Loading and wetting oedometer test using micro porous membrane

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Abstract: Recent advances in constitutive modeling of unsaturated soils and expansive soils are reviewed. The development of mathematical models is significantly behind similar developments for fully saturated soils or soils with zero suction. This study developed an pedometer apparatus for measurement of vertical deformations under suction changes, which equipped a microporous membrane, a high-air entry disc (i.e., ceramic disc) and relative humidity controlling system. Three different items correspond to the variation in the suction range. The micro-porous membrane is certification for 0 kPa to 20 kPa in small suction accuracy. The high-air-entry disc has an air entry of 1.0 MPa, and the high-air-entry disc and the microporous membrane are useful as a pressure-filter technique in suction-control technology. A relative humidity control system is produced to describe the unsaturated soil properties and is based on vapor pressure technique. A silty soil is used for this testing program, and both suction increment and suction recrement are repeated in the pedometer cell. The suction ranged from zero to 296 MPa over a wide range. The specimen verified effort deformations according to the suction change through seepage, which led to variations in the yield surface.

Introduction

Unsaturated soils are frequently encountered in civil engineering applications, typically as compacted materials in earth structures such as dams, roads, highways, airport runways, and embankments. The construction of earth structures, especially when employing soils characterized by low permeability, such as clays, is expected to induce elevated pore water and pore air pressures within the soils. The concept of stress state variables to describe the behavior of unsaturated soils and shear strength was introduced by Vanapalli et al. [1]. Zhang et al. [2] mentioned that the effect of negative pore-water pressure is often ignored in geotechnical engineering practice. Ning, et. al. [3] presented the concept of the suction stress characteristic curve for unsaturated soil. The matric suction is considered a variable that governs or influences on each phenomena and the engineering behavior of variably saturated soils [4].

Blatz and Graham [5] proposed a new method for controlling soil suction in triaxial tests. The method is based on suction measurement using thermocouple psychrometers and suction control using the vapor technique equilibrium. Blatz et al. [6] examined the constitutive behavior of unsaturated compacted bentonite sand mixture materials. Delage et al. [7] reviewed some developments in the effective techniques of suction control using the axis translation method, the osmotic method and the vapor control technique.

Zhang et al. [8] used a membrane, and the validity of the pressure membrane method was confirmed by comparing the test results with those of the pressure plate method, which has been widely adopted for unsaturated soil tests in the past. Wang et al. [9] introduced a membrane filter as an alternative to a ceramic disk is revealed through diffusion and hydraulic conductivity tests. It was found that air diffusion through the membrane filter was significantly affected by the suction magnitude, and the hydraulic conductivity of the membrane filter could be easily affected by the quality of the water used in the test. The application of a membrane filter to undrained cyclic loading tests of unsaturated sandy materials shows the response of the membrane filter pedestal in a modified triaxial system [10]. Wang et al. [11] evaluated the water retention characteristics of typical iron ore fines (IOF). The tests were conducted in three suction ranges to examine the effect of the void ratio. Nishimura [12] study focused on the shear strength of unsaturated soil subjected to creep stress loading for large deformation using a membrane.

Bradford and Gupta [13] considered that the compression of soil is due to the exclusion of air or water from the void spaces, rearrangement of soil particles, compression and deformation of solid particles, and compression of the liquid and gas within the voids. Fredlund [14] emphasized that unsaturated soil mechanics is presented herein in the context of having a limited number of physical areas of application, shear strength, and volume-mass change (including swelling and collapse). Matheus et al. [15] investigated the compression process by measuring the strength, swelling, and compressibility characteristics of unsaturated soils with contrasting textures. Shahbodagh and Khalili [16] reported that the magnitude of excess pore water and pore air pressure generated governs the stability and settlement of the earth structure during construction.

The collapse behavior of compacted, uncemented soil is studied within a theoretical context consistent with the concepts of unsaturated soil mechanics [17]. Fredlund and Rahardjo [18] consider the collapse that the soil structure may experience collapse with the result. The load is transferred to the water phase. Rao and Revanasiddappa [19] derived red soil in India. The porous and unsaturated nature of red soil makes it susceptible to collapse upon wetting under load. The present study analyses the collapse behavior of an unsaturated bonded. Munoz-Castelblanco et al. [20] investigated the compression and collapse behavior of a natural unsaturated loess. They investigated a series of constant-rate strain compression tests.

Ng and Yung [21] investigated the effects of wetting–drying and stress ratio on anisotropic shear stiffness of unsaturated decomposed tuff using a modified triaxial testing system. Gallage et al. [22] measured the unsaturated hydraulic conductivity using a new permeameter during drying and wetting processes. Goh et al. [23] studied the shear strength characteristics of unsaturated soil under multiple drying and wetting cycles. Estabragh et al. [24] conducted several experiments involving wetting and drying cycles. Laboratory tests were conducted on compacted samples of expansive soil.

