II-3 Studies on the Method of predicting area in Danger of devastation and Flood Runoff

II-3-1 Studies on the method of predicting watershed in danger flood runoff

(1) Method of study

The following methods can be cited as the method of predicting watershed in danger of flood.

i) Method by excessive probable flood

Amount of flood and its probability of occurrence expected in the future are calculated based on the record of past flood for each of the watersheds, and the danger is measured by the figures.

ii) Method by excessive probable rainfall

The higher the amount of rainfall, the more is the risk of flood occurrence, and the danger is ranked by estimating the amount of heavy rain, its probability of occurrence, and regional distribution based on the past records of rainfall in the same way as i).

iii) Method by watershed variables

Although the direct cause of flood is the conditions of rainfall, the occurrence of flood is also governed by the response of the watershed against the rainfall. Therefore, in this method the danger of flood occurrence is predicted in relation with topographic conditions and ground coverings.

Of the above three methods, i) and ii) are suitable for the watershed of medium to large area watershed, in view of arrangement and availability of necessary data, but they are difficult to apply to small area watershed. The method iii) can be applied to any of watersheds of large, medium, and small area; but it would be suitable to medium to small watershed when the amount of works required for measuring watershed factors is considered.

Occurrence of flood is thus governed by a series of complex factors, besides it is an organic phenomenon. Measurement of many characteristic values such as watershed conditions and rainfall conditions are necessary for explanation, and spatial-temporal variation of the characteristic values is governed by many factors. In addition, the characteristic values measured influence one another in many cases. Therefore, the method of multivariate analysis, that is a method of analysis by consideration of mutual relation between characteristic values, would be a better method for explanation of the phenomena.

Various analytical methods have been adopted for predicting watershed in danger of flood or landslide.

Relationship between watershed factors (also called watershed variable), such as geology, topography, soil, forest, etc. of the watershed that are regarded as primary cause, and flow factor of the watershed, such as peak specific flow, increment flow, etc., has been investigated in Japan and other countries by multiple watersheds method. (3.1-1) Correlations between various watershed factors and peak specific flow and other flow factors were obtained. Then in this method, the multiple regression equation was introduced for obtained peak specific flow, by taking various watershed factors as independent variables, and degree of danger of flood in the watershed was predicted. In other words, the method iii) above was adopted.

It would be desirable as the means of research by São Paulo Forestry Institute that examination be extended for the analytical techniques in such a direction that not only interval scale but also nominal scale be applied to explanation variable and objective variable, with reference to comparatively simple analytical method such as multiple regression analysis and accumulating experience, so that the content of investigation and research be graded up.

(2) Result of Study

1) Study plan

Initially, the method of predicting watershed in danger of flood was scheduled to be carried out in the watershed of Rio Una. Rio Una is a branch of Rio Paraiba, and it joins Rio Paraiba on its right bank in the east of Taubate City. The watershed of Rio Una is the water reservoir for the service water of the city; and Taubate City is an especially important district geographically and economically as it is located between the two largest economic centers in Brazil, São Paulo and Rio de Janeiro.

The land that once produced coffee as the major producing land and brought prosperity to Brazil is now deprived of the original plants, and "semi-arid forest in Paraiba Valley" is left in a very small area in Serra Quebra Cangalha. The land is barren, and from the remain of coffee farm, reddish yellow podzol and clay soil runs off after conversion into grazing land or farm, owing to a poor maintenance; and the river water of Rio Una is colored red. Therefore, the watershed of Rio Una is especially important in terms of watershed management. The watershed of Rio Una was wisely selected as subject of study in this sense.

The consistent research, that was intended at first as regards items of study, such as setting of experimental watershed by multiple watersheds method based on examination of analytical method and hydrological observation, was not developed owing to difficulty in arrangement in time and personnel. But the method of measuring and indicating watershed factors, flow measuring method, etc. that are basic items of investigation in the method for predicting watershed in danger of flood were executed in Reserva Estadual de Cunha in the line of research object that investigating method based on multivariate analysis be conveyed and contribution to establishing the method of predicting the watershed requiring forest restoration in the devastated watershed be made.

2) Conveyance of basic investigation for predicting watershed in danger of flood

Multiple watersheds method is generally adopted for studying method of predicting watershed in danger of flood, and basic investigating operations for collection of various data are required accordingly. One of them is measuring operations for watershed conditions in the number of watersheds to be investigated, such as topographic factor, geological and soil factor, ground cover factor, etc. The second one is flow observing operation by investigation of runoff from the watershed by rain that constitutes necessary objective variable, such as peak specific flow, runoff increment, etc.

As the former operation, four watersheds in the initial schedule were investigated by means of the topography map of

Reserva Estadual Cunha in 1/5,000 scale; and the result of investigation is shown in Table II-21.

Table II-21 Topographic Characteristics of Watershed

Factor/name of watershed	A	B	C	D
Watershed area (ha)	37.50	36.68	40.73	56.04
Altitude range (m)	1030-1175	1025-1199	1050-1188	1048-1222
Relative height (m)	145	174	138	174
Length of main stream (m)	1070	920	800	1260
Relief ratio	0.136	0.189	0.173	0.136
Mean slope (°)	18°48'	18°38'	19°26'	25°10'
(tan θ)	0.340	0.337	0.353	0.470
Mean watershed width (m)	350.5	398.7	509.1	444.8
Form factor	0.328	0.433	0.636	0.353
Watershed perimeter (m)	2800	2750	2450	3450
Compactness factor	0.775	0.781	0.923	0.769
Elongation ratio	0.892	0.739	0.960	0.649
Circularity ratio	0.603	0.609	0.853	0.592
Forest area ratio	0.958	0.934	0.833	0.676

note: Topographic measurement was made referring to topographical map of 1/5,000 scale. Forest area ratio was read from aerial photograph of 1/45,000 scale.

As the latter operation, investigation was carried out right after runoff of high water level, refering to the simple method whereby flow Q was obtained from water flow cross section area A and average velocity V as the product. Q = AV, obtaining the water level of flood at its peak by the mark left on the stream bank, bridge pier, etc., obtaining cross section area of flow by survey, and calculating hydraulic radius R. On the other hand, water surface slope I was obtained by survey, on assumption that it is the same as that of the stream bed. The coefficient of roughness n was decided according to the conditions of the point, and average velocity was calculated by the Manning formula, $V = 1/2\ R^{2/3}\ I^{1/2}$. The cross section area was multiplied by the average velocity, and the peak flow from the watershed as the time of flow at the mark level was obtained.

As other methods of observating water level, simple maximum water level mark meter can be manufactured tentatively and inexpensive maximum and minimum water level meter can be purchased and installed. For a higher accuracy in observation, gauging weir shall be contructed and self-recording must be carried out.

As to flow observation, river traversing survey and flow measuring method were conveyed under guidance of Fujieda in Rio Paraiba.

As explained above, setting of experimental watershed for studying the method of predicting watershed in danger of flood was planned, and basic operation procedure and manual have been conveyed to the counter part, except techniques of analysis, by practical guidance.

3) Turbidity investigation

Turbidity of runoff water seems to be effective data as watershed index in a period of flood, as it reflects soil erosion arising by varying mode of land utilization in the watershed and proves erosion of river bank and river bed scouring. Turbidity was observed in the watershed of Rio Paraibuna, that is the source of Rio Paraiba, at two points of forest watershed, one point of grazing land, and in Rio Paraibuna after confluence of the said streams. (3.1-2) Determination was conducted by accurate turbidity meter of NSK-2P type, manufactured by Nikkyo Manufacturing Co., and provided by Japan.

A part of the result of observation is shown in Table II-22, Fig. II-23, and Fig. II-24; and the summary of the result is as follows:

Table II-22 Turbidity by month

Month			Forest (1)	Forest (2)	Pasture Land	Rio Paraibuna
1983	June	average	2.8	1.8	3.8	15.2
		range	2.0-4.5	1.0-4.0	1.5-9.5	6.5-70.0
	July	average	2.6	1.7	3.8	9.6
		range	2.0-5.5	1.0-6.5	2.0-20.0	4.5-55.0
	August	average	2.6	1.9	3.0	5.0
		range	2.0-3.5	1.5-3.0	2.0-5.0	4.5-7.0
	September	average	4.5	3.4	7.9	53.9
		range	2.5-10.0	2.0-8.0	4.5-16.0	5.0-230.0
	October	average	4.1	3.0	6.8	15.3
		range	2.0-8.0	1.5-8.5	4.0-13.5	5.5-65.0
	November	average	3.3	2.6	3.8	8.6
		range	2.5-4.0	2.0-3.0	2.5-5.0	5.0-13.0
	December	average	6.0	4.5	14.2	81.5
		range	3.0-7.5	3.0-6.5	6.5-26.5	22.0-148.0
1984	January	average	5.3	3.2	6.2	14.6
		range	2.5-10.0	2.0-10.0	3.5-13.0	5.5-58.0

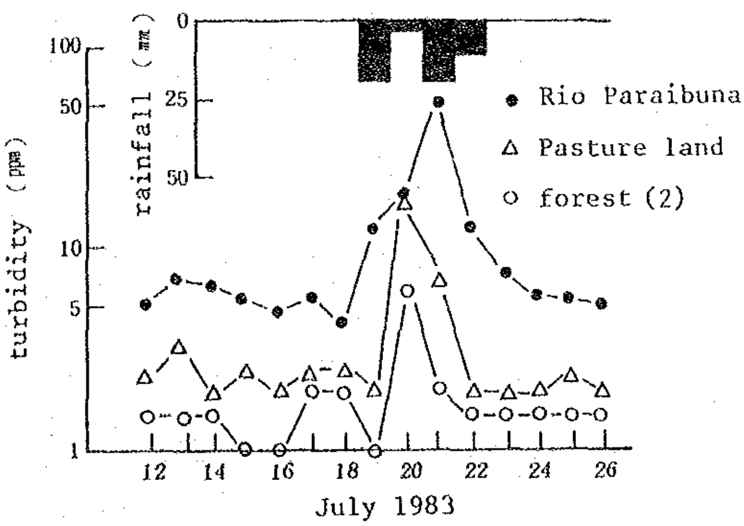

Fig. II-23 Turbidity change

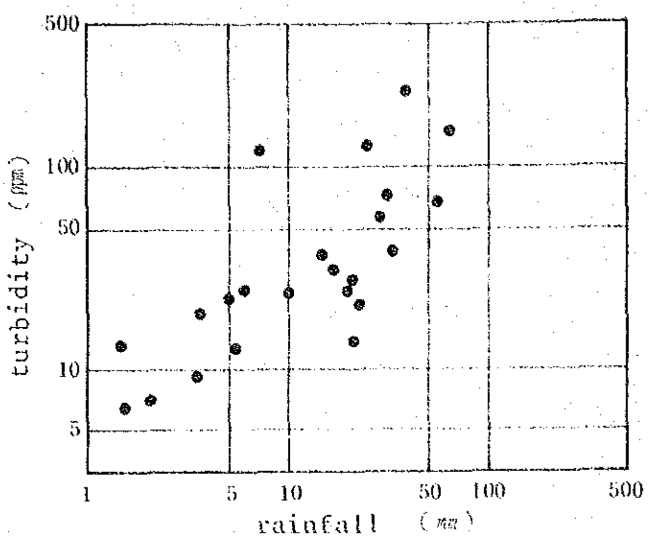

Fig. II-24 Relationship between rainfall and turbidity (Rio Paraibuna)

i) Turbidity in normal time was 1.0 - 3.0 ppm in the forest watershed, 2.0 - 4.0 ppm in the grazing land watershed, and 4.0 - 6.0 ppm in Rio Paraibuna, ii) Turbidity in flooding time was about 10 ppm in the forest watershed, but in Rio Paraibuna including farms and grazing land in the watershed, it was 200 ppm or higher in some cases, iii) Turbidity as high as that was not shown in grazing land, iv) while the turbidity in the forest watershed of Rio Paraibuna in normal time was 5 - 10 ppm, in Rio Una in Taubate District, it was as high as 450 - 500 ppm, and 100 ppm even upstream in the branch, showing the difference by the mode of land utilization.

4) Method of predicting watershed in danger of flood

(a) Example of predicting watershed in danger of flood in the past

Here the method of multiple regression analysis will be shown from examples in Japan and other countries. The method is simple and independent variable as well as criterion variable can be expressed in interval scale.

Actual examples of multiple regression equation introduced from the result of observation by multiple watersheds method are as follows:

i) Example in Tenryu River, Ogawa River River System in Japan

The 15 forest watersheds were of 1.1 - 28.0 km^2 area, and the multiple regression equation for a rainfall of 50 mm was (3.1-3).

$$q = 3.22\gamma_r - 0.44B - 2.44L - 0.07fc + 15.8$$
$$(R = 0.70)$$

where q : flood specific flow ($m^3/sec/km^2$)

γ_r: mean inclination of main stream

B : mean width of watershed (km)

Lc: Concentration ratio of watershed.

fc: forest coefficient (product of forest area and square root of growing stock per km^2)

ii) Example in State of California, U.S.A.

The result of investigation of 38 watersheds of 0.1 - 201 $mile^2$ area in California, U.S.A. gave (3.1-4).

$$\log Q = 3.624 + 0.928\log A + 0.723\log P$$
$$+ 0.860\log rb.rs/rl - 1.152\log C$$
$$(R=0.983)$$

where Q : maximum momentary peak discharge (ft^3/sec)

A : area of the watershed ($mile^2$)

P : maximum 24-hour precipitation (in)

rb: bifurcation ratio

rs: slope ratio

rl: length ratio

C : average cover density

iii) Example in Nigeria

Case of 15 watersheds in southwest Nigeria having 2.0 - 18.8 km^2 watershed area was (3.1-5).

$$\log RO_1 = 37.6 + 0.47\log S_1 - 0.23\log S_2 - 0.52\log S_3 - 0.40\log S_4 + 0.84\log S_5 - 2.21\log S_8 + 0.91\log S_9 \quad (R^2 = 0.94)$$

where RO_1: annual runoff (mm)

S_1 : percentage of basin area underlain by quartzites (%)

S_2 : percentage of basin area underlain by granite and gneisses (%)

S_3 : percentage of basin area underlain by amphibolites and schists (%)

S_4 : drainage basin area (km^2)

S_5 : drainage density (km^{-1})

S_8 : total dry-season rainfall (mm)

S_9 : maximum weekly rainfall in October (mm)

5) Trial for predicting the degree of danger of flood in four watersheds in Reserva Estadual de Cunha

Analysis for predicting the danger of flood was tried as example, although for 4 watersheds only, using the result of measurement of topographic factors in four watersheds A, B, C and D in Reserva Estadual de Cunha with past examples of study as reference.

First flood peak specific flow was taken as object variable. It would be a rule to obtain peak specific flow of each of the watersheds by water gauging observation and other means of investigation, but here the flow of three watersheds other than watershed D were estimated from the existing data for Watershed D, and the peak specific flow were used.

Forest area ratios in the four watersheds were calculated as vegetation cover factor in the watersheds, before starting multiple regression analysis, in addition to topographic factors already measured, by means of aerial photographs at 1/45,000 taken in 1977. (Table 3.1-1)

As to the flow factors, the peak specific flow 160.73 ℓ/sec/ha in Watershed D that was caused by the concentrated heavy rain of 435.5 mm a continuous rainfall from 16 o'clock January 23, 1985 to 3 o'clock January 25, 1985 (49.5 mm hourly maximum rainfall, 199.5 mm 6-hour rainfall) was referred to and peak flow in other watersheds were estimated by the rational equation. Here 424 mm maximum 24-hour rainfall of the rain was used as probability rainfall in the equation, and the runoff coefficients for Watersheds A, B and C were calculated from 0.73 (3.1-6) *annual runoff rate for Watershed D on an assumption that they* are in inverse proportion to forest area ratio. Peak specific flows in Watersheds A, B and C were estimated by simple proportion calculation using the rate of calculated value for watershed D by the rational equation based on the rainfall data against the observed value as the factor. The reason why peak specific flow thus calculated on such assumption was used as the index is that marks of flood were hardly recognized by the investigation that was undertaken about 9 months after the flood occurrence. Therefore, it should be noted that the analysis in the four watersheds in Reserva Estadual de Cunha is just for showing the researching procedures as an example and that the result obtained has no strict meaning in the values.

The multiple regression equation obtained for the peak specific flow by selecting watershed factors highly correlated with peak specific flow is as follows:

$$q = 2.64X_1 - 66.02X_2 + 56.60$$
$$(R = 0.991)$$

where q : peak specific flow (ℓ/sec/ha)
X_1: watershed area (ha)
X_2: *forest area ratio*

The equation shows that the peak specific flow increase as the area of watershed increases and that it decreases as the forest area ratio increases, as a very plausible result by the common sense. However, as shown in several examples of research in the past, the constants for the independent variables in the equation can be either positive or negative depending on the experimental watersheds, even if the same independent variables are used.

The relative importance of the independent variables in the multiple regression equation for Reserva Estadual de Cunha is calculated at $X_2:X_1 = 1.0 : 2.8$, showing that watershed area affects the peak specific flow about three times as much as forest area ratio, between two factors, but what we can change by our effort is the forest area ratio, and the difference may not be regarded very large.

The prediction of degree of danger in the four watersheds can be estimated from the values of peak specific flow, but we predicted according to the example by Mashima (3.1-7) by weighted total of the watershed factors, as calculated by multiplication of watershed factors by the coefficient of relative importance and summing up the products. The larger the weighted total, the larger is the danger. The result of calculation gave that the danger of flood is the largest in Watershed D, followed by Watershed C, Watershed B, and Watershed A. Electronic computor FACOM-230-28, that is a provided machine, was used for calculation.

The result of predicting watershed in danger of flood was made based on the result of calculation using estimated values by a bold assumption, and more detailed information will be obtained when water gauging weir in Watersheds A and B are completed, accurate observation is continued, and calculation is carried out based on the actual flood flow observed.

6) Selection of investigation watershed in danger of flood by multiple watersheds method

It is desirable in studying the method of predicting watershed in danger of flood to collect a large number of data in many watersheds and introduce multiple variable analysis.

For this reason the present study was re-examined, including the initial plan, and the watershed of Rio Antas, that is a branch of Rio Una, was selected as subject. In this district, watersheds of various kinds of land utilization can be selected, including forest land, besides fundamental investigation for geology, division of land utilization, etc. is already finished. Investigation of water quality is also going on in this watershed among other investigations, and the district lies in a geographically convenient position for observation, being near to Taubate nursery Office of Forestry Institute. Hydrological data by Taubate DAEE and others can be used and compared, and this also gives convenience. The district was surveyed, and experimental watersheds were selected, water level observation points were selected, cross section at the points were surveyed, and longitudinal survey for riverbed inclination was conducted is fundamental investigation for flow measurement. As to the method of water level recording, inexpensive method for recording the water level during the period will be sought in order to save the expense.

As to the analysis of the data collected, program for electronic computor as developed by the remote sensing department will be utilized.

(3) Future outlook and problems

It would be safe to say that the concept and procedures for studying the method of predicting watershed in danger of flood, that is one of the pillars of studies on watershed management techniques, were mostly understood. However, execution of studies will require more skill and knowledge besides a vast amount of operation and expense in practice.

Firstly, in collecting related data, it is necessary to start with arranging data, that can be utilized, clearly. For example, data should be gathered from aerial photographs and Landsat Satellite data so that many watershed factors such as topography, geology, soil, land utilization, vegetation, etc. be obtained. In examination and fractionation of factors deeply related with runoff, the level of comprehensive research must be raised in order that original items and categories for classification suitable for Brazil and State of São Paulo be found. For example, techniques for collection of forest information factors affecting water circulation, such as tree species construction, amount of resources, growth characteristics, etc., should be advanced. This is a problem not only of Forestry Institute but much could be obtained by exchanging studies with other research organizations and other fields.

In practical planning and promotion of studies on the present subjects, studies should be started by a method for general comparison and analysis in simple method and by small expenditure. After accumulation of experience, experimental watersheds shall successively changed, accuracy of data accumulation raised, and analytical techniques designed and advanced into higher stage. This would be a practical way of advance.

Forestry Institute has an experience in only a short period in water gauging experiment, and the method of predicting watershed in danger of flood was taken up in the final stage of cooperation and the techniques were conveyed. Thus they have no experience. Therefore, exchange of information and personnel between Forest Institute and Japanese side will be needed in the future. The effect of the present research cooperation will further be enhanced as a result.

At the same time, the number of researchers on hydrology in Forestry Institute should be increased.

