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Mechanisms and Evolution of the Ichinose Complex Landslide Triggered by the 2024 Noto Earthquake

〇Jiangkun HE, Gonghui WANG, Fanyu ZHANG, Gen FURUYA, Issei DOI, Koichi HAYASHI, Yasuhiko OKADA

1 Introduction

During the 2024 Noto Peninsula Earthquake, thousands of landslides were triggered, including a large-scale landslide in the Ichinose area of Wajima City, Ishikawa Prefecture. This landslide exhibited high mobility, traveling more than 1 km, destroying several houses, and causing one fatality. To investigate the mechanisms and evolution of this landslide, we conducted field surveys, microtremor observations, seismic monitoring, and laboratory tests on samples collected from various locations within the landslide, and report some preliminary research results here.

2 Ichinose Landslide

The head of the Ichinose landslide is composed mainly of conglomerate, tuffaceous sandstone, and andesitic pyroclastic rocks, while the middle to lower parts are characterized by alternating layers of sandstone, mudstone, and conglomerate. Field investigations indicate that the landslide involved three sequential movements, as schematically illustrated in Fig. 1a. First, instability was triggered by strong ground shaking during the earthquake in Area 1, forming the main scarp shown in Fig. 1b. The lower part of Area 1 became highly fluidized, generated a debris flow approximately 6 m in depth, and was eventually deposited in residential areas located about 600 m from the original landslide toe. Second, the wedge-shaped Source Area 2 (Fig. 1c) failed and subsequently accumulated at the base of the newly formed scarp. Finally, Source Area 3 (Fig. 1d) also failed, with part of the sliding mass deposited in a lateral gully and the remainder on the exposed sliding surface of Source Area 1. It is noteworthy that the fluidization at the toe played a critical role in significantly amplifying the overall impact and extent of the disaster.

Fig 1. (a) Overview of Ichinose landslide; (b) Landslide scarp of Source area 1; (c), (d): Source area 2 and 3.

3 Experimental Examination

To study the mechanisms and evolution of the landslide, we took samples from different locations of the landslides and used a ring-shear apparatus (DPRI-5) to examine their shear behavior. The structure of the DPRI-5, the principle of shearing the sample in ring-shear tests, and the method of sample preparation have already been reported in the literature (Sassa et al. 2003).

In this study, undrained cyclic loading tests as well tests for measuring the residual strength and examining the rate effect were conducted on samples S1-S3, which were collected from the bottom of the landslide deposits on the sliding surface outcropped on Source Area 1, from the top of the landslide, and from the toe of the landslide deposits, respectively.

4 Results and Discussion

Some typical test results are shown in Figs. 2–4. The cyclic loading tests for S1 indicate that pore-water pressure increased only slightly during cyclic loading. Rate effect tests show that S1 exhibits rate-strengthening behavior at low shear rates but rate-weakening behavior at high shear rates. In contrast, S2 showed a rapid increase in pore-water pressure during cyclic loading and failed quickly. And during rate-controlled shearing, S2 consistently exhibited rate-strengthening behavior, independent of stress level. The rate effect results for S3 display an opposite trend to S1, with rate-weakening behavior at low shear rates and rate-strengthening behavior at high shear rates.

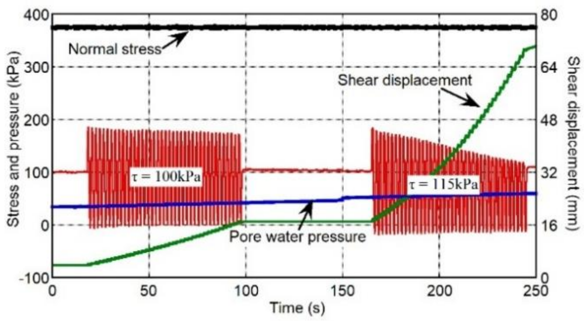

Fig 2. Undrained cyclic loading test on S1

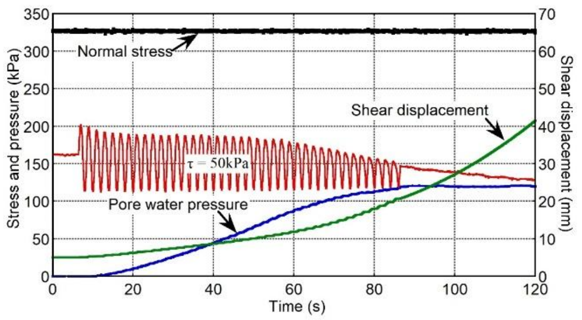

Fig 3. Undrained cyclic loading test on S2

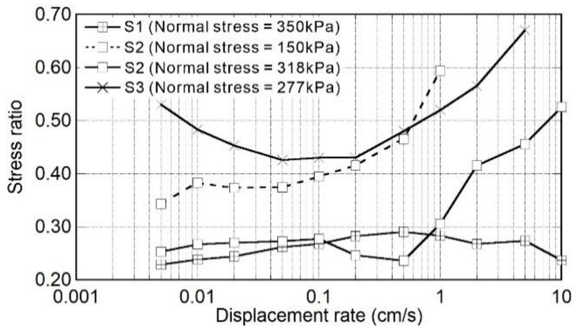

Fig 4. Drained rate-dependent shear test on all samples

The rate-strengthening behavior and relatively low liquefaction potential of S1 at low shear rates suggest that material from Source Area 1 is unlikely to fail without significant external disturbance. Nevertheless, its rate-weakening behavior at high shear rates implies that once failure is triggered, it may rapidly develop into catastrophic failure, which could explain the fluidized landsliding observed in video records. In contrast, S2 exhibits rate-strengthening behavior under various stress conditions, indicating that Area 3 is unlikely to fail under seismic loading alone. However, considering the steep slope of Source Area 3, failure of Source Area 2 and the formation of a free face at the toe could destabilize Source Area 3 and induce subsequent sliding, consistent with our field observations.

5 Conclusions

Some preliminary conclusions are summarized below:

1. The Ichinose landslide exhibits complex behavior and can be divided into three sequential subblocks. The first subblock moved downslope with fluidization at its toe, followed by failure of the second subblock, which deposited on the upper source area of the first. Finally, the third subblock failed from the uppermost source area, also with toe fluidization. Overall, the landslide showed high mobility and a small travel angle.

2. The fluidization at the landslide toe is primarily attributed to rate-weakening behavior combined with high water content. Fluidization in the upper part may be related to steep topography or changes in rate effects, which require further study.

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Reference

Sassa et al. (2003): Landslides 1(1): 7-19