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Consideration on the Influence of Seismic Shaking on Forest Slope Stability and Landslide Warning Rainfall in the Aftermath of the Strong Earthquake

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The research concerning about the warning rainfall criteria of landslides after strong earthquakes is conducted associated with the great earthquake in Eastern Japan in 2011 ($M=9.0$). After this kind of strong earthquake, soil strength of the slopes in the region that were exposed to the strong seismic forces is generally reduced by seismic shaking (vibration). In this situation, the revised rainfall criteria for landslides are required. On this point of view, the response of landslide to rainfall under this weaken soil condition was studied. Hence, the impact of rainfall events on the specific landslide slopes that experienced the strong seismic shaking is analyzed using numerical simulation method i.e. finite element method (FEM) in order to evaluate the critical rainfall threshold for landslide occurrence. Consequently, we obtained following results.

In the result of FEM analysis, the cracks induced by the earthquake are effective to increase the seepage and render the slopes instable. The slope deterioration mentioned above due to the impact of earthquake causes temporarily 40~50% reduction of critical rainfall for landslide occurrence, corresponding to decrease in safety factor “ F_s ” of the slopes from $F_s=1.02\sim1.04$ to $F_s=0.83\sim0.95$. This reduction rate of critical rainfall is at same level as in the earlier researches based on field observations.

Key words: earthquake, FEM, landslides, rainfall, slope stability

INTRODUCTION

The research on the warning critical rainfall threshold of landslides after strong earthquakes is conducted associated with the great earthquake in Eastern Japan in 2011 ($M=9.0$). After this kind of strong earthquake, soil strength of the slopes in the region that were exposed to the strong seismic forces are generally reduced by seismic shaking or vibration and disturbance with certain slope deformation (Abe, 2011). In this situation, the revised rainfall critical threshold for landslide occurrence are required.

On this point of view, we are intrigued to elucidate the response of landslide to rainfall under this weaken soil condition. Hence, the impact of rainfall events on the specific landslide slopes that experienced the strong seismic shaking is analyzed using numerical simulation method i.e. finite element method (FEM) in order to evaluate the critical rainfall threshold for landslide occurrence.

METHOD

Field investigation and geotechnical indoor test with samples collected from the landslide slopes (Figs. 1~5) are conducted to obtain the basic data for FEM analysis such as hydraulic conductivity “ k ” and soil shear strength at the slopes that experienced strong earthquake. Then,



Fig. 1. An example of landslide scarp induced by Earthquake in Shikanoshima (Granite).



Fig. 2. An example of landslide induced by Earthquake in Shikanoshima (Granite).

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Fig. 3. An example of landslide in Shintate area (university forest, Schist).



Fig. 4. An example of landslide scarp in Shintate area (university forest, Schist).



Fig. 5. The whole view of a sample landslide in Shintate area (in university forest, Schist).



Fig. 6. An example of crack on the slope generated by an earthquake.

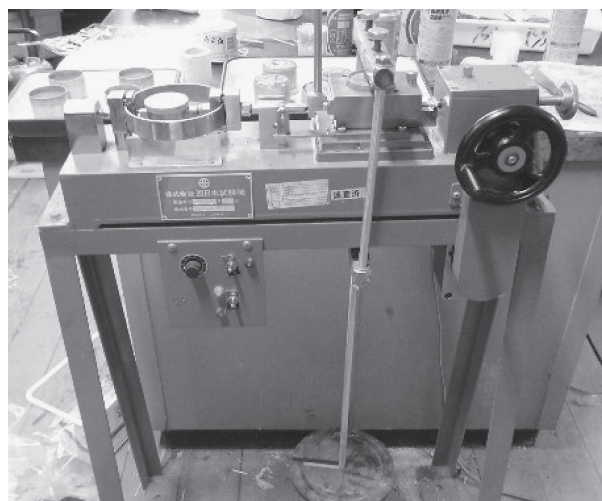


Fig. 7. The simple shear test machine.

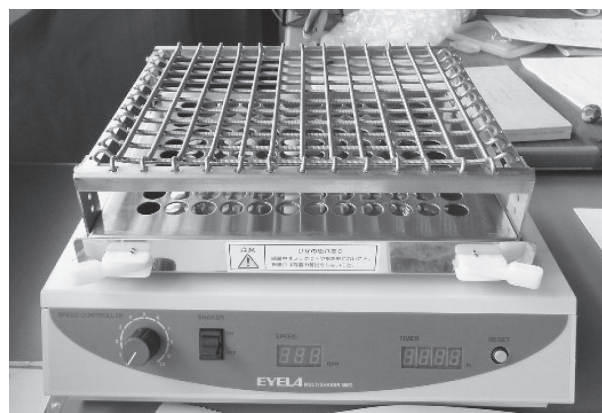


Fig. 8. The mechanical shaker to give soil samples a shaking impact.

