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The Effect of Mineralogy on Engineering Behaviour of Sand

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This study was conducted as post doctoral study

Abstract
In this study, the changes in the engineering properties of sand with different minerolagical properties were tried to be investigated. Four different sand samples were taken from the Black Sea and Aegean Regions for the experiments. These sands were named as Trabzon, Sinop, Zonguldak and Çine. The engineering and mineralogical properties of the samples were determined. Shear box test and consolidation processes were implemented in order to determined to engineering properties of the sands. Grain distribution was determined with wet mechanical analysis. They were classified as "poorly graded sand". Also, the index properties of the samples like specific weight and dry unit weight were determined. Mineralogical properties were determined by X-RD and SEM. Their origin were determined as sedimentary, magmatic and metaporphic. It was understood that different mineralogical properties cause to different engineering behaviours.
As a result, it was understood that not only the mineralogy but also the marine or river origin are important in the grain distribution, void ratio and odeometre test. However, mineralogy is important in specific gravity, water content, shear box experiment.

Keywords: Sinop, sand, shear box, consolidation, mineralogy

1. Introduction

The soil consists of grains and voids. Voids can be completely or partially filled with water or air. Properties such as formation of soil, geology, size and proportions of granules, stresses affecting ground environments, local conditions, properties of ground water and straticification status make soil behaviour very complicated (Çelik, 2004). Since the soils are geological formations, they are expected to be affacted by geological events. The same physical and mineralogical properties of the two clays may have different compressions. On the other hand, the clay can change its properties over time like other materials (Yüksel, 2007; Yükselen, 2007). The grain forming the natural soils are formed by the mechanical and chemical decompositions of the rocks. The rocks forming the grain have very different mineralogical constructions, and factors leading to divergence are diverse so there are different sizes and forms in natural soils. While more stable minerals in the rocks bring the bigger minerals to produce, less stable minerals turn into secondary minerals, which are the chemical decomposition endings (Özaydın, 2000). There is a close relationship between ground texture and engineering properties. The mineral content, the grain shape and distribution, the grain size distribution and water content can be considered as characteristics which determine the stress-strain behaviour (Sezen, 2003). Microscopic examination of the granular soil may provide an improved understanding of the soil behaviour at the macroscopic scale (Çinicioğlu, 2010). In a monolithic structure, the granules are in contact with each other. The shape, size and relative positions of the grains effect the density of the soil. When fine grains and coarse grains come together, fine grains settle in spaces between coarse grains so that monolayer structures may be loose or tight (Gökoğlu, 2009). The shape of the sand, silt and gravel particles can be sharp-cornered or rounded. Sandstones and graveles are called coarse grain soil. The degrees in the soil have different sizes and shapes and these properties plan an important role in engineering behaviour. Rounded particles are usually found in places where the soil is highly weathered. However, cornered particles are usually found near the rocks forming them (Condulto, 1988). Rock breaking apart and weathering determines the characteristic of the sand grain. For this reason, it is neccesary to know the main rock of the area to determine the characteristics of the sand. Photographs of minerals were taken with an illuminated and

optical microscope.
The content is important in the odometer test for clay and silty material. Each experiment was conducted one or two weeks before the end of the session.
X-Ray diffraction is a widely used method to identify materials of cohesive soils and to determine crystal structures. Thanks to X-ray diffractograms, it is determined what kind of material the sample is made of. Each crystalline material has its own peaks and these peaks are located in certain positions.
Samples were prapared at different stiffness degress and then consolidation tests were carried out. Dense sand is over consolidated compared to the loose sand with normal console features.
The samples were taken from Sinop, Trabzon, Zonguldak and (Çine) Aydın. 10 kg. samples were taken from each area (Figure 1).

Figure 1. Sampling Point

During the field studies, geological maps were used in the fields in addition to observation previously made. Before the experiment, clays were removed with wet mechanical analysis. Specific gravity experiements were conducted to determine void ratio. For shear box test and consolidation, different loads were applied to the samples which have different stiffness values. The volume change values of the samples were determined. Mineralogical evaluations were also made by taking xrd, optical miscroscope and sem views of the samples.
In this study, the changes in the mineralogical properties of the sand samples from different regions and their engineering properties were investigated. Additionally, the mineralogical properties of sand were determined in terms of the engineering behaviour of marine or river origin sands.

