Monitoring System for Slope Stability under Rainfall by using MEMS Acceleration Sensor IC tags

S Murakami¹, A Dairaku¹, H Komine¹, N Sakai², T Isizawa², O Saito¹ and I Maruyama³

¹ Ibaraki University, Nakanarusawa 4-12-1, Hitachi, Ibaraki, 316-8155, Japan
² National Research Institute for Earth Science and Disaster Prevention, Tennodai 3-1, Tsukuba, Ibaraki, 305-0006, Japan
³ Fukuyama Consultants Co., Ltd., Hakataeki-higashi 3-6-18, Hakataku, Fukuoka, 812-0013, Japan

E-mail: murakami@mx.ibaraki.ac.jp

Abstract. Real-time warning system for slope failure under rainfall is available to disaster prevention and mitigation. Monitoring of multi-point and wireless measurements is effective because it is difficult to conclude the most dangerous part in a slope. In order to investigate the applicability of the proposed system, a large-scale model test of artificial slope subjected to rainfall has been performed. MEMS acceleration sensor IC tags has been located on the slope and ground acceleration caused by forced vibration has been measured until the model slope collapses. The experimental results show that the MEMS acceleration sensor IC tag is comfortably available under rainfall, the characteristics of ground accelerations varies with changing the condition of the slope subjected to rainfall, and the proposed method can be applied to a real-time monitoring system for slope failure under rainfall.

1. Introduction

Real-time warning system for slope failure under rainfall is available to disaster prevention and mitigation. Monitoring of multi-point and wireless measurements is effective because it is difficult to conclude the most dangerous part in a slope. This paper proposes a monitoring system by used multi-point and wireless sensor. The sensor is MEMS acceleration sensor IC tag. MEMS acceleration sensor IC tag is an acceleration sensor microminiaturized by a technology of Micro Electro Mechanical Systems on board IC tag. Especially, low cost of the sensor will yield to the realization of the system. In order to investigate the applicability of the proposed system, a large-scale model test of artificial slope subjected to rainfall has been performed. MEMS acceleration sensor IC tags has been located on the slope and ground acceleration caused by forced vibration has been measured until the model slope collapses. The experimental results show that the MEMS acceleration sensor IC tag is comfortably available under rainfall, the characteristics of ground accelerations varies with changing the condition of the slope subjected to rainfall, and the proposed method can be applied to a real-time monitoring system for slope failure under rainfall.
between a transmitter and a receiver because 2.4GHz radio wave has a high straight line. However, the sensor is very useful because a cost of it is low and the multi-point and wireless measurements can be put into practice.

2. Large-scale model test of artificial slope subjected to rainfall
Failure of natural slopes and embankments under rainfall causes due to changing mechanical properties of soils depending on water content. Generally, strength and stiffness of soils decrease with increasing degree of saturation. Therefore, most of monitoring systems for slope failure develop by directly measuring the change of saturation degree of soils and groundwater level in the slope. However it seems that it is difficult to understand the whole condition of slope. The purpose of this study is to apply the MEMS acceleration sensor IC tags to understand variations of slope conditions under rainfall. Ground vibration characteristics of slopes will change the mechanical properties of soils with saturation degree. In order to investigate the possibility and applicability of measuring ground vibrations on a slope subjected to rainfall, a large-scale model test of artificial slope has been performed. On the basis of experimental results, the followings have been confirmed,
1. To measure ground vibrations by forced vibration that cannot affect the stability of slope

![Figure 4. Rise in groundwater level with elapsed time](image)

![Figure 5. Groundwater level with elapsed time](image)

2. To receive the real-time data in the rainfall.

3. To understand changes of ground vibration characteristics of a slope with elapsed time.

Figure 2 shows a diagram of a large-scale model test of artificial slope. The MEMS acceleration sensor IC tags have been set on the slope as shown in Fig. 2. ID01, 02, 09, and 10 have been located on the level surface. The boxes of the sensors set on the surface, directly. ID03, 04, 05, 06, 07, and 08 have been located on the slope face. Forced vibrations have been applied at the location where is 10m distance from the tow of the slope. Method of forced vibrations is a metal falling bob in shown Fig.3. A size of model slope is 10m in length, 3.9m in width, 1m in depth, and 30 degree in angle. Top of a slope is 0.8m in length. Bottom surface with protuberances is made by mortar and side frames are steel plates. Soil of slope is weathered granite soil so called “Masado” in Japan. Model slope has been constructed by compaction using the soil which initial water content is approximately 7.9%.

