International Journal of Earth Sciences Knowledge and Applications (2020) 2 (2) 92-101

IJESKA
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www.ijeska.com
ISSN: 2687-5993

International Journal of Earth Sciences Knowledge and Applications

RESEARCH ARTICLE

The Effects of Quartzite on the Swelling Behaviors of Compacted Clayey Soils

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INFORMATION

Article history
Received 02 June 2020
Revised 24 June 2020
Accepted 25 June 2020
Available 01 August 2020

Keywords
Clayey soil
Quartzite
Soil stabilization
Swelling potential
Swelling pressure

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ABSTRACT

The expansive soils have significant volume change associated with changes in water content. These soils be exposed to adverse changes in volume and hydraulic conductivity due to the seasonal changes in moisture content. Lightweight structures are severely affected due to high swelling pressure exerted by these soils. To prevent the damage of the constructions built on the expansive soils, these soils is improved in terms of the engineering properties. Soil stabilization is one of the most widely followed techniques to control the swelling behavior of expansive soils in lightly loaded structures. In this study, an expansive soil was stabilized by using quartzite as additive material. To determine the effects of quartzite on the swelling characteristics of stabilized clayey soils a series of tests were performed on the natural and stabilized samples with different percentages of quartzite material. For this purpose, the consistency limit tests, odometer tests and vertical swelling tests were carried out under the laboratory conditions. According to the results of experimental study showed that the swelling behavior of quartzite-stabilized clayey soil samples changed. The results of experimental study showed that the swelling pressure values, the swelling pressure values and the vertical swelling percentage values of quartzite-stabilized clayey soil samples decreased due to the addition of quartzite. As a result, the quartzite played an important role in improving the swelling behavior of the expansive soils. The test results showed that the quartzite material can be successfully used to improve the swelling characteristics of expansive soils.

1. Introduction

Expansive soils, frequently encountered in arid and semi-arid regions of the globe, are known to exhibit large volume changes. These soils have significant volume change associated with changes in water contents (Nelson and Miller, 1992; Ito and Azam, 2010; Jones and Jefferson, 2012). These soils primarily composed of expansive clay minerals exhibit high water absorbing and water retention abilities (Ito and Azam, 2009). These types of soil widely distributed throughout the world (Huang and Wu, 2007; Sabtan, 2005) are especially abundant in arid zones, where conditions are suitable for the formation of clayey minerals of the smectite group such as montmorillonite or some types of illites (Avsar et al., 2009; Nowamooz and Masrouri, 2008; Sabtan, 2005). These clays are characterized by having a very small particle size, a large specific surface area (SSA) and a high Cation Exchange Capacity (CEC) (Nalbantoglu and Gucbilmez, 2001; Nalbantoglu, 2004; Fityus and Buzzi, 2009; Seco et al., 2011). The mica-like group including illites and vermiculites can be expansive but generally does not cause significant problems (Zhang and Cao, 2002).

Volumetric changes of expansive soils in presence of water are undesirable due to stability reasons (Chen, 1975; Sridharan et al., 1986; Nagaraj et al., 2010). Expansive soils be exposed to adverse changes in volume and hydraulic conductivity due to the seasonal changes in moisture content (Sharma and Phanikumar, 2005; Puppala et al., 2006; Soundara and Robinson, 2009; Öncü and Bilsel, 2017). The expansive soils swell by absorbing water in wet season while they shrink when water gets evaporated in dry seasons (Chen, 1988; Nelson and Miller, 1992; Madhyannapu and Puppala, 2014). The rate of swelling potential depends on the coefficient of permeability, thickness and soil properties. The amount of swell to satisfy the suction pressure depends on the magnitude of the vertical loading and soil properties that include soil composition, natural water content and density, and soil structure (Chen, 1975; Sridharan et al., 1986; Nagaraj et al., 2010).

