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Ultrasonic waves for unsaturated soil characterization

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1. Introduction

Soils are commonly regarded as fully saturated or fully dried. Soils, however, are commonly unsaturated in the near surface. Particularly, the soils used dams or bridge foundations are mostly existed as the unsaturated. The stiffness of soils is affected by the amount of air and water. The unsaturated soils are drying, the volumetric water content decreases and the matric suction of the unsaturated soils increases. The goal of this study is to characterize the unsaturated soils by using the ultrasonic waves including ultrasonic compressional and shear waves. The elastic waves are measured at the different degree of saturation by controlling the matric suction. Thus, the unsaturated soils are characterized at the difference levels of matric suction. Ultrasonic shear and compressional waves are measured by using the bender elements and the piezo disk elements, respectively. The bender elements and the piezo disk elements can change the electric energy to mechanical energy. Both transducers are commonly installed the consolidation cells or the field penetration devices for the seismic investigations by Lee et al.[1)] In this study both transducers are installed on the walls of the rectangular unsaturated soil characterization cell. This paper is organized as follows. In the unsaturated soils, the method which finds the change of the porosity by using the ultrasonic wave velocities is proposed. After completing the experiment through the prepared test process, by using obtained data, the aperture ratio was estimated.

2. Porosity of Unsaturated Soils

Matyas [2)] reported that the volume of unsaturated soils is effected by $u_a - u_w$ and $\sigma - u_a$. Where u_a , u_w , σ are pore-air pressure, pore-water pressure, normal stress. The term of $u_a - u_w$ is the matric suction and the term of $\sigma - u_a$ is defined as the net normal stress. In case matric suction reduces or net normal stress increases, the volume of the unsaturated soils decreases. The constitutive relationship in consideration of the net normal stress and the matric suction, is (Fredlund and Rahardjo)[2];

$$d\varepsilon_v = 3\left(\frac{1-2\mu}{E}\right)d\left(\sigma_{mean} - u_a\right) + \frac{3}{H}d\left(u_a - u_w\right) \quad (1)$$

Where, $d\varepsilon_v$ is volumetric strain change for each increment and μ is the Poisson's ratio. E is the modulus of elasticity and H is the modulus of elasticity for the soil structure with respect to a change in matric suction. The modulus of elasticity, the shear modulus of elasticity and the Poisson's ratio can be estimated based on the elastic wave velocities. Which is the obtained value given, the change of the volume can be predicted.

3. Experimental Study

In this study, the volumetric pressure plate extractor (VPPE) was used. The VPPE was improved for the application of the axial load through the center rod as shown in **Fig. 1**. Fig. 1. shows schematic drawing of the VPPE and peripheral electronics.

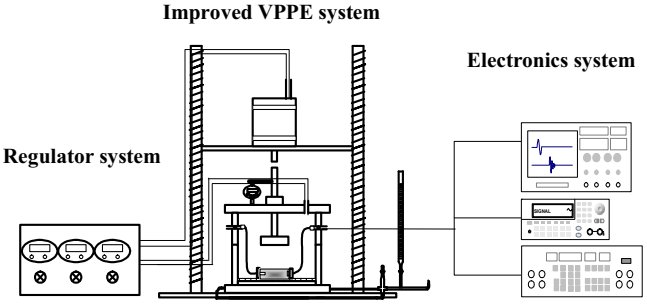

Fig. 1. Improved VPPE and peripheral electronics

Uniform grain sized sands with mean diameter of 0.45mm was used. Wet sands are placed into the rectangular cell, which was put on the ceramic plate of the VPPE. The rectangular cell was equipped with the bender elements and piezo disk elements for the generation and detection of the ultrasonic waves. After specimen was placed into the cell, the VPPE was closed; the matric suction was applied. As the matric suction applied, the degree of saturation of the unsaturated soils changes. Note the vertical axial stress was applied for control the mean normal stress. The applied air pressure matric suction was 10, 20, 50, 100, 200, and 400 kPa. The ultra sonic waves were continuously measured according to each matric suction. After the matric suction was applied, soils slowly became the equilibrium stage. Thus, the ultrasonic waves were measured 1, 4, 9, 16, 25 minutes and 1, 2, 4, 6, 24 hours after the application of matric suction. Thus, the ultrasonic shear and compressional wave

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velocities were obtained at each degree of saturation. After the matric suction of 400 kPa was applied, the matric suction was slowly decrease to 10kPa.

