and the probable floods over the residual basin. The results are indicated in Table 6-21. Flood frequency analysis by the two distributions are shown in Figs. 6-15 6-17.

6.6 Probable Maximum Flood

(1) Probable maximum Precipitation

The probable maximum flood (PMF) can be estimated from the probable maximum precipitation (PMP) by hydrological techniques. There is a reasonable basis on which to analyze the basic factors of major floods, i.e., storm rainfall and snowmelt, and to maximize them to their upper physical limits consistent with accepted meteorological and hydrological knowledge. For the period from 1959 to 1984 historical major storms were selected. The average precipitation over the main Coruh river basin and the Oltu-Tortum river basin of the Yusufeli dam site were respectively estimated by the Thiessen method. The estimated precipitation during these storms are given in Table 6-22.

Storm maximization consists of multiplying the observed storm rainfall amounts by the ratio (γm) of the maximum precipitable water (Wm) for the storm location to the precipitable water (Ws) estimated for the storm, that is, $\gamma m = Wm/Ws$. Precipitable water from the 1,000 mb surface to various altitudes can be presented as a function of the dew point temperature. Maximum precipitable water values used for storm maximization are usually estimated from maximum persisting 12-hour 1,000 mb dew points or vapor pressure values. In and around the catchment area of the Yusufeli dam site, there are eight (8) meteorological stations at Artvin, Bayburt, Ispir, Oltu, Tortum, Ardanuc, Erzurum and Gumshane where vapor pressure values are observed at 7, 14 and 21 o'clock. All values of monthly maximum persisting 12-hour vapor pressure selected directly from the records are plotted against the corresponding date and smooth enveloping curves are drawn in consideration of vapor pressure values of the 50 years return period for these stations, as illustrated in Figs. 6-18 (1) 6-18 (4).

