Laser Scanner Application in Monitoring Short-Term Slope Deformation

Kiminori Araiba and Naoki Sakai

Abstract

In order to develop a method to estimate the risk of secondary disaster during rescue activities at a site suffering from slope failure, a method for using repeated surveying by means of laser scanner installed on the ground is proposed. Eight experiments of slope failure including one carried in a natural slope were done. To improve the accuracy in the deformation, spatial stacking of data was adopted. Availability and reliability of the method, characteristics of deformation measured are discussed.

Keywords

Laser scanner • Precursor • Delayed collapse

Introduction

Assessing and controlling the risk of a secondary disaster during a search and rescue (S&R) operation at a disaster site are difficult because both the quantity and quality of information regarding the disaster are usually inadequate due to the limited time and space available for investigation. As an example, 60 fire-fighting volunteers were killed during an S&R activity because of a secondary failure of a slope that occurred approximately 4 h after the initial slope failure, which had buried 1 person in Shigeto, Kochi prefecture, Japan, in 1972 (Nakagawa and Okunishi 1977). Figure 1 is a picture of a landslide caused by an earthquake in Fukushima Prefecture on 11 April, 2011. Fire fighters conducted S&R activity in the deposit. They recognized that the slope was still moving. The activity was finished on the next day, recovering a body.

Extensometers are frequently used to monitor movement in the slope failure site. Saito and Uezawa (1961) first discussed the prediction of failure using extensometer data; related studies have been carried out (e.g., Varnes 1982; Fukuzono 1985; Hayashi and Yamamori 1991). An extensometer is easy to set up, and it provides one-dimensional data; therefore, it is easy to handle. On the other hand, it has the following drawbacks:

1. It measures the variation in the distance between two posts. One post must be located on the stable ground and the other on the potential failure mass. However, it is difficult to recognize the failure part and stable part before failure actually occurs, especially in cases where numerous cracks exist on the slope.
2. The installation must be carried out in an unstable area.
3. The direction of movement of the sliding mass is not always parallel to the direction of the extensometer's sensitivity.

By means of repeated surveying, it is possible to monitor the spatial distribution of the deformation on a certain extent of the slope; therefore, shortcomings 1 and 3 of the extensometers can be overcome. With regard to shortcoming 2, some survey methods, such as, use of laser scanners, photographic measurements, and fringe analyses require no targets. These methods can reveal three-dimensional deformations that can provide information for understanding the mechanism of a potential failure. The application of such

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Fig. 1 A S&R activity was done in the deposit of a landslide where mass of up-slope was still sliding during activity

a method to monitoring of a slope failure can allow the monitoring to start quickly and safely, which are the desirable aspects of an emergency response.

In this study, availability and reliability of repeated surveying using a laser scanner installed on the ground for monitoring pre-failure deformation of slope was investigated by means of model slope experiments and a model slope failure experiment, and the characteristics of measured surface deformation are discussed.

Method

Method for Deformation Measurement

The laser scanner measures distance to a part of a target that lies within the angular width of the laser pulse beam divergence, and it automatically scans the designated vertical and horizontal angle widths by using designated angle intervals. The accuracy of the laser scanner is not as good as that of conventional total stations; however, it can quickly measure wide areas. The survey technique was applied to seven model tests to verify the possibility of detecting pre-failure deformation.

Specifications of the laser scanner used in this study are listed in Table 1. Result of accuracy check and method of data process were described in Araiba (2006). Definition of coordinate system is shown in Fig. 2.

Shape of slope was measured by each scan and representative Y value was calculated for 20 cm mesh by averaging data in each mesh. Deformation of slope can be detected as variations in the representative values.

Method of Experiments

Seven experiments (No. 1–7 in Table 2) involving model slope failure induced by artificial rainfall were performed in the large-scale rainfall simulator at the National Research Institute for Earth Science and Disaster Prevention (Fukuzono and Terashima 1985).