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II-3-2 Studies on the method of predicting area in danger of erosion

(1) Method of study

(1) Area division in predicting area in danger

The land in São Paulo is utilized as non-forest zone such as farm, grazing land, and unutilized land for a large part; and the frequency of sudden rain is large. Therefore, erosion is advancing widely on the slope in the whole area of the state, and prediction on danger of erosion will be needed in a large range. Two methods are conceivable as means of sectioning land as object of prediction of danger of erosion, one sectioning land into several hectare or tens of hectare of the same inclination or shape of slope, or so-called slope sectioning method, and the other mechanical method of sectioning land in predetermined size in equal intervals east-west and north-south, or so-called mesh sectioning. The former has an advantage of making land of similar conditions related with erosion, such as inclination and shape of slope, as unit of prediction, while the latter of making the area of all sections equal and the result of sectioning objectively the same.

Photo II-5 Erosion in Taubate grass land for pasturing

Mesh sectioning was adopted for prediction in São Paulo State, considering the need of prediction for a large area, so that the same sections will be treated regardless of the researchers and with advantage in treating data by electronic computor. Especially in the present study, the period is limited; and advantage in the mesh method of easy collection of many data in statistical treatment was considered.

The size of mesh was decided at 100 m square (1 ha). Based on the existing topographic map, conditions of erosion, land covering, and other data were entered with interpreting to aerial photographs.

(2) Investigating Procedure

The intensity of erosion was taken as external standard y, and the factors considered as causes of devastation, such as inclination, direction of slope, vegetation, etc. were taken as internal standards x_i, the following equation was obtained by multiple regression analysis based on digitalizing theory, and the degree of effects of each of the factors on erosion were grasped quantitatively.

$$y = ax_1 + bx_2 + \ldots\ldots + nxi$$

where y : degree of danger of erosion

x_1: inclination

x_2: direction of slope

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a_1, b_2, ... n: constants

i) The degree of erosion was rated none, slight, and heavy by interpreting aerial photograph (1973, 1:12,500 scale followed by enlargement by 2), and the result was transferred into topographic map of 1:10,000 scale.

ii) The rate of area for every grade of erosion was measured within the 100 m mesh (1 ha).

iii) As related factors, ground covering and pasturing density were interpreting from the aerial photograph (twice enlarged one hereafter), field survey was carried out to supplement the interpreting of photograph to enhance accuracy, and the kind of largest area was adopted for the section.

iv) A district of the same geology was selected as subject of investigation as far as possible.

v) Topographic map was used for finding inclination, direction, longitudinal cross section, traversing cross section, and slope length, along with interpreting of aerial photographs; and the accuracy was raised.

vi) The depth of soil was obtained from the existing soil map (1:250,000 scale) and aerial photograph, along with the result of field survey for a higher accuracy.

vii) Single correlation analysis was conducted between each of the factors and erosion so that proper category sectioning (sectioning factors into classes of factors) needed in multiple regression analysis be properly made.

viii) Category weights were obtained for each of the factors by multiple regression analysis (quantification of Class II). The reason for using quantification Class II is that the reading of the degree of erosion that is to be a dependent variable (y) remains in stages.

ix) Multiple regression analysis was repeated several times to enhance correlation ratio and judge appropriateness of the category weights of related factors; and predicting of land in danger for all of the sections was carried out using the category weights obtained by the proper multiple regression analysis.

x) The result of judgement was compared with the actual conditions of the result of analysis was examined.

(3) Land investigated

In São Paulo State, Taubate District that was selected for investigation of the danger of erosion is the oldest region of development where many forests were developed for culture of coffee plant or sugar cane. Later, the land turned barren, and farms on inclined land disappeared. The land has been utilized mainly as grazing land. It is located about 130 km to the east of São Paulo City, and it seems to lie within the economical sphere of the city.

There is a slope of comparatively gentle inclination beyond the ridgeline of coastal mountain range (about 1,000 m above sea level) that rises northwestward as a steep slope from the Atlantic coast. Further to the north of the investigated land, Serra da Mantiqueira is located, including Campos Jordaõ.

The investigated land is situated in the watershed of Rio Pedra Negra (2291 ha, Fig. II-25) upper stream Rio Una, surrounded by the two mountain ranges within 45°26'00" - 45°29'21" west longitude and 23°09' - 23°14' south latitude. In the central and lower regions of Rio Pedra Negra, the slope of the hill is gentle, but in the upper region in the south, the slope is comparatively steep. The difference in altitude between the northern and southern ends of the investigated land is about 400 m.

(4) Items of investigation

Detail of investigation is explained in remote sensing department, and the following is an outline.

(a) External standard used in factor analysis

External criteria to be used as index of erosion danger in factor analysis were examined. The conditions of erosion in the land of investigation can be classified into four items as follows.

i) surface erosion
ii) rill erosion
iii) gully erosion
iv) erosion after stream collapse

of the above mentioned classification, iv) erosion after stream collapse was not taken up in the present investigation.

The conditions of erosion was classified by interpreting aerial photograph into two types. The borderline

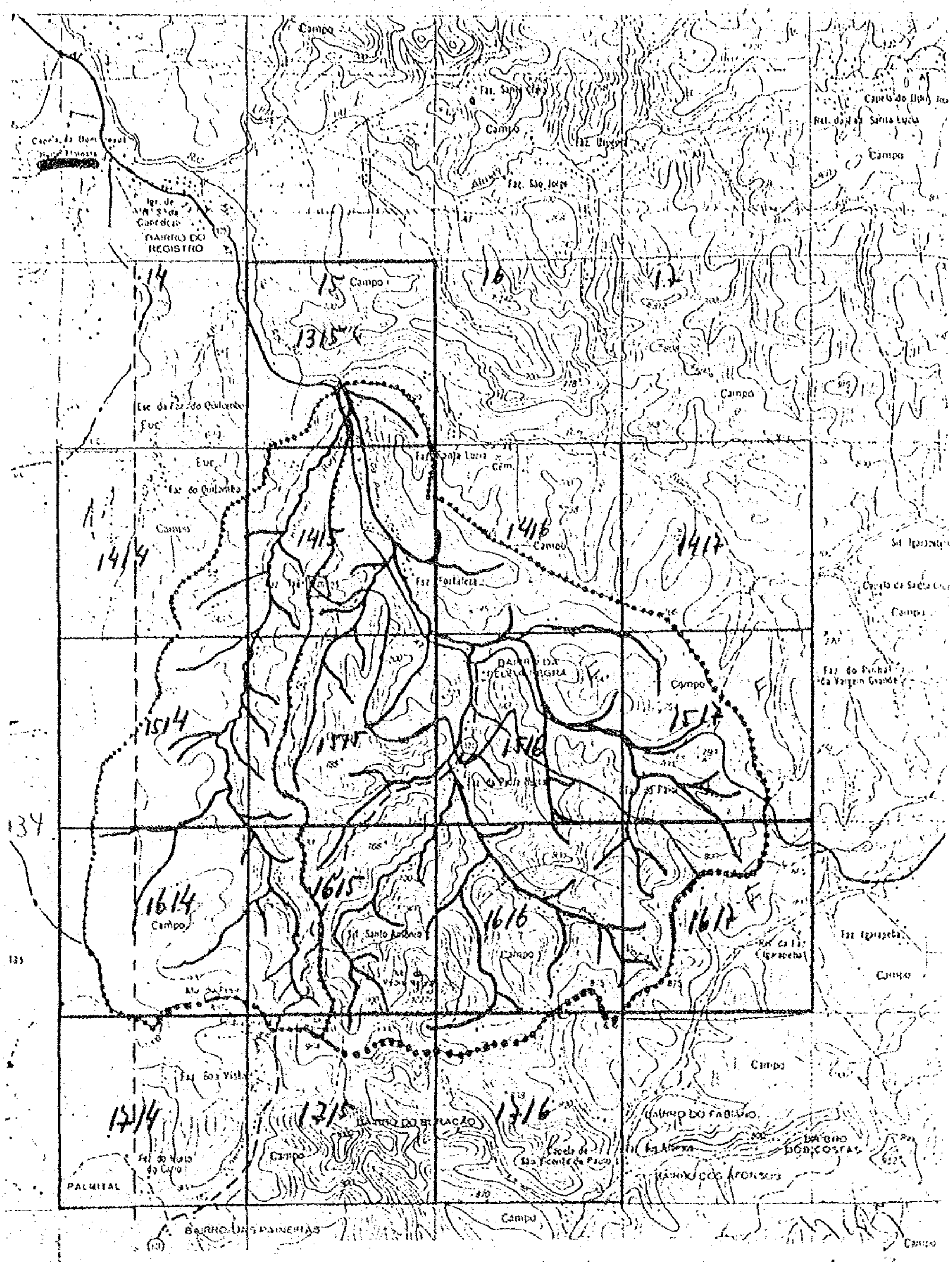


Fig. II-25 Subject land for investigation of danger of erosion between the two types lies at the medium degree of the rill erosion. The two types of erosion was transferred on the topographic map, and the rate of area in the mesh was measured.

(b) Ground covering

Land was classified by the mode of utilization by interpreting aerial photographs, and unutilized dry riverbed, villages, farms, and quarries were excluded. As a result, the total area of investigation turned to be 1966 ha, or 1966 meshes, which are investigation data. Therefore, the following items also were for the 1966 meshes.

The first problem of interpreting aerial photograph was whether vegetation classes in the grass land, that occupies more than 70% of the total area (meaning 1966 meshes hereafter), can be classified by interpreting. The result of interpreting was actually classified into three classes as shown in Table II-2B. Bias was formed in the rate of occupied area by each of the three sections.

Table II-23 Ratesor area occupied and invaded by causal factors

	Ground covering	Occupied area		Eroded area	
		ha	%	ha	%
1	Grass land of 30cm or lower	1030	52.4	102.1	9.9
2	grass land of 30-100cm height	252	12.8	10.3	4.1
3	tree and grass land of 1m or larger height	109	5.5	1.4	1.3
4	Secondary forest of 80% or more stand of 2m or lower	131	6.7	4.9	3.7
5	Artificial forest	274	13.9	1.7	0.6
6	Natural forest	170	8.6	1.1	0.6

Inclination	Occupied area		Eroded area	
	ha	%	ha	%
1 0 - 10°	219	11.1	9.4	4.3
2 11 - 15°	608	30.9	33.3	5.5
3 16 - 22°	941	47.9	66.7	7.1
4 over 23°	198	10.1	12.1	6.1

Longitudinal cross section	Occupied area		Eroded area	
	ha	%	ha	%
1 Concave	473	24.1	34.7	7.3
2 Convex	1177	59.9	75.9	6.4
3 Even	316	16.1	10.9	3.4

Slope length	Occupied area		Eroded area	
	ha	%	ha	%
1 0 - 40 m	1234	62.8	72.7	5.9
2 41 - 80 m	589	30.0	38.7	6.6
3 over 81 m	143	10.1	10.1	7.1

Pasturing density	Occupied area		Eroded area	
	ha	%	ha	%
1 sparse	1559	79.3	71.4	4.6
2 medium	308	15.7	28.5	9.2
3 dense	99	5.0	21.6	21.8

Direction		Occupied area		Eroded area	
		ha	%	ha	%
1	N	234	11.9	22.9	9.8
2	NE	340	17.3	26.6	7.8
3	E	197	10.0	6.3	3.2
4	SE	220	11.2	8.1	3.7
5	S	103	5.2	0.2	0.2
6	SW	207	10.5	5.5	2.7
7	W	229	11.6	12.3	5.4
8	NW	352	17.9	37.0	10.5
9	None	84	4.3	2.6	3.1

Traverse cross section section		Occupied area		Eroded area	
		ha	%	ha	%
1	Concave	429	21.8	28.3	6.6
2	Even	1096	55.7	61.7	5.6
3	Convex	441	22.4	31.5	7.1

Soil depth		Occupied area		Eroded area	
		ha	%	ha	%
1	Latosol (thick)	853	43.4	49.5	5.8
2	Podosol (thin)	1113	56.6	72.0	6.5

Secondly, conditions of forest was interpreted, as has been the case in Japan, by degree of number of trees, density, tree height, etc. No data were available on the forest age of man-made forest, and it was not used. However, the rate of forest area against the total area was small, and the man-made forest was classified into two classes and natural forest only in one class.

(c) Inclination

The number of contours in a mesh was counted, and it was converted into inclination angle.

(d) Direction

Average direction of inclination in a mesh was classified into 8 directions. However, considering the difference between individuals by the counterpart and operator at the time those meshes having two or less contours were regarded "no direction" mechanically for the sake of accuracy.

(e) Longitudinal cross section

The distance between two contours up and down along the slope was compared and longitudinal cross section was judged.

(f) Traverse cross section

The degree of bending of contours was measured by angle.

(g) Slope length

The flow line of water was traced from the center of mesh, and the horizontal distance along the line of maximum inclination upto the upper ridgeline was measured.

(h) Soil depth

Soil depth was investigated in the field by the cut face of road construction at ten and odd points. The depths of layers A, B, and C were measured, and the 1.4 m depth of podsol and 2 m or larger of latosol were obtained as the result. Soil map of 1:250,000 was used (Fig. II-26) with correction according to the investigation in site. Thus distribution of soil type and that of soil depth became the same.

The geology was all of migmatite except of granite in the northern part of investigated land.

(i) Pasturing density

It seems likely that there is a strong correlation between pasturing density and erosion in a grass land, but there are difficulties in obtaining accurate or objective data at present as follows:

i) The aerial photographs were taken in June 1973 for investigation of erosion and land covering conditions at that time, but it is difficult to grasp the number of cows to be compared with the photographs.

ii) The conditions of pasture differ between milk cow and beef cow, and the rate between the two kinds of cows are changing complexly year after year.

iii) It is difficult to grasp the border of property land correctly.

For the reasons stated above, digital grasping of pasturing density was abandaoned.

On the other hand, method of grasping relatively from the aerial photograph and conditions of grass, but this gave nearly the same result as three classes of grass land in ground covering factors, and the result was abandoned.

For the reasons explained above, trial as follows we made as a model.

i) Pasturing density in forest zone was assumed at zero.

ii) Eight cowhouses are located in the investigating area, and "devastation conditions" were interpreted in the aerial photograph near the cowhouses to give grades of devastation.

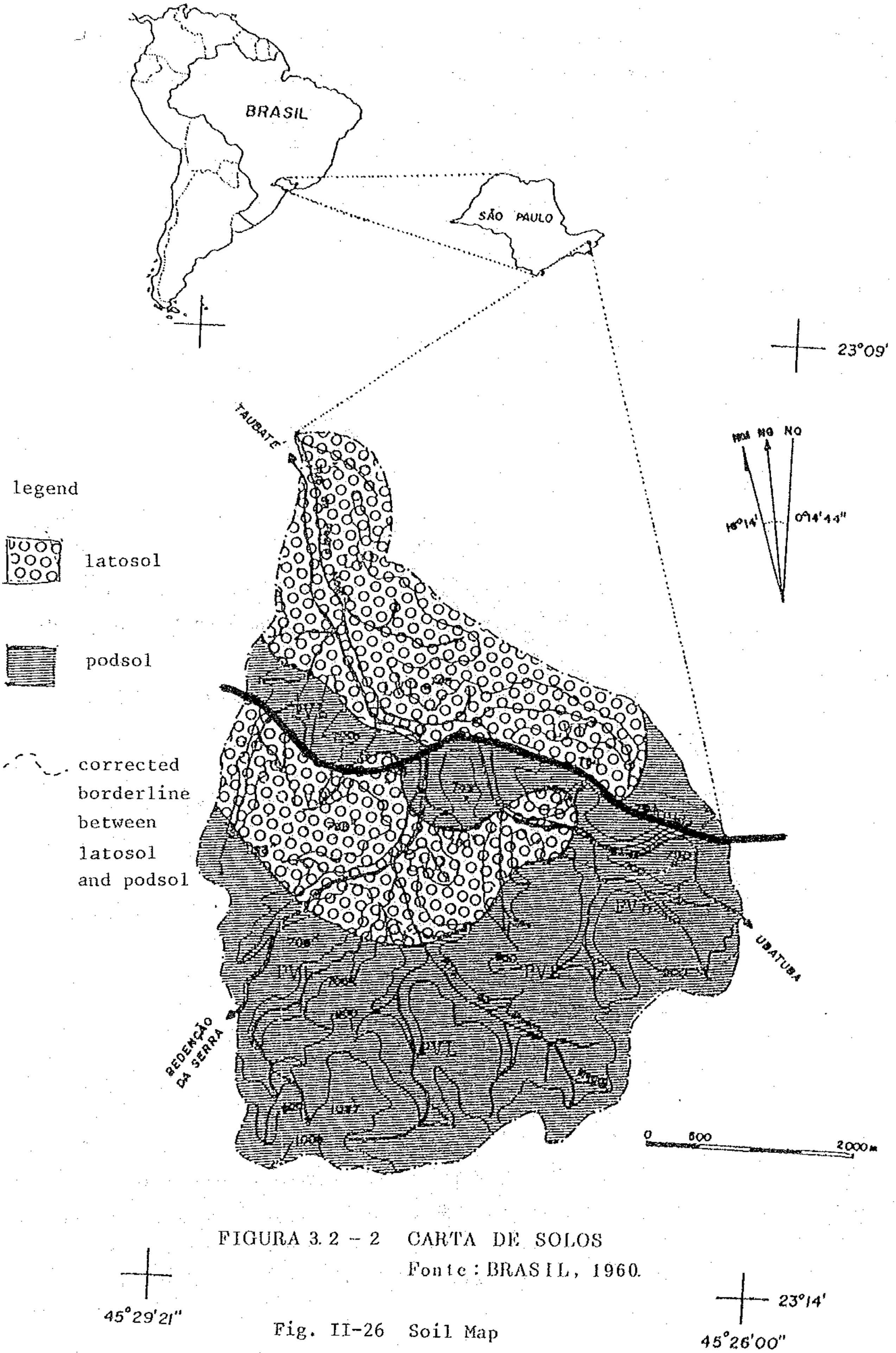


FIGURA 3.2 – 2 CARTA DE SOLOS
Fonte: BRASIL, 1960.

Fig. II-26 Soil Map

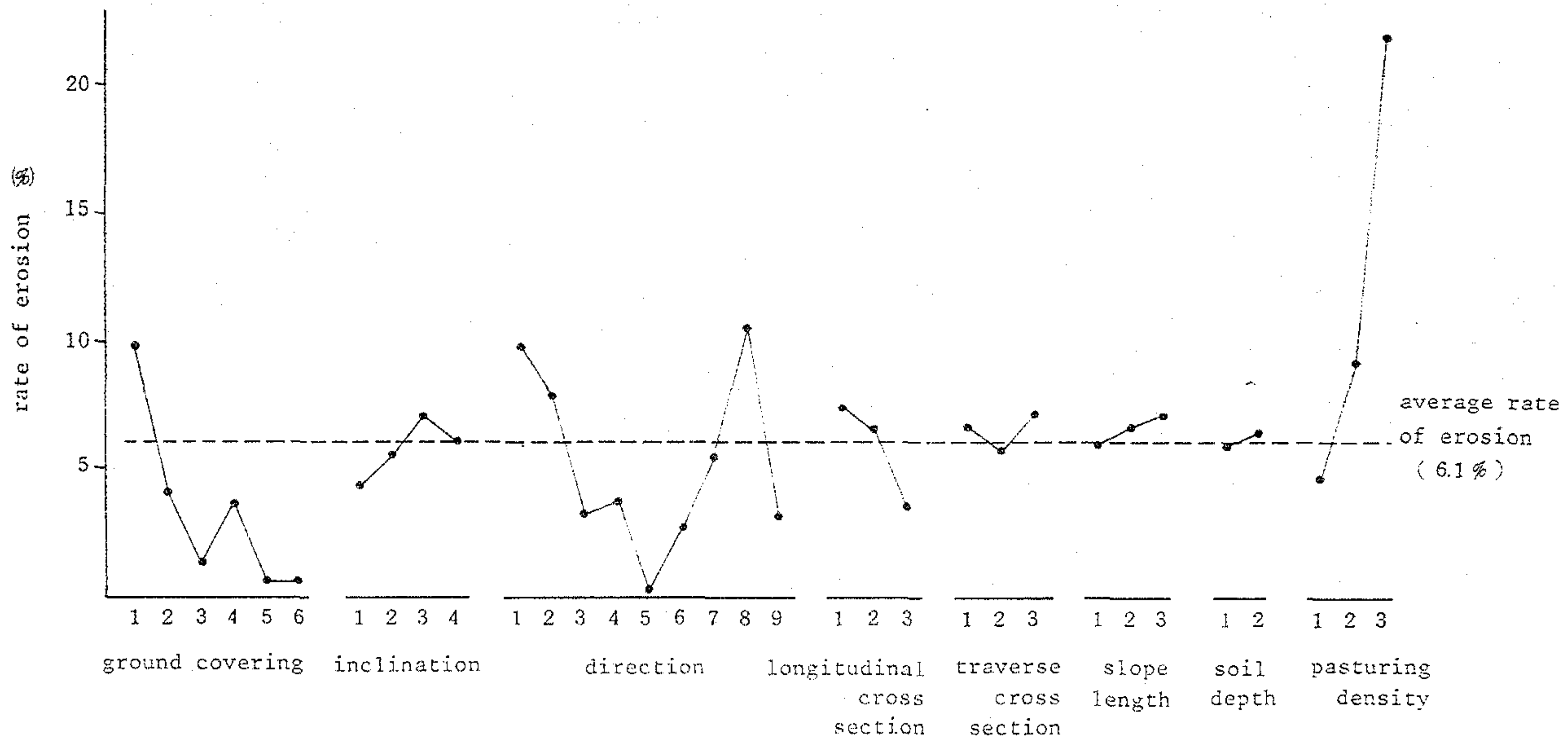


Fig. II-27 Rate of area of erosion by causal factors

Table II-24 Index of occupied area rate in slope in classification of ground covering

	Ground covering	Occupied area (%)	Index of occupied area rate in slope				
			Total	0-10°	11-15°	16-22°	more 23°
1	Grass land of 30cm or less	52.4	100	11	35	46	8
2	Grass land of 30-100 cm	12.8	100	10	26	57	7
3	Grass tree land of 1m or higher	5.5	100	8	28	40	24
4	Secondary artificial forest	6.7	100	7	28	60	5
5	Artificial forest	13.9	100	13	34	48	5
6	Natural forest	8.6	100	9	18	45	28
	Total	100.0	100	11	31	48	10

Table II-25 Standard for sectioning rate of eroded area

Group of section	Type of erosion 1	Type of erosion 2	Mixture of erosion types Type 1	Type 2
Group (1)	0%	0%	0% less than 10%	0% less than 20%
Group (2)	less than 50%	less than 20%	" 20% " 30%	" 10% " 10%
Group (3)	50% or larger	20% or larger	10% or more 40% "	20% or more 10% "

iii) The intensity of pasturing density was assumed at the graded values and those mechanically reduced by one grade for every 300 m distance from the cowhouse.

