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*The paper was published in the proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR 2019) and was edited by Jianye Ching, Dian-Qing Li and Jie Zhang. The conference was held in Taipei, Taiwan 11-13 December 2019.*

# Performance Evaluation Method for Slope Monitoring System Based on On-Site Visualization

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**Abstract:** It is popular to use slope monitoring system when a construction company cuts or fills the slope under construction. The monitoring systems are applied by the administrator of the project to ensure the safety of the workers near the slope at the construction site, with much tolerance of the confirmations of slope stability and displacement of ground. But if the slope is near the road or residential area, the administrator of the project ought to carry out risk management using these monitoring systems that ensure the safety of road transportation or safety of residences. Administrator reviews design of slope or takes isolation at the time of the emergency using the results of monitoring. At this time, if the performance of monitoring is low, the risk would increase as the administrator takes wrong choice. However, there has been no method that describes performance level of monitoring systems in the field of slope. This paper introduces a performance evaluation method for the slope monitoring system and assesses the efficiency of monitoring system based on On-Site Visualization considering the usability for the administrator.

Keywords: Performance evaluation; monitoring system; slope management; on-site visualization.

## 1 Introduction

The number of natural disasters and victims by natural disasters, especially by sediment-related disasters, shows a declining trend on a long term basis in Japan. However, there have been over a thousand events of debris flows, landslides, and slope failures on average for 10 years from 2007 to 2018. Particularly 2018 was the worst year from 1982. There were 3,451 sediment disasters and 161 persons got lost (Figure 1).

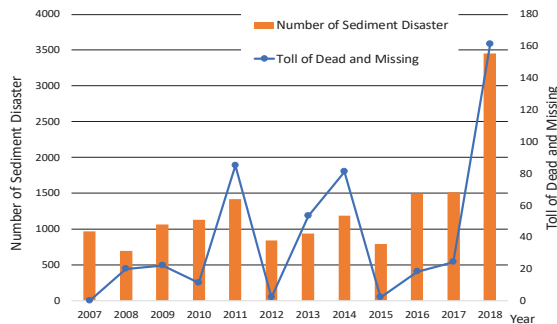


Figure 1. Number of sediment disaster and toll of dead and missing in Japan (2007-2018).

Figure 1 shows natural disasters at a scale of causing over a thousand deaths and missing persons occurred frequently from 1940s to 1960s in Japan, but the number of deaths and missing persons rapidly declined from late 1960s, and remained decreasing until it reached as low as several dozen or hundreds victims in the last two decades except for the great Hanshin-Awaji earthquake and the great east Japan earthquake, which caused over six thousand and 20 thousand casualties respectively. Nevertheless, the number of deaths and missing persons by sediment disasters has been among the highest of all disasters on a steady basis. Although Japan government provides substantial annual budget to implement measures to prevent and control sediment disasters in every part of the country, the investment in social overhead capital is still insufficient for implementing all measures in full

*Proceedings of the 7th International Symposium on Geotechnical Safety and Risk (ISGSR)*

Editors: Jianye Ching, Dian-Qing Li and Jie Zhang

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Published by Research Publishing, Singapore.

ISBN: 978-981-11-2725-0; doi:10.3850/978-981-11-2725-0.IS6-6-cd

scale, and that is why there remains many unsafe places with neither disaster prevention facilities nor smooth operation of evacuating activities before the occurrence of a disaster. For this reason, an approach combining structural and non-structural measures is adopted to implement infrastructure development in prioritized areas, or to establish a safe, correct and precautious evacuation system through self-help actions, mutual aid, and public assistance<sup>1)</sup>.

## 2 New Method for Slope Monitoring System

In recent years, the sensors, which were not seen before, have been utilized or under development in slope construction. Moreover, as for the target persons who receive the information and react, some efforts are made to expect more active actions, together with the understanding of the thinking of self-help and mutual aid. In this study, focusing on slope construction, a monitoring system is positioned as the actions with 3-stage process. By evaluating the performance of each process, a method for describing the performance of comprehensive monitoring system is proposed.