2. Comparison of the Mineralogical Properties of Sands
The quartz sand consists of silica granules with a grain size of 1/16-2 mm. It consists of the alteration of siliceous-rich rocks. The sample of sands used in the study were washed so that sands were obtained. As a result of the analysis made on the sand, mineral names and perecentages were determined. If the SiO_2 ratio is high, it means that sand is of good quality and clean so it is preferable to wash the sand before the experiment. It is possible for SiO_2 ratio to increase after washing due to the relative decrease in fine materials and relative increase in SiO_2 ratio. This ratio is also increasing in the samples taken from the sea. During the experiements, character changes were observed in the materials which are under load. It has been determined that size of granule decreased to below 2 mm. However, the fact that it has the size of a clay does not neccesarily mean that it will mineralogically behave like a clay. In this study, side rocks and formation basins have been taken into consideration in the selection of the sample. Sand samples have been taken from eastern, central and western regions of The Black Sea Region and a river bed in Aegean region. Trabzon sand is volcano-sedimentary series, Sinop and Zonguldak sands are located in sedimanter basin and Çine sand is located in a metamorphic area.
In order to understand the mineralogy of the sand used in the study, sem X-ray diffraction (XRD analysis), epi-illimunination and binocular optical microscopes were used for analysis. XRD was used to determine SiO_2 values of the sand. If the amount of SiO_2 is high, this shows the amount of quartz contained in the sample. These values were compared to the studies performed with XRD and binocular microscope.
It is determined that SiO_2 values of the sand ratio in the sea sand is higher than river sand. At the end of the analysis, the following results have been obtained; Sinop sand consists of quartz, anorthile,

muscovite; Trabzon sand consists of anorthoclase, augite, hedenbergeite, diopside, fayalite; Zonguldak sand consists of quartz, anorthite; Çine sand consists of quartz, anorthite, muscovite and anorthclase minerals (Table 1).

Table 1. Xrd results of Sinop, Trabzon, Zonguldak and Çine sand

Mineral and Formula	Sinop	Trabzon	Zonguldak	Çine
Kuvars SiO_2	X		X	X
Anortit $CaAl_2Si_2O_8$	X		X	X
Muskovit $KAl_2Si_3AlO_{10}(OH)_2$	X			X
Anortoklas $(Na, K)(Si_3Al)O_8$		X		X
Ojit $Ca (Mg, Fe) Si_2O_6)$		X		
Ojit $Ca (Mg, Fe, Al) (Si, Al)_2O_6$		X		
Hedenberjit $CaFe^{+2} Si_2O_6$		X		
Diyopsit $Ca (Mg, Al) (Si, Al)_2O_6$		X		
Fayalit $Fe^{+2} SiO_4$		X		

Sinop, Trabzon and Çine sand have similiar mineralogical contents but Trabzon sand has a different mineralogical structure. SEM images of the sands have been taken to examine the grain structure. According to the figure classification, Sinop and Zonguldak sands have angular grain. Çine sand generally consists of semi-angular and semi-rounded granules and Trabzon sand generally consists of sharp-shaped corners. Trabzon sand is composed of dark colored granules and Çine sand is composed of light colored granules. While Sinop and Zonguldak sands have similiar images, Sinop sand has larger grains than Zonguldak sand.
Sinop and Zonguldak sands are sedimantian, Trabzon sand is volcanic and Çine sand is metamorphic. As a result, it can be understood that not only the geology of sand but also the sample location (sea or river) is effective on mineralogy.

3. Comparison of Engineering Properties of Sands

Wet mechanical analysis was performed on the sands to be used in the experiments. Index properties were determined to prepare samples at different stiffness values. Shear Box and consolidation experiments were conducted. Test results were compared.

3.1 Comparison of Index Properties

The void ratio (e) is one of the important and fundamental parameters governing the geotechnical behavior of a soil. Significant differences are observed in characteristics of the strength or compressibility of a soil with the same void ratio. One of the reasons for such different behavior is caused by a difference in the arrangement of the soil particles, even at the same void ratio. Pore size distribution (PSD) of soils can be determined quantitatively by mercury intrusion porosimetry method. It is postulated that some soil index properties have influence on the pore size distribution of soils. The index properties of the sand used in the experiments were determined by laboratory tests (Table 2).

