

NEW EQUIPMENTS FOR PREVENTION OF SEDIMENT DISASTERS; AERIALLY PLACEABLE FLOATING WATER GAUGE AND REAL-TIME SHALLOW LANDSLIDE DETECTION SENSOR

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ABSTRACT

In recent years, massive sediment disasters caused by an large earthquake and heavy rainfall occurred like Chuetsu Earthquake (2004), Iwate-Miyagi Inland Earthquake (2008) ,and Yamaguchi heavy rainfall(2009) in Japan. It is reaffirming the significance of monitoring sensor for debris flow, slope failure and landslide dam. In order to crisis management against sediment disaster, we have developed two new equipments, an aerially placeable floating water gauge (APF gauge) and real-time shallow landslide detection sensor (RT-SLDS) which has resolved problems of traditional equipments.

Key Words: Landslide dam, Slope failure, Measurement and Detection sensor

INTRODUCTION

In above-referenced disasters, many landslide dams were formed due to large slope failure in mountain area. It could be expected occurring inundation of building in upstream and debris flow in downstream if water level rises. In other words, it is a higher risk for occurring secondary disaster. In order to prevent secondary disaster, it's absolutely essential that we urgently install water level gauge to monitor landslide dam. Traditional equipments such as water level gauge or satellite communication units were fixed mount type and quite heavy.

These equipments had to be delivered to site by land routes and installed by hand. Consequently, there were two issues. The first was how we go to the site if roads are blocked by the earthquake. The second was in danger of secondary disaster. It took several days or one month to install traditional equipments due to above issues. On basis of past issues, we developed an aerially placeable floating gauge (APF gauge) has installed in Yuhama landslide dam caused by Iwate-Miyagi inland earthquake for verify availability of an APF gauge. Many slope failure caused by heavy rainfall has occurred at a site other than mountain area. Slope failure is hard to identify site of occurrence and initiation time. In general, precipitation information was useful as indicator of evacuation against sediment disaster but not always correspond with sediment disaster (e.g., Nishimoto *et al.*, 2008). Traditional equipments such as extensometer or GPS were quite expensive and it had to take a lot of trouble with

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installation and maintenance. In order to resolve these problems, we developed a new real-time shallow landslide detection sensor (RT-SLDS) with low-cost, easy installation and maintenance for guidelines on the issuing evacuation advisories to local residents if sensor can be detected early and distributed information of landslide occurrence (e.g., Yanagimachi *et al.*, 2007). RT-SLDS has installed in Rokko mountains to check the performance of this equipment against disaster monitoring.



Roads blocked by earthquake



Time-consuming and dangerous works

Fig. 1 Problems of traditional installation

AERIALLY PLACABLE FLOATING GAUGE (APF GAUGE)

Development of APF gauge

For new equipment which can be installed on disaster site rapidly and safely.

- Transport and install by the helicopter
- Water gauge with measuring range over 10m
- Utilization of communication media during a disaster (also available for use in mountain area)
- Long-term operation using small battery

Based on the above, we developed an aeriably placeable floating gauge (APF gauge) is composed of buoy and cage part. Buoy part has satellite communication terminal which is small and low power consumption with a small battery. Cage part has a water pressure gauge with measuring range over 10m. Satellite communication is using LEO (low-earth-orbit) satellite system available for non-directional antenna and communication media during disaster (also available for use in mountain area).

Table 1 Specification

Items	Specifications
Composition:	Buoy part (with satellite communication terminal and a small battery) Cage part (with water gauge)
Principle of water gauge:	Pressure type
Measurement range of water gauge:	10m or 40m
Method of data transmission:	LEO (low-earth-orbit) satellite system
Method of data monitoring:	E-mail attachment (with date, water level data, and battery voltage data)
Power supply:	Sealed lead acid battery (DC12V-40Ah)
Dimension:	Buoy part: $\phi 700 \times H600$ (mm) Cage part: $W700 \times D700 \times H700$ (mm)
Weight:	Buoy part:30kg, Cage part:30kg



Fig. 2 APF gauge

Installation method of APF gauge

APF gauge is transported by the helicopter to the landslide dam site because it is not affected by ground disaster. Dropping point of APF gauge is place where is no submerged plants and low-gradient bed. After installation, APF gauge is automatically isolating into buoy and cage part. The buoy floats to the surface and the cage sinks to the bed. APF gauge can be installed in only about one hour without ground workers and started to monitor water level swift and safety.

