CHARACTREISTICS OF LABOR ACCIDENTS CAUSED BY SLOPE FAILURE DURING SLOPE CUTTING WORKS AND APPLICATION OF TILT SENSOR FOR MEASUREMENT OF SLOPE MOVEMENT

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***Abstract*— Sudden failure of slope during or just after the slope cutting works causes many accidents which sometimes takes the lives of workers. Lives of the workers and properties could be saved if early predictions of failure could be made. Many instruments have been developed to measure the movement of slope just before the failure. But most of them are either difficult to set up in the real field or are expensive to opt. In this paper, the characteristics of labor accidents caused by slope failure during slope cutting works in Japan are explained firstly. Then, the guideline for prevention of labor accidents caused by slope failure during slope cutting works is summarized. Finally, a case history of field measurement during slope cutting and nailing slope works is introduced.**

Keywords—labor accidents due to slope failure, monitoring, field measurement

I. INTRODUCTION

Mountains and hilly terrain account for 70% or more of Japanese national land area. Japan is located in one of the world's premier mobile belts and in the past, intense crustal disturbances had taken place, which formed precipitous features with weak and complicated geological structures. Moreover, the feature of Japanese climate, such as rainy seasons, typhoons with localized severe rain, and freeze-thawing in cold districts, could make landslides, cliff failures, rock falls, and avalanches of rocks and earth more likely to occur. However, the main transportation networks of railways and roads run below steep slopes in mountain areas or along the coastline, and urban development reaches the hilly zones and the bases of mountains. In addition, many houses are constructed close to slopes and cliffs. Under severe circumstances, such advanced and over-concentrated land usage poses risks of slope failure accidents.

There are two main causes of slope failure: 1) natural phenomena such as torrential rain or earthquakes, and 2) human-induced construction works. Human-induced causes lead to the labor accidents that take the lives of construction workers. Most of the accidents are either fatal or serious. Accidents involving death of workers are termed as fatal and those involving at least two worker casualties are termed as serious. Figure 1 illustrates the annual death toll of labor accidents caused by slope failure along with that of the whole construction industry and "Land collapses or Sliding debris, etc.". The annual number of fatal accidents in the whole construction industry had been constantly at around 1000 and gradually decreased since 1996. As for the target accidents of this paper, the number had fluctuated at

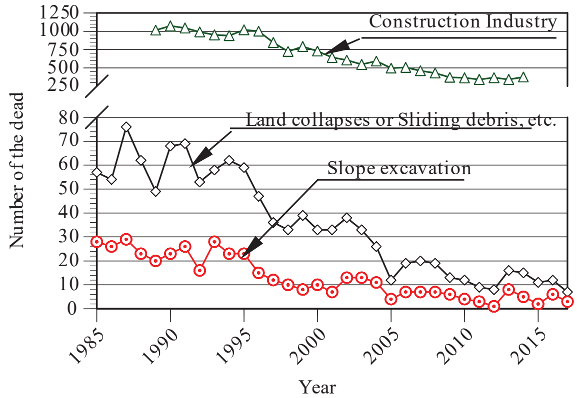


Figure 1 Annual number of labor accidents during construction works.

between 20 and 30 (except for 1992) until 1995 and decreased since 1996, which corresponds to the tendency of the whole construction industry.

When construction works are conducted for stabilizing the slope, there is a risk of slope failure. Most of the slope failures occur due to destabilization of a slope when the lower part of a natural slope is removed or a part of the slope is steepened during construction work, specifically during the slope-cutting work. In addition, no clear signal appears before slope failure, which leads to labor accidents. In many cases, slope failure occurs so suddenly [1],[2] that the workers have no time to evacuate from such sites and eventually casualties occur. However, it is possible to prevent such labor accidents caused by slope failure during construction works by taking elaborate measures in each phase of the construction, including planning, designing, and implementation. This is because most of such accidents are caused by man-made factors.

In this paper, the characteristics of labor accidents caused by slope failure during slope cutting works in Japan are explained firstly. Then, the notification from government named "Guideline for prevention of labor accidents caused by slope failure during slope cutting works" issued by Ministry of Health, Labor, and Welfare (MHLW), Japan in 2015, is summarized. After that, one of this monitoring methods where tilt sensors are used for the measurement of early response of failure just before the failure, is explained. Finally, a case history of field measurement during slope cutting and nailing slope works is introduced.

II. Characteristics of Labor Accidents Caused by Slope Failure During Slope Cutting Works

Various studies have been conducted on the characteristics of labor accidents caused by slope failure during slope cutting works in Japan. The first report of survey data of labor accidents in Japan was that of Mae et al. [3], who proposed that it is necessary to investigate the actual conditions (workers, environment, geology, etc.) of these accidents. Since then, classifications of various factors using labor accident data have been carried out by Itoh et al. [4], [6] and Toyosawa et al. [5]. Some important information is extracted from the survey results reported by Itoh et al. [4] and introduced in this chapter.

