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Landslide and Falling Rock Measurement Using Piezoelectric Smart Sensors

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Abstract- The prediction of landslide and falling rock occurrence is important, but such predictions are difficult. To resolve this difficulty, this study assessed measurement of the degree of danger by measuring the risk to the landslide fence at the time of rainfall and falling rock according to changes in the load and the impact of voltage proportional to the avalanche barrier deformation. This measurement system has fixed sensors attached with mounting brackets to a dedicated landslide prevention measurement fence. It measures the pressure and vibration measurement of the snowfall at the time of landslide or rock fall occurrence at the main fence structure. Furthermore, this fence made of lumber from thinned timber is useful as a defensive barrier countermeasure against landslides and falling rock. It is designed to withstand a mudslide load of 3–5 [t / m2] during a landslide.

Keywords- *Insert Smart Sensor, Piezo Electric Sensor, Thinned Timber, Landslide Accumulation Measurements Fence*

I. INTRODUCTION

Japan, a volcanic archipelago, has a very high probability of occurrence of a huge earthquake compared to those of Europe and the United States. Nevertheless, the current situation is that concrete measures related to disaster prevention are progressing slowly, which presents an important difficulty. In particular, a technical delay exists with regard to the field of defining measurement techniques for estimating the strength of protective measures against falling rocks and their range of impact and judgment criteria used for predicting danger. The best method of obtaining characteristic data of falling rocks is to drop the fallen rock on the slope and observe the result. However, the current situation is based mainly on simulation evaluation because of safety aspects and restrictions of surroundings [1]-[5]. We inferred that if we were able to reproduce this drop test using a simple method, we could contribute to society if we were able to obtain materials that can assess the occurrence of falling rocks and landslides and can investigate and prevent damage expansion .Based on results of fundamental experiments, attention has been devoted to output characteristics related to the load and the drop energy using piezo-limit sensors and the piezo-vibration sensors. We conducted loading tests in the field and the rolling drop energy tests with spheres using an inclined surface. We used this measurement system to study the effectiveness of sensor performance and monitoring techniques.

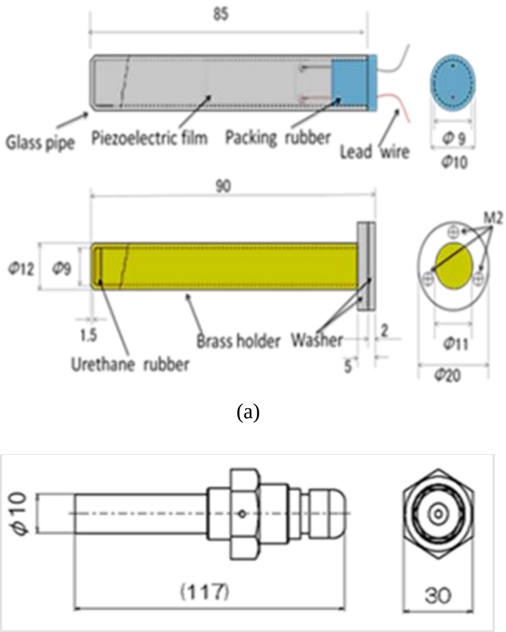
II. CONSTRUCTION OF SIMPLIFIED MEASUREMENT SYSTEM

The measurement fence using the thinned timber shown in Figure 1(a) devised for this research demonstrates that it is only necessary to set up several measuring fences of about 3360 mm length, 3800 mm width, and 3350 mm height. As shown in Figure 1(b), a piezo-limit sensor was fixed to the center part with a dedicated metal fitting. Radio communication equipment for data transmission was arranged in the lower part. This sensor has the convenience of not requiring a power supply for measurement by the sensor itself outputting the voltage in proportion to the magnitude of the damage received by the measuring fence such as shock and breakage because of falling rocks. As communication equipment for monitoring, i-SENSOR (Ap-plied Geology Co., Ltd.) was used. It has been proven in outdoor observations. The threshold value is set by a microcomputer from the value obtained using the destructive test of the measurement fence. Transmission is performed only for output voltage of not less than the threshold value. It is designed to ensure communication for about one year considering high-capacity communication (sampling frequency 10 Hz) and power consumption (20mW/h). An important shortcoming is the measurement fence size and weight, but it is designed with consideration of simplification and transportation by assembly such that it is useful even in mountainous areas.