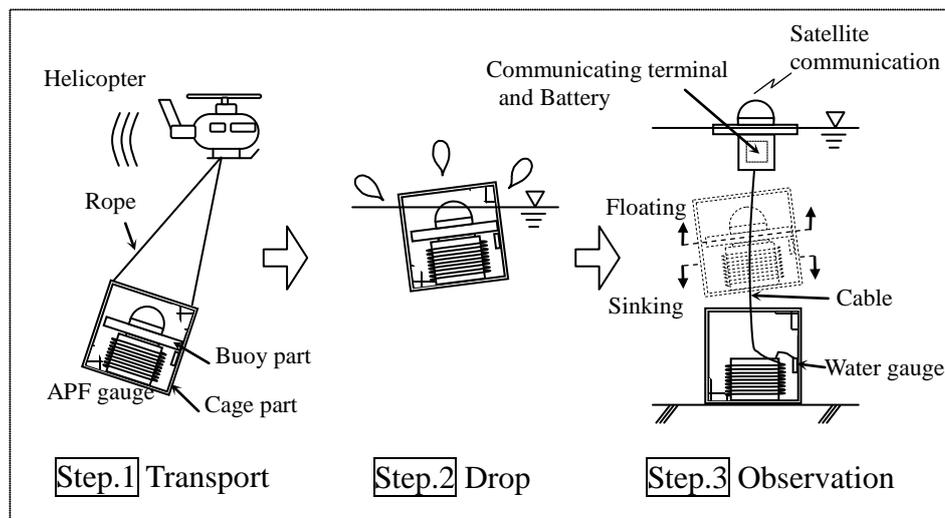


Fig. 3 Installation method of APF gauge

Monitoring water level

Observed water level data is transmitted to earth station via the LEO (low-earth-orbit). Then, users are received the data by E-mail and monitored hydrograph of landslide dam on personal computer in real-time. Monitoring of water level data is used as “Raising of water level for hazard prediction” and “Decreasing of water level rapidly for dam break”. Observation interval is remote-controlled depending on situation of water level, users can also control battery consumption and communication cost.

Application for landslide dam caused by Iwate-Miyagi Inland Earthquake

1. Situation of landslide dam and need of monitoring

June 2008, large 15 landslide dams were formed in Iwate-Miyagi inland earthquake (M7.2). In particular, Yuhama area was formed large landslide dam as 1200m in length and 50m in width and 45m in height by massive deep-seated landslide. For safety of disaster countermeasure works at downstream, monitoring of water level was emergency issue since it is expected to discharge over 100m³/s if dam breaks at full water. However, it was extremely difficult to install traditional monitoring equipment because it has blocked the roads to Yuhama area by earthquake. Based on above situation, the Tohoku Regional Bureau of MLIT (Ministry of Land, Infrastructure, Transport and Tourism) has asked us to install APF gauge in Yuhama landslide dam.

2. Transportation and installation

APF gauge transported to site from temporary heliport near disaster area using helicopter. It had to adjust flight velocity for avoid swing backward because total weight of APF gauge is 60kg and light. After reached the skies over landslide dam in Yuhama, we tried to find the dropping point (place like low-gradient bed, no submerged plants, and depth of water is not too deep) Then, APF gauge dropped to place as mentioned above. This equipment automatically isolated into buoy and cage part. Buoy floated to the surface and cage sank to bed. The operation was moving smoothly as we had expected. The data had transmitted immediately from APF gauge and we received the data by e-mail. This showed to provide effectiveness of APF gauge due to brief installation and easy observation without ground workers. In addition, we measured the difference in height between levee crown of landslide dam and water surface for grasping condition of overflow.

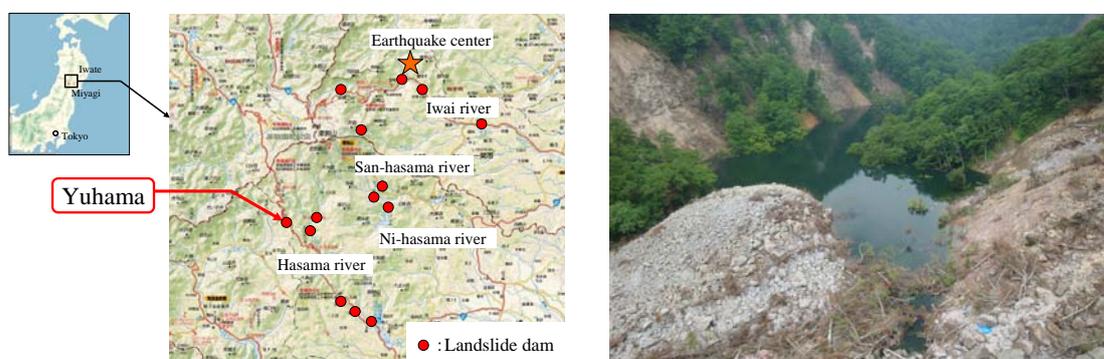


Fig. 4 Location and view of landslide dam in Yuhama



Courtesy of Tohoku Regional Bureau, Ministry of Land, Infrastructure, Transport and Tourism.

