SENSING AND MONITORING FOR ASSESSMENT OF RAINFALL-INDUCED SLOPE FAILURES IN RESIDUAL SOIL

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Effect of climatic changes on slopes can be assessed using real-time monitoring. Several geotechnical instruments such as piezometer, tensiometer, soil moisture sensor and instruments for measuring changes in local climate such as rainfall gauge and weather station can be installed within the slope area. The data from these instruments are captured automatically using a data acquisition system and the data are transported to a secured website in real time using a General Packet Radio Service (GPRS). The real-time information can then be processed by different public authorities to assess the impact of local climatic changes such as precipitation and evapotranspiration on stability of the monitored slopes. Warning and evacuation order can be issued once the stability of the slope approaches a dangerous level. The cost of installing the real-time monitoring system can be costly. Therefore, there is a need to have a methodology to select critical slopes for monitoring of the stability of these slopes using a comprehensive field instrumentation throughout the year.

In this study, the Transient Rainfall Infiltration and Grid-Based Regional Slope-Stability (TRIGRS) model (Baum et al., 2008) is used to generate slope susceptibility map in Singapore. The TRIGRS separates the soil into unsaturated and saturated zones above and below water table, respectively. For the unsaturated zone, the code solves the 1-D Richard's equation expressing the rate of change in volumetric water content or infiltration within a soil depth and vertical flow through the unsaturated zone. On the other hand, an analytical solution to a pore-water pressure diffusion equation based on Iverson (2000) is used to model the pore pressure increase at basal boundary in the saturated zone. The required SWCC and permeability function variables in TRIGRS model include residual water content (θ_r), saturated volumetric water content (θ_s), slope of SWCC (α).

The study area was limited to residual soil from Bukit Timah Granite in Singapore. In the selected region, seven zones were created based on the underlying geology and the values of the soil parameters: hydraulic conductivity, hydraulic diffusivity, effective cohesion, effective friction angle, and ϕ^b angle were assigned using the data from the previously investigated sites (Rahardjo et al., 2014) within each zone. The soil properties were incorporated in the TRIGRS analyses to obtain the minimum factor of safety after 24 hours of 22 mm/h of rainfall. Figure 1 exhibits the slope susceptibility map generated using coupled 1-D infiltration and slope stability analysis incorporating soil properties from previously investigated sites.

TRIGRS system helps to determine zones which are highly susceptible to failure. Hence, the instrumentation can be used to monitor the characteristics of pore-water pressure and water content within high risk area during dry and rainy periods. Slope instrumentation were performed within residual soil slope A (Figure 1) which is located at high risk area (Factor of safety less than 1.5). The slope was instrumented with 16 tensiometers, 3 piezometers and 1 rain gauge (Figure 2). Tensiometers were installed at shallow depths to monitor the changes of negative pore-water pressures in the slope. Piezometers were installed to observe the change in the position of ground water table. Rain gauge was installed to measure the rainfall intensity on the observed slope. All instruments were connected to a data logger for real-time monitoring. The data logger was powered using photovoltaic batteries. Maintenance of tensiometers were performed regularly to ensure the accuracy of the reading. Remote access from the data logger is possible using GPRS. The raw and processed data from real-time monitoring can be accessed through a secured website (Figure 3). The changes of pore-water pressure with time during wet and dry periods are used for slope stability analyses. The data were also used for a warning system developed on the basis of the threshold values obtained from the seepage and slope stability analyses performed on Slope A. The alert and alarm levels were sent to users (Figure 4) so that they can follow up with the required preventive measures.

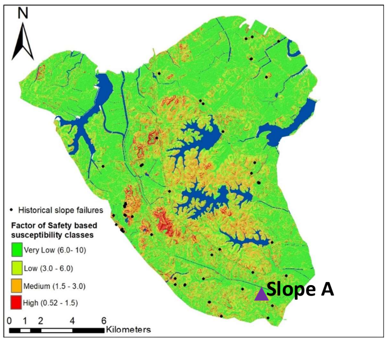

Figure 1. Slope susceptibility map within central region of Singapore

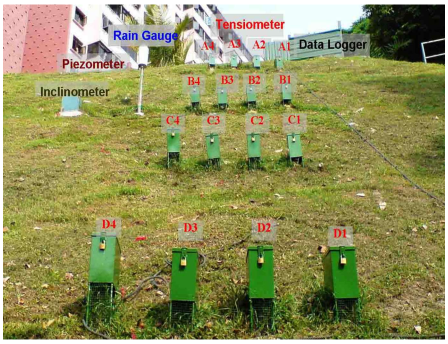

Figure 2. Layout of slope instrumentation at Slope A

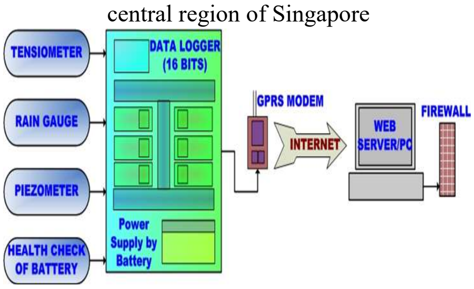

Figure 3. Schematic diagram of on-line monitoring system

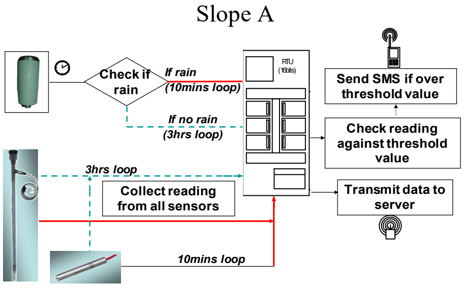

Figure 4. Schematic diagram of warning/alert system

Keywords: rainfall-induced slope failure, residual soil, slope monitoring, unsaturated soil

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