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ANESTIMATION OF DEBRIS PRODUCTION BY LANDSLIDES IN THE UPPER TENRYU RIVER BASIN

By *Isao* NISHIHATA*

INTRODUCTION

Many reports and papers are published up to the present on researches for the debris production by landslides in upper river basin, or the volume of bed load sediments supplied by landslides to river courses. There are two ways to research these phenomena. The first one is the method depending on the geomorphic cycle theory, by which the variation of mountainous volume or the process of the slope formations are elucidated. The other one is to research landslides which are grown by heavy rainfall in short term, and to estimate the volume of debris production. The latter one is classified into more three items as follows.

(a) The research for the relationships between the debris volume and the elements such as rainfall amount, geological character, vegetation and others.

(b) The research by the stochastic theory assuming that the phenomena of the rainfall and landslide abode by the theorem of probability because of their uncertainty and casualty.

(c) The research by the quantification theory appreciating the informations obtained from the aerial photographs.

The papers on the first category appear in those by Murano1) and Hirono2). On the latter category, research papers by Nishihata3), Murano4),5),6), Uchihagi7),8), Yano9),10) and Ashida11) deal the item (a), those by Murota and Hashino12) belong to the item (b) and by Maruyasu13),14) and Kubomura15) the item (c).

However, the mechanism of landslide in mountainous area is very complex, and then, we have few knowledge on the relations between the debris volume and the each element such as rainfall amount, geological character, topographical nature, scale of landslide, drainage density, etc., which concern the debris production. It is generally difficult to understand as related serial phenomena for debris production, transportation and sedimentation, and also to decide an effective plan training the debris on the programs of river basin development. In recent years, Japanese river beds have remarkably desended due to excavation because most of aggregate demands are supplied by river bed materials. Therefore, the training plans are going to be investigated for many river courses.

The author took an interest for years in the studies of debris production, transportation and sedimentation in river course, and investigated the landslides in the upper Tenryu River area. The author tried to find the standard value of debris production that would be caused mainly by landslides. In this paper, the author shows some results of studies on the relations of debris productions and of their transformation for long terms noted mainly on the Tenryu River areas.

1. GEOLOGICAL OUTLINES OF THE UPPER TENRYU RIVER BASIN

The Tenryu River is one of the medium rivers located in the Honshu, central part of Japan. It rises from the Suwa Lake, and flows into the Enshu Sea, the Pacific Ocean. The upper Tenryu River basin defined in this paper is limited in the north from Ina City to Iida City in the south. It is surrounded by the South Japan Alps to the east, and by the Central Japan Alps to the west. There are some large tributaries such as the Mibu River and the Koshibu River on the left side against the main stream, however on the right side, there are many short and steep grade tributaries as shown in Fig. 1.

The main Tenryu River flows to the south. The geological distribution in this area is shown Fig. 2. The Median Tectonic Line runs from the north to the south between the Ina Mountains

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* Dr. Engg., Professor of Civil Engineering, Nagoya University.

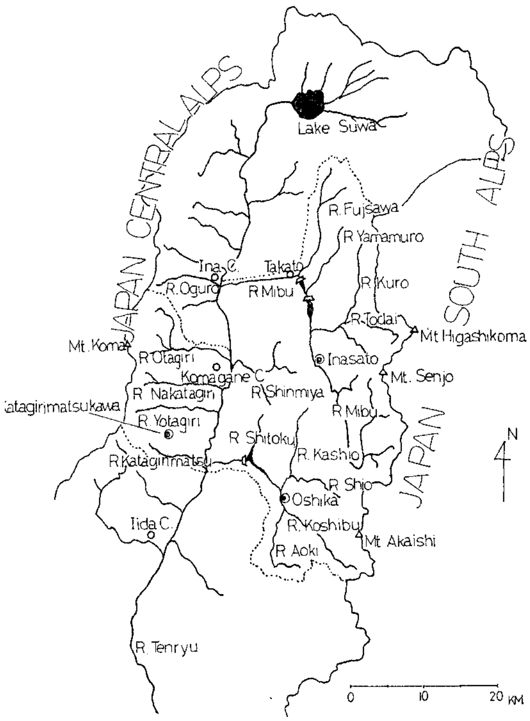

Fig. 1 Upper-stream Basion of River Tenryu.

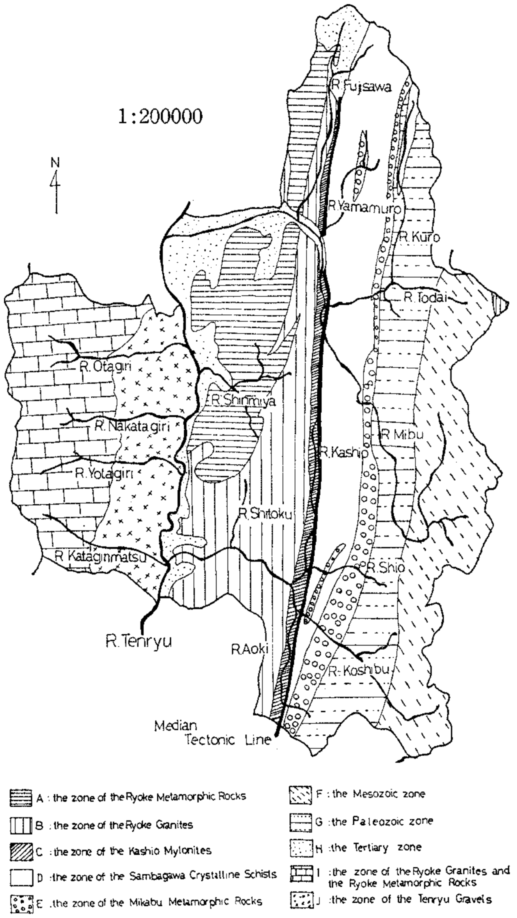

Fig. 2 Geologic Map.