Fig. 5 Installation of APF gauge

3. Observed water level data

Observed water level data shown in Figure.6. Primary finding according to this data are as follows.

1. In July 6 (day after installation), water level rose to 0.6 meters and reached at levee crown of landslide dam, started overflow slightly.
2. In non-rainfall time, the dam has not overflowed when water level was hovered approx 0.4 meters.
3. In rainfall time, the dam has overflowed when water level rose between 1.1 and 1.7 meters.
4. In July 24 2008, water level rose to 0.4m at aftershock. For the reason, the cage of APF gauge fell below due to seismic movement and depth of water level gauge also fell below.
5. In October 24 2008, water level rose to 1.75m by heavy rain (130 mm per day), the dam has recorded maximum water level since it had started observation. The dam has presumed unbroken since water level was not decreased rapidly. By this rain, other landslide dam has largely eroded and water level was rapidly decreased approx 10m in short time.
6. APF gauge could monitor water level data without missing.

The data has transmitted to Tohoku Regional Bureau of MLIT, administration of this disaster countermeasure, in real-time. This data was used as a mean of alerting information for local residents and countermeasure works for disaster.

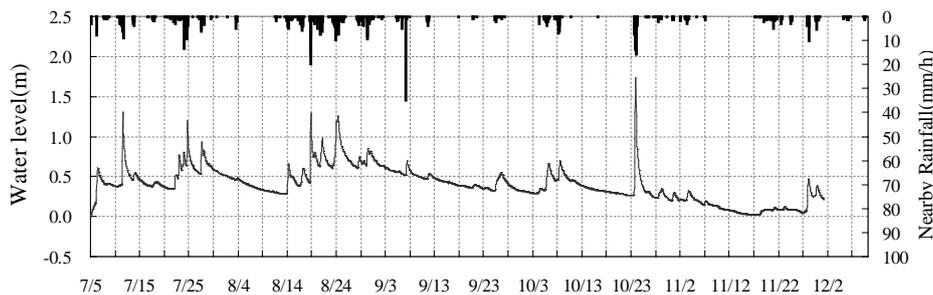


Fig. 6 Hydrograph of landslide dam in Yuhama 0m at beginning of installation

4. Transmission delay of satellite communication

APF gauge is occurred transmission delay by using satellite communication. This indicated that obtained 754 data in August 2008 occurred transmission delay as shown Table.2. 90% of them were delay within 5 minutes. As a result, it should be considered within allowance for water level observation of landslide dam.

Table 2 Delay time of satellite communication

Delay time (min)	Frequency	%
0 - 1	60	8%
1 - 2	380	50%
2 - 3	143	19%
3 - 4	68	9%
4 - 5	41	5%
5 - 6	29	4%
6 - 7	19	3%
7 - 8	9	1%
8 -	5	1%

1-31 Aug, 2008

5) Power consumption for battery

Battery voltage was 12.7V at beginning of installation. It has become approx 11V after 3 months. It is not reached minimum clamping voltage (approx 8V) of APF gauge operating. This showed that this battery is capable of at least 3 months of continuous operation without battery charge (Measuring interval: once per an hour). This result shows that the battery has enough capacity for initial monitoring of landslide dam.

6) Installation for solar-buoy

A year has passed since APF gauge was installed in Yuhama landslide dam, it was still continued monitoring water level but this gauge requires replace of battery. Consequently, we installed another buoy for charge the battery. This buoy has solar panel (40W) with snow protection cover. It is charging the internal battery of APF gauge during the day.



Fig.7 APF gauge and solar buoy

REAL-TIME SHALLOW LANDSLIDE DETECTION SENSOR (RT-SLDS)

Background and objectives

In Japan, precipitation information is using as indicator of evacuation against sediment disaster. While, since precipitation information is not directly related with sediment disaster, local residents and governmental officials pointed out that if sensor can be detected early and distributed information of landslide occurrence, these systems should be very effective (Yanagimachi et al, 2007). However, until now, sediment disaster detection sensors with low-cost, easy installation and maintenance were not available. So, in this study, we set the following development goal of real-time shallow landslide detection sensor (RT-SLDS).