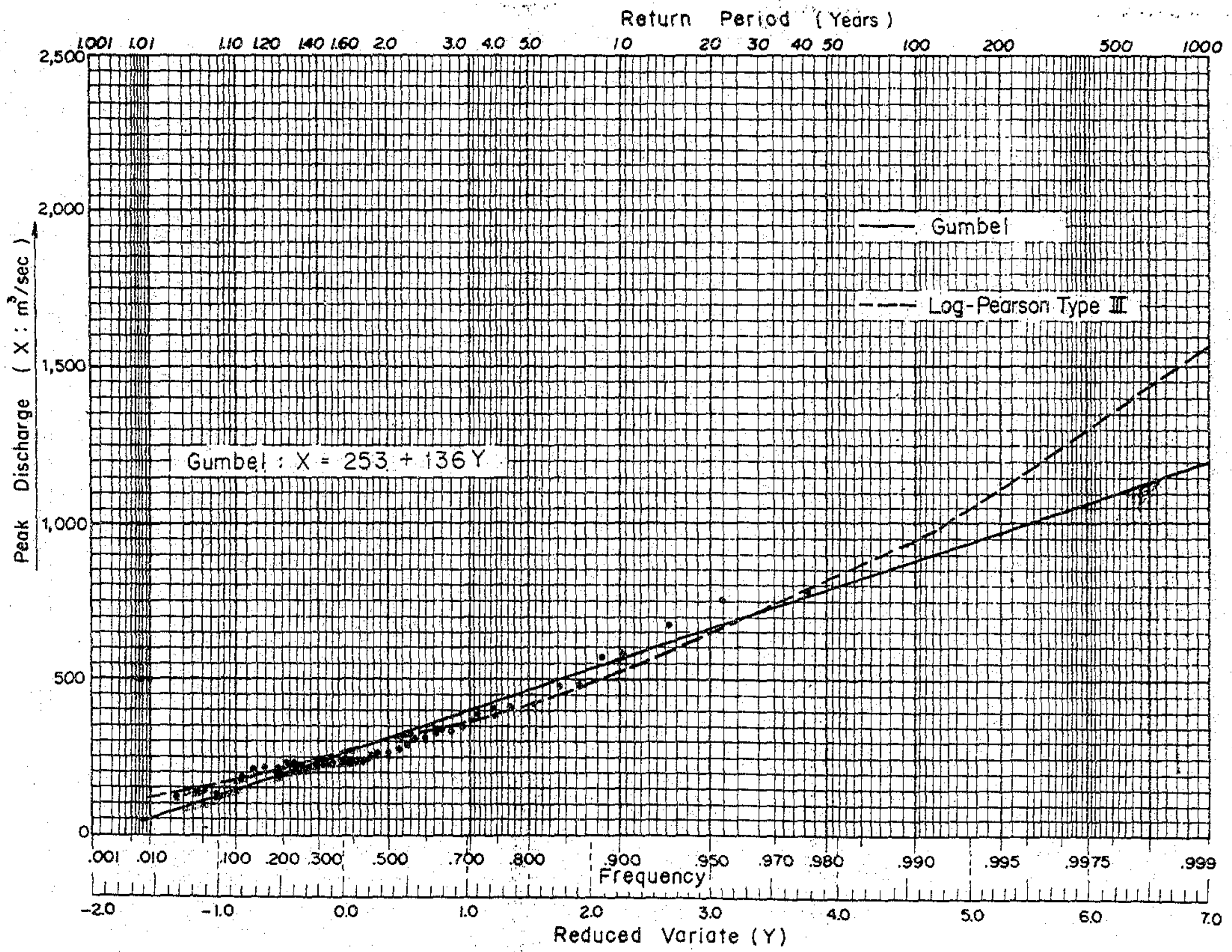


Fig. 6–15 Flood Frequency at No. 2305 Station

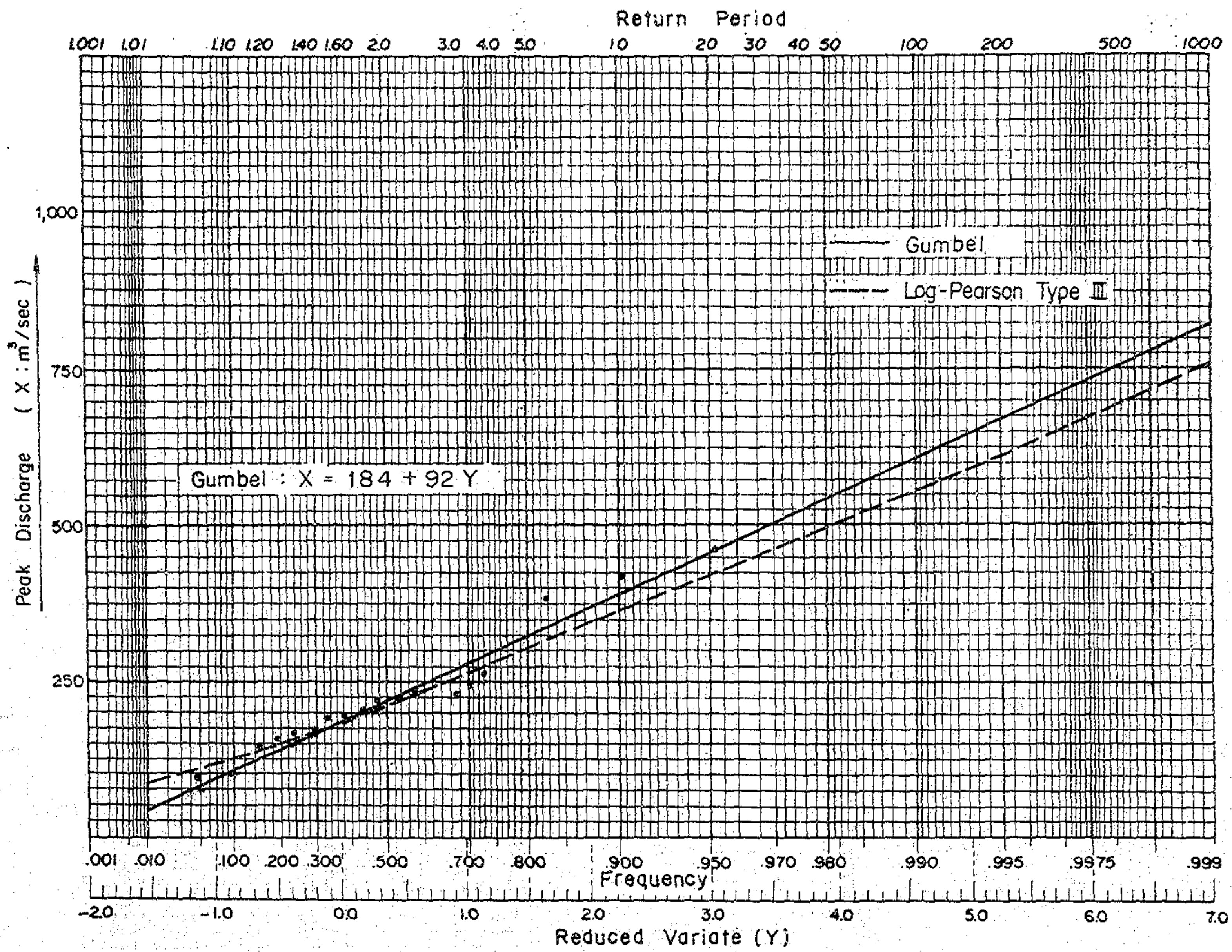


Fig. 6–16 Flood Frequency at No. 2323 Station

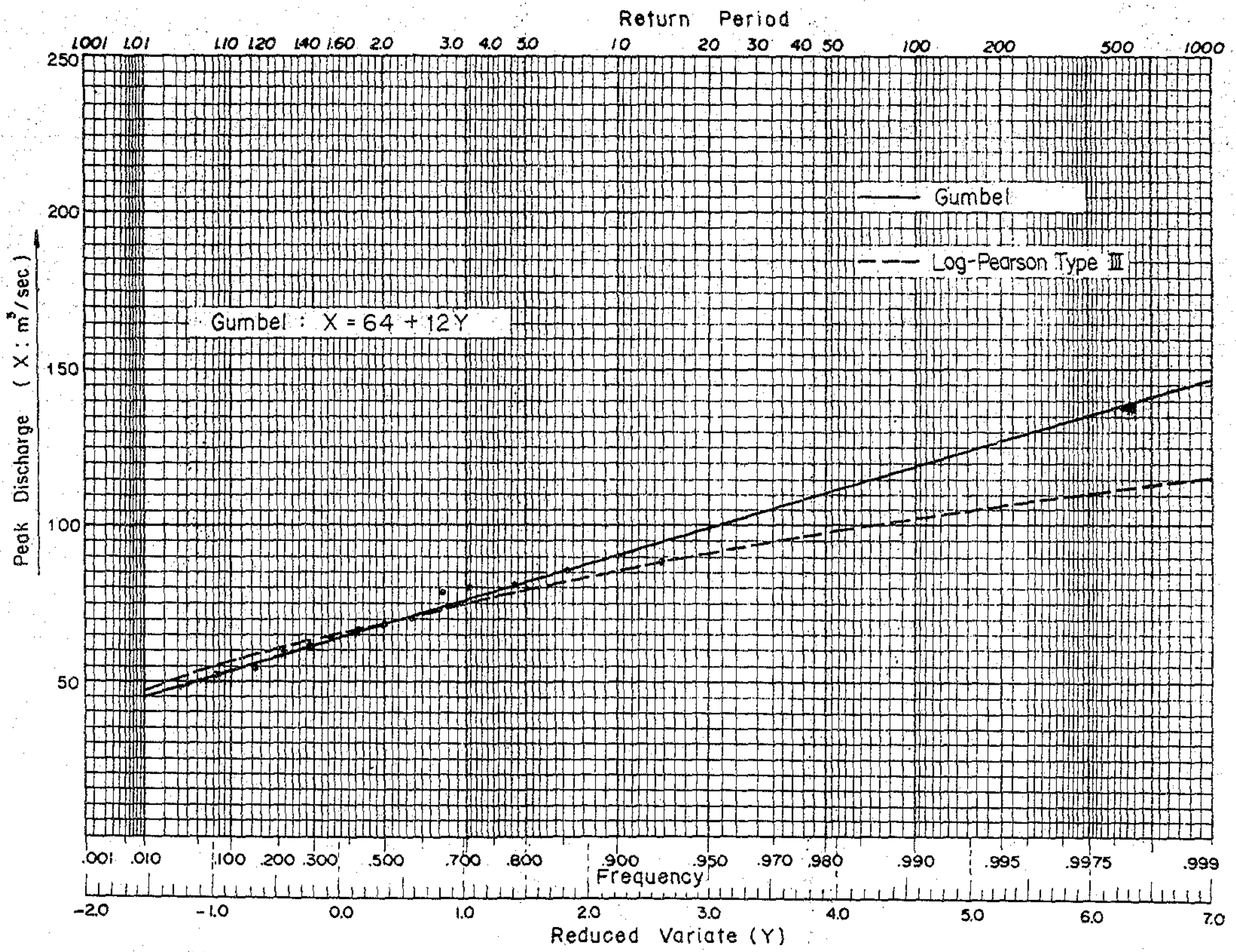


Fig. 6–17 Flood Frequency at No. 2321 Station

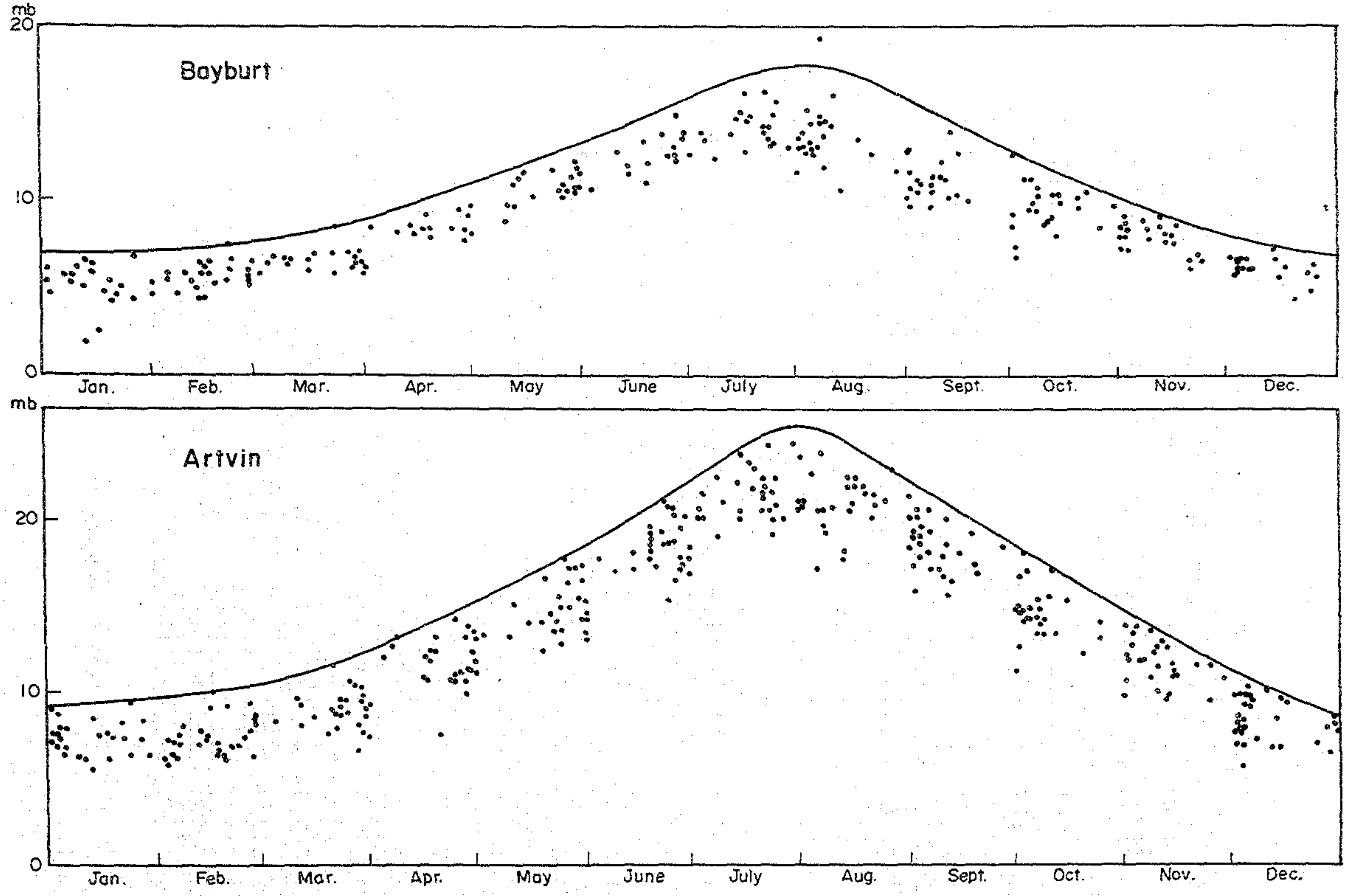


Fig. 6–18 (1) Enveloping Curves of Maximum Persisting 12 hour Vapor Pressure

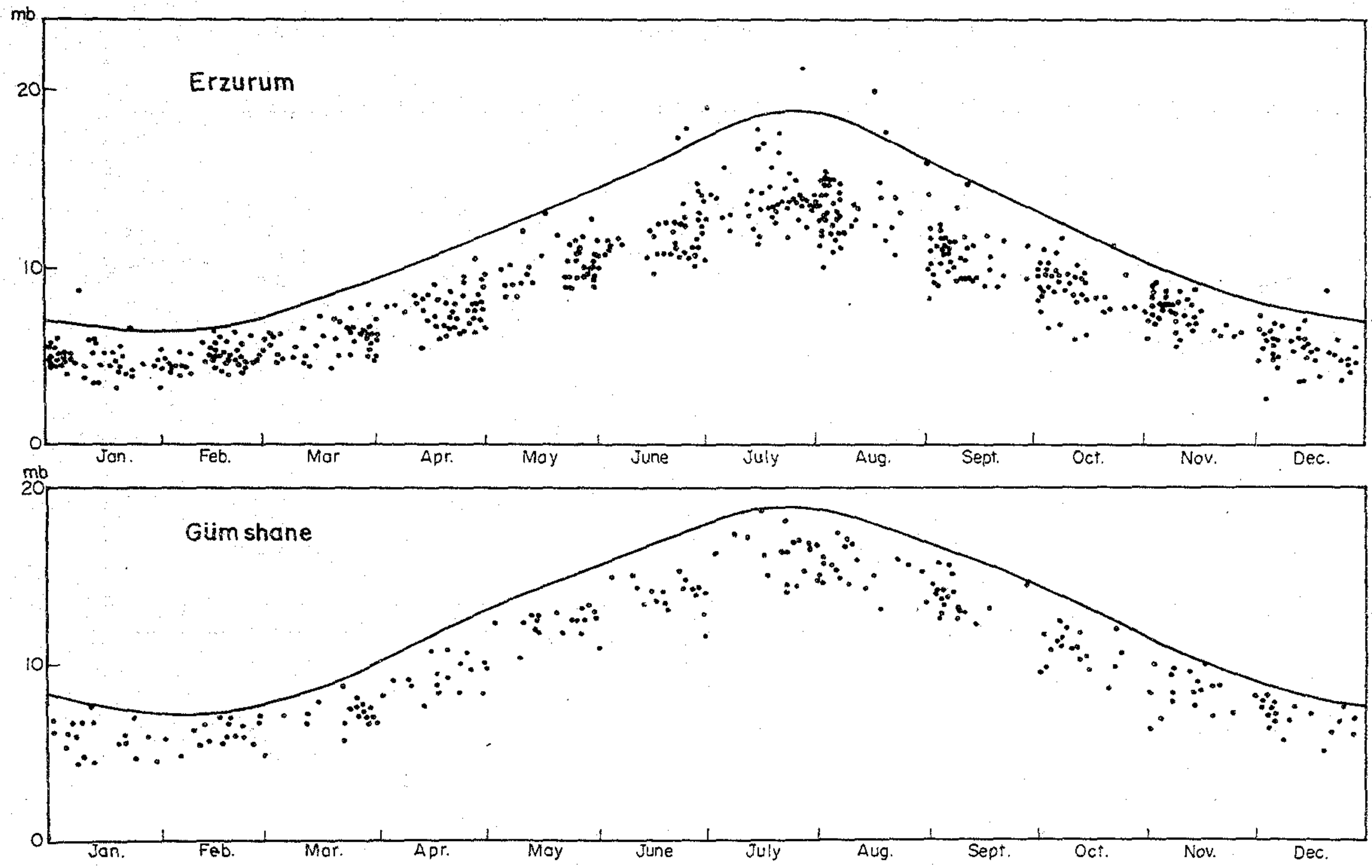


Fig. 6—18 (2) Enveloping Curves of Maximum Persisting 12 hour Vapor Pressure

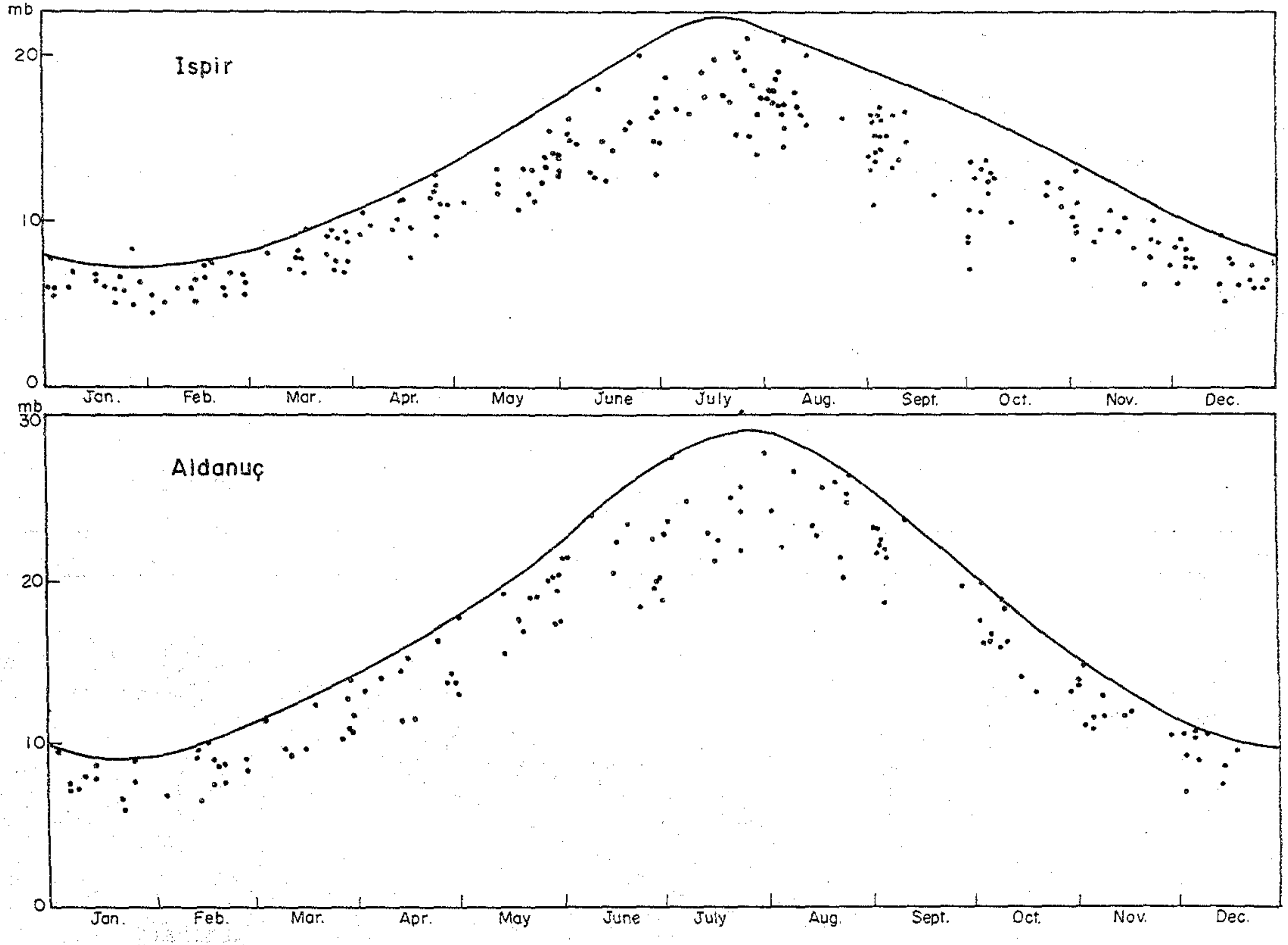


