

Relationships between Morphology Aspect and Slope Failure Probability by Using 3D Slope Stability Analysis in Yamasubaru Sub-basin, Miyazaki Prefecture, Japan

Hendra Pachri ⁺, Yasuhiro Mitani, Hiro Ikemi, and Ryunosuke Nakanishi

Graduate School of Engineering, Kyushu University, 744 Motooka, Fukuoka, 819-0395 Japan

Abstract. Recently, the assessment of probabilistic slope failure hazard at basin scale is a one part of decision analytical approach to slope failure risk assessment and management. This paper demonstrates the integrating of deterministic and statistical approach to assess the performance of the predicted results based on a factor of safety (FS) of whole slope units. Therefore, the spatial probabilistic modeling of slope failures using a combined Geographic Information System (GIS), 3D slope stability analysis, and Monte Carlo simulation approach is applied in the slope failures-prone area of Yamasubaru sub-basin, Miyazaki Prefecture. As the predicted results have been evaluated by the actual data of slope failure caused by the typhoon 14 in 2005, the validity of this model has shown enough. Therefore, the best value shows a highest of the factual slope failure occurred in SU04 for $FS \leq 1.5$, about 93.07 %. Furthermore, the relationships on between of morphology and the probability of slope failure shows a varying of the morphology aspect classes are the causal factors in determining the occurrence and distribution of slope failure predicted.

Keywords: Slope Failure, GIS, 3D Slope Stability, Morphology.

1. Introduction

In the Mimikawa River Basin, Typhoon No.14 was brought about a severe sediment attributable to mountain slope failures in Miyazaki Prefecture, Japan in September 2005. An awareness of the potential risk from sediment disasters is needed to prediction the occurrence in the basin in future. Therefore, assessment of probabilistic slope failure hazard at basin scale is a one part of decision analytical approach to landslides risk assessment and management. Landslides susceptibility mapping has shown a great deal of importance for suitable urban development [1]. Numerous efforts have been devoted by many researchers to develop landslide susceptibility maps in over the last three decades [2]. These maps describe areas where landslides are likely to occur in the future and classify those areas into different susceptibility zones from very low to very high susceptible zones.

The engineering analysis of landslides risk has essentially two components, the probability of occurrence and the resulting consequence. The deterministic approach to slope failure usually requires of a factor of safety, from geometry, shear strength and pore pressure [3]. The use of two- or three-dimensional raster-based GIS currently requires the transfer of slope data and hydrologic data from a GIS to external slope stability program. A new GIS grid-based 3D deterministic model has been developed, and only one stratum has been considered for landslide hazard mapping [4]. In order to assess the landslides and potential of debris flow hazard of the mountainous region, the study of historical landslides is critical. Therefore, the study of the mechanisms and properties of past slope failure is a valuable reference for assessing the future slope failure hazard in its adjacent or geotechnical similar area.

Here, we demonstrated the implementation of the Frequency Ratio (FR) model with the support of the 3D slope stability tools to assess the factor of safety (FS) of the whole slope units based on sub catchment and

⁺ Corresponding author. Tel.: + 81-80-3986-2908; fax: +81-092-802-3396.
E-mail address: hendrapachri@hotmail.com.

produce a reasonable cohesion, friction angle, and unit weight values. The critical 3D slope stability simulation gave the results about the relationship on between morphology aspect and geotechnical parameters. The FS values have become important to explain the susceptibility of landslide. In this analysis is concern for three parts of FS value ranges, such as $FS \leq 1.0$, $FS \leq 1.2$, and $FS \leq 1.5$. Furthermore, the observation of relationships between distribution of slope failures in the past and probability of the occurrence slope failure based on 3D slope stability analysis is carried out to determination the best-fit model for each geotechnical parameter values. Moreover, the relationships of between on slope stability results and morphology aspect (slope angle, elevation, and slope angle) have been analyzed to obtained more knowledge about morphology control in slope failure susceptibility.

Table 1: Geotechnical values on 3D Slope stability simulation.

