROCEDURE

2.1. Compaction set

In this study, a modified compaction set was produced with a square cross section to investigate the compressive strength effect of the orientation grades of the particles and pores of the soil. It was ensured that the size and properties of this set corresponded to the standard compaction set (Fig. 2)



(a) (b) (c)

Figure. 2. Modifiye Proctor set and its apparatus (a), hammer (b) and mould (c)

The purpose of this tool is to subject the soil samples of which their particles and pores were horizontally oriented by compaction to compressive strength tests from three directions perpendicular to each other without removing the soil samples from the mould so that the soils samples were not disturbed. All surfaces of the mould can be opened and closed again

2.2. Soil

In this study, micaschist soil containing platey and elongated particles were used with fly ash to measure how the particles and pores orientations affected the compressive strength in the compressive strength tests. The reason for using micaschist soil, due to its elongated and platey particles content, is to concretize the orientation using compaction, and the reason for adding thermal power plant fly ash is to eliminate particles orientation during compaction due to the spherical shape of fly as particles. Micaschist clayey soil sample used in this study was obtained from the clay deposit of Ömerli Brook located in Turgutlu (Manisa) in the west of Turkey and the fly ash was obtained from Soma Thermal Power Plant located in the west of Turkey.

2.3. Soil Classification

Quantitative analysis of the clayey soil used in this study revealed that the proportion of smectite (montmorillonite) was 51%, illite 35% and kaolinite 14%. Particle size analysis and Atterberg limit tests were performed according to the Unified Soil Classification System (USCS) for the classification of micaschist clayey soil and fly ash used in the experiments. In these experiments, the standards of the American Society of Testing Materials ASTM D 422-63 (2003) and ASTM D 4318-00 (2003) were followed, respectively [17, 18]. The particle size distribution curves and other index characteristics of the micaschist clayey soil and fly ash are given in Fig. 3, Table.1, respectively.

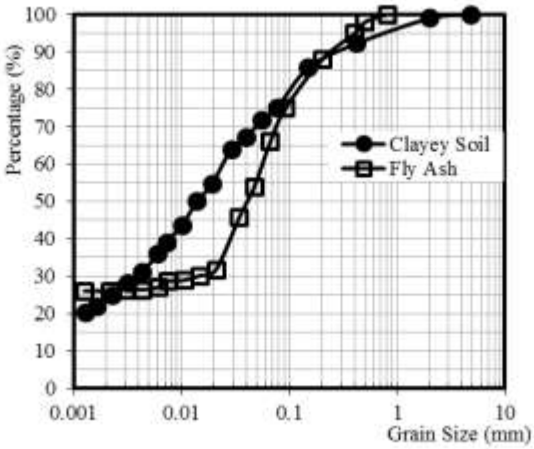


Figure 3. Grain-size distribution for the soil and flay ash used in the study.

Table 1. Clayey soil and fly ash properties

	Clayey soil	Fly ash
maximum dry unit weight (gr/cm^3)	1,73	1,34
optimum moisture content (%)	1,80	29,0
Liquid limit (%)	28,8	--
Plastic limit (%)	22,2	Not plastic
Plasticity index (%)	6,6	--
Specific gravity	2,72	2,32
Particle sizes (%)		
Gravel	1,0	0,0
Sand	26,0	37,0
Milt	51,0	37,0
Clay	22,0	26,0
Soil type (USCS)	CL-ML	CL-ML
Description	Sandy silt-clay	Sandy silt-clay

According to the Unified Soil Classification System (USCS), micaschist soil was classified as well-graded CL-ML (inorganic silty clay with medium and slight plasticity) type inactive soil. Fly ash was classified poorly graded and showed no plasticity.

2.4. Compaction tests

Following the classification tests, to investigate the effects of the orientation of soil particles, pores and other constituents on compressive strength according to ASTM D 698-00a (2003) standards, compaction tests were carried out by laying a single layer of sole micaschist soil or sole fly ash separately onto the compaction mould and compacting the samples. The reason for using a single layer instead of three layers in the compaction procedure and not following the standards is to eliminate the effect of water passage between the layers in the compressive strength tests. Then, the soil mixtures formed by 10%, 20%, 30%, 40%, or 50% fly ash addition to the clayey soil was subjected to the same process (Fig. 4).

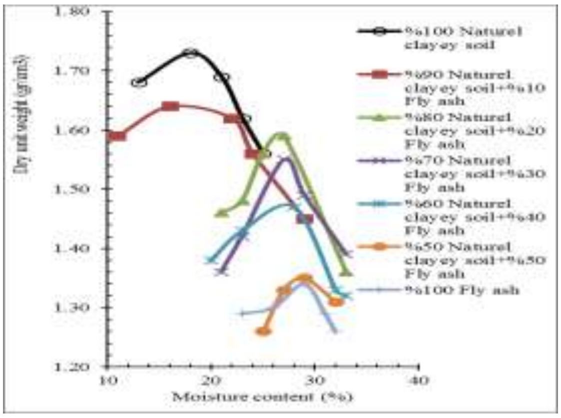


Figure 4. Standard proctor compaction curves for micashist soil, fly ash and mixed soil samples.

