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Characterization of shear zone using ultrasonic waves

YoungHo Kim[1], Yong-Hoon Byun[1], Myung-Jun Song[2], Jong-Sub Lee[1¢] ([1]Korea Univ., [2]Hyundai Engineering & Construction)

1. Introduction

If the normal deformation is constrained during shearing in the granular media, the shear behavior may be affected by the density. The change of shear behavior is related to the stiffness in the normal direction of the deformation. The shear strengths increases with an increase in the stiffness because normal stress increases with an increase in the normal displacement, which occurs during shearing (Indraratna et al.)[1]. In this study, the vertical displacement and stress according to the shear displacement are measured during the direct shear test. In additions, the change of the shear planes during shearing are examined by using the ultrasonic shear waves. This study consist of experiment setup, test result, and anlayses of shear strength and ultrasonic shear wave velocity during shearing.

2. Experimental setup

Conventional direct shear device allows the normal deformation during shearing. The vertical deformation during shearing may affect on the shear strength. The direct shear device was modified to control the normal deformation and to measure ultrasonic waves during shearing. Schematic diagram of the modified direct shear device is shown in **Figure 1.**

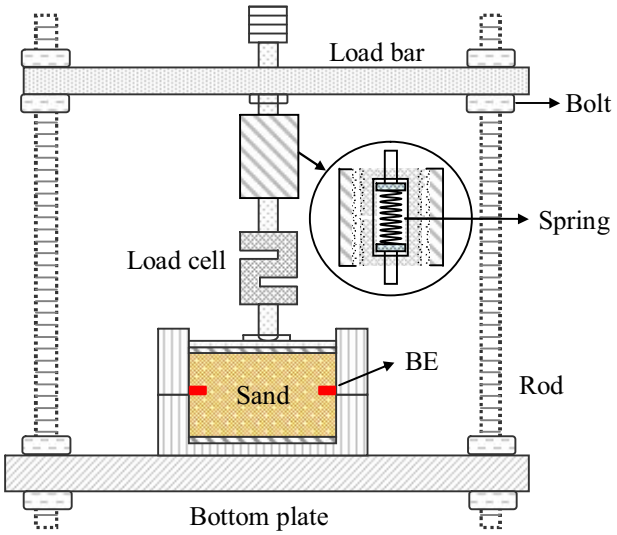

Fig. 1. Direct shear test machine. The BE denates ultrasonic transducers

jongsub@korea.ac.kr

For the generation and detection of the ultrasonic shear waves, the bender elements were used as shown in Fig 1. A single sinusoidal signal of the frequency of 5.5kHz was generated from a signal generator to excite the source bender elements (Lee and Santamarina)[2]. The shear wave that originated from the source bender elements propagated through the specimen and was detected by the receiver bender elements. When shear wave reaches the receiver bender element, it reflects the characteristics of a shear plane. The signals were averaged 1024 times for the short-duration monitoring during the direct shear test (Lee and Satamarina.)[3]. Taking the near field into account, the shear wave velocity was calculated from the tip-to-tip distance and the selection of the arrival time.

3. Experimental procedure

For the preparation of the specimen for the shearing, sand was used. For the comparison of the density effect, dense and medium specimens are prepared. The densities of the dense and medium specimen are 75% and 50%, respectively. The specimen was prepared in the cell, whose dimensions are 600mm in width, 600mm in length and 600mm in height. The direct shear tests were conducted at the different normal stress of 100kPa, 200kPa, 400kPa, and 800kPa. Thus, total 8 sets of specimens were prepared. During shearing the shear waves at the shear zone continuously recorded at each 30 second. The shearing was finished when the shear displacement reaches 12mm.

4. Results and Analyses

The shear stress versus horizontal displacement curves of the specimens at a density of 50% and 75% are plotted in **Figure 2.** The shear strength of the 50% specimen is smaller than that of the 75% specimen under same normal stress. In the specimens of 50% and 75%, the shear strength can be affected by the dilation and stiffness of vertical direction. The effects of the dilation and stiffness on the specimen are evaluated by shear strength at the 75%, as shown in Fig 2 (b). Note that at the dense specimen, the normal load acting on the specimens increase due to interaction between the dilation and the stiffness. As the initial normal stress increase from 100kPa to 800kPa, The peak strengths were changed from 86kPa to 440kPa and from 95kPa to

523kPa at Fig 2(a), (b), respectively. The effect of the relative density on shear strength at the higher normal stress was more dominant than the stiffness.

