# On the Statistical Study of Landslides by Heavy Precipitation in Asigawa Watershed.

Masaharu Kikuchi.

# 豪雨による芦川流域の山地崩壊に関する統計的解析について

菊　地　政　泰

**要旨：** 1966年の台風26号による芦川流域の山地崩壊について、統計解析を行った。その結果は次のようである。

(1) 齢級別面積割合からいえば、林分の若いほど、崩壊の発生は激しい。

(2) 斜面傾斜の構成分布を調べると、崩壊は傾斜の急なほど発生しやすい。これまで、35°附近が崩れやすいとされて来たが、根拠はない。

(3) 確率雨量を調べた結果、芦川の場合、最大日雨量よりも、最大時間雨量に大きく影響されたと考えられる。

(4) 流域に1kmの方眼をかけ、地質別に地形要素を調査して、崩壊との関係を解析したが、単相関係数はいずれも低い値を示した。

(5) 地質の影響について、分散分析を用いて、崩壊の発生頻度を検討した結果、第三紀層地帯と花崗地帯では差のあることが解った。

(6) 各々の方眼内の要素と崩壊発生について、多重回帰解析を行ったが、0.1%の危険率で有意といえた。さらに偏相関係数によって、崩壊に与えた平均傾斜と谷密度の重みは1：1となり、差は現われていない。

今後、林況の因子を加える必要があろう。

## Introduction.

Many studies have been carried out on the landslides and related phenomena. They are generally classified into two large groups.

In the first group,[1] it has been studied experimentally by means of natural or artificial precipitation how the water condition of natural or arificial slopes varied in proportion to increment of ground storage, and the results of experiment will be applied deductivelly to mountain slopes.

The other is the inductive method,[2] which is to investigate the several fundamental factors in unit areas, for example, the areal and numeral ratio of landslides, the averaged gradient of slopes, the areal ratio of age class, and so on.

The effects of the enviromental factors on occurrence of landslides has been analyzed by statistical method.

In either case, the final purpose of their study is to know the truth of occurring landsides and to take precautions against a possible calamity. It is now important for explaining of landslides phenomena to accumulate many studies on both view points.

This reports deals with the statistical analysis on the occurrence of landslides to make clear the related factors on them. Though for presumming exactly the occurrence, primary subjects of study should be "when, where, how", they are too difficult to solve directry. The writer will obtain the relative indices to occurrence of landslides on natural slopes, on the assumption that the geological features and precipitation in the researched watershed is identically.

**acknowledgment**

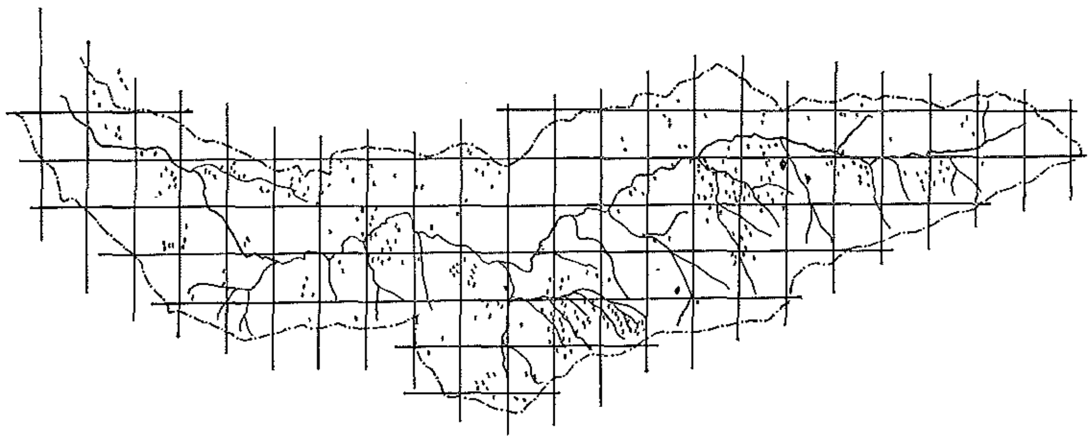
The writer would like to express his appreciation to the late Dr. Aiji ANDO, the Director of Yamanashi Prefectural Forest Experiment Station, for his guidance and interest. And also the writer heartily extend his thanks to the staff of the Department of Forestry and the Experiment Station in Yamanashi Prefecture for cooperation and discussion to investigate the primary data.

