SIMPLE AND LOW-COST EARLY WARNING SYSTEM FOR SLOPE FAILURE DUE TO RAINFALL AND EROSION

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A simple and low-cost early warning system is developed, and its applicability and effectiveness was tested on model slopes under artificial heavy rainfall. The system works with batteries, and transfer real time data via wireless network. It is low-cost and simple so that non-expert residents in risk area can buy and handle it easily by themselves, even in developing countries. Traditional approaches to prevent rainfall-induced landslides, such as stabilization of unstable slopes by installation of retaining walls and ground anchors, has been useful. But, they are not very helpful in mitigation of small slope failures, which are less significant in scale but numerous in numbers, because of their cost of installation. In consequence of recent residential developments in hilly area and water front, the risk of smaller landslides has been realized. There is extravagant number of slopes with potential of such failure, and it is not financially realistic to use traditional approaches for each of them. Low-cost and simple early warning system is needed to deal with such problems.

Key Words : *Slope stability, Monitoring, Wireless network, Inclinometer, Warning system*

1. INTRODUCTION

There is a long history in prevention and mitigation of rainfall and/or scouring-induced landslides. Typical measures to prevent slope failure are retaining walls and ground anchors which improve factor of safety against failure. These measures have been widely used everywhere in the world and have been effective. However, they take a lot of cost, resulting in a limited application only for large scale slopes. In reality, most of landslide occurs at small scale slopes, but with a large number. It is not realistic to apply mechanical reinforcement measures for these slopes with potential risk.

The authors have proposed an early warning system for slope disasters, as one of more feasible countermeasures for small-scale slope disasters. The system watches minimum number of items and places on a slope with low-cost and sophisticated sensors, and the data is transferred through wireless network. Thus, the system is low-cost and simple enough so that the residents in risk areas can handle it to protect themselves from slope disasters (Towhata, et. al. 2005).

Herein, prototype devices developed by the authors are introduced, and some results from verification tests with artificial slope models are described.

2. PROPOSED MONITORING SYSTEM

The system consists of (1) several sensor units placed at every measurement points, (2) a gateway unit for a site, and (3) a data server on internet. It has two following features:

(a) Wireless data transfer: The sensor unit measures physical values on the slope, and transfer the data to the gateway using low-power radio signal. As relatively lower frequency (429 MHz) is used, the signal can be delivered through 300 to 600 m of distance with a low battery energy consumption. The gateway collects the data and forwards it to the server using cell phone network. The server collects and stores the data so that everyone can access the data via internet, and also issue warning automatically if the data shows a risk of failure. Every sensor unit and the gateway works on battery, without commercial power supply. Being wireless, the system can be quite easy and low-cost to install at site. But, consequently, higher technologies on battery power management and radio communication control are essential.

(b) Simplified measurement items and methods: The items to be measured on the slopes, and the sensors for the measurements, are carefully selected. Orense R.P. et. al. (2003 & 2004) conducted small-scale model tests, and found that gradual deformation on the slope surface and high saturation ratio at the slope toe are observed as precursors of failure. Thus, the one to be watched is rotation on the slope surface. Conventionally, extensometers are commonly used to measure the displacement, but it is not easy to install and manage, because they use long wires along slopes to be kept undisturbed. The proposed system uses inclinometers in place of extensometers, as its installation is quite simple. In addition, a smart inclinometer chip based on MEMS (micro machines) technology is employed. They are cheep (5 to 60 USD), tiny (5 to 15 mm in length), with high resolution (0.001 degree at highest), and with low power consumption (3V, 0.5mA). The other item to be measured is water distribution in the slope ground. A volumetric water contents meter, which measures changes in permittivity of soil with water, is employed in stead of conventional porous cups to measure the suction. This type of sensor is much easier to deal with than measurement of suction which requires careful treatment of the porous cup to keep it fully saturated.