In this study, the monitoring system is defined as that achieved by the communication between 3-stage processes and their intervals, in terms of the cases that each process is independent and possible to be designed. In the evaluation of each process, Failure Mode and Effect Analysis (FMEA) is introduced as an approach to failure analysis for the evaluation of reliability of mechanical products etc. FMEA focuses on the defect mode in mechanical products composed of complicated processes. Hence, with the method for evaluation from the viewpoint of impact level and possibility of occurrence, it is possible to output the defects needed to solve in the order of priority of measures by the monitoring system composed of several processes.

## 3 Proposal for Method for Performance Evaluation of Monitoring System

### 3.1 Definition of function and performance of monitoring system

The function of monitoring system can be decomposed into the combination of the process of measurement, judgement and on-site data output, the internal communication in the system, the alarm output for the workers who are the final recipients and the related citizens, and the external communication by evacuation announcement. The scope of monitoring system is expanded to the cognition of final recipients, which could be considered as the generalized one. In the study, the performance of generalized monitoring system is defined. Because in slope construction the monitoring system and communication can be extracted as the independent function in many cases, it is thought the performance can be prescribed in each function and its value can be given as the evaluation. Furthermore, it should be considered that the performance of monitoring system is the comprehensive result of the performance of each process and communication. And the performance of monitoring system should be evaluated with its performance value.

Here, the performance value  $P$  for monitoring system can be defined as follows,

$$P = P_1^\alpha \times P_2^\beta \times P_3^\gamma \quad (1)$$

where  $P_1$  is the performance value of monitoring tool and measurement;  $P_2$  is the performance value of measuring value judgement;  $P_3$  is the performance value of result expression in the field;  $\alpha$ ,  $\beta$ ,  $\gamma$  are the factors determined by importance of each performance value. In Eq. (1), although  $P_1$ ,  $P_2$ , and  $P_3$  are independent processes, the monitoring system is thought to play the role when each process begins to work.

### 3.2 Indexation of performance value of monitoring tool and measurement

Performance value  $P_1$  of monitoring tool and measurement can be defined as follows by the evaluation based on the performance of extraction of proper subjects, selection of proper measuring device, and measurement with proper intervals

$$P_1 = P_{1-1} \times P_{1-2} \times P_{1-3} \quad (2)$$

where  $P_{1-1}$  is the performance evaluation value of the extraction of proper subject;  $P_{1-2}$  is the performance evaluation value of proper measuring device;  $P_{1-3}$  is the performance evaluation value of measurement with proper measuring intervals. Here, it is noted that  $P_{1-1}$ ,  $P_{1-2}$ , and  $P_{1-3}$  should be determined when all the performance takes effect. Extraction of proper subject is defined when introducing the monitoring system. That is, the smallest independent unit aggregation should be grasped that the unexpected situation is possible to happen, from the viewpoint of safety management of the construction site and slope needed to manage. The smallest unit should be recognized totally. The concept of unit in slope construction is illustrated as shown in Figure 2. Nearby structures, surrounding loading, and change of landform etc., can be chosen as the subjects that the unexpected situation might happen. It is necessary to conduct monitoring in order to ensure the safety of

slope. Therefore, these monitored subjects are set up as the unit respectively. For example, suppose that there are some problems with the independent 3 units, in the case necessary to monitor the movement of soil, ground water level change in each unit, there should be 6 units in total. That is to say, the monitoring of slope can be covered as long as there are 6 units monitored. Here it should be noted that, in the case that the small landslide exits in the large landslide, the large landslide would still take place though the small landslide unit has no change. We think this unit concept can be used any type of monitoring site.