Table 1

Class	Elevation	Slope Angle	Available Relief	Relative Height
i	2 500 (m)	45°	151～277	Large
ii	2 000	30°	83～147	Medium
iii	under 1 800	30°	60～ 85	Medium or Small
iv	under 800	under 24°	31～ 68	Small
v	2 500	35°	155～221	Large

Note: Available Relief $=\left(\frac{h_m+h_l}{2}\right)_{\text{mean}} \times (h_m-h_l)_{\text{mean}}$

h_m=Maximum height in 2 km square.
h_l =Lowest height in 2 km square.

and the Japan South Alps. It separates distinctly the geological structures. The fluvial terraces develop on whole area between the Mt. Ina and the Central Japan Alps.

The geological distributions in this area are parallel each other in the direction of the meridian corresponding to the laies of the lands, and may be classified as follows.

(i) The zone along the ridges of the Japan South Alps (The Akaishi Mountains).

This is the Paleozoic zone which is constituted mainly by the alternate strata of the sandstones and clay slates. In this stratum, sometimes the chert or the lime stones are included.

(ii) The piedmont zone of the Akaishi Mountains.

This zone is located in the east side of the Median Tectonic Line and constituted by the crystalline schist such as the green schists, the black schists, and the Mikabu Intrusive Rocks.

(iii) The zone of the Ina Mountains.

This zone is located in the west side of the Median Tectonic Line and constituted mainly by the Metamorphic Rocks and the Ryoke Granites. In this zone, the coarse-grained granites such as the gneissose granites and the Ikuta granites exist mainly and have weathered extremely. Also, mylonit are found.

(iv) The Tenryu Fluvial Terrace zone.

This is the zone in both sides of the

Tenryu River. The terrace gravels, the pliocene conglomerates and the mudstones exist in this zone.

(v) The zone of the Central Japan Alps.

Mainly the Ryoke Granites and the Ryoke Metamorphic Rocks exist in this zone. While the medium grained granite is found, too.

The elements of the lay of the land in this area corresponding the geological distribution are shown in Table 1.

2. A BRIEF HISTORICAL REVIEW ON THE STUDIES OF LANDSLIDES IN THE UPPER TENRYU RIVER BASIN

The Sabo-works or the erosion control works has started in this area since 1933 and the studies of landslides followed as every occasion that needed. The Ministry of Construction has investigated the status of the landslides and debris from 1950 to 1960 in order to obtain the variation and the transportation of the debris. The reports concern are published in 1960 from the Ministry.16), 17) The status of landslides in the areas of Mibu River and Koshibu River is shown in Table 2 quoted from the reports.

Table 2

	Number of landslides	Density of landslides per km^2	Area density of landslides m^2/km^2	Mean area of landslides m^2
Mibu River area	379	2.21	12 100	5 330
Koshibu River area	423	1.57	28 100	17 900

Table 3

	Mibu R.	Koshibu R.	Ōtagiri R.	Yotagiri R.
Area of Basin (km^2)	289.3	295.0	61.5	42.7
Number of Landslides	2 249	7 476	527	837
Density of Landslides per km^2	7.8	25.3	8.6	19.7

On the 27th June 1961, a heavy rainfall attacked these areas caused by rainy front. Many landslides and a large scale yield of debris arised that never observed ever before. The Ministry restarted the investigation by means of aerial photographs as well as field surveys. A proceeding report is published in 1964 18). The outline of the landslides caused by the last heavy rainfall is shown in Table 3 quoted from the report. Researches of the transformation of landslides and the debris production are carried out by many students after 1961.3), 4), 5), 6), 19) Moreover, the investigation of the status of landslides in this area was carried again mainly by means of aerial photographic surveys and by sample spot surveys by the Ministry in 1969.

The author has researched for years on the phenomena of rivers and took a chance to calculate the volume of debris produced by landslides. The author analyzed in this research the data which appeared in the reports of the Ministry and estimated the unit volume of debris which are supplied from the unit source area to river courses by per one year or one rainfall for long term.

3. THE STATES OF LANDSLIDE TRANSFORMATIONS

(1) The Outline of Rainfalls from 1961 to 1969

It is recognized that there are four types of landslide transformations by the results observed from the aerial photographs comparing those of in 1969 to the ones of in 1961. The four types are 'enlarging', 'reducing', invariable' and 'disappeared' transformations which mean respectively, the landslides are observed to be enlarging its scales, reducing its areas, seemed to be invariable states and not found any features of former landslides.

Moreover, there lies new landslides too. It is required to consider the condition of rainfalls within the period for new occurrences of landslides, because the rainfalls have the leading role to make landslides. The author therefore took averaged rainfalls for consideration of the rainfalls at Inasato, Oshika and Katagiri-Matsukawa sites assuming that the mean value of every three rainfalls represents the average rainfall in the upper Tenryu River basin. The average monthly rainfalls in these areas is shown in Table 4 calculated from the data of 1955 to 1969.

It is found from the Table 4 that the monthly rainfalls in June 1961 is extremely unusual, and that those from 1962 to 1969 are relatively seem to be usual on this area. Consequently, the author supporsed that the transformations and the new occurrence in the term from 1962 to 1969 would be usual phenomena under normal rainfalls.

Table 4 The average monthly rainfall.

