Anisotropic behavior of sand reinforced with short fibers subjected to monotonic loading

Reinforced sand, triaxial compression, anisotropy

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1. Introduction

It is well-known that geo-materials are considered to have an anisotropic behavior. The mechanical behavior of geo-materials having a certain degree of anisotropy varies depending on many factors. A sample preparation method (soil deposition) of both cohesive and cohesionless soils can be considered as one of the factors influencing the anisotropy of specimen. Previous studies[1)2)3)] showed that sand specimens have different anisotropy due to the different placement methods of sandy soils (tamping/vibration in dry/moist conditions). The anisotropic behavior was observed in different initial stiffness and volumetric change behavior in drained triaxial compression tests and the difference in stress paths in undrained triaxial compression and extension experiments. The effect of sample preparation on the anisotropic behavior was also proved in torsional shearing[4)].

Having analyzed the above-mentioned outcomes and the experimental study conducted on the investigation of shearing behavior of fiber-reinforced sand[5)], the present study aimed at a comprehensive analysis of the anisotropic behavior of unreinforced and fiber-reinforced Toyoura sand and the effect of fibers on the degree of anisotropy. Additionally, the possible mechanism of fiber-reinforcement was also discussed based on obtained experimental results.

2. Materials and methods

Toyoura sand was used for all the experiments. The sand is classified as clean and uniform fine sand (SP) in the Unified Soil Classification System (USCS), with sub-angular and angular shaped particles. Its physical properties are as follows: specific gravity G_s = 2.646; maximum and minimum void ratios e_{max} = 0.985 and e_{min} = 0.639, respectively; uniformity and curvature coefficients of 1.33 and 0.98, respectively.

Polyvinyl alcohol (PVA) fibers with 12 mm length and 0.04 mm diameter have been used as a reinforcing material. The fibers have a specific gravity of G_f=1.3, tensile strength τ=1560 MPa, and elastic modulus E=41 GPa. The fiber content is defined as $w_f=m_f/m_{sp}$, where m_f and m_{sp} are the mass of the fibers and mass of sand particles, respectively. In this study, three different fiber contents of 0.0%, 0.2%, and 0.4% were adopted to obtain a correlation of fiber-reinforcement.

Consolidated drained (CD) and undrained (CU) triaxial compression tests were performed under three confining pressures (p'_0=50, 100, and 200kPa). Unreinforced and fiber-reinforced sand specimens, prepared by mixing sand with fibers in dry condition, have been placed by side-tapping/vibration in dry condition. The uniformity of the fibers distribution was checked by the reproducibility of experiments. The specimens were prepared in three density conditions as loose, medium dense and dense (D_r=30, 60, 80%) for CD tests, while only a medium loose condition with D_r=40% were utilized in CU to properly investigate not only a small-strain anisotropic behavior, but also the effect of fibers on the pore water pressure generation at higher axial strains (ε_a=20%).

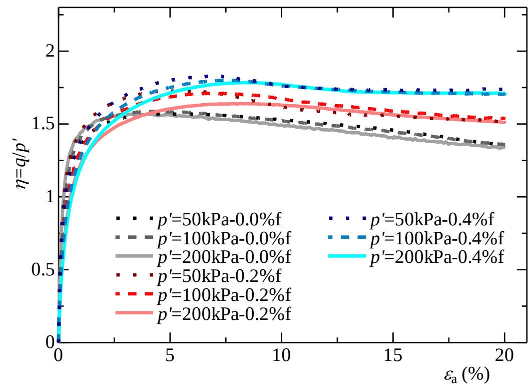

Fig. 1. CD test results of unreinforced and 0.2%, 0.4% fiber-reinforced sand with D_r=80% represented by stress ratio – axial strain dependency[5)]

3. Results and discussion

CD test results performed under three different confining pressures on dense specimens are shown in Fig. 1 by stress ratio – axial strain dependency. The stress ratio increased with the increase in fiber content and all stress ratios reached to the same value relatively the fiber content. Contrary, small strain characteristics point at smaller initial stiffness of fiber-reinforced sand compared to unreinforced sand (Fig. 2a). The initial stiffness had a decreasing tendency with the increase in

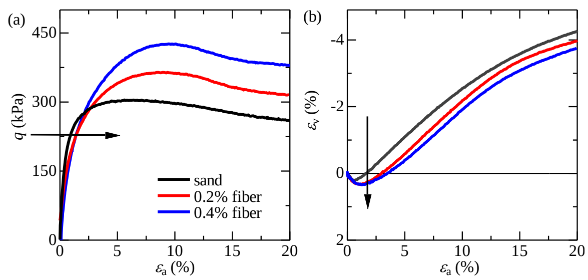

Fig. 2. Comparison of CD test results (D_r =60%)

短繊維で強化された砂の単調載荷時における挙動の異方性に着目した考察

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fiber content. Also, fiber inclusions brought a higher initial compression and less volumetric expansion at the end of shearing.