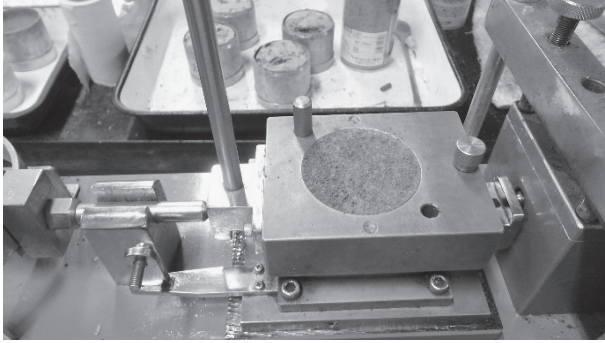


Fig. 9. The mechanical shear test of soil samples.

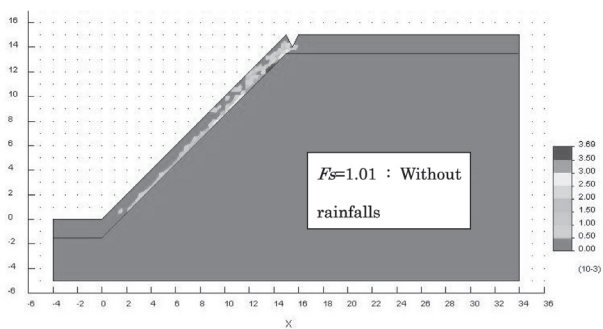


Fig. 10. An example of the FEM slope stability analysis on a disturbed slope by the earthquake (Shikanoshima, Shallow slide, Granite, maximum increment of the shear stress with tension crack at the slope top).

FEM analysis which combines rainfall seepage analysis and slope stability analysis with the rainfall data at nearest meteorological observatory is conducted under the earthquake impact i.e. the slope condition with cracks (Fig. 6) which are located at the top of the slope and have high “ k ” or reduced soil strength. Comparing the FEM results with ones without earthquake impact, the influence of the earthquake shaking to the landslide slopes is estimated.

Simultaneously, some soil samples of weathered schist were also prepared for shear tests with roots and without roots, to clarify the influence of seismic shaking on soil strength (Figs. 7~9). The seismic shaking was generated by mechanical shaker up to 1,500 gal.

In the result of FEM analysis (Figs. 10, 11, 12), the cracks induced by the earthquake play a great roll to increase the rainfall seepage effectively and render the slopes unstable. Also, reduced soil strength such as 4% decrease in internal friction angle as its residue strength (Nagamine, 2009) due to the deformation in the slope stratum caused instability of the slope.

The slope deterioration mentioned above due to the impact of earthquake causes 40~50% reduction of critical rainfall threshold for landslide occurrence temporarily (Figs. 13, 14). It is corresponding to the decrease in the safety factor “ F_s ” of the slopes from 1.02~1.04 to F_s =0.83~0.95 (Figs. 13, 14). This reduction rate of critical rainfall mentioned above is as same level as ones in the

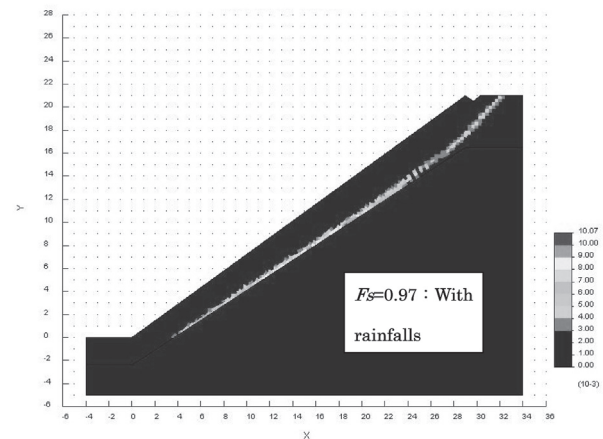
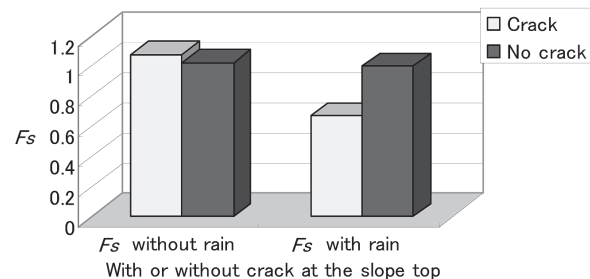
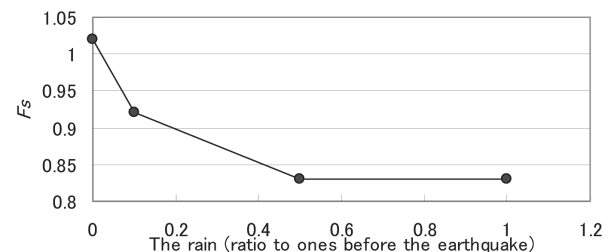