As the fly ash addition increases, the optimum water content (w_{opt}) increases but the dry unit weight (γ_k) decreases. The reason for this is the poorly graded spherical shapes of fly ash particles with no plasticity. In the thin section photographs of soil samples removed from the mould without disturbing the soil samples after each compaction stage, taken in the compaction direction, it was seen that platey micaschist particles and other soil constituents were initially distributed and oriented randomly in the clayey soil dough whereas the location and positions of platey micaschist particles tended to oriented in the horizontal direction. The tendency of the soil particles and pores in the thin sections of the standard compaction test specimens are towards the edges, whereas in the middle they are parallel to the applied force (Fig. 5). In the fly ash granules, regardless of the stress, the orientation is not noticeable due to their spherical shapes (Fig. 6).

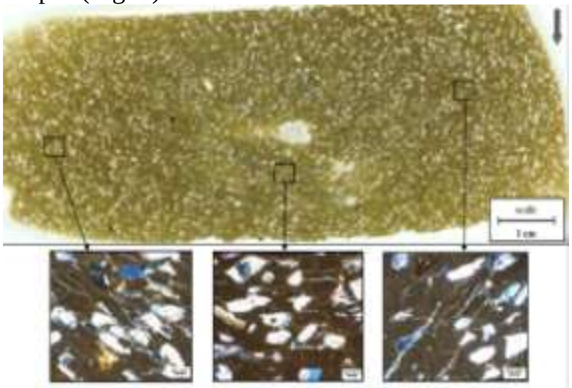


Fig. 5. General view of thin sections area of specimen compacted at 20.8% moisture content showing curved trajectories which are typical of structures seen wet of optimum. Arrow shows axis of compaction towards bottom [13].

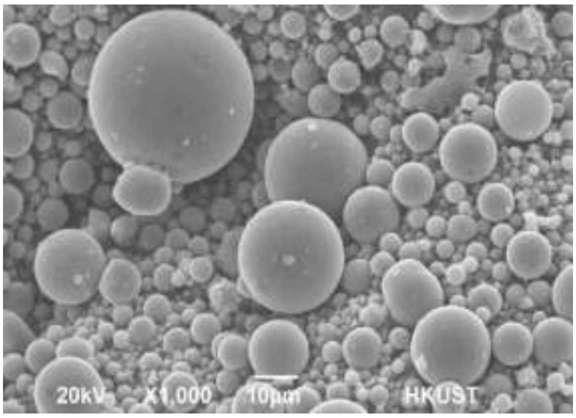


Fig. 6. SEM image of fly ash [19].

The maximum dry unit weight (γ_k) and the optimum water content (w_{opt}) of micaschist clayey soil were determined and soil mixture supplemented with fly ash were laid and compacted again in the square section mould and seven standard proctor tests were carried out. This procedure oriented the long axis of micaschist particles, platey micaschist particles and pores used in the tests in the horizontal direction (Fig. 7).

At the end of each test, the specimens compacted in the optimum water contents were removed from the molds without being spoiled with a hydraulic jack. These samples were then dried at room temperature for use in experiments such as the planned compressive strength tests (Fig. 8 a, b).

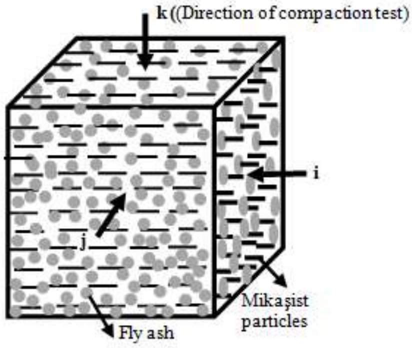


Fig. 7. The symbolic appearance of the soil constituents horizontally oriented compaction sample

(a)

(b)

Fig 8.a) Remove the samples from the mould with a hydraulic jack and b) its dried at room temperature

2.5. Measurment of compressive strength

Compressive strength measurements was performed in the laboratory on direct method (Fig 9). In each experiment, the samples were directly subjected compressive strength tests Compressive strength tests were carried out on samples of which their soil particles, pores and other constituents were oriented close to horizontal direction in cube shaped soil samples obtained by compaction at optimum water contents in the compaction direction and in the two other directions perpendicular to the compaction direction by rotating the soil sample (opposite direction). During each experiment, the compacted sample was rotated 90^0 and the compressive strength test was repeated for each of the three positions (Fig. 10)

