Morphological Study on the Prediction of the Site of Surface Slides[1]

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Abstract: The annual continual occurrence of surface slides in the basin was estimated by modifying the estimation formula of Yoshimatsu. The Weibull Distribution Function revealed to be usefull for presenting the state and the transition of surface slides in the basin. Three parameters of the Weibull Function are recognized to be the linear function of the area ratio a/A. The mapping of the hazardous zones could be successfully done using the stream line distribution map and the relief map.

Sediment yield produced by frequent surface slides on the mountain slopes of granitic rocks become as dangerous as those produced by gigantic landslides or large scale slope failures, because of the high frequency of occerrence in a basin in spite of the dimension.

It is recognized that surface slides will occur on the mountain slopes of every geology. As for the investigations on surface slides, almost all papers in Japan deal with surface slides which occur on the mountain of granitic rocks which are often severely weathered and distribute widely in the south-western district of Japan and disasters due to this geology occur frequently on the occasion of heavy rain which will be brought about by the typhoon or the frontal storm.

ESTIMATION FORMULA OF SURFACE SLIDES

In order to express the condition of the occurrence of surface slides in a basin, usually the parameter a/A; the ratio of the total area of surface slides to the area of a basin (the terminology "area ratio" is used hereafter)is used. In most of the studies concerning the occurrence of surface slides, efforts were made to express the area ratio as the function of the precipitation and formulas by Uchiogi(1) and Yoshimatsu(2) are the presentative ones. Here, the formula below by Yoshimatsu is taken to be discussed.

$$a/A = K \times Rr \times (R-r)^{1.5} \quad \text{------ (1)}$$

where, "R" is the amount of precipitation of one continual rain which has led to the disaster occurrence of surface slides, "r" is the invalid limited precipitation being of no effect on the occurrence of surface slides, Rr is the relief ratio and K is the coefficient.

In Table 1, values concerning the above formula by Yoshimatsu are indicated;area of the basin, total area of surface slides in the basin, area ratio and relief ratio and Figure 1 shows the relation between the area ratio and the amounts of continual precipitation both for measured and calculated are shown, and both values show good conformity.

Table 1--States of the occurrence of surface slides due to heavy rain(by Yoshimatsu(2))

(i)R.Kamanashi basin

Precipi-tation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
275	4.58	0.0120	0.0026	0.38
300	3.46	0.0510	0.0147	0.51
325	7.67	0.1795	0.0234	0.51
350	13.98	0.5595	0.0400	0.47
375	16.65	0.7693	0.0462	0.57
400	13.27	1.1986	0.0903	0.67
425	6.11	0.9829	0.1609	0.76
450	5.68	0.9632	0.1696	0.80

(ii)R.Tenryuu basin

Precipi-tation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
350	2.00	0.0140	0.0070	0.24
375	5.66	0.0907	0.0160	0.27
400	5.26	0.1230	0.0234	0.24
425	7.72	0.4284	0.0555	0.36
450	12.87	0.7627	0.0593	0.38
475	15.84	1.2451	0.0786	0.36
500	10.05	1.0213	0.1016	0.34
525	7.99	0.8741	0.1094	0.30
550	14.17	1.8614	0.1314	0.30

(iii)R.Kizu basin

Precipi-tation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
425	3.41	0.0446	0.0131	0.18
475	25.28	0.3257	0.0129	0.20
525	22.59	0.5110	0.0226	0.18
575	12.07	0.4371	0.0362	0.18

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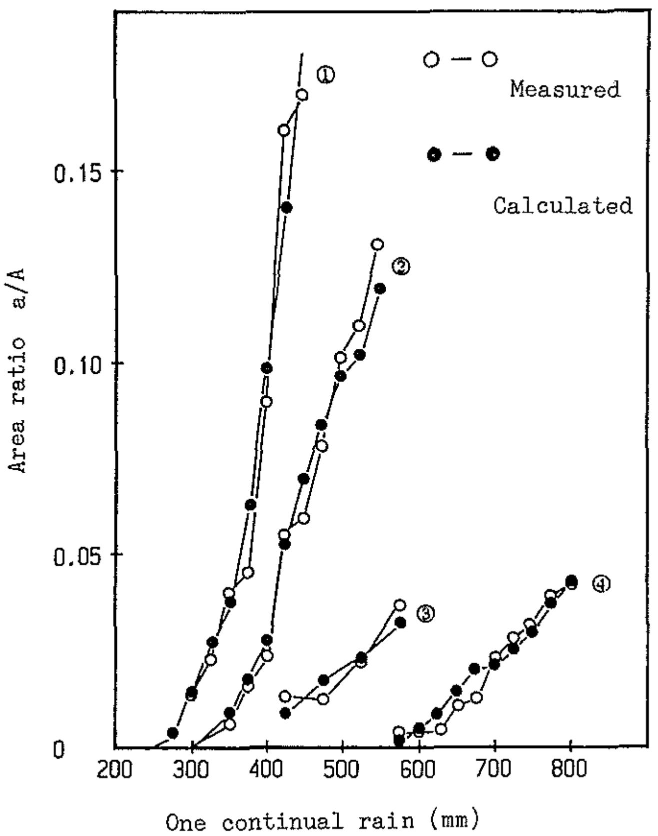
(iv)R.Arita basin