Fig. 11. An example of the FEM slope stability analysis on a disturbed slope by the earthquake (Shintate, Deep slide, Schist, with tension crack at the slope top).



The slope stability (factor of safety F_s) of the shallow landslide after earthquake

Fig. 12. The influence of cracks by the earthquake on the shallow landslide stability F_s .



The rainfall at the shallow landslide slope after the earthquake and slope stability F_s (Under the premise that the coefficient of permeability is fivefold of original one.)

Fig. 13. The influence of increase in hydraulic conductivity “ k ” at the shallow landslide.

former several researches.

However, the influence of the seismic shaking on soil strength obtained from the mechanical shear test (Itoh *et.al.*, 2013) is not obvious (Figs.15, 16). In Fig. 6, the cohesion C is bigger in the case with roots than the one without roots and tends to reduce after 1,500 gal earthquake shaking. On the other hand, the inner frictional angle ϕ is obviously increased after 1,500 gal earthquake shaking while the difference by the existence of roots could not be found.

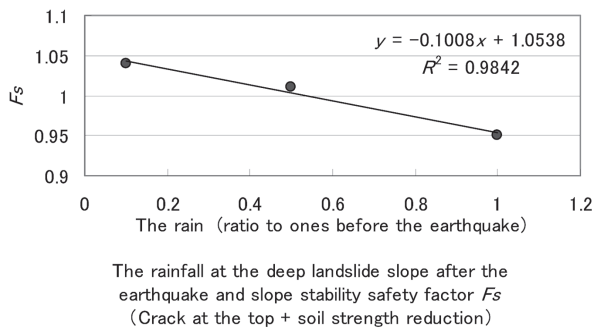


Fig. 14. The influence of cracks and reduction in soil strength at the deep landslide.

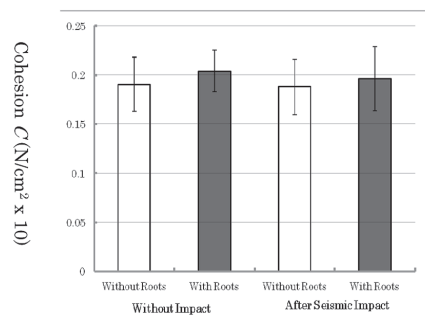


Fig. 15. Influence of seismic shaking on the soil strength (cohesion C).

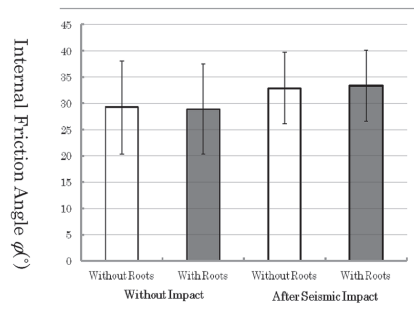


Fig. 16. Influence of seismic shaking on the soil strength (internal friction angle ϕ).

CONCLUSION

Consequently, the impact of giant earthquakes causes at most 50% reduction of the critical rain threshold (rainfall criteria) over which landslides may occur. It is quite large influence that we have to consider in the aftermath of strong earthquake.

The conclusion summary is given in followings.

- 1) In the result of FEM analysis, the cracks induced by the earthquake are effective to increase the seepage of rainfall and render the slopes instable.
- 2) The slope deterioration mentioned above due to the impact of earthquake causes temporarily 40~50% reduction of critical rainfall for landslide occurrence, corresponding to decrease in safety factor “Fs” of

the slopes from $F_s=1.02\sim1.04$ to $F_s=0.83\sim0.95$.

- 3) This reduction rate of critical rainfall is as same level as in the former researches based on field observations.
- 4) On the other aspect, the influence of the seismic shaking on soil strength obtained from “the mechanical shear test” is not obvious.

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