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主　論　文　の　要　旨

論文題目　Experimental and Numerical Analysis of Mechanical Behavior of Fiber–Reinforced Sands based on Critical State Soil Mechanics

(限界状態理論に基づく繊維補強砂の力学挙動の実験および数値解析的解釈)

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論　文　内　容　の　要　旨

Reinforcing soils with tension resisting elements are alternative soils improvement technique confirmed by a series of experimental studies. Several types of ground improvement methods that employ fiber-reinforcement have been developed in recent years. However, despite numerous studies performed in the past few decades there is still a gap between theoretical understanding and practical implementation of fiber-reinforcement on a production scale. For this purpose, this study is aimed to comprehensively investigate the mechanical behaviour of fiber-reinforcement through experimental and numerical analysis with the particular attention to the reinforcing effect and interaction mechanism between soil particles and fibers. This study is divided into two main parts: experimental study and simulation of experimental results by utilizing an existing constitutive model super/subloading yield surface Cam-clay model (SYS Cam-clay model).

Experimental work firstly considered a sample preparation issue, including mixing fibers with sand and placement, where the optimum way of sample preparation was proposed. After that, isotropic compression and consolidated triaxial compression and extension experiments in both drained and undrained conditions were performed on both unreinforced and fiber-reinforced sand specimens.

First, a series of consolidated drained triaxial compression and extenstion tests were conducted here to examine the effect of short fibers on the mechanical properties of sand. As for the fiber, discrete polyvinyl alcohol fibers with the length of l_f=12mm and vinylon filament fibers were utilized with the proportion of 0.0%, 0.2%, 0.4%, and 1% of the dry weight of sand. Specimens were sheared under five different confining pressures of p'_0=50kPa, 100kPa, 200kPa, 400kPa and 600kPa and prepared in three different initial relative densities of D_r=30%, 60% and 80%. The test results showed that the maximum and residual deviator stresses increased, whereas the volumetric expansion decreased with an increase in fiber content in compression. Although the stress ratio η (=q/p') and specific volume changed depending on the fiber content and confining pressure with shear progression, they each reached the same values for a definite fiber content at the end of shearing, independently of initial relative density. In other words, the unique critical state line can be found for a definite fiber content. Moreover, the greater the fiber content, the larger the slope of the critical state line at the end of shear.

Next, a series of undrained triaxial compression and extenstion experiments were conducted. Specimens were prepared with initial relative density of D_r=40% to fully investigate the pore water pressure generation at higher strains and all specimens were sheared under three different confining pressures of p'_0=50kPa, 100kPa, 200kPa. Both unreinforced and fiber-reinforced sand specimens showed similar tendency of mechanical behavior as in drained compression tests. Particularly, despite being sheared under different confining pressures, both unreinforced and fiber-reinforced sands prepared with the same initial relative densities reached to the same deviator stress at around 20% axial strain. Furthermore, residual stress ratio η_r values (critical state parameter M) were similar as were obtained in drained tests. The pore water pressure generation in undrained tests were similar to the volumetric change behavior in drained condition, where fiber-reinforced specimens initially had a higher positive pore-water pressure and had a smaller generation of negative pore water pressure at the end of shearing. Also, fibers were also effective in enhancement of the tensile strength in undrained triaxial extension experiments. With the increase of fiber contents, the tensile strength increased, and there were no transferred shear band as in drained condition.

Finally, numerical analysis of compressive behavior of unreinforced and fiber-reinforced sand were performed. Based on the experimental studies, where even fiber-reinforced sand had a similar mechanical behavior as unreinforced sand and the possibility of describing their mechanical behavior through critical state soil mechanics was revealed, the super/subloading yield surface Cam-clay model (SYS Cam-clay) was used to reproduce the experimental results. The reproduced results were in good agreement with experimental results. Both simulated and experimental results showed that an increase in fiber content led to decrease in initial stiffness and increase in initial volumetric compression. This was attributed to the lower initial anisotropy of reinforced sand due to the fiber inclusions. Furthermore, the simulation results indicated that the fiber inclusions inhibited the development of anisotropy compared to unreinforced sand. Consequently, a higher peak and post-peak stresses with increased critical state parameter M, and less volumetric expansion at higher strain rates observed in fiber-reinforced sand.