Table 1 Specifications of laser scanner used in this study

Precision in distance	Resolution in angle	Beam divergence	Scan rate
8 mm	0.009°	1.2 m rad.	1,000 points/s

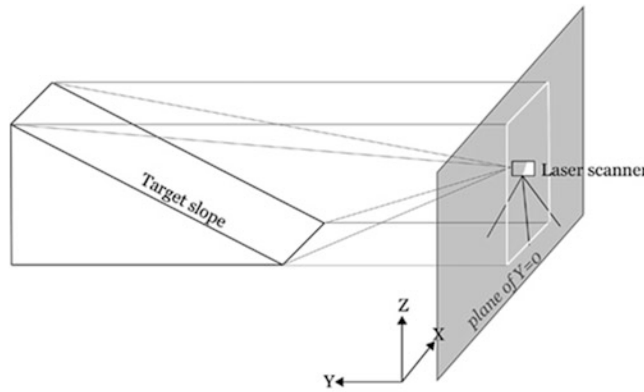

Fig. 2 Definition of coordinate system

A model slope covered by a soil layer with a height of 5 m, width of 4 m, depth of 1 m and an inclination of 30° was constructed using material listed in Table 2. Water was sprayed from nozzles that were set at a 6-m-high ceiling. A series of preparatory sprays were applied to the model slope for about 10 days. Each preparatory spray application was done for 8 h per day; its intensity was increased on a daily basis from 15 to 45 mm/h. On the final day, the intensity was increased to the value in Table 2, and water was sprayed until the model slope eventually failed. Figure 3 shows photographs of the model slope before and after the failure.

One experiment (No. 8 in Table 2) involving slope failure induced by artificial rainfall was performed in a natural slope mainly consists of decomposed granite soil. The detailed conditions of this experiment were reported in Ochiai et al. (2004). A section of the natural hill slope was isolated by driving steel plates into the ground. The isolated segment was 5 m wide, about 30 m long and had an average surface gradient of about 33°. The topsoil comprised weathered decomposed granite. The original vegetation was removed and the ground surface was covered by straw mats in order to prevent surface erosion and to improve the infiltration of water into the ground.

Water was sprayed from nozzles attached to steel pipes at a height of 2 m above the ground. The intensity of the spray was 78 mm/h. The lower half of the segmented slope failed approximately 6 h after the start of spraying. The maximum depth of the failed mass was about 1.2 m. Figure 4 shows the photographs of the slope before and after failure. The pair of white arrows indicates the location of the head of the failure.

Table 2 Experiment conditions

No.	Material	Water spray intensity (mm/h)	Slope angle (degree)	Scanner—slope distance (m)	Horizontal scan angle (degree)	Horizontal scan step (degree)	Vertical scan angle (degree)	Vertical scan step (degree)	Time for one scan (min)	No. of data (approx.)
1	River sand	100	30	12	21.6	0.108	18.0	0.054	4.0	35,000
2	River sand	50	30	10.5	20.6	0.200	17.0	0.1	1.5	13,500
3	River sand	50	30	16.5	26.2	0.153	17.0	0.099	2.4	14,000
4	River sand	50	30	10.5	23.0	0.297	20.2	0.126	1.4	6,400
5	River sand	50	30	10.5	19.4	0.243	16.2	0.081	1.2	12,000
6	Decomposed granite soil	50	30	8.8	24.4	0.216	21.2	0.054	1.8	21,000
7	Decomposed granite soil	30	40	13.3	22.4	0.216	15.9	0.054	1.5	12,400
8	Natural slope	78	33	40	7.0	0.054	27.0	0.054	1.5	20,000

Fig. 3 Model slope used in experiments No. 1–7. (**a**) Before failure; (**b**) after failure

Fig. 4 Slope after the experiment No. 8

Result and Discussion

Characteristics of Deformation

Figure 5 shows the deformation of slope prior to failure measured in experiment No. 4. Blue colour indicates progressive deformation and red colour indicates retrogressive deformation. Distinct deformation can be observed about 880 s before the failure and the amount of deformation became larger with time.

Figure 6 shows changes in the cross section of model slope with time in experiment No. 2 where the amount of deformation is magnified by 20 times. The amount of retrogressive deformation in the upper region of slope has positive correlation with height and, on the other hand, that of progressive deformation in the lower part does not show correlation with position.

Figure 7 is a picture of slope about 1 min before failure, captured from video in experiment No. 4. Two clear lines (compression cracks) can be seen in the lower part of slope and one tension crack can be seen on the top of the slope.

Retrogressive deformation was observed in the region below the tension crack and its amount has a positive correlation with height, which indicates that the deformation accompanied rotation. On the other hand, progressive deformation does not show such tendency. Slope seems to have dislocated at the compression cracks with slight changes in the angle of slope surface.