3. PROTOTYPE TESTS

In 2006, the authors developed prototypes, and tested them on a 1 m-high model sandy slope under artificial heavy rainfall, whose test was conducted by Public Work Research Institute (PWRI), Tsukuba, Japan (Figure 1). The slope model had a gradient of H=2 : V=1, and it was made of a compacted sandy material (Dmax = 4.57mm, D50 = 0.17mm, Fc = 14.3%, Gs = 2.69, ρ_d = 1.37 g/cm3, Dr = 80%), and its initial water contents was 19%. After filling water on the back side of the slope to simulate a situation of river dike, an artificial continuous rainfall of 15 mm/h was given. Two sensor units, equipped with an inclinometer and a volumetric water contents meter, were installed on the slope as shown in Figure 1. The installation work was simple, just embedding the unit and the attached water content meter on the slope to a depth of 20 cm, taking less than 30 minutes for each unit. As the power saving techniques were not completed at this time, the power for the sensor units were supplied by cables, but the data was sent to the gateway wirelessly, and recorded every 1 minute. The radio communication worked properly even in heavy rainfall conditions.

Figure 2 shows the behaviours of the inclination and water contents at each sensor unit. The slope failure was progressive starting from the toe, and the lower part with sensor unit 2 was failed around 2 hours after starting rainfall. The inclination showed extraordinary behaviours 30 minutes before that. Such behaviour could be used as a signal for early warning. However, the upper part around the sensor unit 1 was failed after 3 hours of rainfall, but the behaviours of the inclinometer were not clear as the lower part. The behaviour of inclination before failure is case-by-case, and thus, criteria to issue warning should be defined carefully.

On the other hand, the behaviours of the volumetric water contents were shown in Figure 3. As the void ratio is e = 0.935, volumetric water contents will be 0.48 if fully saturated. The measured water contents increased after starting rainfall, but it did not show nearly saturated condition before the failure. Thus, it was difficult to detect precursor of failure only watching water contents. At the lower unit 2, the measured value of water contents suddenly dropped at failure.

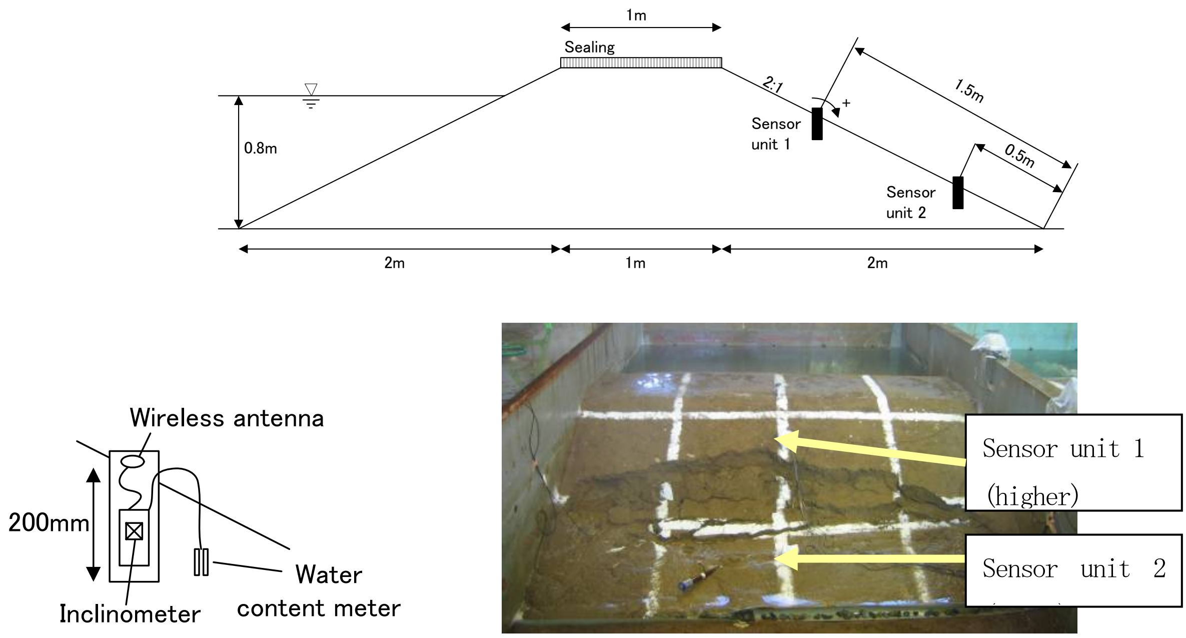
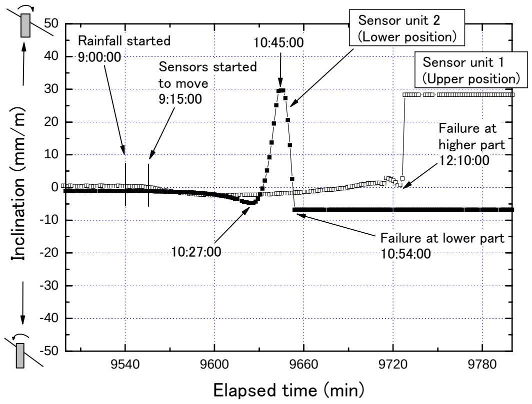