The background as basis of said model and the problem will be given as follows: The investigated land lies among the milk-supplying area for the city of São Paulo, and it is estimated that the pasturing conditions are those of milk cows rather than of beef cows. In milk cow management, all of the cows owned are milked twice a day by the owner; and erosion and devastation should proceed in the surrounding of the cowhouse in proportion to the number of cows owned, and the pasturing density the lower, the farther the land from the cowhouse. However, the number of cows at the time was not available, as started above; and this should be one of the subjects left for the future, along with establishing correlating equation between the distance from cowhouse and pasturing density.

(2) Result of study

(1) Rate of erosion by each of the causes

The rate of eroded land area against the total area was 6 %, and the rates of eroded land by each of the factors are shown in Table II-23 and Fig. II-27. The rate of eroded area was calculated by assuming eroded area by simple addition of areas of erosion type 1 and type 2 and dividing it by the area of each of the categories. The number of meshes where erosion is taking place was 403, or 20.5% of the total number of meshes investigated.

(a) Land covering

The higher the rate of covering by vegetation, the lower the rate of area being eroded in inclined land, generally speaking.

Secondary planted forest consisting of 80% or more of trees of 2 m or lower height is found among pine forest only in planted forest, but in eucalyptus forest, among renewed forest by sprouting in addition to planted forest. Eucalyptus forests in Brazil are generally cut every about seven years, and the forests are renewed by sprouting from the stocks and cutting every seven years is repeated. However, after three cuttings, sprouting in 21st year is remarkably poor, and the forest thereafter are not recognized as economical forests usually at present. Therefore, a few percent of high trees are left uncut in renewing forest by sprouting in many cases, and such forests correspond to secondary or tertiary planted forest with 80% or more trees of 2 m or lower tree height. Erosion seems to proceed in such forests of eucalyptus by agitation of ground surface in cutting in many cases, and this is estimated to be the cause of a rather higher rate of eroded area.

Most of the areas of grass-and-tree land of 1 m or larger height are found around natural forests, and it is estimated that they had been used as pasture or for cultivation of coffee plant or sugar cane.

(b) Inclination

Result of the higher rate of eroded areas was obtained, the larger the inclination of the land. The rate of eroded land seems to be too low on slopes of 23° or higher inclination, but this seems to be due to the higher rate of forests on the slopes as shown in Table II-24.

(c) Direction

The rate of eroded area was generally higher on sunlight north-facing slopes but lower on south-facing slopes. This is judged to be caused by moisture situation in the soil and poor growth of plants on the north-looking slope.

The lands of category 9, or "no direction", are flat lands of 6 - 7° or lower inclination; and many of the meshes in this class are located near the summit of a hill, as unutilized land on dry riverbed, villages, farms, etc. are excluded, and the rate of eroded land there is low.

(d) Longitudinal and traverse cross section

No remarkable difference in eroded area can be found

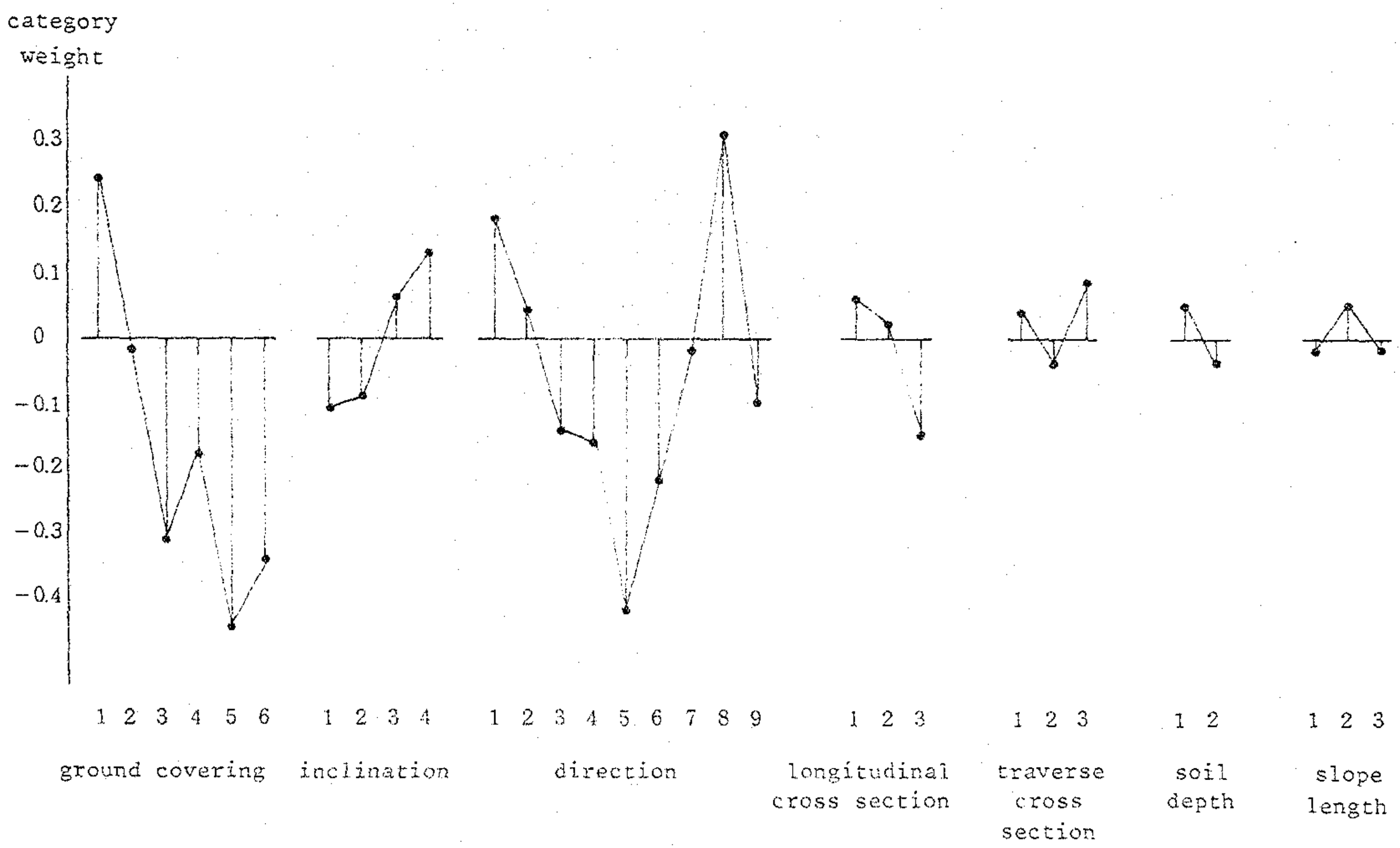


Fig. II-28 Category weight of erosion factors

1. note: Classification into groups of 1, 2 and 3 according to Attached Table II-25.

Combination frequency

11	904
12	295
13	362
14	0
15	0
16	0
17	0
18	0
19	0
20	0
21	65
22	97
23	142
24	0
25	0
26	0
27	0
28	0
29	0
30	0
31	14
32	19
33	69

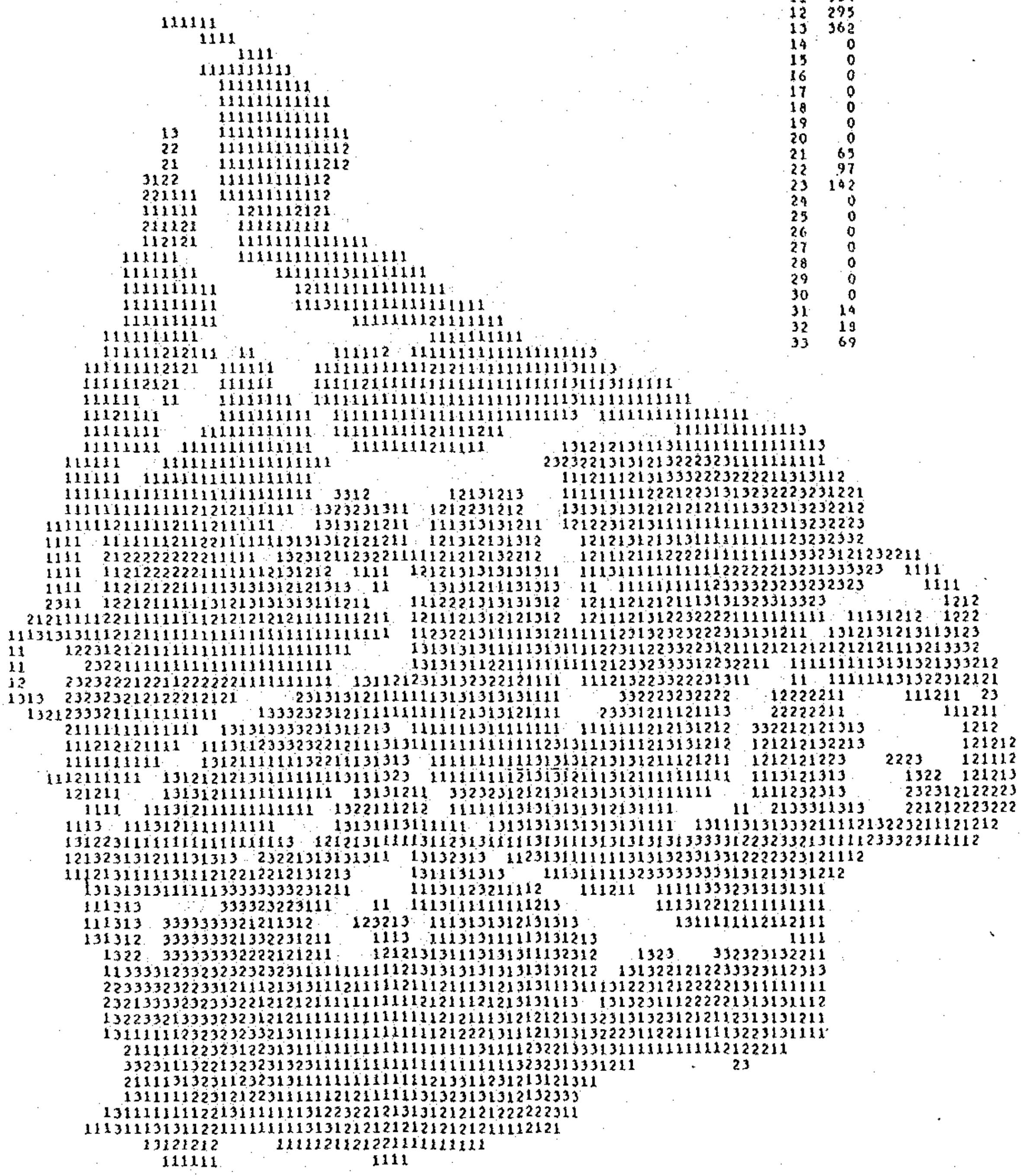


Fig. II-29 Occurrence of erosion, observed value (left) and estimated value (right) by the difference in convex and concave shape of the ground surface. The rate of eroded land seems to be somewhat larger on lands of balanced topography.

(e) Slope length

The difference in the rate of eroded area by the categories is small, but the rate of eroded area is the larger, the longer the slope length.

(f) Soil depth

The rate of eroded area was higher in the category of shallow soil, but the difference was extremely small.

(g) Pasturing density

Category 1, or "slight", includes forest zone of zero pasturing density. On the other hand, category 3, or "heavy" shows an extremely high rate of eroded area. This shows that erosion proceeds remarkably around cowhouses. But it is unreasonable to conclude correspondence between pasturing density and erosion in other places by the remarkable devastation near cowhouses, and we refrained from conclusion.

(2) Result of multiple regression analysis

Multiple regression analysis by quantified calculation of class II was conducted 27 times in total in order to obtain causal relation between various factors related to erosion and occurrence of erosion. As a result of calculation, where classification of external standard into grades and categories was the best suited, the ratio of correlation was 0.3566.

(a) Classifying external standard into grades

In order to decide combination of erosion type 1 and erosion type 2 obtained, number of classes of external criteria, standards for classifying, etc., calculation was repeated by trial and error under conditions of 5 kinds of standard of type 1, type 2, type 1 + type 2, type 1 + 2 x type 2 and type 1 + 3 x type 2, and number of classes at 4 respectively. As a result, it was decided to use combination by addition of the rate of eroded area for the meshes of type 1 and twice the rate of eroded area for the meshes of type 2. As a result of further calculation by the combination and in the range of 2-6 number of classes, the classifying standard shown in Table II-25 was judged the best suited.

(b) Factor analysis

Calculation was repeated by trial and error by three categories of erosion as shown in Table II-25 and changing the classification into categories for each of the factors. Table II-25 shows the best result of classification into categories for every factors, among those after omission of pasturing density for the reason explained in Paragraph (d) that follows.

Category weights are as shown in Fig. II-28, and they show a more reasonable tendency by approximate agreement with the tendency for the rate of eroded area as shown in Fig. II-27. Accordingly, the causative factors of the highest effect on occurrence of erosion are direction and ground covering, followed by inclination. Other factors were not found in clear correlation with occurrence of erosion by the present result.

(c) Result of prediction in danger

The result of rating of the land investigated for the danger of erosion based on said external criterian and classification of factors into categories is shown in Fig. II-29. The figures on the left side are for actual observation and those on the right side estimated values.

(d) Examination of pasturing density factor

No reliable method was found for collection of pasturing density factor, but it was found as a result of tentative calculation based on the category standard in Table II-23 that the factor has a very large weight, too large to allow analysis of other factors, and it was omitted as the factor.

On the other hand, if a category is arranged by judging the pasturing density at zero in forest land, it coincides perfectly with the category of forest, making the internal correlation almost 1, and calculation is impossible. Therefore, in order to conduct factor analysis with pasturing density in forest at zero, existence of category sections of zero pasturing density in grass land becomes a necessary condition.

(3) Total discussion

About the same tendencies were shown for the rate of eroded area by each of the factors of cause and for the rate of contribution of each of the factors to the rate of eroded area from the result of multiple regression analysis. Among the factors of cause, effect of ground covering, direction, and inclination is remarkable, while that of slope length, soil depth, longitudinal and traverse cross section of the slope, etc. was not very clear. Effect of pasturing density is large also theoretically, but there was problems in investigation as stated above; and it was not adopted as factor in multiple regression analysis. About the same tendency was shown as to ground covering and inclination as one in Japanese study of erosion, but the difference in direction of slope was unexpected, differing between north-facing slope and south-facing slope. The difference seems to be caused by the difference in moisture content of soil that causes difference in vegetation.

The result of estimation of degree of danger of erosion, as estimated for each of the meshes in the area of investigation by the final multiple regression analysis by category classification by Table II-23, was compared with the actual result of erosion. This showed that the result of estimation was generally satisfactory as shown in Fig. II-29.

(3) Future outlook and problems

As a result of studies on the method of predicting land in danger of erosion in Taubate District, similar tendency was obtained for the relationship between erosion and inclination and ground covering to one in Japanese studies. The result on the effect of direction of land gave an unexpected difference between north-facing slope and south-facing slope, but a reasonable explanation was given for the difference. However, no definite tendency was recognized for the effect of soil depth, slope length, and longitudinal and traverse cross section of slope. The strong effect of pasturing density is clear, but it was not taken up as a factor in multiple regression analysis because the actual state at the time of taking aerial photographs could not be grasped. The result of estimation by studies agrees with the result of field investigation in many of the meshes as shown in Fig. II-29, and it seems possible to forecast land in danger of erosion by three factors of inclination, ground covering, and slope direction; but in order that judgement in a wide range of the state of São Paulo be conducted, more studies especially as regards difference by the type of soil could be accumulated.

The causal relation between erosion and each of the factors as obtained by the statistical means should be proved by field survey or experiment. The relationship between the direction of land and erosion that was found in the present studies was proved by comparison of slopes on both sides of road in a cutting. The slope facing the north was easily dried, and the vegetation there grew poorly, and the result of statistical treatment was supported by actual observation. The relationship between ground covering and erosion was also confirmed by the tendency in the field.

Summing up, in order to establish the method of predicting area in danger of erosion in the state of São Paulo, many studies by statistical means must be accumulated and the result proved by comparison with the fact in the future. For the time being, the studies would desirably be advanced in the order of i) similar analytical analysis in adjacent district to Taubate, ii) similar statistical analysis in districts other than Taubate, and iii) confirmation of the result of statistical cause analysis in the field.

II-3-3 Studies on the method of predicting area in danger of slope collapse

(1) Method of studies

(1) Method of predicting area in danger

There are two means of predicting area in danger of collapse, one a so-called inductive method where actual site of collapse in the district and factors related with collapse, such as geology, topography, forest type, etc., are investigated and the relation between collapse and the factors is analyzed from the result of investigation, and location in danger of collapse in the future is forecast, and the other a positive method where the actual site of slope is investigated and the danger of collapse in the slope is estimated from the structural conditions of soil layer. The former method allows investigation by means of topographic map, soil map, aerial photograph, etc., and it is suitable for prediction in a large area, and the latter is suitable for prediction of a specific slope, for investigation of soil layer on individual slope is required. For prediction of area in danger of collapse in Brazil, the method must be applied to a wide range of mountain land, and the former method was resorted to, that is a method of statistical analysis of the relationship between collapse and factors related to collapse where the rate of contribution of each of the causal factors is obtained and used for forecast of danger of collapse.

(2) Section as unit of predicting area in danger

The district as subject of prediction for danger of collapse is sectioned and each of the sections is judged for the danger.

In so-called slope sectioning the district is usually sectioned into several or several tens of ha of similar inclination or slope shape to be units of prediction, while in mesh sectioning, mechanically into squares of predetermined size by straight lines in the directions east-west and north-south. The former is of advantage, because the inclination, shape of slope, forest type, etc. that are deeply related to collapse can be the same within a section, while the latter of advantage, because the sectioning is operated mechanically and objectively and the area of sections can be the same.

Predicting of area in danger of collapse is required for a vast area in the state of São Paulo, starting with the steep slope on the eastern coast; and operation on a large area is anticipated. Therefore, sectioning by the mesh method was adopted in the present study, so that the sectioning can be the same regardless of the investigator, that the area of the sections are the same, and that it is convenient in treatment by electronic computor. Particularly in the present studies, most of the operations must be finished in the former half of 1985 fiscal year, and investigation is a large range was impossible; and the advantage of the mesh method of possible small area of a section and advantage of many sections in statistical treatment were considered.