For initial detection of falling rocks, it is necessary to measure the vibration measurement directly by shock and structure displacement of the measurement fence. We thought that it would be desirable to enable "measurement" and "effects of suppressing rockfall expansion during initial drop" by installing an inexpensive large fence considering the effective use of thinned wood.

(a) (b)

Figure 1. Measurement fence during mounting. a) measurement fence, b) network system



(a)

(b)

Figure 2. Structure of each sensor. a) piezoelectric limit sensor, b) piezoelectric vibration sensor

Figure 2(a) shows a pie-zo-limit sensor, which measures the load only when the glass tube breaks. The piezo-limiting sensor is made by closely fixing a piezo film [6] (DT-2-028 k / L; Tokyo Sensor Co. Ltd.) [7] in a hard glass tube with ultraviolet curing resin (UV). Urethane packing was used after inserting the lead wire into the rubber stopper. A connector was added to connect with an external cable. This glass tube is inserted into the metal holder and is used with a gap related to the degree of tolerance to clearance. The sensor exterior holder material can be changed to aluminum, brass, iron material, etc. so that it is useful for structures other than avalanches in this measurement. The brass exterior was selected for the sensor used in this test. In response to the destruction, the sensor main body is damaged by shearing or crushing, etc. The piezo film inside the glass tube is de-formed according to the applied force. Therefore, it is possible to produce output by voltage corresponding to dam-age sustained by the measuring fence. When the output voltage is generated, one can obtain the stress at which the fracture of the measurement fence starts because of the snow pressure load and displacement leading to complete destruction.

Figure 2(b) shows the piezo-vibration sensor [8]. This sensor can measure vibration in the entire circumferential direction approximating to the accelerometer. After inserting the cable-shaped piezoelectric sensor (AWG 80 mm; Tokyo Sensor Co. Ltd.) into the center of a hollow urethane resin (10 mm × 80 mm), it is adhered and fixed so that the external shape is a cylindrical bolt shape. The sensor characteristics can be output by voltage proportional to the magnitude of vibration. In addition, to enable wired connection to a high-performance memory logger (LR 8431; Hioki Corp.), the sensor is insulated by connecting 2 m of coated 2 mm lead wire.

III. MEASUREMENT FENCE STRENGTH MEASUREMENT IN THE ROOM

First we conducted a test of the measurement fence in the laboratory. As Figure 3(a) shows, the test measurement fence was fixed to the stand so that the measurement fence would be the same as the state installed on the slope of the mountain. Loading on the measurement fence was reproduced using the retraction force in the opposite direction by the hydraulic jack. The vertical fence (vertical strut) was pulled by a hydraulic jack, deformation situation in the force direction of the strut part, sensor response, load was measured and compared. As presented in Figures 3(a) and 3(b), the piezo-limit sensor is inserted and fixed in a dedicated metal fitting (sensor mounting bracket) at the joint part of the central vertical post. The output of the sensor changes according to force and displacement. We measured the relation in chronological order. A displacement meter was also installed to measure the deformation of each joint and beam (Figure 3(a): (1) horizontal wood). The measurement fence is designed to be destroyed completely at the maximum allowable load of 50–65 kN loaded in the central portion. Figure 3(c) presents the relation between vibration frequency and sensor output by a piezo-vibration sensor. The output voltage increases proportionally to the vibration magnitude. Test results show that displacement of the beam in both left and right directions occurred as the force increased. Figure 4 shows the relation between applied force and piezo-limit sensor out-put. Near the left ellipse in the figure, the first large voltage output was recognized from the piezoelectric limit sensor at the applied force of about 20 kN. At this time, because the displacement in the central rafters (Figure 3(a): (2) upper wood diagonally) was measured as about 10–15 mm, which is inferred as the moment when the first destruction occurred within the safety allowance at the time of design. The second large voltage output was observed when the applied force was about 45 kN near the central ellipse in the figure. Result of frequency of output by piezoelectric vibration sensor in Figure 3(c). We measured the output voltage of the piezoelectric sensor, changing the amplitude (both side) of the vibration test device 0.05 mm initially, then 0.1, and finally 0.2 mm progressively. The amplitude was measured by the laser displacement sensor set outside. According to the result we verified almost linear relation between frequency and output voltage for each amplitude, which convinced us to use the sensor for our tests. Finally we tested frequency response of the sensor to verify the sensor performance.