Fig. 6–18 (3) Enveloping Curves of Maximum Persisting 12 hour Vapor Pressure

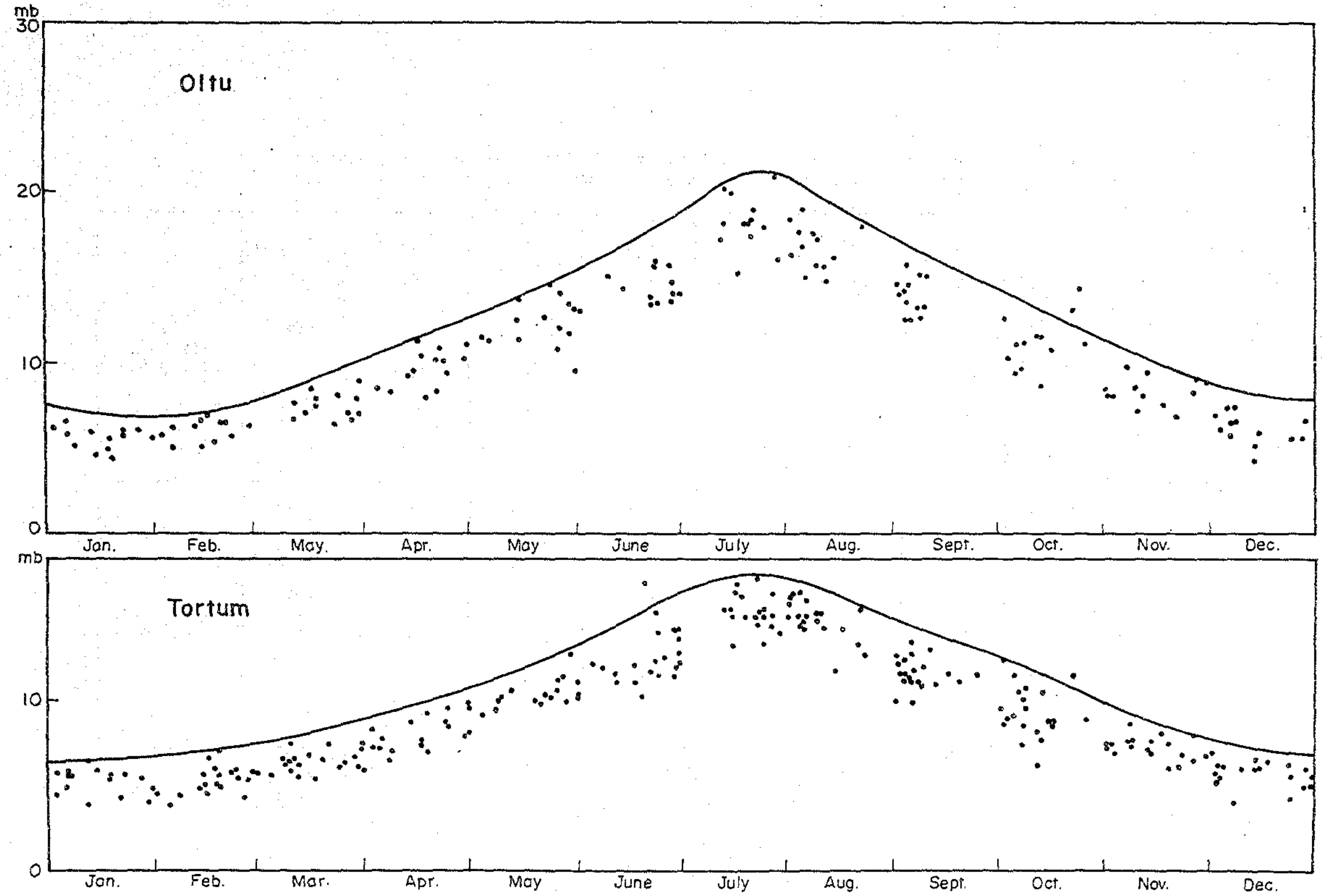


Fig. 6–18 (4) Enveloping Curves of Maximum Persisting 12 hour Vapor Pressure

Table 6–21 Probable Floods at Damsites

(unit: m3/sec)

	Return Period (years)	No.2305 Stream G.S	No.2323 Stream G.S	No.2321 Stream G.S	Yusufeli dam		Artvin(I) dam		Artvin (II) dam	
					Residual Basin	Total*	Residual Basin	Total*	Residual Basin	Total*
Gumbel Distribution	5	457	322	82	45	906	58	919	69	930
	10	559	391	91	52	1,093	66	1,107	80	1,121
	25	688	478	102	61	1,329	78	1,346	94	1,362
	100	879	607	119	74	1,679	95	1,700	114	1,719
	1,000	1,192	819	147	96	2,254	123	2,281	148	2,306
	10,000	1,506	1,031	175	118	2,830	151	2,863	182	2,894
Log-Pearson Type III dis.	5	417	302	80	43	842	55	854	66	865
	10	520	362	86	49	1,017	63	1,031	75	1,043
	25	679	438	93	57	1,267	73	1,283	88	1,298
	100	944	554	102	69	1,669	88	1,688	106	1,706
	1,000	1,560	757	116	94	2,527	120	2,553	145	2,578
	10,000	2,455	978	129	126	3,688	161	3,723	194	3,756

* Probable floods at the damsites are respectively calculated as the total of probable floods for No.2305, No.2323 and No.2321 stream G.S and residual basin.

