A Pilot Construction of a Real-Time Monitoring System for Slow-Moving Landslide, Republic of Korea

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The objective of this paper was to introduce a recent case of slowing-moving landslide in Republic of Korea, and discuss utility of a monitoring system for the landslide as a preventive measure. The study site was a 2.6 ha slow-moving landslide area situated in the Southern part of Korean Peninsula. Preliminarily, eight-month-temporary monitoring with fixed stakes was conducted, and its result indicated the moderate probability of landslide movement despite of measurement error. Moreover, following detailed site investigation support the landslide progress with the results of underground tests. Considering results of the preliminary monitoring and investigation with an expense of restoration work, a real-time and sensor-based monitoring system using the ubiquitous sensor network technique was finally introduced to the study site. The system was designed to provide emergency measures by real-time monitoring for the slow-moving landslide. The results of its three-month operations showed that the landslide appeared to enter a stable phase, but the system had high missing rate of sensors more or less. Consequently, the monitoring system could be cost-effective measure compared to restoration work, but it still requires improved hardware performance such as lower data missing rate.

Key words: slow-moving landslide, real-time monitoring system, non-structural measure, sensor threshold

1. INTRODUCTION

In Republic of Korea, 10-year average of damaged area by sediment-related disaster has been increased by threefold from 231 ha in 1980's to 713 ha in 2000's [*Korea Forest Service*, 2013]. However, it has shown signs of decrease to 256 ha in 2010's (2010-2017). Accordingly, budget for structural measure such as debris barrier dam has been reduced gradually since middle of 2010's. A reduction in the budget for the structural measure causes various changes in the policy of sediment-related disaster. Against this backdrop, the Korea Forest Service (KFS) is committed to fully utilizing cost-effective non-structural measure such as operation of shallow landslide forecast system, establishment of early warning and evacuation system, and designation of vulnerable area.

Sediment-related disaster occurring in Republic of Korea has some characteristics: it occurs mostly in the rainy season, and the dominant types are rapid, shallow landslides and its transformed debris flow. Meanwhile, although a slow-moving landslide has been rare in Republic of Korea so far, recent years has witnessed an increase in the number of such landslide with official reports of the slow-moving landslide including 28 cases in 2013 and 35 cases in 2017. Because compared to its very slow progressing pace of 0.01-10mm per day [*Woo et al.*, 1996], it happens in huge area relatively deep underground and occurs around urbanized areas such as construction area in mountainous residential area or road slope, slow-moving landslide has drawn social interest.

In other countries, various types of study on slow-moving landslides have been conducted since mid 1900's along with long term monitoring. *Handwerger et al.* [2013] analyzed the deformation characteristics of ten slow-moving landslides ranged from 16 to 310 ha in North California, U.S. by InSAR technology. In addition, *Miao et al.* [2014] conducted ring shear tests on soil samples taken from 21 slow-moving landslide sites to identify mechanism of the landslides in Jurassic red-strata in the Three Gorges Reservoir, China. In this study, the sizes of the slow-moving landslides were 2 to 50 ha and they were monitored using by GPS system. Meanwhile, *Van Asch et al.* [2007] discussed problems in predicting the mobility of slow-moving landslides based on monitoring result of the La Valette landslide, the 7.2 ha-landslide areas located in the French Alps. However, while the events of slow-moving landslides in abroad are mass-scale but occurred in non-urban areas, Korean events have characteristics of occurring mostly in urban areas. Against this backdrop, the Korean government has to come up with much active and systematic policy to deal with this situation.

The present paper is to introduce a recent case of slowing-moving landslide monitoring and the establishment and operation of the real-time and sensor-based monitoring system in Republic of Korea. Furthermore, advantages and shortcomings of establishment and operation of the monitoring system as for countermeasure against a newly emerging ‘slow-moving landslide’ are discussed.