The displacement of the rafters in this time was about 18–20 mm. Furthermore, near the right ellipse in figure 4, when the applied force was about 65 kN, the third large output was shown. The rafter displacement in the center showed a large value of 30–35 mm. Subsequently, because the measurement fence was destroyed completely, it is apparent that this third output signals the complete destruction of the measurement fence.

As shown in Figure 2(a), the piezo-limit sensor is a structure in which a glass tube and a piezo-element are combined and inserted into a protective metal tube. Be-cause the piezo-element enclosed in the glass tube is fixed as normal (healthy state), the sensor output is not measured.

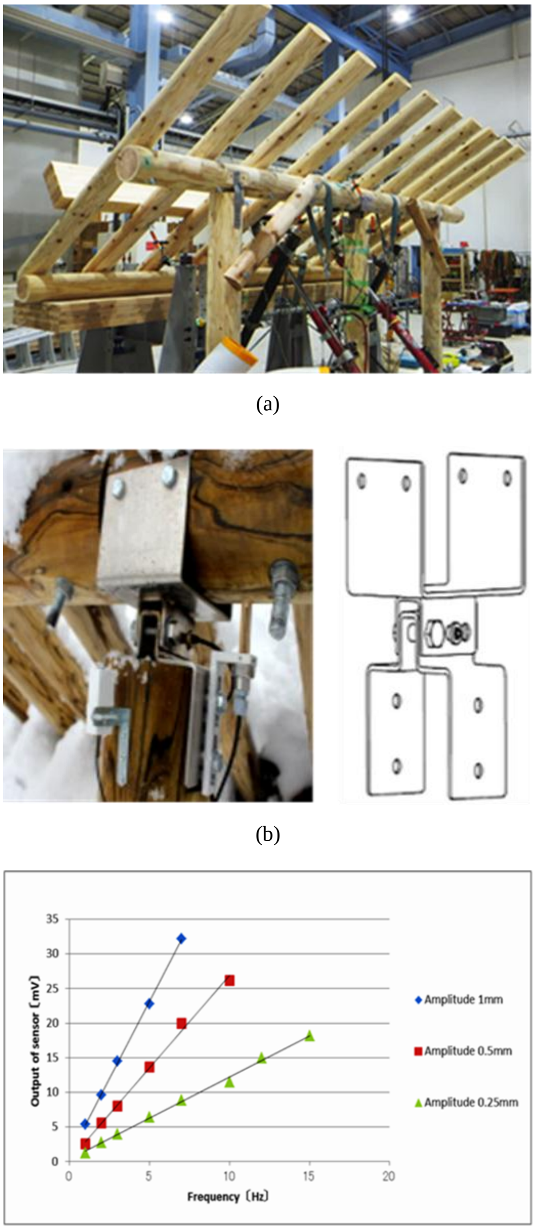
However, when displacement or load exceeding the design safety value occurs, such as with partial breakage, the voltage output from the piezo-element fluctuates be-cause of the shock to the metal fittings. The results of this test demonstrated that the piezoresistive sensor can signal a dangerous situation of a measurement fence in three stages in real terms: First, it is necessary to devote prompt attention to the first output. It is then necessary to predict the danger immediately at the second output. Furthermore, the sensor output can be sensed as within the numerical value of the maximum permissible load when initially designing the measurement fence. Therefore, its reliability is apparent.