## I. General Situation of Asigawa Watershed.

On September 24, 1966, Typhoon "No. 26" brought the heavy precipitation amounting to more than 300㎜, and many parts in Yamanashi Prefecture. suffered disasters.

Since the disaster, the primary researches on the matters pertainning to occurrence of many new landslides have been done by the staffs of Forest Goverment. Its primary date for investigation are presented in the reports of the Department of Forestry.[3) 4)]

Under this extraordinary precipitation, in Asigawa watershed which is upper reaches of the river Fuji, it suffered severely mud and debris flows with the occurrence of many landslides in the mountain rainge. (Fig 1)



Fig－1 **The point of landslides in each section in Asigawa Watershed.**

This researched watershed is situated in the north side of the mountain rainge from the Kurodake makes the wall of the kōfu basin.

Main course of the river Asigawa has an overall length of 28-kilometer, and its watershed coveres an area of 90 square kilometer approximately.

The Geological features have the two type of granite zone and Tertiary zone which can be divided the stratum of the Nishiyatushiro, Tenshisan, Takitoyama, Ōishi, and Misakasan. (Fig 2)

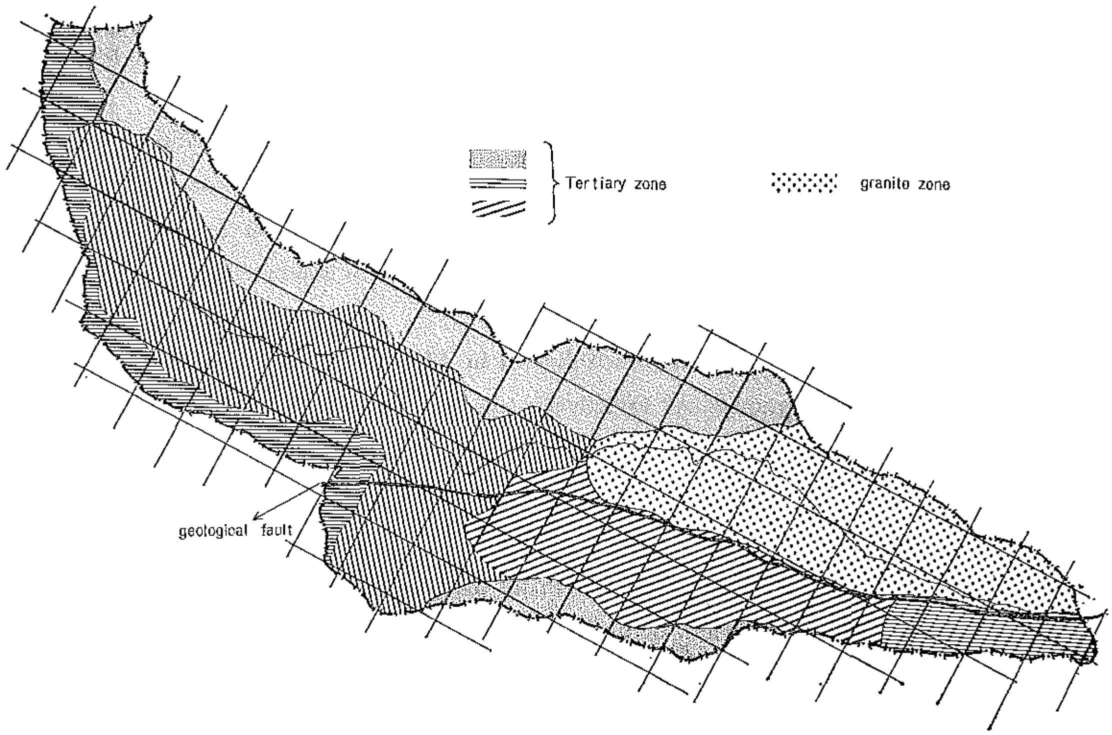



Fig 2 —The Geolgical feature in Asigawa

Its stratum consists of the volcanic rocks, granite, diorite, quartz-andesite and basalt. The line of fault which is usually considered that the landslides are easy to occur is observed between granite zone and Tertiary zone.