2. STUDY SITE

The study site is a slow-moving landslide area situated in the Hadong city, Gyeongsangnam province of Korean Peninsula (**Fig. 1**). With an estimated damaged-area of 2.6 ha, the site of slow-moving landslide is located in the quite low hill whose highest elevation is 300 m a. s. l. Its ground comprises of anorthosite of metamorphic rock and is predominantly occupied by 40-years-old oak species and bamboo species. At the upper part of the landslide area, forest road was constructed for forest management. And the reservoir for drinking water is close to lower part of the area. If sediment inflows to the reservoir when slow-moving landslide happens, reservoir overflow could cause secondary damages to neighboring residential areas. Although slow-moving landslide was reported by local governmental officials in Korea for the first time in April 2015, it is assumed from local residents’ statements that such phenomenon has already been progressed since early 2000’s.

At this area, indicators following slow-moving landslides, including tensile crack and trees growing bended and twisted, are easily found. *Western Regional Office of KFS* [2016] reported that tensile

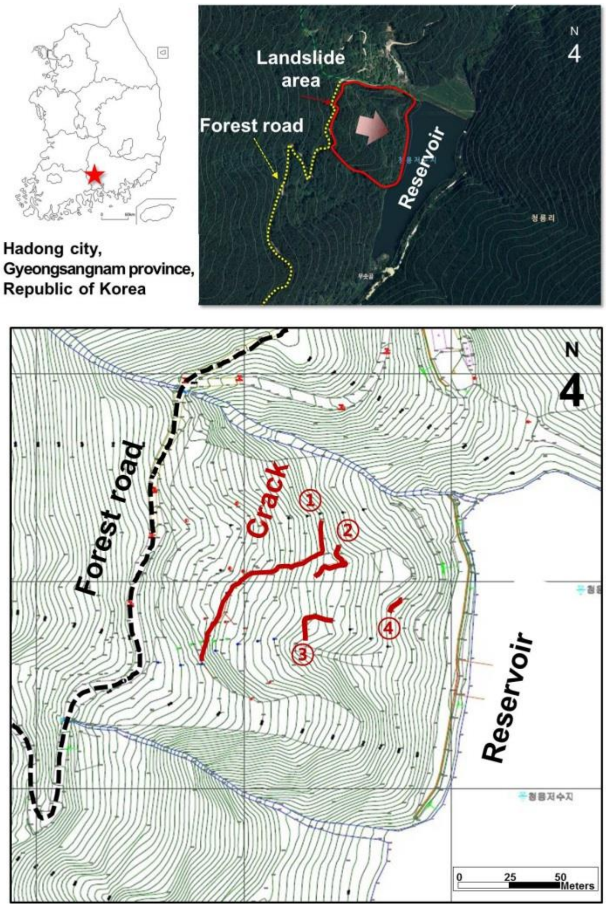

Fig. 1 Location of the study site and the distribution of tensile cracks

Fig. 2 Site photos taken from the tensile crack of the study site (upper: crack ①, lower: crack ②)

cracks were found in 4 areas (**Fig. 1** and **2**) and assumed that tensile cracks developed as slow-moving landslide progressed toward south-east. The width of each tensile crack ranged from between 0.2 to 0.5 m with its level difference from 0.25 to 0.45 m. A total length of 4 areas of tensile cracks is 170 m, and among which, the longest crack of more than 100 m is situated in the upper slope.

Kim et al. [2016] conducted temporary monitoring on displacement of tensile fracture by using fixed stakes from August 2015 to March 2016. They installed 5 fixed stakes at 5 meters apart to manually measure lengths between each 5 fixed stakes every month on the longest tensile crack.

The results found that the final length increased by 10.4 cm compared to the initial length measured eight months ago. Based on the results of the temporary monitoring, the need to conduct detailed site investigation had been steadily raised.

3. DETAILED SITE INVESTIGATION

Western Regional Office of KFS assigned detailed site study for slow-moving landslide to the National Forestry Cooperative Federation to conduct surface survey, underground survey with borehole test, in-situ geotechnical test and electrical resistivity test in July of 2016.

