CHARACTERISTIC ANALYSIS OF LANDSLIDES AND SLOPE FAILURE IN THE IMO RIVER BASIN INDUCED BY THE MID NIIGATA EARTHQUAKE USING GIS

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ABSTRACT

The Mid Niigata Prefecture earthquake on October 23, 2004 caused many landslides and slope failures in the Chuetsu region of Niigata Prefecture, particularly in the Imo River basin. GIS was used to analyze the characteristics of the landslides and slope failures caused by the earthquake in the Imo River basin. Quantification theory Type 2 was used to analyze the critical factors that controlled the occurrences of slope failures and landslides. Slope, vegetation and geology (in order of significance) were found to be critical factors that controlled slope failure occurrences. Hysteresis of landslide, direction of slope, and geology (also in order) were found to be the critical factors that controlled landslide occurrences. Based on the computed category score, ranking maps of vulnerability to slope failures and landslides were made. The distributions of slope failures and landslides were predicted reasonably well by these ranking maps.

Key Words: GIS, Landslide, Mid Niigata Prefecture earthquake, Quantification theory Type 2, Slope failure

INTRODUCTION

The Mid Niigata Prefecture earthquake of October 23, 2004 caused many landslides and slope failures in the Chuetsu region of Niigata prefecture, particularly in the Imo River basin. This area is known to be a zone of frequent landslides. This earthquake provided scientific data about slope disaster caused by an earthquake with its epicenter within pre-existing landslide topography areas. It was previously known that forests affect slope failure (Abe, 1997). Slope failures and landslides caused by the Mid-Niigata Prefecture earthquake have been previously analyzed from the viewpoints of topography, geology and so on (Gonda *et al.*, 2007). However, so far no analysis has focused on the influences of either forest or field vegetation and their effect on the occurrence of slope failures and landslides.

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In this study, the characteristics of landslides and slope failures caused by the earthquake in the Imo River basin were analyzed using GIS. An analysis was conducted using quantification theory Type 2 to determine the critical factors that controlled the occurrences of slope failures and landslides. Ranking maps of vulnerability to slope failures and landslides were made by quantification theory Type 2.

MID NIIGATA PREFECTURE EARTHQUAKE

At 17:56 on October 24, 2004, an intense earthquake occurred in the mountainous area of the Chuetsu region with the epicenter at 37° 17.4″N, 138°52.5″E. The earthquake originated at a depth of approximately 13 km and had a magnitude of 6.8 on the Richter Scale (Yamagishi *et al.*, 2006). Serious blockages were caused by a large volume of sediment produced by slope failures and landslides that accumulated in the river courses, particularly in the Imo River basin which is located close to the epicenter. Consequently, heavy damage was caused in the entire basin including disruption of roads and inundation of residential areas near rivers (Nakaide *et al.*, 2004). There were reports of damage to the forest on the mountain ridges, because of the Mid-Niigata Prefecture earthquake which occurred in that mountainous area (Sekiguci, 2006).

IMO RIVER BASIN

The Imo River basin is located in an area that includes Nagaoka City and Ojiya City (Fig.1). Imo River is a tributary of Uono River which belongs to the Sinano River system. The Imo River basin has an area of about 38 km^2, an average slope of 22.6 degrees, a maximum elevation of 680 m, and a minimum elevation of 75 m. The basin is located in an area called Higashiyama Hill

