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On the shear behaviors of weathered diatomaceous mudstone and their implication for coseismic landslides in the Noto Peninsula, Japan

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1 Introduction

The Noto Peninsula, Japan's largest diatomite-producing region, features widespread deposits of diatomaceous mudstone and is prone to frequent geological activity. In weathered diatomaceous areas, where the soil is highly susceptible to disturbance, the risk of geohazards is significantly high. Several diatomite landslides, characterized by their unique mechanical behavior, were triggered by the 2024 Noto Earthquake. While previous studies on diatomite landslides have focused on effect of diatom content on the shear behavior of sliding surface materials, the underlying mechanisms related to this, especially to the undrained shear behavior of saturated sample, for example, the effect of breakage of diatom frustule particle on the pore-water pressure generation remains unclear. Therefore, this study examined diatomaceous soil from the Inafune area of Wajima City, utilizing a large-scale ring shear apparatus to investigate the effects of mechanical stress, pore water pressure response, and microstructural particle breakage on the mechanical behavior and liquefaction susceptibility of diatomite.

2 Field Survey

A field survey was conducted on a landslide in Inafune Town, Wajima City, situated in a geological setting dominated by diatomaceous mudstone (Fig. 1). The main landslide associated with the sampling points trends N81°W and dips at approximately 20°, with a total vertical displacement of about 40 meters.

The sampled diatomaceous mudstone is characterized by low density, high porosity, and intensive weathering, which collectively contribute to its weak mechanical properties. Scanning Electron Microscopy (SEM) observations were conducted on naturally air-dried specimens to preliminarily identify diatom frustule morphology, as shown in Fig. 2.

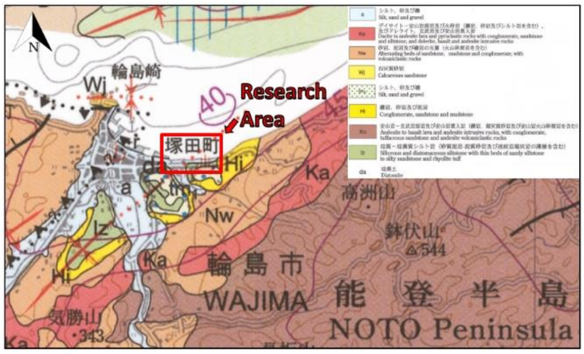

Fig 1. Geologic map of the Inafune area (From GeomapNavi[2]).

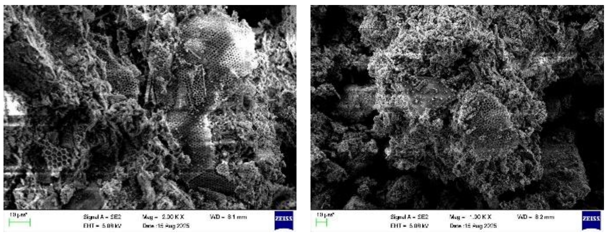

Fig 2. SEM results of Inafune sample.

3 Test Procedure

The experimental soil samples were collected from the slide surface in the Inafune area, naturally air-dried, and passed through a 2-mm sieve.

To investigate the evolution of pore water pressure during the shearing process of diatomite, undrained monotonic shear tests were first conducted on the specimens. Subsequently, to examine whether diatom frustule crushing serves as a dominant mechanism for pore-water pressure accumulation, the following supplementary experiments were performed:

Tests D1–D4: Dry shear experiments were conducted at different shear displacements. Following the tests, specimens were extracted from the shear zone to calculate their breakage index (*Br*).

Tests M1–M3: Drained slow shear experiments were performed under different consolidation ratios (OCRs). The hydraulic conductivity (*k*) was derived from the vertical displacement changes recorded during the consolidation phases both pre- and post-shearing based on consolidation theory.

Table 1 Test condition of dry shear tests.

Test	Sample (Apparatus)	Maximum particle size (mm)	Normal stress (kPa)	Shear control type	Shear displacement (mm)
D1	Diatomite from Inafune (DPRI-5)	2	200	Shear stress control	100
D2					200
D3					1000
D4					2000

Table 2 Test condition of drained slow shear tests at different OCRs.