The effect of wetting and drying cycles in expansive soil is to cause swell-shrink actions resulting in undesirable volume changes depending upon the stress history and suction (Gens and Alonso, 1992; Singhal et al., 2015; Wang and Wei, 2015; Zhang et al., 2016). The cyclic swell-shrink behaviour causes great distress to rigid and flexible structures laid on expansive soils if it is not controlled (Katti, 1978; Rao et al., 2001; Yazdandoust and Yasrobi, 2010; Kayabali and Demir, 2011; Selvakumar and Soundara, 2019; Yarbaşı et al., 2007; Yarbaşı and Kalkan, 2020). If a structure is founded on such expansive soils, then its presence along with the foundation prevents this volume increase and as a consequence, leads to swelling pressure. This swelling pressure has serious consequences in the form of cracks and distress on the structures founded on expansive soils. Lightweight structures are severely affected due to high swelling pressure exerted by these soils. These aspects of swelling and their consequences on building have been well documented in the literature (Chen, 1975; Sridharan et al., 1986; Nagaraj et al., 2010).

There are three types of factors relating to the swelling of expansive soils. These factors are geology, the engineering factors of the soil, and local environmental conditions (Seco et al., 2011). While geology primarily determines the presence in the soil of these types of expansive clay minerals but the soil moisture content, plasticity and dry density are among the factors affecting the engineering properties of soil. The amount of the clay fraction in the soil, its initial moisture conditions and confining pressure are the most important local environmental conditions. These factors must be considered at the geoenvironmental and related applications (Sabtan, 2005; Kalkan and Bayraktutan, 2008; Seco et al., 2011). The volume changes in the expansive soils are a major cause of natural disasters, since they cause extensive damage to the superstructure and infrastructure (Chen et al., 2007; Assadi and Shahaboddin, 2009; Avsaret al., 2009; Huang and Wu, 2007; Ferber et al., 2009; Seco et al., 2011).

Although it has been noted in the literature that the expansive soils may result in considerable distress and consequently, in severe damage to overlying structures, particularly to single-family residential buildings and buried lifelines (Erguler and Ulusay, 2003; Sabtan, 2005; Kalkan and Bayraktutan, 2008; Kalkan and Akbulut, 2004; Kalkan, 2009a; Kalkan, 2011; Kalkan, 2013), they are very important in geology, construction, and environmental applications due to their wide usages as impermeable and containment barriers in landfill areas and other environment-related applications (Keith and Murray, 1994; Murray 2000; Kalkan, 2018).

To prevent the damage of the constructions built on the expansive soils, these soils is improved in terms of the geotechnical properties. Soil stabilization is one of the most widely followed techniques to control the swelling behavior of expansive soils in lightly loaded structures (Selvakumar and Soundara, 2019). The stabilization techniques to control the swelling characteristics in expansive soils can be grouped into mechanical, chemical and polymer as well as unconventional stabilizer methods (Petry and Little, 2002; Akbulut et al., 2007; Ikizler et al., 2009; Estabragh et al., 2014; Kalkan et al., 2019; Kalkan, 2020; Yarbaşı and Kalkan, 2020). In the chemical stabilization, some additives such as lime, cement, fly ash, silica fume etc., are added, which physically interacts with the soil and change the index properties (Chen, 1988; Çokça, 2001; Kalkan and Akbulut, 2004; Kalkan, 2009; Kalkan, 2011; Jamsawang et al., 2017; Chittoori et al., 2018; Kalkan et al., 2019). In recent times, the use of polymer based product such as geosynthetics in expansive soil stabilization (Al-Omari and Hamodi, 1991; Sharma and Phanikumar, 2005; Viswanadham et al., 2009; Buzzi et al., 2010) is widely practiced due to their desirable properties and durability (Jewell, 1991; Koerner, 1999; Selvakumar and Soundara, 2019).

In this study, an expansive soil was stabilized by using quartzite as additive material. Aim of this experimental study carried out under laboratory condition was to determine the effects of quartzite on the swelling characteristics of stabilized clayey soils. To accomplish this aim, a series of tests were performed on the natural and stabilized samples with different percentages of quartzite material.

2. Material and Methods

2.1. Main material

In this study, the clayey soil was used as main material for stabilization of expansive soil. The clayey soil was supplied from the clay deposits of Oltu Oligocene sedimentary basin, Erzurum, NE Turkey. The clay-rich sedimentary basin is deposited in shallow marine and lagoonar mixed environments. In this basin, the smectite group clay minerals are abundance it consists of montmorillonite, nontronite, halloysite, palygorskite, and hydrobiotite. This soil is defined as high plasticity soil according to the Unified Soil Classification System (Akbulut, 1999; Kalkan, 2003; Kalkan and Bayraktutan, 2008). Its granulometry curve and X-ray diffraction pattern was given in Fig. 1 and Fig. 2.

