AN ATTEMPT TO CONSTRUCT SLOPE HAZARD MAP BASED ON SPATIAL DATA OF PAST FAILURES

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ABSTRACT

"Slope hazard map" expressing the information on susceptibility to landsliding is strongly required in mountainous countries. If distribution data of past slope failures are available, they may give valuable information on susceptibility to future failures in each location. Then, we have attempted to construct slope hazard maps on the basis of the distribution of past slope failures occurred just after intense rainfall in Japan.

The distribution map of slope failures was converted to digital data through high resolution scanning. Statistical analyses were made on the basis of these digitized data. The occurrence ratio of slope failures, which is defined as the ratio of the area of failure to total area of same slope angles, tends to increase with slope angle. The relation is expressed by a simple linear equation, $r = a\theta + b$. Here, r and θ are the occurrence ratio and slope angle, respectively. Coefficient "a" is high in the area of schistose rocks and volcanic rocks whereas low in granitic rocks area. If enough data on slope angle and litho types were obtained in any domains, we can construct a distribution map of the occurrence probability using this relation and coefficients depending on litho types. The map gives a " slope hazard map" for future occurrence under same rainfall intensity.

1. INTRODUCTION

Slope failures occur frequently in mountainous countries during rainy season, and they give great damages to facilities and peoples who live in there. Predicting the occurrence of slope failures and determining the locations susceptible to them are fundamental subjects for such countries. However, it is generally difficult to obtain the degrees of instability for individual slopes, because methodology is not established and fundamental data are not enough.

Frequent occurrence of failures means that distribution of failures recorded in the past may give valuable information on dangerous locations. If any distribution of past slope failures was obtained, and was combined with topographical and geological data for any domain, the relations among them may be available for statistical prediction for future occurrences. Expressing the occurrence probability on a map, it gives a "slope hazard map".

2. DISTRIBUTION OF SLOPE FAILURES

2.1 Slope hazard map and empirical methods

In general, slope hazard maps should include the information on the degree of susceptibility to landsliding in terms of space, and it is generally expressed by the distribution of the occurrence probability in the style of mesh data (Figure 1).

Many attempts have been made to construct such maps during these two decades (for example, Guillande *et al*.,1991; Fatemi *et al*.,1994; Yokota, 1995, 1996, Aleotti and Chowdhury,1999). According to these, methodology to evaluate the degree of susceptibility is roughly divided into two; one is geotechnical method on the basis of kinetic balance using physical data, and the other is empirical method using records of past failures. Regarding the former, it is generally difficult to obtain physical data for individual small slopes.

On the contrary, many distribution data of slope failures have been recorded in Japan during 30 years, and such data are available for the purpose. Then, the authors have attempted to analyze the distribution of slope failures occurred at 1983 in Japan, which are known as the San'in heavy rainfall disaster. The study area is located in western Shimane, Japan (Figure 2). Principle of the process was outlined in Edgar and Yokota (2001).

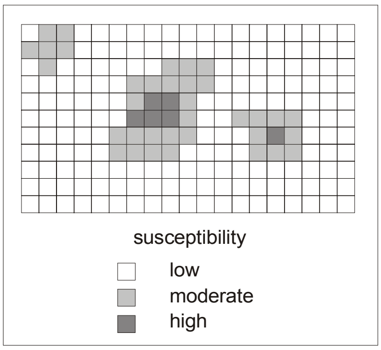

Figure 1. An image of slope hazard map.

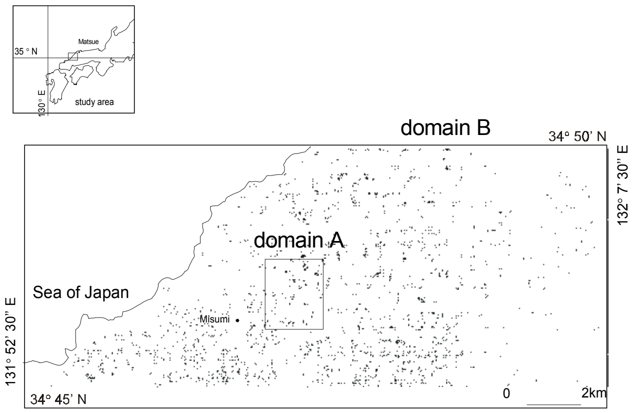

Figure 2. Distribution of slope failures at heavy rainfall disaster in western Shimane, Japan.