Configuration of the ground is very steep, and the relief energy is shown with the high values.

## Ⅱ. Method of analysis.

All this while, the statistical studies of landslides have been discussed with the factor of circumstance for a only point of its,[5] for example, the area of landslides, the slope gradient, stand conditions, and so on.

However it is presented exactly that we must take up the relationship between the enviromental factors at the unit area including landslides and its factors upon them for the statistical analysis. Because if the forest description is covered the coniferous forest, the landslides is naturally situated on coniferous stand.

Generally it is mentioned that many landslides occurred on slope of 30-40 gradient, but the many natural slopes are usually composed of their gradient slopes.

Several methods can be consdered on the deviation of the unit area at the researched watershed. Y.Mulano makes use of the method of the order analysis.

This order analysis takes an attempt to determine the stage of erosional conditions in the unit watershed. This deviation makes differ the area and configuration of this watershed, but it is easy to investigate the factors in enviroment. And also we can find the fault which several regions are omitted from the researched unit, and it is difficult to remove the effects of each differential areas.

The writer made use of the method which divided in 1-kilometer grid sections on the map of 1:5000 from aerial photographs, and investigated the enviromental factors, for example, the valley density, the areal and numeral ratio of landslides, the relief energy, and the averaged gradient in each sections for analyzing the relationship between the areal and numeral ratio of landslides and several factors.

The valley density was measured the all length till the point which the length of embayment on contour line is equal to the width of its.

On the analysis of the relationship between slope gradient and landslides it is necessary to obtain the ratio of the each gradient range in watershed.

The gradient line has been universally considered as the method of research[6] but the determination of gradient line is arbitrary and easy to make a personal errors. Therefore the writer made use of method which coloured the slope in gradient 0-4°, 5°-14°, 15°-24°, 25°-34°, 35°-44°, 45°-, and computed the ratio of areas among the interval of 3-5 contour line. The measurement of each areas has been taken up by means of cutting and weighting of the parts in each unit sections.

The averaged gradient was presumed from tangent in proportion to the area of each gradient grade. This method is more exact than the gradient line.

The area, gradient, type of slopes, and area of age class on the landslides were taken up from the fundamental data at the Goverment of Forestry in Yamanashi Prefecture.

## Ⅲ. Peculiarity of landslides in Asigawa Watershed.

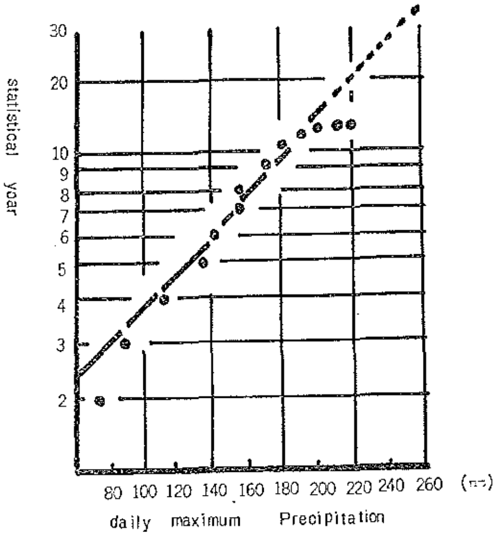
1). The statistical charactor of rainfall.

The heavy precipitation by the typhoon No. 26" which occasioned directly their disaster were continuing from September 21 to 26, and its tatal precipitation is 300㎜ at Kamikuishiki village, 241㎜ at Ashigawabashi on the mouth of this river.