No	ID Geotechnical values	Lithology	Cohesion (kN/m ²)	Friction angle (°)	Unit weight (kN/m ³)
1	SU01	Shale	35	17.5	18
2	SU02	Sandstone	35	15	18
3	SU03	Sandstone	35	22.5	18
4	SU04	Shale	20	17.5	18

2. Data and Methodology

2.1. Slope Failure in Yamasubaru Sub-basin

In this study, slope failures location map is prepared based on of the previous researches conducted on the area and aerial photographs. In addition, field work has been carried out to map recent landslides. A total of 923 landslides were mapped in the area. The instability factors were chosen based on the above-mentioned studies which were carried out on the study area, the bibliographical review and from field investigations.

2.2. Spatial Database Preparation by Using GIS and Remote Sensing

Digital Elevation Model (DEM), which represents the land surface terrain of the surface terrain of the area, was generated with a 10 m grid from the ASTER GDEM. Using this DEM, the three topographic parameters, slope gradient map, slope aspect map and elevation map were automatically derived and convert into ASCII data. From the lithological point of view, nine units were classified from seamless digital geological maps of Japan (1:200.000) obtained from Geological Survey of Japan, AIST 2005 [5]. Geotechnical data including cohesion, friction angle, and unit weight, were derived from the laboratory test of previous studies conducted on the area and literature review.

2.3. 3D Slope Stability Analysis

The availability of the geographical information system (GIS) can facilitate the use of a deterministic or a probabilistic geotechnical approach as part of a methodology on assessment of slope failure hazard. Regarding the attributing factors, the assessment of slope failure susceptibility is carried out by using the Slope Failure Analysis System (SFAS) GIS. Based on the model of slope stability analysis and Monte Carlo simulation, the critical slip surface and minimum 3D safety factor can be obtained for each slope unit [6].

A GIS-based hydrologic analysis and modelling tool, Arc Hydro tool is employed to draw dividing lines for forming slope units automatically. In this study, the unit size of watershed subdivision is 500, obtained from digital elevation model (DEM) data. By inputting these parameters into the model of slope stability, the value of a safety factor or failure can be obtained. Based on Hovland's (1977) model, the 3D safety factor can be expressed as following equation:

$$F_{3D} = \frac{\sum_J \sum_I (cA + W \cos \theta \tan \phi)}{\sum_J \sum_I W \sin \theta} \quad (1)$$

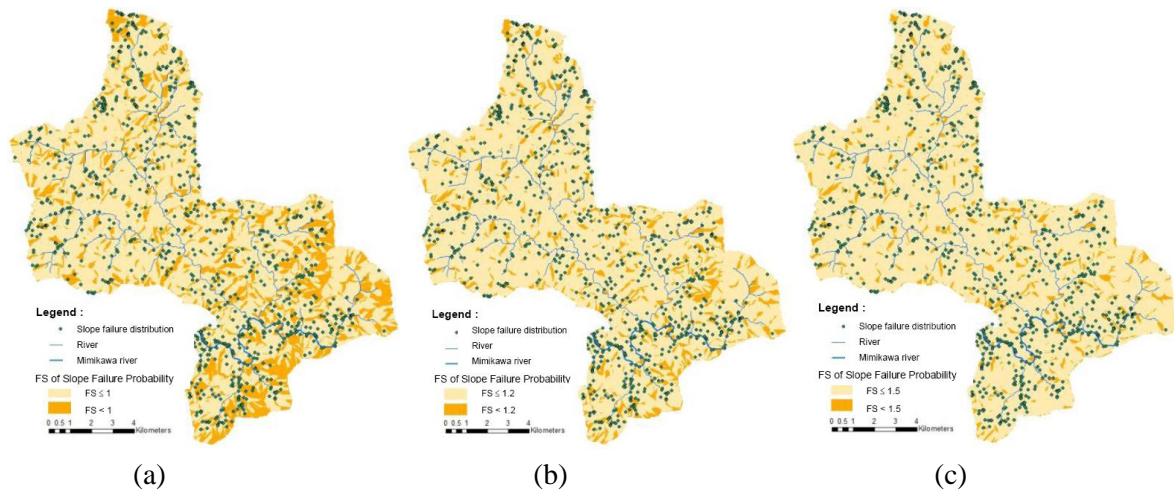


Fig. 1. The slope failure probability map produced by 3D slope stability analysis. (a) $FS \leq 1$; (b) $FS \leq 1.2$; and (c) $FS \leq 1.5$.