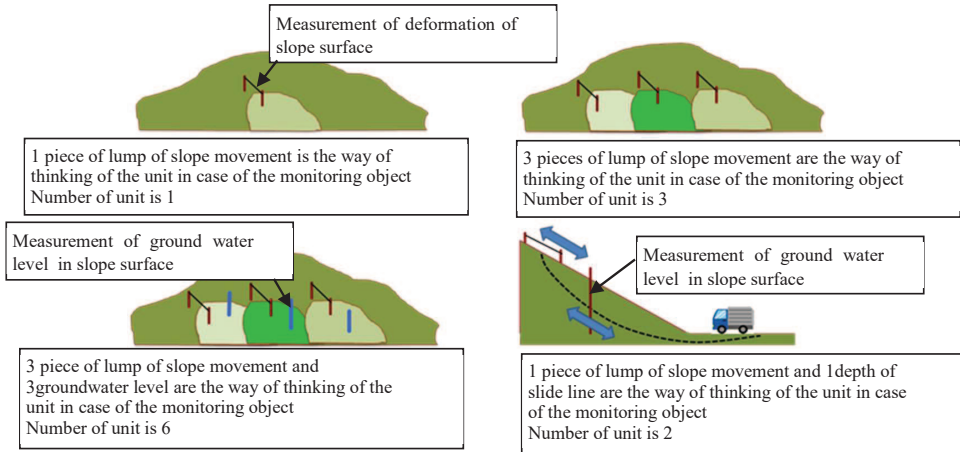


Figure 2. Method for count number of Unit.

### 3.3 Indexation of performance of measuring value judgement

Performance value  $P_2$  of measuring value judgement is defined as follows,

$$P_2 = P_{2-1} \tag{3}$$

where  $P_{2-1}$  is the performance value determined by the method with the reasonable threshold value in terms of safety.

### 3.4 Indexation of performance of result expression

Performance value  $P_3$  of result expression after the process of measurement and judgement is the necessary performance for the final recipients of information to react to evacuation etc., or take necessary measures to strengthen and conduct traffic control in predetermined time, corresponding to the performance of generalized monitoring system. The performance value is defined as follows.

$$P_3 = P_{3-1} \times P_{3-2} \times P_{3-3} \tag{4}$$

Where,  $P_{3-1}$  is the performance evaluation value of transmitting time before the time when information is necessary.  $P_{3-2}$  is the performance evaluation of the rightness of the information,  $P_{3-3}$  is the performance evaluation of recognition of the information contents, safety or not safety on this place on time.  $P_{3-1}$  was studied from the debris flows disaster at Gifu prefecture in 2014. Even administrator of local government received the information and the data from measurement tools on the river which was needed to make judgement of risk, they delayed the judgement and making information of evacuation. At the result, there was no information for the people who lived near the river, and many people got lost in the debris flows. On-Site Visualization device of result expression is connected measurement and judgement processes directly, administrator can decrease the time of communication within each process.  $P_{3-2}$  or  $P_{3-3}$  determines the result of self-help actions and mutual aid and public assistance against the disaster. If the process of  $P_{3-2}$  or  $P_{3-3}$  is wrong, the People who received the important information of risk can not make the action to help themselves.

Education and training to the action from disaster is important and keep high potential to the motivation against the risk. Maintenance and action for the education and training against the risk is responsibility for administrator even using the On-Site Visualization system.

Tables 1 to 3 show every performance contents under FMEA matrix. On this table, performance ratio is explained simple evaluation points by 4steps (1-4). After evaluating the performance of the slope monitoring system, administrator evaluate the total risk and estimate the cost of disaster response accurately.

**Table 1.** Index of performance value of monitoring tool and measurement ( $P_1$ )

$P_{1-1}$	$P_{1-2}$	$P_{1-3}$	Performance comments	Point
All systems are kept under control including a critical unit	The precision appropriate to the demand, a durable instruments are chosen	For the measurement time appropriate to the demand, a measurement interval is realized	Perfect	1
Many critical units are grasped, but is difficult to all systems	The precision appropriate to the demand, a durable instruments are chosen,; but over specifications	It is shorter than the measurement interval appropriate to the demand	Passing	2
The critical unit is not grasped	It is an instrument of the precision appropriate to the demand, but is not certain about the durability	It is longer than the measurement time appropriate to the demand	Improvement required	3
No Monitoring system	The instrument that the precision appropriate to the demand, the durability are not met is chosen	A measurement interval is not considered	Failure	4

**Table 2.** Index of performance of measuring value of judgement ( $P_2$ ).

$P_{2-1}$	Performance comments	Point
The threshold by a technical standard or a positive law learned by experience is decided	Perfect	1
The threshold is suggested by the analytic examination that modelled the field or a law learned by experience	Passing	2
Some kind of threshold is determined	Improvement required	3
There is not a judgment logic only by state indication	Failure	4