Purpose of this study

Recent advances in constitutive modeling of unsaturated soils and expansive soils are reviewed. The development of mathematical models has significantly behind similar developments for fully saturated soils or soils with zero suction. This study develops an oedometer apparatus for measurement of vertical deformations under suction change, which is equipped through a microporous membrane, a high-air entry disc (i.e., a ceramic disc), and relative humidity control system. Three different items correspond to the variation in the suction range. The microporous membrane is certification for 0 kPa to 20 kPa in small suction accuracy. The high-air-entry disc has an air entry of 1.0 MPa, and the high-air-entry disc and the microporous membrane are useful in the pressure filter technique in suction control method. The relative humidity controlling system has been developed to improve unsaturated soil properties and is based on the vapor pressure technique. A silty soil was used for this test, and both the suction increment and suction recrement were repeated in the pedometer cell. The suction ranged from zero to 296 MPa over a wide range. The specimen verified effort deformations according to suction change through seepage due to water, which leads to variation in the yield surface.

Test procedure

Soil material

This study used nonplastic silty soil, which has uniformity in grain size distribution and a maximum soil particle size of 2.0 mm. Proctor compaction test results indicated that the maximum dry density was 1.540 mg/m3, and the optimum water content was 17.0%. The water content of the soil material is regulated by supplying distilled water to dry soil. After regulation of water content, the soil material is storage through 24 hours subject to create the uniformity. The water contents required were 10%, 17%, and 20%. The water content is employed on the dry and wet sides to obtain the optimum water content.

Soil specimen

All specimens were prepared in the steal mold described below with the difference water contents using an oil jack. The oil jack has an activity capacity of 10 MPa. The soil material was statically compacted without friction along the lateral surface between the steal mold and soil material. The specimen are a height of 20 mm high and 60 mm in diameter. Pressure rod top

Photo 1: Developed oedometer apparatus and basement including micro porous membrane and high air entry disk.

connected the steal plate, and the thickness was 7.0 mm. A slight tapper angle is manufactured in order to delete the friction between the steal plate later surface and mold surface when statical compaction was applied. The limitation is controlled through the compaction process and is effective when the height of the specimen approaches 20 mm, and the stopper is effectively. The period for statical compression is at least 30 minutes over with a remaining height of 20 mm. This testing program prepares various dry densities with the three difference as following: the dry densities are 1.000 Mg/m^3, 1.200 Mg/m^3 and 1.400 Mg/m^3. The water contents were 10%, 17%, and 20%, respectively.

Apparatus for developed oedometer for unsaturated soil test

This study used the pedometer apparatus as shown in Photo 1, which was developed for effective performance. The instructions for the developed apparatus is following: the steal mold is placed in the acyl cell. The plate has two difference filters, which one is a microporous membrane and another is a high air entry disk (i.e., ceramic disc). The microporous membrane controls the low matric suction (i.e., less than 20 kPa). A high-air entry disk is common on pressure plates. Two water paths were connected to each filter, and these water paths are through double glass buret that is possible to measure both adsorbed water and drainage water associated with soil moisture in the specimen. The upper-plate-installed air supply valve works for the application of matric suction in possible. The dial gauge placed outside of the cell measures the vertical deformation of the unsaturated condition and saturated condition when the specimen receives water adsorption, suction change effort, and vertical external loading similar to the oedometer consolidation test. Each filter (i.e., micro porous membrane and high air entry disc) connected the difference water tubes to glass buret and the diameters were 20 mm for the micro-porous membrane and 20 mm for the high-air-entry disc. The thickness of the micro-porous membrane is thin comparison to the high air entry disk that is further contribution to water and actually induces shortening in testing.

Test series for this study

This testing program included the mechanical process and hydration performance, which consisted of four difference series. These series are composed based on one-dimensional compression. In Series No.1 the influence of dry density is focused on the compression properties along the compression index. The prepared physical value that the dry density has a range from 1.000 Mg/m^3 to 1.400 Mg/m^3, and the water content was 10%. The maximum applied compression stress was 400 kPa. Series No.2 conducted out compression test under variation of water content at constant dry density that required water contents of 10%, 17%, and 20%, and the dry density was 1.400 Mg/m^3. The compression stresses were loaded in steps until they reached 400 kPa. The measured vertical deformation was calculated using the void ratio for each compression stress. The compression curves were estimated from the obtained void ratio. The compression index was estimated throughout the influence of water content. Beyond equilibrium at a compression stress of 400 kPa, the specimens were applied to saturation due to water absorption from the bottom surface. The collapse deformations were measured. This study measured negative pore water pressures to determine the influence of water content and dry density on suction in Series 3. The prepared specimens had a dry density of 1.000 Mg/m^3 and variation in water content. The measurement method that is used a microporous membrane. The microporous membrane was installed on the pedestal. The pore pressure sensor is connected to the water supply tube. The occurrence of negative pore pressures is measured under atmospheric pore air pressure. To measure the suction remained until a dry density of 1.905 Mg/m^3 according to the compression path. For Test Series 4, the specimen was subjected to a compression stress of 50 kPa. The saturation application is attempted using distilled water through a microporous membrane. The water injection was produced from the bottom of the specimen, and the collapsing deformation was measured over time. After equilibrium in deformations, a suction of 8 kPa is applied in order to remove from saturation to unsaturation. The water injections and suction application are repletely that the decreasing of void ratio until a suction of 40 kPa is achieved. The soil moisture passes through a high-air entry disc (i.e., a ceramic disk) associated with generating the air pressure at a suction of 40 kPa.