(mm)

Year	1955	56	57	58	59	60	61	62	63	64	65	66	67	68	69
May	155.9	333.1	219.0	112.3	150.2	175.3	230.0	217.4	244.7	72.0	217.4	210.6	78.3	87.6	107.4
June	164.4	260.9	314.8	94.8	108.8	178.0	*584.0	370.2	242.0	264.5	220.9	233.9	190.7	140.6	355.9
July	154.3	119.4	308.1	316.1	297.8	99.0	113.2	181.8	155.4	225.1	348.1	254.1	234.5	193.7	283.3
August	147.9	241.1	109.1	235.9	289.0	353.9	63.6	113.8	211.9	69.2	50.9	72.1	85.0	423.3	228.8
September	201.1	316.0	346.5	259.3	233.1	209.2	119.4	74.9	89.8	240.0	274.9	224.5	42.9	31.0	176.9
October	189.0	135.0	54.1	211.5	191.0	88.0	229.7	123.6	80.2	117.3	62.2	92.4	138.9	104.2	47.6
Annual	1668.4	2016.8	1928.4	1860.1	2275.3	1551.9	1737.3	1477.1	1457.5	1603.6	1651.7	1736.7	1603.3	1480.2	1768.3

Notes: (1) The values are the means of 3 rainfalls at Inasato, Ōshika and Katagiri-Matsukawa.
(2) The values for the dry season are omitted.

(2) The Rearrangement of the Date on Landslides

The data on the landslides in 1961 were rearranged by the geological condition and the area scale of landslides. Mean values of areas, mean volume of debris and remained volume were calculated against each item of categories which shown on following articles. In order to clarify the phenomena, the data of the year 1969 are requested to arrange similarly. However, it is rather impossible to compare them directly to those of 1961 because the sample landslides investigated on 1961 are not always the same ones of 1969. For this reason, the author classified the data into following grades and compared the mean values of them respectively.

Table 5 Number of landslides.

		Geological condition									
		A	B	C	D	E	F	G	H	I	J
New landslides		52	102	38	127	39	221	255	6	1 121	15
Type of transformation	Enlarging	0	2	7	26	9	80	44	2	157	0
	Invariable	55	270	25	120	33	501	180	2	1 047	23
	Reducing	137	1 497	98	287	207	690	502	20	880	4
	Disappeared	233	2 364	74	589	178	87	235	60	687	70

Table 6 Percentage of area scale distribution per geological condition in 1961.

		Geological condition									
		A	B	C	D	E	F	G	H	I	J
Scale of area	I	(218) 77.2	(3 075) 74.1	(149) 60.6	(1 197) 68.7	(81) 45.2	(955) 59.2	(575) 56.6	(15) 100.0	(1 587) 58.7	(65) 48.5
	II	(58) 20.5	(921) 22.2	(74) 30.0	(425) 24.4	(77) 42.9	(487) 30.2	(297) 29.2	(0) 0	(952) 35.2	(59) 43.5
	III	(6) 2.3	(141) 3.4	(19) 7.8	(80) 4.6	(13) 7.3	(92) 5.7	(94) 9.3	(0) 0	(111) 4.1	(8) 5.6
	IV	(0) 0	(13) 0.3	(3) 1.2	(28) 1.6	(6) 3.4	(42) 2.6	(31) 3.1	(0) 0	(43) 1.6	(3) 2.4
	V	(0) 0	(0) 0	(1) 0.4	(10) 0.6	(1) 0.6	(26) 1.6	(18) 1.8	(0) 0	(6) 0.2	(0) 0
	VI	(0) 0	(0) 0	(0) 0	(2) 0.1	(1) 0.6	(11) 0.7	(0) 0	(0) 0	(5) 0.2	(0) 0
Total		(282) 100.0	(4 150) 100.0	(246) 100.0	(1 742) 100.0	(179) 100.0	(1 614) 100.0	(1 016) 100.0	(15) 100.0	(2 704) 100.0	(135) 100.0

a) The Zones Divided by the geological Conditions

The author divides this area into ten zones by the similar conditions refering the geological map (Fig. 2) as follows.

Zone A: The zone of the Ryoke Metamorphic Rocks on the east side of the Tenryu River. (gneisses, hornfels, etc.)
Zone B: The zone of the Ryoke Granites on the east side of the Tenryu River. (gneissose granodiorite, coarse-grained granites, etc.)
Zone C: The zone of the Kashio Myronits.
Zone D: The zone of the Sambagawa crystalline schists. (black schist, green schist, etc.)
Zone E: The zone of the Mikabu Metamorphic Rocks. (serpentine peridotite, green intrusive schist)
Zone F: The Mesozoic zone. (sandstones, clay slates, etc.)
Zone G: The Paleozoic zone. (sandstones, clay slates, cherts, lime stones, schalstein, etc.)
Zone H: The Tertiary zone on the east side of the Tenryu River.
Zone I : The zone of the Ryoke Granites and the Ryoke Metamorphic Rocks on the west side of the Tenryu River.
Zone J : The Tenryu Gravel zone, on the west side of the Tenryu River.

b) The classification of the Landslide Area

The landslides are classified by the scales of the area as follows.

I : The area is under 500 m^2.
II : The area is 500-2 000 m^2.
III: The area is 2 000-4 000 m^2.
IV: The area is 4 000-8 000 m^2.
V : The area is 8 000-16 000 m^2.
VI: The area is larger than 16 000 m^2.

c) The Classification by the Types of the Transformation

The transformations are classified into four types, enlarging, reducing, invariable and disappeared, exclusive of the new landslides, and it seems that the each type has the special character for the production of the debris which is carried by the water. Therefore, in this paper, the author classifies the landslides which are found on the aerial photograph in 1969 into five types including new landslides, on the basis of the states of the landslides in 1961

d) The Number of the Landslide Corresponding to the each Type of the Transformation

Table 7 Number distribution of landslides per scale, type of transformation and geological condition.