The size of mesh was decided at 100 m square (1 ha) that is the smallest unit conceivable for the scale of drawings (1:10,000) to be used, with reference to the result of studies in Japan.

(3) Procedures for investigation for prediction in danger

i) The investigation and analysis were meant for investigation of the rate of collapsed area, inclination of the land, micro topography, vegetation covering, direction, soil depth, and presence of stream for every mesh sectioned and for obtaining the following equation by multiple regression analysis based on digitalization theory between the rate of collapsed area as external standard (function) Y and each of the causal factors as internal standard (variable) Xi, so that the degree of effect of each of the factors on collapse be grasped quantitatively.

$$Y = aX_1 + bX_2 + \ldots\ldots + nX_i$$

where Y : degree of danger of collapse

X_1: inclination

X_2: local topography

a, b, ... n: constants

ii) The shape of collapse was read from twice-enlarged aerial photograph, taken in January, 1973 by Agricultural Bureau of the state of São Paulo on 1:25,000 scale and transferred onto a contour map of the investigation area in 1:10,000 scale.

iii) Meshes of 100 m square (1ha) were drawn on the contour map, and the area of collapse was read in each of the meshes.

iv) Inclination (degrees), micro topography (concave or convex of contours, balance), and directions (four directions) were obtained from contour map, along with aero-photo interpretation for raising the accuracy.

v) Soil depth was obtained by investigation around the land of collapse, on cliffs along streams, etc. and observation of topograph in the aerial photograph. The soil depth was classified into four classes and soil depth map was prepared.

vi) Simple correlation analysis was made between collapse and individual factors related with collapse, and rough estimate of suitable category classification (into classes of factor) to be adopted in multiple regression analysis was made.

vii) Multiple regression analysis by digitalization of class II was conducted to obtain category weights of collapse-related factors. Dependent variable (Y) was classified into three or four classes, and classification that gives the best result was adopted after trial and error. As to the program, the same digitalization of class II was used as in the case of predicting area in danger of erosion in the preceding paragraph.

viii) Multiple regression analysis was conducted several times to raise the correlation ratio, and the best result of calculation was adopted with consideration of the appropriateness of the relative size of category weights of collapse-related factors. Danger of collapse in all of the meshes in the investigation district was judged using the category weights of the factors obtained by the adopted calculation.

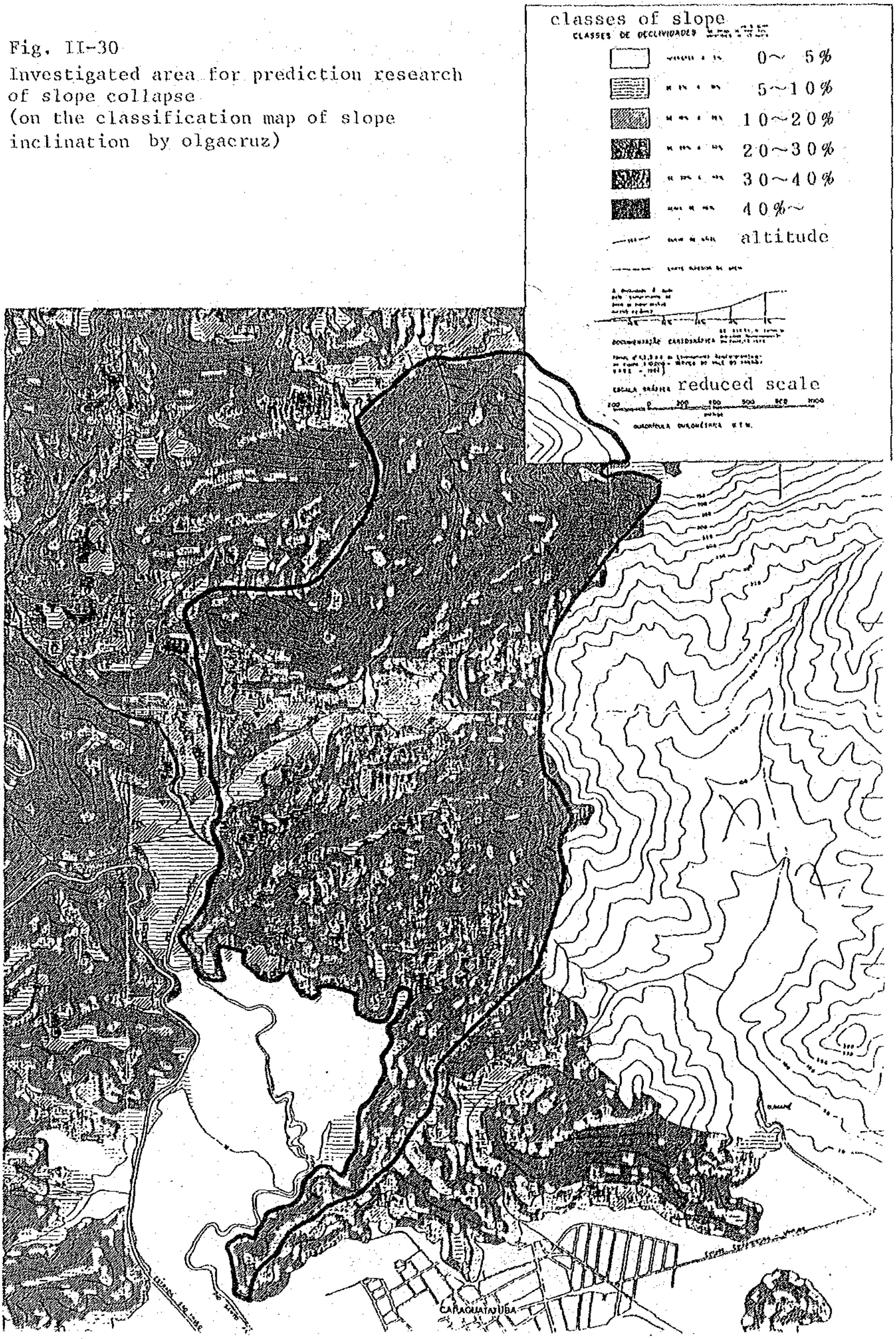
ix) The result of predicting was compared with the actual conditions of collapse taking place, and appropriateness of the result of investigation and analysis was examined.

(4) Subject district for investigation

Mountain land of about 800 ha near Caraguatatuba was selected as investigation district.

All of the state of São Paulo is covered geologically by

Fig. II-30
Investigated area for prediction research of slope collapse
(on the classification map of slope inclination by olgacruz)



granite or its metamorphic rocks except basalt zone in a small part. The basic rock in the district of investigation in the mountain land along the easter coast near Caraguatatuba is granite, and the depth of soil in the mountain land is generally small, while a depth of 5 m or larger is often found for the deposited soil of weathered rock in the mountain land in the inland part. This seems to be due to the steep slope in the east, which is of 30 degree or larger in many places, and 800 m altitude of Serra do Mar is lost in a short range to the coast. Rainfall is large near the Atlantic coast than in the inland part, and this causes an easier collapse by heavy rain along with the steep inclination.

The forest in the district is mostly natural, but trees of a large diameter are cut or secondary forest growing after total felling are included in some part.

The investigated district is a mountain land of a steep inclination located to the north of the city of Caraguatatuba, consisting mostly of forest owned by the state; although private pasture is included in a small part. It is in the range of 10 - 750 m above sea level, belonging to the watershed of Rio San Antonio. It is situated on the east side of the national road connecting São Paulo and Caraguatuba, and it is a mountain land of about 800 ha area, as shown in Fig. II-30. Investigation land was selected from among the land satisfying the following conditions: collapse is often taking place, collapsing points are not continuous and the starting point can be identified individually as far as possible, forest and grass land are included and the forest types are various, aerial photograph before and after disaster and contour map of good accuracy can be obtained for the conditions.

Collapse occurred in the present district by the heavy rain on March 18, 1967. The daily rainfall at the time was 240.8 mm at Caputera in the city of Caraguatatuba and 195.5 mm at Rio de Ouro near Caraguatatuba Station of Forest Institute. The rainfall in the urban district was not very large, but abnormally high rainfall of 420 mm was recorded at Empresa that is a mountain land to the west of the investigation district on the same day; and it is estimated that a heavier rainfall took place in mountain land of higher altitude than in Caputera and Rio de Ouro in a flat land. On January 24 of the same year, rainfall of 351.9 mm was recorded in the neighboring land of Ubatuba. Maximum daily rainfalls on different days in Caraguatuba and Ubatuba about 40 km apart respectively show the remarkable difference in the rainfall between adjacent land. It suggests that local concentrated heavy rain takes place in the district during January to March in the summer.

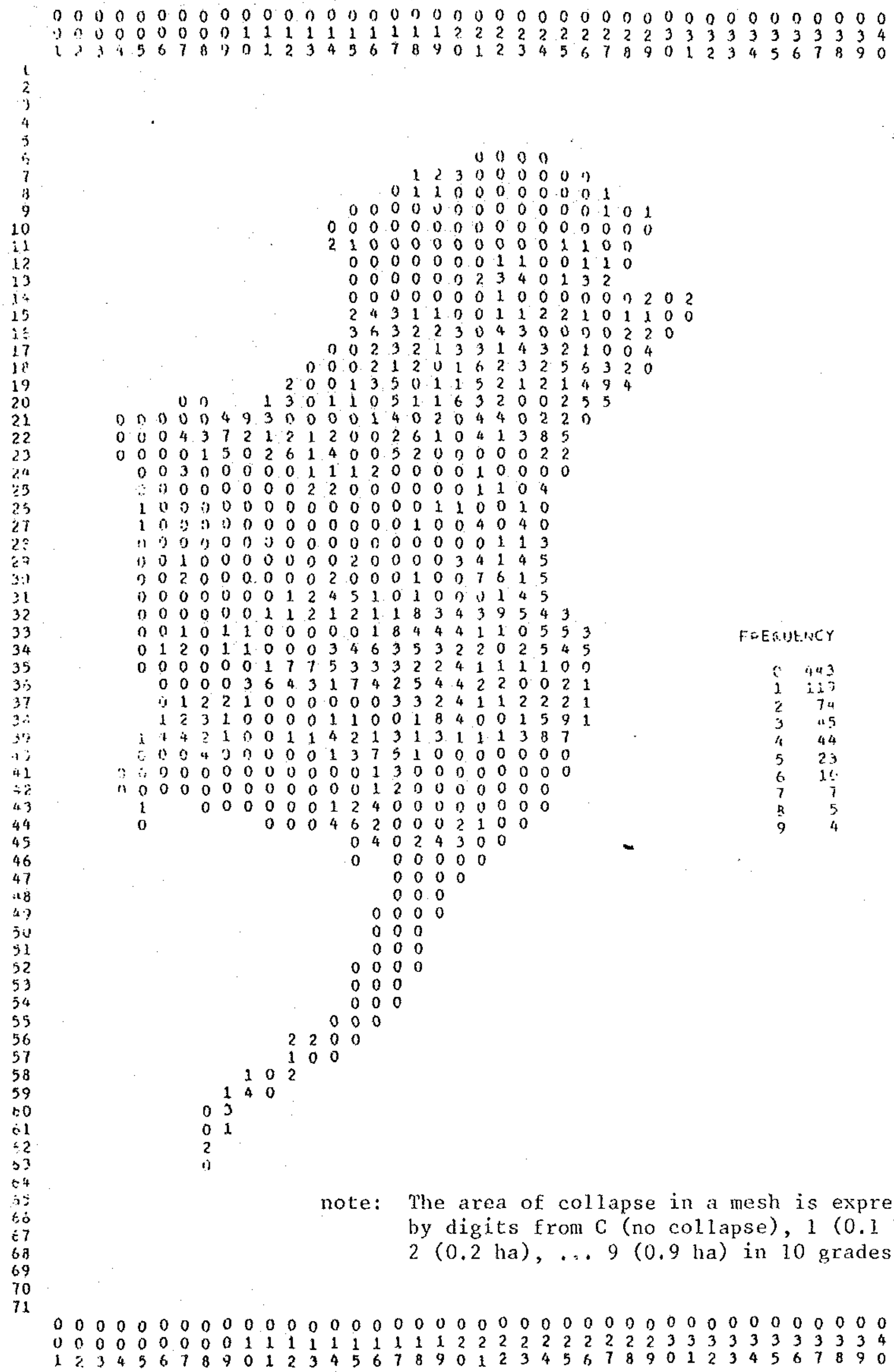
(5) Items of investigation

The method of investigation is described in Remote Sensing Department, and here a brief explanation will be given.

(a) External standard

As index to be used as external standard (dependent variable) in factorial analysis for predicting area in danger of collapse, area of collapse or the soil volume collapsed is generally used. In the case of the area of unit section for predicting, is different from one section to another, collapsed area or soil volume is divided by the area of section and the index is obtained; but in the present case, this is not necessary as the areas of all of the sections are equal. In the case of sectioning taking a slope as a unit, collapse takes place within a unit, but in the case of sectioning into meshes, collapse often takes in multiple meshes. In such a case, the area of collapse is measured in each of the meshes involved. The soil volume is usually measured by multiplication of the area by the average depth, but in the case of mesh sectioning, the calculation is complex as multiple meshes are involved. Damage is given by the collapse on the timber producing capacity of forest in proportion to the area of forest in collapse taking place in forest, and the area of collapsed land in each of the meshes was taken as external standard (dependent variable) in the present studies, with consideration of this situation.

Collapsed land was read from the aero-photo taken in 1973, and the result of reading was transferred onto a contour map of 1:10,000 scale, prepared by forest institute,



FREQUENCY

0	443
1	117
2	74
3	45
4	44
5	23
6	16
7	7
8	5
9	4

note: The area of collapse in a mesh is expressed by digits from C (no collapse), 1 (0.1 ha), 2 (0.2 ha), ... 9 (0.9 ha) in 10 grades.

Fig. II-31 Collapsed area in each of the meshes

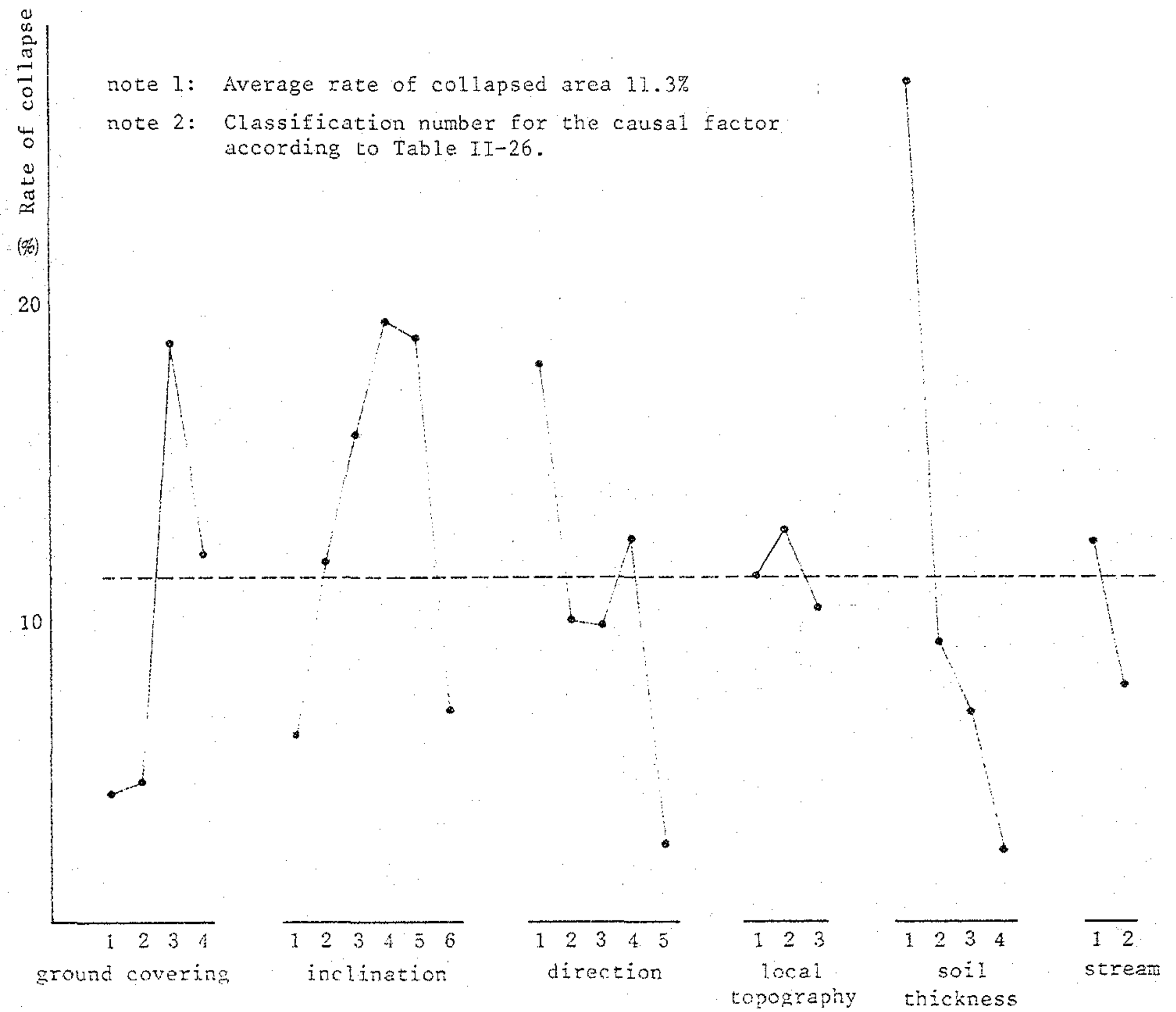


Fig. II-32 Tendency in rate of collapsed area by causal factors to measure about the collapsed area. Since the aero-photo was taken seven years after occurrence of collapse, the scraped part and heaping part were discriminated comparatively easily because of the plants invading into the latter part, although this is usually difficult right after the collapse.

The area of collapse was measured down to 0.1 ha, that is the accuracy needed and sufficient for factorial analysis by digitalization of class II by visual determination of the area occupied by the collapse in each of the meshes. Fig. II-31 shows the result of determination each expressed by a digit, 0, 1, 2, ... 8, or 9, is 10 stages, meaning that the area in the mesh is 0.1 ha or less, 0.2 ha or less, 0.3 ha or less, ... 0.8 ha or less, or over 0.8 ha respectively.

(b) Vegetation covering

Firstly, residential area, dry riverbed, and farm were excluded by aero-photo interpretation for the investigation area, and the total area of the subject left was 774 ha, or 774 meshes.

Next, pasture in the investigation area was separated, and the forest land was classified into three kinds, natural forest having high trees of large-diameter stem, natural forest near the ridgeline not containing large-diameter trees, and secondary forest formed within 20 years by cutting etc.

(c) Inclination

The altitude above sea level was obtained at four corners of each meshes from 1:10,000 scale contour map, and inclination was calculated by electronic computor.

(d) Direction

Average direction of inclination in each meshes was classified into four directions. It was judged, similarly to the case of inclination above, from the altitude at four corners of a mesh by calculation by computor. If the inclination was 5° or less, the mesh was given no direction.

(e) Micro topography

In addition to the height at the corners of a mesh, the height at the center of mesh was obtained, the distance of the center from the imaginary plane formed by the four corners was calculated by a computor, the ratio of the distance against the side of mesh was calculated, and the slope in the mesh was rated convex if the center is above plane by 1/15 or more, concave if it is below plane by 1/15 or more, and even if otherwise.

(f) Soil depth

Soil depth was obtained by investigation in the field in the investigation district, the result was plotted on the aero-photo and contour map, that shows the tendency of soil depth on slopes and land shape by location, and soil depth map was completed. Studies on predicting area in danger of collapse in Japan was referred to, and the soil depth was classed into 4 stages of less than 50 cm, 50 cm to less than 1 m, 1 m to less than 2 m, and 2 m or more than 2 m.

(g) Presence of stream

In addition to collapse on hillside, collapse on the bank of stream by encroaching of the stream was anticipated, and presence of stream in a mesh was investigated. Stream was defined not only by the part entered in the topographic map but also to include the part of valley in usual sense where the distance of contours bending into hillside is larger than the width of valley as measured by the length of tangent line touching the next contour line. Even if there is a part of continuous stream that does not fall under the definition, the whole was regarded as continuous stream if it does upstream and downstream.