At the detailed site investigation for the slow-moving landslide area, a total of 8 borehole investigations were conducted to identify geological, geotechnical and hydrological characteristics of the area. The results showed that while the maximum thickness for colluvium for this area was 12.8 m and weathered soil layer was between 3.0 m to 19.4 m, the thickness for weathered rock layer was distributed thinly within 1.5 m. In addition, when looking up the slow-moving landslide slope with backdrop of the reservoir, soil layer of the left side was thicker than one of the right side from the same altitude above sea level. Therefore, it was concluded that the thick soil layer of the left side reflected the slope of rock layer.

Along with this, the electrical resistivity survey on crack ① in **Fig. 1** proved that distribution of weathered layer gradually became thicker from right to left of the layer, corresponding well with those of borehole investigations. In addition, the borehole image log interpretation on the center of the landslide slope found cavity at the depth of between 8.3-8.8 m under surface, and direction of the joint set of bedrock was similar with those of slow-moving landslide slope as 37 °/157 ° (dip angle/dip direction).

Overall, it was assumed that colluvium and weathered anorthosite layers distributed thickly as well as loosely had the site move downwards slowly. Moreover, on the evidence of a possibility of having cut the lower part of the area when constructing the reservoir and the potential changes of groundwater level cause by the reservoir water level, 'constructing reservoir' was judged as one of the critical factors that accelerated the slow-moving landslide.

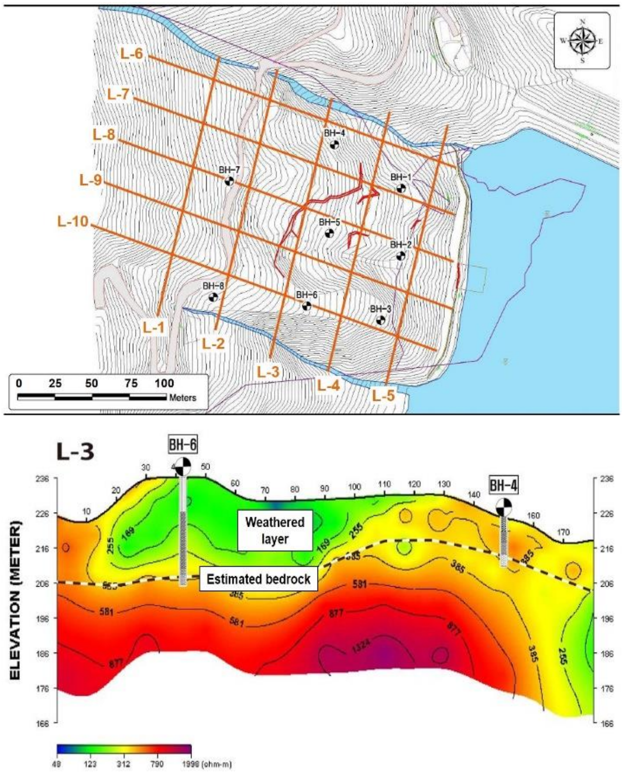

Fig. 3 Result of the electrical resistivity survey (L-3 cross section) on the study site

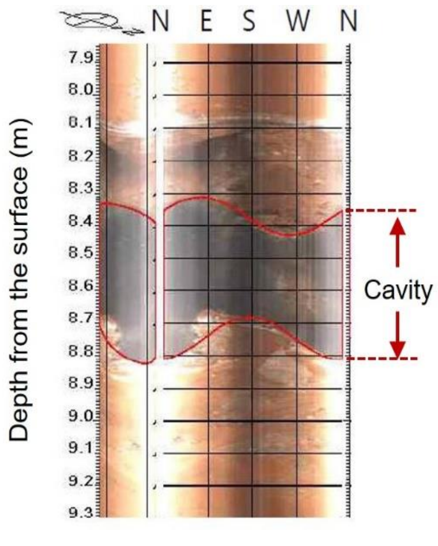

Fig. 4 The borehole image capturing cavity at the depth of 8.3-8.8 m from the ground surface

4. REAL-TIME AND SENSOR-BASED MONITORING SYSTEM

4.1 Overview

Generally, landslide restoration works including pile and water collector well have been carried out as preventive measure after detailed filed investigation in Republic of Korea. However, monitoring system using measuring sensors were finally chosen at the site of slow-moving landslide in Hadong after considering issues of securing expenses of restoration work and slow pace of the slow-moving landslide.