Geological Condition	Type of Trans-formation	Scale of Area					
		I	II	III	IV	V	VI
A	New	40	11	1	0	0	0
	Enlarging	0	0	0	0	0	0
	Invariable	42	12	1	0	0	0
	Reducing	106	28	3	0	0	0
	Disappeared	180	48	5	0	0	0
B	New	76	23	3	0	0	0
	Enlarging	2	0	0	0	0	0
	Invariable	200	60	9	1	0	0
	Reducing	1 109	332	51	5	0	0
	Disappeared	1 752	525	80	7	0	0
C	New	23	11	3	1	0	0
	Enlarging	4	2	1	0	0	0
	Invariable	16	7	2	0	0	0
	Reducing	60	29	8	1	0	0
	Disappeared	45	22	6	1	0	0
D	New	87	31	6	2	1	0
	Enlarging	18	6	1	1	0	0
	Invariable	82	29	6	2	1	0
	Reducing	197	70	13	5	2	0
	Disappeared	405	144	27	9	4	1
E	New	18	17	3	1	0	0
	Enlarging	4	4	1	0	0	0
	Invariable	16	14	2	1	0	0
	Reducing	94	89	15	7	1	1
	Disappeared	80	76	13	6	1	1
F	New	130	66	13	6	4	2
	Enlarging	47	24	5	2	1	1
	Invariable	296	151	29	13	8	4
	Reducing	409	208	39	18	11	5
	Disappeared	52	26	5	2	1	1
G	New	144	74	24	8	5	0
	Enlarging	25	13	4	1	1	0
	Invariable	101	53	17	6	3	0
	Reducing	283	147	47	16	9	0
	Disappeared	133	69	22	7	4	0
H	New	6	0	0	0	0	0
	Enlarging	2	0	0	0	0	0
	Invariable	2	0	0	0	0	0
	Reducing	20	0	0	0	0	0
	Disappeared	60	0.	0	0	0	0
I	New	658	395	46	18	2	2
	Enlarging	93	55	6	3	0	0
	Invariable	614	369	43	17	2	2
	Reducing	516	310	36	14	2	2
	Disappeared	403	242	28	11	1	1
J	New	7	7	1	0	0	0
	Enlarging	0	0	0	0	0	0
	Invariable	11	10	1	1	0	0
	Reducing	2	2	0	0	0	0
	Disappeared	34	30	4	2	0	0

The numbers corresponding to the tranformation types of landslides are calculated on the map protted from the aerial photographs, per each geological zone. The number distribution of landslides is shown in Table 5 against each type of transformation, and each geological zone.

e) The Distribution of the Landslides per each Class of Area

Ordinarily, the number of the landslides per each class of area can be calculated by reading the map protted from the aerial photographs. But, in this area, the ordinary method is not reliable, because the scale of map is smaller, then the distribution of the landslides per each class of area is supposed as follows. The distribution rate per each class of area, and each geological zone has been calculated in 1961. (Table 6) Then, the author suppose that the above distribution rate is able to apply to the each item in Table 5, and the distributions of the landslides obtained by this mean, are shown in Table 7.

f) The Mean Area against each Item in Table 7

The mean area against each item in Table 7 is calculated on the sample data which was surveied in 1969. The number of the sample landslide in 1969 is 427, and for the calculation of the mean area against each item in Table 7, firstly, the site of the sample landslide in 1969 is found on the map in 1961, and its area, as of 1961, is estimated on the map. Secondly, the estimated areas are averaged, against each item.

The mean area in 1969 against each item is calculated easily on the sample data, and it is shown in Table 8.

g) The Gross Area of the Landslides against each Type of the Transformation

The gross area of the landslides against each type of the transformation is calculated as follows.

(i) The gross area of the new landslides, A_n; A_n=the total sum of the new landslide area.

(ii) The gross area of the enlarging landslides, A_e;

$$A_e=\sum_{i=I}^{VI}\{(A_i-B_i)\times l_i\}$$

A : the mean area of the enlarging landslides in 1969 belonged to the

Table 8 Mean area of landslide in 1969.

Type of trans-formation	Scale of area	Geological condition									
		A	B	C	D	E	F	G	H	I	J
Enlarging	I	—	*840	*340	*700	*650	250	*1 080	*600	*790	—
	II	—	—	1 200	*2 100	*1 900	1 375	6 000	—	2 500	—
	III	—	—	*3 180	*5 000	*4 200	3 200	5 000	—	7 400	—
	IV	—	—	—	*9 000	—	8 900	*24 600	—	20 000	—
	V	—	—	—	—	—	21 300	*51 950	—	—	—
	VI	—	—	—	—	—	37 500	—	—	—	—
Invariable	I	*400	220	*320	450	*280	300	257	*320	205	259
	II	*1 000	1 500	900	2 000	*1 290	942	1 040	—	1 230	1 100
	III	*3 000	2 400	2 100	*2 880	2 250	3 160	2 612	—	3 333	2 450
	IV	—	*6 000	—	5 600	*7 500	4 610	5 767	—	4 500	7 500
	V	—	—	—	13 500	—	10 788	*14 000	—	12 300	—
	VI	—	—	—	—	—	51 692	—	—	*46 300	—
Reducing	I	*40	189	*290	225	200	236	134	*200	208	*200
	II	*100	411	650	509	*900	732	635	—	798	*800
	III	300	1 063	1 800	992	1 850	1 954	1 841	—	1 907	—
	IV	—	3 213	6 000	4 617	*5 250	4 343	4 360	—	4 650	—
	V	—	—	—	6 206	*9 095	7 560	12 500	—	*9 190	—
	VI	—	—	—	—	15 000	27 072	—	—	14 800	—
Disappeared	I	400	310	320	330	280	319	290	320	290	259
	II	1 000	1 060	1 120	1 250	1 290	1 014	1 080	—	1 048	1 031
	III	3 000	3 410	2 970	2 880	3 110	3 247	2 680	—	2 824	3 000
	IV	—	6 000	6 330	6 240	7 500	5 269	6 630	—	6 354	5 250
	V	—	—	—	12 330	13 000	11 100	14 000	—	15 036	—
	VI	—	—	—	27 670	19 000	25 000	—	—	46 300	—

Note: 1. Mean areas in the column of Disappeared represent the mean areas of landslides against each items in 1961.

2. * shows the assumed number by the similar geological condition samples.

class i of the area scale in 1961,

B_i: the mean area of the landslides belonged to the class i of the area scale in 1961,

l_i : the number of the enlarging landslides belonged to the class i of the area scale in 1961.

