Improvement of Prediction Accuracy of System of Real-Time Type Hazard Map of Slope Failure Disasters Caused by Heavy Rainfalls

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ABSTRACT: Japan has been vulnerable to landslide disasters caused by heavy rainfalls. The most common trigger of landslide disasters in our country is slope failure. In order to mitigate landslide disasters, it is important to evaluate the potential of slope failure events in space and time quantitatively and to develop the system that send the disaster information based on result of the evaluation. We have developed the system of real-time type hazard map of slope failure disasters caused by heavy rainfalls. In this paper, we focus on the depth of surface soil layer, which is one of the input parameters, and aim at a further improvement of prediction accuracy of the slope failure potential.

1. INTRODUCTION

In recent years, the assessment of landslide disaster risk has become a topic of major interest in many parts of the world. In Japan, the mountainous and hilly areas make up 70% of the total land area and weak geological materials are widely distributed. In mountainous areas, the local depopulation leads to inadequate forest management, thereby resulting in mountain devastation. With these natural and social conditions, our country has been vulnerable to landslide disasters caused by heavy rainfalls and earthquakes frequently every year, and landslide disasters account for about a half of the dead and missing people by natural disasters. In order to prevent landslide disasters, structural measures such as the construction of sabo facilities are necessary. However, new land development has increase the threat of landslide disaster and an enormous amount of money and time will be required to make all these hazard areas safe by only structural measures. Therefore, it is necessary not only structural measures but also non-structural measures to protect human lives and properties from landslide disasters. The most common trigger of landslide disasters in our country is slope failure (shallow landslide). These slope failures are often triggered during heavy rainfalls when pore-water pressures build up at the contact between the surface soil layer and the underlying bedrock. Rainfall-triggered slope failures are controlled by rainfall characteristics, namely intensity, duration and distribution, slope topographic attributes and soil properties such as thickness, density, shear strength and permeability. Therefore, in order to mitigate slope failure disasters, it is important to evaluate the potential of slope failure events in space and time by considering these parameters and to develop the system that send the disaster information based on result of the evaluation.

We have developed the system of real-time type hazard map of slope failure disasters caused by heavy rainfalls (Torri et. al, 2009). This hazard map is digital map that expressed slope stability evaluation result by Okimura and Ichikawa model (Okimura and Ichikawa, 1985) and slope failure dangerous area that changes hour by hour can be displayed by inputting the short-term rainfall prediction information. The validity of the prediction accuracy of our system was verified by using a past disaster case. As a result, our system can be considered moderately accurate as the system of real-time type hazard map. However, a lot of potential failure cell appeared, where slope failure did not occur actually. Therefore, it was necessary to improve the accuracy of the input parameter in order to attempt further accuracy improvement of the evaluation result. In this paper, we focus on the depth of surface soil layer which is one of the input parameters and aim at a further improvement of prediction accuracy of this system.

2. SYSTEM OF REAL-TIME TYPE HAZARD MAP

2.1 Composition of system

The composition of the system of real-time type hazard map is shown in Figure 1. First, how the groundwater level in the field area changes at time is calculated by using rainfall data, digital elevation model (DEM) and soil information such as the depth of surface soil layer and soil parameters. Next, how the degree of slope failure potential (safety factor) in the area changes at time is calculated by using the result of the groundwater level, DEM, soil information, and vegetation information. Finally, these calculation results displays on Geographic Information System (GIS) as the real-time type hazard map.

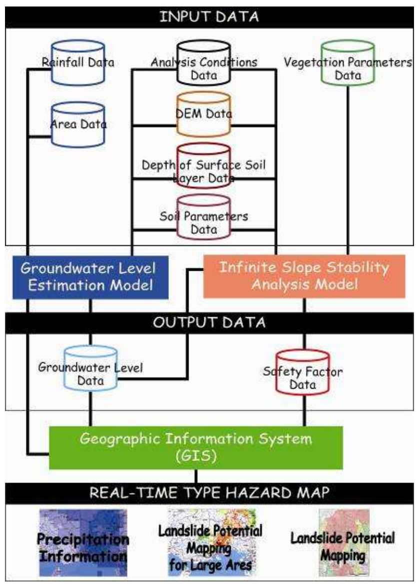


Figure 1. Composition of the system of real-time type hazard map

2.2 Evaluation model for the potential of rain-induced slope failure

Among many kinds of approaches to mapping the slope failure potential, one that seems to fulfil the necessities is the use digital elevation data and simple coupled hydrological and stability models to delineate those areas more prone to instability (Dietrich et. al, 1995). The model, used on our real-time type hazard map, was proposed by Okimura and Ichikawa (1985).