Fig. 9. Compressive strength measurements the laboratory on direct method

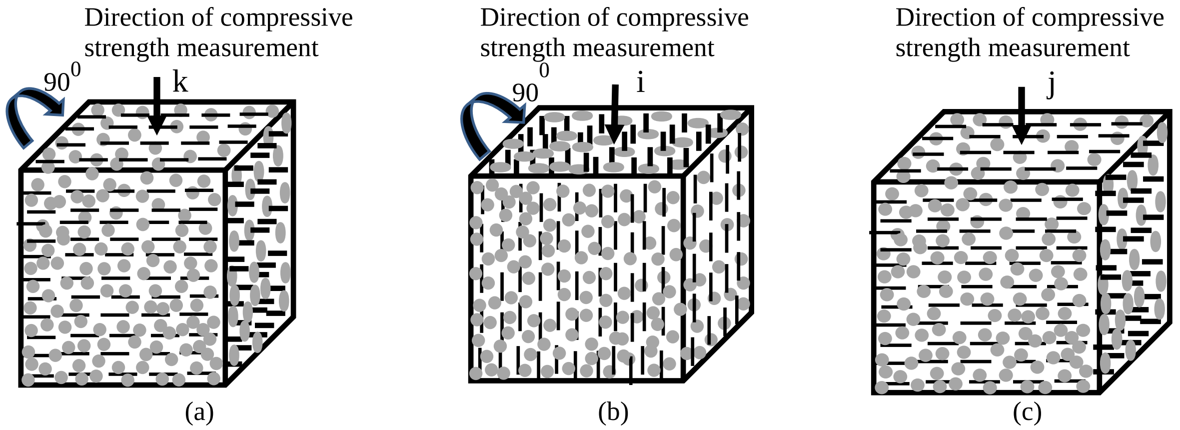


Fig. 10. Compressive strength tests in the direction of compression (a) and in perpendicular to each other two directions (b and c).

Compressive strength tests were carried out on samples having approximate dimensions of 90,37x90,37x90,37 mm^3. Opposing two surfaces of the samples was polished sufficiently to provide good coupling and the compressive strength was measured on the polished opposing surfaces of the samples. And then compressive strength was measured in parallel and perpendicular directions to the soil-oriented particles, pores and other constituents in all samples.

III. RESULTS

The compressive strength of sole micaschist soil in the compaction direction (k) and the compressive strength in the other directions perpendicular to the compaction direction (j) were close to each other and measured to be approximately 1160 kPa. However, the compressive strength on the other direction perpendicular (i) was 1060 kPa, which was 100 kPa smaller (Fig. 11). This appears to be caused by the orientation of the soil constituents. With the spherical fly ash mixture, the compressive strength (i, j and k) on all three directions decrease and the difference between the compressive strengths decreases. Although the compressive strength in all three directions decrease until the ratio of the spherical grain fly ash mixture reaches 20%, i direction values were lower than j and k values. The effect of orientation on the compressive strength completely ceases when the ratio of fly ash reaches 30% due to the spherical shapes of fly ash particles and the compressive strength in each three directions (j and k) decrease and become very close to each other, measured to be approximately 980 kPa. No orientation was observed in the compressive strength tests conducted on sole fly ash due to the spherical shapes of fly ash particles and the compressive strength values in all three directions were found to be equal to each other and measured to 800 kPa (Fig. 11)

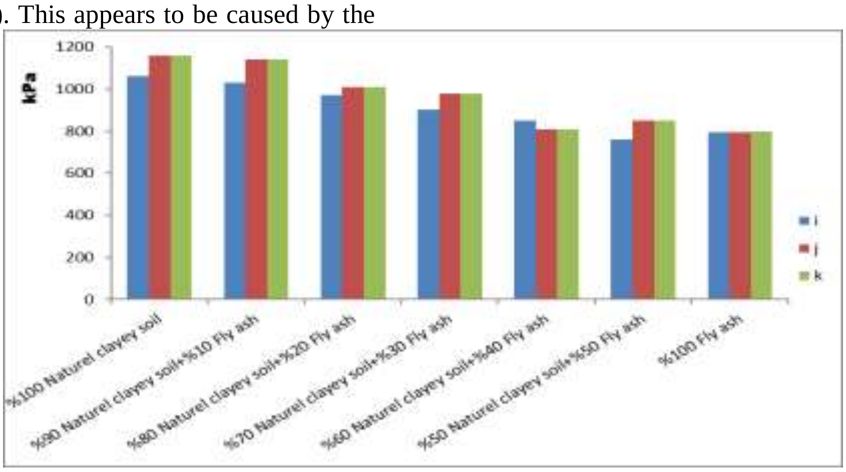


Fig. 11. Compressive strength values in the direction of compression (k) and in perpendicular to each other two directions (j and i)

The tests have shown that the effect of soil particle orientation had a direct effect on compressive strength. Until this day, it has been stated that the other two directions (i, j) perpendicular to the compaction direction were isotropic and their engineering properties were the same, therefore the engineering characteristics of the soil in these two directions have not been distinguished. In this study, it has been shown that, on the contrary to popular belief, the compressive strength may be different in both directions (i, j) in soils containing elongated particle.

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