**Table 3.** Index of performance of result expression ( $P_3$ ).

$P_{3-1}$	$P_{3-2}$	$P_{3-3}$	Performance comments	Point
Other than urgent refuge, time necessary for an action for damage minimization is secured	Information is transmitted definitely	A meaning of the information is completely recognized definitely by education and coping of the indication method	Perfect	1
Minimum time necessary for urgent refuge is secured	Information is transmitted approximately definitely	A meaning of the information is recognized approximately definitely by education and coping of the indication method	Passing	2
The information comes by occurrence of disaster, but urgent refuge is not guaranteed	Something including the heterology comes	It is recognized that something is abnormal	Improvement required	3
Information has less time by occurrence of disaster	Information is not transmitted	A meaning of the information does not come	Failure	4

In this paper, most perfectly evaluation of performance will be taken 1point, next 2, and lowest evaluation will be taken 4point using FMEA method. And Performance of monitoring system ( $P$ ) is defined Eq. (1). Each index can be decided by subjectivity without quantifying method. Performance range ( $S$ ) is defined as below (Table 4). Each range ( $S$ ) should be ranked by statistical threshold.

**Table 4.** Performance range and meaning.

Performance range $S$	Performance comments	Contents
I	Perfect	The system which included guarantees security of the refuge enough including the property maintenance
II	Passing	The system which expected the mutual assistance, and guarantees security of the refuge at the minimum necessary for life maintenance
III	Improvement required	II is not certain, and needs improvement
IV	Failure	The system which urgently needed improvement or should give an alarm bell for construction, the continuation of the facilities maintenance plan

4 Applicable Confirmation on Site

This example is excavation of the soil slope running out of temporary construction in a road planned for the purpose of local site seeing by using cut and fill tunnel structure(Figure 3,4). As for the construction, slope A led and was performed. Because the outer layer exfoliated into a block form and repeated small collapse after July,2011, administrator of contractor reinforced it in mortar spraying and reinforcing rod insertion mechanics each time and carried out the devaluation of slope. At October,2011, Big collapse occurred from top of slope (Photo 1). The chart of measurement of ground surface deformation said observation data grew 3.8mm which was near the level to watch out when the day before collapse, and at 8:00am of the next day when the start of measurement from night interval, observation data grew up emergency level. After 7hours the slope has broken and monitoring system has lost (Figure 5). This result said  $P_{1-1}$  and  $P_{1-2}$  had no problem, but performance of measuring intervals  $P_{1-3}$  had a problem which could not catch the emergency signal from measuring devices.

The cause of this reflection, at the measurement plan for the slope B have made resettlement of the measuring devices and reviewed cover ability of independent unit. And have reviewed the measuring intervals  $P_{1-3}$ .

New intervals changed interval time to get data each 10 minutes include midnight, even before slope A have got data each 1hours and stopped might time (18:00pm-7:00am). And adopted On-Site Visualization devices, which leads no-time result expression when they judge emergency.

On April,2012, slope B damaged local deformation cause the heavy rain, On-Site Visualization devices(S2-2) caught the movement for tension side when it began to slide, and rapid judgement for the reinforce prevented expansion of the damage of slope B. At the result, a few drainage boring and reinforcing metal rods for the slope surface were treated. Then stability of slope was kept and construction program had finished under safety.

Now we can evaluate performance of the correspondence in these slopes with table 3 as below. On this evaluation we judge the result of performance value ( $P$ ) of slope A was class IV, and slope B was class II (Table.5). On this example, each value factors  $\alpha$  to  $\gamma$  are 1 because of insufficient data.

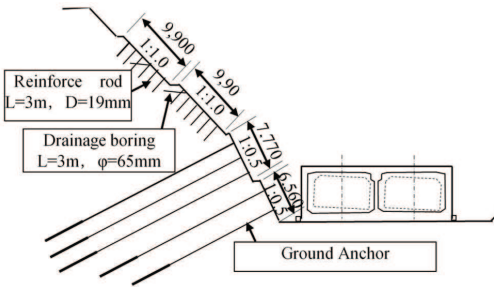


Figure 3. Cross section of tunnel and slope.



Photo 1. Collapse of slope A.