1. Install the sensor on steep slope and detect landslides without delay.
2. Transmit a detection signal by wireless.
3. Long-term operation with small dry-cell battery.
4. Inexpensive price.
5. Useful life approx 10 years.
6. Install by human-powered easily.

Development of prototype

Following 3 types (prototype) of sensor to archive development goal.

- Type-1(Falling detection type): Detecting and transmitting by wireless if sensor is inclined over 30-degree by landslide. Distinctive features are simple-configuration, low-cost and users can choose two wireless types (Specified low power radio or low-frequency electromagnetic radio) depending on the site situation.
- Type-2(Regularly measuring inclination angle type) : Measuring inclination angle and soil moisture, and transmitting the data at regular interval by wireless(Specified low power radio). Users can accurately understand the precursory change of landslides.
- Type-3(falling down ball type) : Falling down small iron ball through the tube from the sensor depending on soil expansion if the landslide is occurred. Then, signal board will be mechanically changed in color as Fig.8. Distinctive features are unwanted electrical power, simple-configuration, low-cost and easy maintenance.

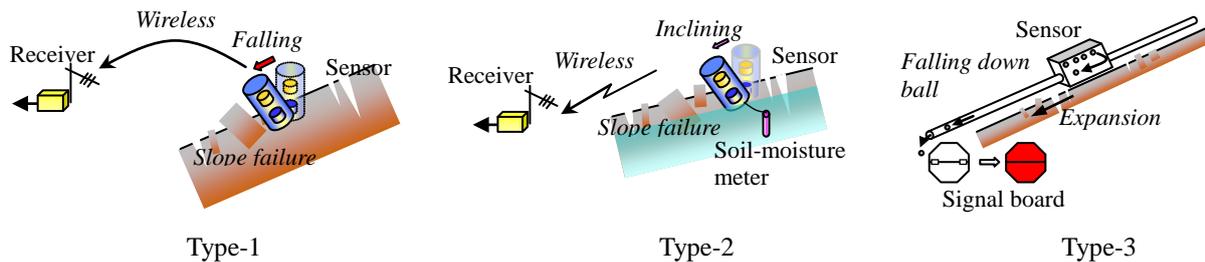


Fig. 8 Detecting method of each types

Examination for detection accuracy

This verification examination is whether type-1 sensor can be detected landslide occurrence without delay. The sensor installed in the slope (angle of inclination: 40 degrees), and artificial rain has conducted and forcibly poured water into the ground to cause slope failure. The sensors have fell and detected over 30 degrees when slope failure was occurred, as a result, this examination successfully made wireless transmission from sensor without delay.

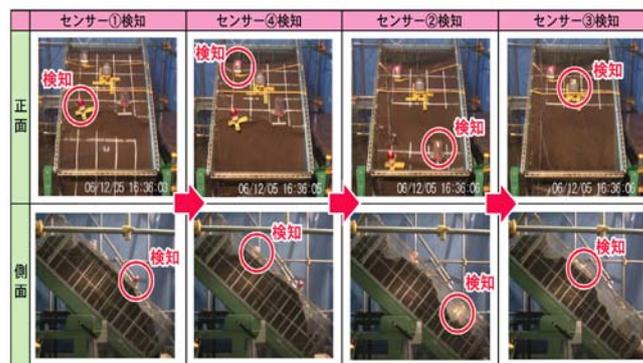


Fig. 9 Appearance of examination

Examination for transmitting by wireless

To confirm radio attenuation caused by shielding as trees and land form using type-1 (Two wireless types: Specified low power radio and low-frequency electromagnetic radio), we conducted examination. The details are as follows.

- Specified low power radio type:

In case of none shielding, it was transmitted 1000 meters. On the other hands, it was transmitted only 300-500 meters due to shielding attenuation as trees and land form. Since transmitting distance is fluctuated by site condition, it is necessary to execute this test in every actual place when sensor is installed.

- Low-frequency electromagnetic radio type:
Transmitting distance was only 110m but it could be constant communication regardless of shielding as trees. The result indicates it is not influenced to attenuate by trees and have applicability to many condition fields.

Table 3 Examination result of transmission

Condition	Specified low power radio	Low-frequency electromagnetic radio
Flat and good view	1000m	110m
Flat and trees	500m	110m
Shield and trees	300-400m	untested

Examination for long-term endurance

To verify long-term endurance, we have installed each type of RT-SLDS in Rokko mountains, Hyogo pref, also installed rain gauge, extensometer, soil-moisture meter and inclinometer for comparative verification. This examination is verifying practical effectiveness of performance of RT-SLDS such as detection accuracy, functional maintenance, power consumption for battery, transmission performance and maintenance under natural condition. About two years have passed since we installed and started maintenance on once per two month basis, durability of this sensor is good at current moment. In addition, we will continue this examination.