(iii) The gross area of the invariable landslides, A_u;

$$A_u = \sum_{i=I}^{VI} B_i \cdot m_i$$

m_i: The number of the invariable landslides belonging to the class i of the area scale.

(iv) The gross area of the reducing landslides, A_r;

$$A_r = \sum_{i=I}^{VI} \{(B_i - C_i) \times n_i\}$$

C_i: the mean area of the reducing landslides in 1969 belonged to the class i of the area scale in 1961,

n_i: the number of the reducing landslides belonged to the class i of the area scale.

(v) The gross area of the disappeared landslides, A_d;

$$A_d = \sum_{i=I}^{VI} B_i \cdot P_i$$

P_i: the number of the disappeared landslides in 1969 belonged to the class i of the area scale in 1961.

The calculated values by above equations are shown in Table 9.

h) The Area Rates per each Type of the Transformation of Landslides

The author defines the ratio of the gross area per the transformation type to the area of its geological zone as the area rate per the type of the transformation of landslides. Each area ratio in the upper Tenryu River basin is shown in Table 10.

i) The Produced Volume of Debris from the Landslides per the Type of the Transformations of Landslides.

It is necessary to clarify the debris volume fell down and the remained debris volume on the spot as well as the area of the landslides for the estimation of the debris volume which are carried down to the river courses. Fortunately in this basin, the sample landslide survey was carried twice in 1961 and in 1969 and there are many data on the landslides. Then, the author divides these sample data into the items of the type of the transformation, and calculates the mean volume of debris against each item, and then,

Table 9 Gross areas of the landslides against the type of the transformation.

(m^2)

Type of transformation	Geological condition									
	A	B	C	D	E	F	G	H	I	J
New landslides	35 700	42 400	22 090	73 100	3 650	127 170	143 690	28 800	479 470	4 180
Enlarging	0	1 064	480	16 640	5 010	35 148	148 810	560	194 570	—
Invariable	31 800	161 600	14 700	136 880	34 540	675 680	202 080	640	916 760	23 800
Reducing	71 460	483 290	28 840	116 630	84 630	188 280	198 820	2 400	251 380	580
Disappeared	135 000	141 440	63 190	974 560	237 870	105 830	274 460	19 200	580 790	62 240

Table 10 Area ratio of landslides against the type of the transformation.

($\% \times 10^4/km^2$)

Type of transformation	Geological condition									
	A	B	C	D	E	F	G	H	I	J
New landslides	290	298	891	370	159	825	820	355	4 860	43
Enlarging	0	7	19	72	219	228	849	7	1 262	—
Invariable	258	1 135	593	693	1 508	4 385	1 153	8	5 945	245
Reducing	581	3 394	1 163	591	3 696	1 222	1 135	30	1 630	6
Disappeared	1 097	993	2 548	4 943	10 390	687	1 567	237	3 766	640

estimates the mean depth of the carried down debris as follows.

But in this case, the author supposes that the slided debris volume swells 1.7 times of the original volume because the swell coefficient of hard rock is about 1.7.

(1) The mean depth of debris produced from the new landslides, d_n;

$$d_n=\Sigma(h_i\cdot A_i\cdot n_i)/\Sigma A_i\cdot n_i$$

$h_i=\Sigma(V_s-V_r)/\Sigma A$

A_i = mean area of the new landslide against the area scale i,

n_i = number of the new landslides against the area scale i,

V_s = slided debris volume of each landslide against an area scale,

V_r = remained debris volume of each landslide per an area scale,

A = are of each landslide per an area scale.

(2) The mean depth of debris produced from enlarging landslides, d_e;

$$d_e=\Sigma V_{e,i}\cdot n_i/\Sigma A_{e,i}$$

$V_{e,i}=\sum_{1}^{n}\{1.7a_i\cdot b-(c+d)\}/n$

a_i = mean depth of slided debris of

Table 11(a) Mean depth of run off debris from newlandslides. d_n.

		Geological conditions									
		A	B	C	D	E	F	G	H	I	J
Run off debris volume	Area scale of landslide I	*36 800	*43 800	*24 070	124 070	*12 300	*90 690	82 660	*4 930	210 400	*4 600
	II	*24 750	57 960	*43 490	*134 850	*84 430	210 730	25 640	—	624 500	*10 090
	III	*8 100	*31 920	40 180	*66 350	*50 380	*165 200	129 600	—	252 300	*7 200
	IV	—	—	64 440	48 000	*43 570	*110 670	72 000	—	288 800	—
	V	—	—	—	*66 460	—	*285 900	*613 200	—	64 000	—
	VI	—	—	—	—	—	*280 000	—	—	*233 300	—
	Total volume (m^3)	69 650	133 680	172 180	440 160	190 680	1 143 190	923 100	4 930	1 673 300	21 890
Total area of new landslides (m^2)		30 000	75 190	34 920	117 510	43 800	267 290	310 020	1 920	909 360	12 030
Mean depth d_n (m)		2.32	1.78	4.94	3.75	4.35	4.28	2.98	2.57	1.84	1.82

Note: * shows the volume which is calculated on the data of landslides in 1961 because there are no samples in 1969.

Table 11(b) Mean depth of run off debris from enlarged area of landslide. d_e.

