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## **Dependency of shallow landslides on geometric parameters and its potentiality.**

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The study of shallow landslides is very important from many points of view, especially recently, when urban development rich up to foot of mountain slope, where most of slope movements occur. Every year, thousands of people are killed by landslides, therefore the monitoring of old slope movements as well as predict a suitable area for their development become today one of the most important task for scientists. The authors expect the example from recreation area Aburayama in Fukuoka district could give any suggestion for solving and prediction of similarly problems in the short future.

### **INTRODUCTION**

In June 1999, extensive and heavy rains triggered the occurrence of many shallow landslides in Kyushu and Chugoku region of Japan. The most damaged area in Fukuoka district was recreation area Aburayama, located in south direction from Fukuoka city (Fig. 1.), where 26 landslides occurred. Most of these landslides are situated in cutting respective filling part of slope along roads. For calculations of geometric parameters were used data from digital Suuchichizu, which do not reflected artificial intervention to the natural condition. We tried to find the relationship between geometric parameters of study area under natural condition and spatial distribution of landslides as well as to find the cause development of landslides. Also, we tried to chalk out the areas with higher potentiality for development of landslides.

By reconnoiter of study area location of landslides and some basic characteristics have been recorded. As mentioned above, the most of landslides are located in filling and cutting parts of slope along the road. For the calculation of geometric parameters, these data were insufficient because the data set was limited by number of landslides and the data do not reflected parameters under natural condition, but they are represent only small local area.

*Key words: morphometric analysis, shallow landslides, calculation of geometric parameters, probability*

### **MATERIALS AND METHODS**

#### ***Surface geometry analysis***

Geometric analysis is to analyze a spatial distribution of value of geometric parameters and also analysis of properties and spatial differentiation of georclief as a whole (Krcho, 1990; Mitášová, Hofierka 1993).

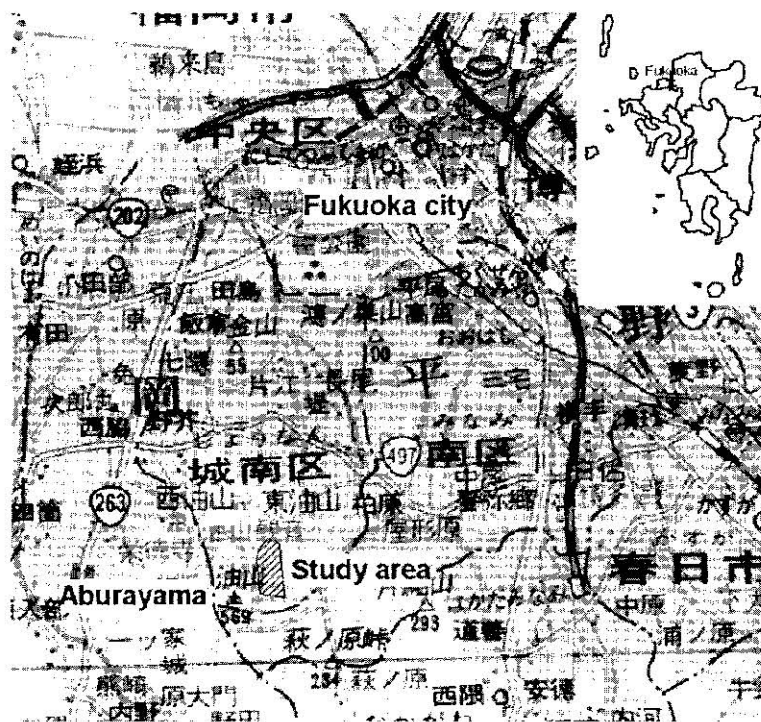


Fig. 1. Location of recreation area of Aburayama in Fukuoka district.

Before deriving mathematical expression for geometric parameters, we can definite partial derivation as follow:

$$f_x = \frac{\partial z}{\partial x}; f_y = \frac{\partial z}{\partial y} \quad (1)$$