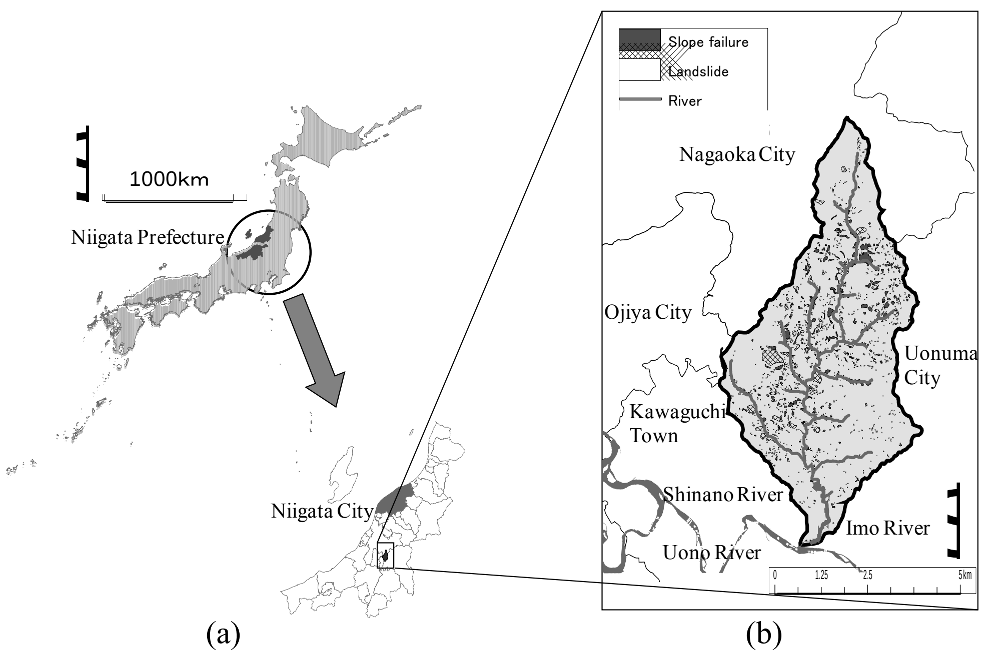

Fig.1 a: Location map of Imo River basin in Niigata prefecture, Japan. b: Distribution of slope failures and landslides caused by the mid Niigata earthquake in the Imo River basin

where landslides have frequently occurred. Many slope failures and landslides were induced by the Mid-Niigata Prefecture earthquake in the Imo River basin. The geology of the basin consists of sedimentary rocks of the Tertiary-Quaternary period such as sandstones, mudstones and alterations of these two rock types (Kobayshi *et al.*, 1991).

METHOD OF ANALYSIS

The following data sets were inputted into the GIS for analysis: (1) slope failure and landslide distribution maps obtained from the Yuzawa Sabo Office, Ministry of Land, Infrastructure, Transport and Tourism; (2) forest register maps (scale 1:50 000) obtained from the Niigata Agriculture and Forestry Marine Products Department; (3) geological maps (scale 1:50 000) of Nagaoka and Ojiyaobtained from the Geological survey of Japan; (4) landslide distribution maps (scale 1:50 000) of Nagaoka and Ojiya obtained from the National Research Institute for Earth Science and Disaster Prevention; and (5) a 10-m mesh digital elevation model (DEM) obtained from Hokkaido Chizu Co., Ltd.

The slope failure and landslide rates per area in specific areas, selected for analysis because of local conditions, were calculated using Eq. (1).

$$C = B/A \times 100 \qquad (1)$$

where: A is the extent of the selected area (ha), B is the extent of either the slope failure area or landslide area (ha) within the selected area; and C is the slope failure and landslide rate per area (%).

Hayashi’s quantification theory, developed by Chikio Hayashi, includes a set of statistical methods, namely, Hayashi's quantification Types 1 to 4. In Japan, Hayashi’s methods of quantification are well known and widely used in various fields in which information is obtained mainly in the form of qualitative categories, such as social and marketing surveys, psychological and medical research, etc. Hayashi’s quantitative theory Type 2 is a method of multivariate discrimination analysis which is used to manipulate attribute data as predictor variables (Jiang *et al.*, 2009).

In this study, the outside variable is the occurrence of slope failure or landslide: a) occur or b) not occur. The predictor variables, also called the items, are the influence factors.

RESULTS

Number, area, and rate per area of slope failure and landslide

The rate per area of slope failure and landslide in the Imo River basin was as high as that following the 1923 Kanto and the 1999 Taiwan Chi-Chi earthquakes. The number and total area of slope failures were greater than those of landslides. However, the size of the average area of landslides was greater than that of slope failures (Table 1).