2.2. Additive material

The quartzite was additive material of this experimental study. The expansive clayey soil was stabilized by using this material. It was supplied from Demirözü district of Bayburt, NE Turkey. It is a metamorphic rock formed by compaction and recrystallization of quartz sandstone. This quartzite, which has an ortho-quartzite formation, contains feldspar, mica, clay, magnetite, hematite, garnet rutile and limestone. There is more than 95% quartz in its composition (Kalkan et al., 2019). Its granulometry curve and X-ray diffraction pattern was given in Fig. 1 and Fig. 3.

2.3. Sample preparation

The clayey soil and quartzite were milled and dried before preparing their mixtures. Then, to prepare mixtures of clayey soil and quartzite, they were blended under dry conditions. The amounts of quartzite material were selected to be 3%, 5%, 7% and 10% of the total dry weight of the mixtures. The dry mixtures were mixed with the required amount of water that recognized to give the optimum moisture content (Kalkan, 2009a). All mixing was done manually and proper care was taken to prepare homogeneous mixtures at each stage.

The samples of swelling pressure, swelling potential and vertical swelling tests were prepared by compacting technic at optimum moisture content. The compaction process was carried out by using the Standard Proctor apparatus in its standard mold (ASTM D 698, 1995). The samples for tests were taken from the compacted mixtures in the mold by using cylindrical metal samplers. The mixtures of dry clayey soil and quartzite were then blended with the required amount of water for optimum water content. All blending was done manually and proper care was taken to prepare homogeneous mixtures at each stage of blending. The mixtures of clayey soil-quartzite were compacted at optimum water content to obtain the stabilized clayey soil samples. For swelling tests, cylindrical metal molds of 70 mm in diameter and 20 mm high were used to prepare samples for each combination of clayey soil and clayey soil-quartzite mixtures. The swelling tests were carried out in accordance with ASTM D 4546 (1990). For vertical swelling percentage tests, cylindrical samples with 35 mm in diameter and 55 mm in length in metal molds of the same size were prepared from compacted samples using the Standard Proctor molds.

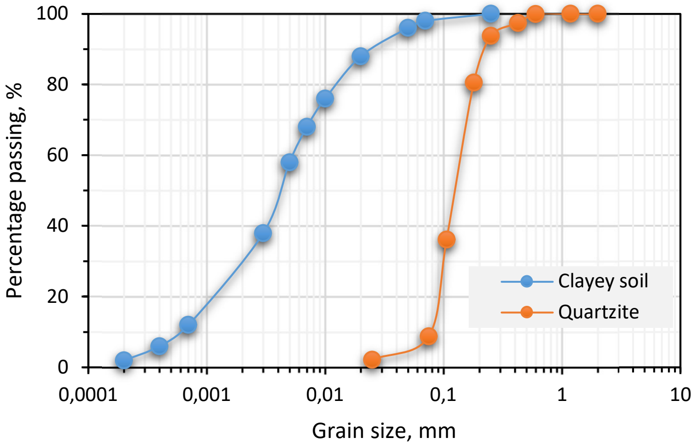

Fig. 1. The grain size distributions of clayey soil and quartzite

2.4. Atterberg tests

In soil mechanics, the consistency limits are the most distinctive and the easiest property of fine-grained soils to measure. As they depend on the same physical factors as the other mechanical properties of soils, the values of the liquid and plastic limits would be a very convenient basis for their prediction (Dolinar and Škrabl, 2013). The consistency limits of clayey soils are determined by Atterberg tests. In this experimental study, the natural and quartzite-stabilized clayey soil samples were subjected to liquid limit and plastic limit tests in accordance with the ASTM D 4318 (1995).

2.5. Swelling pressure test

To determine the effects of quartzite on the swelling pressure values of stabilized expansive soils, the swelling pressure tests were performed in the standard one-dimensional oedometer apparatus in accordance with ASTM D 4546 (1990). The samples were laterally restrained to prevent their lateral expansion and axially loaded in a consolidometer with access to free water. The samples were inundated and allowed to vertically swell at a nominal seating pressure until primary swell is complete. Then, the loading was incrementally lperformed to cancel the deformation due to swelling (Ito and Azam, 2010; Kalkan, 2011). The swelling pressure of each sample was directly measured from the surcharge, which loads the sample. The sample was confined in the consolidation ring of 74 mm diameter and 20 mm high, and water was allowed to flow into the sample. The samples were submerged in water. The deflection of the dial gauge was set to zero. As a result, when the samples showed no further tendency to swell, the maximum surcharge load, PMS, at that point was used for the calculation of the swelling pressure. The swelling pressure was calculated by Eq. 1.

$$S_{PR} = {}^{P_{MS}}/_{A} \qquad (1)$$

In the Eq. 1, the S_{PR} is the swelling pressure, the P_{MS} is the maximum surcharge load on the sample and the A refers the area of sample.

