Wave velocity affected by soil moisture and shear deformation in multi-layer shear model tests

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1. Introduction

Rainfall-induced slope failure caused severe human and infrastructure damages in mountains area all over the world every year. This paper presents elastic wave velocity affected by soil moisture and shear deformation in slope surface layer using multi-layer shear model tests. The purpose of this study is to investigate wave velocity behaviors with soil moisture and shear deformation, to find out the relationship of the elastic wave velocity with soil moisture and shear deformation and try to apply to early warning system to predict slope failure.

2. Methodology

The idea of predicting slope failure by elastic wave is trying to apply the sensitivity of wave velocity with soil moisture and shear deformation (Fig. 1). The apparatus is a Multi-layer shear model with a total height of 1m because most of rainfall-induced slope failure is shallow failure, average depth is 1.2m (Uchimura, 2015). It is a model including 20 layers. Every layer has a height of 0.05m, length of 0.6m and width of 0.54m. Horizontal force is applied by air cylinder to simulate the shear stress corresponding to the slope angle. Displacement sensors are also set at every layer. Rainfall intensity is 60mm/h. Exciters, receivers and soil moisture sensors are set in the model (Fig. 2), Compression wave (Vp) is generated by exciter and sensed by the receivers in vertical direction.

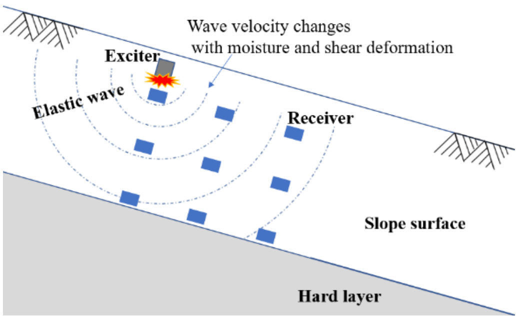


Fig. 1. Determination soil moisture and shear deformation on a slope surface by elastic wave

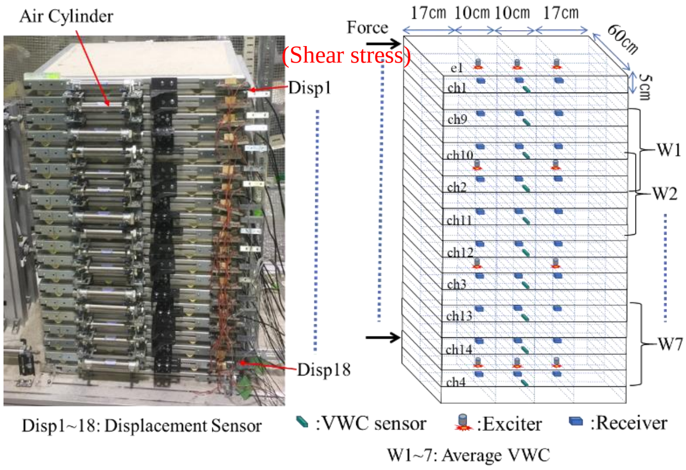


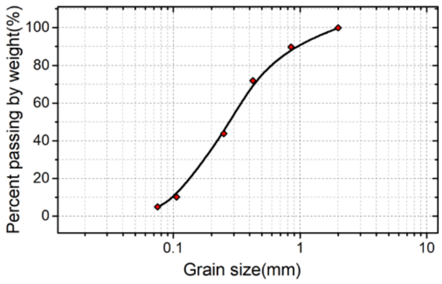
Fig. 2. multi-layer shear model and sensors layout

Test material is comprised of Silica sand No4, No5, No7 and No8 mixed with ratio of 1:1:3:1. Its physical property is shown in Table 1. The relative density was 50% and the VWC (Volume Water Content) was 7.4%, 4 hours rainfall and 2days drain has been done at the initial state. Vp(initial) was the maximum velocity in the initial state.

Three tests are presented in this paper. In the first test, slope angle was zero (Fig. 3a), kept rainfall until VWC became stable. Water was drained out from bottom. In the second test, set horizontal force corresponding to the slope angle (Fig. 4a), velocities and shear stress were analyzed at constant VWC. The third is set horizontal force to a slope angle of 33 degree and not changed VWC, displacement continuously increased until failure (Fig. 5a).

Table. 1. physical properties of soil

Maximum dry density	ρ_{dmax}(g/cm^3)	1.707
Minimum dry density	ρ_{dmin}(g/cm^3)	1.308
Dry density(Dr=50%)	ρ_d(g/cm^3)	1.481



Keywords: slope failure, early warning, elastic wave velocity, soil moisture, shear deformation
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3. Results

Fig.3 shows the response of wave velocities at different VWC in the first test. Fig.3a) shows the changes of VWC during the rainfall and drain event in the time series. In the rain event, the VWC near the top surface increases from 0.1 to 0.25m^3/ m^3, where the VWC near the bottom is from 0.27 to 0.31 m^3/m^3. Fig.3b) shows wave velocities response with rain and drain event in time series. With soil moisture increasing in the rain event, wave velocities decreased. During the drain stage, wave velocities increased. Fig.3c) shows the wave velocities at every receiver against the VWC. The wave velocities reduced by 10%~20% when VWC increased from 0.1~0.27 m^3/m^3. There is hysteresis between the wave velocities and VWC.