The field area is subdivided in grid units (pixels or cells), and by information extracted from the elevation model geometry for each cell is grasped. The slope failure potential is evaluated by means of numerical analysis based on two models: groundwater level estimation model and infinite slope stability analysis model of the Mohr-Coulomb failure law. The outline of each model is as follows.

2.2.1 Groundwater level estimation model

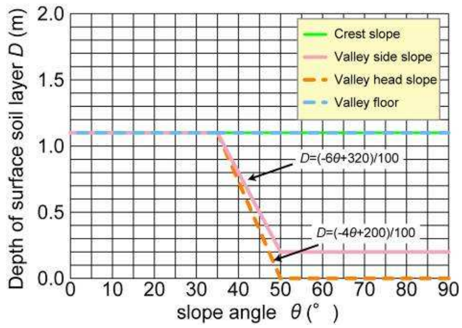
Groundwater level estimation model is obtained by applying a runoff model (Kawatani, 1981) to groundwater movement in the surface soil layer at each cell unit. The flow characteristics are given by the continuity condition and by Darcy's Law. Based on these equations, the groundwater level at each time, is obtained using the finite difference method with a rectangular DEM mesh (cell); this groundwater table at the center of a cell. This model is underpinned by a number of assumptions: 1) Rainfall water immediately infiltrates vertically and forms a groundwater table. 2) The hydraulic gradient is assumed to be the bedrock inclination obtained at the center of neighboring cells. The hydraulic conductivity is assumed to be uniform with depth. 3) The volume of outflow from a cell does not exceed the storage volume at that time. If the summation of the outflow exceeds the storage capacity, the storage volume is distributed in each direction in proportion to the calculated outflow volume. 4) The Hortonian overland flow is ignored and only subsurface flow is considered.

2.2.2 Infinite slope stability analysis model

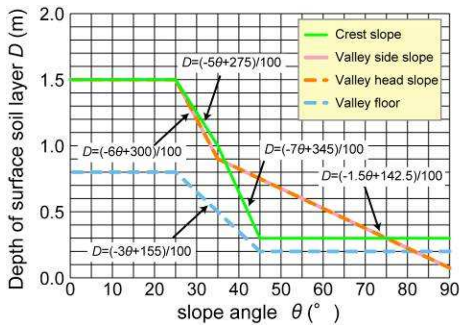
Infinite slope stability analysis has long been applied in investigations of slope stability, where the thickness of the surface soil layer is much smaller than the length of the slope and where the failure plan is approximately parallel to the slope surface. Based on infinite slope stability theory, the model calculates for safety factor, as function of soil mechanical properties, depth of surface layer and slope angle. The safety factor changes with time for each cell. The model also includes parameters for vegetation; one for root cohesion and other for tree surcharge as mentioned below. The slope angle of each cell is defined as the inclination of the plane trend surface (Davis, 1973).

3. PREDICTION MODEL OF DEPTH OF SURFACE SOIL LAYER

The depth of surface soil layer is a key parameter to control the result of groundwater level estimation model and infinite slope stability analysis model. It is important to consider the spatial variation of it in target area. In order to obtain the spatial variation of it, it is necessary to carry out field investigation such as portable penetration test (PPT). However, it is not realistic procedure to do it for the large area because it required tremendous amounts of money and time. Therefore, in general, a simple prediction model, by using the direct correlation of slope angle with soil thickness of limited sampling points, is often applied to estimate it. In our former research (Torri et. al, 2009), we used the relation of soil thickness with slope angle of cell, too. Specificity, in order to consider the formation process of the surface soil layer, the relation was set in each microtopographical unit as shown in Figure 2a). The validity of the prediction accuracy of our system was verified by using a past disaster case. As a result, our system can be considered moderately accurate as the system of real-time type hazard map. However, a lot of potential failure cell appeared, where slope failure did not occur actually. Especially, the potential failure cell appeared frequently like the row at the crest slope and valley floor. Therefore, it was necessary to improve the accuracy of input parameters in order to attempt further accuracy improvement of the evaluation result. In this paper, we attempt to modify the prediction model of the depth of surface soil layer. Specifically, the following corrections are added: 1) The relation into which the depth of surface soil layer is changed according to the slope angle is set in crest slope. 2) The value of the depth of surface soil layer in valley side and head slope is greatly set overall so that the mean of prediction and the average of the actual measurement may almost become equal. 3) The relation into which the depth of surface soil layer is changed according to the slope angle is set in valley floor. In addition, in order to consider that the soil layer is formed with the material of transported soils, cohesion of it is set small. Figure 2b) shows new prediction model based on the above-mentioned concept. Moreover, in order to consider the case that it applies to wide area, the automatic classification technique by using DEM is used as microtopographical classification.