Figure 1. Arrangement of slope model and sensor units for the test 200



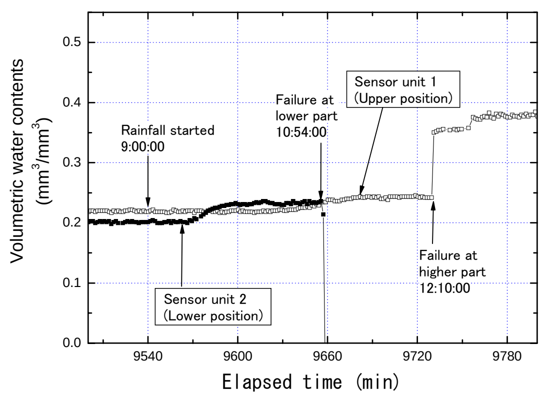


Figure 2. Behaviours of inclination for the test 2006. Figure 3. Behaviours of water contents for the test 2006.

In 2007, a modified version of prototype was developed, and tested on a slope model by PWRI again. This time, a low-power MEMS inclinometer and a low-power micro computer were used, and the power supply for the sensors and radio transmitter was turned off when they were not in use. The power for the micro computer was also cut off by using sleep mode. As a result, the units worked for more than 4 months with 4 AA alkaline batteries, while measuring and transferring the data every 1 minute. The units became completely independent without any wiring works, and its installation became much easier. As the measuring and transferring interval in practical operation will be 10 minutes or more, they can run for several years.

Figure 4 shows the arrangement of the model and the sensor units. The slope is 3 m-high with a gradient of H=2 : V=1, and made of the same material as the previous slope. Four sensor units were installed at the three different levels on the slope (two of them were at the middle height with some horizontal distance).

Figure 5 and 6 show the behaviours of inclination and water contents at each unit, respectively. Again, some gradual changes in inclination were observed more than 30 minutes before the failure at each unit position, but their behaviors are not constant.

The volumetric water contents were also below the level of saturation before failure, but they suddenly decrease or increase after failure. These behaviours of water contents may be due to cracking in the soil around the sensors. When the soil is detached from the surface of sensors, low water contents are observed. And if the crack around the sensor is poured with water, the measured water contents show higher values than saturation.