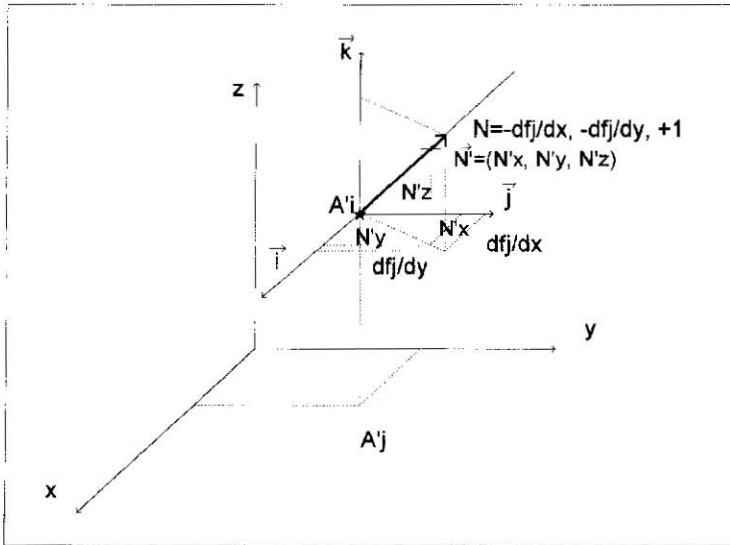
The calculation of geometric parameters in the detail we can find in the works Krcho, (1990); Mitášová, Hofierka, (1993). For clearly understanding of mathematical expression, we can consider part of relief, where the geoid is sufficiently flat, that means it represents a plane. On this plane we can choose Cartesian coordinate system  $\langle 0, i, j, k \rangle$ , where  $i, j, k$  are unit vectors in direction of  $x, y, z$  axis respectively. For each point of relief we are able to give a value of altitude  $z$ , in direction of the normal vector  $N$  (Fig. 2).

### **Slope and aspect analysis**

The dip slope angle  $\gamma_N$  as well as aspect angle  $\alpha_N$  are calculated from gradient elevation array as follow (Krcho, 1993).

$$\nabla f = f_x i + f_y j \quad (2)$$

Vector gradient  $f$  has an orientation in the direction of normal vector to contour line



**Fig. 2.** Definition of normal vector  $N$  and implementation of Cartesian coordinate system  $\langle 0, i, j, k \rangle$ , where  $i, j, k$  are unit vectors in direction to axes  $x, y$  and  $z$  respectively. (taken from Krcho, 1990).

in each point of scalar field (Krcho, 1990). It has an absolute value in the corresponding point:

$$\nabla f = \tan \gamma_N = \sqrt{f_x^2 + f_y^2} \quad (3)$$

where from

$$\gamma_N = \arctan \sqrt{f_x^2 + f_y^2} \quad (4)$$

where  $\gamma_N$  is a dip slope angle.

We can consider the direction of normal vector to contour lines with the respect to sidelong decreasing scalar vector. The direction of this vector can be expressed as:

$$\tan \alpha_N = \frac{-f_y}{-f_x} \quad (5)$$

where from

$$\alpha_N = \arctan \frac{-f_y}{-f_x} \quad (6)$$

where  $\alpha_N$  is an aspect angle of vector gradient  $f$  and also operative orientation of georelief to cardinal points.

## RESULT AND DISCUSSION

### Geometric parameters

In the given area geometric parameters were calculated, then compared with spatial distribution of landslides. As source data have been taken from Suuchichizu with size of mesh 50 m published by Japan Geographic Institute.

As mentioned above, data were provided from Suuchichizu. The spatial distribution of data was equally distributed, with distance 2.25" in x-axis and 1.5" in y-axis, respectively. Original data were transferred to ASCII file format x, y, z. The digital terrain model of study area was computed from 2014 data points using interpolation with regularized spline. The detail process of interpolation by regularized spline with tension is in works Mitášová, Mitáš (1993), Mitášová, Hofierka (1993). Values of elevation, slope, aspect are computed in  $97 \times 167$  grid cells, what means grid unit size  $10 \times 10$  m for the whole study area.