		Geological conditions									
		A	B	C	D	E	F	G	H	I	J
Run off debris volume	Area scale of landslide I	—	*1 600	*400	*19 800	*7 200	4 700	*37 500	*720	55 800	0
	II	—	—	1 800	*20 400	*12 000	55 200	113 100	—	0	—
	III	—	—	*1 700	*6 000	0	0	—	—	55 200	—
	IV	—	—	—	*8 300	—	15 000	*23 400	—	168 000	—
	V	—	—	—	—	—	23 400	*45 600	—	0	—
	VI	—	—	—	—	—	72 000	—	—	—	—
	Total volume (m^3)	—	1 600	3 900	54 500	25 800	170 300	219 600	720	279 000	—
Total area of enlarged ports (m^2)		—	1 064	480	16 640	5 010	35 150	148 810	560	194 570	—
Mean depth d_e (m)		—	1.50	8.10	3.27	5.15	4.85	1.47	1.28	1.43	—

Note: * shows the volume which is calculated on the supposition that the landslide has the nearly same enlarging ratio of area in the similar geological condition because there are no sample data in 1969.

landslides which were belonged to the area scale i, assuming that the mean depth of enlarging section is equal to the original one.

b =area in 1969 each enlarging landslide sample belonging to the area scale i,

c =run off volume of debris from the sample landslide in 1961,

d =remained debris volume in 1969 in the sample landslide,

n =sample number of enlarging landslides belonging to the area scale i,

n_i =number of enlarging landslide against the area scale i,

$A_{e,i}$=total enlarged area of landslides against the area scale i.

(3) The mean depth of debris produced from invariable landslides, d_u;

$d_u = \Sigma(V_{r,i} - V'_{r,i})n_i / \Sigma A_i$

$V_{r,i}$=mean remained debris volume of the sample landslides in 1961 against area scale i,

$V'_{r,i}$=mean remained debris volume of

Table 11 (c) Mean depth of run off debris from invariable landslides. d_i.

			Geological conditions									
			A	B	C	D	E	F	G	H	I	J
Reduced volume of remained debris	Area scale of landslide	I	*1 680	10 000	*320	10 660	*1 440	47 360	9 090	*140	128 940	*550
		II	*1 440	0	1 050	19 140	*840	0	13 700	—	0	1 800
		III	*200	0	6 120	*7 320	330	8 410	14 280	—	0	880
		IV	—	*2 400	0	17 140	1 750	0	66 000	—	86 700	5 500
		V	—	0	—	14 270	0	0	7 800	—	—	—
		VI	—	—	—	0	0	0	0	—	—	—
	Total volume (m^3)		3 320	12 400	7 490	68 530	4 360	55 770	110 950	140	215 640	8 730
Total area of Invariable landslide (m^2)			31 800	161 600	14 700	136 880	34 540	675 680	202 080	640	916 760	23 800
Mean depth d_i (m)			0.10	0.08	0.51	0.50	0.13	0.08	0.55	0.22	0.22	0.37

Note: * shows the volume which is calculated on the data of the remained debris volume assuming that it is reduced at the similar rate of the sample landslide against the same or similar geological condition, because there are no samples in 1969.

Table 11 (d) Mean depth of run off debris from reduced landslides. d_r.

			Geological conditions									
			A	B	C	D	E	F	G	H	I	J
Run off debris volume	Area scale of landslide	I	*7 420	11 090	2 400	19 700	23 500	44 990	28 300	*2 000	103 200	*100
		II	*5 600	89 640	13 920	75 600	40 940	83 200	80 850	—	108 500	*360
		III	1 300	54 060	20 640	15 600	20 550	81 900	108 100	—	324 000	—
		IV	—	27 600	26 700	—	*30 100	68 400	144 000	—	32 200	—
		V	—	—	—	25 200	*20 000	253 000	49 500	—	*4 000	—
		VI	—	—	—	—	—	85 000	—	—	40 000	—
	Total volume (m^3)		14 370	182 390	63 660	136 100	135 090	616 490	410 750	2 000	611 900	460
Total area of reduced landslide (m^2)			71 460	483 290	28 840	116 630	84 630	188 280	198 280	2 400	251 380	580
Mean depth d_r (m)			0.20	0.37	2.20	1.17	1.60	3.26	2.06	0.83	2.44	0.79

Note: * shows the volume which is calculated on the data of landslides in 1961, because there are no samples in 1969.

Table 11 (e) Mean depth of run off debris from disappeared landslide. d_a.

			Geological conditions									
			A	B	C	D	E	F	G	H	I	J
Run off debris volume	Area scale of landslide	I	12 600	17 520	1 800	40 500	20 000	5 720	13 300	*6 000	80 600	1 700
		II	9 600	141 750	10 560	155 520	34 960	10 400	37 950	—	48 700	5 400
		III	2 250	84 800	15 480	32 400	17 810	10 500	28 600	—	25 200	3 520
		IV	—	38 640	26 700	—	25 800	7 600	63 000	—	25 300	11 000
		V	—	—	—	50 400	20 000	23 000	22 000	—	2 000	—
		VI	—	—	—	31 000	—	17 000	—	—	20 000	—
	Total volume (m^3)		24 450	282 710	54 540	309 500	118 570	74 220	164 850	6 000	201 800	21 620
Total area of disappeared landslide (m^2)			135 000	141 440	63 190	974 560	237 870	105 820	274 460	19 200	580 790	62 240
Mean depth d_a (m)			0.18	2.00	0.86	0.32	0.50	0.70	0.60	0.31	0.35	0.35

Note: The volumes against each item in this table are calculated on the same data of the reduced landslides.

the sample landslides in 1969 against area scale i,

n_i =number of the invariable landslides against area scale i,

A_i =total area of the invariable landslides against area scale i.

(4) The mean depth of debris produced from reducing landslides, d_r;

$$d_r=\Sigma(V_{r,i}-V'_{r,i})n_i/\Sigma A_i$$

where,

$\left.\begin{matrix}V_{r,i}\\V'_{r,i}\end{matrix}\right\}$ the same definition as (3),

n_i =number of the reduced landslides against area scale i,

A_i =total reduced area of the reducing landslides against area scale i.

(5) The mean depth of debris produced from disappeared landslides, d_a;

$$d_a=\Sigma(V_{r,i}-V'_{r,i})n_i/\Sigma A_i$$

where,

$\left.\begin{matrix}V_{r,i}\\V'_{r,i}\end{matrix}\right\}$ the same definition as (3),

n_i =number of the disappeared landslides against area scale i,

A_i =total area of the disappeared landslides against area scale i.