a) Former model



b) New model

Figure 2. Prediction model of depth of surface soil layer

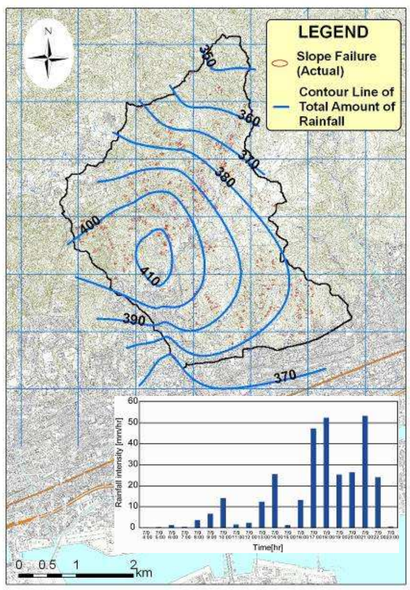


Figure 3. Location of the Sumiyoshi river basin, distribution of slope failures and rainfall record in the disaster

4 COMPARISON OF PREDICTION ACCURACY BY NEW AND FORMER MODEL

The comparison of heavy rainfall induced slope disaster hazard prediction accuracy, when new or former model is used as the prediction model of the depth of surface soil layer, is evaluated by the reproducibility of a past disaster case. Specifically, the system of real-time type hazard map is applied to the Sumiyoshi river basin (see Figure 3), in Mt. Rokko located in Kobe, Japan. A lot of slope failures were induced on July 9, 1967.

4.1 Input Data

4.1.1 DEM data

The size of cell is decided in consideration of the general size of slope failures in Mt. Rokko. In this study, we use 10m_DEM. 10m_DEM made from the elevation data measured by the Airlines laser measurement is used.

4.1.2 Depth of surface soil layer data

The microtopographical classification result and the prediction result of the depth of surface soil layer by new model are shown in Figs. 4 and 5, respectively.

4.1.3 Soil parameters and vegetation parameters data

Each soil parameters are set referring to the soil test by Okimura (1985) as shown in Table 1. Because vegetation parameters, c_r and q_0, were not able to be obtained, they were assumed to be zero.

4.1.4 Rainfall data

The rainfall data that caused catastrophic landslide disaster in Mt. Rokko on July 9, 1967 is used (see Fig. 3). As mentioned above, because we are taking the use of the short-term rainfall prediction information into consideration, we divide study area into mesh like the area size of the information dataset. Specifically, the Sumiyoshi river basin and the surrounding area were divided into 1km mesh (see Fig. 3), and the hourly rainfall intensity, obtained from isohyetal on each cell, is used.

