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Determination of the Hydraulic Conductivity Behavior of Seaweed Added Zeolite-Bentonite Mixtures in the Presence of Temperature with Empirical Relationships

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ABSTRACT

The temperature factor is of great importance in areas that directly affect the environment and engineering parameters of liners, such as solid waste storage areas. It is known that the temperature value increases as a result of the degradation of waste in these areas, and temperature changes affect the engineering properties of the soils. Properties vary depending on the soil type, and additives that can be used to improve the engineering properties of soils come to the fore. One of the most important criteria is that the additive to be used is sustainable and environmentally friendly. Zostera marina, with its terminological name, or dried seaweed an aquatic plant and is a sustainable, low-cost material used in thermal insulation. In this study, dried seaweed additive was added to zeolite-bentonite mixtures and compression parameters were determined under room temperature and 40°C. Hydraulic conductivity values of seaweed-added mixtures were determined with the help of volumetric compression coefficient (m_v) and consolidation coefficient (c_v) parameters and empirical relationships obtained as a result of consolidation tests. Its potential to be used as a buffer material in the presence of temperature in solid waste storage areas evaluated. The tests results showed that the seaweed additive decreased the hydraulic conductivity values of zeolite-bentonite mixtures at room temperature and under 40°C.

Deniz Yosunu Katkılı Zeolit-Bentonit Karışımlarının Sıcaklık Varlığında Hidrolik İletkenlik Davranışının Ampirik İlişkilerle Belirlenmesi

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ÖZ

Katı atık depolama alanlarında çevre ve mühendislik parametreleri açısından sıcaklık faktörü de önem arz etmektedir. Bu alanlarda atıkların bozunması sonucunda sıcaklık değerinin yükseldiği bilinmektedir ve sıcaklık değişimleri zeminlerin mühendislik özelliklerini etkilemektedir. Zemin cinsine bağlı olarak da özellikler değişim göstermektedir ve zeminlerin mühendislik özelliklerinin iyileştirilmesinde kullanılabilecek katkı malzemeleri ön plana çıkmaktadır. Burada en önemli kriterlerden biri kullanılacak katkının sürdürülebilir ve çevreyle dost olmasıdır. Terminolojik adıyla Zostera marina yani kurutulmuş deniz yosunu, bir su bitkisi olup sürdürülebilir, maliyeti düşük ve ısı yalıtımında kullanılan bir materyaldir. Bu çalışmada kurutulmuş yosun katkısı, zeolit-bentonit karışımlarına eklenerek oda sıcaklığı ve 40° C sıcaklık altında sıkışma parametreleri belirlenmiştir. Konsolidasyon deneyleri sonucunda elde edilen hacimsel sıkışma katsayısı (m_v) ve konsolidasyon katsayısı (c_v) parametreleri ve ampirik ilişkiler yardımı ile yosun katkılı karışımların hidrolik iletkenlik değerleri belirlenmiştir. Katı atık depolama alanlarında sıcaklık varlığında tampon malzeme olarak kullanılma potansiyeli değerlendirilmiştir. Deney sonuçları yosun katkısının, zeolit-bentonit karışımlarının hidrolik iletkenlik değerlerini oda sıcaklığı ve 40 °C sıcaklık altında azalttığını göstermiştir.

1. INTRODUCTION

Studies in the field of geotechnical engineering under higher temperatures are gaining importance day by day. Because the increasing world population, the ability to meet the energy needs of the population in a sustainable way, and the orientation towards alternative energy sources instead of fossil fuels have resulted in an increase in the use of energy geo-structures.

It is known that the engineering behavior of soils changes to a non-negligible extent in areas where high temperatures occur, such as solid waste and nuclear waste storage areas [1,2]. Solid waste is decomposed by bacteria and during this process, the temperature values in the environment rise. In order for decomposition to occur, the temperature value must be between 35-40 °C and 50-60 °C. These values vary depending on the type of microorganism that performs the decomposition. [3]. It has been recorded that it is 55 °C and below for multiple solid waste storage areas [4-6]. It has been determined that temperature values in areas with high temperature storage areas, which is a different concept, reach 100 °C [7]. For instance, high temperature values resulting from the decomposition of waste by microorganisms in solid waste storage areas [3] affect the hydraulic conductivity coefficient (k), one of the most important parameters in these areas, and accelerate permeability, leading to undesirable results. The exposure of the soil to temperature does not only occur due to the above-mentioned structures. Seasonal changes, melting of frozen ice masses and mixing into the soil play an important role in changing the temperature values of the soil [8,9]. Although hydraulic conductivity is one of the most basic engineering parameters, it varies depending on many factors such as temperature, viscosity, void ratio, mineralogical structure, dry density and stress history [10]. As the temperature increases, permeability increases due to the decrease in viscosity [11-13].