Monitoring system was designed to provide emergency measures such as evacuation measure for local residents if necessary by monitoring slow-moving landslide real-time. Monitoring system consists of three main parts, of i) sensor part, ii) communication part, and iii) data collection server and analysis system (**Fig. 5**). Sensor part refers to all sorts of sensors installed at the site to notice slow-moving landslide directly or indirectly. In December of 2016, 6 wire extensometers, 2 borehole inclinometers, 2 groundwater level meters and 1 rainfall gauge were placed. 6 wire extensometers were installed centering on the 2 tensile cracks situated on the up-slope of the site. A borehole inclinometer and a groundwater level meter were set up respectively at the upper and lower part of the slope. As for the rainfall gauge, it was set up closer to the forest road with its top exposed to prevent interference of trees(**Figs. 6** and **7**).

Communication part where ubiquitous sensor network (USN) is applied is in charge of transmitting data measured from the sensor to data collection server indoor. Every single data measured from each sensor is collected to the gateway through the sensor node. And then, such collected data from the gateway is transmitted to data collection server in the analysis center of the National Institute of Forest Science in Seoul, Republic of Korea. There is a total of 4 sensor nodes and 1 gateway installed at the competent area of slow-moving landslide (**Fig. 7**).

Data collection server and analysis system is responsible for continuously storing raw data measured from the gateway, conducting close analysis on the hazard information and sending them to persons in charge of. If the measured data reaches beyond the threshold which had been set by sensors before, analysis system forwards hazard information through SMS to the designated persons. This system also allows users to search for and display the existing data stored before.

Monitoring system for the slow-moving landslide in Hadong completed its installation in December 2016. After undergoing setting time for

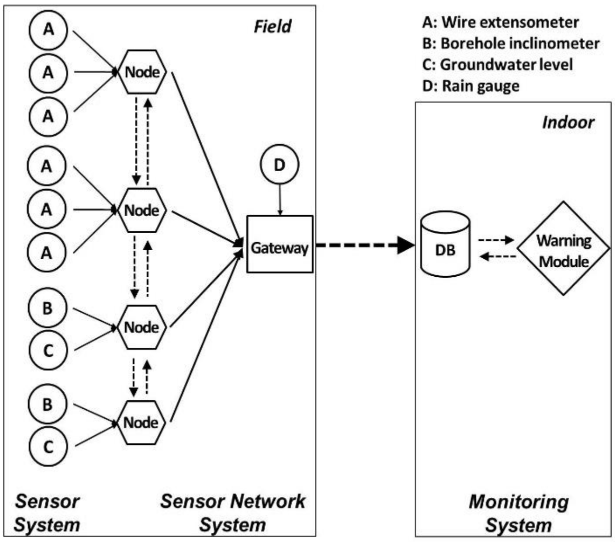

Fig. 5 Schematic diagram of the slow-moving landslide monitoring system at study site