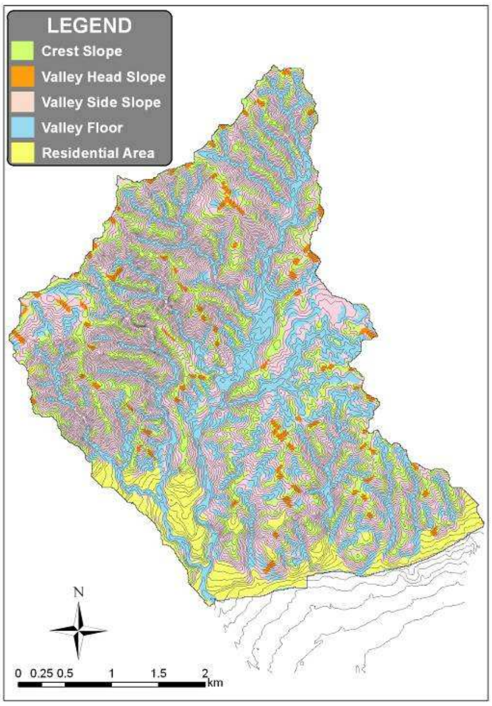


Figure 4. The microtopographical classification result

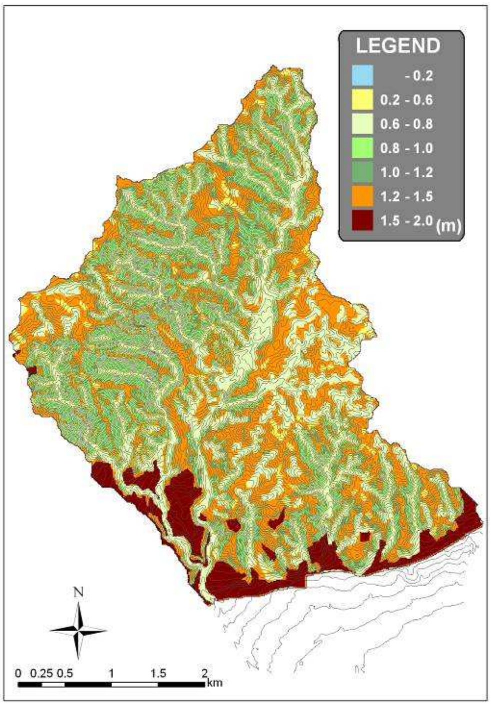


Figure 5. The prediction result of the depth of surface soil layer by using new model

Table 1. Soil parameters

Soil Parameters	Unit	Value
unit weight of the soil	kN/m^3	17.0
saturated unit weight of the soil	kN/m^3	19.0
effective cohesion	kPa	5.0
effective cohesion (valley floor)	kPa	3.0
effective internal friction angle	deg	31.0
effective root cohesion	kPa	0.0
tree surcharge	kPa	0.0
effective porosity		0.35
hydraulic conductivity	m/hr	2.0

4.2 Result of mapping of slope failures

The both prediction results of the degree of slope failure potential is shown in Figs. 6 and 7, respectively. The results of both are quantitatively compared by using two following evaluation indexes.

$$AR = (A+D)/(A+B+C+D) \times 100 \quad (1)$$

$$FAR = C/(A+B+C+D) \times 100 \quad (2)$$

Here, *AR* is accuracy rate (%), *FAR* is false alarm rate (%) and A,B,C and D (see Table 2) .

From Figure 6 and 7, the number of potential failure cell decreases greatly, where slope failure did not occur actually, by using new model and the number of it is almost halves. In addition, a lot of potential failure cells, which appear like the row, almost disappear (see Fig. 8). From Table 3, in using new model, it can be judged that the prediction accuracy improved from both evaluation indexes.

Figure 9 shows the relation between the average rainfall intensity on July 9, 1967 and the number of the potential failure cell. From this figure, the potential failure cells increase sharply at 20:00-22:00, and this result is in good agreement with disaster report; "The landslide disaster occurred until about evening - night". Moreover, it is predicted that the collapse has not been generated at a small rainfall of beginning.

From these results, our system can display the information of slope failure hazard that reflects the latest predictive rainfall data and it can visually be recognized whether or not the degree of slope failure potential has risen by using this system several hours ago.

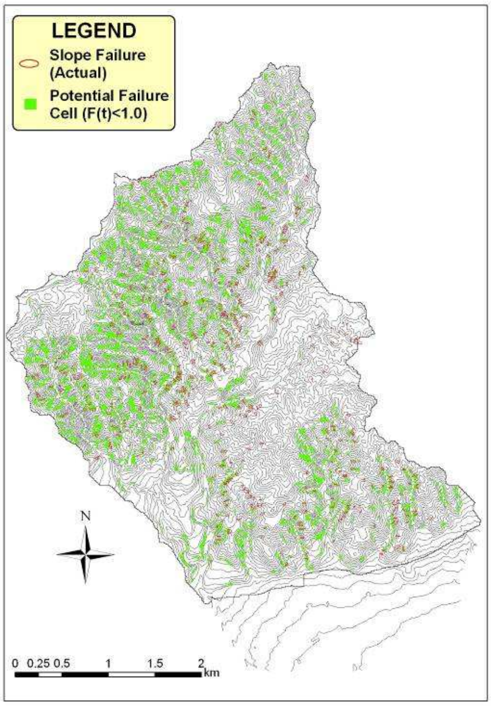


Figure 6. Distribution map of slope failures of actual vs predicted by using former model