Test results

Compression curves with variation of dry density (Series No.1)

Various dry densities were prepared using a water content of 10% in constant that compression tests were conducted out. First, a compression stress of 10 kPa was loaded, and the compression stress was increased 400 kPa. Relationship between the void ratio and compression stress such as compression curves as shown in Fig. 1 Clearly, a comparison of the compression properties is indicated. The initial dry density is generally an influence of compression properties. When the dry density is 1.600 Mg/m^3, the compression index is small.

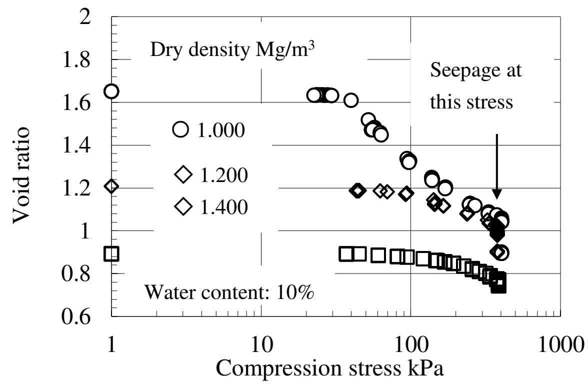

Figure 1: Compression curves with variation of dry densities.

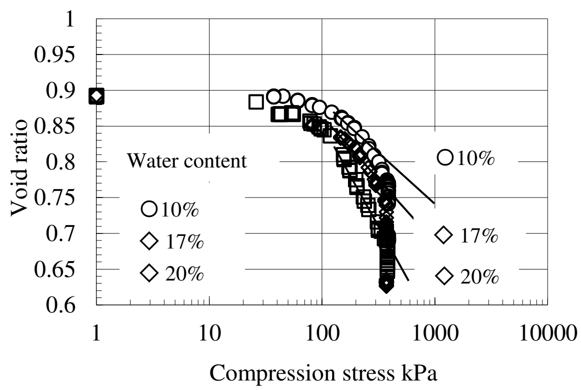

Figure 2: Compression curves with variation of water content.

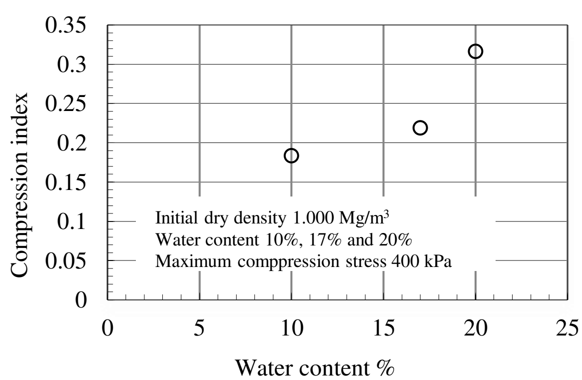

Figure 3: Influence of water content on compression index.

Compression curves with variation of water contents (Series No.2)

All specimens had a dry density of 1.000 Mg/m³ with water contents of 10%, 17%, and 20%. The compression stresses were 400 kPa applied to the specimens. The deformations were measured against each stress, and the void ratios were plotted against the compression stress, which were the compression curves. All specimens exhibited a smooth reduction in the void ratio up to a compression stress of 120–200 kPa. Reduction of void ration depend on the water

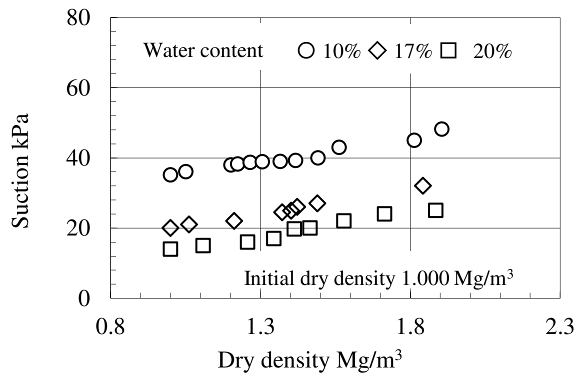

Figure 4: Increment of suction through compression stress.

content when the water content is 10%, the decrease in the void ratio is small, and it is obvious suction effort. A water content of 20% described much reduction of void ratio, as shown in Fig. 2. Each compression index is summarized in Fig. 3. The obtained compression index with a large value is indicated by a decrease in water content. Beyond a compression stress of 400 kPa, absorption is applied to the unsaturated specimens in order to saturation that water supply from the bottom surface of all specimens. The saturation process induced sufficiently collapsing deformations.