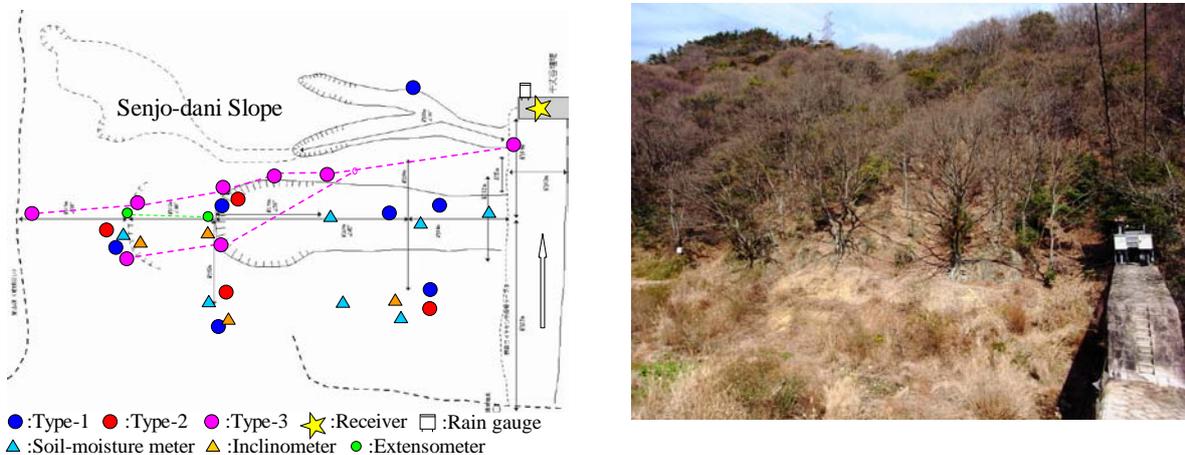


Fig. 10 Configuration of sensors and view of Rokko mountains

Application to disaster site

November 2008, landslide had occurred in Sionokawa, Fukushima pref and RT-SLDS (Type-1) was installed instantly on this site for safety countermeasure of neighbor sabo works. And wire-sensor and extensometer were also installed for multiple monitoring such as expanding of slope failure and re-movement of sediment. When these phenomena are occurred, it can has been instantly alarmed by the siren and warning light to sabo works site.

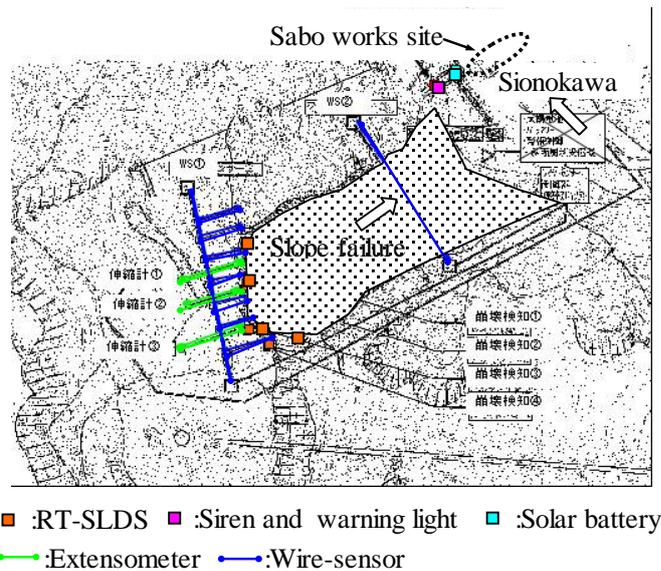


Fig. 11 Disposition and view of sensors in Sionokawa

CONCLUSIONS

Based on text and application result for APF gauge and RT-SLDS, it can be judged that these sensors were enough for practical use at current moment. APF gauge have resolved previous problems as swiftness and safety at installation. This could speed up dramatically to improve disaster-prevention measures at landslide dam occurrence. RT-SLDS had put in place new detection method that was not only lower cost, easy installation and easy maintenance but also increase public awareness of risk of landslide and expect to proceed smoothly for evacuation. In addition, by the use combination of APF gauge and RT-SLDS for landslide dam, it can be performed comprehensive monitoring (water level, slope failure to expand, re-movement of sediment). In the future, we will study additional inspection and improvement of APF gauge and RT-SLDS and try to promote two sensors as new tool to prevent sediment disaster.

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