Table 2. Maximum dry density–minimum void ratio, maximum dry density-minimum void ratio and Gs

Sand	dmax	emin	dmin	emax	Gs
Sinop	1.706	0.550	1.48	0.851	2.74
Zonguldak	1.710	0.596	1.498	0.850	2.75
Trabzon	2.061	0.660	1.800	0.910	3.44
Çine	1.715	0.596	1.427	0.931	2.75

The specific gravity of the sand used in the experiment varies between 2.74 – 3.44. XRD results show that iron, mica and muscovite minerals formed in sand samples give high specific gravity. Specific gravity values depend on mineral content and grain size. Trabzon sand has the highest Gs value with 3.44. The other three sands show standart values. Çine has the minimum and maximum void ratio values.

3.2 Comparison of Sieve Analysis Results

In the study, clean sand was prepared using 200 mesh sieve. Clay particles sticking to the sand particles were removed by a washing sieve analysis. It has been determined that "SP" is poorly graded for the four sand samples. When the results of sieve analysis were evaluated, it was determined that Sinop sand has the coarse material and Çine sand has the fine material (Table 3). While Trabzon and Zonguldak show similiar grain distributions, Çine and Sinop show differences. While the sands of Trabzon, Zonguldak and Sinop are composed of medium and coarse grains, Çine sand is composed of fine and medium grains. Cr and Cy values of sand were calculated. Sinop, Trabzon and Zonguldak gave similiar valuesbut Çine sand showed a change (Table 3).

Table 3. Particle distributions of sand

Tanım	Sinop	Trabzon	Zonguldak	Çine
$Sand_{Fine}$	%88	%94	%94	%54
$Sand_{Medium}$	%12	%06	%06	%46
$Sand_{Coarse}$	%0	%0	%0	%0

Both of Trabzon and Zonguldak marine sands gave similiar results. Çine sand has river sediments and behaves differently compared to sea sands.Sinop sand has both marine and river sediments. For this reason, it behaves in both ways. It was determined that the environment of formation is effective in grain distribution rather than origin.

For the odometer test, the void ratio values were calculated at different tightness values. It was determined that in all sand experiments initiated with different starting void ratios, the experimental end void ratio reached a smaller value. Volumetric compression coefficients were calculated for these samples prepared at different stiffness values. At the end of the experiment, the sand samples lost more volume. Sands from different regions have different deforming behaviours at the same load level because they have different stiffness values. At the same load level, the volumetric compression coefficient (mv) values and volume changes reduced as the sand gap ratio increased. At the same Δp load increment but different load stages, the ground reaction was not the same. This process has tried to determine the differences in the strenght of sand samples by applying four different origions.

Experimental studies have attempted determine whether the mineralogy of the material is important and how many sand samples may be exposed in the selection of sand samples. In this study, the relationship between the volume change behaviour and the first void ratio and void ratio change revealed. It has been seen that the effect of the initial void ratio in volume change properties of the soil is undeniable. In the study, the independent variables – stiffness and the stress – and the volumetric stiffness coefficient values depending on them were calculated. The values of volumetric stiffness (mv), stress level and water content of each sample obtained from the different consolidation tests that were carried out on sand samples were determined. Samples were prapared at different stiffness by determining the initial voit ratios of four sand samples. At the end of the experiment, the values were calculated all mv final values are close to zero.

3.2.1 Trabzon Sand

Trabzon sand used in the study was prepared at 40%, 58%, 61% and 73% density. At the end of the experiment, an average of %27 compression was observed. The change in the void ratio is an average of 0,1. The volume unit deformation coefficient was 40%, 58%, 61% and 73% respectively.