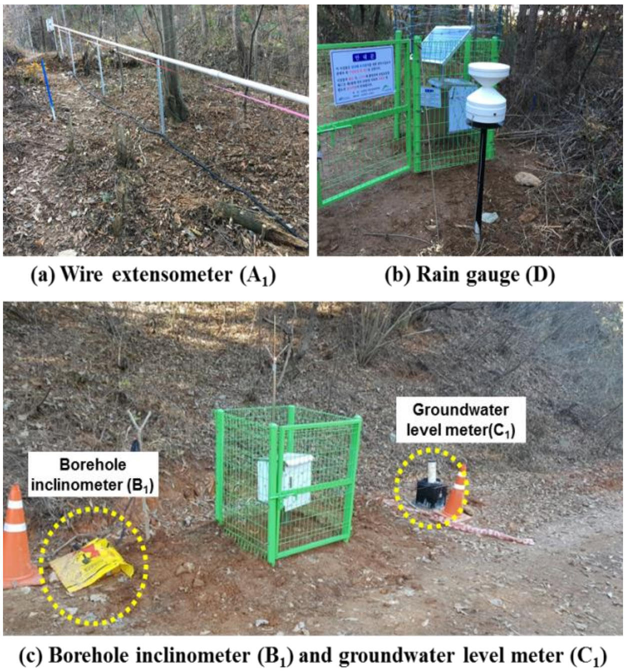

Fig. 6 Sensors installed at the site

smooth operation of the instrument, monitoring system has been in full operation since May first, 2017. Currently, it is run on solar battery with its measurement interval of every hour. Threshold of hazard messaging for sensor is only applied to the wire extensometers. When the measured displacement of each wire extensometer exceeds 10 mm, it is supposed to be sent to persons in charge of from the National Institute of Forest Science and Korea Forest Service.

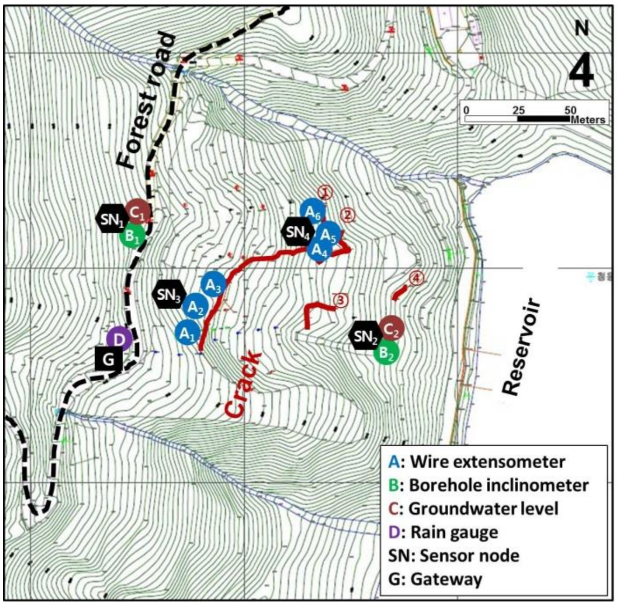

Fig. 7 Sensor arrangement of the monitoring system at the field

Table 1 Result of ratio of missing values by sensor nodes

Month	Sensor node			
	#1	#2	#3	#4
May	0.3%	0.7%	0.3%	9.9%
June	1.7%	4.4%	2.2%	12.5%
July	0.3%	7.0%	0.4%	10.9%
August	0.8%	3.2%	0.8%	8.3%
September	2.1%	2.9%	0.6%	1.9%
October	1.3%	1.9%	0.3%	0.5%
November	0.4%	0.4%	0.4%	0.4%
December	5.5%	8.9%	5.6%	5.9%
Average	**1.5%**	**3.7%**	**1.3%**	**6.3%**

4.2 Result of monitoring

Since May 1st in 2017, monitoring has been conducted until now and this paper includes data analyzed for 8 months from May to December, 2017. The monitoring results showed that the landslide was not accelerated during the period. The monthly rainfall ranged from 0 mm (November) to 270 mm (August), and the groundwater table varied depending on rainfall but finally get lowered to 14.0 m underground at the upper slope (C1) and 12.5 m underground at the lower slope(C2), respectively (**Fig. 8**). Meanwhile, there were no significant displacements exceeding measuring errors of sensors for 6 wire extensometers and 2 borehole inclinometers, respectively.

Table 1 presents results of missing rate of measurement data by monthly and each sensor node. During the period, the total missing rate stood at 3.2% and monthly missing rate of sensor node #4 was 6.3% of the highest. When considering the fact that all the missing values occurred simultaneously from the sensors connected to the same sensor nodes, cause of the missing was boiled down to 'communication part', that is to say, the matter of sensor nodes. It is reasonable to conclude that weather conditions, i.e. daily highest and lowest temperature, were the main cause of communication part error when assuming from the relationship of temperature and missing rate in daily. However, to pinpoint the clear cause of the missing data, close analysis is required on the results conducted during relevant monitoring period.