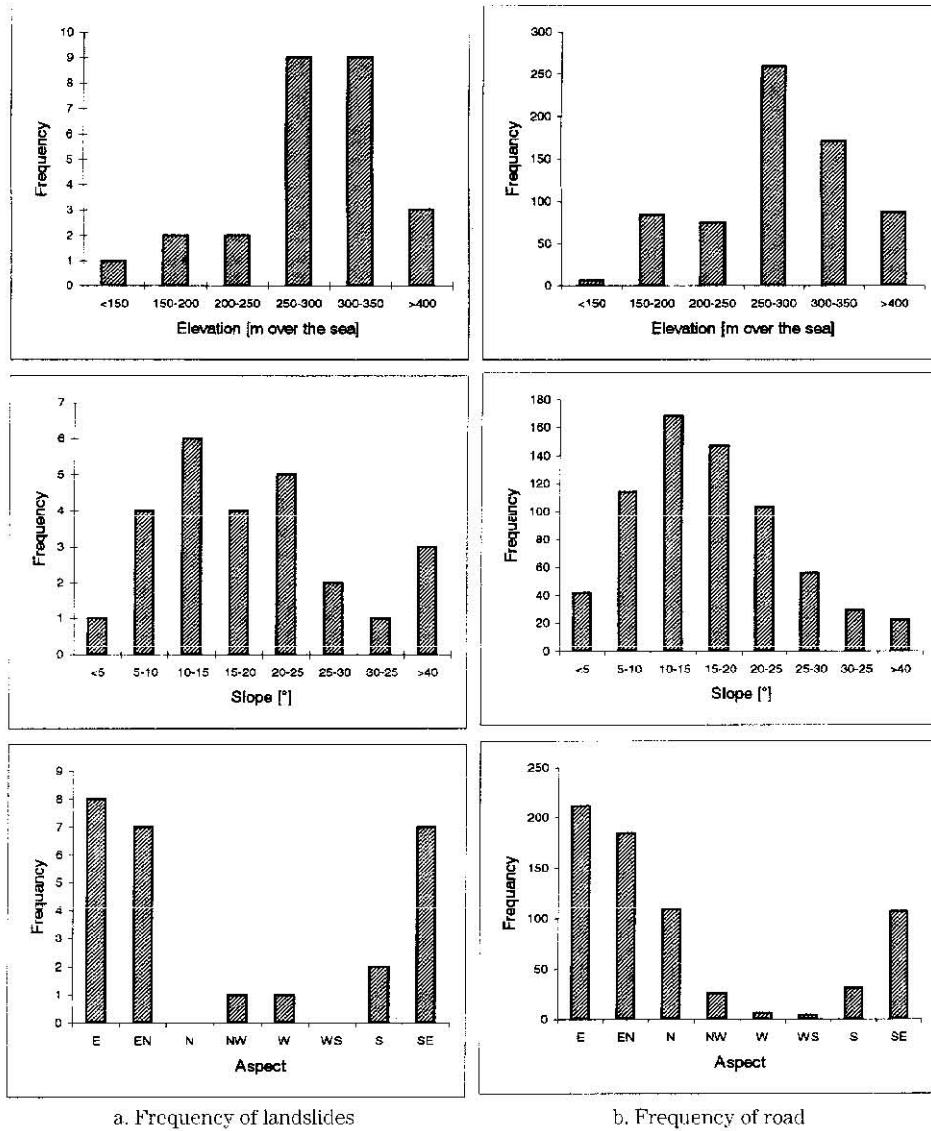
### Slope and aspect analysis

Slope angle  $\gamma_N$  is calculated in degrees from  $0^\circ$  (horizontal plane) to  $90^\circ$  (vertical uphill) at every unit cell on our selected grid. For the location of landslides, a centroid of landslide has been selected. For the calculation of  $\gamma_N$  equation (4) was used. Unlike slope analysis, an aspect analysis provides as with direction of the slope angle  $\gamma_N$  at each grid cell. In other words, this operation defines the direction in which water would flow over the surface. Aspect angle values  $\alpha_N$  are reported in degrees, where  $360^\circ$  due to East and  $90^\circ$  due to North respectively. Aspect angle  $\alpha_N$  was calculated from equation (6).

The altitude in the study area ranges between 111 and 496 m over the sea level respectively. This range was reclassified to the six categories with step 50 elevation meters. That means, each category represents area with different rank of elevation. In case of slope layer, the inclination floated between  $0^\circ$  up to  $44^\circ$ . Also this layer was reclassified to the eight categories with step  $5^\circ$ . Values of aspect layer were reclassified to the eight categories according to the cardinal points. The detail categories of individual layer shows Table 1. For the aggregation of landslides by region in individual layers, layers were overlaid in respect to elevation, slope and aspect with landslides. Then landslides were inspected for corresponding value of elevation, slope

**Table 1.** Chosen range categories in individual layers.

Categories	Elevation	Slope	Aspect
1	<150	<5	East
2	150–200	5–10	East–North
3	200–250	10–15	North
4	250–300	15–20	North–West
5	300–350	20–25	West
6	350–400	25–30	West–South
7		30–35	South
8		>40	South–East



**Fig. 3.** Frequency of landslides and road's inspected points from elevation, slope and aspect points of view.

and aspect respectively. The spatial distribution of landslides with respect to elevation, slope and aspect in individual categories is shown in Fig. 3a. In the rank from 250 m to 350 m more than 60% of all landslides are concentrated. Unlike elevation frequency, the distribution of landslides with respect to slope seems as random one. The most of landslides are concentrated on slope with inclination ranges from  $10^{\circ}$ – $15^{\circ}$  and from  $20^{\circ}$ – $25^{\circ}$ . It represents more than 40%. The aspect analysis is corresponding with natural location of recreation area Aburayama, which is located on the eastern side of Mt. Aburayama.

