MECHANICAL BEHAVIOUR OF VOLCANIC ASH SUBJECTED TO INTERNAL EROSION OBSERVED IN TORSIONAL SHEAR

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1. INTRODUCTION

Internal erosion is defined as detachments of soil particles from the main structure inside the ground due to mechanical or chemical actions of seepage flow. The result of internal erosion can be observed in the field as chains of macropores on the ground surface. The degree of migration of fine particles can affect both micro and macro structural behaviour of soil. Many researchers have conducted experimental investigations on different aspects of internal erosion such as the susceptibility of soil and progression of internal erosion using gap graded soils. However, a few studies have used hollow cylinder apparatus and widely graded volcanic soil to explore the effect of internal erosion. This paper analyses the impacts of internal erosion on the mechanical properties of volcanic ash in torsional shearing.

2. MATERIAL PROPERTY

Satozuka soil (volcanic ash soil) (G_s = 2.391, e_{max} = 2.192, e_{min} = 1.275, w_{opt} = 42.6%) was used in the present tests. Particle-size distribution (PSD) of the collected soil, sieved below 10 mm is shown in Fig. 1; the soil has a median particle size (D_{50}) of 0.1 mm with a non-plastic fines content (*FC*) of approximately 45%. Fig. 2 shows the cumulative pore volume of D^P under relative densities (D_{r0}) of 30%, 50% and 00%, where macropores dominate. As a result, the soil is categorized as partially unstable; however, it is not easy to erode the soil due to a high *FC* value of 45%.

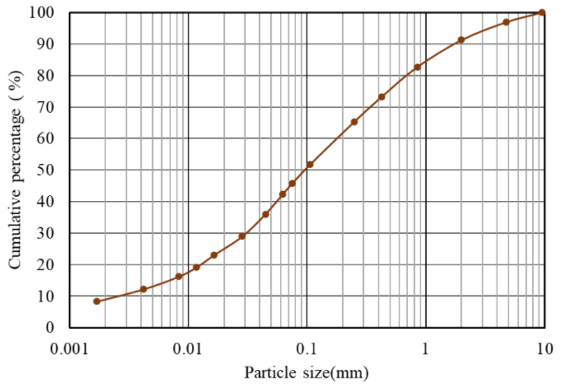

Fig. 1 Particle size distribution of Satozuka soil

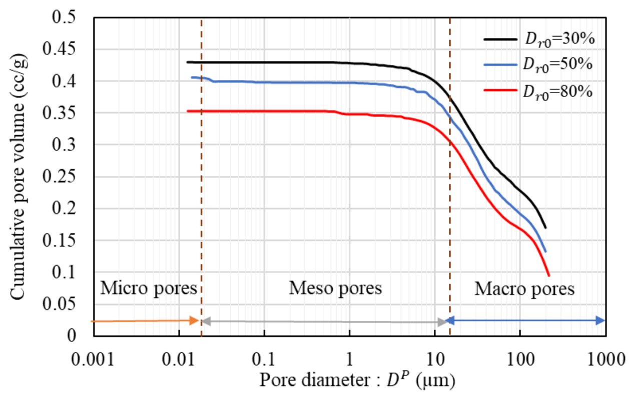

Fig. 2 Pore size distribution of Satozuka soil

3. TEST METHOD

A high-capacity torsional shear test apparatus, developed at the Institute of Industrial Science, the University of Tokyo, was employed in this study. Specimens with outer diameter D_o = 100 mm, inner diameter D_i = 60 mm and height H = 100 mm were used. LVDT (external displacement transducer) was placed on the outside of the cell to measure the vertical strain ε_a of the specimen. A potentiometer was used to measure the large shear strain γ, which was attached to the loading shaft outside the cell. A pair of gap sensors (GS1 and GS2) embedded on the top platen in the cell of the torsional apparatus with a capacity of 4 mm were used to estimate small-range shear strain γ. HCDPT (high-capacity differential pressure transducer) was used to measure the effective stress in the soil specimen during the tests. The average horizontal strain ε_h was calculated from the CGs (Clip gauges), during the consolidation and erosion. The test was conducted as follows. First, the specimen was prepared using the moist tamping method (Ladd, 1970) into five layers of equal thickness. Following the specimen preparation, 30 kPa of isotropic confining pressure was imposed on the specimen and maintained until the end of the test. Then double vacuum and saturation were applied to reach B>0.95. After applying 200 kPa backpressure (230 kPa cell pressure) the tank valves were closed, and the corresponding B value was checked. Subsequently, the tank valves were opened, and the specimen was consolidated to an effective stress of 00 kPa. After that soil specimen was eroded using back pressure (<50 kPa) applied through the water tank. Then, a turbidity meter was used to measure the turbidity of the collected water every ≈60 minutes for 300 minutes. Finally, torsional monotonic shearing was applied to specimen until shear strain, γ reached to 30%. Drained tests were conducted on samples with relative densities, D_{r0} of 00% (dense), 50% (medium dense) and 30% (loose), subjected to seepage, along with a sample that had not been subjected to erosion.

Keywords: Volcanic-ash, Internal erosion, Torsional shear, Drained monotonic shearing
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4. RESULTS AND DISCUSSIONS

Cyclic torsional loading at small-strain levels (γ < 0.001%) was applied before and after the erosion tests in order to estimate the small-strain shear modulus, G_{max}. Fig. 3 shows the variation of G_{max} along with the void ratio, e for the specimens confined at 80 kPa. Post erosion global void ratio, e increases due to fine removal and seepage process as shown in Fig. 3. Post-erosion G_{max} increases in loose and medium dense cases compared with post-consolidation G_{max} under the same stress amplitude, except in dense case. This is probably because the force chains are benefitting from an increase in number of inter-particle contacts caused by the rearrangement of the soil skeleton during erosion at the low strain range for medium dense and loose cases.