Table 1 The rate per area of slope failure and landslide induced by earlier earthquakes (Gonda *et al.*, 2007)

	Rate per area of slope failure and landslide (%)	Study area (km^2)	Reference	Note
Chi-Chi Earthquake Taiwan (1999)	7.0	690	Hayashi *et al.* 2002	Includes slope failure by the typhoon after the earthquake
Kobe Earthquake Japan (1995)	0.2	140	A report of Ministry of Construction	
Niigata Earthquake Japan (1964)	0.2	151	Oomura *et al.* 1980	
Kantou Earthquake Japan (1924)	7.0	86	Japan Society for Natural Disaster Science 1982	Includes slope failure by rainfall after the earthquake

Relationship between rates per area of slope failure and landslide and the environmental factor

(1) Relationships between slope, slope failure and landslide
Slopes distributed over the Imo River basin were classified into 5 classes: 0~10°, 10~20°, 20~30°, 30~40°, and 40°~. The rates of slope failure and landslide were calculated for each class. The rate of slope failure increases with slope inclination. Landslides were most common at slope inclinations in the range of 10–20° (Fig. 2).

(2) Relationships between geology, slope failure and landslide
The geology of the Imo River basin was classified into five units: (1) massive dark gray mudstone, 2) marine silt, sand and pebble, 3) sandstone, 4)alternation of sandstone and mudstone, and 5) others. The rates of slope failure and landslide were calculated for each unit. The rates of slope failure and landslide were higher in sandstones and in sandstone and mudstone alterations (Fig. 3).

(3) Relationships between hysteresis of landslide, slope failure and landslide
Many pre-existing landslide topographys are distributed in Imo River basin. Imo River basin was classified into two topographical area: the pre-existing landslide topography area, and the other area. The rates of slope failure and landslide were calculated for each areas. The rates of slope failure and landslide in the pre-existing landslide topography area were greater than in the other area. In particular, there was a large difference between landslide rates in pre-existing landslide topography area and the other area (Fig. 4).

(4) Relationships between vegetation, slope failure and landslide
The Imo River basin was classified into four areas according to the following four types of vegetation: conifer, broadleaf, grassy, and others. Rates of slope failure and landslide were calculated for each area. The rate of slope failure was higher in areas with grassy fields than in areas with conifer or broadleaf vegetation. The rate of slope failure was also higher in areas with other features such as fields, ponds, or rivers. The rate of landslides was only weakly related to vegetation (Fig. 5).

