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Time-prediction of an Onset of a Rainfall-induced Landslide Based on the Hybrid Monitoring of Surface Displacement and Groundwater Level

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Landslide disasters result in significant damage to human life and property all over the world. An early warning system is an effective tool to mitigate the damage caused by landslides. Monitoring of displacement or groundwater level is one of the way for an early warning against rainfall-induced landslides. Devices for monitoring have been developed while procedure for time-prediction of an onset of a landslide based on the monitoring has not been fully sophisticated. Simple and practical procedure for time-prediction of an onset of a rainfall-induced landslide, namely GLDIS method, based on hybrid monitoring of the displacement and the groundwater level in the slope are proposed in this report to utilize the monitoring technique for an early warning system. Time-prediction for model slope experiment are conducted and the result is compared with the prediction by other time-prediction methods based on the monitoring of the surface displacement.

Model slope was constructed and the surface displacement and the groundwater level were monitored under sprinkling water to examine the utility of the method. Model slope was 600 cm long, 150 cm wide, and 57.7 cm deep in the gravitational direction with the inclination of 30 degrees and made of granite soil (D_{50} = 1.3 mm, U_C = 22.23, F_C = 13.2%). The surface displacement and the groundwater level are measured by extensometer and water level gauge respectively in model experiment under rainfall intensity of 50 mm/h. Extensometer consists of Rotating sensor at upper boundary of the slope and peg on the slope surface. Peg moves downward along slope surface according to shear deformation of the slope due to rainfall infiltration. Rotating sensor measures the distance between the sensor and the peg.

The procedure for time prediction by GLDIS method is proposed as follows.

(1) Relationship between the groundwater level and the surface displacement on the slope is assumed to be hyperbolic based on many model experiments. Non-linear regression analysis between the groundwater level 'GWL' and the surface displacement 'ds' until any time before the failure of the slope is conducted for the hyperbolic relationship as in Eq.(1). It can produce the groundwater level at failure 'GWL_{max}' as a constant in the hyperbolic function.

$$ds = \frac{1}{G_{sur.}} \frac{GWL_{max} \cdot GWL}{GWL_{max} - GWL} \qquad (1)$$

Here ds: surface displacement, GWL: groundwater level, G_{sur}: experimental constant and GWL_{max}: groundwater level at failure. G_{sur} and GWL_{max} are determined by the regression analysis.

(2) Then non-linear regression relationship between time and the groundwater level was derived based on the measured data until same time with the first analysis. Here logarithmic function as in Eq.(2) is adopted for the analysis.

$$GWL = a_1 \cdot \ln(t) - a_2 \qquad (2)$$

Here a_1 and a_2 are experimental constants and determined by the regression analysis.

(3) Incorporating the groundwater level at failure 'GWL_{max}' derived from Eq.(1) into the regression equation between time and the groundwater in Eq.(2) produces predicted failure time of the slope 't_r' as in Eq.(3).

$$t_r = \exp\left(\frac{GWL_{max} + a_2}{a_1}\right) \tag{3}$$

The procedure described as above uses only the monitored data of the surface displacement and the groundwater level and does not need other soil mechanical test. It does not need complex numerical calculation scheme for coding time-prediction procedure to establish early warning system.

Time-prediction by GLDIS method is conducted for the monitored data of the surface displacement and the groundwater level in the model experiment and the result is compared with predicted failure time by 2 kinds of prediction method based on Fukuzono’s theory. Fukuzono’s theory is based on the experimental formula between the velocity of the surface displacement and the acceleration of the surface displacement as Eq.(4) established based on the monitored data in many model slope experiments.

$$\frac{d^2x}{dt^2} = a\left(\frac{dx}{dt}\right)^{\alpha} \tag{4}$$

Here x and t are surface displacement and time respectively while a and α are experimental constants. 2 kinds of method, 3 point prediction method and detailed prediction method, are based on the Fukuzono’s theory but have different procedure for deriving failure time of the slope. Time variation of predicted failure time by GLDIS method is shown in Fig.2 in comparison with those by exsting methods based on Fukuzono’s theory. This comparison reveals that the time variation of the predicted failure time by GLDIS method does not scatter so much and approaches to the actual failure time just before the failure of the slope. Scatters of the results by 3 point prediction method and detailed prediction method are more than that by GLDIS method. It suggests that GLDIS method can be practically utilized to time-prediction of an onset of a rainfall-induced landslide based on the monitoring.

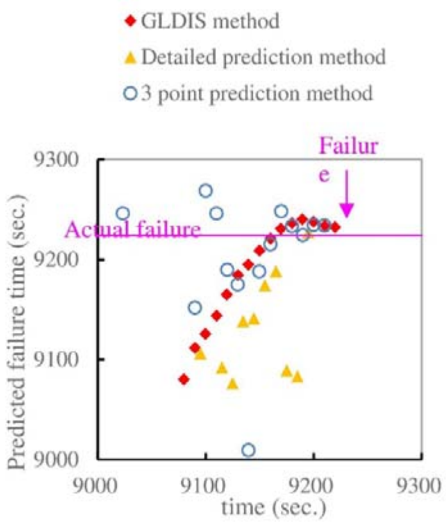

Fig.2 Comparison of predicted failure time by GLDIS method to that by other method based on Fukuzono’s theory

Keywords: Rainfall-induced landslide, groundwater level, surface displacement, time-prediction