IV. EXPERIMENTS AND ANALYSIS

A. *Demonstration test of measurement fence loading on a slope*

For the measurement fence installed on the outdoor slope in the laboratory site, we conducted a force test to load up to 5 tons of sandbags, each of 500 kg, using a crane. The test execution situation is presented in the figure 5(a). This test verified whether the setting of the detection range examined from the load and displacement data obtained in the laboratory test was valid. To measure the measurement fence deformation, major positions were monitored during the test using multiple displacement sensors. Figure 5(b) shows, installation status of measuring instruments.

Figure 6 portrays the relation between the load and the piezo-limit sensor output. A signal indicating damage at a load of around 10 kN, a danger signal at around 30 kN, and a limit signal indicating breaking at a weakness of less than 50 kN were recognized. For the same indoor test results shown in Figure 4, the damage signal is measured near 20 kN, the danger signal near 45 kN, and the limit signal near 65 kN. The difference between the required signals of the outdoor test and the indoor test is probably the result of using different test bodies. The load ratio at the time of required signal output of the measurement fence of destructive force 65 kN used in the field test and the measurement fence of destructive force 50 kN used in the in-door test is about 0.7 times. It is judged that the same characteristic is obtained. A falling test was conducted by simulating the falling rock situation on the measurement fence installed on the outdoor slope. Setting of the detection range was verified using the value calculated from shock vibration data obtained from the indoor test. The measurement situation test of rolling fall energy of falling rock is presented in figure 7.



(a)

(b)

(c)

Figure 3. Fitting of sensors and frequency of output. a) measurement fence loading test, b) sensor unit and bracket, c) frequency of output by piezoelectric vibration sensor

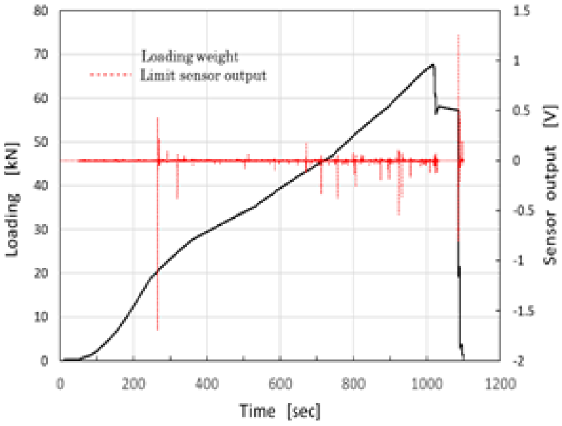
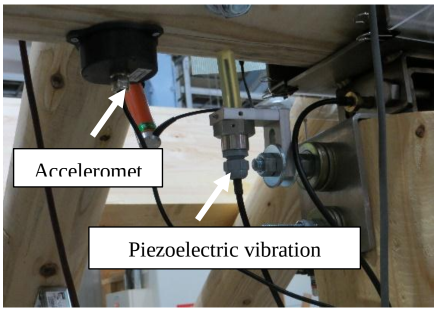


Figure 4. Relation between loading force and piezoelectric limit sensor output of frequency

(a)



(b)

Figure 5. Loading test in the field. a) upper surface of measurement fence in loading test, b) installation status of measuring instruments

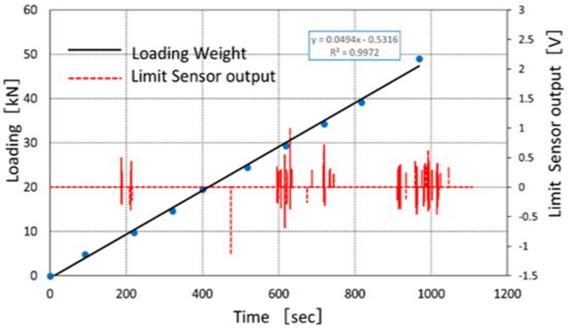


Figure 6. Relation between loaded load and piezo limit sensor output.