Precipitation(mm)	Area of basin	Total area of slides	Area ratio	Relief ratio
575	10.49	0.0470	0.0048	0.29
600	32.01	0.1205	0.0038	0.33
625	14.97	0.0605	0.0040	0.38
650	13.24	0.1436	0.0108	0.43
675	9.59	0.1152	0.0120	0.44
700	7.69	0.1801	0.0234	0.35
725	4.02	0.1139	0.0283	0.32
750	1.84	0. 581	0.0316	0.32
775	0.97	0.0374	0.0386	0.33
800	1.50	0.0631	0.0421	0.33

The values of the relief ratio could be considered to have constant value when we think of it for a fixed basin. The value of the coefficient K can be the presentative constant of a basin and when the value of K is bigger, sediment yield due to surface slides or other mass movements seem rather vivid in the basin than others.



① R.Kmanashi $a/A = 0.8x10^{-4}(R-250)^{1.5}x\ Rr$
② R.Tenryuu $a/A = 1.0x10^{-4}(R-300)^{1.5}x\ Rr$
③ R.Kizu $a/A = 0.45x10^{-4}(R-325)^{1.5}x\ Rr$
④ R.Arita $a/A = 0.325x10^{-4}(R-500)^{1.5}x\ Rr$

Figure 1--Relation between the area ratio and precipitation of one continual rain

As a result, this formula represents only the state of the occurrence of surface slide and only represents that the more the the amount of precipitation augments, the bigger the value of the area ratio becomes. In other words, the temporal increase of the number of surface slides in a fixed basin can not be estimated.

As for the value of the invalid precipitation; r of these formula are determined by the data in order to reduce the formula and subsequently the precipitation of one continual rain which would lead to the occurrence of surface slides is not necessarily bigger than the derived "r" value. So, in the following part, in order to predict the amount of surface slides which will occur repeatedly in the same basin, derived value of "r" are not used, and treating "r" as a variable, determined it to suit the real state of the temporal increase of surface slides.

TRANSITION OF THE AREA RATIO IN A BASIN

Before discussing about the transitionsin of the value of area ratio, it is necessary to know the upper limited value of the area ratio. Figure 2 shows the relation between the total area of surface slides;a and the area of the basin;A. The oblique line in the Figure is the line when a/A = 1.0 and in this case, all part of the mountain of a basin is bare due to surface slides, consequently, the total area of surface slides should be plotted beneath the oblique line.

When the area of two basin are decided arbitrary and if there are no surface slides, the initial states are plotted on the abscissa as shown in Figure 2 by ○ and ●, and these two points move directly upwards as the total area of the surface slides increases. Even when the values of "a" are same for two different basins, the values of a/A differ to each other because of the value of the area of the basin are not the same. In this condition, the larger the area of the basin becomes, the less the value of a/A becomes. Subsequently, in the case of discussing exactly about the area ratio, the value of the area of basins should be made uniform. But, to discuss about it here is not the aim of this paper, the author only point out the importance of this subject.

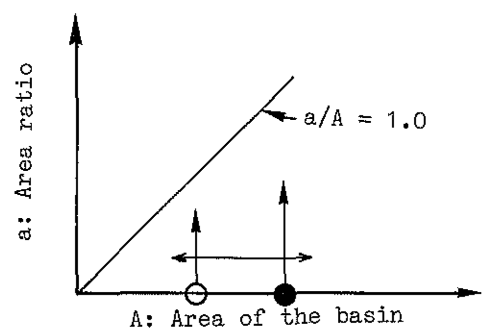


Figure 2--Relation between the total area of surface slides and the area of the basin

Figure 3 and 4 show the relation between the total area of surface slides and the area of the basin by the author and Yoshimatsu respectively. As shown in both figures, common envelope curves are drawn and in this case, the value of the area ratio is 1.5 and this value can be the upper limited value of the area ratio. This value coincides with that of the R.Kamanashi basin which is given by Yoshimatsu, though the conditions of the occurrence of surface slides seems extremely ruined condition.