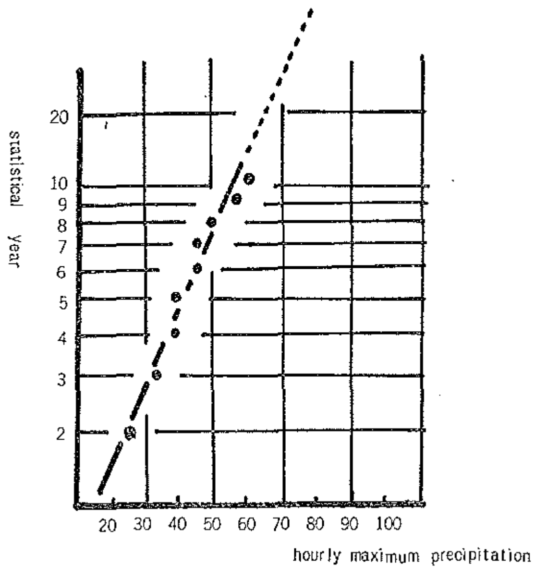
The each daily and hourly maximum precipitation are 199㎜ and 99㎜ at Kamikuishiki, 182㎜ and 61㎜ at Ashigawabashi.

The observation of precipitation in their regions has been continued since the year 1952. From this data the maximum possible amount of precipitation can be computed stochastically. It can be approached by plotting on the semilogalithmic paper in the case of few data approximatelly.

At the Kamikuishiki, the daily and hourly precipitation of the stochastical maximum in each year as follows;




Fig－3 **The stochastic precipitation of daily maximum at Kamikuishiki**




Fig－4 **The stochastic precipitation of hourly maximum at Kamikuishiki.**

From this analysis, the daily precipitation of 200㎜ which was brought by the typhoon No. 26 can be occurred once in 10-15 years nearly. However the maximum hourly precipitation of 99㎜ at Kamikuishiki can be occurrence in 150-200 years.

From this point of view, it can be considered that this hourly precipitation stands in causal relations directly to mud and debris flows with many landslides than the maximum daily precipitation.

2). The depth and type on slopes of landslides.

The averaged depth of landslides in researched watershed is less than 1.00 meter practically and is severally observed to be less than 0.50 meter. The landslides on granite zone appears to be shallower comparatively than the others of heavy rains.

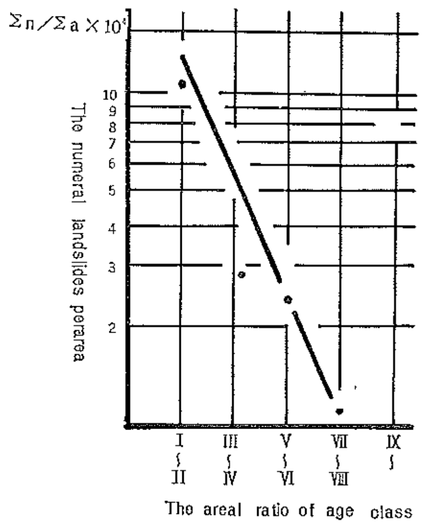
The gravitational landslides may be many in this watershed according to heavy precipitation in short periods.

On the type of slope occurred them, there are more landslides on the uniform and concave slope than the convex slope, but it is difficult to make clear what any slope is easy to occur the landslides by only this data. It have to be evidential the area of distribution slopes.

## Ⅳ. The relationship between of landslide and its factor.

Although the relationship between condition of forest covers and of landslides has been discussed for a long time, the forest influence for its can not be made clear even now. It is difficult probavely to take out only effects of the forest stand from its of the other factors.

In this paper the relationship between forest age and landslides is analyzed in researched watershed. The results of its is as follows;




Fig—5 **The relationship between numeral ratio of landslides and the arial ratio of age class.**

The numerals of landslides in each unit sections are more on the low forest age than the high.

At least, it may be mentioned that the condition of forest stand was concerned with the occurrence of landslides in this watershed.

However the ratio of forest age in each sections cannot be pursued regretably by reason for small area in this region.

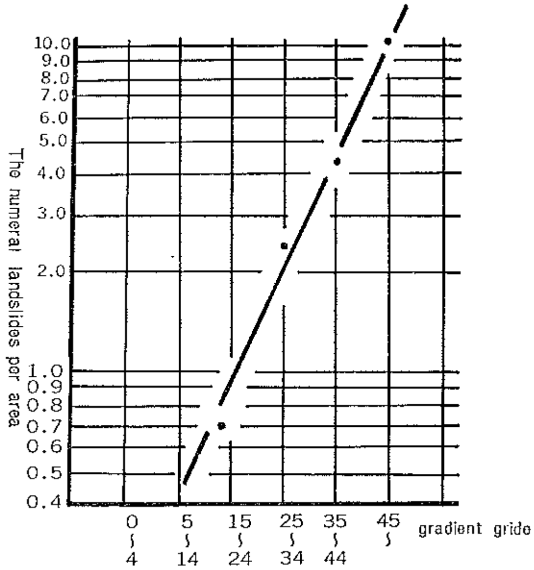
Next it has to be analyzed by means of Ⅱ-chapter what the distributed constraction of slope takes up upon the mountain rainge in this watershed. The relationship is shown in Fig 4. as follows; As the inclination of slope makes to be steeper, the landslide is taken up easier to occur.