2.2 Slope failures at the 1983 San'in heavy rainfall disaster

The data used here for analyses are the distribution of slope failures occurred due to heavy rainfall from July 20th to 23rd, 1983. Total rainfall recorded attained to more than 700mm during three days. This intensive rainfall caused numerous slope failures in there, and the latter brought about debris flows in many places. Consequently, more than 100 lives were lost due to slope failures, debris flows, and flooding (Research Group, 1984).

According to previous reports (Research Group, 1984 and others), slope failures are shallow and involved residual soil and colluviums, and they may depend on litho-type, soil type and thickness. Figure 2 shows their distribution obtained by air photo interpretation. Although size of individual failures is small, it seems to distribute uniformly in the area.

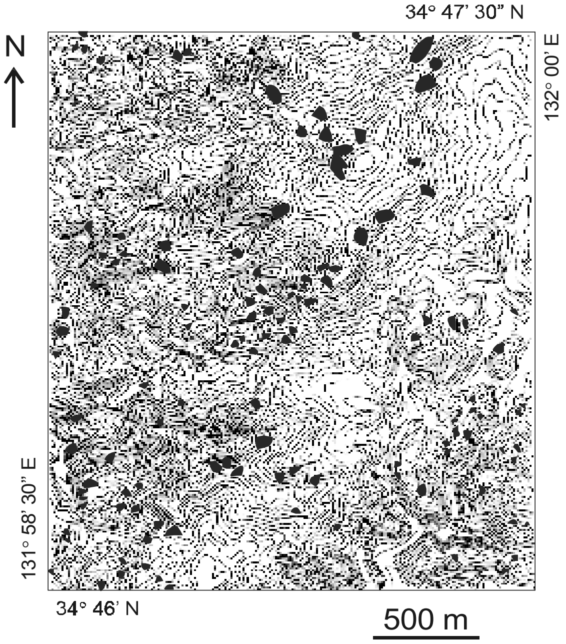

Figure 3. Topography and distribution of slope failures in the domain *A*. Location of *domain A* was indicated in Figure 2.

3. ANALYSES OF SMALL AREA (DOMAIN *A*)

3.1 DEM and slope failure data

Firstly, we selected and analyzed data in small domain of 6.3km^2 indicated as "*domain A"* in Figure 2. Figure 3 shows the topography and their distribution in the domain. Many slope failures are recognized along mountainous slopes. Both elevation and distribution of slope failures were converted into 15-m mesh raster data. Slope angles in each mesh (cell) were calculated from elevation data (DEM). Based on these mesh data, we can obtain any empirical relation between the area, where failure occurred (number of cells), and slope angle θ in the domain.

3.2 Relation between slope failure and slope angle

Figure 4 shows the relation. Total number of cells t in each slope angle increases with θ between 0° and 20° , and it decreases in steeper zones (Figure 4(a)). In addition, we calculated the numbers of cells f, where slope failures occurred, for each slope angle. As shown in Figure 4(b), the change of f with θ is also similar to that of (a). Here, taking a ratio of f to t, the change of the ratio f / t with θ is not constant, and it tends to increase with θ (Figure 4(c)).

The ratio $r = f / t$ means the occurrence probability of failures in each slope angle. Assuming that the ratio f / t increases linearly, it is expressed as;

$$r = f / t = a\,\theta + b \qquad (1)$$

where a and b are constants.

The relation (1) is also mechanically supported by simple kinetic model that surface weathered portions of rock mass controls the occurrence of shallow failures. Although the occurrence probability is expected to be higher in steeper zones, the ratio is no higher in steeper zones (Figure 4 (c)). This is interpreted as that slope failures in steeper zones tend to occur frequently but their volume is small. Therefore, it may possible to neglect the decreasing portion, and we can use the linear increasing function of (1) for steeper zones also.

Based on practical data in Figure 4, coefficients a and b are 0.0014 and 0.011, respectively. That is;

$$r = f / t = 0.0014\,\theta + 0.011 \qquad (2)$$

If slope angle θ in any location was obtained from detail DEM, we can estimate the ratio $r = f / t$ for the location by substituting the value of θ into the equation (2). Considering that the ratio means the occurrence probability of slope failures, we can estimate the probability of future occurrence of slope failures in the location.