(2) Result of study

(1) Trend in rate of collapsed area by each of factors

The total of collapsed area in 774 ha investigation subject district was 87.8 ha, or 11.3%. The result of collapsed area rate by each of the categories is as shown in Table II-26 and Fig. II-32. The number of meshes including collapse of 0.1 ha or larger area was 331, or 42.8 % of the total.

(a) Vegetation covering

Table II-26 shows that the rate of collapsed area of grass land and secondary forest is small, while that of the two kinds of natural forest was pretty large. The tendency is different from the result of ordinary investigation, but this seems to be due to the grass land and secondary forest being located only in low land of small inclination. In the natural forests, the rate of collapsed area is larger in forests not containing trees of large diameter.

Table II-26 Rate of collapsed area by causal factor

Ground covering	Occupied area		Collapsed area	Rate of collapse
	ha	%	ha	%
Grass land	68	8.8	2.9	4.2
Secondary forest	69	8.9	3.2	4.6
Natural forest not including large-diameter tree	74	9.6	14.0	18.9
Natural forest	563	72.7	67.7	12.0

Inclination		Occupied area		Collapsed area	Rate of collapse
		ha	%	ha	%
1	below 21°	330	42.6	20.1	6.1
2	22° - 25°	137	17.7	16.1	11.8
3	26° - 29°	110	14.2	17.5	15.9
4	30° - 33°	90	11.6	17.6	19.6
5	34° - 40°	81	10.5	14.7	18.1
6	above 41°	26	3.4	1.8	6.9

Direction	Occupied area		Collapsed area	Rate of collapse
	ha	%	ha	%
North	57	7.4	10.4	18.2
East	90	11.6	8.8	9.8
South	307	39.7	29.8	9.7
West	308	39.8	38.5	12.5
Non	12	1.6	0.3	2.5

Micro topography	Occupied area		Collapsed area	Rate of collapse
	ha	%	ha	%
convex	239	30.9	26.7	11.2
even	254	32.8	32.4	12.8
concave	281	36.3	28.7	10.2

Soil Depth	Occupied area		Collapsed area	Rate of collapse
	ha	%	ha	%
to 50 cm	148	19.1	40.5	27.4
to 1 m	352	45.5	32.3	9.1
to 2 m	192	24.8	13.1	6.8
over 2 m	81	10.5	1.9	2.3

Presence of stream	Occupied area		Collapsed area	Rate of collapse
	ha	%	ha	%
without stream	609	78.7	75.1	12.3
with stream	164	21.2	12.7	7.7

(b) Inclination

The rate of collapsed area is small in lands of 21° or smaller inclination, but it increases gradually until 40° over which it decreases to a remarkably small rate. The relationship is often observed in slopes of steep inclination.

(c) Direction

The rate of area of collapse is the largest in meshes directed to the north, although the number of meshes in the direction is small. Among those of other directions, those directed to the west shows somewhat larger rate; and the rate is approximately the same in meshes directed to east and south. Effect of the direction of wind in concentrated heavy rain or that of fractured zone, etc. can be conceived as the reason. A trend of somewhat larger inclination of slopes directed to the north can be noticed on the coutour map.

(d) Micro topography

The rate of collapsed area differs by the local topography of the land, being somewhat larger in even topography and somewhat smaller in concave topography; but the difference is slight.

(e) Soil depth

The rate of collapsed area is higher in land of 50 cm or smaller soil depth, and it is the smaller, the larger the depth.

(f) Presence of stream

The rate of collapsed area in meshes without stream was higher than one with stream. This seems to be due to rare occurrence of collapse on the bank of stream.

(2) Result of multiple regression analysis

In order to analyze integrated causal relation between various factors and occurrence of collapse, multiple regression analysis by digitalization of class II was carried out eight times in total, and the result of calculation where stage classification and category classification of external standard seemed the best suited was adopted. The external standard was classified in four stages, and the final category classification of factors was the same as one in Table II-26 except one for inclination.

(a) Stage classification of external standard

The external standard was classified into four stages of 1. no area, 2. 0.1 ha or less, 3. 0.11 - 0.3 ha, and 4. 0.31 ha or larger area of collapse as a result of eight times of multiple regression analysis in trial and error with varying category classification of the factors.

(b) Factorial analysis

Classification of inclination was made as shown in Table II-27.

Table II-27 Category classification of inclination

Inclination	Category classification
25° less	1
26° - 29°	2
30° - 33°	3
34° - 40°	4
more 41°	5

Among the classes of direction, the number of meshes without direction was small, and the meshes were included in other classes of direction.

The correlation ratio obtained by calculation was 0.5059 and category weights as shown in Fig. II-33, and this roughly agrees with the tendency of the rate of collapsed area by factors shown in Fig. II-32. Factors of the largest effect on occurrence of collapse are soil and inclination. Among vegetation covering, negative category weight of grass land is conspicuous, and among directions, positive category weight of north; but there is a possibility of their being excessively emphasized, because the areas occupied are in the section of the smallest area among those of the

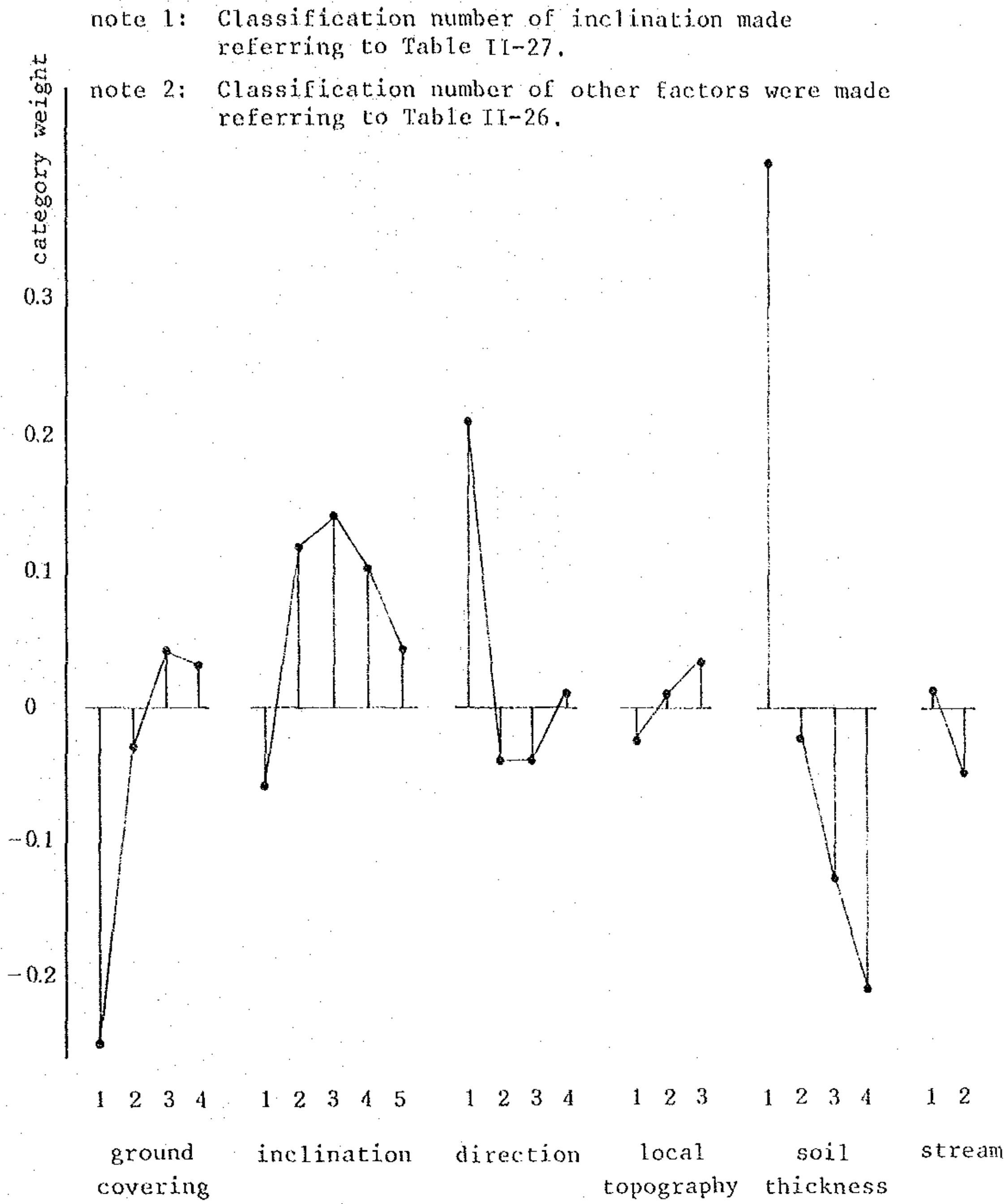
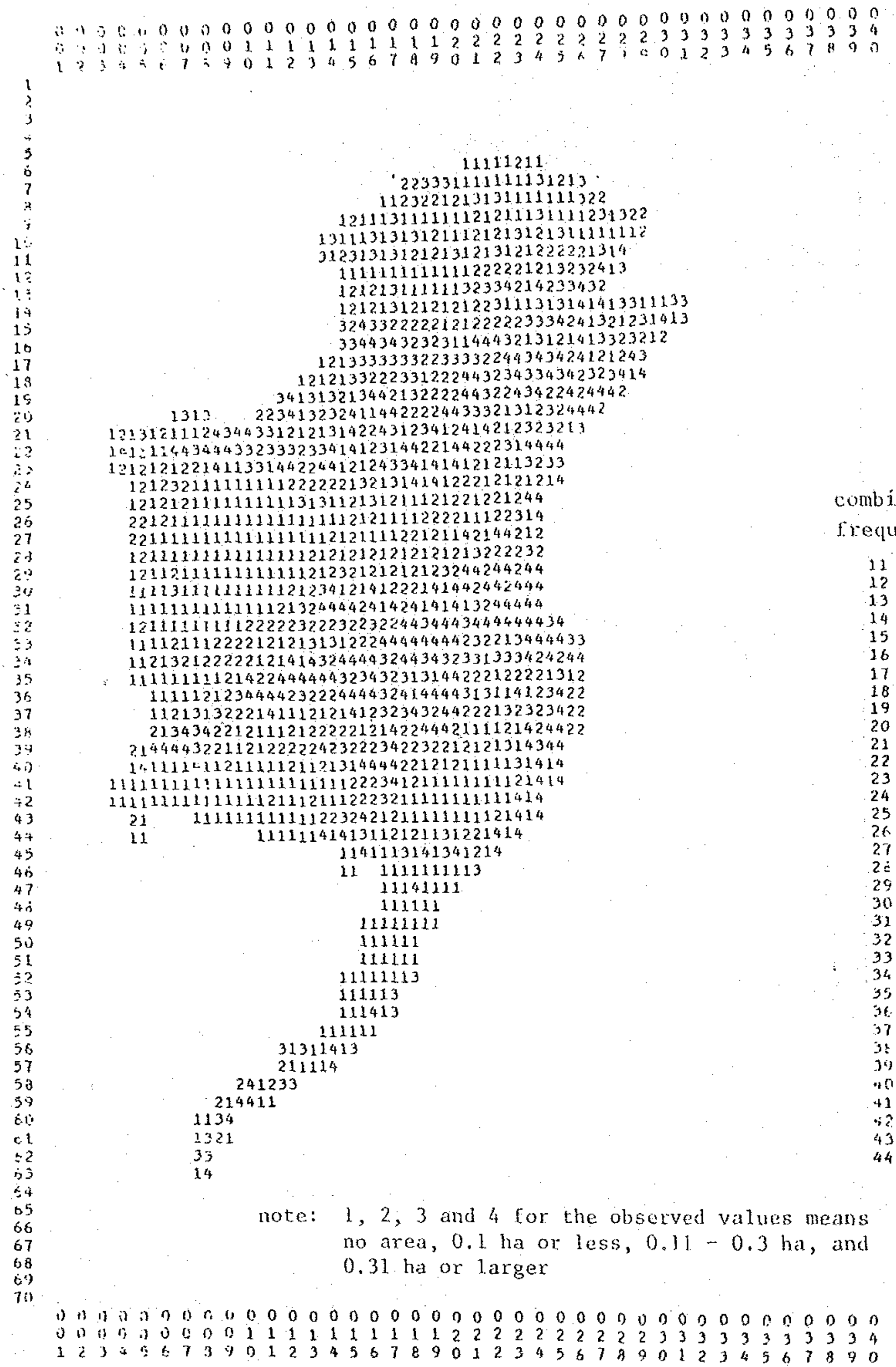


Fig. II-33 Category weight of causal factor by multiple regression analysis



note: 1, 2, 3 and 4 for the observed values means no area, 0.1 ha or less, 0.11 - 0.3 ha, and 0.31 ha or larger

combination	frequency
11	201
12	134
13	59
14	45
15	0
16	0
17	0
18	0
19	0
20	0
21	24
22	71
23	13
24	11
25	0
26	0
27	0
28	0
29	0
30	0
31	22
32	44
33	22
34	31
35	0
36	0
37	0
38	0
39	0
40	0
41	3
42	19
43	7
44	59

Fig. II-34 Occurrence of collapse, observed value (left) and estimated value (right) factors in both of the cases. Especially in vegetation covering, 70% or more of the area is covered by natural forest and the area of other vegetation is small; and category weights of other sections are apt to be emphasized too much. The relationship between micro topography and presence of stream and occurrence of collapse is not as clear as it is in other factors.

(c) Collating the result of factorial analysis

The degree of danger of each of the meshes in the investigation district was calculated using the method of category sectioning and category weights of each of the sections as obtained by multiple regression analysis of the causal factors of occurrence of collapse. The degree of danger of each of the meshes was expressed in four stages that are the same as those for the external standards. The result of calculation is shown in Fig. II-34. The figures on the left side of each of the meshes shows the rate of collapsed are in stage number and those on the right side, estimated value of degree of danger.

(3) Total Discussion

The tendency in size of the rate of collapsed area by each of the causal factors and the tendency in the size of the rate of contribution, or category weight, to the rate of collapsed area of each of the factors as obtained by multiple regression analysis agreed roughly with each other except in some detail. Among the factors, soil depth and inclination showed the largest correlation, but micro topography and presence of stream showed no remarkable relationship. As to the direction of slope, slopes directed to the north showed a larger tendency of collapse, and this seems to be related with petrographic structure such as fractured zone etc., although this must be confirmed by further investigation. The result of analysis on vegetation covering showed many collapses in natural forests, giving a large weight; and collapse preventing function of forest was not proved. However, this seems to be due to the fact that collapse being mostly concentrated in the upper part of slopes where the soil depth was small and that most of the part was covered by natural forest. The natural forests were unable to prevent collapse in the land of a small soil depth because the surface of granite is too smooth to allow forest trees to grasp the base rock firmly enough. Among natural forests, forests having no trees of large stem diameter tended to show a larger chance of collapse. The secondary forests were mostly located on lands of gentle slope in sedimentation zone, and this affected the analysis and showed small number of collapses. Small rate of collapsed area in slopes of extremely large inclination is usual in steep mountain side, and this is due to the loss of most of the soil by past runoff of soil or collapse and to a too small amount of soil left to give a collapse. The weight decreased in the category of 34° or larger in the present investigation, and said reason is plausible as the actual inclination in the field is usually larger than one in topographic map. Soil was the most deeply related with occurrence of collapse, and the amount of daily rainfall in the mountain at the time of collapse is estimated at 300 mm or so. Saturation of the soil by the rain is the cause of collapse, and the combination of shallow soil and amount of rain to make it saturated caused to grow the category weight.

Comparison of the estimated degree of danger of collapse for each of the meshes, as obtained by using category weights that were the best in multiple regression analysis, with the actual occurrence of collapse revealed that the result of analysis was generally appropriate (Fig. II-34).

(3) Future outlook and problems

The result of studies on the method of predicting area in danger of collapse in Caraguatatuba District gave relationships between collapse and factors such as inclination or slope direction, that are similar to those obtained by studies in Japan. However, as to the relationship between collapse and soil depth or vegetation covering, effect of smooth granite lying at a small depth in Caraguatatuba was observed. No definite tendency by the micro topography and presence of stream was grasped. The rate of area of collapse in grass land was unexpectedly small, but there is a possibility of restoration of collapsed land by the landowners as the aero-photo were taken 6 years after occurrence of collapse. As explained above, it is necessary to prove the mechanism of correlation between the factors of collapse as estimated by the factorial analysis with collapse by detailed investigation in site, but this is very difficult at present 20 years after occurrence of collapse. It is worth making trial concerning vegetation covering to use the amount of accumulation per ha, that can be expressed quantitatively, as the factor. On the other hand, as seen in Table II-26, there is a difference in the numbers of meshes in a category section, some of them being extremely small. In order that such small number of meshes in a section be avoided, it is necessary to investigate and analyze an area of at least 2,000 ha; but it was impossible in the present study in a limited time. As a summary of the above discussion, it would be advised that the studies for predicting area in danger of collapse in the state of são Paulo in the future should be carried out in the following order: (1) Investigation for predicting area for danger shall be carried out in a district adjacent to the investigated district by the present investigation in similar manners, and multiple regression analysis be made over again for the data newly, obtained and those obtained in the present investigation altogether. (2) Similar investigation and analysis shall be carried out for a district other than Caraguatatuba. (3) The result obtained shall be proved by confirmation in the field. (4) Preparation of standards for predicting area in danger of collapse in São Paulo.

For (4) above, the standard for predicting area in danger of slope collapse in Japan as shown in Table II-28(1) can be referred to. It could be used for prediction in São Paulo for the time being.

Photo II-6 Mountainside collapse in Caraguatuba

Table II-28 (1) Method of Predicting Area in Danger of Collapse in Japan

Casual factor	Score						Remarks
Inclination	class	0-40%	50%	60%	70-80%	90%-	Scores for ground condition and forest condition are obtained by totaling the respective scores for each of the causal factors. (example) Inclination 60% 1.9 Horizontal cross section 180° 1.3 Presence of stream none 1.0 Soil depth 0.5m 1.9 Tree kind NL 1.2 Tree age (age class) 3 1.7 Total scores for (ground condition, forest condition) 9.0
	score	0	1.7	1.9	2.2	2.1	
Horizontal cross section	class	0-150°	160-210°	220°-	-	-	
	score	1.8	1.3	0.8	-	-	
Presence of stream	class	present	none	-	-	-	
	score	2.6	1.0	-	-	-	
Soil depth	class	0-0.5m	0.6-1.0m	1.1-2.0m	2.1m-	-	
	score	1.9	1.0	0.9	0.7	-	
Kind of trees	class	N	NL	L	-	-	
	score	1.7	1.2	1.1	-	-	
Age of trees (age class)	class	1.2	3.4	5-8	9-	-	
	score	3.2	1.7	1.0	0.4	-	

Table II-28(2) Geological characteristics score

Classification	Score	Remarks
a. Fractured granites (intruding rock)	1.3	
b. Volcanic deposit of tertiary period and quaternary period (including area mixed with deposited rock)	1.2	
c. Fractured zone and of Mesozoic era and Paleozoic era (including Paleogene)	1.1	
d. Fractured zone and of Neogene (including Tuff)	1.1	
e. Others correction (reason)	1.0	In case of correction, give reason clearly and correct by ±0.1 max.

Table II-28(3) Disaster susceptibility score

Item	Classification	Score
a. Number of dwelling houses in dangerous area concerned	50 houses or more	0.3
	10 houses or more	0.2
	5 houses or more	0.1
	4 houses or less	0
b. Public facilities in dangerous area concerned	present	0.2
	none	0
c. Farms in dangerous area concerned	3 ha or more	0.1
	less than 3 ha	0
Other correction (reason)		

Disaster susceptibility score is obtained by totaling scores for all of the items.

(example)

Number of houses	15	0.2
Public facilities	present	0.2
Farms	2 ha	0
Total (disaster susceptibility score)		0.4

In case of correction, correct within the range of ±0.1 by stating the reason clearly.

(example)

Corrected by 0.1 if disaster occurred in the past.

Table II-29 Method of Predicting Area in Danger of Collapse in Japan

(1) Deciding Area in Danger and Ranking Degree of Danger

a. Deciding area in danger

Area in danger shall be decided in the following procedure.

(a) Obtain natural condition scores for each of the meshes. (rounded to the first decimal place)

natural condition score = ground condition forest condition score x geological characteristics score

Ground condition forest condition scores shall be obtained based on Table(1), and geological characteristics score on Table(2).