Where, F_{3D} : the 3D slope safety factor; W : the weight of one column; A : the area of the slip surface; c : the cohesion; ϕ : the friction angle; θ : the normal angle of slip surface; and J, I : the numbers of row and column of the fixel in the range of slope failure. In this case study, the sliding surface is assumed to be confined to the surface layer. The thickness of the landslide body is set in the range of 5-30 m, which is the same as the depth of surface layer. Slope angle that less than or equal value take as flat is 5° . The final critical 3D safety factor is the minimum safety factor of 50 times random calculations.

3. Results and Discussions

3.1. Slope Failure Probability of Yamasubaru Sub Basin

The analysis of slope failure probability analysis has been simulated that related to geological information, geomorphologic aspect, geotechnical parameters for obtained the relationships between morphology aspect and slope failure probability. Table 1 shows the geotechnical values based on the results of small catchment analysis in Yamasubaru sub-basin. The detail of a slip surface is uncertain because the lack information that obtained from a previous report. To detect the 3D critical slip, the search is performed by means of a minimization of the 3D safety factor using the Monte Carlo simulation.

The 3D slope stability analysis clearly indicated that the spatial and temporal distribution of slope failure probability is strongly controlled by the geotechnical values and by surface topography through slope angle, elevation, slope aspect (Fig. 1). Here we built upon the results of the statistical analysis to explore the utility of spatially distributed by deterministic of slope failure probability. In this study, the criteria of slope failure probability have been divided into three classes based on a factor of safety values, such as (1) $FS \leq 1.0$; $FS \geq 1.0$, (2) $FS \leq 1.2$; $FS \geq 1.2$, and (3) $FS \leq 1.5$; $FS \geq 1.5$. The Fig. 1 is representative of the fourth of 3D slope stability simulation results by comparing of slope failure evidence that SU04 is the large number of slope failure probability, such as $FS \leq 1.0$, $FS \leq 1.2$, and $FS \leq 1.5$. The results attest that the total number of slope failure predicted increases when the limit of Factor of Safety (FS) increases about 3927, 4456 and 4682 of 5830 slope unit at whole area. Moreover, the SU01, SU02, and SU03 are representing geotechnical values of the whole area in simulation. These results show the influence of cohesion (c) and friction angle (ϕ) values that the number of slope failure predicted increases when cohesion and friction angle values decrease.

3.2. Evaluation of the Slope Failure Probability Map

Spatial effectiveness of the susceptibility map will be checked by the highest percentage of the actual slope failure by comparing the predicted unstable site. The rate graph will be created for varying of geotechnical values, and their percentage will be calculated. The rate explains how well the model and controlling factors predict the landslide. The model with the highest percentage is considered to be the best. Fig. 2(a) shows a representative the evaluation of slope failure predicted that produced by 3D slope stability analysis on varying of geotechnical values for each factor of safety classes. In fact, the slope failure occurred in the SU04 value was higher than other values, where the calculated probability can be over 75%. In order,

the graph shows a highest of the actual slope failure occurred in SU04 for $FS \leq 1.5$, about 93.07%. The total number of slope failure is increase, when the value of a factor of the safety increases.