Changes of suction through compression process (Series No. 3)

This study focused on the matric suction in unsaturated specimens with various water contents and a constant dry density of 1.000 Mg/m3 through the compression process. The specimens with three difference water contents were prepared in a steel mold, and negative pore water pressures were measured through a saturated microporous membrane. The measured negative pore-water pressures are indicated by the increment in dry density s, as shown in Fig. 4. The obtained results included three different water content (i.e., water content of 10%, 17% and 20%). All specimens had an initial dry density of 1.000 mg/m3. The compression stress was gradually increased and the dry density was incremented. The measured suction were plotted against the dry densities associated with compression. Suction was calculated using measured negative pore pressures, which were defined as the difference between the pore air pressure and the pore water pressure. It is obviously the difference for suction that the influence of water content is significant. As following; initial suction are 25.1 kPa, 20.0 kPa, and 14.0 kPa, corresponding to 10%, 17%, and 20%, respectively. Several negative pore-water pressures were verified, and the results are shown in Fig. 4 with dry densities. The suction increased with increasing dry density through a constant water content. Considering the rate of increment of suction against to growing of dry density, a water content of 10% indicated the largest increment of suction according to the increment of dry density.

Collapsing due to seepage and suction application in repletely (Series No.4)

The specimen was prepared which the physical properties is as following; a dry density of 1.400 Mg/m^3, compaction water content of 10%, a dimeter of 6.0 cm, and a height of 2.0 cm. The

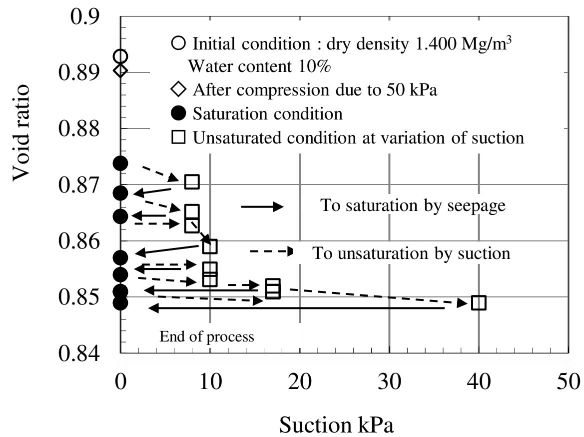

Figure 5: Collapsing due to saturation-unsaturation using suction application.

developed pedometer apparatus has a two-filter, a microporous membrane and a high-air-entry disc. First, the specimen in the unsaturated condition was subjected to a compression stress of 50 kPa. Subsequently, smooth water absorption was supplied through bottom surface in order to saturation using the microporous membrane. Shrinkage deformations such as collapsing during sorption, to be equilibrium of axial deformation in shrinkage estimate to be saturation that meant the delete matric suction. After void ratio reduction, the drying and saturation performances were repeated. The drying process occurs in the suction supply at 8, 10, 17, and 40 kPa. In the range of 10–17 kPa, a micro-porous membrane was used for injection and outflow, and only a suction of 40 kPa corresponded using a high-air-entry disc. Changing the void ratio described under saturation-unsaturation repeat what due to suction generation and suction delete. It is common for suction increments and decrements to influence further volume changes, and the obtained results are similar to general interpretation. In particular, this testing program attempted the saturation-unsaturation cyclic performance. Unsaturation and saturation cyclic occurred three times when the matric suction were 5 kPa, 10 kPa, and 17 kPa. Reduction of void ratio was reduced by soil moisture drainage, as shown in Fig. 5. The growing of void ratio moves to be small with the number of unsaturation and saturation repeats.

Conclusions

This study focused on the compressibility of unsaturated nonplastic soil, including matric suction measurements, using a developed pedometer apparatus. The microporous membrane is useful for shortening the experimental time for suction applications. The obtained results are summarized follows. The compressibility of unsaturated specimen indicated large comparison to high water content under constant dry density. Also, the unsaturated specimen with a higher dry density exhibited high stiffness in case of water content is same. This study measured the suction (i.e. negative pore water pressures) under atmospheric conditions. The matric suction increased with water content reduction, even if the dry density was the same. Unsaturated specimen occurrence shrinkage or decrement of void ratio subjected to drying and saturation, which applied suction are small value with a range from 0 kPa to 50 kPa.

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