Table 6–22 Storm Maximization of Historical Storms

Storm Date	Number of Stations	Storm Duration (hr.)	Average Precipitation (mm)		Wm/Ws = γ_m	Maximum Precipitation (mm)	
			Coruh-Altiparmak	Oltu-Tortum		Coruh-Altiparmak	Oltu-Tortum
18 - 20 May 1959	12	32	52.5	42.5	20.5/7.9 = 2.60	137.0	110.1
20 - 21 May 1964	18	12	28.7	16.4	20.1/9.7 = 2.07	59.4	33.9
17 - 18 Apr. 1965	16	12	27.1	33.3	15.5/6.9 = 2.25	61.0	74.9
15 - 16 May 1966	20	24	23.5	22.2	19.3/8.5 = 2.27	53.3	50.4
17 - 18 Apr. 1968	19	12	26.9	21.2	15.5/8.5 = 1.82	49.0	38.6
11 Sep. 1968	20	12	24.8	21.4	25.4/13.5 = 1.88	46.6	40.2
5 - 7 Oct. 1969	20	36	25.8	29.5	19.9/12.6 = 1.58	40.8	46.6
16 - 17 Oct. 1977	23	24	26.1	20.3	18.3/6.8 = 2.69	70.2	54.6
8 - 9 Apr. 1978	15	32	32.4	13.8	13.8/7.7 = 1.79	58.0	24.7
23 Apr. 1982	20	12	21.0	10.2	15.1/7.1 = 2.13	44.7	21.7
31 May-1 Jun. 1983	22	12	10.9	6.0	23/11.4 = 2.02	22.0	12.1
24 - 25 Sep. 1983	22	12	21.1	21.4	22.3/7.1 = 3.14	66.3	67.2
3 - 4 Oct. 1983	22	12	11.6	20.8	19.9/5.3 = 3.75	43.5	78.0
30 - 31 Oct. 1983	22	12	14.9	11.2	15.3/8.5 = 1.80	26.8	20.2

Representative persisting 12-hour storm dew point temperatures are estimated as average values of persisting 12-hour 1,000 mb dew points at the above stations. In maximizing storm rainfall the mean crest elevation of the mountain barrier of 2,500 m which lies to the south of the basin was selected as the base of the moisture column. Maximizations were made on the basis of the maximum persisting 12-hour dew points within 15 days of the storm occurrence dates. For the storm in May 1959 only two stations, Artvin and Erzurum, have vapor pressure records measured in Hg. Representative persisting 12-hour 1,000 mb dew point temperature was estimated to be 11.7°C as follows.

Station	Persisting 12-h vapor pressure (mb)	Persisting 12-h dew point (°C)	Persisting 12-h 1,000 mb dew point (°C)
Artvin	12.9	10.8	13.6
Erzurum	5.7	-0.9	9.7
			Average 11.7°C

The maximum persisting 12-hour 1,000 mb dew point temperature was also estimated to be 20.0°C from the following eight stations.

Station	Max-persisting 12-h vapor pressure (mb)	Max-persisting 12-h dew point (°C)	Max-persisting 12-h 1000 mb dew point (°C)
Artvin	20.0	17.5	20.0
Bayburt	14.1	11.6	18.8
Ispir	18.4	16.0	21.0
Oltu	16.0	13.8	19.3
Tortum	14.6	12.3	19.4
Ardanuc	23.5	20.0	22.2
Erzurum	14.5	12.2	20.5
Gumshane	15.5	13.0	18.5
			Average 20.0°C

The precipitable water values used in determining Wm and Ws are for a moisture column with base at 1,000 mb and top at 200 mb minus the precipitable water in a column with base at 1,000 mb and top at the elevation of 2,500 m. γ m was determined as follows.

$Wm = 52.0 - 31.5 = 20.5$

$Ws = 25.1 - 17.2 = 7.9$

$\gamma m = Wm / Ws = 2.60$

The maximization results of historical selected storms are given in Table 6-22.

Regional and time distributions of the PMP were studied for following four (4) cases to produce maximum runoff.

	Regional Distribution		Time Distribution	
Case	①	②	①	②
A	0		0	
B	0			0
C		0	0	
D		0		0

where,

regional distribution ① : The PMP based on May 1959 precipitation uniformly distributed over the entire catchment area of the Yusufeli damsite.

regional distribution ② : The PMP based on May 1959 precipitation, as given in Table 6-22, 137.0 mm and 110.1 mm over the main Coruh river basin and the Oltu-Tortum river basin of the Yusufeli damsite respectively.

time distribution ① : actual time distribution of the PMP based on May 1959 precipitation.

time distribution(2): time distribution based on depth-duration curves in Fig. 6-19 obtained by using the PMP values including other storms in April and May.

As the result of studies the case D was found to produce maximum runoff. Table 6-23 gives the rearranged effective PMP duration, assuming uniform rainfall loss of 2mm/hr.

(2) Unit hydrograph

Using the Snyder's concept of "Synthetic Unit Hydrograph", unit hydrographs of the main Coruh river, the Altiparmak river, the Oltu river and the Tortum river were constructed under the following conditions:

Rainfall duration ; 12-hour
Rainfall intensity; 10 mm

Unit hydrographs are illustratively shown in Figs. 6-20 and 6-21.

(3) Probable maximum flood due to PMP

Probable maximum flood hydrographs resulting from the 12-h rainfall increments in Table 6-23 are given by multiplying the unit hydrograph of the Coruh-Altiparmak river or the Oltu-Tortum river by the effective precipitation.

The total hydrograph is the sum of two hydrographs. Though the peak value is calculated to be 6,120 m^3/sec, the value of 6,200 m^3/sec in round numbers is applied as shown in Fig. 6-22.

(4) Snow melt

In the catchment area of the Yusufeli damsite snowmelt is an important factor in major floods. The snowmelt season extends from March to May. In estimating the snowmelt amount, a degree-day factor or the ratio of snowmelt to concurrent degree-days was used. The maximum melting rate was determined to be 0.158 cm/deg.-day after investigating accumulated snowmelt runoff and degree-days.

The snow line or the lower limit of snow cover was considered to be 1,600 m in elevation. The maximum temperatures of 10-day duration in April at Bayburt Station were converted to those at an average elevation of 2,150 m above the snow line. Maximum snowmelt runoff at the Yusufeli damsite is given in Table 6-24.

(5) Probable maximum flood

The probable maximum flood hydrograph was presented as the sum of the PMP hydrograph, snowmelt hydrograph and the estimated base flow of 330 m^3/sec, as given in Fig. 6-23.
Table 6-25 gives the PMF values of planned dams in Turkey.
Figs. 6-24 and 6-25 show the relation between the catchment areas and PMF discharges of existing and planned dams in Turkey, and their locations.