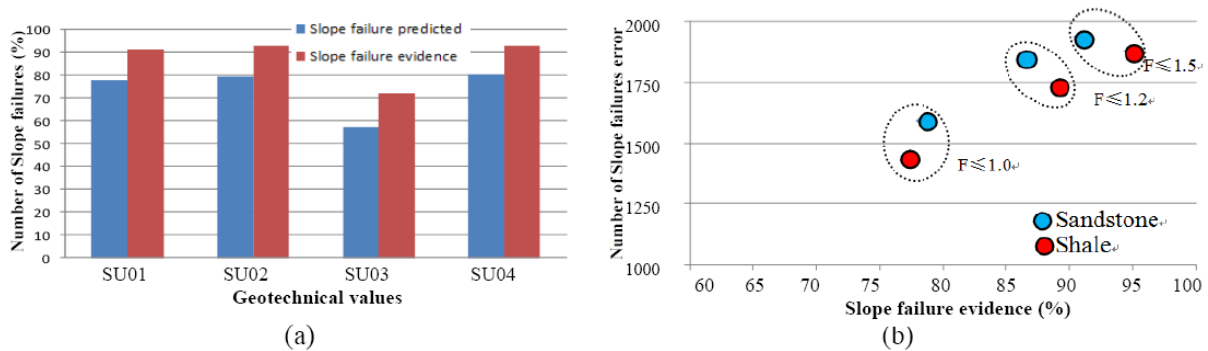


Fig. 2. Evaluation of slope failure probability that produced by 3D slope stability analysis. (a). Percentage of the slope failure ($FS \leq 1.5$); (b). The evaluation was checked by calculate the error of slope failure.

Moreover, the evaluation of spatial effectiveness was also checked by calculate the error of slope failure. The error of slope failure is the number of slope failure predicted minus the number of actual slope failure. These results are obtained from all the varying of geotechnical values. In this study, variety scenarios were described two assumptions. Firstly, the using each of values for whole area, and secondly, by divided the geological unit in two geotechnical values, such as shale and sandstone. These results show the error of slope failure strongly related to slope failure predicted and the factual slope failure. The error of slope failure is increase when the number of the factual slope failure is increase. Therefore, the evaluation by use of each geotechnical values show the relationship is linear, that the slope failure evidence will increase when the error slope failure is increase. In particular, the evaluation of spatial effectiveness by divided the geological unit is performed for three factors of safety classes, such as 1.0, 1.2, and 1.5 (Fig. 2(b)). The $FS \leq 1.2$ and $FS \leq 1.5$ of shale rock show a good relationship that the percentage of actual slope failure is increase when the error of slope failure is increase.

3.3. Relationships between Morphology Aspect and Slope Failure Probability

Fig. 3 shows the frequency distribution of slope failure predicted of SU02 as represent a sandstone rock and SU04 as represent a shale rock for the three topographic attributes (elevation, slope aspect, and slope angle). The following is relationships of morphology aspect and slope failure predicted, such as:

- Elevation: the maximum of the number of slope failure predicted the both SU02 (sandstone) and SU04 (shale) on 600–700 m. However, in the SU02 show to almost increase on 100–700 m when the factor safety class increase, and is decrease of 700 m to over than 1000 m. Moreover, in the SU04 shows the number of slope failure predicted is decrease on 100 – 700 m when the factor safety class is increase, and is decrease of 700 to over than 1000 m (Fig. 3(a) and Fig. 3(d)).

- Slope aspect: the both of the slope aspect of SU02 (sandstone) and SU04 (shale) show the number of slope failure predicted of the North (N)–North East (NE) and the South (S)–North West (NW) directions are increase. However, the North East –South (S) direction is decrease. Furthermore, each slope aspect classes show the different of the number of slope failure predicted when the factor of safety classes is increase (Fig. 3(b) and Fig. 3(e)).

Slope angle: the number of slope failure predicted is increased when the slope angle classes are increase on $10^\circ - 40^\circ$. However, the slope angle is decrease when it is over than 40° . Moreover, the both SU02 (sandstone) and SU04 (shale) show the different pattern of maximum of the number of slope failure predicted on $20^\circ - 30^\circ$ when the factor of safety classes is increase (Fig. 3(c) and Fig. 3(f)).