3.2.2 Sinop Sand

Sinop sand used in the study was prepared at 40%, 52%, 83% and 85% density. At the end of the experiment, the samples prepared at the consistency of 40% and 52% were tightened by an average of 34.5% while the samples prepared at 83% and 85% tightness were tightened by an average of 16% at the end of the experiment. The change in void ratio gives an average value of 0.12 for sample prepared at 40% and 52% density at the end of the experiment and 0.06 for samples prepared at 83% and 85 % density. The volume deformation coefficient gave a higher value at 40% and 52% but it gave lower value at 83% and 85%. The results show that the samples prepared at low density for this sand are more compacting than the samples prepared at high density. Therefore, as the values for sample prepared at nominal density in the void ratio increase to higher values, they give low values for high density. The volume deformation coefficient gives a high value at nominal density and low values at high density.

3.2.3 Zonguldak Sand

Zonguldak sand used in the study was prepared at 40%, 58%, 60%, 65% and 70% density. At the end of the experiment, the void prepared at 40% density was 60% tightened, while the void prepared at 58%, 60%, 65% and 70% densities were tightened by 35 % on average at the end of the experiment. The change in void ratio gives 0.16 for the sample prepared at 40% consistency at the end of the experiment and 0.092 for the samples prepared at 58%, 60%, 65% and 70% density. The volume deformation coefficient gives a higher value at 40% and 58% while it gives a lower value at 60%, 65% and 70% density. The results show that the sample prepared at low density is more pressed than the sample prepared at high density. The results show that the sample prepared at low density is more compressed than the sample prepared at high density. The volume deformation coefficient was 40% and 58% respectively while the values were 60%, 65% and 70% respectively.

3.2.4 Çine Sand

Çine sand used in the study was prepared at 40%, 61% and 70% density. At the end of the experiment, the specimens prepared at 40% tightness were compressed by 48% while the specimens prepared at 61%, 65% and 70% tightness were compressed by 35% on average at the end of the experiment. The change in void ratio is 0.597 for the sample prepared at the end of the test and 45% and 0.129 for the samples prepared at the stiffness of 61%, 65% and 70%. The volume unit deformation coefficient gave a higher value at 40% and 58% tightness, 60%, 65% and 68% respectively. The results show that sample prepared at low tightness is more compressible than the sample prepared at high density. Therefore, while the void ratios give high values for the sample prepared at low density, they give low values for high density. The volume unit deformation coefficient gives close values for all stiffness values. The experiment was completed in a short time (two hours) and the value of water content did not matter. Even so, the water contents were determined at the end of the odometer test made with the sand material (Table 4).

Table 5. Water content of consolidated sand after the experiment

Trabzon		**Sinop**		**Zonguldak**		**Çine**	
%W	**Dr**	**%W**	**Dr**	**%W**	**Dr**	**%W**	**Dr**
23.418	55%	25.248	48%	26.301	40%	24.725	45%
22.440	58%	25.961	52%	25.857	58%	24.971	61%
23.187	61%	24.611	83%	24.984	60%	24.231	65%

The values of water content were not taken into account in the odometer results for the sand but values were calculated in order to follow the change. Trabzon sand, which is different than the others has 23.01 % water content while Sinop sand has 25.27%, Zonguldak sand has 25.71% and Çine sand has 24.64% water content. As the value of density increases, the ratio for the same sand decreases. At low density,

Çine sand shows similiar properties to Sinop sand while Çine sand with high density shows similiar characteristics to Zonguldak sand. Trabzon sand which is completely different than the other sands gave higher values than the others.

3.3 Comparison of Shear Box Results

Cohesion was not includen in calculations due to low value of cohesion in sandy experiments. Low cohesion values were obtained in specimens prepared with different density values between 30% and 90%. Cohesion gave negative value for all sand types, particularly at low density. Cohesion increased positively with the increase in density. The internal friction angles were determined for each sand according to the density interval values.

The maximum difference in the angle of internal friction belongs to Çine sand. This sand is a river sand unlike other sands. The main reason why it is different is that the shape of the grain is different. Sinop sand also shows difference in terms of angle of internal friction. There are also irregularities in the shape of the grain. The internal friction angle obtained from each sand is presented in Table 5.