Reliability of Measurement

Figure 8 shows time series of specific meshes where large deformation was observed. Remarkable deformation was observed in all of tests. We can conclude that deformation prior to failure can be detected with high possibility in slopes that consists of the sandy material.

Retrogressive deformation shows acceleration with time; on the other hand, slight acceleration can be seen in progressive deformation.

Figure 9 shows result of test No. 8, which is done with natural slope. Although the surface of slope was covered by straw mats, which must have disturbed measurement, the deformation prior to the failure can be detected about 20 m away from slope. The amount of deformation is large and acceleration can be observed in Fig. 9.

The reason that acceleration can be observed in some cases and cannot in the other cases is considered due to the noise in the measurement and resolution. In order to improve the accuracy in the deformation, all laser spots within 10 cm mesh are averaged in this method, thus spatial resolution is compromised.

The dislocation at the compression is spatially sharp as shown in Fig. 7 and 10 cm mesh is larger than the area of dislocation, thus deformation values at meshes involving compression cracks must be smaller than values of dislocation. Furthermore, laser beam have a certain divergence therefore shape of laser-spot at the slope is in the shape of an ellipse. To measure more accurate value of dislocation, it is necessary to make the size of mesh smaller and area of laser-spot smaller. Further research in optimizing resolution of measurement, robustness of measurement, scan rate and scan position is necessary.

Conclusions

In order to develop a method to estimate the risk of secondary disaster during rescue activities at a site suffering from slope failure, a method for using repeated surveying by means of laser scanner installed on the ground is proposed.