2.6. Swelling potential tests

It is generally recognized that the best indication of the susceptibility of a soil to shrinkage or swelling due to decreases or increases in moisture content is provided by the swelling potential test (Carter and Bentley, 2016). The swelling potential tests were carried out in a similar way as swelling pressure test. However, the sample was allowed to swell under a small load. The samples were loaded to a static pressure of 0.7 kPa. The natural and stabilized clayey soil samples were submerged in pure water. The samples were allowed to swell under the initial seating load. The dial gauge readings were recorded periodically until there were no further changes in swelling. The swelling percentage values was calculated by Eq. 2.

$$S_{PT} = {}^{H_{MS}}/_{H_{OT}} \qquad (2)$$

In the Eq. 2, the S_{PT} is the swelling percentage, the H_{MS} is the axial expansion and the H_{OT} refers the original thickness of the sample.

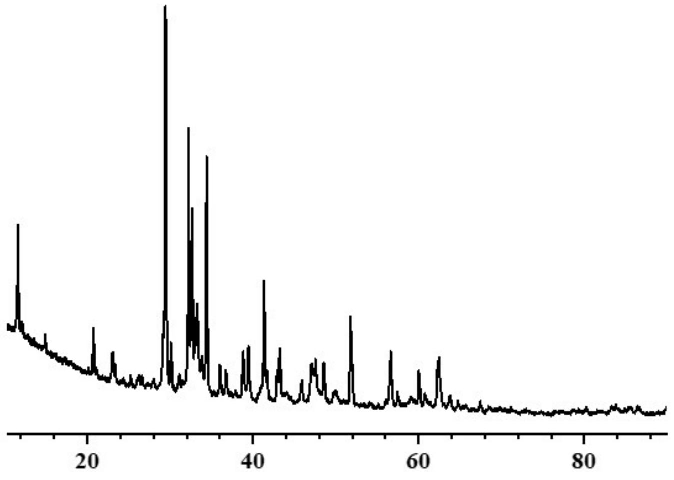

Fig. 2. The X-ray diffraction pattern of clayey soil

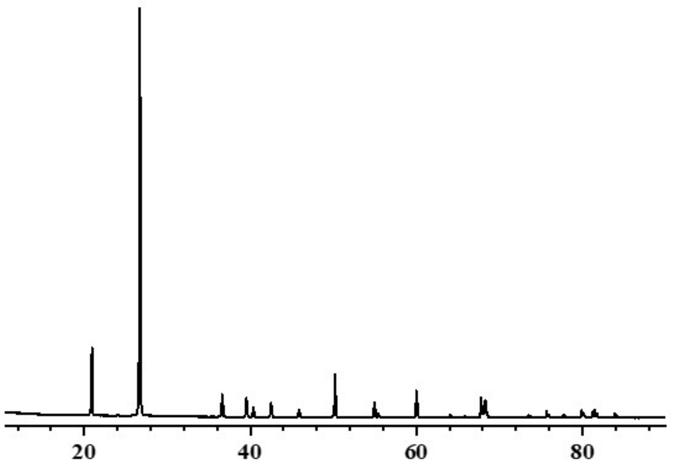

Fig. 3. The X-ray diffraction pattern of quartzite

2.7. Vertical swelling tests

The unstabilized and stabilized samples were tested to obtain the vertical swelling percentages. The samples used for the vertical swelling percentage tests were first compacted at optimum moisture content and then extruded through a cylindrical mold with a 35 mm diameter and 70 mm height. The upper sides of the cylindrical samples in the cylindrical mold were trimmed. The remaining height of the new samples was 55 mm. The upper empty space (15 mm) of the cylindrical mold was filled with water. Afterwards, these samples were left to swell for 48 h. At the end of the tests, the amount of swelling was measured in each sample. The amount of vertical swelling reported as a percentage was calculated (ASTM D 4546, 1990). The values of vertical swelling percentage were calculated by Eq. 3.

$$S_{VP} = {(L_2 - L_1)}/{L_1} * 100 \qquad (3)$$

In the Eq. 3, the S_{VP} is the percent vertical swelling, the L_1 is first height of sample before the addition of water and the L_2 refers the final height of sample after it had been allowed to swell for 48 h.