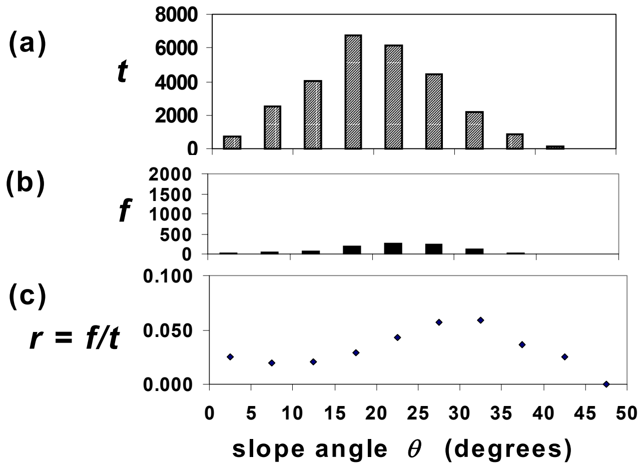

Figure 4. Relation between occurrence of slope failures and slope angle θ in domain A. (a) Area (number of cells; t) and slope angle θ. (b) Area of failures (numbers of cells; f) and slope angle θ. (c) Ratio $r = f / t$ and its changes with slope angle θ.

4. ANALYSES OF WHOLE AREA (*DOMAIN B*)

4.1 Litho-type dependency

Next, we analyzed the whole area of the domain B shown in Figure 2. This corresponds to two adjacent topographic quadrangles of 1/25,000. Here we can use published DEM of 50m-mesh. Slopes in this domain are mainly composed of three major litho types; schistose rocks (Mesozoic metamorphic rocks), granitic rocks (Cenozoic intrusives), and volcanic rocks (Paleogene), respectively.

Here, we can obtain the coefficients a and b for major litho types by using similar method in the domain *A*. Figure 5 show the ratio $r = f / t$ in the *domain B*. Graphs of (a), (b), (c) are schistose rocks, granitic rocks, and volcanic rocks, respectively. Although the tendency is not distinct, similar relations are also recognized in Figure 5. Then, expressing the relation (1) for each litho types, we can obtain the coefficients *a*. That is, *a*=0.0022 for schistose rocks and volcanic rocks, whereas 0.0012 for granitic rocks. Coefficients *b* is 0.089 for schistose rocks, 0.070 for granitic rocks, 0.011 for volcanic rocks, respectively. Coefficient *a* means the dependency of the probability on slope angle, and *b* means the susceptibility of each litho types to rainfall intensity. This difference in litho types may also include the difference in weathering characteristics of each rock. Consequently, the ratio *r* depends on both slope angle and litho types.

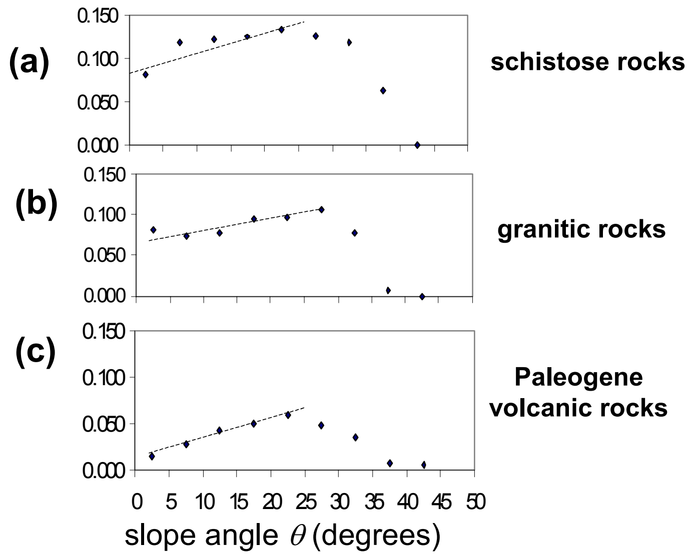

Figure 5. Litho types dependency of the ratio $r = f / t$ in the domain *B*.
(a) schistose rocks, (b) granitic rocks, (c) volcanic rocks.