For the main purpose, to find the cause of landslides same analysis were done with line of road. For this purpose, the whole length of road, 6.81 km, was inspected in each 10 meters for elevation, slope and aspect values. We got 681 inspected points, which covered the whole length of line roads. Also these points were overlaid and inspected over the elevation, slope and aspect layers. Points were aggregated to the same range and from same point of view as landslides (Tab. 1.). That means, elevation values of inspected points were aggregated to the six, slope values to the eight and aspect values also to the eight categories. Figure 3b. shows spatial frequency of road's points from traced points of view. The percentual representation of individual ranges of elevation, slope and aspect respectively calculated from inspected points of road and from landslides respectively is shown in Tab. 2. The data were postprocessed by regression analysis as shown in Fig. 4. The figure shows clearly linear dependency between percent of landslides and inspected points of line road in all traced aspects. It means the landslides are equally distributed along the road's sides. Percentual number of landslides and line of road from elevation point of view has the correlation coefficient 0.923 and 0.844 from slope point of view, which are significant at 1% level (Ishikawa, 1964) and from aspect point of view 0.823, which is significant at 5% level. Shortly we can say that the main cause of occurrence of landslides is anthropogenous effect to the natural condition. The heavy rainfall seems as secondary factor and its function was only as trigger which starts slope movements.

**Table 2.** shows percentual representation of landslides and road in individual ranges of elevation, slope and aspect respectively.

Elevation			Slope			Aspect		
Altitude [m]	Landslides [%]	Roads [%]	Inclination [°]	Landslides [%]	Roads [%]	Aspect	Landslides [%]	Roads [%]
100–150	3.85	0.88	<5	3.85	6.18	East	30.77	31.13
150–200	7.69	12.33	5–10	15.38	16.74	East–North	26.92	27.17
200–250	7.69	11.01	10–15	23.08	24.67	North	0.00	16.15
250–300	34.62	38.03	15–20	15.39	21.59	North–West	3.85	3.81
300–350	34.62	24.96	20–25	19.23	15.12	West	3.85	0.88
350–400	11.54	12.78	25–30	7.69	8.22	West–South	0.00	0.59
			30–35	3.85	4.26	South	7.69	4.55
			35–40	11.54	3.23	South–East	26.92	15.71
Correlation coefficient	0.923		Correlation coefficient	0.844		Correlation coefficient	0.823	

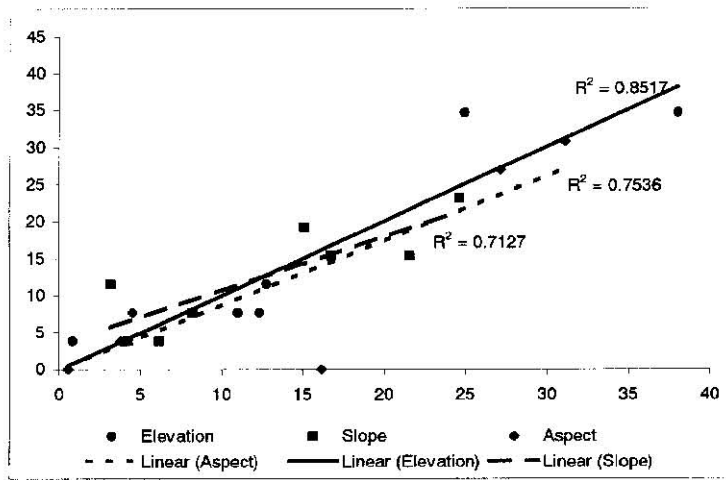


Fig. 4. Regression analysis of percentual representation of landslides and road in individual ranges of elevation, slope and aspect respectively.