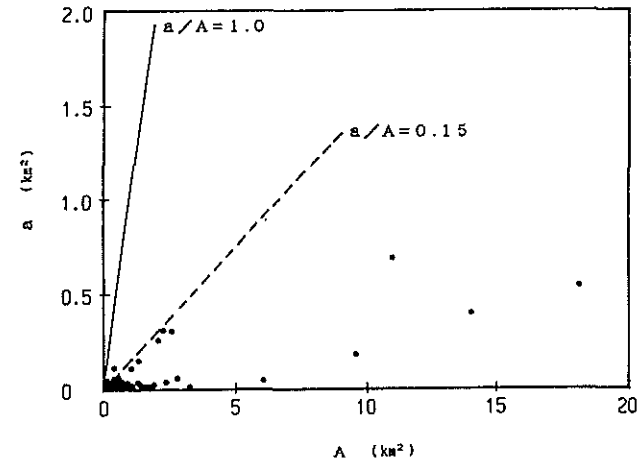


Figure 3--Relation between the total area of surface slides and the area of the basin by Hiura

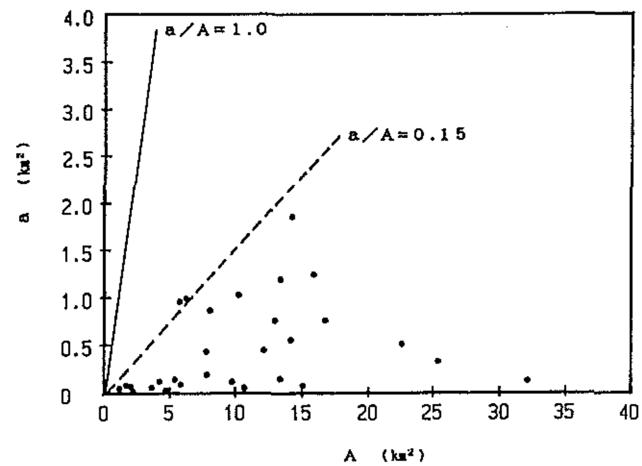


Figure 4--Relation between the total area of surface slides and the area of the basin by Yoshimatsu

Transition of the number of surface slides

Figure 5 shows the yearly fluctuation of surface slides of the Tsuchiyabara district(R.Kizu). As seen in Figure 5, the values of the area ratio tends to increase and converge to a final value. The values of the area ratio in 1971 and 1976 are indicated below;

Year	Area ratio
1971	0.0450
1976	0.0492

and the maximum precipitation of a year during 1971 and 1976 are as follows;

Year	1971	1972	1973	1974	1975	1976
Precp.(mm)	166.3	203.0	133.1	144.0	157.5	240.0

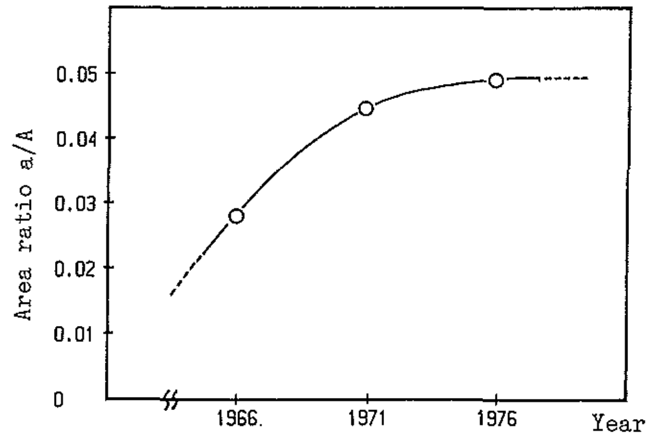


Figure 5--The yearly fluctuation of the area ratio of R.Kizu basin

These values do not exceed the invalid precipitation 325mm which is presented by Yoshimatsu. Thus, it is clear that the formula can not be used for the estimation of the yearly increment of the area ratio. So, as mentioned above, taking the invalid precipitation as a variable, and dividing precipitation into two groups;R>200mm and R<200mm and assuming the value of the area ratio to be a/A =0.0012 and 0.0006 correspondingly to the precipitation respectively. The results of the estimation of the invalid precipitation are indicated in Table 2 as well as the maximum precipitation, the difference of both precipitations;the valid precpitation;(R-r) and the area ratio. As the mean value of the area of the basin is approximately ten km from Table 1, then annually fifty slides when R>200mm and twenty-five slides when R<200mm will occur accoding to the estimation of this paragraph and these values seem reasonable.