Figs. 3-4 shows CU test results performed on unreinforced and 0.4% fiber-reinforced sand, respectively. In a high strain behavior, the effectiveness of fiber inclusions was in a higher shear stress and a higher stress ratio. The pore water pressure (PWP) generation in CU tests was identical with the volumetric change behavior in CD test. When the fibers included into the sand, the reinforced specimen initially experienced a higher positive PWP, while generating smaller value of negative PWP with the shear progression.

Fig. 5 shows the effect of fiber content on CU test behavior of 40% in relative density. The reinforced specimens experienced decreased initial stiffness similarly as in CD tests. The stress path of fiber-reinforced sand underwent a larger decrease in mean effective stress *p*' before reaching the transformation point, and then, eventually reaching a higher stress ratio. In both cases of experimental work (CD and CU), the sample preparation was identical, and according to the previous studies[1,2], the dry deposition by vibration created more horizontally preferred orientation of sand particle in unreinforced sand, which refers to a higher degree of initial anisotropy. Effect of a higher degree of anisotropy brought a less decrease in *p*' in the stress path of the identical specimens with the same relative density sheared under the same confining pressure. From the experimental results it is clear that fiber-inclusions prevented preferred orientation of sand particles and led to a smaller degree of initial anisotropy. The decrease initial stiffness and a lower stress path conditioned with the different degree of anisotropy at the initial stage of shearing indicate that the fibers are more effective at higher strains.

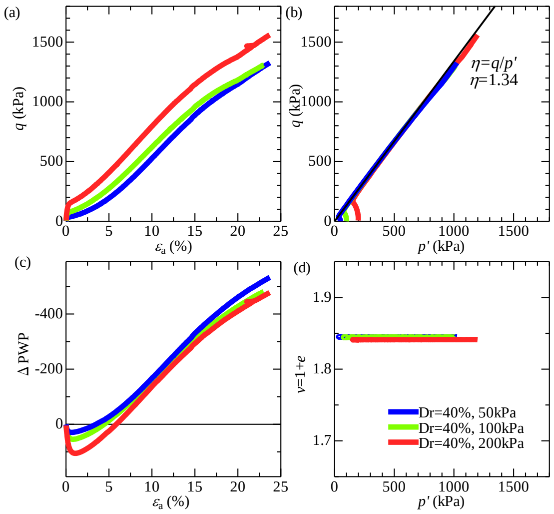

Fig. 3. CU test results of unreinforced sand sheared under different confining pressures

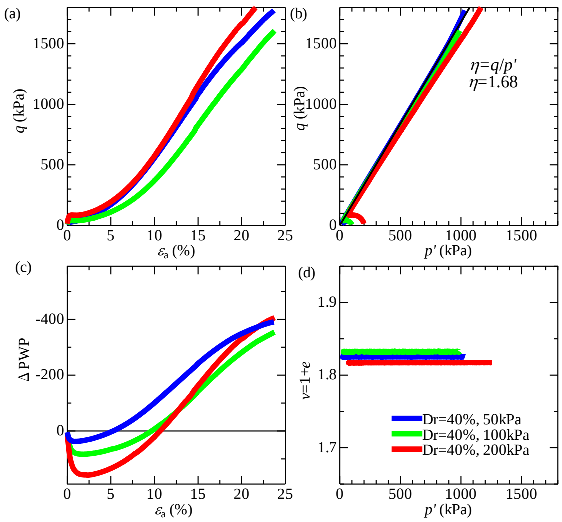

Fig. 4. CU test results of 0.4% fiber-reinforced sand sheared under different confining pressures

4. Conclusions

CD and CU tests showed that the fiber inclusions possibly created less preferred orientation of sand particles in specimens prepared by dry vibration, which leads to a smaller degree of initial anisotropy, where the reinforced specimens experienced smaller initial stiffness and a higher initial volumetric compression (CD) and a higher PWP (CU).

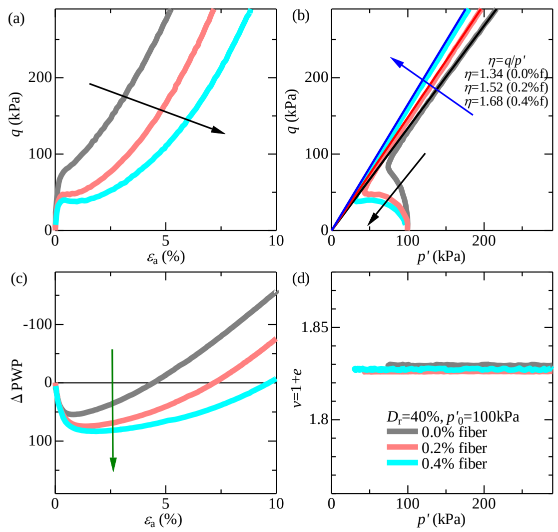

Fig. 5. Comparison of CU test results

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