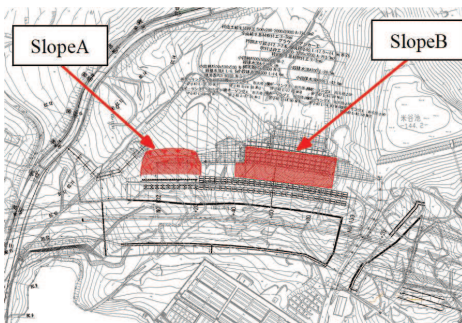


Figure 4. Location of tunnel and slope.

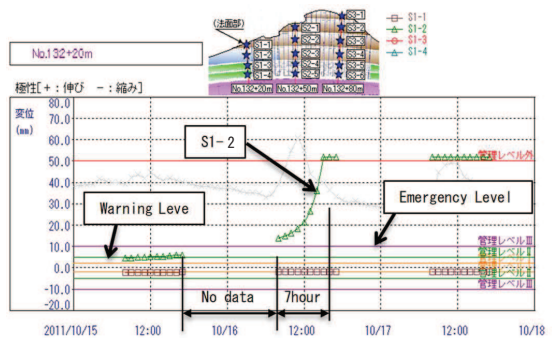


Figure 5. Monitoring data of Slope A.

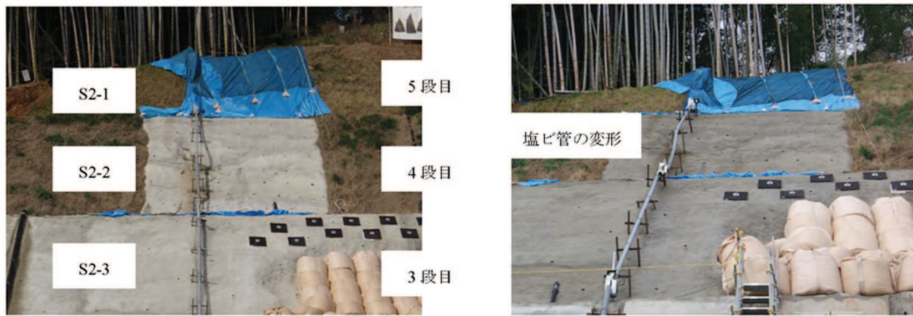


Photo 2. Deformation of slope B.

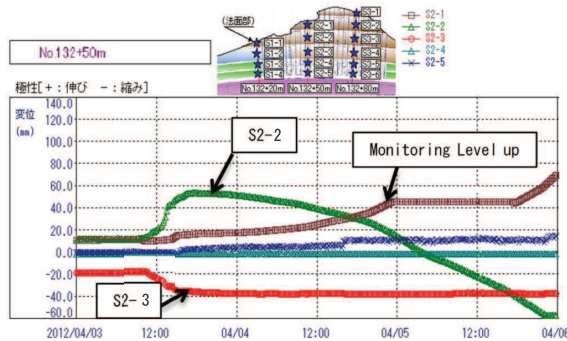


Figure 6. Monitoring data of Slope B.

Table 5. The review for Slope A and Slope B with FMEA method

Performance indicator		Slope A		Slope B	
$P_1$	$P_{1-1}$	6	2	1	1
	$P_{1-2}$		1		1
	$P_{1-3}$		3		1
$P_2$		1	1	1	1
$P_3$	$P_{3-1}$	16	4	8	2
	$P_{3-2}$		2		2
	$P_{3-3}$		2		2
$P$		96		8	
$S$			IV		II

5 Conclusion

In this study, we took recognition that we need the performance evaluation method in the management system of the slope construction, and this paper proposed and inspected the effectiveness about the simple and easy method to evaluate the performance of the measurement system which is used FMEA system.

If using this method, administrator can evaluate the performance of the measurement system for the slope construction about our three processes, measurement, judgement, indication On-Site and can clarify necessary improvement in the smallest procedure. Furthermore, we push forward collection and the study of the example and set the threshold of the performance rank corresponding to various slopes, can judge the safety rank as and can thereby evaluate it after having digitized performance.

References

Nomura, M., Akutagawa, S., Sato, T. (2017). A research proposal for estimating performance of a monitoring system in slope construction. *Journal of Japan Society of Civil Engineers F4 (Management of Civil Engineering)*, 73(4), 33-44.