All this while, it is generally mentioned that the landslide is easiest to occur nearly on the slope of 35-gradient, but it is necessary to be corrected.

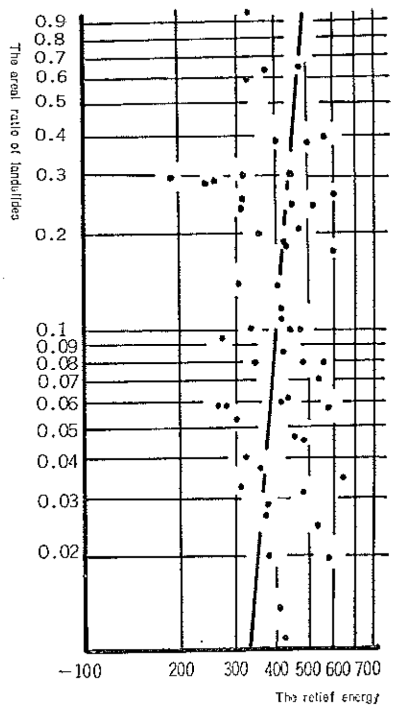
This conclusion was indicated by Y.MURANO simaltaniously.

The topographical factors, for example, the averaged gradient, the valley density, and the relief energy, have been taken up in each sections and analyzed in causual relationship to the occurrence of landslides.

Their every correlation coefficients were significant low. The relationship between the relief energy and the numbers of landslides in each sections is shown in Fig-6.




Fig—6 **The relationship between numeral ratio of landslide and the gradient gride.**




Fig—7 **The relationship between the landslides and the relief energy.**

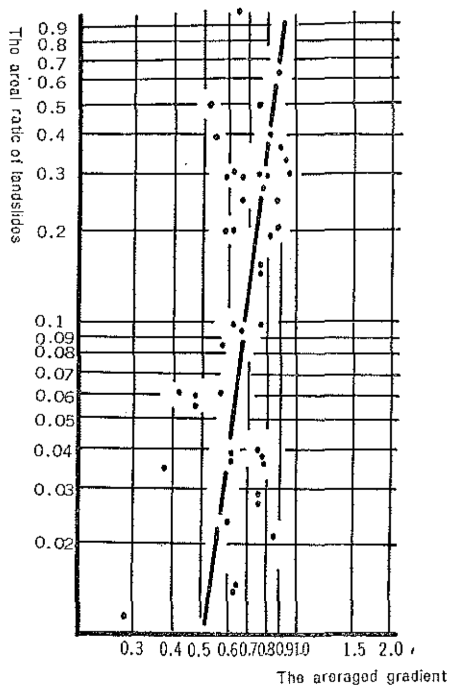
From this results, the following two reasons may be considered, the cause for matters which every simple correlation coefficients is significant low.

In the first case, it is able to say that as several factors effect coincidentally on the landslides, the single correlation cofficients have not significant.

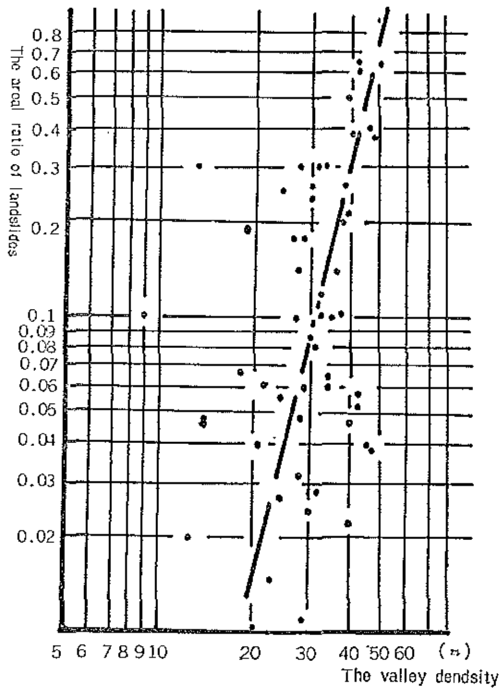
In the other, it may be given rise to discussion divide in grid sections at the investigative watershed.