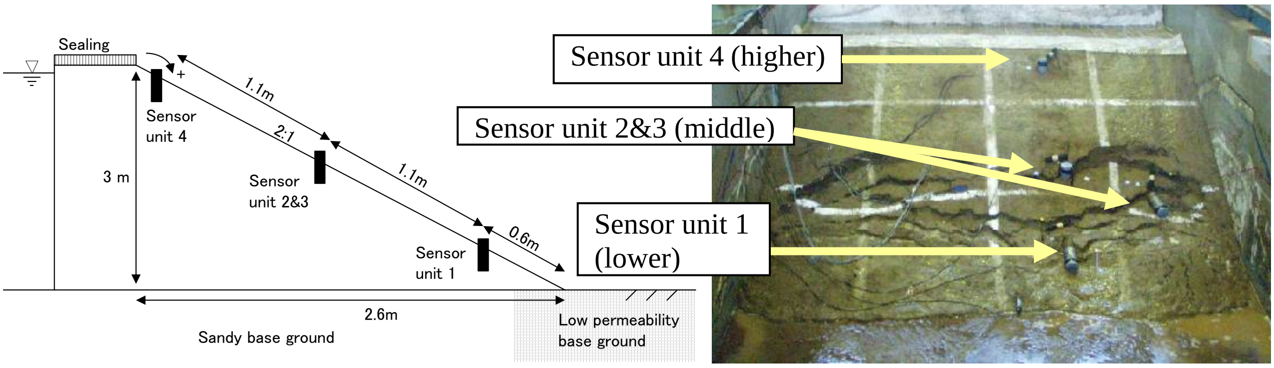
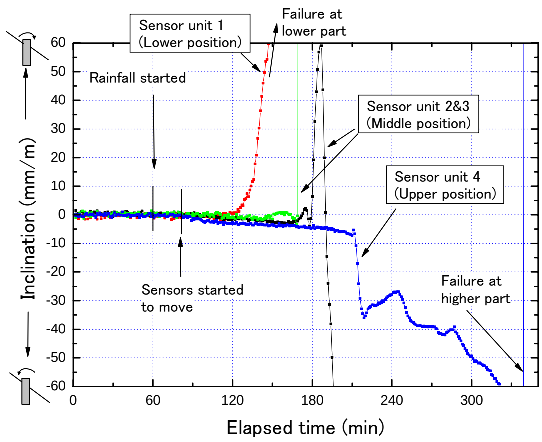


Figure 4. Arrangement of slope model and sensor units for the test 2007.



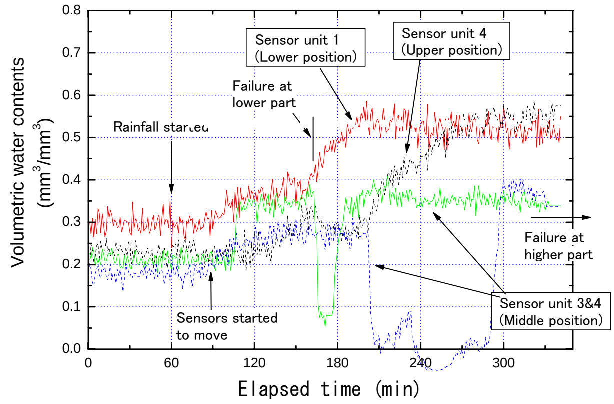


Figure 5. Behaviours of inclination for t8ihe test 2007.

Figure 6. Behaviours of water contents for the test 2007.

4. CONCLUSIONS

A low-cost and simple early warning system is proposed, and its prototypes were tested on a model slopes to be fail in an artificial heavy rainfall. Each sensor unit was equipped with an inclinometer and a volumetric water contents to watch the behaviours of slope. It works with batteries for a long life, and sends the measured data to a gateway periodically. The radio communication worked properly for data transfer even in heavy rainfall conditions.

The inclinations on the slope surface showed gradual change more than 30 minutes before failure, but their behaviours depend on cases. A careful consideration is needed to define the criteria to issue warning.

The volumetric water contents did not show nearly saturated conditions near the slope surface before the failure. The measured values were also affected by the cracking and other deformations on the slope surface. It is recommended to use water contents in combination with other monitoring items like inclination or displacement.

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REFERENCES

1) Orense R.P., Towhata I., Farooq, K. : Investigation of failure of sandy slopes caused by heavy rainfall. Proc. Int. Conf. on Fast Slope Movement-Prediction and Prevention for Risk Mitigation (FSM2003), Sorrento, 2003.
2) Orense R.P., Farooq, K., Towhata I. : Deformation behavior of sandy slopes during rainwater infiltration. Soils and Foundations 44(2):15-30, 2004.
3) Towhata,I., Uchimura,T. and Gallage,C.P.K. : On early detection and warning against rainfall-induced landslide, Proc. of The First General Assembly and The Fourth Session of Board of Representatives of the International Consortium on Landslides (ICL), Washington D.C., Springer, pp.133-139, 2005.