Another parameter affected by temperature changes belongs to consolidation. In cases where the compression index, consolidation coefficient and creep mechanism occur, creep behavior is affected by the temperature increase. In the most basic way, it can be said that the void ratio decreases with increasing temperature and therefore the compression increases [14]. The creep behavior, that is, the part that expresses how consolidation occurs in the heating-cooling cycle of the soils, refers to the drainage of excess pore water from the voids [15-16].

Within the scope of this study, dried seaweed additive was used to be used as a buffer material in solid waste storage areas. This aquatic plant, whose terminological name is Zostera marina, has been used for years for purposes such as roof insulation in cold countries such as Denmark, and is low-cost, sustainable and resistant to thermal changes. In this study, the hydraulic conductivity behavior of dried seaweed-added zeolite-bentonite mixtures were examined with the help of the parameters obtained as a result of consolidation tests carried out at room temperature and 40°C. The dried seaweed additive effect on the permeability of mixtures and the mechanism of permeability changing with temperature are discussed.

2. MATERIALS AND METHODS

2.1. Materials

In this study, bentonite, zeolite and dried seaweed (as additive) were used.

Figure 1. Dried seaweed additive

Materials were obtained from local companies. The physico-chemical properties of bentonite and zeolite are given in Table 1. Seaweed (Zostera marina) is a marine plant whose habitat is an aquatic area, which grows under water, and whose leaf length is maximum 1100 mm. Underwater leaf blade width is approximately 2-12 mm. The seaweed used as additive material in the tests was provided in dried form (Figure 1).

Table 1. Physicochemical properties of the materials

Property	Zeolite	Bentonite
Specific gravity	2.40	2.70
Liquid limit (%)	50.0	476.0
Plastic limit (%)	N.P.	70.1
pH	7.6	9.5

2.2. Methods

The Standard Proctor tests [17] were conducted on the samples. According to the optimum water content (w_{opt}) and maximum dry unit weight parameters ($\gamma_{dry,max}$) obtained from these tests, mixtures were prepared and the consolidation test was started.

Figure 2. Consolidation test equipment at room temperature and 40°C

Consolidation tests were carried out according to ASTM D2435 [18]. The tests were carried out at room temperature and under 40°C. Loadings started from 0.25 kg/cm^2 and continued up to 2 kg/cm^2. Then the unloading phase started. For the tests under high temperature, a heat ring was placed inside the cell, precautions were taken for evaporation by supplying water from the water tank through pipes, and the cells were covered with a thick membrane (Figure 2). The tests were started and terminated at 40°C. After then, the samples were placed in the oven for water content determination. By comparing the test results, the high temperature effects were observed.

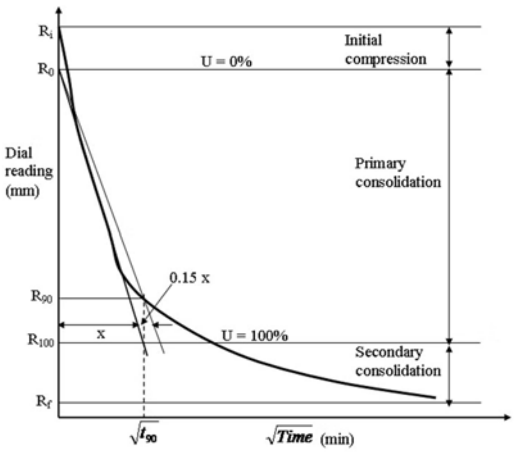

Figure 3. Square root of time method [19]

The square root time method was used to calculate the consolidation coefficient, c_v (Figure 3). After determining the t_{90} value with this method, the c_v value was obtained by substituting in Equation 1. The m_v value was obtained with the experimental data during the calculation of the compression amount. The hydraulic conductivity coefficient was calculated using the consolidation coefficient (c_v) and volumetric compression coefficient (m_v) parameters obtained at room temperature and under 40°C. The permeability coefficient (k) was calculated by Equation 2.