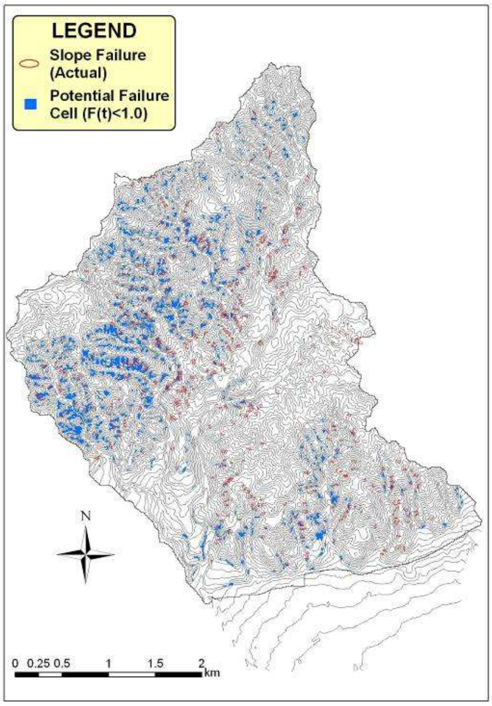


Figure 7. Distribution map of slope failures of actual vs predicted by new model

Table 2. Categories for evaluation index

		Predict	
		Unstable **$F(t)$<1.0**	**Stable** **$F(t)$>=1.0**
Actual	Unstable	*A*	*B*
	Stable	*C*	*D*

A, *B*, *C*, *D*: number of cell on each category

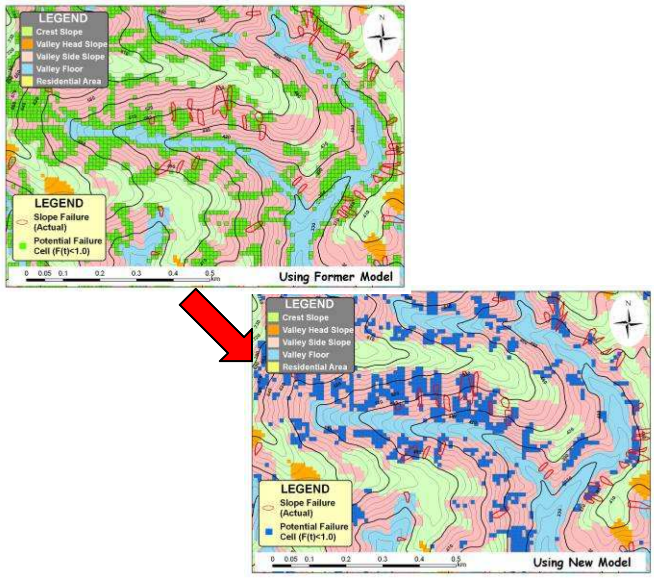


Figure 8. Changing in appearance position of potential failure cell

Table 3. The calculation result of evaluation parameters

	New	**Former**
AR	94.2%	91.1%
FAR	3.3%	7.0%

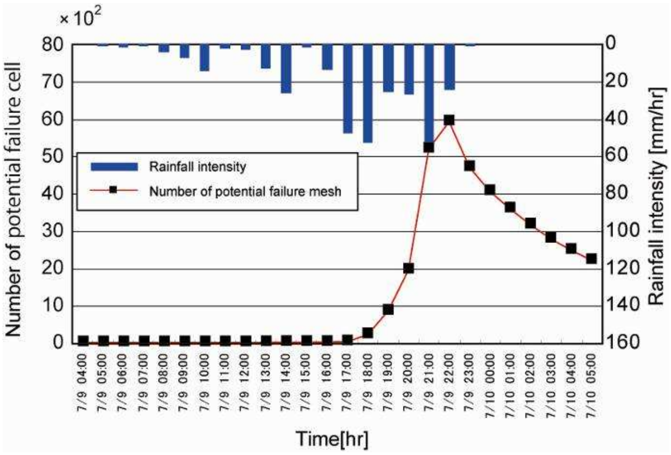


Figure 9. Transition of the number of potential failure cell

5. CONCLUSION

In this paper, we modified the prediction model of the depth of surface soil layer in order to improve prediction accuracy of the system of real-time type hazard map of slope failure disasters caused by heavy rainfalls. As a result, the number of potential failure cell decreased greatly, where slope failure did not occur actually, by using new model and a lot of potential failure cells, which appear like the row, almost disappeared, that was the problem of former models. And, the prediction accuracy improved as compared with using former prediction model.

As future tasks, it is necessary to verify applicability to another region and geology. In addition, it is necessary to examine the expression technique of the degree of slope failure potential and transmission of disaster and emergency information for to aim at practical use.

6. ACKNOWLEDGMENT

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