Figure 2 shows the relationship between the number of accidents and that of the workers presented at the time of the accident by bar graph, and a cumulative relative frequency of number of the accidents by line graph. This figure estimated that 84% of the accidents occurred in the construction projects with less than 8 workers on the construction sites. Since the number of workers can be related to the size of the contractor, the accident rate also corresponds to it as well and the possibility of accidents is higher with small-middle-sized contractor. This is probably due to the facts that the small-middle-sized contractors have problems of not only shortage of operation chiefs and/or workers with appropriate knowledge concerning safety and health management but also shortage of budgets for adequate safety equipment. Based on these findings, it can be concluded that the labor accidents are likely to occur in the small-middle-sized construction projects with small budgets and relatively short construction period conducted by the small-middle-sized contractors.

There are mainly two slope stabilizing construction methods which cause slope failure accidents: retaining wall method and slope protection method as shown in Figure 3. According to the investigation conducted by Itoh et al. [4], approximately 73% of the labor accidents occurred during slope stabilization construction works by the retaining wall method. In contrast, the number of accidents that occurred during works using the slope protection method was much smaller (approximately 16%). This is probably caused by the facts that the retaining wall construction generally includes the excavation of steep and unstable slope (Figure 4, [7]),

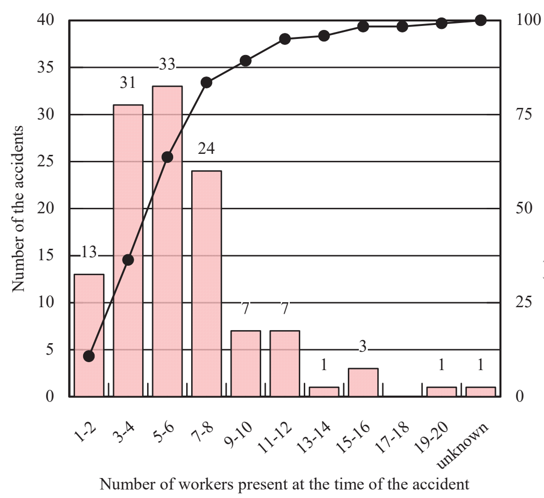


Figure 2 Number of workers present at the time of accident [4]

and various construction works such as assembling/dismantling of formworks (Figure 5, [7]), smoothing of base and so on have to be carried out in a narrow space between the retaining wall and the excavated ground. Therefore, it is too difficult and too little time for workers to evacuate from such narrow working space when slope failure suddenly occurs.

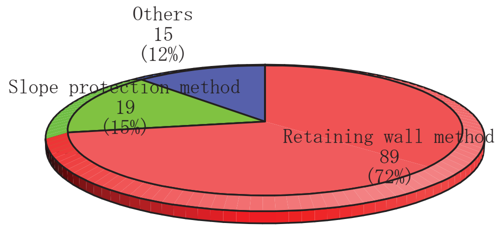


Figure 3 Classification of slope failure accidents by construction methods [4]

Figure 4 Accident site at concrete frame construction work [7]

Figure 5 Accident site at frame dismantling work [7]

III. GUIDELINE FOR PREVENTION OF LABOR ACCIDETNS COUSED BY SLOPE FAILURE DURING SLOPE CUTTING WORKS

A. JNIOSH report

In 2003, National institute of industrial safety (Currently known as National Institute of Occupational Safety, Japan, JNIOSH) has started a special research project to investigate the labor accidents caused by slope failure [8]. Based on these results, JNIOSH established the "Commission of inquiry on prevention of labor accidents caused by slope failure" under the leader of Prof. Kusakabe (Tokyo Institute of technology) with external experts as its members, which subsequently met on four occasions to discuss the matter [9]. It concluded that there are three factors to prevent the labor accidents due to slope failure as follows.

i) Shearing the Information among employers, contractors, and designers about labor accident risk assessment.
ii) Examination into the safety of construction site from the viewpoint of labor accident.
iii) Concept of effective construction method to prevent the possibility of labor accident caused by slope failure.

B. Guideline for prevention of labor accidents caused by slope failure during slope cutting works by MHLW, Japan.

After the publication of the JNIOSH report [9], "Guideline for prevention of labor accidents caused by slope failure during slope cutting works" was issued by Ministry of Health, Labor, and Welfare (MHLW), Japan in 2015. The outline of its chapters is shown in Table 1 [10]. In order to enforce the article 355 and 358 of Ordinance on Industrial Safety and Health (OISH) securely, this guideline was notified. The text of the article 355 and 358 of OISH is shown in Table 2. Making the persons concerned understand the safety of slope cutting works at each construction phase, it shows three types of checklists: design and construction procedures checklist, daily checklist, and ground deformation checklist. Furthermore, there is a troubleshooting sheet to report any trouble information and share it with the persons concerned, if any kind of trouble occurs.

