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Evaluation of failure of slopes with shaking-induced cracks in response to rainfall

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Introduction

In some areas where earthquakes and rainfall are the common factors causing instability of slopes, the study of the combined effect of both hazards is critical to the understanding of slope behavior and the preventive measures needed to mitigate disasters. In the past several earthquakes including the 1995 Kobe Earthquake (Tomita et al. 1995), 1999 Chichi Earthquake (Lin et al. 2004), 2008 Sichuan Earthquake (Tang et al. 2011), many slopes showed surface fissures and cracks after the shaking, which induced landslides during the next rainy seasons (Lin et al. 2003; Tang et al. 2011). It was speculated that post-earthquake rainfall might cause the failure of slopes with fissures or cracks. However, the landslide triggering mechanism was still not clarified. In this study, centrifuge model tests were performed to evaluate the failure triggering mechanism of crack-containing slopes subject to rainfall and differentiate slopes with cracks from those without cracks in response to rainfall.

Test program

Model tests on slopes subject to dynamic loading and/or rainfall were carried out in the Kyoto University centrifuge.

Two tests were discussed in this paper and the test program was given in Table 1 where k_s stands for the saturated permeability of the soil.

Table 1

Test	Shaking intensity	Rainfall intensity
A	None	7 k_s
B	200 m/s^2	7 k_s

The configuration of the model slope is shown in Fig. 1.

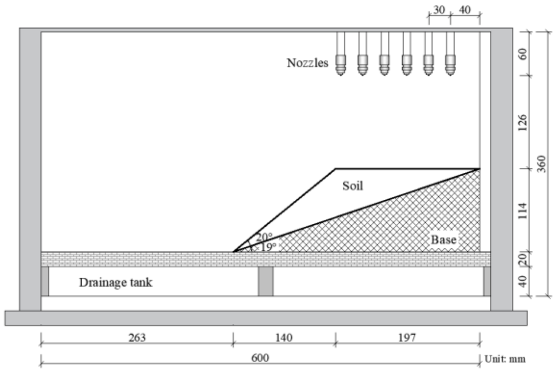


Fig. 1 Model slope

Pore water pressure transducers and accelerometers were placed inside the model slope while preparing the model by layer-by-layer compaction. Markers were also inserted along the model profile so that the soil movement during testing could be traced and quantified through image analysis of photos taken by the high-speed camera.

Results

Before comparing the behavior of slopes during rainfall, the response of slopes to shaking was first introduced here.

The input shaking waves in test B are shown in Fig. 2. After shaking, few surface cracks were left near the shoulder of the slope, as displayed in Fig. 3.

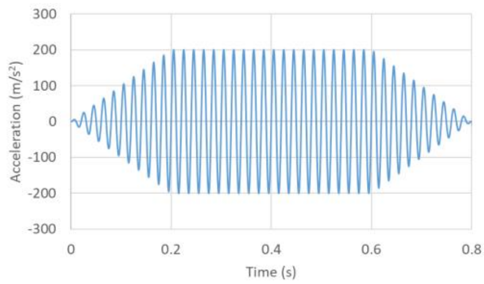


Fig. 2 Input waves in test B

Fig. 3 Surface cracks in test B

The displacement of three markers as shown in Fig. 4 were chosen here for analysis.

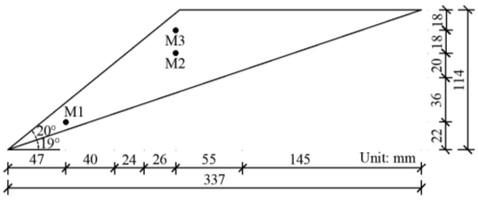


Fig. 4 Markers for analysis

Soil deformation in tests A and B demonstrated in Fig. 5 started to develop roughly 33 s since the onset of rainfall and approximately 6 s later, a sudden upsurge in the displacement of M1, M2, and M3 (Fig. 5) was prompted, and the velocity at which soil traveled in test B was significantly larger than that in the crack-absent slope in test A.

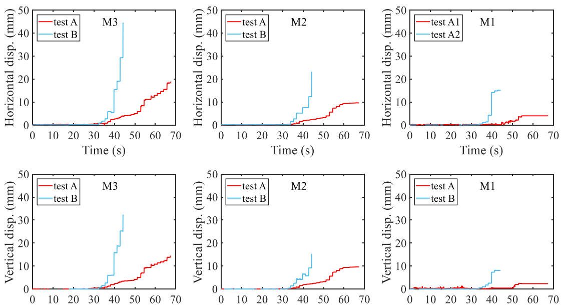
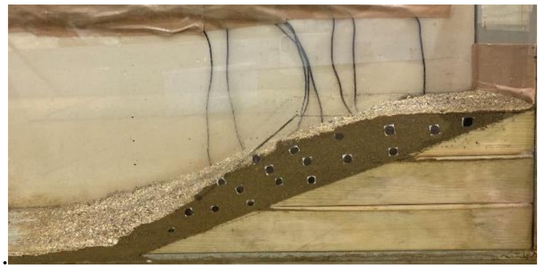
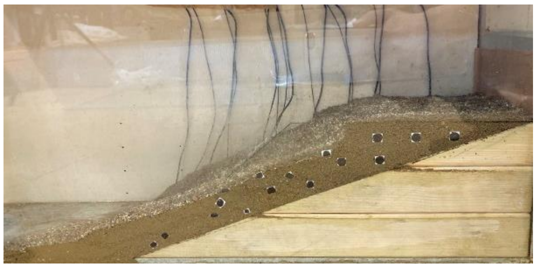


Fig. 5 Disp. of markers during rainfall in tests A and B

The deformation was enormous and the landslide occurred instantly with considerable momentum in test B. The photos taken after the completion of slope failure in tests A and B in Fig. 6 clearly show the difference of failure pattern between two tests.



(a) slope after failure in test A



(b) slope after failure in test B

Fig. 6 Failure of slopes in tests A (a) and B (b)

Conclusion

The failure mode of the slope with cracks during rainfall was different from that displayed by the slope without cracks. When cracks were generated by shaking on the surface of the slope, the mobilized soil slid along the slip surface that deformation of soil around cracks was much fast and failure completed in a very short time.

References

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Tang C, Zhu J, Qi X, Ding J (2011) Landslides induced by the Wenchuan earthquake and the subsequent strong rainfall event: A case study in the Beichuan area of China. Engineering Geology 122(1-2):22-33.

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