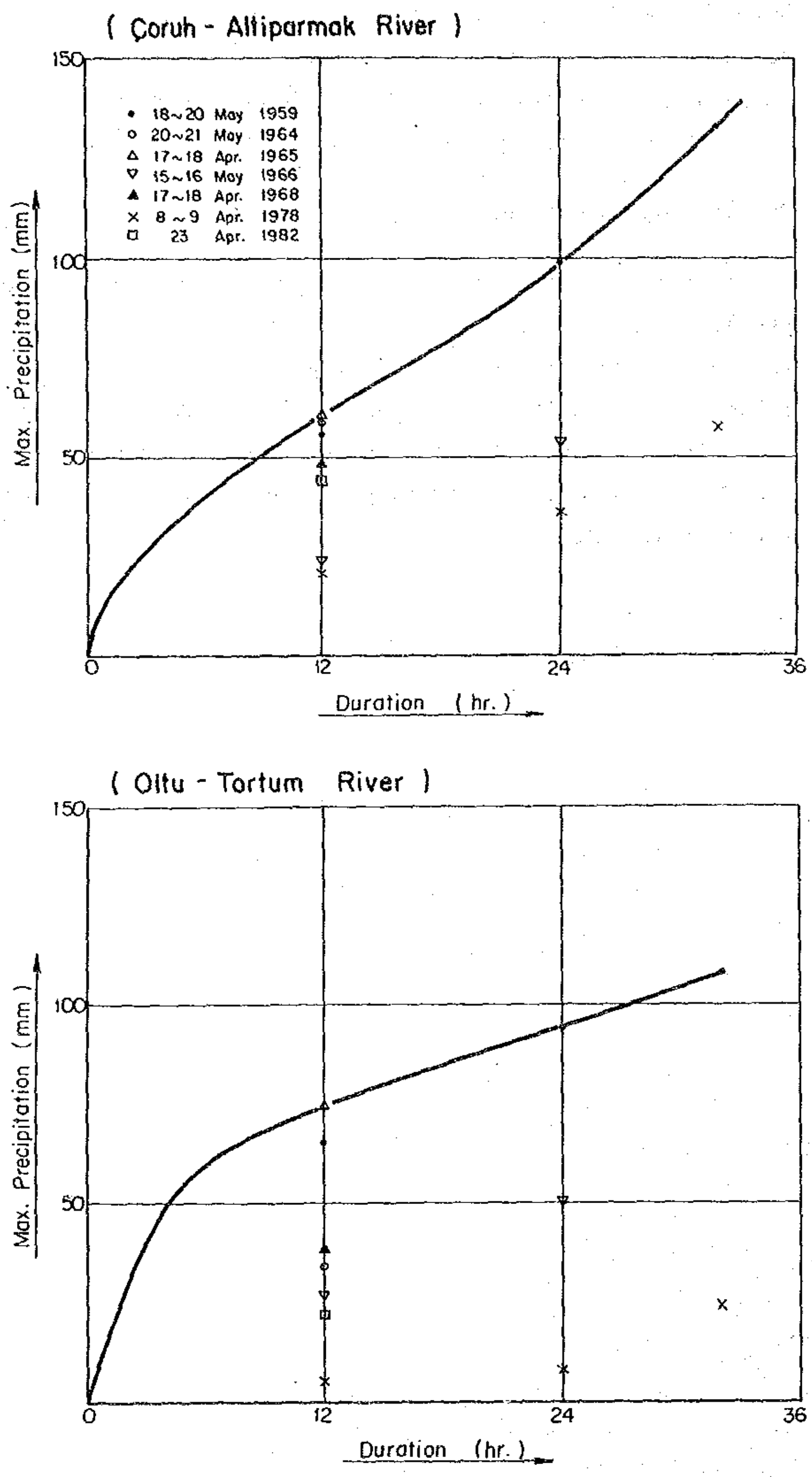
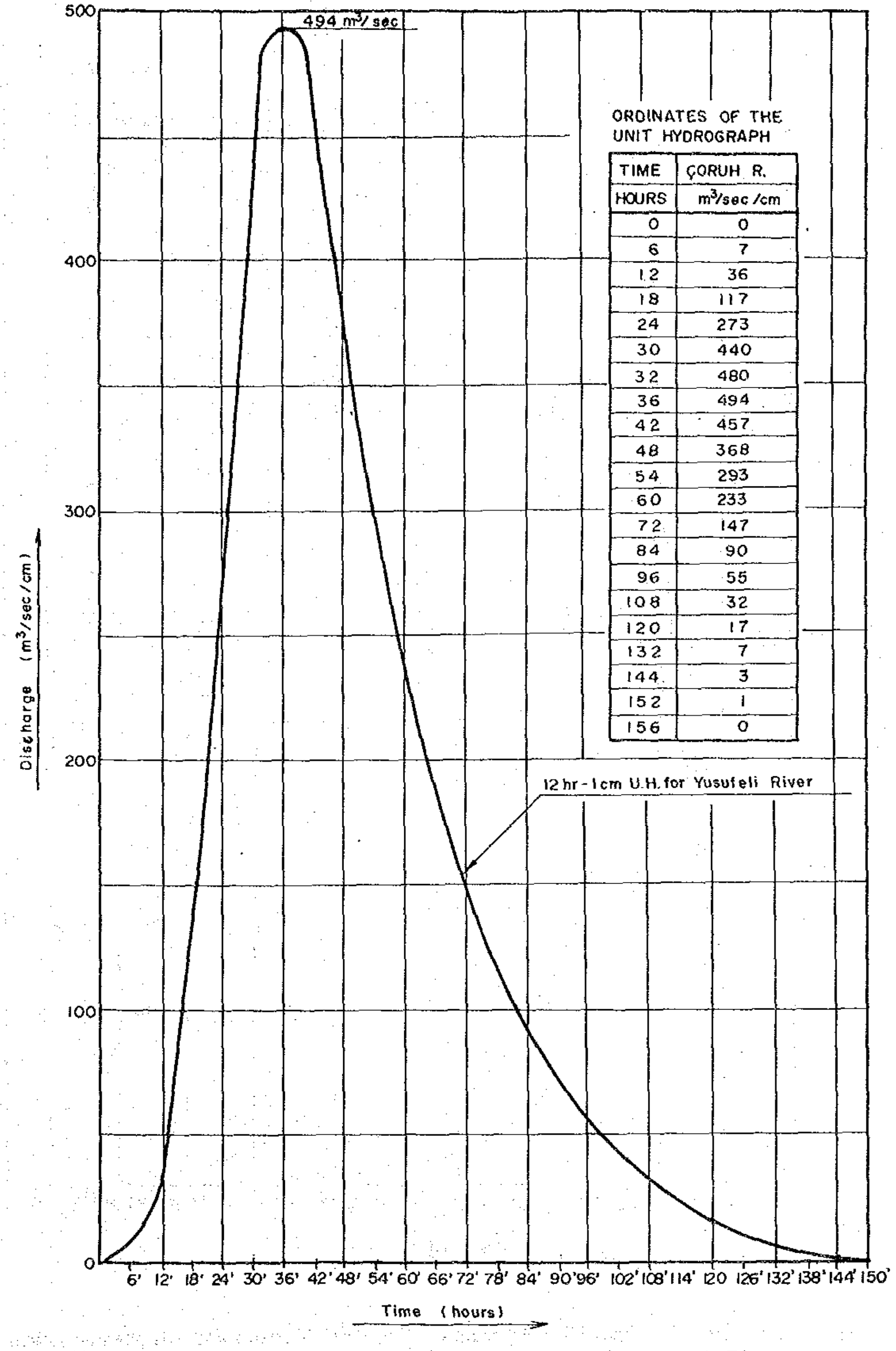