Monotonic torsional shear tests were conducted under drained condition. Fig. 4 illustrates the relationship between shear strain, γ_s and torsional shear stress, τ. Non-eroded (NE) specimens show a strain-hardening behaviour up to medium-strain range, and then reach the critical state except for dense case; the dense case shows a strain-softening in the medium strain range and reaches the critical state. After the erosion, a reduction in the peak shear stress, τ_{peak} is observed, although a steady state is reached after γ_s = 25%. The reduction in shear strength for the eroded cases could be a result of the reduced density due to the particle removal, the disturbance of the microstructure due to erosion, or combination of both. Moreover, the reinforced soil skeleton established by the erosion did not resist against shear loading. Besides, the soil strength is reduced to a lesser extent for the dense specimens (compared with the loose specimens); hence, in the dense soils the stress transmission is given mostly by the primary fabric, while in the loose soils the fines play a more important role in the strength.

Fig. 5 shows the volumetric strain changes with shear strain under different densities. Moreover, ε_v values of non-eroded soils display an increasing dilatancy with increasing D_{r0}. Loose and medium dense cases show contractive behaviour up to their critical state, while dense specimen shows initial volumetric contraction followed by dilation. Dilatancy ratio $\left(\frac{\partial \epsilon_v}{\partial \gamma_s}\right)$ at any point increases after the erosion for dense and medium dense cases, which confirms that dilatancy behavior is improved by erosion.

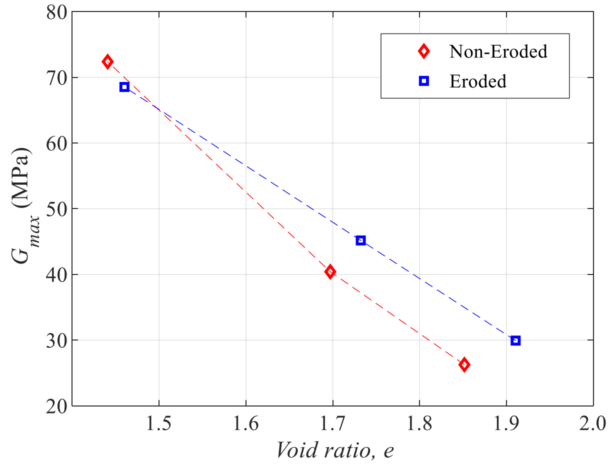

Fig. 3 Dependency of G_{max} on void ratio, e

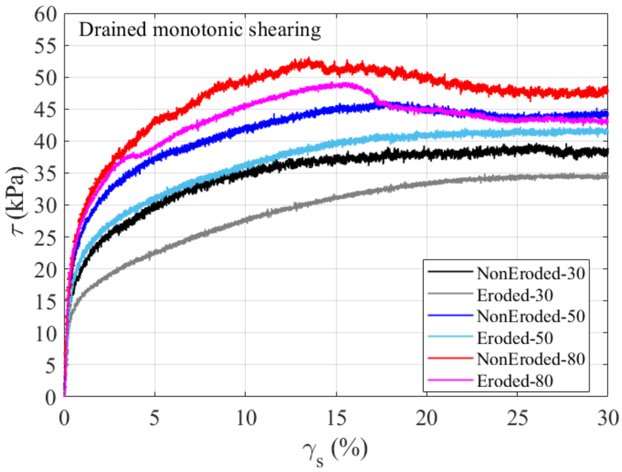

Fig. 4 Shear stress - shear strain relationship

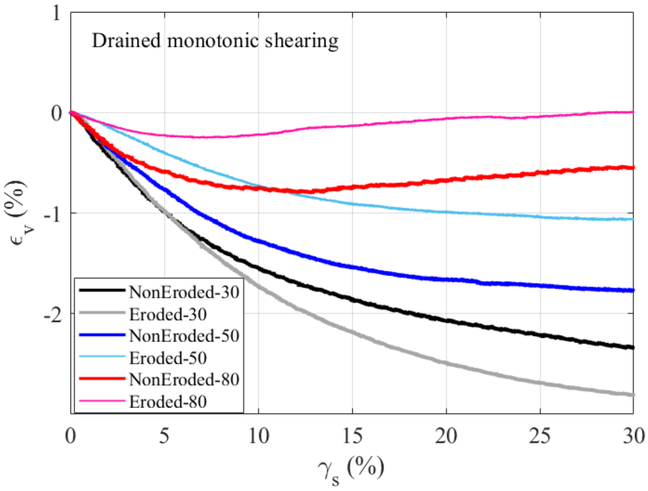

Fig. 5 Volumetric strain of eroded and non-eroded soil

5. CONCLUSION

An experimental investigation was conducted to study the post-erosion mechanical behavior of volcanic ash. In torsional shear, the specimens subjected to erosion exhibit a reduction in their strength: peak shear stress and increase in shear modulus (G_{max}). The reduction of the strength might be due to the internal rearrangement of fabric and reduction in density. The structure of the sample was probably affected due to removal of fines, leading to the collapse of coarse particle packing or infilling of the initial void with fine particles.

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