The each mean depths are shown in Table 11 (a), (b), (c), (d) and (e).

4. THE VOLUME OF DEBRIS WHICH IS PRODUCED FROM THE LANDSLIDES

As the results of this analysis in the upper Tenryu district, the facts are known as follows:

(1) The geological zones in which the much debris is apt to yield by new landslides, are I, C, F and G.

(2) The zones in which the much debris is apt to yield by enlarging landslides, are I, G, F and E.

(3) The zones in which the much debris is remained on the landslide spots and the debris run off in large quantities from them, are E, I, F, G and C.

Moreover, it is found on the original data that the number of landslides in the zones D, E, F and G increases corresponding to the quantity of rainfall.

Now, the area rate and the mean depth of debris per each type of the transformation of landslide are calculated per the geological zone in the upper Tenryu River barin. If it is allowable to suppose that the distribution of the number and the area scale of the landslides in each geological zone is constant, in usual rainfall condition, the volume of debris which will produce from the new and old landslides per the geological zone will be equal to the sum of the product of area rate, geological zone area and the mean depth of debris per the each type of transformations.

The debris volume which is calculated by this mean, is shown in Table 12 (a) and (b) on the catchment area of the Miwa Reservoir. But, the values in the Table 12 are the sum of the debris volume which was produced during eight years from 1961 to 1969. Refering the Table 12 (a) and (b), it is found that the volume of run off debris

Table 12(a) The debris volume ran off from the new and enlarged landslides in the catchment area of the Miwa Reservoir.

		Type of transformation	Area (km^2)	Area ratio (%)	Mean depth (m)	Debris volume (m^3)
Geological condition	A	New L.	3.3	0.0290	2.32	2 220
		Enlarged L.			—	—
	B	New L.	19.2	0.0298	1.78	10 180
		Enlarged L.		0.0007	1.50	200
	C	New L.	3.7	0.0891	4.94	16 290
		Enlarged L.		0.0019	8.10	570
	D	New L.	59.0	0.0370	3.75	81 860
		Enlarged L.		0.0072	3.27	13 890
	E	New L.	8.1	0.0159	4.35	5 600
		Enlarged L.		0.0219	5.15	9 140
	F	New L.	108.8	0.0825	4.28	384 170
		Enlarged L.		0.0228	4.85	120 310
	G	New L.	106.6	0.0820	2.98	260 490
		Enlarged L.		0.0849	1.47	133 040
	H	New L.	3.5	0.0355	2.57	3 190
		Enlarged L.		0.0007	1.28	30
	I	New L.	0	0.4860	1.84	0
		Enlarged L.		0.1262	1.43	0
	J	New L.	0	0.0043	1.82	0
		Enlarged L.		—	—	0
Total			312.2			1 041 180

Table 12(b) The debris volume ran off from the invariable, reduced and disappeared landslides in the catchment area of the Miwa Reservoir.

		Type of transformation	Area (km^2)	Area ratio (%)	Mean depth (m)	Debris volume (m^3)
Geological condition	A	Invariable L.	3.3	0.0258	0.10	90
		Reduced L.		0.0581	0.20	380
		Disappeared L.		0.1097	0.18	650
	B	Invariable L.	19.2	0.1135	0.08	1 740
		Reduced L.		0.3394	0.37	24 080
		Disappeared L.		0.0993	2.00	38 130
	C	Invariable L.	3.7	0.0593	0.51	1 120
		Reduced L.		0.1163	2.20	9 470
		Disappeared L.		0.2548	0.86	8 110
	D	Invariable L.	59.0	0.0693	0.53	21 670
		Reduced L.		0.0591	1.17	40 800
		Disappeared L.		0.4943	0.32	93 300
	E	Invariable L.	8.1	0.1508	0.13	1 590
		Reduced L.		0.3696	1.60	47 900
		Disappeared L.		1.0390	0.50	42 080
	F	Invariable L.	108.8	0.4385	0.49	233 770
		Reduced L.		0.1222	3.26	433 430
		Disappeared L.		0.0687	0.70	52 320
	G	Invariable L.	106.6	0.1153	0.55	67 400
		Reduced L.		0.1135	2.06	249 240
		Disappeared L.		0.1567	0.60	100 220
	H	Invariable L.	3.5	0.0008	0.22	10
		Reduced L.		0.0030	0.83	90
		Disappeared L.		0.0237	0.31	260
	I	Invariable L.	0	0.5945	0.22	0
		Reduced L.		0.1630	2.44	0
		Disappeared L.		0.3766	0.35	0
	J	Invariable L.	0	0.0245	0.37	0
		Reduced L.		0.0006	0.79	0
		Disappeared L.		0.640	0.35	0
Total			312.2			1 468 050

from the new and enlarging landslides is smaller than the volume of them from the invariable, reducing and disappeared landslides.

Consequently, the total sum of the calculated run off debris is 2 510 000 m^3, and aside it, the volume of the sedimented materials in the Miwa Reservoir and its upper river beds was calculated as 2 850 000 m^3 and 65 000 m^3 in this period by the reports of the Construction Ministry.[21] Considering that the volume of the sedimented materials in the reservoir contains the debris, which ran off from the weathered surfaces of the mountains, the calculated debris volume which ran off from the landslides would be reasonable.

5. THE RELATION BETWEEN THE DEBRIS RUN OFF FROM LANDSLIDES AND THE RAINFALL CONDITION

It will be able to suppose that the volume of debris run off from the invariable, reducing and disappeared landslides per year is nearly constant, if the special heavy rainfall does not occur in the considering period. But, it is supposed that the growth of the new and enlarging landslides corresponds to the rainfall which stimulates it.

In June, 1961, the rainfall continued from 23th to 30th and the extremely heavy rainfall occured on 27th. It is presumed that the most landslides occured in the period from the midnight of the 27th to the early down of the 28th. Refering this fact, it is supposed that the necessary conditions for the occurence of the landslide are the antecedent rainfall and the some heavy rainfall which induces the landslide.