4. Results

The matric suction versus volumetric water content, which is call as the soil water characteristic curve(SWCC), is plotted in **Fig. 2**.

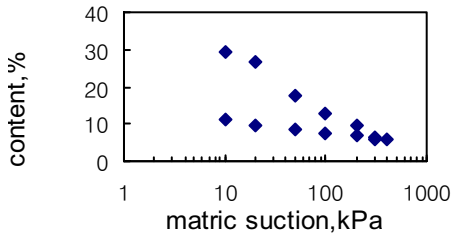

Fig. 2. SWCC according to matric suction

Volumetric water content reduces gradually according to the matric suction increases and it increase according to the matric suction decreases. The ultrasonic wave velocity versus the degree of saturation was plotted in **Fig 3**. and **4**.

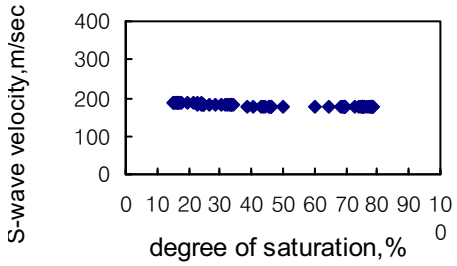

Fig. 3. ultrasonic shear wave velocity vs. degree of saturation

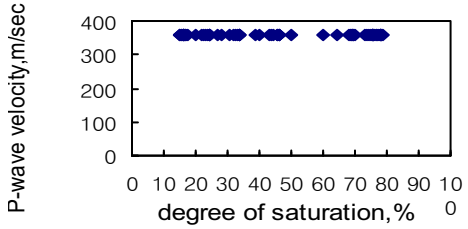

Fig .4. ultrasonic compressional wave velocity vs. degree of saturation

The initial degree of saturation of the test showed up as 78%. This is determined the residual air contained in the water. And loss of the water generated in the process of adding the stress of the initial 350kPa.

5. Analyses

The degree of saturation range from 15% to 80%. In this range, the ultrasonic wave velocities are almost constant. The elastic modulus, the shear modulus, and the Poisson's ratio could be estimated based on the measured ultrasonic wave velocities. From the measured ultrasonic wave velocities and Eq (1), the porosity can be estimated. The calculated wave based void ratio versus volumetric void ratio is plotted in **Fig. 5.**

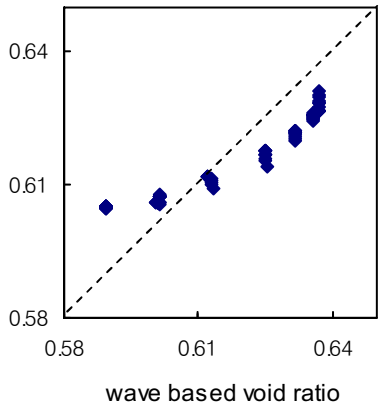

Fig. 5. Volumetric void ratio vs. wave based void ratio

The void ratio reduced as the matric suction increased. The wave based void ratio shows the tendency to be similar to the volumetric void ratio.

5. Conclusions

In this research, the matric suction was controlled by using the improved VPPE system. This system was comprised in order to simulate the unsaturated condition of the near surface. The ultrasonic wave velocities could be obtained in the unsaturated soils. The ultrasonic wave velocities are almost constant between the degree of saturation range from 15% to 80%. The characteristics of the unsaturated soils are evaluated by using the ultrasonic wave obtained velocities. The void ratio was estimated in near surface. The experimental result shows that the wave based void ratio was confirmed to display the tendency to be similar to the real soil behavior. This study suggested that applicability about the behavior prediction of the unsaturated soils using the non-destructive investigation.

Acknowledgement

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