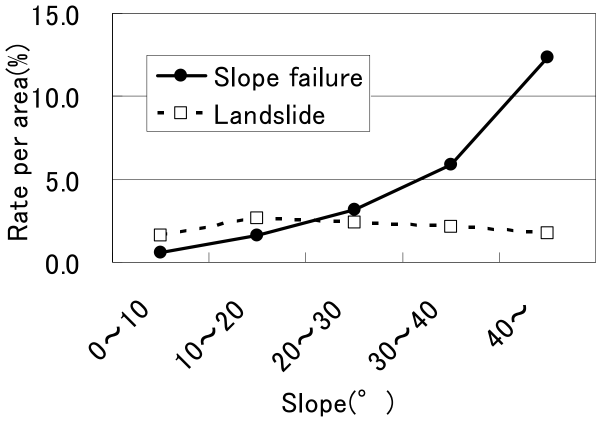

Fig.2 Relationship between slope, slope failures and landslides

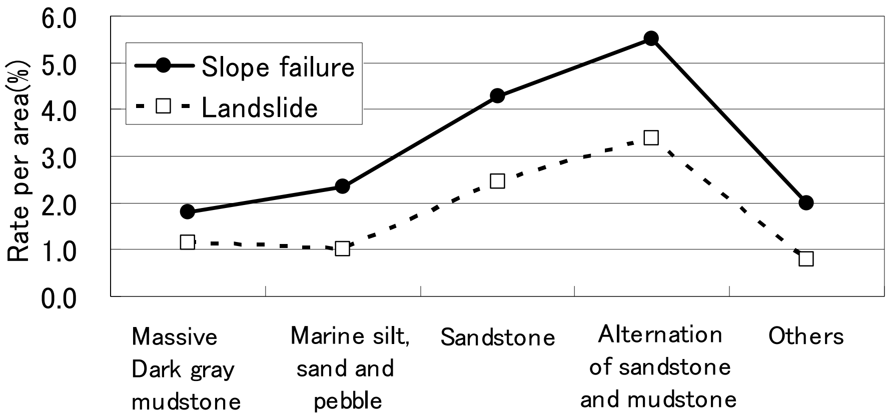

Fig.3 Relationship between geology, slope failures and landslides

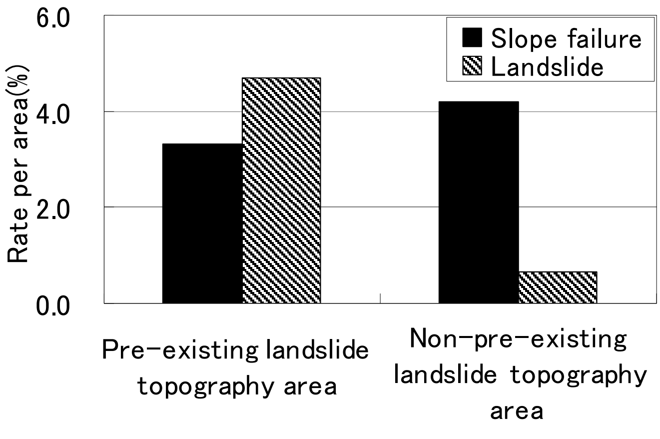

Fig.4 Relationship between hysteresis of landslide, slope failures and landslides

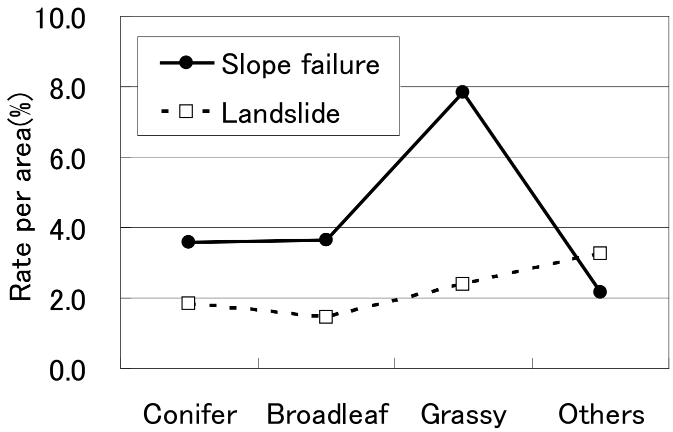

Fig. 5 Relationship between vegetation, slope failures and landslides

Analysis using quantification theory Type 2

Eleven environmental factors, vegetation, geology, hysteresis of landslide, elevation, slope, direction of slope, vertical curvature, plan curvature, flow accumulation, length of slope, and position of slope, were chosen as items for analysis. The 11 items (environmental factors) were divided into 46 categories (Fig.6 and Fig.7). Each environmental factor can be quantified on the basis of the category score and item range of the raw data. Quantification theory Type 2 was used to implement this quantification. That allowed us to analyze the relative contribution of each of the 11 items (environmental factors) to the occurrence of slope failures and landslides. The contribution of each item, expressed as standard category scores and item ranges, can be seen in Figures 7 and Figure 8. Factors with larger category scores contribute more to occurrences of slope failure and landslide. A positive value indicates that the corresponding category will promote occurrences of slope failure and landslide; in contrast, negative values indicate that the corresponding category will restrain the negative values indicate that the corresponding category will restrain the occurrences of slope failure and landslide.

Discriminative ratios of slope failure and landslide were 75.8% and 72.6% respectively. Judging from the range of category scores related to items contributing to slope failures, the critical factors that controlled slope failure occurrences were found to be: [1] slope (range 2.6), [2] vegetation (range 1.0), and [3] geology (range 0.7) (Fig.6). Judging from a range of environmental factors contributing to landslides, critical factors that controlled landslide occurrences were found to be: [1] hysteresis of landslide (range1.4), [2] direction of slope (range 1.2), and [3] geology (range 1.0) (Fig. 7).