(b) The area showing 8.5 or higher scores for natural condition is regarded dangerous area. The area shall be indicated by the number of meshes showing 8.5 or higher score. (If the number of meshes of 8.5 or higher score is n, the ages of land in danger shall be n ha.)

Even if none of the scores of the meshes exceed 8.5, the area can be judged dangerous if collapse has occurred actually and regarded to be dangerous area. In this case, the area of the land in danger shall be indicated by the number of meshes where collapse has actually occurred. (If the number of meshes regarded dangerous by presence of collapse etc. is n, the area of land in danger shall be n ha.)

b. Ranking degree of danger in dangerous area

Ranking of degree of danger shall be made in the following procedure.

(a) Calculate danger score for every area in danger. (Round the figure to the first decimal place.)

Danger score = mean value of scores for meshes of 8.5 or higher natural condition score x (1 + disaster susceptibility score)

For dangerous area having no mesh of over 8.5 natural condition score, calculate by assuming 8.5 for the natural condition score.

(b) Degree of danger shall be classified in three ranks of A, B and C according to the score of degree of danger. The degree of danger in areas where conservation works are roughly completed shall be C regardless of the score.

Rank	Danger degree score
A	15.0 -
B	12.0 - 14.9
C	8.5 - 11.9

II-4 Studies on the method of simple forestry conservation structures application

II-4-1 Method of applying simple conservation structures

(1) Background and object

Devastation in the state of São Paulo is taking place in a wide range and many places, by erosion on hillside in the inland part, by collapse on steep slopes along the Atlantic coast, and in many other modes. Devastation of land causes turbidity of river water by the soil runoff on one hand and increases amount of flood water by reduction of water permeability of soil on the other hand. Therefore, devastation is a serious problem for conservation of water and soil in a watershed.

If it is possible to change the devastated land, at least those in the location of importance in view of watershed management, into forest, it would be very effective in preventing soil runoff and flood.

Most of the devastated lands have lost their soil in the course of felling the forest, culture of coffee plant, sugar cane, etc., and finally grazing on grass land; and they are quite infertile at present. Besides, atmospheric temperature in the state of São Paulo is higher than one in Japan, owing to the lower latitude and the rainfall showing a higher bias by the seasons; and the soil is apt to be dry.

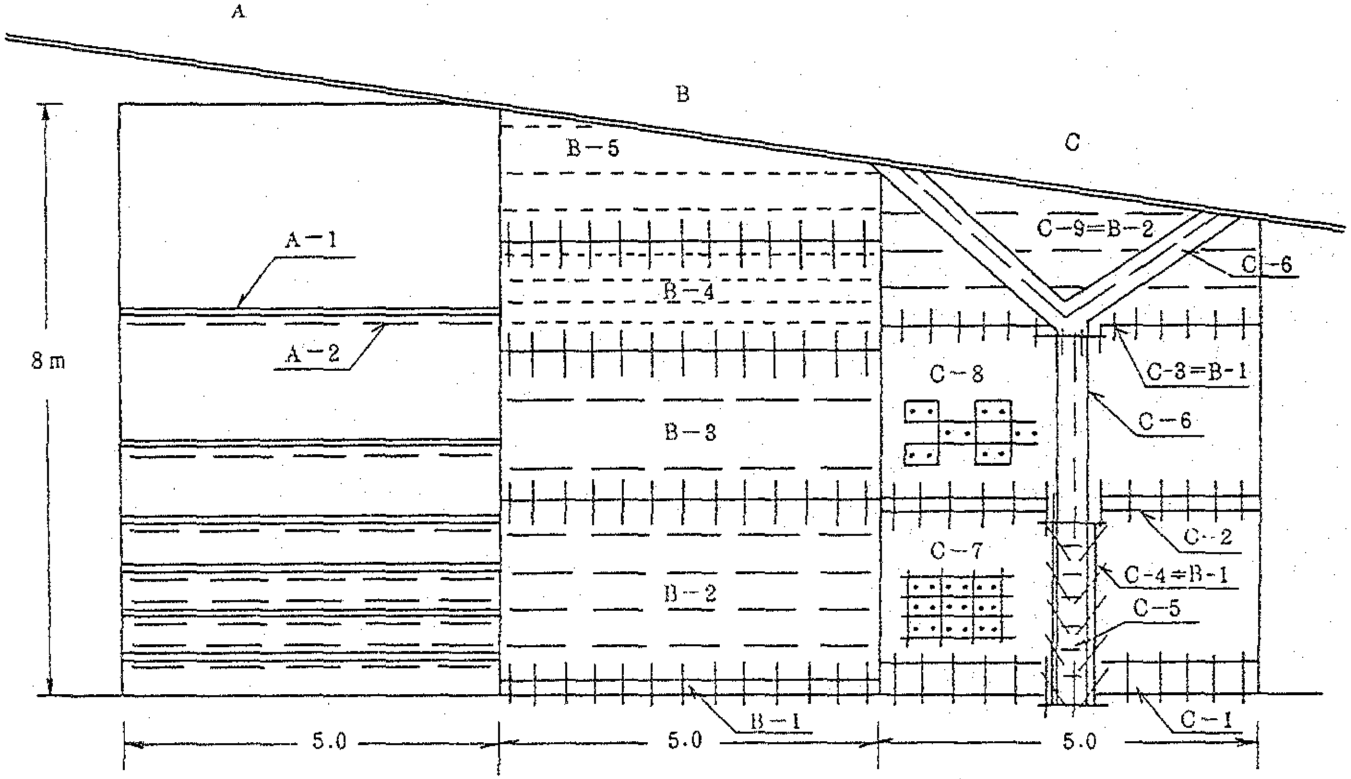
Under these conditions, forest is hardly restored in the devastated land under the natural conditions, especially in the inland part; and techniques are required for an early establishment of forest by arranging structures for soil conservation, supply of fertilizer to the soil, gathering of plant seeds, and planting seeds, roots, saplings, etc.

This kind of works, so-called forestry conservation work in Japan, is not carried out in Brazil on natural slopes, except treatment of slopes after cutting of roads. However, when districts are indicated for forest culture as important areas for water and soil conservation, as a result of studies on the testing methods of forest hydrology and studies on the method of predicting area in danger of devastation and flood runoff, as the two other major subjects in the watershed management in the present project, techniques for the method of conservation work etc. will be required. There are differences between Japan and Brazil in the soil and atmospheric temperature, as explained above, grasses and trees used for plantation on slope, and economical conditions such as material cost and labor, etc. Therefore, studies in the field should be started urgently, as a considerably long time will be required for studies by trial and error before the techniques are established. Naturally it is impossible for us to give any conclusion within the limited time of cooperation for the project, but we can except advance of studies by Forest Institute on prevention of erosion and collapse in the future by arranging a model of advancing studies on the kind and arrangement of structures, method of using plants and fertilizer, method of appraising the result of working, and other method of applying means of forestry conservation work.

(2) Progress and result

(1) Progress

It was agreed at the start of the present project to include studies on the method of simple forest conservation structures of watershed management along with two other studies on the method of forest hydrology tests and on the method of predicting area in danger of devastation and flood, as three major subjects in watershed management department. Later on plans were prepared for model arrangement of various kinds of structures to be applied to each of the devastated lands by classification of devastation types in the state of São Paulo. However, the plans were made without deciding the subject slopes, and the content of works in the testing plot was changed considerably. Besides, a plot testing ground was designed and constructed in the testing ground in Cunha for application of simple works for management of mountainside on a small scale. The works gave very useful suggestions in designing and working full-scale tests in Cunha Experiment area that was carried out during two years of extended period.



A-1: step work
A-2: sod step work

B-1: fascine fence work
B-2: sod step work (straight height 0.5m)
B-3:
B-4: cogon step work
B-5:

C-1,2: board fence work
C-3 : fascine fence work
C-4 : fascine fence channel work
C-5,6: sodded channel work
C-7 : completely sodded work
C-8 : 1/2 sodded work
C-9 : sod step work

Fig. II-35 Plan view of executing simple soil conservation works (1983)

(2) Studying method

(a) Design and execution in 1983

a) Test plot of conservation work

Design and operation were carried out for a bare land located in Cuhna Experiment Area near the office building. The plot was of about 0.11 ha area and 30 - 35 degrees inclination. Most of the surface of the slope to be treated was covered with a layer of weathered product of migmatite that is the base rock, deposited layer of collapsed soil being found in some part.

Cunha Experiment Area is located in the watershed of Rio Paraibuna, a branch of Rio Paraiba; and the annual average atmospheric temperature there is 16.7°C, annual average rainfall 2,276 mm, according to the observation in the testing ground. About 70% of the annual rainfall is concentrated in the rainy season in October to March in the following year. The base rock is said to be migmatite or millonite, and the layer of weathered soil reaches as much as 5 m in depth at the ridge near the testing slope. The soil layer contains practically no boulders or gravel, and it consists of sand or silt particles with a very small amount of grains of quartz of diameter 5 mm or smaller.

b) Policy in test working

It is difficult to decide the best suited content of conservation work of respective hillside unless many examples of working are accumulated even in Japan where many examples have already been accumulated. In Brazil, there is no such examples in the past, and the period of tests was limited. Therefore, the tests in 1983 was carried out with emphasis on the following points.

i) To find out the kind of structure that is suited to the land.

ii) To search for an appropriate working density for each of the kinds of structure.

iii) To confirm working method for the heaped part of collapsed soil where impregnation of water is expected.

iv) To try application of plants that could possibly be used for restoration of devastated slope.

Therefore, the content of working plan decided at the time did not include researching facilities such as observation channel for runoff soil etc.

c) Content of works

The test plot was divided into three sections, slopes A, B and C, each surrounded by wood panels. The kind of work adopted in each of the sections and idea in deciding the arrangement were: Slope A; Mainly step work with combination of sod step work, changing working density between the upper and lower parts, so that appropriate working density can be found. Slope B: Mainly fascine fence work for stabilization of the slope with sod step work or cogon step work of various density to find appropriate working density. Slope C: A gully formed by surface water is present, although it has no water normally; and sodded channel and fascine channel were worked, the upper layer was stabilized by fascine fence work, the surface of the slope was covered in three kinds of working methods, complete sodding, 1/2 sodding (zigzag), and sod step work, for comparison. Trace of running water was left on the slope and the deposited soil might be moved. Therefore, earth retainer by a single stage of fence of wooden panel was arranged at the lower end and center of the slope respectively. The detail of the work is omitted here, and an outline is shown in Fig. II-35.

(b) Design during 1984 - 1985

a) Plot as subject of works

Hillside works and stream works were operated in the grazing grassland situated to the south of office building in Cunha experiment area.

The problem as regards carrying out studies on the method of applying simple forest conservation works in the experiment area was that there was no devastated land large enough for establishing a test plot. Fortunately, the slope of Cunha experiment area was covered with a thick soil layer of weathered migmatite, and it was decided to remove the vegetation and prepare a bare land of fresh soil on the surface artificially. Thus a part of a model of stream work was decided to be arranged in Cunha District along with research facilities.

b) Definition of simple forest conservation structures and subject of application

Studies on the method of applying simple forest conservation structures as one of the items of watershed management department were planned in the following point of view.

i) Simple forest conservation structures application shall be worked mainly by materials that are easily available in site, such as timber, fagot, saplings, seed, earth, stone etc. and materials of low price and easy transportation to the site owing to the light weight, such as wire, nail, wire net, etc.

ii) The structure shall be of such kind that it can be constructed by manpower.

iii) The object of simple forest conservation work is to establish a forest in the devastated land as early as possible by a simple working, and land to exposed rock or a large scale devastated land of difficult working are excepted.

c) Policy and design of test working

In test working in Cunha, subject area for devastated land on slope was decided to be made by stripping ground covering off, but no suitable valley devastated was found as testing place. However, the conditions of devastation in the state of São Paulo show that working for mountainside alone is not sufficient in most of the cases and stream works must be operated side by side. On the other hand, the structure of stream works is often decided by labor and economy, and problems to be studied are small in number. Therefore, the working in Cunha was decided to be made in the

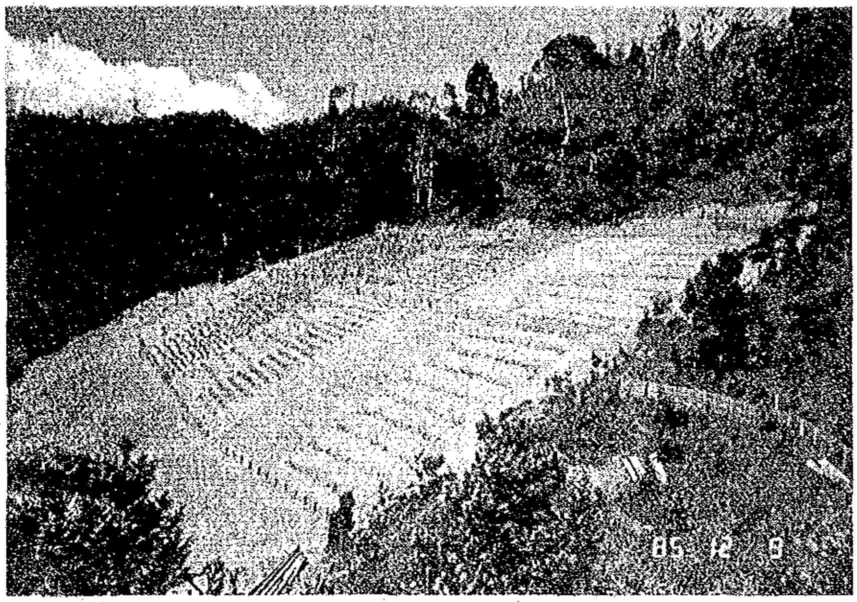


Photo II-10 Execution of simple hillside conservation works (planting)

following policy.

i) As to the working on slope, tentative combination as regards appropriate working density by inclination, effective kind of working, seeds to be used, etc. shall be examined.

ii) As to the stream works, as many kinds of works as possible using easily available materials shall be exhibited with consideration of application to devastated land in São Paulo.

Based on the policy above, works as shown in Fig. II-36 and Fig. II-37 were planned in the design document. On slope, test plots of 7 m width and 10 m horizontal length were designed, eight slopes each of 20 and 30 degree inclination and two slopes of 35 degree inclination. Each of the test plots was provided with a soil collecting channel of 7 m length, 0.40 m width, and 0.32 m depth at the lower end, so that the soil runoff can be collected and measured by the channel. Besides, several working methods were combined by by varying density for arrangement, such as bag step work, where soil, seed, and fertilizer are packed in a bag of net and arranged in the shape of contours, step work of cogon-like grass, sod step work, seed sawing step work, and tree planting work. Identical kinds of works were arranged on slopes of 20 degree and 30 degree inclinations, so that fitness of working density by inclination can be examined. As bags, Ryokka No. 3 bags were planned to be used. For stream works, concrete retaining wall, wire crate retaining wall, timber heaping retaining wall, concrete channel, U-corrugated concrete channel, U-corrugated channel, sandbag + fascine channel, and sodded channel were planned. In addition, on concave slope neighboring the slope work testing plot, that could hardly be called a valley, fascine fence and board retaining wall were planned to be arranged as model.

(3) Result of study

(a) Result of work in 1983

A part of the 1983-worked land was damaged by a heavy rain of 435.5 mm continuous rainfall (49.5 mm maximum hourly rainfall). The rainfall was said to be the heaviest in about 40 years, and necessity of structures for prevention of collapse in slopes was recognized. Further, by observation of the surface conditions of the ground for about 2 years, the content of works necessary for protection of slopes from surface erosion was clarified to some extent. The following is an outline of the findings.

i) The moisture content of soil on a concave slope seems to increase by rainfall even if no running water is observed on the surface normally. Therefore, the soil pressure of the soil layer is unexpectedly large during rain. This is especially so with a layer of heaped soil, and drainage work or other is necessary.

ii) The belting branch for fascine fence decays extremely quickly. Timber retaining wall etc. are desirable if the material is available.

iii) Fence can fall unless piles are rooted deep enough.