3. Results and Discussions

3.1. The effect of quartzite on the consistency limits

The effects of quartzite on the consistency limits such as liquid limit, plastic limit, and plasticity index of the unstabilized and quartzite-stabilized samples are presented in Fig. 4. The results of Atterberg limits tests showed that the quartzite decrease the consistency limits of stabilized samples values comparing with that of the unstabilized clayey soils. With the addition of the quartzite to the clayey soil samples, the clay content, CEC and organic matter content changed in the clayey soil samples and the plasticity index values decreased. de la Rosa (1979) and Seybold et al. (2008) were obtained the same findings and mentioned that the clay content, cation exchange capacity and organic matter had significant influences on plasticity index variability in the clayey soils. There are significant positive correlations between liquid limit, plastic limit and plasticity index and clay content (Mbagwa and Abeh, 1998; Dexter et al., 2008; Zolfaghari et al., 2015).

On the plasticity chart, clayey soil used was in the high-plasticity soil group (CH), according to the Unified Soil Classification System (USCS). After stabilizing, the soil group changed from high-plasticity soil group (CH) to low-plasticity soil groups (MH) due to the change in consistency limits. There are similar results obtained from clayey soil stabilization by using solid additives (Kalkan and Akbulut, 2004; Kalkan, 2009a; Kalkan, 2011).

3.2. The effect of quartzite on the swelling pressure

The effects of quartzite on the swelling pressure values of stabilized clayey soil samples are presented in the Fig. 5. It was observed that the swelling pressure values steadily decreased with increasing in the quartzite content. The decreasing of swelling pressure continued very rapidly up to 7.5% content and then it was very slowly.

The decrease in the swelling pressure values of the quartzite-stabilized clayey soil samples was attributed to the addition of low-plastic materials and the interaction between clay and quartzite particles. Several studies indicate that a number of engineering properties of clayey soils are controlled by the CEC, SSA and pH (Eades, 1962; Erzin and Erol, 2007). There is a linear relationship between CEC and liquid limit. Similarly, there is a linear relationship between SSA and liquid limit (Churchman and Burke, 1991; Locat et al., 1984; Ohtsubo et al., 1983; Sridharan et al., 1988). The decrease in the CEC and SSA values due to the addition of the quartzite.

The addition of the quartzite to the clayey soil decreased the liquid limit values (Kalkan, 2009b). When the quartzite is added to clayey soil, the pH values increase. The increase in pH values decreases the relative clay mineral contents in the quartzite-clayey soil mixtures (Eades, 1962; Kalkan, 2009b). The quartzite-stabilized clayey soil samples with low relative clay mineral contents and low liquid limit displayed low swelling pressure.