$$c_v = \frac{0.848d^2}{t_{90}} \tag{1}$$

$$k = c_v . m_v . \gamma_{water} \tag{2}$$

3. RESULTS AND DISCUSSIONS

The Standard Proctor test results showed that as the seaweed content was increased, the optimum water content increased and the maximum dry unit volume weight value decreased. Consolidation test results indicated that the compression amount of additive free zeolite-bentonite mixtures at room temperature was 19.4%. With 10% and 20% seaweed additive, this rate decreased to 17.7% and 16.8%, respectively. An increase in the amount of compression of the mixtures was observed at 40°C compared to room temperature, it was determined that the additives had an effect on reducing the amount of compression. In parallel with these data, a decrease in the consolidation coefficient was observed with the addition of dried seaweed, and it's change depending on temperature as given in Figure 4. Abuel-Naga et al. (2005) reported that in their study on the normally consolidated soft Bangkok clay at different temperatures that the consolidation rate (c_v) increases with increasing temperature. Delage et al. (2004) studied on the over consolidated Boom clay sample and stated that the changes in c_v and m_v with temperature increase were negligible unless the temperature was higher than 60 °C [20, 21].

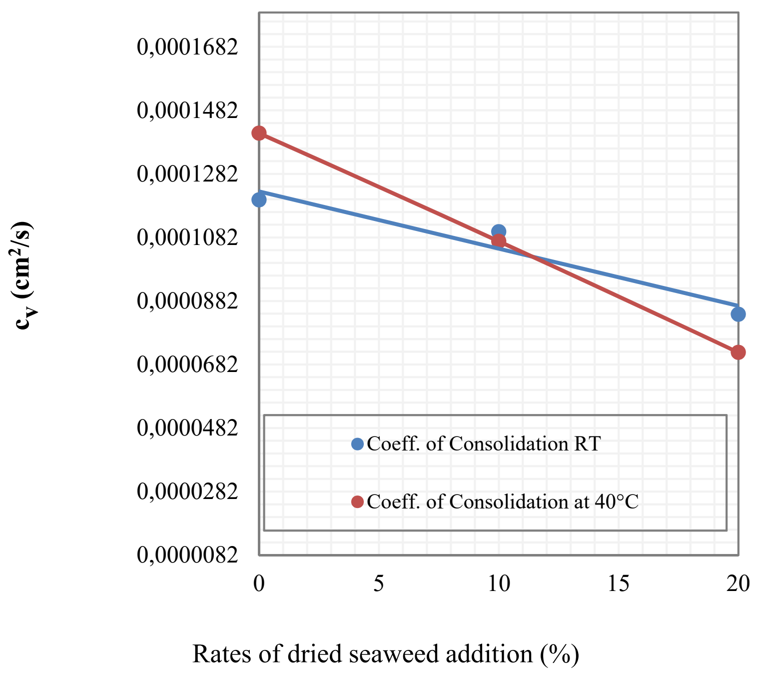

Figure 4. Change of c_v depending on addition amount

The t_{90} value was calculated from the consolidation curve of all mixtures using the square root time method. The permeability coefficient k, determined by empirical methods shows that the value of zeolite-bentonite mixtures at room temperature is 4.1 x 10^{-9} cm/s, while with 10% and 20% seaweed additive these values decreased 3.6 x 10^{-9} cm/s and 2.4 x 10^{-9} cm/s, respectively.

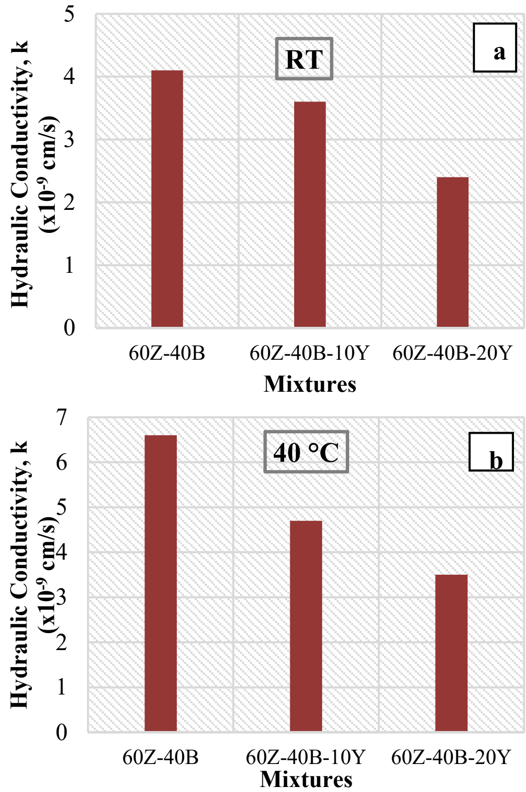

Figure 5. Hydraulic conductivity (k) values of dried seaweed added mixtures a) at RT and b) 40°C