### Probability analysis

In order to create a special map of potentiality area for occurrence of shallow landslides, we started from reclassified layers of elevation, slope and aspect as we used in previous analysis. So, we had six regions in elevation layer, eight in slope layer and also eight one in aspect layer. After that, we calculated how many landslides exist in individual region from elevation, slope and aspect point of view. In these regions probability was calculated by an equation (7)

$$P_{si} = \frac{n_{si}}{N} \quad (7)$$

where  $P_{si}$  is probability in „i“ region of „S“ layer,  $n_{si}$  is number of landslides in „i“ region of „S“ layer and  $N$  is total number of landslides. Then the value of probability  $P_{si}$  was added to the each grid cell, which it fall in region „i“ and layer „S“.

These additional layers, which expressed the information about probability of region, were overlaid into one layer. The representative value of occurrence probability of landslides in each grid cell was calculated as the average of individual probabilities in each grid cell. For calculation equation (8) was used

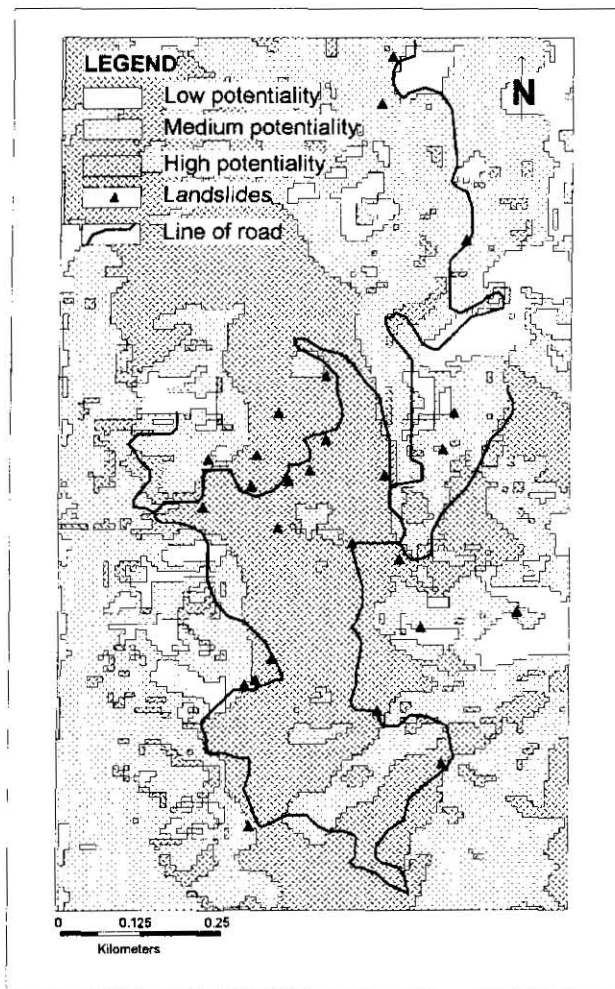
$$P_i = \frac{\sum P_{si}}{n_s} \quad (8)$$

where  $P_i$  is probability occurrence of landslides in „i“ grid cell,  $\sum P_{si}$  is sum of probabilities from elevation, slope and aspect layers respectively in „i“ grid cell and  $n_s$  is number of probabilities.

On the basis of these calculations, the potentiality map on occurrence of landslides



was created. This map is based on an uniformity area. That means we considered that calculated probability in individual range is characteristic for the whole study area, which is representing this range. The occurrence probability of landslides ranges from 0.0128 to 0.2948. This range was divided into three categories, which are less than 0.1, from 0.11 up to 0.2 and more than 0.2. These categories indicate low, medium and high area of potentiality respectively. By this analysis 13.2% of study area is classified into low, 48.5% into medium and 38.3% into high potentiality range. The result is shown in Fig. 5.



**Fig. 5.** Map of probability occurrence of landslides in recreation area Aburayama in Fukuoka district basis on uniformity.

## CONCLUSION

The slopes oriented toward East with the elevation range between 250 m and 350 m and slope range from  $10^{\circ}$  to  $15^{\circ}$  or from  $20^{\circ}$  to  $25^{\circ}$  seem as the most susceptible for slope failures. The probability analysis showed the most dangerous areas. By this method, more than third of study area has high occurrence potentiality of landslides. However, the most important is relationship between line of road and landslides. The regression analysis showed clearly dependency of landslides on road. *Videlicet*, the landslides are equally distributed along the road. So, the main factor of occurrence landslides is not heavy rainfall, but anthropogenous intervention to the natural condition. The rainfall seems as only secondary factor and its function was as trigger which starts of shallow landslides.

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