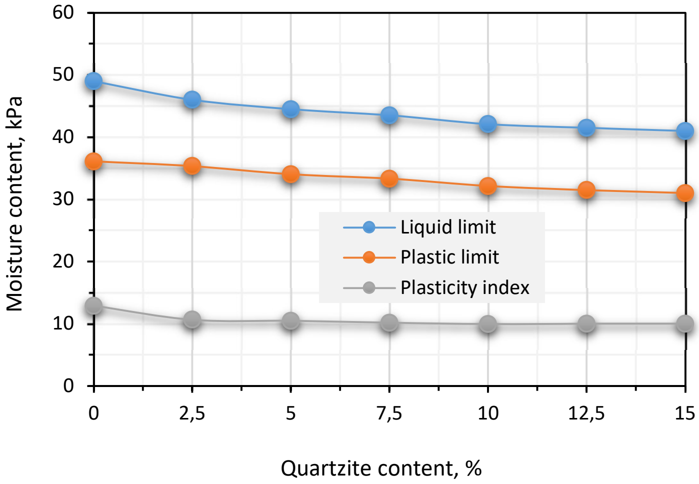

Fig. 4. The effects of quartzite on the consistency limits of stabilized samples

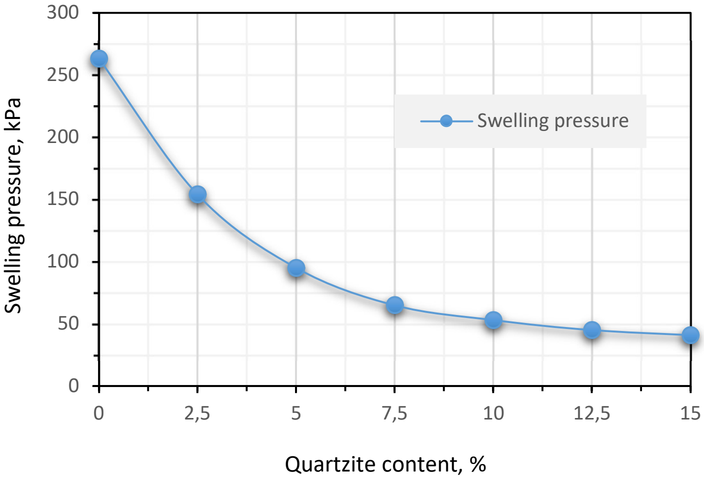

Fig. 5. The effects of quartzite on the swelling pressure of stabilized samples

3.3. The effect of quartzite on the swelling potential

The unstabilized and quartzite-stabilized clayey soil samples were tested to observe the effects of quartzite on the swelling potential values and the drawn graph from test data was peresented in the Fig. 6. As shown in the graph, the swelling pressure values steadily decreased with increasing in the quartzite content. The decrease in the swelling percentage values was pretty fast up to 7.5% quartzite content and then it was much slower.

Due to the addition of the quartzite to the clayey soil, the soil group of the quartzite-stabilized clayey soil samples changed from the high-plastic group to low-plastic group. This was attributed to the soil type (Bell, 1993), the CEC (Okagbue and Onyeobi, 1999; Sivapullaiah et al., 2000), the relative amount of silicate clay mineral in the samples (Schmitz et al., 2004), and the addition of low-plastic material to the soil (Attom and Al-Sharif,1998). Also, the decrease in the swelling potential of the quartzite-stabilized clayey soil samples is due to the addition of low-plastic material and the interaction between clay minerals and quartzite particles. The active silica reacts with calcium and hydroxide and forms calcium silicate hydrate gels (Attom and Al-Sharif, 1998; Kalkan and Akbulut, 2004).

3.4. The effect of quartzite on the swelling percentage

Natural clayey soil and quartzite-stabilized samples were tested to obtain the percentages of vertical swelling. The amount of swelling of natural clayey soil and quartzite-stabilized samples were provided in Fig. 7. It was seen that the adding of quartzite to the clayey soil decreased the vertical swelling. The decrease in the vertical swelling percentage values of the quartzite-stabilized clayey soil samples was attributed to the addition of low-plastic materials and the interaction between quartzite and clayey soil particles (Kalkan, 2006; Kalkan, 2009a; Kalkan, 2009b).

It was noted in literature that the addition of additive changed the composition, mineralogy and particle size distribution of clayey soil (Gillot, 1968; Ola, 1978; Kalkan and Akbulut, 2004; Kalkan, 2013). The addition of low plastic material to the clayey soil (Atom and Al-Sharif, 1998) changed the swelling behaviors of the quartzite-stabilized clayey soil samples from high plasticity to low plasticity (Kalkan and Akbulut, 2004; Kalkan, 2006).

The decrease in the swelling percentage values of the quartzite-stabilized clayey soil samples is due to the addition of low-plastic materials and the interaction between the quartzite and clayey soil particles (Kalkan, 2006; Kalkan, 2009a; Kalkan, 2009b).