In order to make the initial condition of slope, antecedent precipitation and groundwater flow have been applied to the model slope for two week. And then, rainfall with 40mm/h has been applied until slope failure. Figure 4 shows the variations of groundwater levels with elapsed time from starting rainfall to slope failure. Groundwater level increases with elapsed time as shown in Fig. 4. Rise in groundwater level is so fast that the location is upper side of the slope. However, the incremental of rise in groundwater level in middle and lower parts of slope is large after 100min later. Figure 5 shows lines of groundwater level in the slope at 0, 60, 120, and 180 min later. The change of saturation in the slope can be understood in Fig. 5. In order to investigate the change of ground vibrations under rainfall, two kind of forced vibrations have been applied at the elapsed time.

### 3. Experimental results and discussion

Figure 6 and 7 show the time-series acceleration data due to forced vibrations just before slope failure. No influence of forced vibrations on the deformation and stability of slope have been confirmed by comparing between before and after the conditions of the slope. Figures show that the wireless communication was good in the rain of which intensity was 40mm/h. It is successful to apply the MEMS acceleration sensor IC tags for measuring ground vibrations because the experimental results showed forced ground vibrations did not affect the stability and deformation of the slope and real-time acceleration response has been received in the rainfall.

In order to make sure that characteristics of ground vibrations change under the rainfall, dominant frequency characteristics have been investigated. Dominant frequency has been calculated from the observed time-series records of the triaxial accelerations by using the fast Fourier transform (FFT). Number of acceleration data using FFT is 1,024 and the period is equal to 5.12 seconds. Fourier spectrum values of each forced vibrations have been calculated and the maximum value of frequency in a Fourier spectrum has been obtained. Three forced vibrations in the same conditions have been applied in model test. The dominant frequency has been determined by computing the average of the
maximum values of frequency in each Fourier spectrum. Figure 8 shows the variations of dominant frequency. X-direction and Y-direction component of dominant frequency are overall larger with crossing to the forced vibration point. And the value of dominant frequency decreases with elapsed time.

The stiffness and strength of soils decrease with increasing saturation degree. As a result, the stability of slope decreases. The saturation degree of soils continues to increase during rainfall because groundwater level in the slope did not reach to a steady-state condition under rainfall and continued to rise during rainfall as shown in Fig. 5. Therefore, the value of dominant frequency decreased because the stability of the slope reduced as the results that the stiffness and strength of soils decreased with increasing saturation degree. The results indicate it is possible to utilize the MEMS acceleration sensor IC tags for monitoring system for slope stability under rainfall.

4. Conclusions
The purpose of this study is to propose a method of monitoring system with multi-point and wireless measurements for a slope stability using MEMS acceleration sensor IC tags. A large-scale model test of artificial slope has been performed. On the basis of experimental results, the followings have been confirmed,
1. To measure ground vibrations by forced vibration that cannot affect the stability of slope
2. To receive the real-time data in the rainfall.
3. To understand changes of ground vibration characteristics of a slope with elapsed time.
The value of dominant frequency decreased because the stability of the slope reduced as the results that the stiffness and strength of soils decreased with increasing saturation degree. The results indicate it is possible to utilize the MEMS acceleration sensor IC tags for real-time monitoring system for slope stability under rainfall.

References
[1] Saito O, Kuwahara Y, Murakami S, Yasurha K 2010 Ambient Network Sensor IC-Tag Application to Geotechnical Practices J. JGS 58(5) 10-13 (in Japanese)
[2] Dairaku A, Murakami S, Komine H, Sakai N, Ishizawa T, Saito O 2012 Investigation of ground vibration characteristics of slope to forced vibration for establishment monitoring method by using MEMS acceleration sensor IC tags Proc. JSCE Annual Meeting (in Japanese).
[3] Osaki Y 1994 New Introduction to spectral analysis of ground motion Kajima Institute Publishing 37-122 (in Japanese)