Test	Sample (Apparatus)	OCR	Consolidation Stress (kPa)	Shear control type	Shear speed (cm/s)	Reconsolidation Stress (kPa)
M1	Diatomite from Inafune (DPRI-5)	1	130	Shear speed control	0.001	260
M2		1.5	195			
M3		2	260			

4 Results

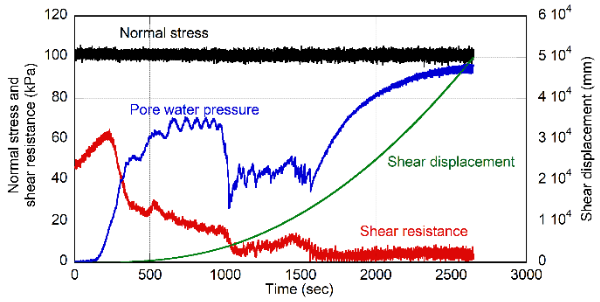

Fig 4. Results of undrained monotonic shear tests.

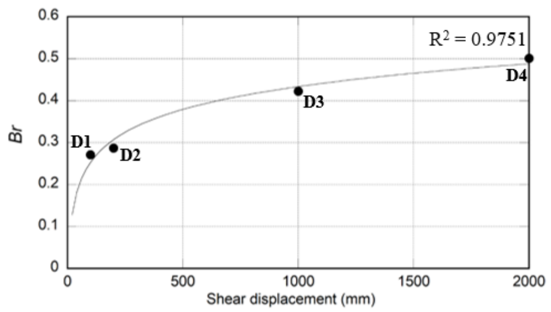

Fig 5. Breakage index results from dry shear tests. (D1–D4 represent the post-test breakage indices of the shear zone soil).

The experimental results reveal a clear coupling relationship among particle breakage, hydraulic conductivity reduction, and pore-water pressure generation.

Fig. 3 shows that during undrained monotonic shearing, pore-water pressure in the Inafune diatomite

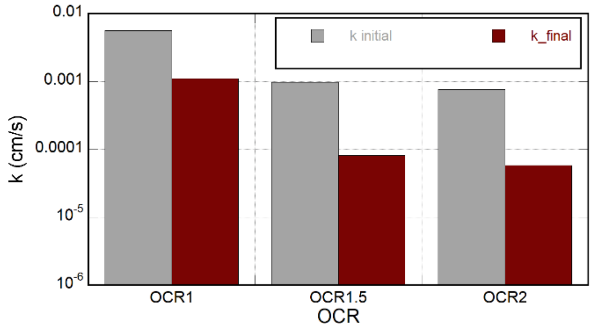

Fig 3. Hydraulic conductivity pre- and post-shearing in drained slow shear tests at different OCRs (k_initial and k_final denote the hydraulic conductivity after consolidation before and after shearing, respectively).

specimens increased continuously and eventually approached the applied normal stress, indicating a high liquefaction susceptibility.

Fig. 4 demonstrates that the breakage index (Br) of the shear zone samples increased progressively with shear displacement, confirming significant crushing of diatom frustules under shear loading.

Fig. 5 indicates that hydraulic conductivity decreased markedly after shearing and with increasing OCR, suggesting that the production of finer fragments reduced the permeability of the shear zone.

These results collectively suggest that diatom frustule breakage plays a key role in both the accumulation of excess pore-water pressure and the post-shear reduction of hydraulic conductivity.

5 Conclusion

The results preliminarily verify that the rise in pore water pressure during the failure process of the Inafune landslide is driven by factors such as particle crushing.

However, field surveys indicate that the slope exhibited limited flow mobility. Although particle crushing promotes rapid pore-water pressure accumulation during shearing, the inherently loose and porous structure of the diatomite enables relatively fast post-failure dissipation, which may explain the limited flow mobility observed in the field.

Future research will focus on comparing the shear characteristics of Noto diatomite with other common slip zone soils in the region, as well as simulating the concurrent accumulation and dissipation mechanisms of pore water pressure in diatomite landslides.