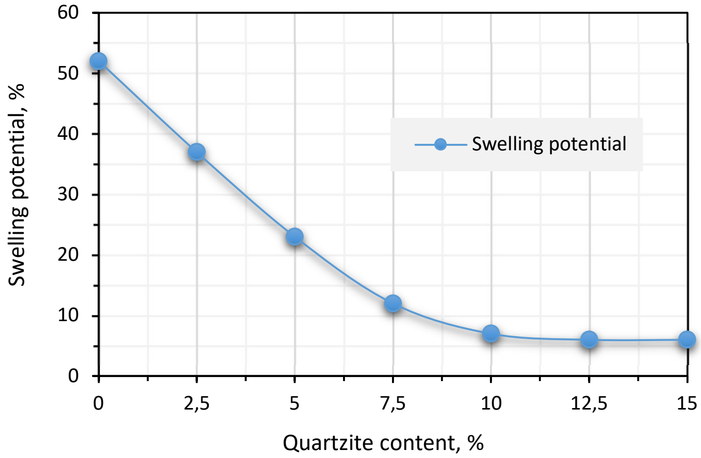

Fig. 6. The effects of quartzite on the swelling potential of stabilized samples

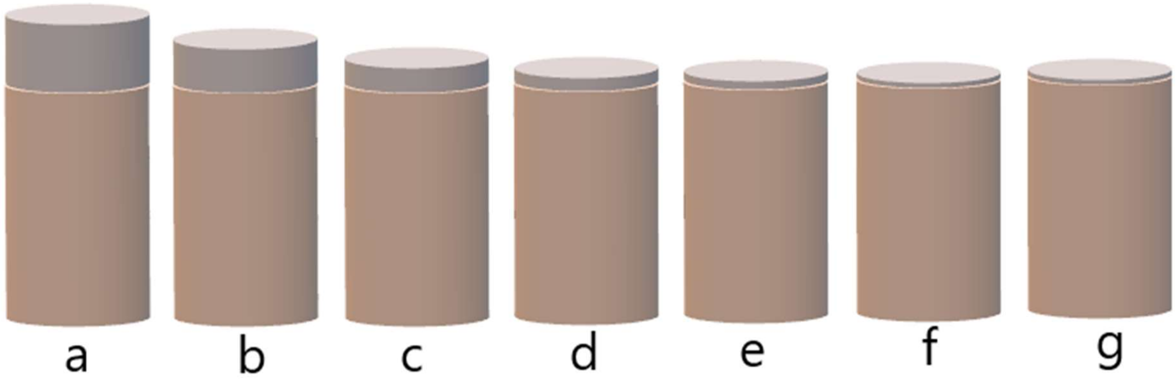

Fig. 7. The effects of quartzite on the vertical swelling percentage of stabilized clayey soil samples; (a) 0%, (b) 2,5%, (c) 5%, (d) 7,5%, (e) 10%, (f) 12,5% and (g) 15% quartzite content

3.5. Image analysis

In this study, the effects of quartzite on the microstructure of quartzite stabilized-clayey soil samples were analyzed by using the scanning electron microscope (SEM images. The variation in the microstructure of samples unstabilized and quartzite stabilized-clayey soil samples is presented in Fig. 8a-d.

It was seen from the images that the addition of quartzite to the clayey soil caused the structural change of stabilized clayey soil. Silt and clay grains of clayey soil showed angular or subangular shapes (Fig. 8a). The quartzite particles settle in the pore space among the silt-clay grains and then the settled quartzite particles react to form hydration products in the surrounding of soil grains (Figs. 8b-d). This textural event caused a significant improvement in the geotechnical properties (Fig. 8d). The bonding of particles into larger aggregates such that the soil behaved as a coarse-grained, strongly bonded particulate material (Okyay and Dias, 2010; Harichane et al., 2011; Kalkan and Yarbaşı, 2013).

As seen from the images, the structure of the quartzite-stabilized clayey soil samples (Fig. 8d) is dense than that of the structure of the unstabilized clayey soil samples (Fig. 8a).