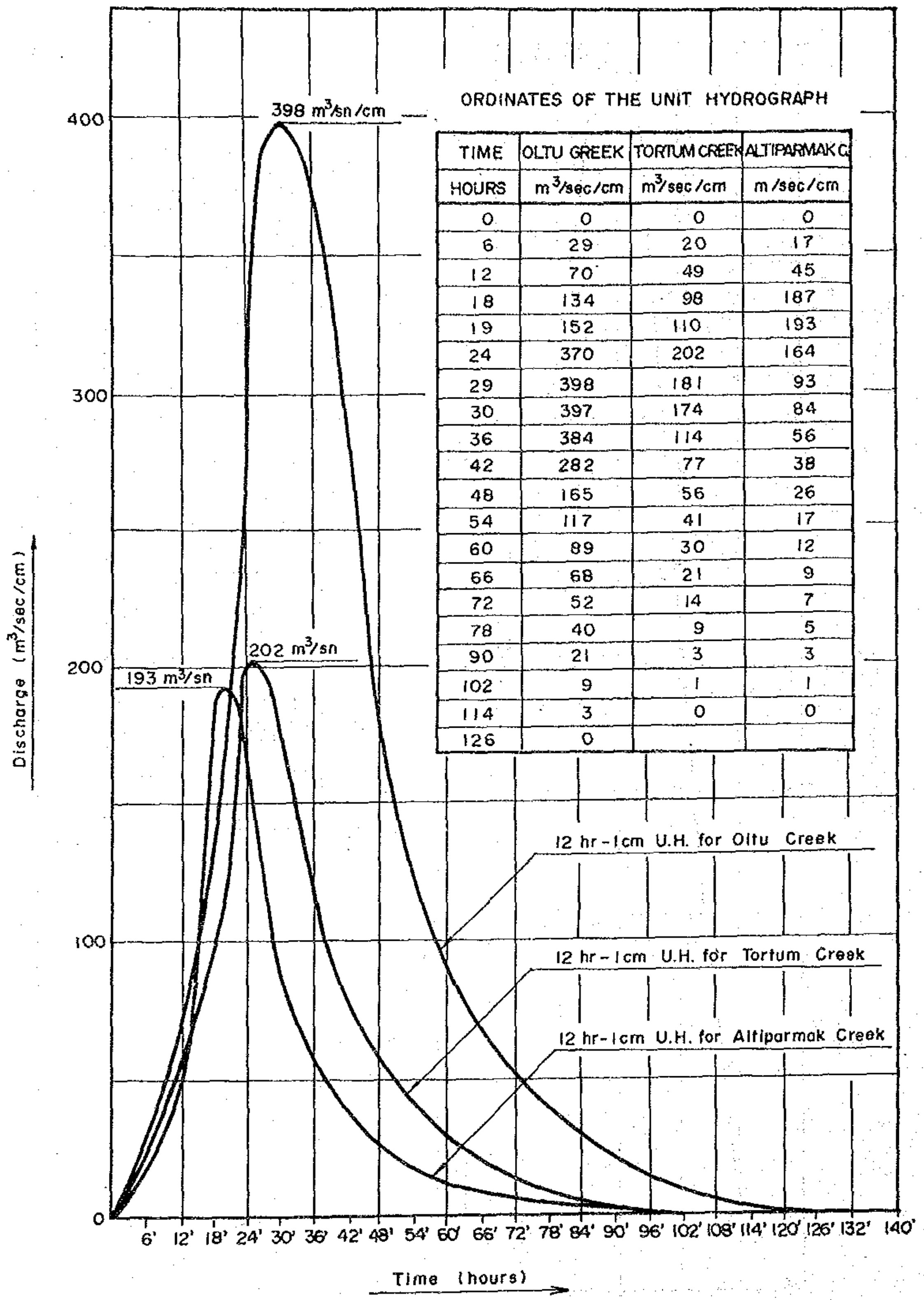
Fig. 6–19 Depth-Duration Curves of Max. Precipitation



ORDINATES OF THE UNIT HYDROGRAPH

TIME HOURS	ÇORUH R. $m^3/sec/cm$
0	0
6	7
12	36
18	117
24	273
30	440
32	480
36	494
42	457
48	368
54	293
60	233
72	147
84	90
96	55
108	32
120	17
132	7
144	3
152	1
156	0

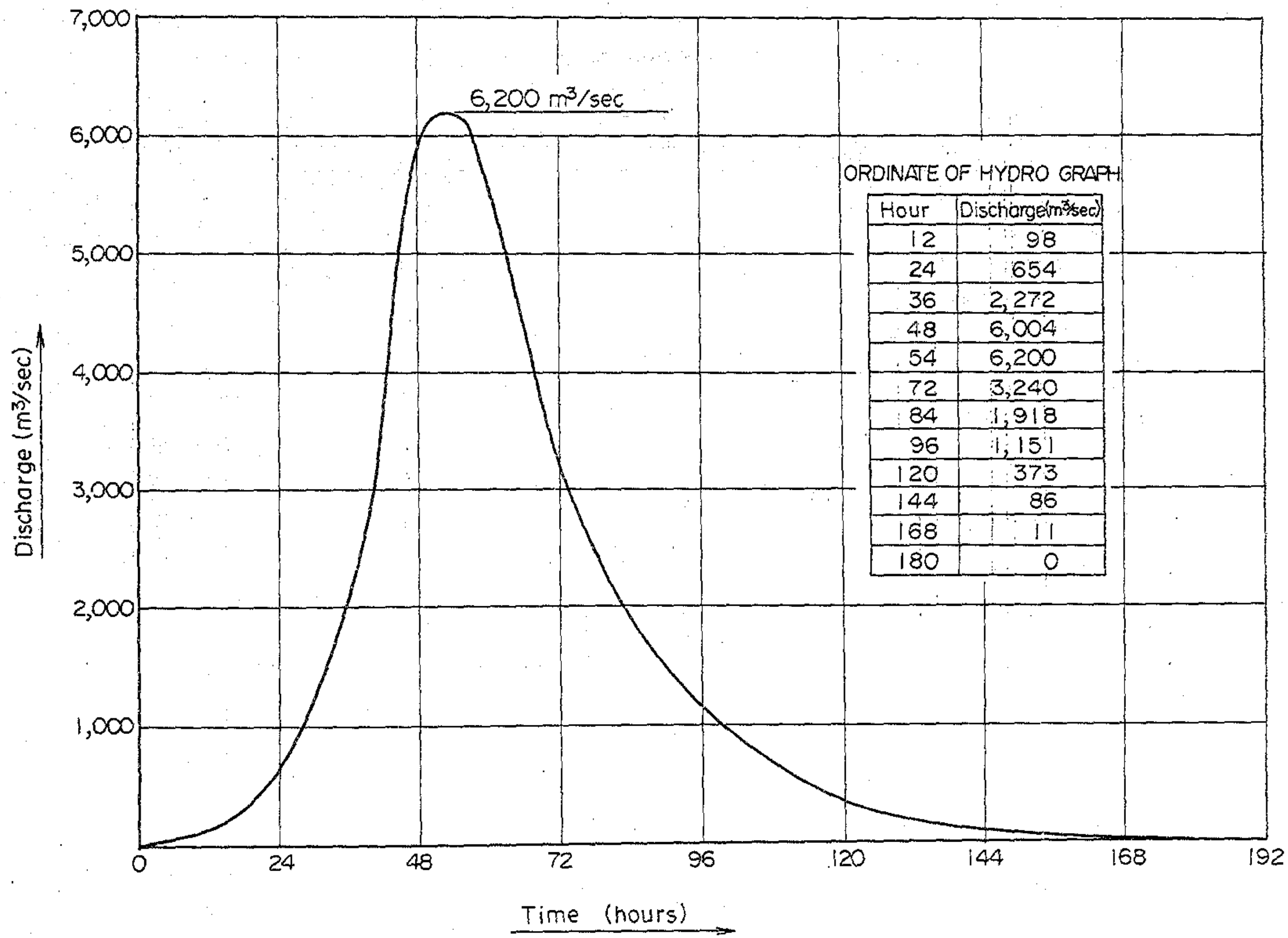
Fig. 6–20 12 hr – 1 cm Unit Hydrograph for Coruh River



ORDINATES OF THE UNIT HYDROGRAPH

TIME HOURS	OLTU GREEK $m^3/sec/cm$	TORTUM CREEK $m^3/sec/cm$	ALTIPARMAK C. m /sec/cm
0	0	0	0
6	29	20	17
12	70	49	45
18	134	98	187
19	152	110	193
24	370	202	164
29	398	181	93
30	397	174	84
36	384	114	56
42	282	77	38
48	165	56	26
54	117	41	17
60	89	30	12
66	68	21	9
72	52	14	7
78	40	9	5
90	21	3	3
102	9	1	1
114	3	0	0
126	0		

Fig. 6–21 12 hr – 1 cm Unit Hydrograph for Oltu, Tortum and Altiparmak Creek



Hour	Discharge (m3/sec)
12	98
24	654
36	2,272
48	6,004
54	6,200
72	3,240
84	1,918
96	1,151
120	373
144	86
168	11
180	0