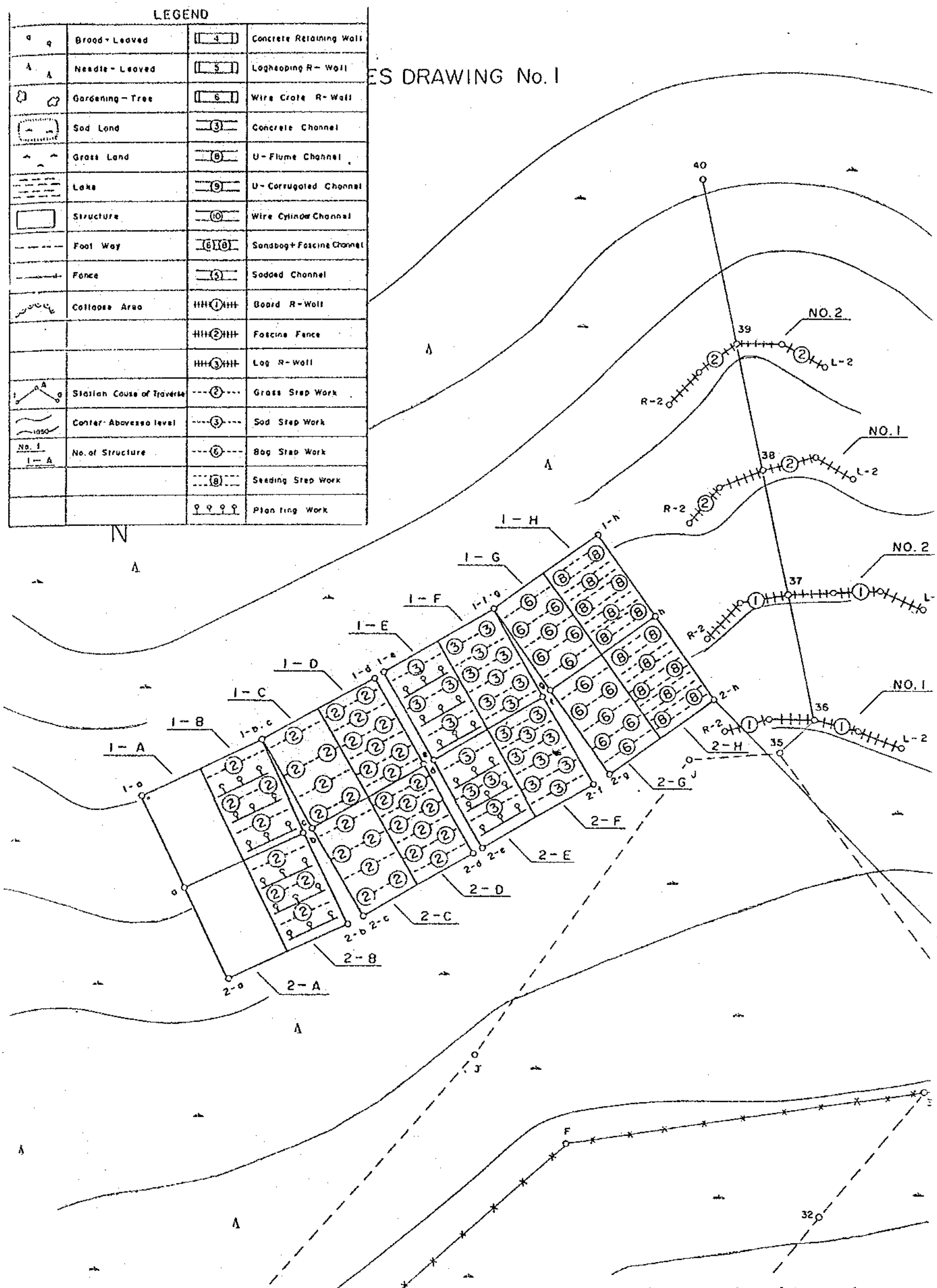


Fig. II-36 Design of hillside work

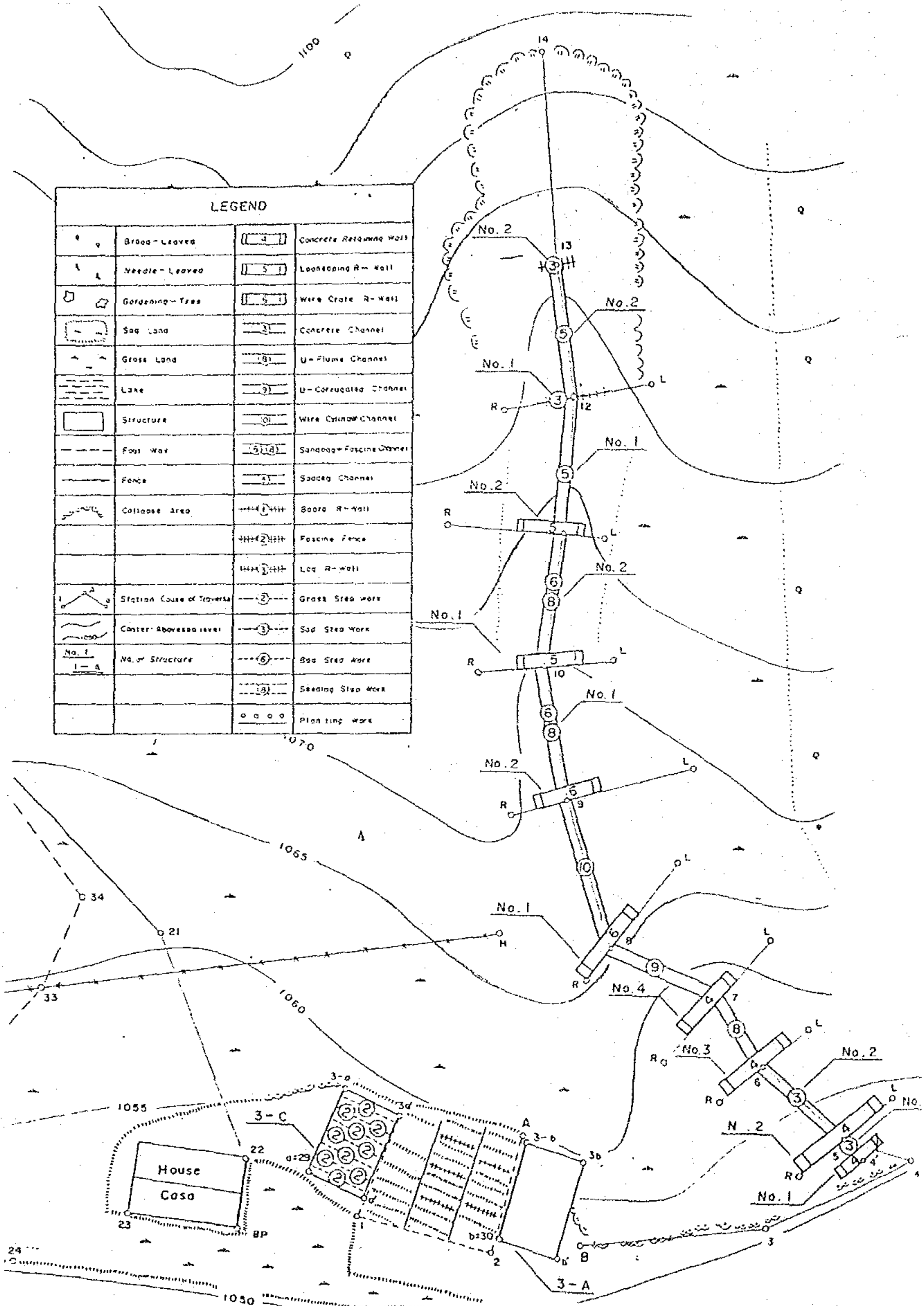


Fig. II-37 Design of stream work

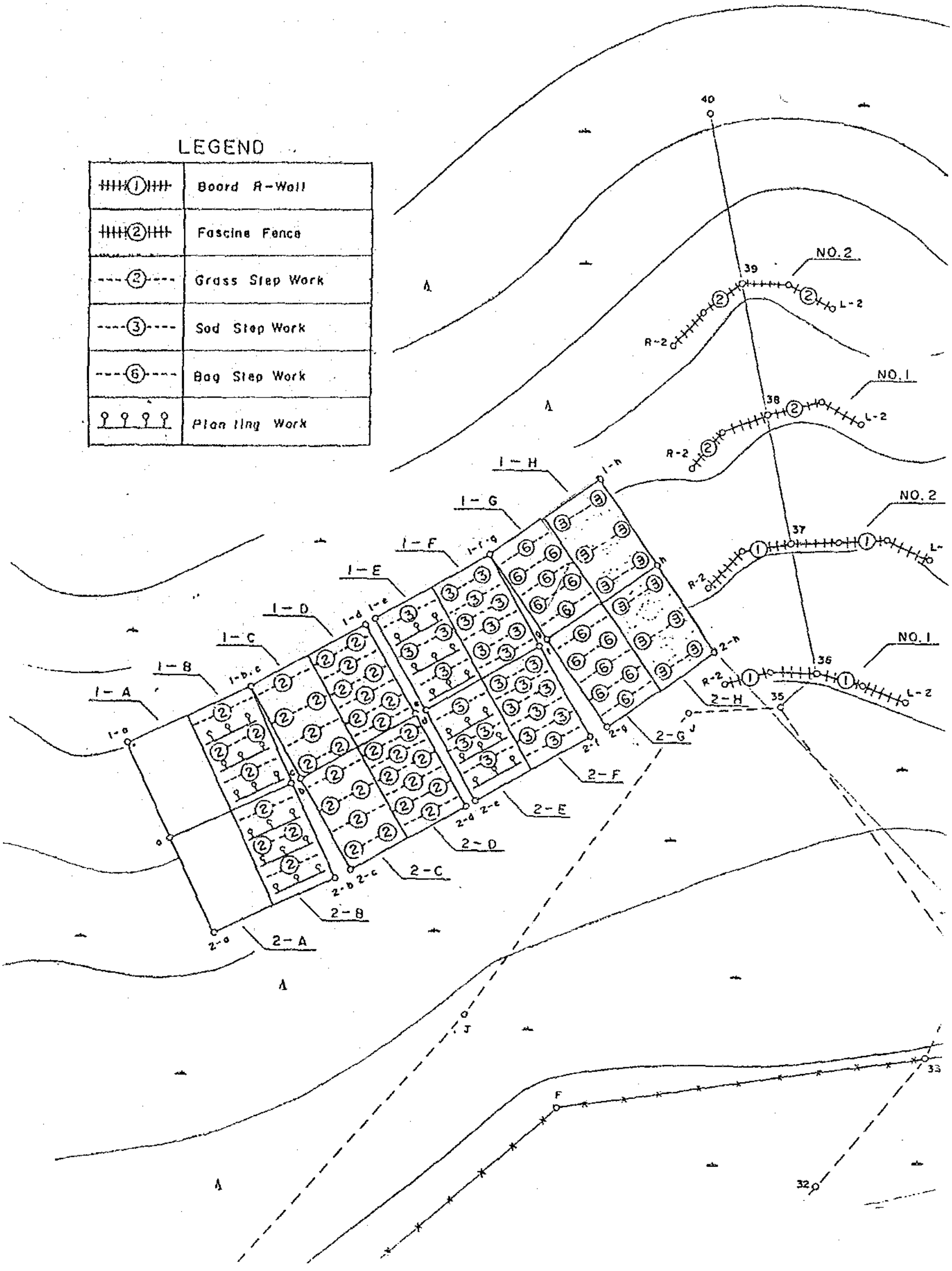
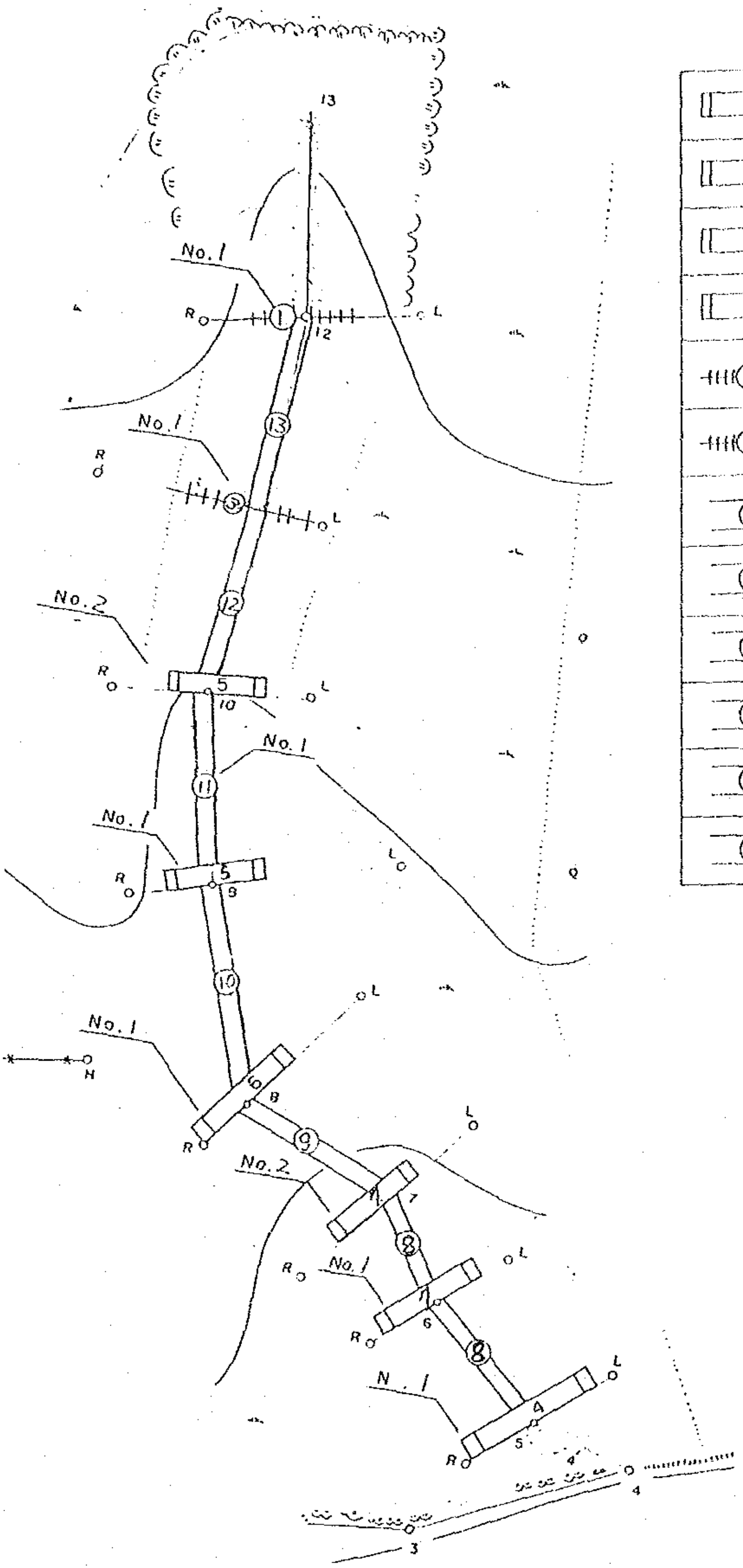


Fig. II-38 Result of hillside work (planting work)



LEGEND

4	Concrete Retaining Wall
5	Logheaping R-Wall
6	Wire Crate R-Wall
7	Logheaping R-Wall
(3)	Log R-Wall
(1)	Board R-Wall
(8)	Log R-Wall+Graveled Channel
(9)	Board R.W+Sandbag Channel
(10)	Board R.W+Graveled Channel
(11)	Board R.W+Sodding Channel
(12)	Sodding Channel
(13)	Dry Moat Channel

Fig. II-39 Result of stream work

iv) The surface of bare land is covered by a layer of paste of silt-rich soil formed by an ordinary rain, which turns into a hard board to cover the ground when it dries up. Thus the ground surface prevents plants from intrusion and causes surface erosion by making the ground surface impermeable against water.

v) In staircase without retaining wall, the horizontal surface is stable and allows easy intrusion of plants; but its vertical surface is eroded severely by the surface water. Therefore, staircase without retaining wall cannot be adopted successfully unless vertical and horizontal surface are completely covered by heaped sod.

vi) Sodding is an ideal method of working. Even half sodding in zigzag arrangement is very effective.

vii) Step work must be at a distance of 1 m or less slope length both in sodded step work and grass step work. Otherwise erosion is started between the steps and steps themselves are destroyed. The grass grows especially slowly, and the effect of erosion is strong in the case of cogon step work.

(b) Result of work in 1985

Said heavy rain destroyed a part of the simple works made in 1983, and this gave us several new knowledges for latter working. But it also disturbed obtaining materials for the works such as wire crate, corrugated channel, U-corrugated concrete channel of planned specification and strength in some cases.

Thus the works on slope were executed after some revision of the original design. Arrangement and content of completed works for slope are shown in Table II-30(1) and Fig. II-38, II-38, and the principal points of alteration are as follows:

i) To reduce concrete retaining walls that are expensive, time-consuming, and difficult to be widely used.

ii) To arrange new working method of timber frame retaining wall (stone-packed wooden frame work).

iii) To arrange wire mesh retaining wall instead of wire crate retaining wall, where ordinary wire mesh is used under support by logs and gravel is packed in manners similar to those in wire crate retaining wall.

iv) To abandon concrete channel, U-flume channel, U-corrugated channel, wire cylinder channel, and fascine fence channel and to work in log fence graveled channel, board fence sandbag channel, board fence graveled channel, board fence sodded channel, sodded channel, and dry channel.

v) The lower end of 30 degree slope (2-A~H) shall be given a board fence work for prevention of collapse.

vi) Step work shall be carried out by somewhat shorter distance.

vii) On the slopes of 35° (3-A, C) no test work shall be given but in general working.

Working was completed in December, 1985, but operation for studies and tests such as comparison of the amount of soil runoff by the kind of works, studies on the relationship between soil runoff and covering by vegetation, etc. are expected in the future. Therefore, as the result of working of simple method of forestry conservation in 1985, examples of revised design and exhibiting effect of various kinds of working methods can be enumerated, but research activities were left as future subject.

(3) *Future outlook and problems*

Works for simple forestry conservation in the state of São Paulo were designed and executed referring to the methods in Japan and with some consideration of the conditions of devastation and supply of materials of construction in the state of São Paulo. However, the difference in climate and soil between Japan and São Paulo is great. The climate in São Paulo dried soil in winter by the low humidity and in summer by the high temperature. This makes invasion of vegetation difficult. The rain in summer is mostly a concentrated rain in a short time, and it is not very effective for plant growth. The soil is acid and organic matters decompose in soil difficulty, and weathered

Table II-30 (1)

Content of works in simple forestry conservation works (1)

(earth retaining work, fence work, channel work)

Concrete retaining work	Measuring point No. 5 L=10.0m H=3.0m V=20.76m^2
Log frame retaining work	Measuring point No. 6, log channel work (gravel charged) L=12.0m L=6.0m H=2.0m A=12.0m^2 main log ϕ10cm bolt fastened
Log frame retaining work	Measuring point No. 7, log channel work L=9m L=4.0m H=2.0m A=8.0m^2 Main log ϕ10cm bolt fastened
Wiremesh retaining work	Measuring point No.8, board channel work (snan bag lined) L=17.0m L=4.0m H=1.5m A=6.0m^2 main pile ϕ10cm #8
Logheaping retaining work	Measuring point No. 9, board channel work (gravel charged) L=13.5m L=4.0m H=1.0m A=4.0m^2 log used ϕ10cm
Logheaping retaining work	Measuring point No. 10, board channel work (sodded) L=13.0m L=7.0m H=10m A=7.0m^2 log used ϕ10cm
Log fence work	Measuring point No. 11, L=13.0m L=13.0m log used ϕ10cm
Board fence work	Measuring point No. 12, dry channel work, L=14.5m L=7.0m pile ϕ10cm L=1.0m
Board fence work	Measuring point No. 36 L=20m Pile ϕ10cm L=10m
Board fence work	Measuring point No. 37 L=25m Pile ϕ10cm L=10m
Fascine fence work	Measuring point No. 38 L=20, pile ϕ10cm L=1.0 - 1.5m
Fascine fence work	Measuring point No. 39 L=20m pile ϕ10cm L=10 - 15m

Table II-30 (2) Content of works in simple forest conservation works (2) (vegetation works)

Kind of work	Tree planting work	Cogon step work	Sod step work	Vegetation bag step work	Specification
1 - A	-	-	-	-	20° inclination, no work kind
1 - B	7 stages 70 trees	7 stages 49 m	-	-	Tree planted= Cogon= at 0.73m interval
1 - C	-	12 stages 84 m	-	-	Cogon= at 0.88m interval
1 - D	-	18 stages 126 m	-	-	Cogon= at 0.85m interval
1 - E	7 stages 70 trees	-	7 stages 49 m	-	Tree planted= Sods= batatais at 0.73m interval
1 - F	-	-	18 stages 126 m	-	Sods= batatais at 0.58m interval
1 - G	-	-	-	14 stages 98 m	Seed= setavia Bermuda 5.2g/bag Chemical fertilizer 25g/bag at 0.73m interval
1 - H	-	-	7 stages 49 m	-	Sods=batatais at 1.46m interval
2 - A	-	-	-	-	30° inclination, no work kind
2 - B	11 stages 110 trees	11 stages 77 m	-	-	Tree planted= Cogon= at 0.50m interval
2 - C	-	19 stages 133 m	-	-	Cogon= at 0.60m interval
2 - D	-	28 stages 196 m	-	-	Cogon= at 0.40m interval
2 - E	11 stages 110 trees	-	11 stages 77 m	-	Trees planted= Sods=batatais at 0.50m interval
2 - F	-	-	19 stages 133 m	-	Sods=batatais at 0.60m interval
2 - G	-	-	-	19 stages 133 m	Seed: Setavia Bermuda 5.2g/bag Chemical fertilizer 25g/bag at 0.60m interval
2 - H	-	-	10 stages 70 m	-	Sods=batatais at 1.20m interval
Total	360 trees	665m	50.4 m	231m	

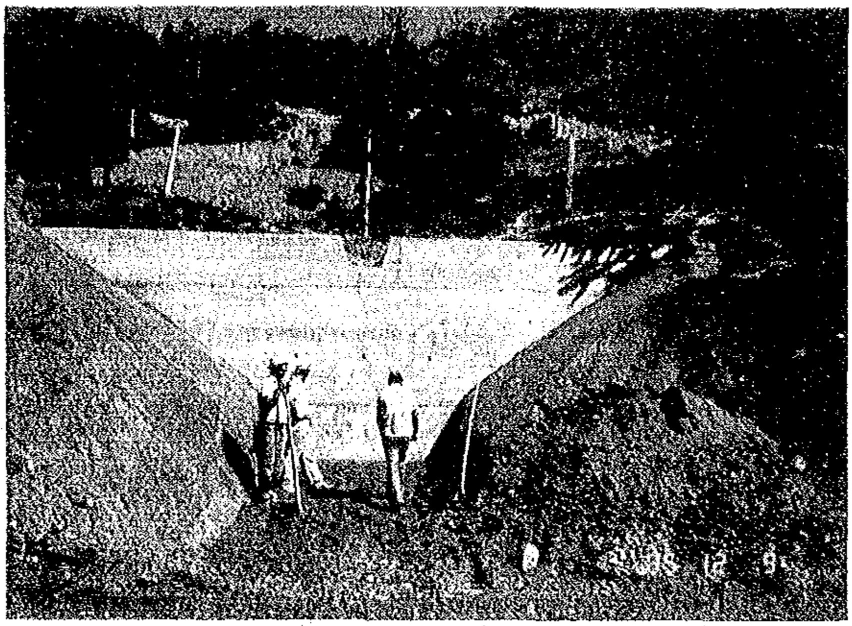


Photo II-11 Execution of simple hillside conservation work (dam)

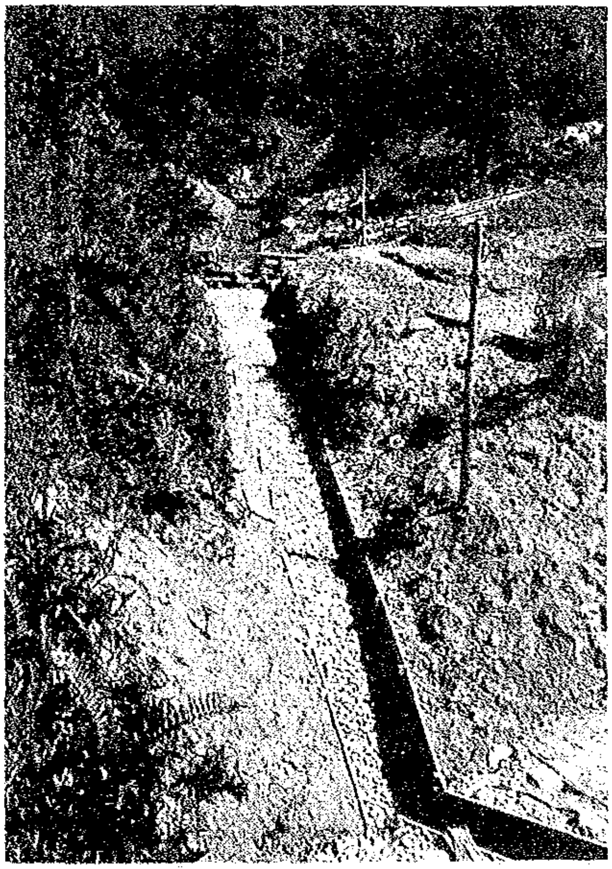


Photo II-12 Execution of simple hillside conservation work (channel) sand turns into soil but very slowly. Content of clay in the soil is very small and the depth of soil is large, and infiltrating water moves deeper into the ground making the ground surface dry. In addition, the plants differ from those of Japan as explained in the next paragraph. These situations made us difficult to decide the kinds of appropriate methods of working and standards of their arrangement during the period of cooperation. Trials and errors must be repeated for the methods of working in the future so that they will be further improved. In the phase of studies, it is necessary in the future to judge the effect of works based on the result of observation of intruding plants on the slope and that of measuring the amount of soil runoff in connection with intrusion of plants. Attention shall be made as future items of study on the following points with consideration of working outside Cunha.

i) To grasp the distance between foundation structures for prevention of collapse on a steep slope. At present, in the case of a steep slope of heaped soil, foundation works for every 10 m is necessary. In São Paulo this should be worked in timber heaping or timber fencing. In the case of timber fencing, the buried part of a timber shall be twice as long as the exposed part. Fascine fence is not advisable, for it decays very quickly.

ii) The distance between step works shall be grasped for prevention of bare land from erosion by rain water. It has been found that a distance of 1 m or larger causes a remarkably fast erosion. It should be noted that the appropriate distance depends on the inclination and kind of working methods.

iii) In stream works, refilling of soil at the approach to wings on both banks is important. Further studies are required for the distance between stream works.

iv) Works in a slope of concave or convex topography for foundation or step work shall be arranged along contours so that erosion by surface water be prevented and moisture conditions of soil be improved.

v) Trees must be planted without fail at the time of vegetation starting to cover the ground surface after step work etc. Fertile soil shall be brought in planting using pots etc.