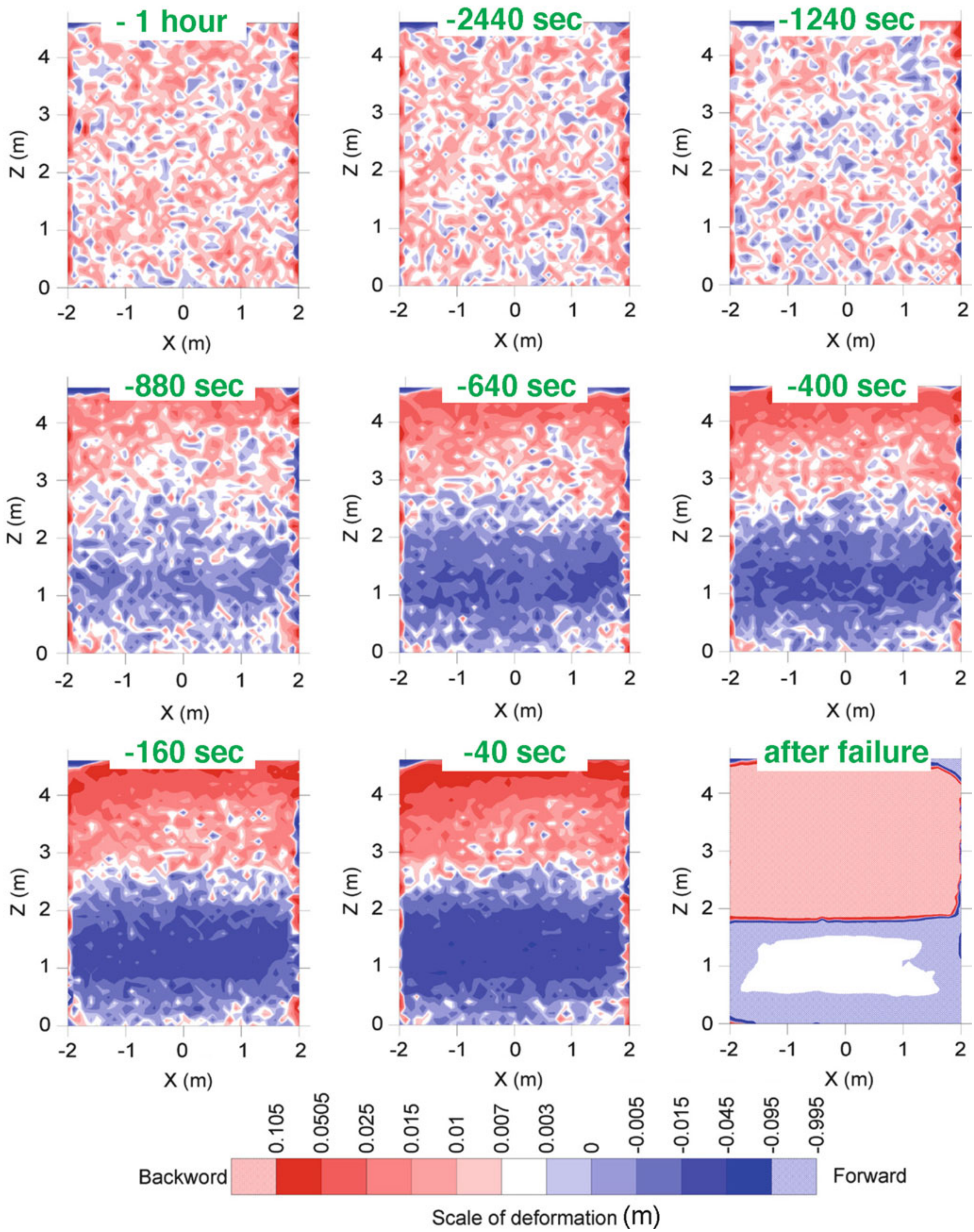

Fig. 5 Deformation measured in the experiment No. 4 projected to the X-Z plane

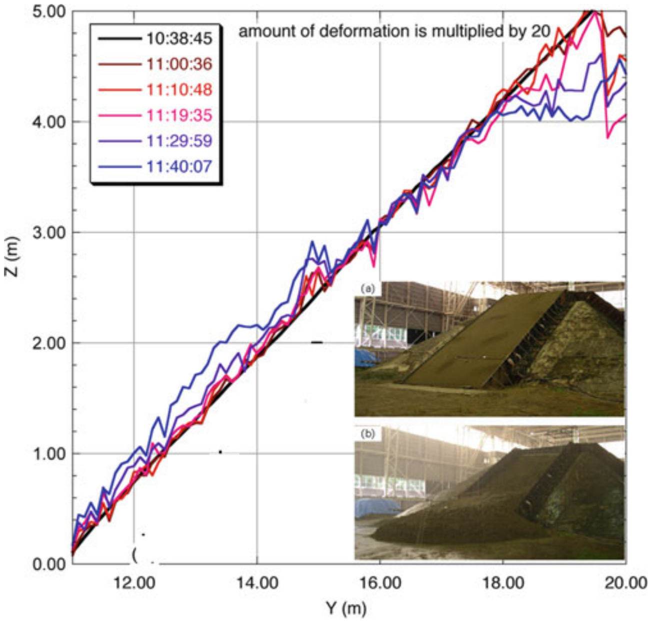

Fig. 6 Change in the cross section of slope with time. The amount of deformation is multiplied by 20

