Slope movement monitoring using LPWA network and slope stability analysis through its observation

Keywords: LPWA, Safety factor, Tiltmeter

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Introduction

The flat and low-lying area is approximately 25% of the country's land in Japan. Therefore, numerous landslides happen in Japan. 167 slope failures occurred in Hiroshima city on August 20th, 2014, which caused 44 injuries and 74 deaths (Wang *et al.*, 2015). In order to reduce the damage caused by a shallow slope failure, slope movement monitoring using the LPWA network can be used to observe the slope movement. This monitoring system used the tilt sensor and extensometer to obtain slope movement data. The tilt sensor was used because their installation and operation are easy and less time consuming (Uchimura *et al.*, 2015). The slope movement data from the field will be transmitted to the receiver using the LPWA network. After that, the receiver will send the data using the internet connection to the website. Therefore, the current situation in the observation site can be monitored because one major demand in hazard monitoring is fast and reliable data to evaluate the current situation (Azzam *et al.*, 2011). On July 7th, 2018, the slope failure occurred at the Tateyama site due to torrential rainfall. This failure can be observed from slope movement data from the website because there was a high tilting rate. The rate of displacement is often used as an index to define the threshold of warning (Uchimura *et al.*, 2015).

Methodology

Since March 2018, ten tilt sensors have been installed at the Tateyama site (**Figure 1**). At the Tateyama site, slope movement data was obtained using the tilt sensors. This tilt sensor can detect slope movement in one direction only. The temperature sensor was also installed in the entire box.

This slope movement data and ambient temperature were sent using the LPWA network to the receiver. LPWA network is low power wide area network. This wireless technology consumes very low power and has long-range communication. LPWA network can be also implemented in a rural area while a cell network is poor (Peña Queralta *et al.*, 2019). Then the receiver sent the data to the website using an internet connection.

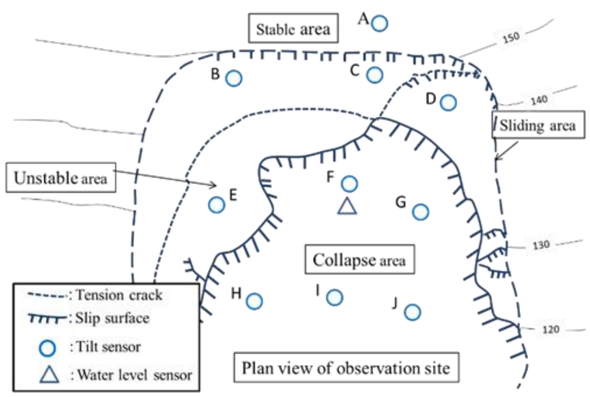

Figure 1: Tateyama site

This slope movement monitoring system was also installed at the Nakayama site. The slope movement monitoring system in Nakayama used ten tilt sensors. This tiltmeter sensor can detect slope movement in the X and Y directions. The temperature sensor was also installed at the Nakayama site to measure ambient temperature. Furthermore, the slope movement data and ambient temperature data were sent using the LPWA network to the receiver. Then the receiver sent the data to the website.

The slope movement monitoring system was also installed at the Arusechiku site. This slope movement monitoring system used an extensometer. Only one extensometer and temperature sensor were installed at this site. The data were sent using the LPWA network to the receiver and then the receiver sent the data to the website using an internet connection.

A site investigation was conducted to check the real condition in sensor H at the Tateyama site where slope failure occurred at this location. The shape of the corrupted area was made by using a topographic map, rangefinder, and tape measurement.

Results

Slope movement monitoring system at the Tateyama site was installed on March 1st, 2018. During collecting data on the slope movement, a torrential rainfall occurred in Shikoku Island in July 2018. Due to this rainfall, slope failure happened in sensor H location on July 7th, 2018. The slope failure was found at the height of 23 m from the bottom part of the slope. The shape is a circular failure. The failure area is around 107 m^2 with a depth of failure ranging from 1 to 2 m (**Figure 2**). Slope stability analysis was conducted using the Bishop method. The result shows a safety factor of less than 1.25. Therefore, the failure may have occurred because slope failure may happen when the safety factor less than 1.25 (Bowles, 1979).