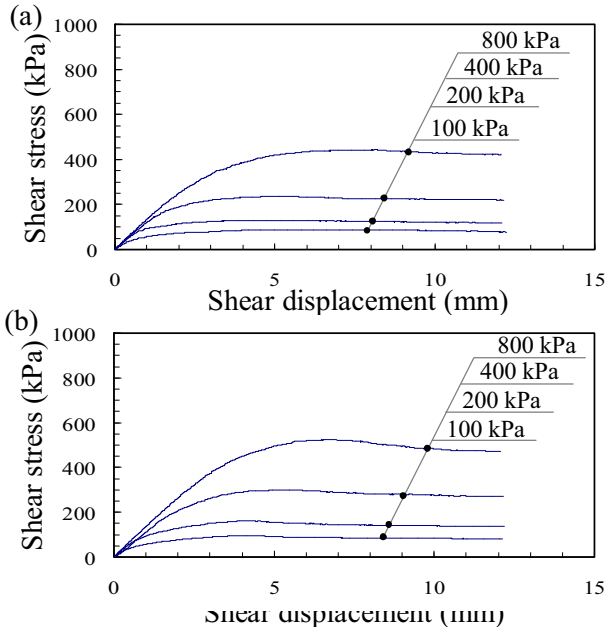

Fig. 2. Shear stress chracteristics: (a) Medium dense specimen; (b) Dense specimen.

During shearing, the ultrasonic shear waves are continuously measured as shown in **Fig 3.** The ultrasonic waves denoted by no. (1) in Figs 3(a) and (b) are measured before vertical loading is applied. The 1st arrival of the ultrasonic wave before loadng is longer than that after loading. During shearing, the 1st arrival of the ultrasonic waves are smaller in dense specimen than in midium dense specimen.

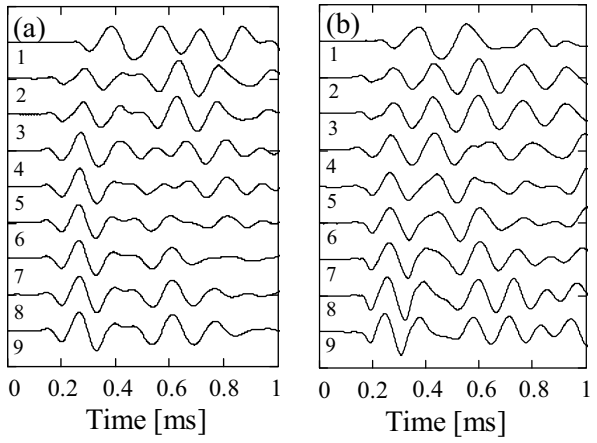

Fig. 3. Measured ultra sonic waves (200kPa): (a) Medium dense specimen; (b) Dense specimen

From the measured ultrasonic shear waves, the ultrasonic shear wave velocity was calculated and plotted in **Fig 4.** Figure 4 shows that the ultrasonic wave velocity is faster in the higer normal stress than in the lower normal stress. This result demonstrates that the effect of the increment in the normal stress on the ultrasonic wave velocity was more dominant than the effect of the density change because an increase in the normal stress causes an increase in the stiffness of the particle skeleton by increasing contact force between the particles.

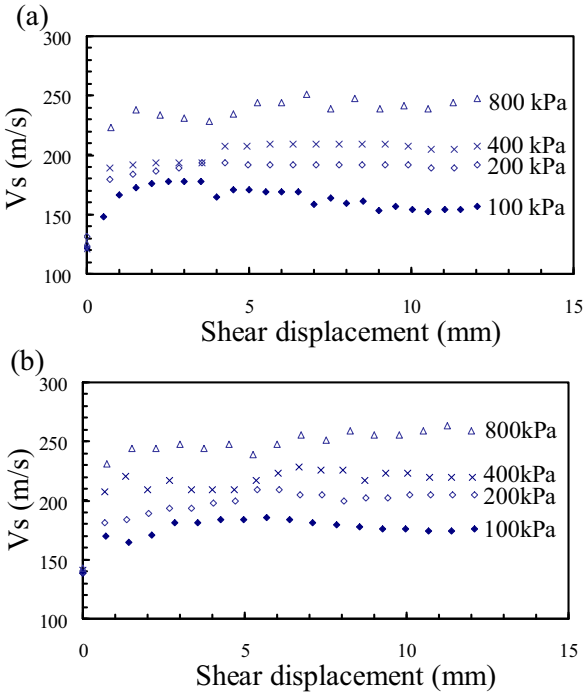

Fig. 4. Measured shear wave velocity: (a) Medium dense specimen; (b) Dense specimen.

5. Conclusion

This study presents that the shear strength and ultrasonic wave velocity in constraint of vertical displacement. Direct shear tests were conducted and the shear waves were continuously measured by the bender elements. The main observations obtained in this study are as follows: The shear strength increases as the normal stress increase. The ultrasonic wave velocity increases with normal stress because the normal stress effects to stiffness of particle skeleton through increasing of particle contact force. The changes in the ultrasonic wave show characteristics for the interaction between shearing particles in share plane.

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