Safety of the slope should be assured throughout the construction process based on the slope monitoring data such as ground deformations obtained from displacement sensors, high precision tilt-sensors, etc. Failsafe measures must be included in measuring and warning systems. Although many instruments for monitoring landslides have been developed to measure the movement of the slope just before failure, most of them are either too difficult to be set up at the construction site or too expensive for small-to-medium-scale slope cutting projects. Nowadays, however, many attempts are being made to develop new applications using the latest technologies such as sensing, computing, and communication technologies by Uchimura et al. [11], [12], Sawada et al. [13], Nishiyama et al. [14], etc. Flexible and innovative designs for monitoring and early warning systems for landslide disasters have been realized by providing accurate, low-cost, and low-power-consumption wireless equipment.

TABLE 1 OUTLINE OF CHAPTERS OF GUIDELINE [11]

Chapter	Contents
1	Aim and objective of this guideline
2	Scope of application
3	Definition of term
4	Necessity in cooperation with employer, contractor, and designer
5	Points to consider regarding designer
6	Points to implementation regarding contractor

TABLE 2 ARTICLE 355 AND 358 OF OISH, JAPAN.

Ordinance on Industrial Safety and Health
(Investigation on Work Place, etc.)

[Article 355] The employer shall, in the case of carrying out an excavating work of natural ground, and when it is liable to endanger workers due to collapse of natural ground, broken underground-installed objects, etc., investigate in advance the natural ground of the work place and its surroundings as to the following matters by boring or other suitable methods, and determine the time and procedures of excavation on the in conformity with what is known by the investigation and carry out by the determinations thereof:

(i) Landform, nature of the soil and conditions of strata.
(ii) Existence and conditions of cracks, water content, spring water and freezing.
(iii) Existence and conditions of underground-installed objects, etc.
(iv) Existence and conditions of high-temperature gas and vapor.

(Checkup)

[Article 358] The employer shall, when carrying out the work of open-cut excavation, take the following measures to prevent workers from dangers due to collapse of natural ground or fallen earth and rocks:

(i) To designate a checker and have the said checker carry out a checkup on the natural ground of the work place and its surroundings before commencing the work for the day, after a heavy rain and an earthquake of medium shock or heavier as to the existence and conditions of loose stones and cracks, and changes in water content, spring water and freezing.
(ii) To designate a checker and have the said checker carry out a checkup on the existence and conditions of loose stones and cracks, after blasting operations, at places where the said blasting operations have been carried out and their surroundings.

IV. CASE HISTORY OF MONITORING DURING SLOPE CUTTING WORKS USING HIGH PRECISION TILT SENSORS

A. *Specication of field site*

The site, shown in Figure 6, located in Shizuoka Prefecture, Japan, was for the project of restoration works for the road damages and the slope failure caused by the heavy rain in 2018. A top-down slope stabilization method was used for the project, which is one of the effective construction methods to prevent the possibility of slope failure and protection materials for the method are short reinforcing steel bars and shotcrete which can be obtained at lower costs than those for the ground anchor method.

Figure 6 installation of this site

Figure 7 IT tilt sensor (AKEBONO Brake Industry Co., Ltd)

TABLE 3 EXCAVATION AND NAILING PHASES DURING THIS CONSTRUCTION

Event	Date
Excavation 1st stage	5/10/2019
Nailing 1st stage	5/25/2019
Nailing 2nd stage	5/25/2019-5/28/2019
Nailing 3rd stage	5/31/2019
Excavation 2nd stage	6/7/2019
Nailing 4 stage	6/20/2019
Nailing 5 stage	6/25/2019

B. *Methodology*

Two types of measuring instruments were used for the project: one wire extensometer and two high precision tilt sensors. A wire extensometer (sensitivity of 0.1mm, SLG-100A, OSASI Technos Inc.) was used to measure the deformation of slope surface. A high precision tilt sensor (IT tilt sensor, AKEBONO Brake Industry Co., Ltd) was equipped with a MEMS tilt sensor as shown in Figure 7. This is used to measure positive and negative angles in both X and Y directions angles. Its measuring range was ±20 degrees with sensitivity of 1/100 degrees. The tilt sensors were placed along the cross section of the site and installed on the single pipes mounted in the holes made by hand augering to a depth of 0.5m. he data logger, powered by three double A (AA) battery, recorded the data at 1 min interval.

Excavation and protection were alternately carried out on the slope in steps to be stabilized from the top to the bottom. Table 3 shows the excavation and the nailing phases under the construction.

