Changes in elastic wave velocity in a slope due to water infiltration and deformation

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論文の内容の要旨

Changes in elastic wave velocity in a slope due to water infiltration and deformation

(斜面の水浸と変形に伴う弾性波速度の変化)

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Slope failures world-wide cause many thousands of deaths each year. It is reported that over 32000 fatalities globally occurred as a result of landslides during the period 2004 to 2010. Furthermore, landslides damage infrastructure and the built environment, costing billions of pounds to repair, resulting in thousands of people being made homeless and the breakdown of basic services such as water supply and transport. The large majority of deaths from slope failures occur in countries located in rainfall and earthquake-prone regions. It is reported that 93% of those landslides were caused by heavy rainfall. Therefore, the demand for monitoring and early warning methods against landslides and slope instabilities induced by rainfall is on the rise in every country.

Current landslide early warning systems rely on monitoring slope movements by means of inclinometers or tilt sensors, in combination with soil moisture monitoring by means of dielectric moisture sensors or tensiometers, etc. A novel concept of landslide prediction by monitoring elastic wave velocity changes in soil was presented, by conducted triaxial tests on soil specimens with varying water content, and injected water into stressed soil sample. The elastic wave velocity was measured by a pair of disk type piezo-electric elements (similar to bender element), and it was found to decrease with increasing water content. More important is the acceleration in decrease of wave velocity, once failure is initiated. Therefore, the author tries to apply this finding to detect the wetting and failure process of soil slope.

Laboratory model test is regarded as a reliable method for studying the rainfall-triggered landslide, in which the soil properties and boundary conditions can be controlled and the water content inside slope and deformation on the surface can be monitored. For the purpose of better understanding the changes in elastic wave velocity in soil slope in wetting and failure process as a result of rainfall, the author performed two types of slope model tests in the laboratory, slope angle = 0 degree (flat condition) for one at which rainfall was given at early period after which soil model was manually inclined without rainfall and 40~50 degree for the other one at which artificial rainfall was continuously applied until slope failure. The changes in wave velocity with coupling effect of water content and deformation or single effect are investigated.

In the first type of test, an attempt was made to separate that two effect factors by a flat soil slope model test carried out in the laboratory. The flat slope model was exposed to rainfall at early period and then was inclined without rainfall to separately unravel the change in elastic wave velocity with increase of water content and deformation. Wave velocity is found to decrease slightly with water content and significantly with deformation. The relationship functions of normalized elastic wave velocity with either volumetric water content or tilt angle were obtained.

It was found from the other type of tests that a gradual decrease in wave velocities was followed by a rapid decrease once the failure was initiated. Wave velocity continued decreasing with an accelerated rate by the coupled effect of increasing water content and deformation that appeared to be interrelated. The effects of soil density, surface layer thickness and slope angle on elastic wave behaviour were investigated during slope failure. The decrease rate of normalized elastic wave velocity with volumetric water content and tilt angle was independent of soil density, surface layer thickness and slope angle. The changes of normalized elastic wave velocity with volumetric water content and tilt angle were simulated by the relationship functions obtained from flat model tests. It showed that the simulated curves agreed well with measured data.

The wave velocity based early warning system was suggested to be installed in the bottom of slope. Such sharp decrease after a threshold about 0.9 of normalized elastic wave velocity can be useful for predicting failure initiation in actual landslide conditions.

A triaxial apparatus equipped with bender element to study the variation of elastic wave velocities (shear wave and compression wave velocities) during drying and wetting path of SWCC was devised. The wave signal detected from model tests fails to be identified as either P-wave or S-wave.

A medium scale model test and a large-scale model test were conducted to confirm the potential of applying the idea of elastic wave velocities to predict such rain induced landslides. The evolution of elastic wave velocity showed consistent observation from small scale model tests.

This finding is practically important with reference to real-time slope monitoring, as the actual slope movements in a slope surface can be identified by monitoring the rate of decrease of wave velocities.

Keywords: *Landslide monitoring, Early warning, Wave velocity, Unsaturated soil*