Table 2--Maximum continual precipitation;R, area ratio;a/A, invalid precipitation;r and valid precipitation;(R-r) for Tuchiyabara district(R.Kizu basin)

Year	Maximum continual precip.	Invalid precip.	Valid precip	Area ratio
1972	203.0(mm)	175.5(mm)	27.5(mm)	0.0012
1973	133.1	115.8	17.3	0.0006
1974	144.0	126.7	17.3	0.0006
1975	157.5	140.2	17.3	0.0006
1976	240.0	212.5	27.5	0.0012

PRESENTATION OF THE STATE OF SURFACE SLIDES IN USE OF THE WEIBULL DISTRIBUTION FUNCTION

It was recognized above that the state of the occurrence of surface slides in a basin at an arbitrary state can be expressed by the area ratio which is the function of the precipitation. On the other hand, the Weibull Distribution Function which the author has employed has successfully presented the state of the yearly fluctuation of surface slides(3). Here, by combining both method, the hazard mapping of surface slides is presented.

Firstly, the foregoing results are summarized and then the method for mapping is presented. It is natural that the value of area ratio of a basin differs to each other according to the difference of the state and history of the occurrence of surface slides in a basin. The Weibull Distribution Function is one of the statistic density functions and originally adopted for the treatment of the experimental data and because of its easiness and conformity, it has come to be used frequently. The formula of this function is expressed below;

$$f(x)=m\alpha^{-m}(x-\gamma)^{m-1}\exp(-((x-\gamma)/\alpha)^{m}) \quad \text{--- (2)}$$

Three parameters included are the location parameter: γ, the scale parameter: α and the shape parameter:m respectively. Thus, the state of the distribution of surface slides of a basin at an arbitrary time can be expressed by these three parameters. The author has already recognized that when the number of surface slides increase yearly in a basin, α and m increase, but γ decreases, and confirmed that the values of three parameters fluctuate in accordance with the transition of the slide numbers.

Area ratio and Weibull parameters

Table 3 indicates the number of slides, the area ratio a/A and values of three parameters of five survey basins(Figure 6). These basisns have different situations concerning the occurrences of surface slides;for exemple:numerous slides have just occurred, the number of slides is increasing or decreasing and so on. Figure 7 shows the relation between Weibull parameters and area ratio . The scale parameter α and the shape parameter m increase with the increase of a/A, and location parameter γ decreases inversely. So, the conditions of the occurrences of surface slides could be presented by a set of Weibull parameter values at an arbitrary value of a/A and in that case, the scale parameter is the most effective one. Following formulas to calculate Weibull parameters using the value of the area ratio were derived using data in Table 3.

$$\alpha = 37.5091(a/A)-0.1272 \quad \text{---------(3)}$$
$$m = 18.2635(a/A)+0.4645 \quad \text{---------(4)}$$
$$\gamma = -10.5580(a/A)-0.0614 \quad \text{---------(5)}$$