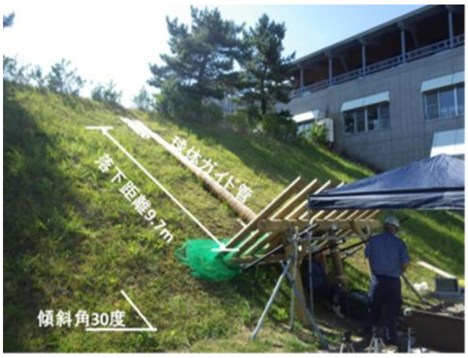


Figure 7. Measurement of falling energy of falling rocks.

B. *Drop test of simulated falling rock*

A sphere simulating a falling rock was dropped from above the measurement fence installed on the outdoor slope. Its impact was observed. A hollow spherical guide tube at the center of the measuring fence was used so that the collision position of the sphere did not change: the ball inside the tube rolls freely. A 31-kg iron ball was used as the sphere, simulating a 30-cm-diameter rock fall. Figure 8 shows an output comparison of the accelerometer and the piezo-vibration sensor in the impact when the iron ball is dropped on the measurement fence. The waveform shown by the solid line is the synthesized output of the triaxial accelerometer. The waveform of the broken line is the voltage output by the piezo-vibration sensor. Comparison of both waveforms shows that it attenuates from a similar initial impact state and converges in about 2 s. Figure 9 presents test results obtained by preparing three spheres with weights of about 6 kg, 11 kg, 31 kg, and falling in the same test. The falling energy for each weight of each sphere was calculated and compared with each sensor output and graphed. The solid line shows the relation between the composite value of the three-axis accelerometer and the drop energy. The broken line is the relation between the piezo-vibration sensor output and the drop energy. Both sensors show a response that is proportional to the sphere weight.

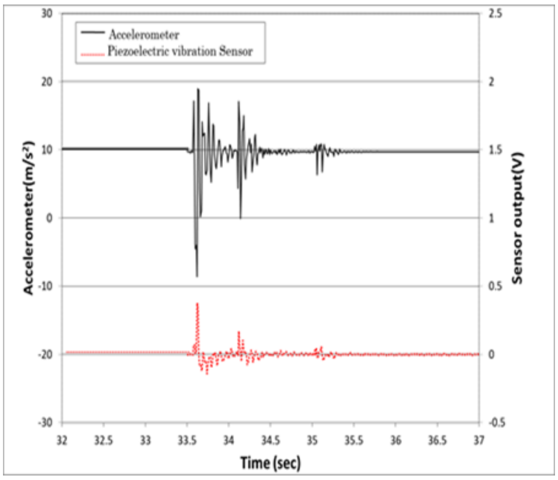


Figure 8. Comparison of outputs of accelerometer and piezo-limit sensor.

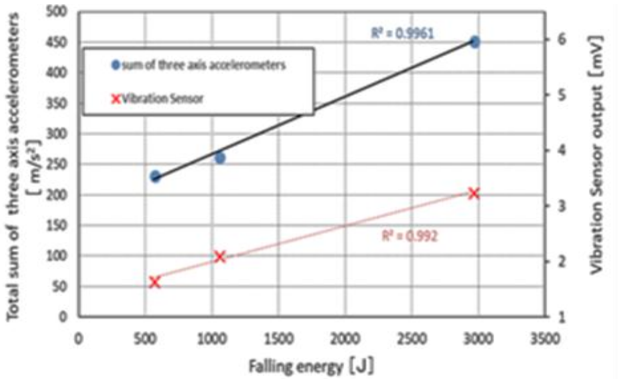


Figure 9. Relation between sensor outputs and drop energy.

V. EXPERIMENTS AND ANALYSIS

We devised a measurement fence system that combines "preventive work" and "measurement" on unprotected steep slopes where countermeasures such as falling rock have not been done. The main measurement system, which effectively uses thinned timber, is inexpensive. It is possible to observe the occurrence of falling rocks or the like autonomously to notify surrounding residents and vehicles in traffic. Furthermore, because measurement fences of the present system made from thinned wood represent little concern related to corrosion, even in mountainous regions where volcanic gas is generated, it is necessary only to protect the measuring devices from gas, rainwater, etc. The system is extremely convenient.

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