5. DISCUSSION AND CONCLUDING REMARKS

Monitoring system has been in operation now since the detailed filed study was completed at the competent area of slow-moving landslide. According to the results of monitoring conducted so far, slow-moving landslide is considered to enter a stable phase. However, it is highly possible that progressing speed will be faster again if groundwater level changes caused by localized heavy rain or reservoir level fluctuation. If current slow-moving landslide continues to reaches the point where accumulated surface displacement exceeds 10 mm by wire extensometers, it is expected that related agencies such as Western Regional Office of KFS could take prompt and expeditious actions by sending hazard information to a person in charge of real time.

Although a slow-moving landslide monitoring system is not the fundamental measure to eliminate dangers, it could be an effective way in terms of installment / operation expenses of monitoring system compared to expense for restoration work. While the minimum expense of restoration works for this area was estimated at 1 million dollars, it took (only) 150,000 dollars to establish the monitoring system. However, relatively high missing rate indicates that monitoring system shall be improved for its better function. And the current sensor threshold used to send hazard information is deduced after applying the Japanese standard shown in **Table 2** [*Public Work Research Institute, Japan*, 2007], not the Korean standard. Therefore, it calls for efforts aiming at drawing the threshold which reflects characteristics of slow-moving landslides occurring in Republic of Korea. The hardware performance and effectiveness of the monitoring system require improvement by carrying out long-term monitoring and flume experiment for various types of slow-moving landslide.

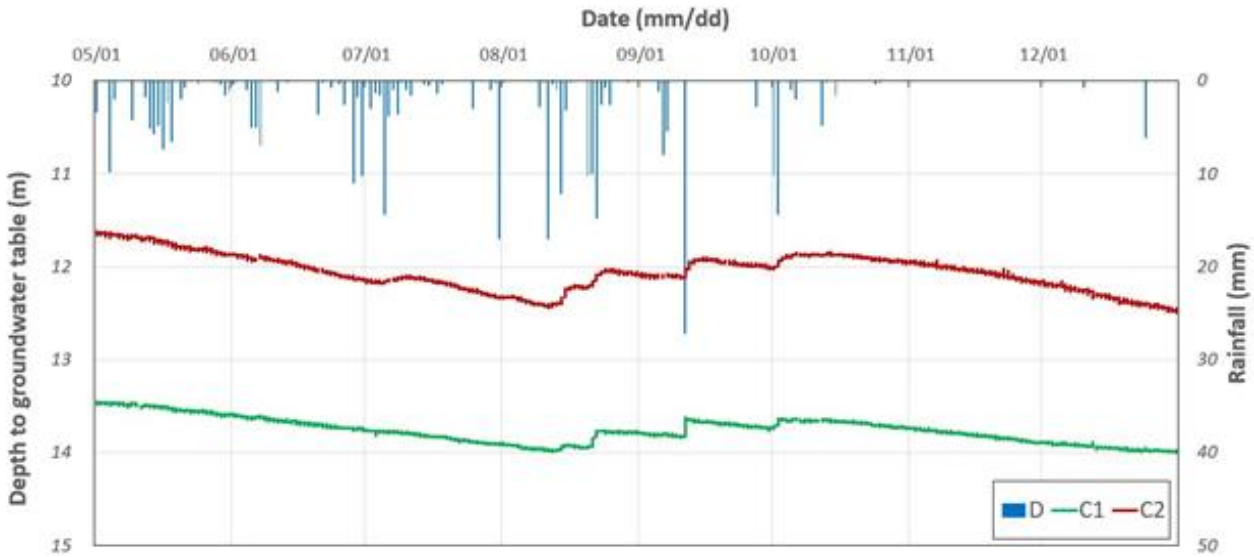

Fig. 8 Temporal variation of groundwater tables of the site with rainfall (D = rainfall, C1 and C2 = groundwater table in **Fig. 7**)

Table 2 The warning thresholds according to wire extensometer measurements

Level	Watch	Alert	Evacuation	No entry
Threshold	1 mm/d	10 mm/d	2 mm/h × 2 or 4 mm/h	10 mm/h

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