Tests on said points are naturally important, but repeated working in actual devastated lands is more important so that experience be accumulated in Brazil and their own techniques be established. There is a large difference in atmospheric temperature, rainfall, and topography even within the state of São Paulo; and it is necessary to work in many places in the future. It would be advisable to think of working by use of timber that can be supplied by Forest Institute.

For the kinds of working methods other than those worked in Culhna testing ground, literatures 4.1-3 and 4.1-4 can be referred to.

Literature

4.1-1 Japan International Cooperation Agency: Report of Investigation on Evalution of Forestry Research Cooperation Project in São Paulo, Brazil, November, 1983

4.1-2 Japan International Cooperation Agency: São Paulo Forestry Research Cooperation Project, Design of Simple Forestly Conservation Works with Tables and Graphs, December, 1984

4.1-3 Japan International Cooperation Agency: Report of Investigation on Design and Execution of São Paulo Forestry Research Cooperation Project, October, 1980
(English edition of the same content available)

4.1-4 Forestry Conservation Research Association: Photographic Explanation of Forestry Conservation Techniques, March, 1984

4.1-5 Japan International Cooperation Agency: São Paulo Forestry Research Cooperation, Explanation on Simple Forestry Conservation Works with Graphs and Table, January, 1986

II-4-2 Selection of Plants for Forestry Conservation

(1) Background and Object

The object of forestry conservation works lies in preventing transfer of soil by constructing structures, introducing grass and trees, and finally converting a devastated land into forest. Therefore, studies on the grass and trees to be used there is as important, as it is to study structures for prevention of collapse and erosion of soil, in establishing techniques for simple works of forestry conservation.

Design and execution of simple forestry conservation works in São Paulo was advanced with reference to those in Japan. Structures for mainly physical effects can be designed and executed merely by consideration of the difference in the quality of soil, but kinds of trees and grasses are quite different between Japan and São Paulo; and examples of trees and grasses selected in Japan can not be applied in São Paulo. In addition, introduction of plants into devastated land in the state of São Paulo is placed under more difficult conditions for growth of plants, due to high atmospheric temperature, dryness as a result of smaller rainfall, and sandy soil, than in Japan. Therefore, selection of plants to be introduced into devastated land is the key for success of the method of simple application of forestry conservation. However, it is one of the fields of studies where many parts were left unclarified during the limited time. Thus the present item was taken up among the studies on application of simple forestry conservation works in a separate paragraph so that the problems be clearly indicated for future study.

(2) Progress and Result

(1) Progress

The progress of studies was already explained in Paragraph 4-1, Studies on the Method of Simple Forestry Conservation Structure Application. First of all, conditions of devastation and vegetation intruding into devastated land in natural conditions were investigated in several districts in the state of São Paulo, such as Piracicaba, Botucatu and Assis.

Secondly, trees and grasses to be used in forestry conservation were discussed based on the conditions of growth in the small test plot operated in 1983. At the same time, kinds of pasturage whose seeds are available were investigated.

As to the kinds of trees to be planted in test plot in Cunha, Tibouchina mutabilis, Tibouchina selobi, Alchornea triplinevea, etc. were proposed by Forest Institute as the kinds they hope for and can provide with.

Alchornea triplinevea that was provided with by Forest Institute for execution in 1985 will be grown as saplings. As to the grass, seeds of wild grass were not available, and pasturages that could be purchased as seeds were used.

(2) Methods of study

The seeds of grasses that we can purchase at present are limited to several kinds of those used in agriculture or grazing, but it is necessary to pick up those kinds of wild grasses that are suitable for forestry conservation work and that can be multiplied by seeds or roots. Therefore, the names of grasses and trees were investigated that showed a favorable results in the small test plot in Cunha made in 1983, although the tests were on a small scale and the examples are of limited ones. The seeds of pasturage purchased were tested for germination and others, and the amount of seeds required was investigated. As to the kinds of trees, they are limited to those held by Forest Institute; and no special study was carried out.

(3) Result of Study

The names and characteristics of plants of the kinds that were found around test plot in 1983 and regarded usable in forestry conservation are as follows:

Paspalum notatum, commonly called Grama batatais likes land of moderate humidity. It is suitable to be used as cut sod, and it grows well on a deposited land but not on dry or barren land. It is regarded to be useful in cut part, rather in the lower part of slope than in the upper part.

Photo II-7 Baccharis triplinervis

Pennisetum clandestinum, commonly called kikuyo, is strong against dryness and multiply on fertile land. It can develop runners even on barren land and expand into the surroundings, and this makes it suitable for forestry conservation work. It flowers but does not give seeds, and it is used as sods for multiplication.

Desmodium canum, commonly called Amores-do-Campo, is a plant of pulse family and it grows on a dry land or barren land. Although the seeds are not sold, it can be used as a plant suitable as forestry conservation plant if the seeds can be collected.

Erigeron bonariensis, commonly called Buva. Erigeron sumatranum is also found. Both of them multiply by seeding. It seems suitable for sawing in deposited land.

Baccharis triplinervis and Penicum maximum are both strong for driness and poorsoil, they can be used by collecting seeds.

Impera brasiliensis, commonly called Sape, or Brazilian cogon, likes moderately humid land. It is suitable for grass step work. It multiplies by the root to form a community.

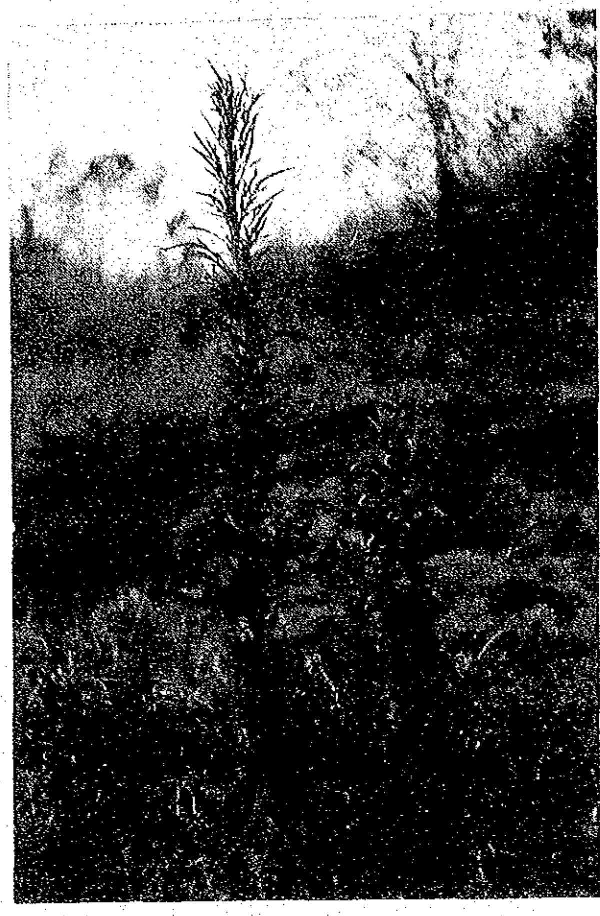


Photo II-8 Erigeron bonariensis

Eupatorim sgualidum, commonly called Cambara-roxo, is a family member of joe-pye weed. It can be used for forestry conservation work by collecting seeds.

Senecio brasilensis, commonly called Maria mole, is a member of aster family an annual herb. It can stand barren land and show a strong multiplication, but the amount of leaves is small and it is an annual herb, and it is not suitable for forestry conservation work.

Andropogon bicornis, commonly called Rabo de Burro, was used as grass step work in test plot in Cunha, but it showed a poor multiplication in the initial stage.

Sporobolus pyramidatus, commonly called Capim *touceirinha*, grows as stubbles. It is distributed widely in the whole Brazil, and it is suitable for forestry conservation. It was used for the purpose in Cunha in place of cogon.

Plants observed in the small test plot in addition to said plants are: Vernonia polyanthos, commonly called Assa peixe, and Calamagrostis viriciflaveseens, commonly called Paira-de-prata.

Of these plants, *batatais and kikuyo* are used as sods and are applicable in sodded step work, and Sporobolus was also used as it multiplies by the roots. However, seeds of other plants were *not available, and they were not* tested in the present works. Some of them may be useful if their seeds can be collected by Forest Institute.

Seeds of pasturage were purchased and used in the present works, although it is a proper approach to use plants existing in site. Two kinds of seeds were selected among seeds on the market, Setaria Pauciforia, commonly called Capin imbaimiragua, and Cynodon dactylon, commonly called Capin de Burro, Bernuda grass; and they were used in vegetation bags. They were used in amounts as shown in Table II-32, considering the rate of germination.

Table II-32 Seeds and fertilizer used in simple forestry conservation work (vegetation bag step work)

Section worked		Amount per bag	Amount used	Remarks
1 - G 20° inclination	Seed 1. Setaria 2. Bermuda	 26 g 26	14 stages x 7 m x 3 bags = 294 bags 1. Setaria 7.44 kg 2. Bermuda 7.44 kg	3 bags each used at 0.73 m interval on 14 stages.
	Fertilizer Chemical fertilizer	25	7.35 kg	
2 - G 30° inclination	Seed 1. Setaria 2. Bermuda	 26 26	19 stages x 7 m x 3 bags = 399 bags 1. Setaria 10.37 kg 2. Bermuda 10.37 kg	3 bags each used at 0.6 m interval on 19 stages
	Fertilizer	25	9.98 kg	

(3) Future outlook and problems

It is not very difficult for Forest Institute to single out trees and grasses that are strong against dryness and in barren land, taking the opportunity of test works and studies in the plot testing ground in Cunha. The problem in the future is the method of multiplication. For multiplication by seedling, abundant supply of seeds is necessary, and root-breeding rather than seedling, and stem-planting rather than root-breeding can give an earlier afforestation and is suitable for forestry conservation. In Japan, plants of willow family are used for stem-planting with a good result but similar plant cannot be found in São Paulo. However, it would be possible to find those kinds of trees that can be multiplied by burying stems or roots in São Paulo, and this would be one of the future subjects.

As to utilization of introduced species, it is necessary to single out shrub plants of Legminosae that can fix nitrogen. For working in a land of remarkable devastation, eucalyptus seems to be the best suited plant for conservation work, but its introduction was refrained from as the state of São Paulo is a specially protected district. Pinaceae grow quickly and are suitable as plants for forestry conservation.

In short, it is necessary in the future to select trees and grasses suitable for forestry conservation, to secure seeds and saplings for the purpose, and to study developing techniques for direct method of plantation on mountainside by stem planting and stem or root buring.

For Cunha test plot, planting of the kind of trees is necessary that can grow into high trees within a year. Use of pot containing fertile soil seems to be useful in planting the plants.

II-5 Application of the Results of Studies in Watershed Control

As has been stated in the beginning of watershed management department, the object of studies in watershed management department among the present project of research cooperation is to verify the necessity of culturing forest in important points of the watershed and to study the techniques for culturing forest. In studies for actual utilization, accumulation of many studied cases is necessary. The result of studies by the research cooperation project during the seven years was obtained by efforts of Japanese and Brazilian parties, but in order to achieve the object stated above, further effort by Brazilian party must be continued in the future.

For example, in the case of forest hydrological tests, data in the forests shall be collected for 5 - 6 years after constructing water measuring dams for Watershed A and Watershed B, and then one of A, B, or D be cut to study the effect of cutting. For comparison of flowrate between forest and grazing land, continued observation for almost 10 years will be necessary until the soil of forest changes into that of grazing land. Therefore, ten and odd years are consumed for observation and data analysis for just this much of studies. The river coefficient gives the ratio of high and low waters, and the coefficient obtained by water flow research in Cunha shows the characteristics of São Paulo. How the coefficient will change by felling of forest must be a matter of great concern for both Japan and Brazil.

Studies on evaporation is also important, for it affects flowrate from the forest. Variation of evaporation by the kind of trees is a problem, and collation of the result of evaporation study with the amount of runoff in Cunha water gauging test ground is important.

State of São Paulo has a large area, and the topography, atmospheric temperature, rainfall, etc. vary by the districts. In studying watershed management for water runoff and soil transfer, effects of these factors is large, and observation and investigation in several points will be necessary in the future.

Tendency of occurrence of more erosion in slopes directed to the north was observed as a result of predicting area in danger of erosion and this seems to be due to drying by the larger amount of sunshine. If so, the trees and grasses to be used in mountainside management must be selected from among those that are strong against dryness.

In Japan and other countries, studies on subjects related to watershed management are continued for several ten years, sometimes nearly a hundred years.

However, even if the cases studied for predicting area in danger of collapse are small in number, predicting standard must be decided to extract area in danger if prediction is required urgently. In such a case, prediction is asked for in spite of some problems not being clarified; and reference to the results of studies in other countries is desirable. In each of the subjects of the present project, counterparts were informed of many results of studies in Japan to enrich them with the knowledge. If they can recognize the difference between Japan and Brazil by their own result of studies in the future, usefulness of their studies will be multiplied in practice many times.

In view of the wide aspects of studying subjects, research cooperation period of seven years cannot be regarded long enough. But exchange of experts and counterparts between Japan and Brazil during the time and readiness in exchanging informations are expected to be of a great help in advancing studies on watershed management department in the future as far as it is continued.

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II.2.2-1 Faria, A.J., Hattori, S., Ometto, J.C., Buzato, O. and Villa Nava, N.A.: Balanco de energia em floresta artificial (Pinus elliottii var. Elliottii), III Congresso Brasileiro de A rometeorologia, 1983

II.2.2-2 Cicco, V., Faria, A.J., Arcova, F.C.S. and Shimomichi P.Y.: Determinacao do balanco hiarico com emprego de bacia hidrografica experimental em mata natural secundaria, Simposio Brasileiro de Hidrologia e Recursos Hidricos Simposio Internacional de Recursos Hidricos em Regioes Metropolitanas. 1985

II.2.2-3 Shimomichi, P.Y., Faria, A.J. and Hattori, S.: Determinacao dos Parametros micromeorolicos para o estudo de evapotranapiracao nos meses de Jan. - Jul./83. na E.E. Mogi-Guacu· Instituto Florestal Boletim Tecnico

II-2.2-4 Shigeaki Hattori, A.J. Faria, and P.Y. Shimomichi: Radiation and Heart Balances in Elliot Pine Forest in São Paulo State, (anticipated for Bulletin of the Forestry and Forest Products Research Institute Ibaraki, Japan)

Results of Studies on Forest Watershed Experiments

II.2.3-1 Walter Emmerich, Alceu J. Faria e Tetsuya Kudoh : Manejo de Bascias Hidrograficas, silvicultura, No.28, 273 - 275, 1982

II.2.3-2 Walter Emerich, Valdir de Cicco, Alceu J. Faria e Motohisa Fujieda: Projeto de Pesquisas Hidrologicas em Floresta Natural na Reserva Estadual de Cunha, Silvicultura em Sao Paulo, No.16, 1937 - 1744, 1982

II.2.3-3 Valdir de Cicco, Walter Emmerich, Motohisa Fujieda: Projeto de Pesquisas Hidrologicas em Floresta na Reserva de Cunha - Determinacao do Balanco Hidrico - , XI Seminario Sobre Atualidades e Perspectivas Florestais, Curitiba, 7 e 8 de Fevereiro de 1984

II.2.3-4 Francisco C.S.Arcova, Valdir de Cicco e Walter Lima: Balanco dos Nutrientes Ca, Mg, Na, K e No em Bacia Hidrografica Experimental com Vegetacao Natural, I Encontro Nacional de Hidrolosia Florestal, Piracicaba-SP, 25 e 26 de Setembro de 1985

II.2.3-5 Valdir de Cicco, Alceu J. Faria, Francisco C.S. Arcova e Shimomichi P.Y.: Determinacao do Balanco Hidrico com Emprego de Bascia Hidrografica Experimental em Mata Natural Secunaria, VI Simposio Brasileiro de Hidrologia e Recursos Hidricos, 11 a 14 de Novembro de 1985

II.2.3-6 Walter Emmerich, Valdir de Cicco e Motohisa Fujieda: Determinacao da Curve do Vertedouro da Bacia Hidrografica Experimental " D " na Reserva Estadual de Cunha, 19 pp., 1983

note 1) 2.3-1 and 2.3-2 are theses.

note 2) 2.3-3, 2.3-4 and 2.3-5 are oral reports.

note 3) 2.3-6 is data.

II.2.3-7 Motohisa Fujieda: São Paulo Forestry Research Project in Brazil A case of the watershed management, EXPERT, No.63, 25-27, JICA, 1984

II.2.3-8 Motohisa Fujieda, Valdir de Cicco: Turbidity measurement in the Cunha experimental forest in Brazil, Trans. 36th Mtg. Jap. For. Soc. KANTO Bra., 173-174, 1985

II.2.3-9 Motohisa Fujieda, Tetsuya Kudoh, Valdir de Cicco & Walter Emmerich
Cunha Forestry Hydrology Research Project in Brazil (I)
Annual Water balance D-basin, Trans. 96th Mtg. Jap. For.
Soc., 557-560, 1985

II.2.3-10 Motohisa Fujieda, Tetsuya Kudoh, Valdir de Cicco & Walter Emmerich
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II.2.3-11 Motohisa Fujieda, Tetsuya Kudoh, Yukio Mashima & Valdir de Cicco
Cunha Forestry Hydrology Research Project in Brazil (III)
Storm Runoff characteristics of D-basin, Presented in
The 97th Annual Meeting of the Japanese Forestry Society,
April, 1986

Result of Studies on the Method of Predicting Area in Danger of Erosion

II.3.2-1 Ryoji Hatamura, Koichi Akiya, Haruo Sawada, R.M. Pfeifer, E. Domingues: Predicting area in Danger of Erosion in Taubate, São Paulo State, Brazil, Presented in 97th Japan Forestry Association General Meeting, April 1986

II.3.2-2 R.M. Pfeifer, E. Dominges, R. Hatamura, K. Akiya, H. Sawada; Prediction research of surface erosion in TAUBATE area (The Presentation is scheduled in 1986)

Result of Research on the Method of Predicting area in Danger of Collapse

II.3.3-1 Koichi Akiya, Haruo Sawada, Ryoji Hatamura, R.M. Pfeifer, E. Domingues; Prediction Research in Danger of Collapse in Caraguatuba, State of São Paulo, Brazil Presented in 97th Japan Forestry Association General Meeting, April 1986

II.3.3-2 R.M. Pfeifer, E. Dominges, K. Akiya, R. Hatamura, H. Sawada: Prediction research of surface erosion in KARAGATATUBA area (The Presentation is scheduled in 1986)