The enviromental factors in each sections became to make no resemblance to their factors upon the point of landslides, because the measurement ef topographical factors have been averaged approximately in each grid sectiions. Therfore the method of deviation upon the investigative watershed will have to be reexamined on be viewpoint determinning the erosional stage. It will take up the other method of division.

The relationship between the areal ratio landslides and the valley, and one between this ratio and the relief energy in each grid sections are shown in Fig-7. and Fig-8. And also the relationship between this areal ratio and the averaged gradient in each grid sections is shown in Fig-9.




Fig－8　**The relationship between the landslides and averaged gradient**




Fig－9　**The relationship between the landslides and the valley density**

Table 1　**Correlations coefficient**

| | The avergaed gradient | The valley density | The reliet energy |
|---|---|---|---|
| The areal ratio of landslides | 0.1277 | 0.1762 | 0.3277 |
| The numeral ratio of landslides | — | — | 0.1884 |

In the next place, the relationship between geological features and the landslides have to be analyzed in each sections.

It is generally mentioned that the factor of geological feature is concerned with the landslides. But it is considerably difficult to analyze calculatively, as the geological feature cannot be measured quantitativelly. In this case, the analysis of variance is used.

This researched watershed makes to be divided into two parts, the granite zone and the Tertiary zone by the line of geological fault. In this paper the homogenity of mean value has been calculated on the areal ratio and numbers of landslides in both geological zone. It is shown in Table 2.

Tablde 2

**The analysis of variance into granite zone and Tertiary zone**

| | Numbers of landslides | degree of freedom | averaged numbers in each section | Variabce analysis |
|---|---|---|---|---|
| Tertiary period | 148 | 37 | 4.0 | 18.65 |
| Granite zone | 114 | 20 | 5.7 | 46.81 |

$$S = 0.247$$

by t — test,

t = 6.88 d.f. = 57

H; = 0 P <0.1%

In this watershed, at least, it is approached to conclude that there are a difference between Tertiary zone and the granite zone. And also it can be conclded simutainiously with 0.1%, the ratio of risk on the areal ratio of landslides.

## V. The relative indices for landslides on the natural slopes.

As the fundamental purpos e of preventive conservation takes to predict the landslides and defend the disaster in minimum, it will be extremly important to obtain the relative indices for its on the natural slopes with the object of making clear the theoretical dangerous zone to occur.[3]

However the multivariate regression analysis has been applied for analysis of them, several methods can be considered. In this chapter, the weight of topographical factors for occurrence of landslides has been researched on this Ashigawa watershed by means of multivariate regression analysis.

Firstly, let the areal ratio of landslides (Y) in each unit sections be the dependent variable, and the averaged gradient ($X_1$) and the Valley density ($X_2$) be the independent variables respectively.

The following function of the multiple regression curve was calculated.

$$Y = a X_1^b X_2^c \quad \cdots\cdots (1)$$

Let take the logarithmic transformations,

$$\log Y = a + b \log X_1 + c \log X_2 \quad \cdots\cdots (2)$$

here,

$$\log Y = y$$
$$\log X_1 = x_1$$
$$\log X_2 = x_2$$

The normal equattion by the method of least squares are

$$\left.\begin{array}{l} n\,a + (\Sigma x_1)\,b + (\Sigma x_2)\,c = \Sigma y \\ (\Sigma x_1)\,a + (\Sigma x_1{}^2)\,b + (\Sigma x_1\,x_2)\,c = \Sigma x_1\,y \\ (\Sigma x_2)\,a + (\Sigma x_1\,x_2)\,b + (\Sigma x_2{}^2)\,c = \Sigma x_2\,y \end{array}\right\} \cdots\cdots\cdots (3)$$

When the data of each factors were appropriated in the function above mentioned.