4. Conclusions

The map of slope failure probability that preferred in the frame of the present work is a step forward in the management of sediment disaster in the Mimikawa River. The 3D GIS analysis and statistical methodology have demonstrated to be a suitable tool when the relationships between slope failure and causal factors have to be analyzed. A result is achieved by the inspection of the frequency ratio that determined the

role played by influencing factors on the investigated phenomenon. The sandstone and shale geotechnical values correspond to area that is particularly prone to slope failure predicted that related to the morphology aspect. Moreover, the influence of the changes of unit weight value will be considered in the analysis in the future.

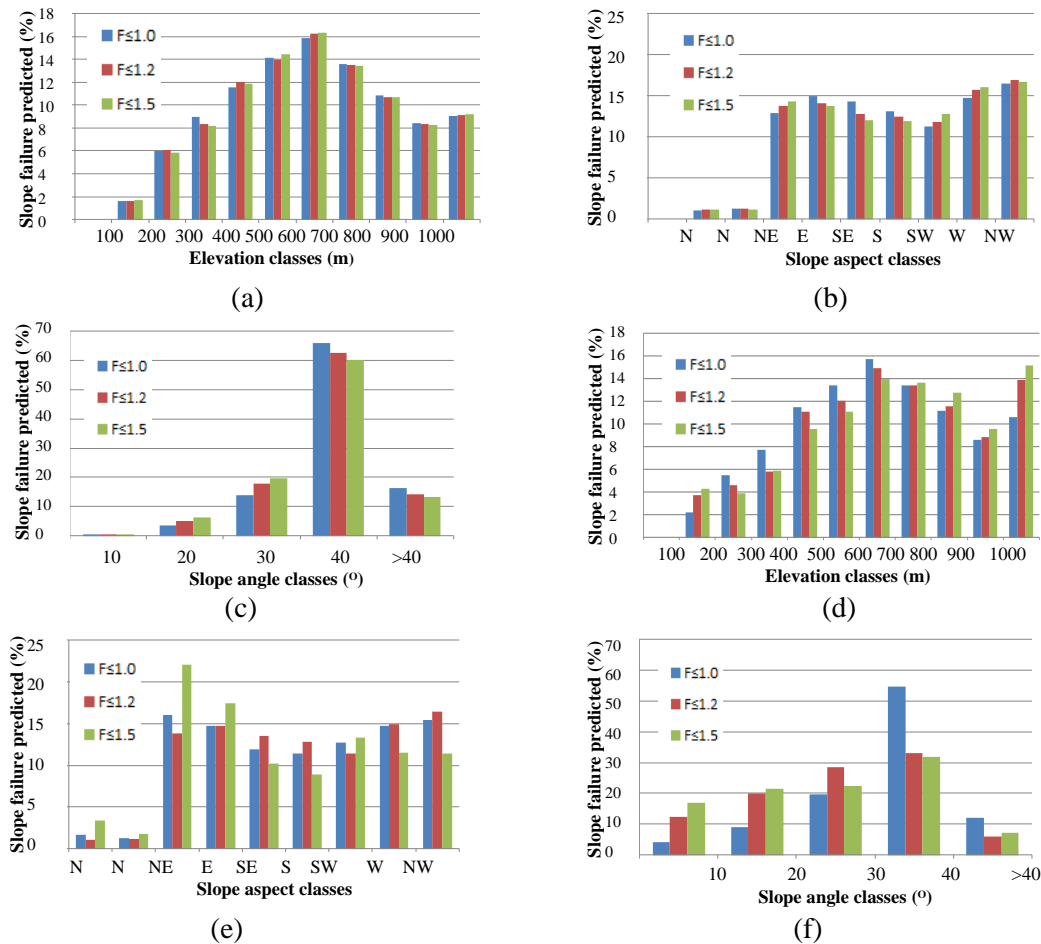


Fig. 3. Relationships between morphology aspect and slope failure distributed by influenced of geotechnical properties. The figure shows SU02 class (a, b, and c) and SU04 class (d, e, and f).

5. Acknowledgements

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