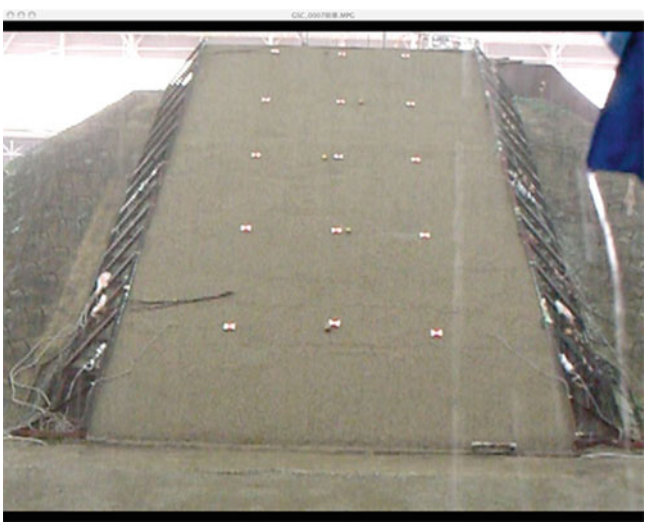

Fig. 7 Picture of model slope about 1 min before failure in experiment No. 4

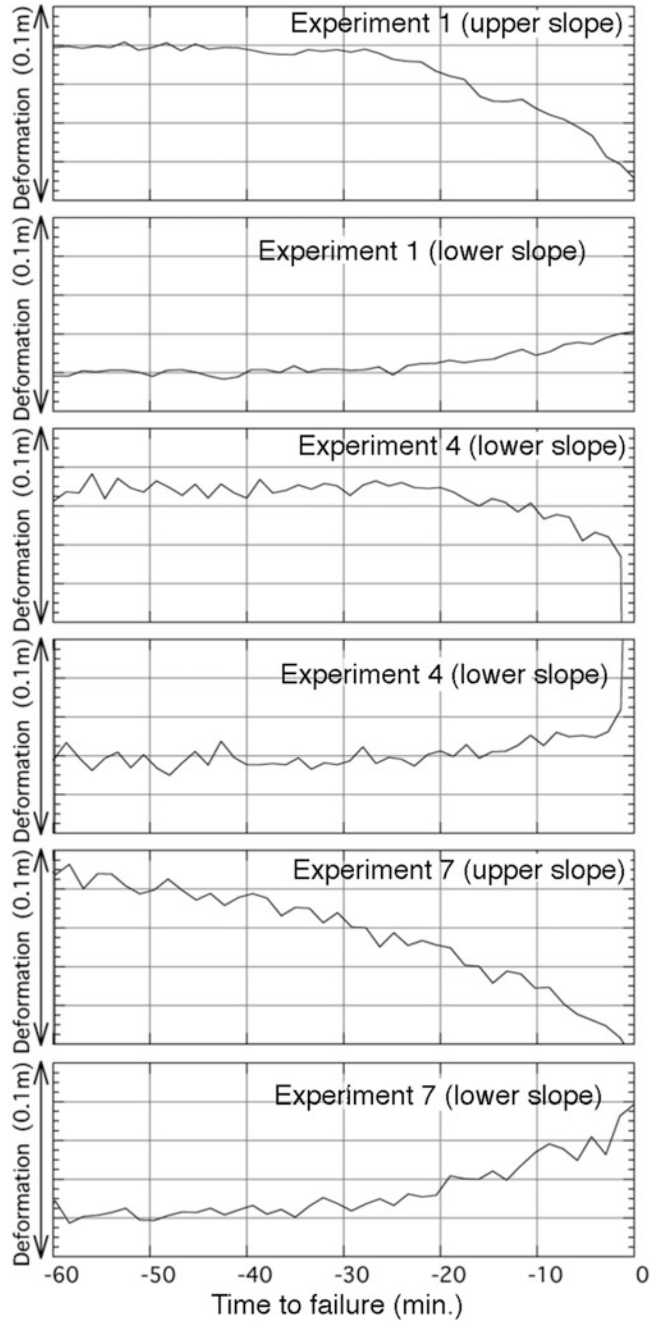

Fig. 8 Time series of deformations

Eight slope failure experiments including one carried out in a natural slope were performed. To improve the accuracy in the deformation, spatial stacking of data was adopted. Availability and reliability of the method was verified.

Progressive deformation in the upper part of slope and retrogressive one in the lower part were detected. Acceleration of deformation was observed clearly in retrogressive deformation and was not clear in progressive one. One possible reason for this difference is considered to be the spatial extent of progressive deformation is limited in a small region. To make more accurate measurements for such spatially sharp deformation, it is necessary to optimize resolution of measurement, robustness of measurement, scan rate and scan position.

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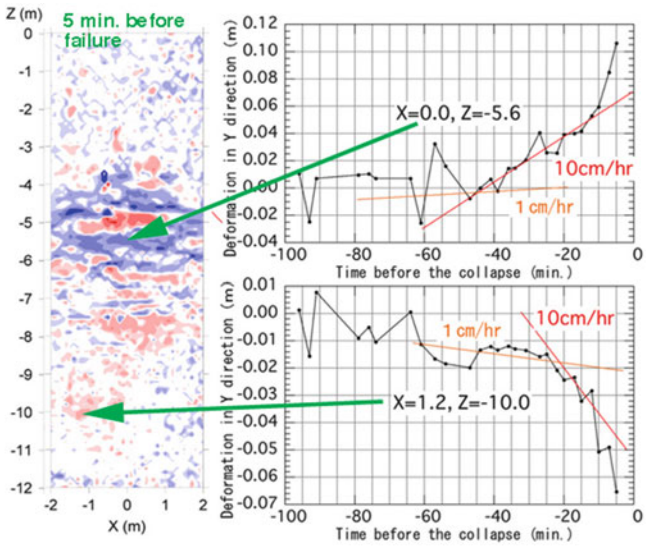

Fig. 9 Measured deformations in test No. 8

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