Item	Category	n	Category score
Vegetation	Conifer	1031	−0.3
	Broadleaf	4243	−0.1
	Grassy	1617	0.7
	Others	3071	−0.1
Geology	Massive dark gray mudstone	919	−0.2
	Marine silt, Sand and Stone	1061	−0.1
	Sandstone	1768	0.1
	Alternation of sandstones and mudstones	4054	0.3
	Others	2160	−0.5
Hysteresis of landslide	Pre-existing landslide topography areas	3774	−0.1
	Non-pre-existing landslide topography areas	6188	0.0
Elevation	～200	2577	−0.3
	200～300	4192	0.2
	300～	3193	−0.1
Slope	0～10	1653	−0.7
	10～20	2456	−0.6
	20～30	2681	0.0
	30～40	2227	0.3
	40～	945	1.9
Direction of slope	North	1044	−0.2
	Northeast	885	−0.4
	East	1344	−0.1
	Southeast	1503	0.1
	South	1532	0.2
	Southwest	1342	0.2
	West	1398	0.2
	Northwest	914	−0.2
Vertical curvature	～−4	893	0.0
	−4～4	8071	0.0
	4～	998	0.0
Plan curvature	～−4	393	0.1
	−4～4	9156	0.0
	4～	413	0.5
Flow Accumulation	0	2420	0.0
	0～5	4261	0.0
	5～25	1987	0.0
	25～125	780	0.1
	125～	514	−0.3
Length of slope	0～100	2526	0.1
	100～200	4974	0.1
	200～	2462	−0.2
Position of slope	0～20	1266	−0.1
	20～40	1432	0.3
	40～60	1877	0.1
	60～80	2370	0.0
	80～100	3017	−0.2

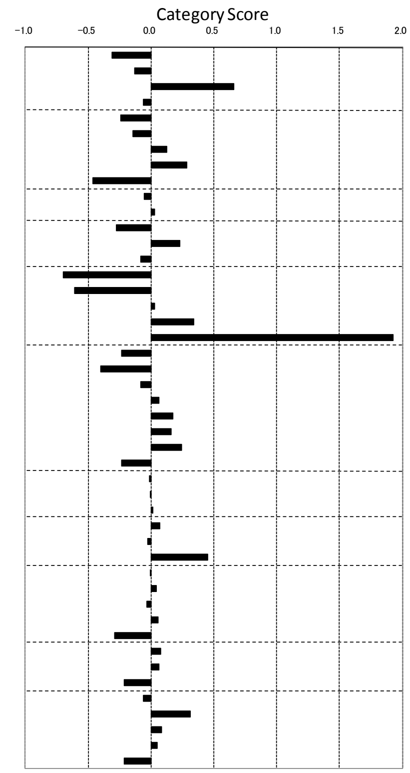

Fig.6. Analysis of slope failure by quantification theory Type 2

Item	Category	n	Category score
Vegetation	Conifer	1031	−0.3
	Broadleaf	4243	−0.1
	Grassy	1617	0.1
	Others	3071	0.2
Geology	Massive dark gray mudstone	919	−0.6
	Marine silt, Sand and Stone	1061	−0.5
	Sandstone	1768	0.2
	Alternation of sandstones and mudstones	4054	0.4
	Others	2160	−0.4
Hysteresis of landslide	Pre-existing landslide topography areas	3774	0.9
	Non-pre-existing landslide topography areas	6188	−0.5
Elevation	～200	2577	0.4
	200～300	4192	0.0
	300～	3193	−0.3
Slope	0～10	1653	−0.3
	10～20	2456	0.0
	20～30	2681	0.0
	30～40	2227	0.2
	40～	945	−0.1
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	40～60	1877	0.1
	60～80	2370	0.2
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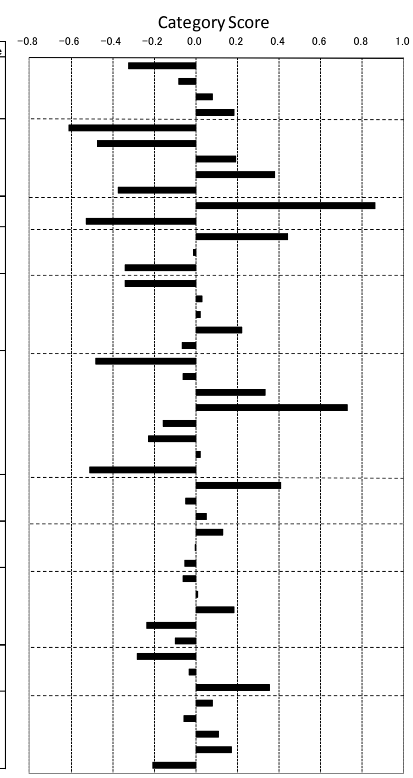