For the explanation of this fact, Kimiya[20] supposed that the infiltrated water perticipated with the landslide only, and after the ground water pressure exceeded a settled level by the infiltrated water, the landslide would occur. According to this supposition, he defined the dry coefficient K which indicated the infiltration condition of rain water, and the rain depth R which was the sum of the effective infiltrated rain ER inducing the landslide, and he found the fact that the peak time of R corresponded well to the time of the occurence of landslides on the Ōkuzure area, Shizuoka Prefecture.

Kimiya defined K and R as follows,

$$K_n = 1 - \frac{(r_{n-1}/2 + r_{n-2}/4 + r_{n-3}/6 + r_{n-4}/8 + \cdots)}{(1/2 + 1/4 + 1/6 + 1/8 + \cdots) \times 5 \times R_A} \quad \cdots\cdots\cdots\cdots (1)$$

where,

K_n : the dry coefficient of nth day which means the last day in the considering period,

R_A : the mean daily rainfall in the corresponding basin,

r_n : the daily rainfall of the nth day in the considering period,

r_{n-1}: the daily rainfall of the $(n-1)$th day.

The equation (1) means that, when the antecedent rainfall is nothing, $K_n=1$, and when it is equal to $5R_A$ every day, $K_n=0$. But, when the antecedent rainfall is larger than $5R_A$, the value of K_n is smaller than zero. In that case, Kimiya proposes to adopt $K_n=0$. Moreover, the coefficient of each term has not the special basis.

$$R_n = ER_n + ER_{n-1}/2 + ER_{n-2}/4 + ER_{n-3}/6 + \cdots \quad \cdots\cdots\cdots\cdots (2)$$

where

$$\begin{aligned} ER_n &= K_n \cdot r_n , \\ ER_{n-1} &= K_{n-1} \cdot r_{n-1} , \\ ER_{n-2} &= K_{n-2} \cdot r_{n-2} , \\ &\cdots\cdots\cdots\cdots , \\ &\cdots\cdots\cdots\cdots . \end{aligned}$$

In the equations (1) and (2), Kimiya applied five to n, by means of the trial and error on this area.

The author modify the Kimiya's dry coefficient K as follows, because the infiltration of rain water does not stop at any time, and then, the author calls it the infiltration index K',

$$K' = 1 - \frac{(r_{n-1}/2 + r_{n-2}/4 + r_{n-3}/6 + \cdots) \times 0.8}{(1/2 + 1/4 + 1/6 + \cdots) \times 5 \times R_A} \quad \cdots\cdots\cdots\cdots (3)$$

but, $K_n'=0.2$ when the calculated value is smaller than 0.2.

The coefficient 0.8 in the eqeation (3), and $K_n'=0.2$ have not special basis, but supposing that the last infiltration capacity value is about 5~10 mm/min in general fields, and run-off coefficient in steep mountainous districts is 0.75~0.90, the author adoptes 0.8 and $K_n'=0.2$ as the minimum value of K_n' in this area. Moreover, the author applies seven to n on this basin by means of the trial and error.

R_n on the upper Tenryu River basin was calculated from 1st May to 31th October, every year, from 1961 to 1969, and the variation of R_n from 1st June to 10th July in 1961 is shown in Fig. 3.

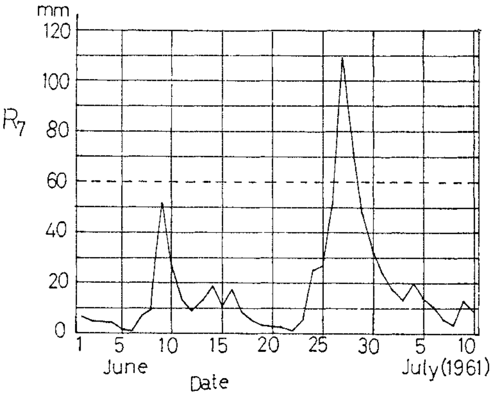

Fig. 3 Variation of $R_{n=7}$.

Refering Fig. 3, it seems that the landslide occurs corresponding to the peak of R_n which exceeds 60 mm, because the landslides in 1961 occured on 27th June. The frequencies of R_n exceeded 60 mm in the period from 1962 to 1969 are shown in Table 13, and if it is allowable to suppose that the debris volume ran off from the new and enlarging landslides is equal per eveay peak of R_n exceeded 60 mm, the ran off debris volume on the catchment area of the Miwa Reservoir, is arranged as Table 14.

Table 13 Frequencies of R_n .

Year	1962	63	64	65	66	67	68	69	Total
Frequency	1	1	3	3	1	2	2	2	15

Table 14 Ran off volume of debris.

(10^3 m^3)

Year	1962	63	64	65	66	67	68	69	Total
Run off volume of debris	253	253	392	392	253	323	323	323	2 512
Sedimented volume in Miwa Reservoir	97	202	206	524	746	462	329	286	2 852

In Table 14, the irregular difference between the run off volume of debris and the sedimented volume in the Miwa Reservoir per each year is found, and it seems that the irregular difference come from the storage action of debris in the slopes of the mountain and the torrent beds.

6. CONCLUSION

The author searched for the mean depth of ran off debris from landslides and the area ratio of randslides per the type of transformation on each geological condition in the upper Tenryu River basin for the long period. The volume of run off debris which is calculated by above searched mean depth and area ratio is similar to the actual volume which was surveied, therefore, the mean depth of run off debris and the area ratio of the landslides are able to apply to any basin which has the same or similar geological condition for the rough estimation of run off debris volume in long period.

But, it is necessary to clarify the debris storage action in the mountain slops and torrent beds for the problem of debris run off in the short period. This paper is the first report of the study on the run off debris in the river basin, and secondly the storage of debris in the mountain area will be studied.

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