

Evaluation of Shear Strength of Volcanic Soils in Mountainous Areas Using In-Situ Direct Shear Test Apparatus

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Abstract: Volcanic pumice soils are widely distributed in Japan and Asian countries, causing serious slope disasters. Their highly porous and loose structure is easily disturbed, so in-situ testing that maintains the original structure is desirable. In this study, a lightweight and small-sized in-situ direct shear test apparatus was newly developed. The improved loading system allows both monotonic and cyclic loading. The developed apparatus was applied to volcanic pumice soils in Japan, and representative examples are presented. The proposed in-situ direct shear test apparatus is an effective method to evaluate the mechanical behavior of sensitive volcanic pumice soils quickly and simply in the field.

Keywords: *In-situ direct shear test, Volcanic soils.*

Introduction

Volcanic pumice soils are widely distributed in Japan and many Asian countries, causing serious slope disasters, resulting in significant damage to human lives and infrastructure. Volcanic pumice soils are generally composed of fragile, porous particles and retain extremely loose structures. The soil structure can be easily disturbed or destroyed during sampling, transportation, and trimming. Once the original structure is destroyed, it is almost impossible to reproduce it. Therefore, it is desirable to conduct tests on site while preserving the in-situ soil structure.

In this study, a lightweight and small-sized in-situ direct shear test apparatus was developed to evaluate the shear strength of sensitive volcanic pumice soils in a simple manner under minimally disturbed conditions. Furthermore, the apparatus was improved by adding a cyclic loading mechanism to estimate not only the peak strength but also the residual strength after large deformation. This paper presents the developed in-situ direct shear test apparatus and their field applications.

Apparatus and testing procedure

Figure 1 shows photographs of the in-situ direct shear test apparatus. The apparatus consists mainly of a rigid frame, a top lid, front and rear fixtures, a jack, measuring devices, and a microcontroller unit. The first version (v1)

allows only monotonic loading because the hand-pumping jack can apply force in one direction, whereas the second one (v2) enables cyclic loading as the screw jack can apply force in both directions. The frame, lid and fixtures are made of plastic molded by a 3D printer. The entire apparatus weighs less than 10 kg, making it easy to carry by hand to the sites in the mountains. The microcontroller unit is used to obtain vertical and horizontal forces as well as horizontal displacement.

Figure 2 illustrates the procedure of the in-situ direct shear test. After excavating a slope horizontally, the rigid frame was placed around a trimmed specimen, and the top lid was set on top of it. The frame was 120 mm square and 60 mm high, corresponding to an upper box of laboratory direct shear test apparatus. After the frame was placed, the front and rear fixtures, shafts, jack, and measuring devices were attached. The normal force was applied by locally available stones or by human weight. The shear force was applied using the hand-pumping jack (v1) or screw jack (v2). When the specimen was sheared by the horizontal movement of the frame, a shear plane formed at the bottom of the specimen. Consequently, the soil structure around the shear plane was untouched before shearing and considered to be little disturbing until the test.

Example of application

The developed apparatus was applied to volcanic pumice soils in Japan. Table 1 shows the physical properties of the tested volcanic pumice soils. Figure 3 (a) presents the result of an in-situ direct shear test conducted on brown pumice at the Dozo-sawa River, where a debris flow occurred during the Iwate–Miyagi Nairiku Earthquake in 2008 (Hashimoto et al., 2023). For comparison, the result of a laboratory direct shear test under the same confining pressure (35 kPa) is also shown. The peak shear strength obtained from the in-situ test was approximately equal to that of the laboratory test using intact specimen, and greater than that of the laboratory test using a reconstituted specimen. Figure 3(b) presents the result of an in-situ cyclic direct shear test carried out on Ta-d pumice at a

site in Hokkaido, where landslides occurred by the 2018 Hokkaido Eastern Iburi Earthquake (Kawamura et al., 2019). The test was conducted under a constant confining pressure of 11 kPa with a cyclic shear displacement of 28 mm double amplitude for 10 cycles. It was observed that the mobilized shear stress gradually decreased with an increasing number of cycles, suggesting that applying large displacements through cyclic loading makes it possible to estimate the residual strength from in-situ direct shear tests.