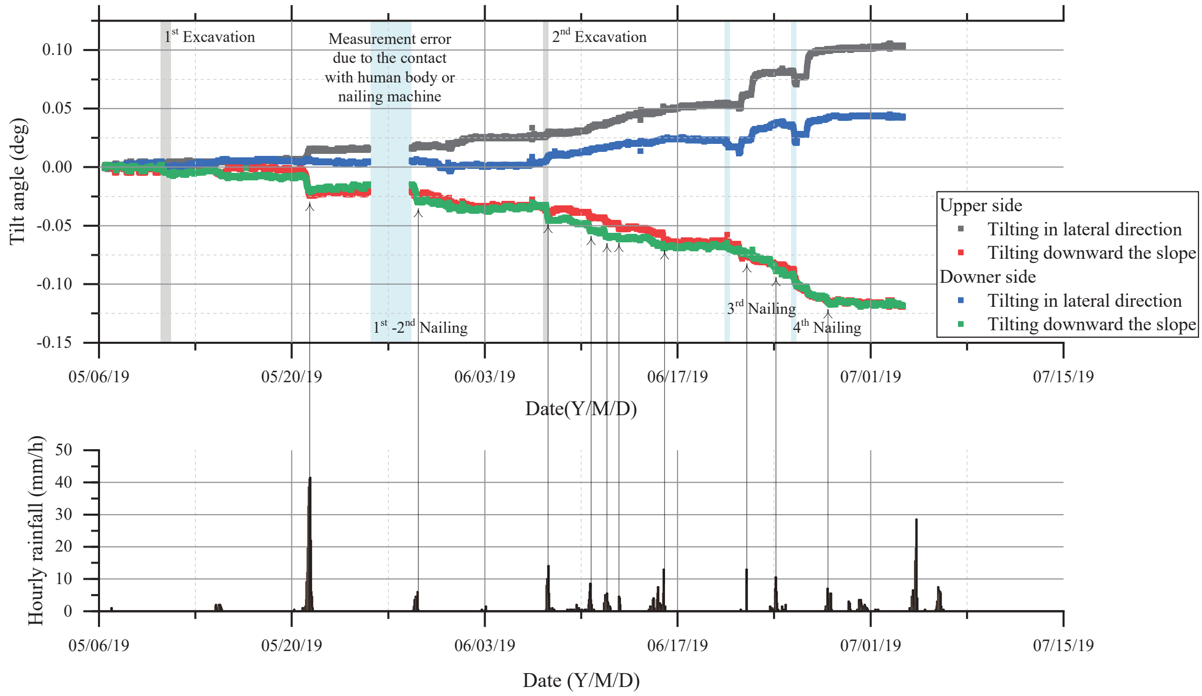
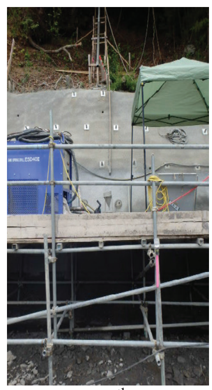


Figure 8 Time history of two tilt sensors and records of rainfall

Excavation 1st stage

Nailing 3rd stage



Naring 4th stage

Figure 9 Excavation and nailing phases during this construction

C. *Tilting behaviour*

A wire extensometer did not record a slope movement during the construction. Figure 8 shows the time history of two tilt sensors including some main events: excavation, nailing, rainfall, etc. Figure 9 shows the photos during and before the construction in this field monitoring site. Movements of X and Y directions were measured by each sensor. A quick tilting in the X and Y directions were recorded on May 21 when the precipitation was 236.5mm. Related to some events such as excavation and nailing (slope protection), gradual change was observed in the tilting angles. Direction of slope movement during various events could be measured by observing the very little movement: sensitivity of 1/100 degrees of tilt sensors along X and Y directions. Safety of slope can be assured throughout the construction process based on the slope monitoring.

V. Conclusions

In this paper, we described the characteristics of labor accidents caused by slope failure during slope cutting works in Japan, and the notification from government named "Guideline for prevention of labor accidents caused by slope failure during slope cutting works." Then, a case history of field measurement during slope cutting and nailing slope works was introduced. As a result, the following conclusions were drawn from this study:

i) 73% of the labor accidents occurred during slope stabilization construction works by the retaining wall method. The main reasons are that the working space was so narrow when conducting this method and the slope failures occurred so suddenly, that there were neither route nor time for the workers to evacuate from the construction site.

ii) In order to make the persons concerned understand the safety of slope cutting works at each construction phase, MHLW, Japan issued the guideline for prevention of labor accidents caused by slope failure during slope cutting works in 2015, where three types of checklists were introduced: design and construction procedures checklist, daily checklist, and ground deformation checklist.

iii) A case history of field measurement during slope cutting and nailing slope works was introduced. Direction of slope movement during various events could be measured by observing the very little movement: sensitivity of 1/100 degrees of tilt sensors along X and Y directions. Safety of slope can be assured throughout the construction process based on the slope monitoring.

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