Fig.7. Analysis of landslide by quantification theory Type 2

Ranking maps of susceptibility to slope failures and landslides

A sample score is the sum of category scores calculated for a point. Ranking maps of susceptibility to slope failure and landslide were made by taking into account the sample score at each point (Fig.8 and Fig.9). Because the threshold score for between occurrence or non-occurrence of slope failure was 0.3322, rank of susceptibility was rendered into four levels: rank D (-2.5892 − 0.3322), rank C (0.3323 − 1.0000), rank B (1.0001 − 2.0000), and rank A (2.0001 − 4.2683) (Fig. 8). Because the threshold score for between occurrence or non-occurrence of slope failure was 0.7127, rank of susceptibility was rendered into four levels: rank D (-3.2630 − 0.7127), rank C (0.7128 − 1.0000), rank B (1.0001 − 2.0000), and rank A (2.0001 − 4.2683) (Fig. 9).

Figures 8 and Figure 9 show that the distributions of slope failures and landslides generally coincide with areas of ranks A and B.

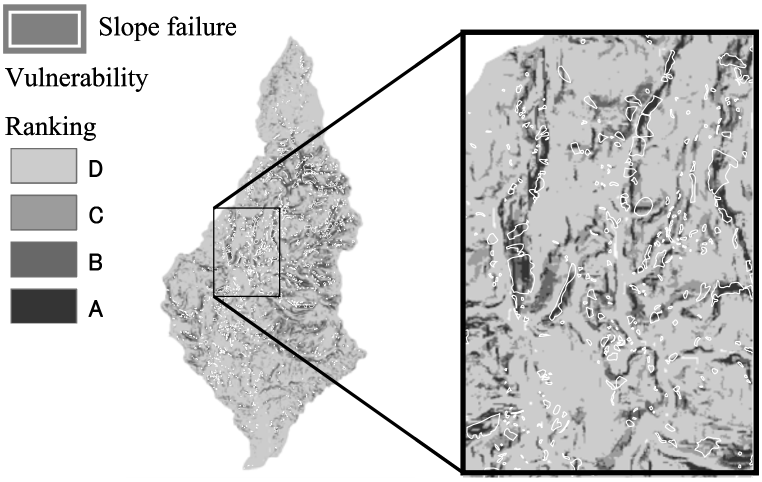

Fig.8 Ranking map of susceptibility to slope failure

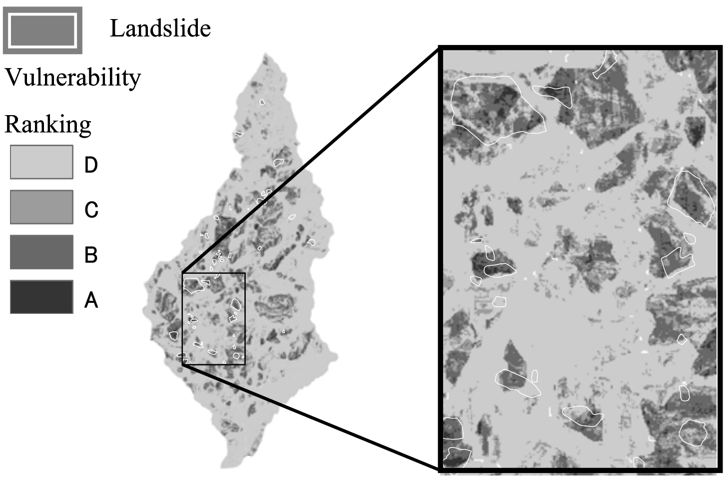

Fig.9 Ranking map of susceptibility to landslide

CONCLUSIONS

This study has clarified the relationship between environmental factors and slope failures and landslides. The environmental factors which affect slope failure and landslide were ranked by means of category scores calculated on the basis of quantification theory Type 2. The order of the critical factors that control slope failure occurrences was found to be slope, vegetation and geology. The ranking maps of susceptibility to slope failure and landslide made by us, predicted slope failures and landslides reasonably well.

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