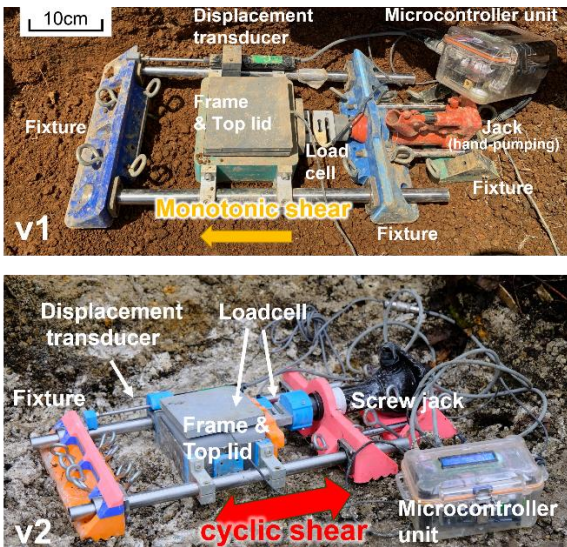


Figure 1, In-situ direct shear test apparatus.

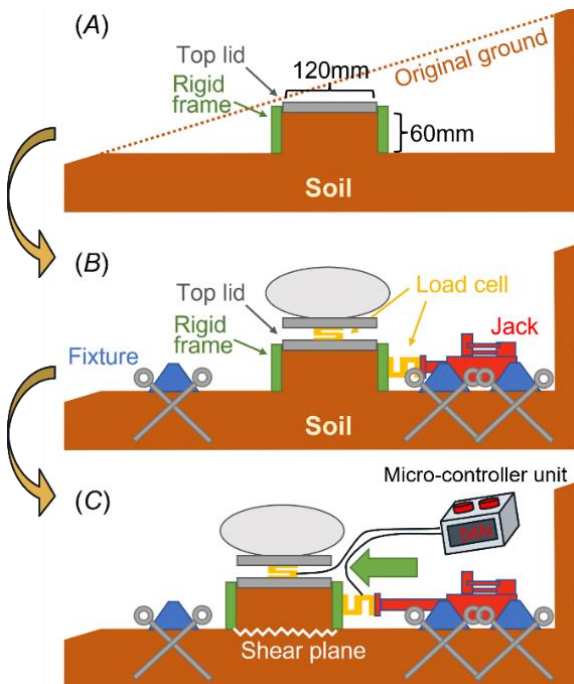


Figure 2, Testing procedure of in-situ direct shear test.

Table 1, Physical properties of pumice soils.

Name	ρ_s (g/cm ³)	ρ_d (g/cm ³)	w_n (%)	e	D_{50} (mm)	w_p (%)	w_l (%)	I_p (%)
Dozou-sawa	2.66	0.93	62	1.84	1.7	53	60	7
Atsuma Ta-d	2.68	0.30	219	7.93	2.5	151	206	55

ρ_s : Soil particle density, ρ_d : Dry density, w_n : Water content in natural condition, e : Void ratio, D_{50} : Mean particle diameter, w_p : Plastic limit, w_l : Liquid limit, I_p : Plasticity index.

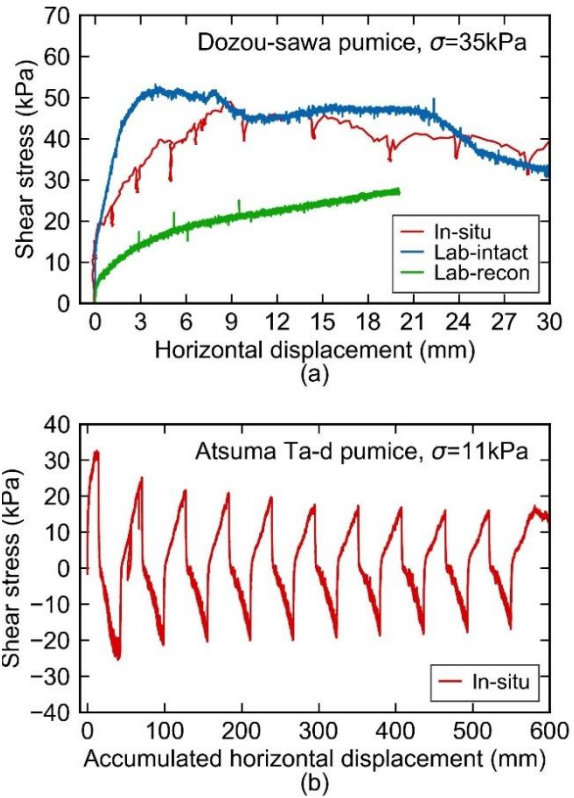


Figure 3, Stress-displacement relationship of in-situ and laboratory direct shear tests on pumice soils.

Conclusion

A lightweight, compact in-situ direct shear apparatus was developed for volcanic pumice soils in Japan. Monotonic tests showed peak shear strength comparable to laboratory tests, while cyclic tests indicated decreasing mobilized strength with larger displacements, allowing residual strength estimation. The apparatus provides a quick and simple field method to evaluate the mechanical behavior of sensitive pumice soils.

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References

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