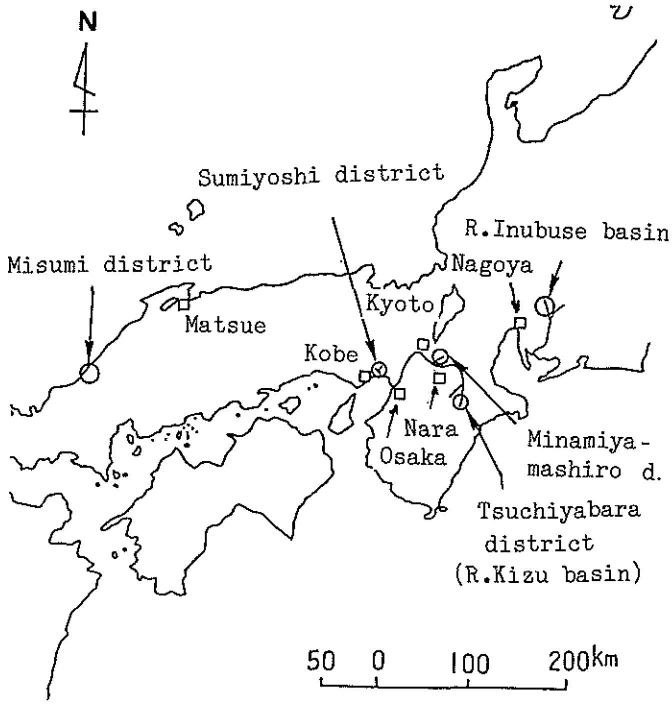


Figure 6--The location map of the survey areas

Table 3--Yearly fluctuation of Weibull parameters

(i)Tsuchiyabara district

Year	Total number of slides	Area ratio	Parameter α	m	γ
1966	1109	0.0282	1.011	0.994	-0.353
1971	1768	0.0450	1.573	1.155	-0.441
1976	1936	0.0492	1.802	1.240	-0.528

(ii)Minamiyamashiro district

Year	Total number of slides	Area ratio	Parameter α	m	γ
1954	1725	0.0254	1.030	1.059	-0.412
1963	2435	0.0359	1.346	1.162	-0.437
1971	1745	0.0257	0.983	1.039	-0.368
1983	614	0.0090	0.324	0.732	-0.182

(iii)Sumiyoshi district

Year	Total number of slides	Area ratio	Parameter α	m	γ
1966	937	0.0196	0.685	0.801	-0.316
1967	1296	0.0403	1.587	1.215	-0.544
1971	623	0.0130	0.448	0.771	-0.216

(iv)Misumi district

Year	Total number of slides	Area ratio	Parameter α	m	γ
1976	355	0.0007	--	--	--
1983	6396	0.0117	0.468	0.836	-0.239

(v)R.Inubuse basin

Year	Total number of slides	Area ratio	Parameter α	m	γ
1964	1321	0.0049	0.067	0.000	0.116
1972	4054	0.0151	0.626	0.934	-0.291

SIMULATION OF THE FUTURE SLIDE DISTRIBUTION AND MAPPING

Of five districts investigated hitherto, in the case of Tsuchiyabara district(R.Kizu basin), the number of surface slides continues to increase . So, the author tried to simulate the plane distribution of slides and to draw them on the map . The simulation was done according to the flow chart shown in Figure 8 and following procedures;

1) As a basis, the distribution map of surface slides existing in 1971 was used and the area ratio was a/A = 0.0450(Table 3). 2) Establish maximum precipitation of each year and calculate annual value of area ratio. 3) In five years from 1971 to 1976, the increment of surface slides is a/A = 0.0042. 4) Substituting a/A = 0.0450 into formulas;(3),(4) and (5), the values of parameters were calculated as follows: α = 1.718, m = 1.363 and γ = -0.581. 5) Calculate by the equation (2), the ratio of each mesh(75mx75m) containing zero to nine slides, and multiplying them by the total number of meshes of the basin(1678 for Tsuchiyabara district), the real number of each mesh is estimated. Table 4 indicates the values of real and estimated number of meshes. 5) Draw the distribution map indicating hazardous mesh suffering from the occurrence of surface slides by the number of slides in 1976.

Table 4--The estimated and real number of each mesh containing slides in 1976 (Tsuchiyabara district:R.Kizu basin)

Number of slides in each mesh	Real Number	Real Ratio	Estimated Number	Estimated Ratio
0	719	42.8	682	40.6
1	416	24.8	530	31.6
2	286	17.0	280	16.7
3	156	9.3	120	7.2
4	55	3.3	45	2.6
5	28	1.7	15	0.9
6	10	0.6	5	0.3
7	5	0.3	1	0.1
8	2	0.1	0	0.0
9	1	0.1	0	0.0
Total number of slides:	1936		1742	
Total number of meshe:	1678		1678	