It is shown in Table 2 that decreasing trend was also seen under 40°C temperature. It was observed that as the temperature increases to 40°C, the increase in the permeability values compared to room temperature. It is possible that a clay mineral with a larger surface area will retain more water than a smaller surface area, and the surface area will be more affected by the increase in temperature [1].

Table 2. The coefficients of permeability, consolidation and volumetric compressibility

Mixtures	Room temperature			40°C		
	c_v (cm^2/s)	m_v (cm^2/g)	k (cm/s)	c_v (cm^2/s)	m_v (cm^2/g)	k (cm/s)
60Z-40B	1.2×10^{-4}	34×10^{-6}	4.1×10^{-9}	1.41×10^{-4}	47×10^{-6}	6.6×10^{-9}
60Z-40B-10Y	1.1×10^{-4}	33×10^{-6}	3.6×10^{-9}	1.07×10^{-4}	44×10^{-6}	4.7×10^{-9}
60Z-40B-20Y	8.4×10^{-5}	29×10^{-6}	2.4×10^{-9}	7.2×10^{-5}	49×10^{-6}	3.5×10^{-9}

Also, the effect of soil mineralogy in the resulting difference cannot be neglected. Different factors such as specific surface area (SSA) and soil minerology change the consistency limits in the presence of temperature, viscosity changes and hydraulic conductivity is affected [22]. The potential for redistribution of intra- and inter-particle pores with increasing temperature may change the permeability coefficient of the soil [23]. As the temperature increases, the size of the diffuse double layer changes with temperature. Water adsorbed at a high temperature can be converted into bulk pore water, resulting in increased hydraulic conductivity [12, 24]. Different additive materials were used to evaluate hydraulic conductivity behavior. Studies have shown that 15% boron additive (tincal) has an effect of increasing hydraulic conductivity by approximately 20 times [25]. In another study, it was revealed that the hydraulic conductivity value of sand-bentonite mixtures increased approximately 3.5 times in the presence of 10% ulexite, another boron mineral, while it did not show a significant change in the presence of 20% ulexite [26].

The behavior revealed that the dried seaweed additive contributes to the permeability-reducing effect and is suitable for use in situations where leachate as well as temperature need to be buffered, such as solid waste storage areas. The sealing limit value k of the material that can be used as a buffer in solid waste storage areas is around ~10^{-11} m/s. It was observed that the permeability of the added and additive free zeolite-bentonite mixtures used in this study was approximately and generally compatible with these limits.

If seaweed is used in applications, it should be evaluated by taking into account the degradation processes and rates according to the type and characteristics of the seaweed. Biodegradation of seaweed depends on the dissolution and degradation of the component called "alginate". Alginate constitutes the main structural component of the cell wall and intercellular matrix of brown seaweeds. however, compounds such as polyphenols in seaweed can also affect biodegradation. Alginates can be degraded by acid and alkali hydrolysis. Hydrolysis refers to the combined dissolution of particulate material as well as the degradation of polymeric substances [27].

4. CONCLUSIONS

In this study, behavior of dried seaweed-added zeolite-bentonite mixtures were determined using empirical relationships at room temperature and 40°C. The k coefficients were determined with the help of c_v and m_v parameters obtained from the consolidation tests. It was observed that when the temperature was increased from room temperature to 40°C, the amount of compression of the mixtures increased in line with the literature, but the seaweed additive had a reducing effect on the amount of compression in both temperature conditions. The test results showed that the dried seaweed additive had a reducing effect on the permeability of zeolite-bentonite mixtures under both conditions. Additionally, it was observed that as the temperature increases to 40°C, the permeability increased in comparison with room temperature. When all the results were evaluated, it was revealed that the mixtures within the scope of the study had a high potential to be used as buffer material in solid waste storage areas.

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