In the Granite zone,

$$Y = -8.531\,X_1{}^{10.410} \cdot X^{2\ 6.514} \cdots\cdots\cdots (4)$$

In the Tertiary zone,

$$Y = -0.783\,X_1{}^{0.719} \cdot X_2{}^{-0.783} \cdots\cdots\cdots (5)$$

where, Y ; The areal ratio of landslides.
$X_1$; The averaged gradient
$X_2$, The valley density

The areal ratio which can be presumed from these functions in each sections is not always exact. Because the occurrence of landslides is influenced by the factors of precipitation and of the others too, and the factors are not contained in this fomula. However it can be to analyze the influence of independent variables for dependent its by calculation of partial regression coefficient.

The partial regression coefficient is given by

$$b'y_{12} = by_{1\cdot 2}\sqrt{\Sigma x^2{}_1 / \Sigma y^2}$$

$$b'y_{21} = by_{2\cdot 1}\sqrt{\Sigma x^2{}_2 / \Sigma y^2}$$

This result is shown in Table 2

Table 3……**The partial regression coefficient**

| | The granite zone | The Tertiary zone |
|---|---|---|
| $b'y_{1\cdot 2}$ | 0.713 | 2.544 |
| $b'y_{2\cdot 1}$ | 0.739 | 2.245 |

In the both of granite and Tertiary zon, the distribution ratio of various factors influenced for landslides has been the ratio of lands lides.

Therefore it is mentioned that the steeper the averaged slopes are and the longer the valley lengt in each sections are, the easier the landslides is occurred.

From the geological points of view, landslides and the related phenomenon are considered important factors of variance on the process of slope development.

The actual morphology in watershed represents one stage.

**Summary**

The relationships between the landslides to be occurred by heavy precipitation of the typhoon "No. 26" (1966) and various topographical factors has been analyzed statistically. The results are as follows,

(1). The younger the age of treesis, the easier the landslides have been occurred over ther in the researched.

(2). The steeper the averaged gradient of slopeis, the easier the landslides have been occurred. It is, therefore, necessary to be corrected that the landslides are easiest to occurr nearly on the slope of 35-gradient.

(3). The occurrence of mud and debris flows with many landslides have been more effected by the hourly maximum precipitation than the daily maximum on account of computation of stochastic precipitation.

(4). The researched watershed is divided in 1-kilometer grid sections on the map of 1:5000 scale. In each unit sections, the relationships between the occurrence of landslides and topographical factors; the averaged gradient, the valley density, and the relief energy, are analyzed statistically. The simple correlation coefficients are significantly low.

(5). On the areal and numeral ratio of landslides, the significant difference was recognized staistically between Granite zone and Tertiary period zone by means of analysis of variance.

(6). In each sections, the weight of the averaged gradient and the valley density has taken the ratio of 1:1 for the occurrence of lanpslides on the both zone of granite and Tertiary period by means of multiple regression analysis.

**Reference**

1). Michitaka Saito and others; (1968)

Anticipation of Behavior and Estimation of Failure of cut Slopes under Rainfall.

The Railway Technical Research Institute, Japanese National Railway. No.630

2). T. Maruyasu;

Statistical Analysis of landslides and Related Phenomenon on Aerial Photographs.

Transactions of the Japan Society of Civil Engineers No. 116 (1965)

3). Department of Forestry, Yamanashi Prefecture;

Statistical Research on the Mountain Landslides by Typhoon No. 26. in Yamanashi. (1967)

4). Depertment of Forestry. Yamanashi Prefecture

Statistical Analysis on the Mountain Landslides by Typhoon No. 26 (1968)

5). D. Sasaki and Y. Ogiwara

A Study on the Flood Runoff at Honzawa by Typhoon No. 26

.Bulletin of Yamanashi University Technology No. 18 (1967)

6).Y.Murano;

A Study on the production of Earth and Sand in Mountain District. Report of Public Works Research Institute Ministry construction No.125(1962)

7). S. Nanba and R. Kono;

Mountain Devastation by Typhoon "No. 26" Storm in Asiwada District and the Relevant Countermeasurres. (1968)

Bulletin of the Goverment Forest Experiment Station No. 215