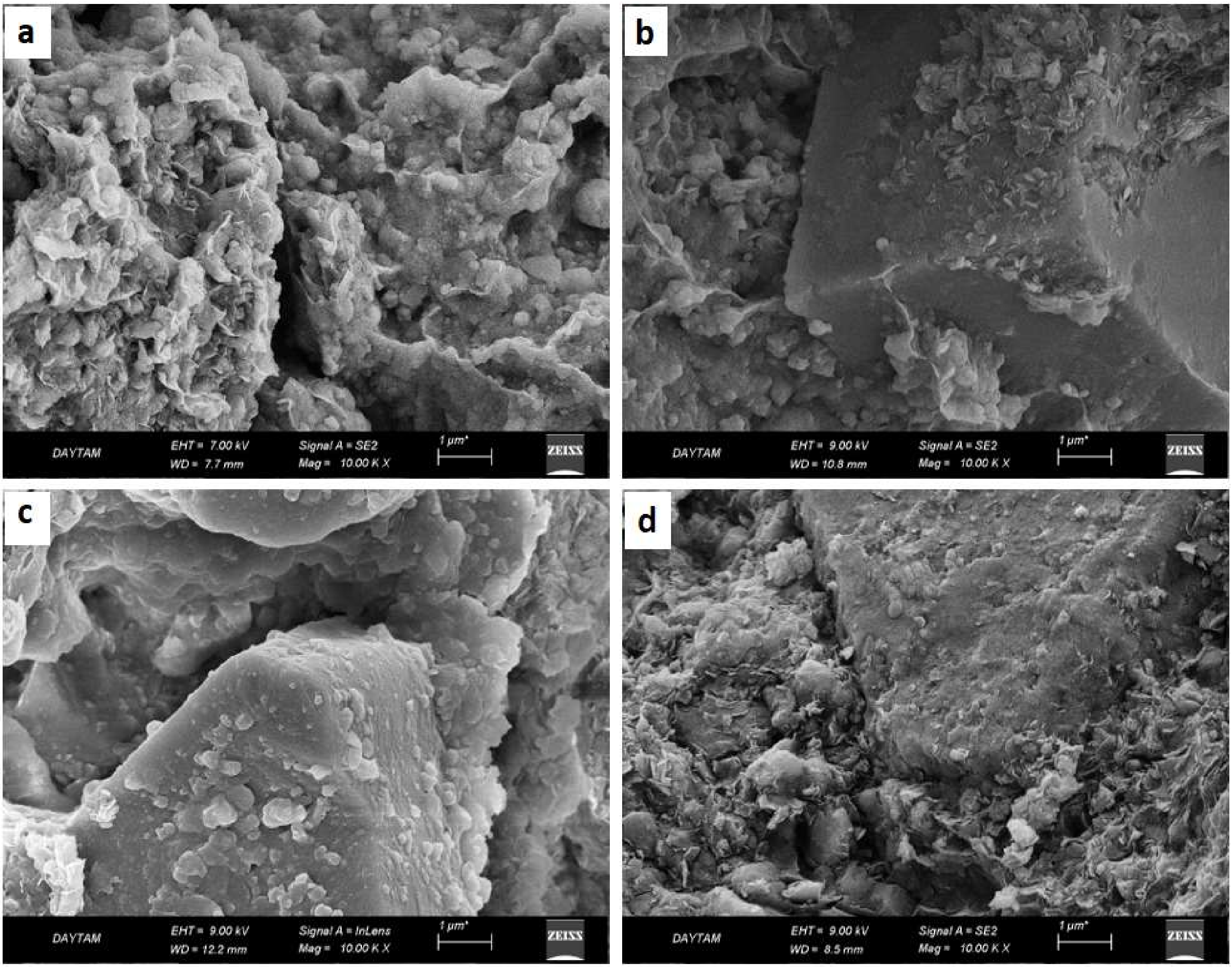

Fig. 8. Variation in the microstructure with quartzite content: (a) stabilized clayey soil sample with 0% quartzite, (b) stabilized clayey soil sample with 5% quartzite, (c) stabilized clayey soil sample with 10% quartzite and (d) stabilized clayey soil sample with 15% quartzite

4. Conclusions

The effect of quartzite on the swelling characteristics of stabilized clayey soils was investigated and the following conclusions were drawn. The liquid limit, plastic limit and plasticity index values of quartzite-stabilized clayey soil samples decreased due to the increase of quartzite content. The results of experimental study showed that the swelling behavior of quartzite-stabilized clayey soil samples changed. With the addition of quartzite to the clayey soil, the swelling pressure values of the stabilized samples decreased. It was seen that quartzite decreased the swelling pressure values of stabilized clayey soil samples. Similarly, the vertical swelling percentage values of quartzite-stabilized clayey soil samples decreased due to the addition of quartzite. As a result, the quartzite played an important role in improving the swelling behavior of the expansive soils. In addition, it can be concluded that quartzite can be used to improve the geotechnical properties of clayey soils in terms of the swelling characteristics.

Acknowledgements

This experimental research was supported by the Scientific Research Project of Ataturk University with the ID number of 7326 code of FHD-2019-7326. So, the authors thank the authorities of the Ataturk University for the support.

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