Fig.4 shows wave velocities affected by shear stress in the second test. When load the shear stress corresponding to slope angle (24,27,29,31degree) (Fig.4a), a drop of 20%~30% wave velocities observed at the layer between ch12 and ch13. Fig.4b) shows wave velocities against the shear stress at every layer with the same VWC. Wave velocities reduced by near 50% at the bottom layer.

Fig.5 shows wave velocities against the displacement. After set the horizontal force corresponding to the slope angle of 33 degree, the displacement started increasing quickly and finally slope failure. With the increasing displacement, the wave velocities also decreased rapidly (Fig.5a). Wave velocities dropped by 20% during a 0.3 cm of displacement (Fig.5b).

4. Conclusion

The results show that the wave velocities decrease by 10%~20% with the increasing soil moisture in the rain event and increase during the drain stage. With increasing shear stress, wave velocities reduce by near 50%. Before failure wave velocities also decrease by 20% with a small displacement. It is meaningful for monitoring the changes of elastic wave in the slope surface layer to detect its instabilities.

Acknowledgement

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Reference

1)Uchimura, T.(2015).Precaution and early warning of surface failure of slopes using tilt sensors, Soils and Foundations ,Volume 55, Issue 5, October 2015, Pages 1086–1099.

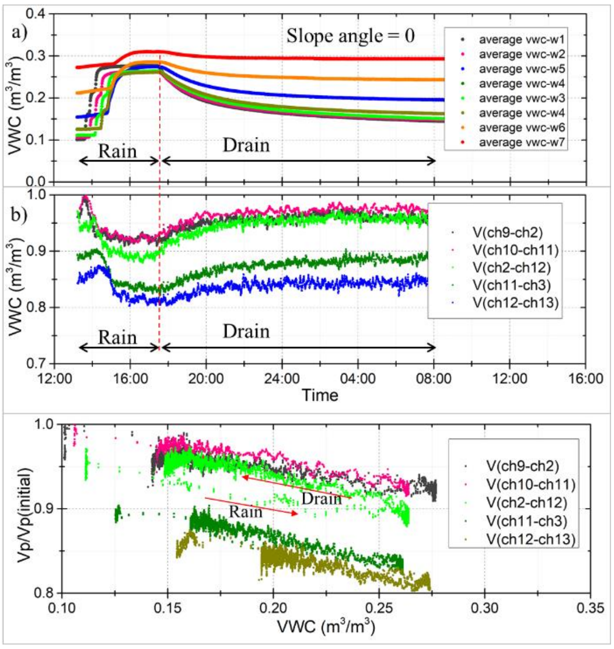

Fig. 3. Response of wave velocities at different VWC

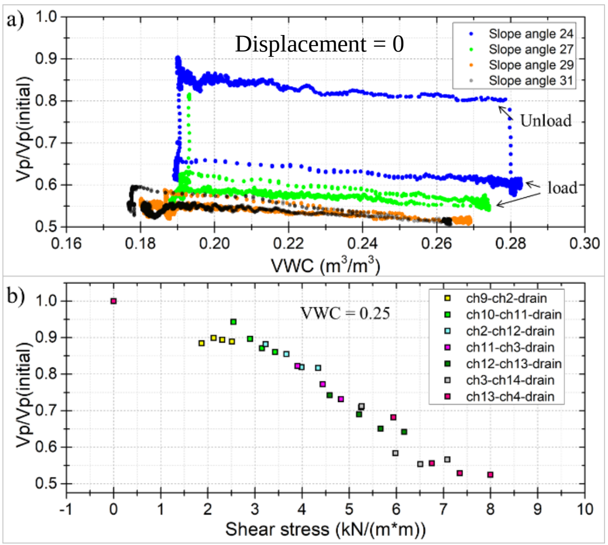

Fig. 4. wave velocities affected by shear stress

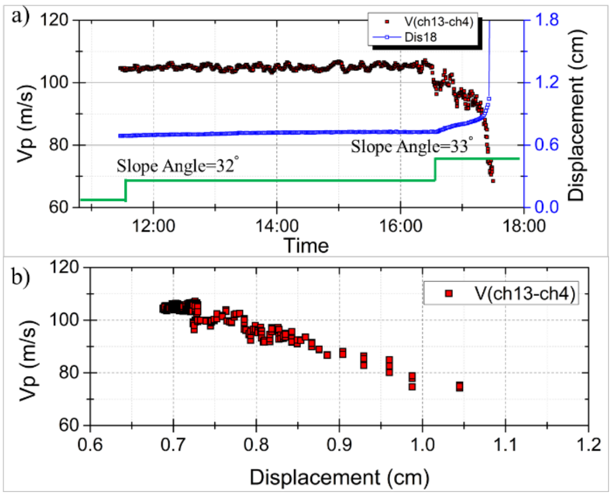

Fig. 5. wave velocities changes with displacement

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