5. CONSTRUCTION OF SLOPE HAZARD MAPS

Considering that the ratio $r = f / t$ means the occurrence probability in each slope angle with each litho types, we can estimate the occurrence probability using this relations. This map gives the degree of instability in each location, and gives a "slope hazard map" for future occurrence under same rainfall intensity. The flowchart to construct such hazard maps on the basis of past data is shown in Figure 6. Figure 7 shows an example of such slope hazard maps calculated on the basis of the flow chart and data in the *domain B*. Degrees of susceptibility are expressed by "low"," mediate", and "high" in the map.

If enough data on slope angle and litho types were obtained in any domains, we can construct a distribution map of the occurrence probability using the relation mentioned above and coefficients depending on litho types.

6. CONCLUSIONS

(1) Topographical information is effective for estimating the occurrence probability in shallow failures, because the occurrence strongly depends on slope angles.
(2) The 15m-mesh DEM was effective to obtain the relation between slope angle and occurrence of failures. Although the published 50m-mesh DEM is poor in its quality, it is

available for this purpose.

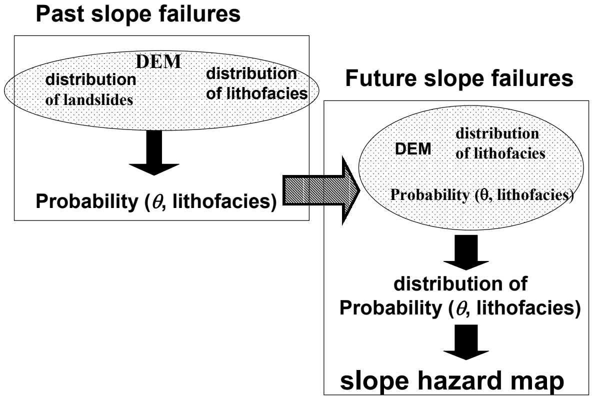

Figure 6. A flow chart to construct hazard maps the authors used.

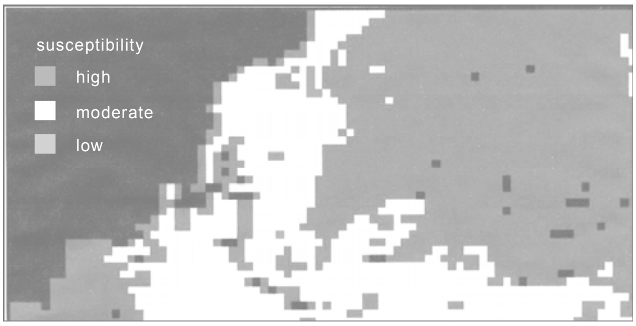

Figure 7. An example of slope hazard maps.

(3) The occurrence ratio of slope failures, which is defined as the ratio of failure area to total area , tends to increase with slope angle.
(4) Coefficient in the relation depends on litho type in addition to slope angle.
(5) Based on these relations, it may become possible to estimate the occurrence probability in any domains.
(6) Using another topographical and geological information in addition to slope angle, and evaluate their relations to past failures in detail, slope hazard map may become possible more effectively.

7. REFERENCES

Aleotti,P. and Chowdhury,R.,1999,Landslide hazard assessment summary review and new perspective, *Bulletin of Engineering. Geology and. Environment*, 58, 21-44.

Edgar, P. and Yokota, S. 2001, An attempt to construct slope hazard maps based on digitized distribution data of past slope failures and high resolution DEM, *Proceeding of* 12th *Geoinforum*, 108-109.

Fatemi,A.M.,Koike,K.,Suzuki,A.and Kitazono,Y.,1994, Geologic hazard risk assessment by using fuzzy sets theory, *Geoinformatics*, 5,113-128.

Guillande,R..Caro,P. and Chorowicz,J., 1991, A first approach to digital mapping of landslide hazards In the Andes of Colombia using remote sensing techniques (GARS project), *Episode*, 14, 364-367.

Research Group of the San'in heavy rainfall disaster, Shimane Univ.,1984, Geological characters of slope failures by heavy rain of July,1983, San'in District, *Geological Reports of Shimane University*, No.3, 3-20 (in Japanese).

Yokota,S.,1995, Problems on multi-purpose digital hazard maps for slope failures, *Geoinformatics*, 6, 123-132 (in Japanese with English abstract).

Yokota, S. 1996, Multi-purpose digital hazard map for slope failures, *Geoinformatics*, 7, 51-59.