Morphlogical analysis

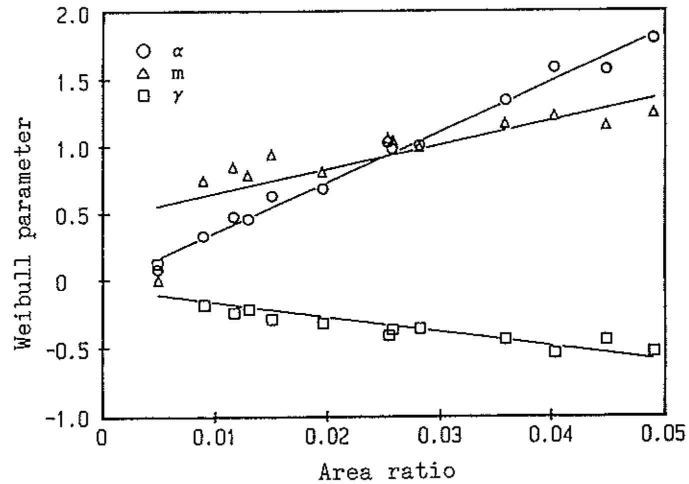


Figure 7--Relation between the Weibull parameter and the area ratio

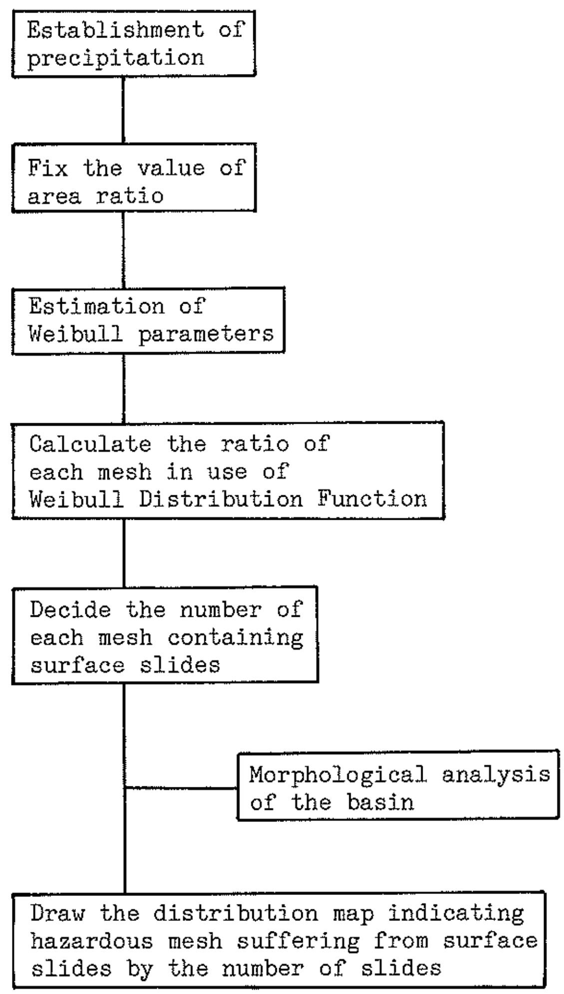


Figure 8--Flow chart to map the hazardous zone of surface slides

Before drawing the map, subsequent morphlogical analysis was done.

In general, a knick point in the longitudinal profile of a stream is recognized as the place where mass movement occurs vividly and many slides also occur at this point. The knick point is located at the uppermost point of a river where a stream line disappear on the topographical map. A point of abrupt change of the inclination seen in the longitudinal profile of a slope can be the point of the occurrence of surface slides and this point can be distinguishes as where the relief of a mesh suddenly diminishes, in other words, the inclnation of the slope turns from steep to gentle when going upstream or going upwards on the slope on the relief map. In the first meaning, the stream line distribution map and in the second meaning, the relief map were used.

The mesh on which the knick point is found and the mesh whose relief indicates the steep inclination are not always the same. So, both when two conditions are overlapped and when either condition is satisfied, the increase of number of slides in the mesh is decided, the former preferentially. As the total number of the meshes is limited, the meshes which are to be increased were selected carefully considering the topographical conditions surrounding them.

Figure 9--Simulated distribution map of surface slides

Distribution map of the future slides

As for the total number of the surface slides, the real number exceeds the estimated value by 194 . This is due to the difference of the number of meshes containing more than three slides in them. The estimated number of meshes containing one slide in them is fairly large. The ratio of the estimated value to the real value is 1.3, so this value could be considered as the safty factor and to prepare for the dangerousness of the disaster using hazard map, this value never seem to indicate the excess value.

Figure 9 shows the numerical map of simulated plane distribution of slides. The circled numerals in Figure 9 are those who make good guesses. There are 600 meshes among 1687 meshes, of which the place of the occurrences of slides were guessed and the ratio of the guess is about 35.8pct. Of meshes containg zero slide, there are 350 meshes among 682 meshes could be guessed and in this case, the ratio is 51.3pct. Consequently, the simulation could be considered to be done successfully, considering the complexity of the process of the mass movement on the mountain slopes.

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