Table 7. Change of internal friction angles according to density intervals

Type	%40-50	%50-60	%60-70	%70-80	%80-90
Trabzon	33	33-34	36	36-37	37
Sinop	33-34	35	36	37	39
Çine	31	31-32	33	37	37
Zonguldak	34	35	35-36	42	

4. Result

It has been determined that Sinop, Trabzon and Zonguldak sands from medium and fine granules of the sand used in the study and fine and medium sand of Çine mound are formed. As a result of the experiments, it was determined that the change of the grain percentages with the sieve analysis has such

an effect that the fine and medium grains have increased.
All the sand used in the experiment have been classified as “poorly graded sand”. Trabzon and Zonguldak sand have 94% Fİne-grains, 06% medium grains; Sinop has 88% Fine and 12% medium grains; Çine has 54% fine, and 65%medium grains. Sinop has the thinnest grained material and Sinop has the thickest grained material. Trabzon and Zonguldak sands showed similiar distributions. Not only mineralogy but also the marine and river origin is effective in the grain distribution.
Specific gravity values of the sands are between 2.60 and 2.75. The specific weights of the sand used in the experiment vary between 2.74 -3.44. Sinop, Zonguldak and Çine sands have specific gravity values of 2.74 and 2.75 because of their muscovite incontent. Trabzon has a specific weight of 3.44. Its augite content caused it to have a specific weight at high values. Sand mineralogy is important in specific gravity rather than its origin.
The void ratio is usually between 0.5-0.9 in sand. It is not predicted that the precentage of vacancies in sand is less than 0.3 and not more than 1.2 (Genç, 2008). The minimum void ratio of the sand used in the study are between 0.550 and 0.660 and the maximum void ratio values are between 0.850 and 0.931. In other words, with the values of 0.550-0.931, it conforms to the standarts. Çine (river sand) has the largest void ratio value. The differences between the maximum and minimum void ratio values are as follows; Trabzon=0,250, Sinop 5=0,300, Zonguldak, 0,254 and Çine 13: 0,335. As the value of density increases, the e ratio for the same sand decreases. At low density, Çine sand shows similiar properties to Sinop sand while Çine sand with high density shows similiar characteristicts to Zonguldak sand. Trabzon sand, which is completely different than other sands, gave higher values than the others. Origin is more effective than mineralogy in terms of void ratio.

5. Discussions

Sands consist of granules which have different sizes and shapes. It also varies according to the its basin and origins. In this study, the effects of properties of sand on the engineering behaviours have been examined.
As a result of the odometer test, it has been determined that all sands except for Çine sand crushed under 3.2 mPa. An increase in the amount of fine sand at lowest density value has not been detected even under the highest pressure applied to the Çine sand. It has been found that the lowest value of fine sand increases by 6% when Trabzon and Zonguldak sands have been applied under the maximum pressure. Sinop sand has been found to have a 10% increase in fine sand value at the lowest density value under a pressure of 3.2 mPa. As a result, it has been determined that the environment of formation is effected by crushing rather than origin. The river sand is composed of more angular grains the sea sand. For this reason, the strenght of Çine sand was higher than the others. They are poorly graded sands so their internal frictions are high. Even a small amount of mans affect soil behaviour. Sinop, Zonguldak and Çine contain mica. This experiment also affected the origin, not the mineralogy.
The values of water content weren’t taken into account in the odometer results for the sand but the values were calculated in order to follow the changes according to the sand. Trabzon sand, which is different than the other sands, has 23.01% water content. Different mineralogical properties have been effective in water content.
There were not any round particles in all the four sands used in the study. This shows that they were not wearing too much and that they were in a nearby area. Trabzon has the most cornered grains. Mineral content causes high resistance to other sand. As it was taken from sea edge, Çine sand has rounded granules due to the effect of transportation and wear. Sinop sand is both marine and alluvial although it was taken from the sea side. It is expected that Trabzon sand will have the highest cutting strenght and Chine sand will have the lowest shear-box test results.
Cohesion were not included in calculations due to low value of cohesion in sandy experiments. Low cohesion values were obtained in specimens prepared with different density values between 30% and 90%. Cohesion is negative for all sand, particulary at low density. Cohesion has increased positively with the increase in density. Çine has the biggest difference in the angle of internal fraction. This sand is a river sand unlike other sands. The main reason for the difference is that the shape of the beans is different. As a result, the mineralogic strain is effective for the shear box experiment.

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