This slope movement monitoring system can show an increment in inclination during the failure. Inclination in sensor H increased rapidly from 0.02° to 0.46° in 4.5 hours. This movement happened due to torrential rainfall on July 7th, 2018. Tilting rate from 3:14 AM to 6:34 AM is 0.01°/h. If the tilting rate is more than 0.01°/h, the slope may be failed. Therefore, a precaution can be issued at a tilting rate of 0.01°/h for safety reasons (Uchimura *et al.*, 2015). The tilting rate from 7:08 AM to 8:14 AM is 0.36°/h, and the tiltmeter stops sending data at 3:27 PM. It indicate that the failure has occurred at the timing. If 0.1°/h were observed, slope failure may occur within 10 hours. Shorter duration remained before failure when a higher tilting rate was observed (Uchimura *et al.*, 2015).

Figure 2: Slope failure in sensor H, Tateyama site

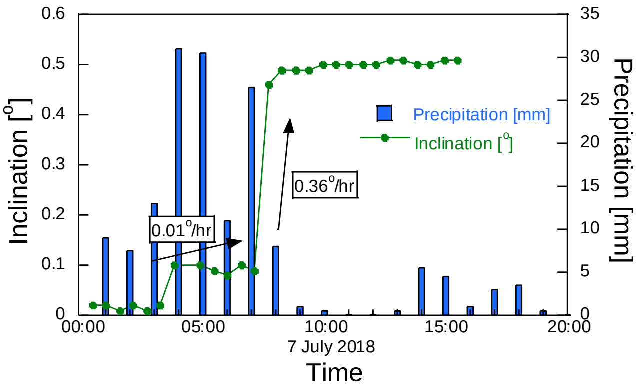

Figure 3: Inclination and rainfall in sensor H, Tateyama site

Ten tilt sensors were installed at the Nakayama site since October 28th, 2019. In this observation site, tiltmeter sensors can obtain data in X and Y directions. Therefore, the direction of slope movement can be known. Ten temperature sensors were also installed in each box. One water level sensor was also installed at the Nakayama site.

Table 1: Tilting rate in Nakayama site on February 16th, 2020

Sensor	Tilting rate (°/hour)	
	X	Y
A	-0.0049	-0.0052
B	-0.001	-0.0011
C	0.0002	-0.0007
D	0.0009	0.0007
E	-	-
F	0.0022	0.0004
G	-	-
H	-0.0037	-0.0043
I	0.0001	-0.000003
J	-0.0006	-0.0008

Several rainfalls happened at the Nakayama site. Until February 2020, landslide does not occur at the Nakayama site. For example, rainfall occurred on February 16th, 2020 in the Nakayama site. On this day, cumulative rainfall was 23.5 mm, and the intensity at 12 AM was 8 mm/hr. However, this rainfall does not cause any significant slope movement at the Nakayama site. From **Table 1**, the tilting rate for all sensors in X and Y directions were less than 0.01°/hr. Tilting rate from sensor E and sensor G location cannot be obtained, because of tilt sensors in this location still in repair.

The slope movement monitoring system was also installed at the Arusechiku site on October 9th, 2020. In this site, an extensometer was used to monitor the slope movement. The slope movement data were successfully sent to the website for several days after installation. After that, the data cannot send to the receiver. Therefore, the slope movement data from the extensometer cannot be monitored on the website, because of extensometer and LPWA network in this site still in repair.

Conclusion

The LPWA network has successfully observed the slope movement. The torrential rainfall on July 7th, 2018 caused a slope failure on sensor H at the Tateyama site. Tilting rate from 3:14 AM to 6:34 AM was 0.01°/h, and it can be the precaution of the failure. The tilting rate from 7:08 AM to 8:14 AM was 0.36°/h, and the sensor H stopped sending data at 3:27 PM, which indicated the slope failure has occurred at the timing. Based on the slope stability analysis, the Tateyama site has a safety factor below 1.25.

On February 16th, 2020, rainfall happened at the Nakayama site. This rainfall did not trigger significant movement due to the tilting rate on this day for X and Y direction were still below 0.01°/h.

The slope movement monitoring system was installed at the Arusechiku site. An extensometer was used to obtain slope movement data. Because LPWA network system is still in repair, slope movement cannot be monitored. After the repairment, monitoring will be resumed and important data will be collected and examined.

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