Fig. 6–22 **PMP Hydrograph**

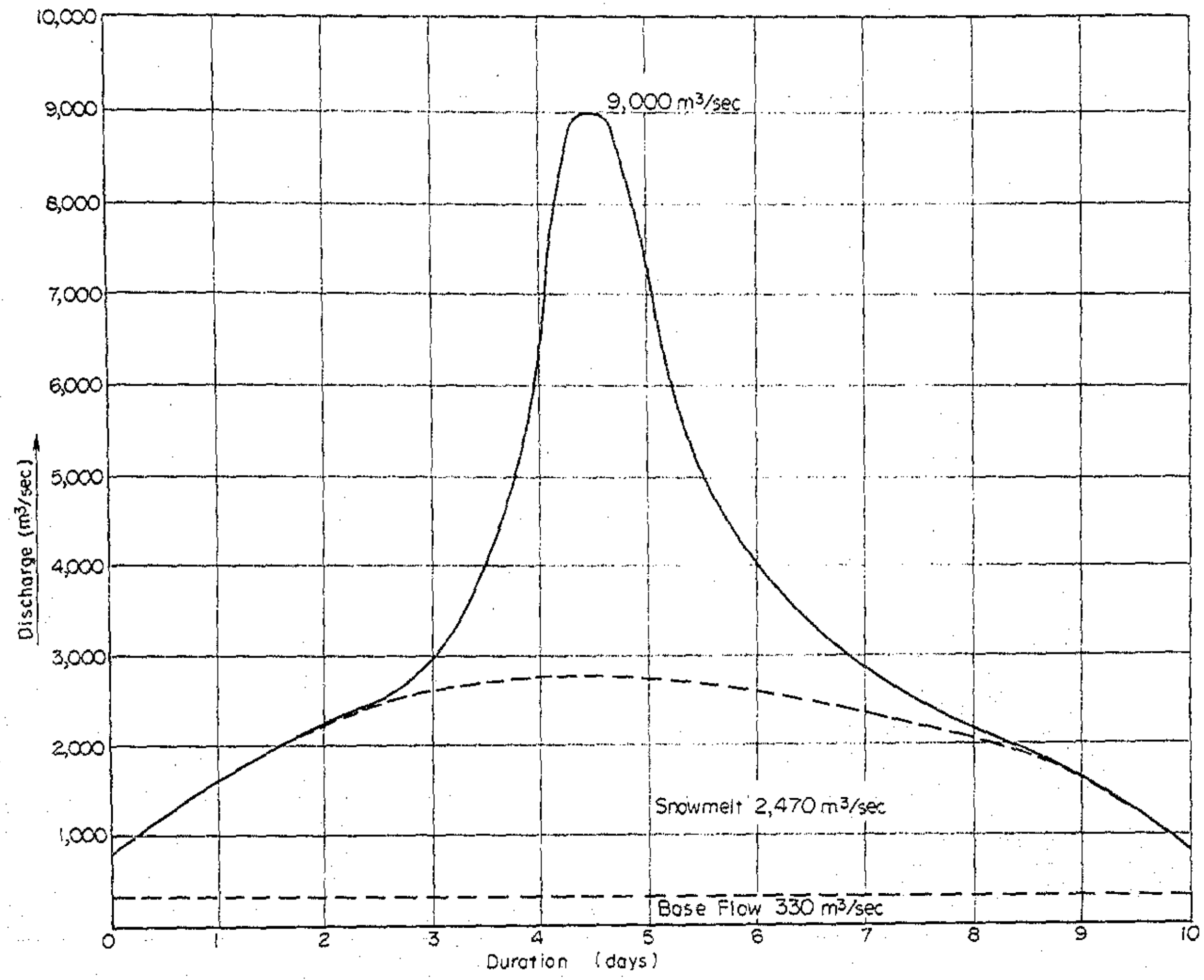


Fig. 6–23 PMP Hydrograph of Yusufeli Damsite

Table 6–23 Time Distribution of PMP

(Coruh - Altiparmak Basin) (unit: mm)

Duration	0 - 12h	12 - 24h	24 - 36h	Total
PMP	36	39	62	137
Loss	24	24	24	72
PMP(*)	12	15	38	65

(Oltu - Tortum Basin) (unit: mm)

Duration	0 - 12h	12 - 24h	24 - 36h	Total
PMP	13	21	76	110
Loss	24	24	24	72
PMP(*)	0	0	52	52

PMP(*): Effective rainfall amounts of PMP

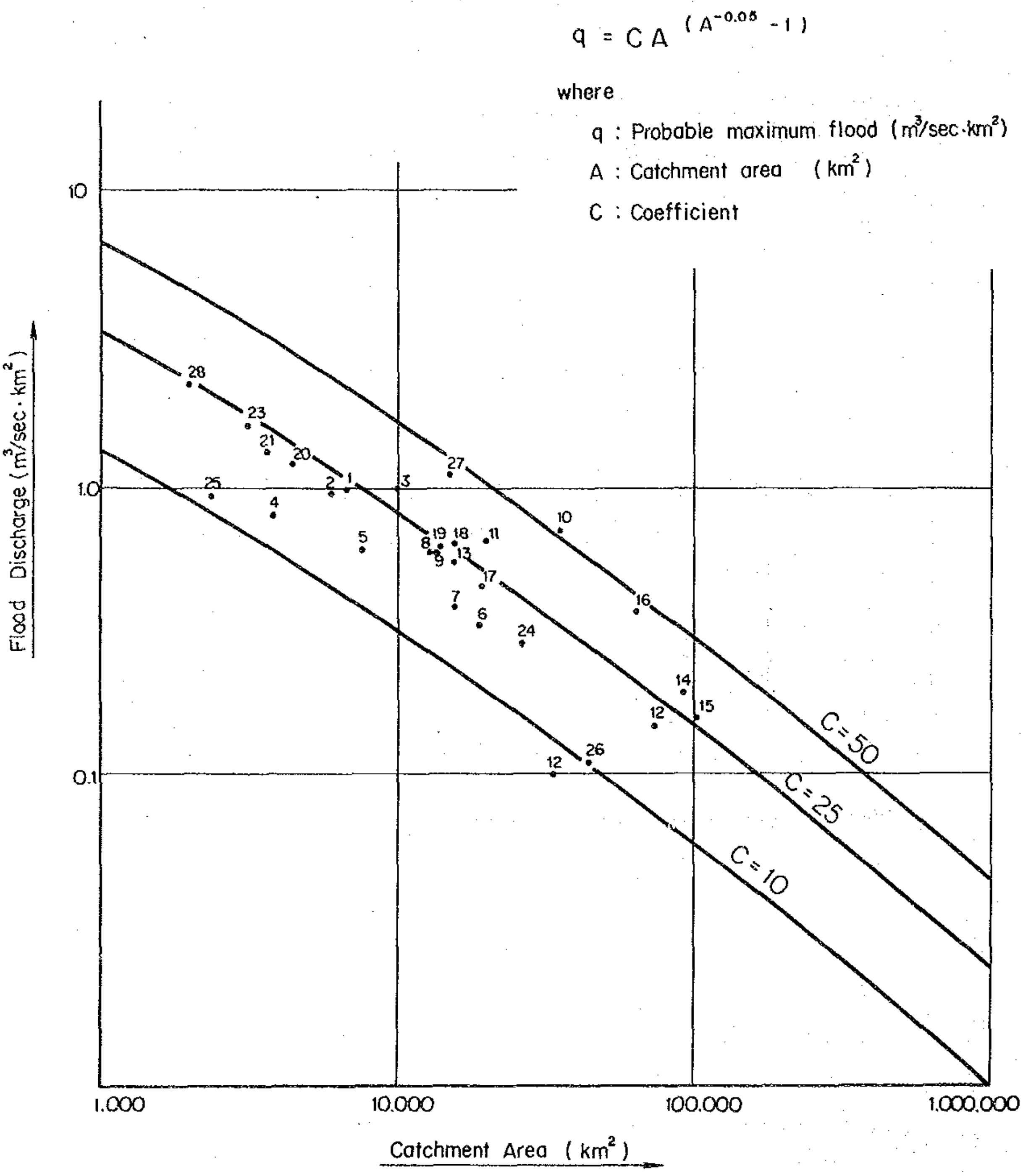
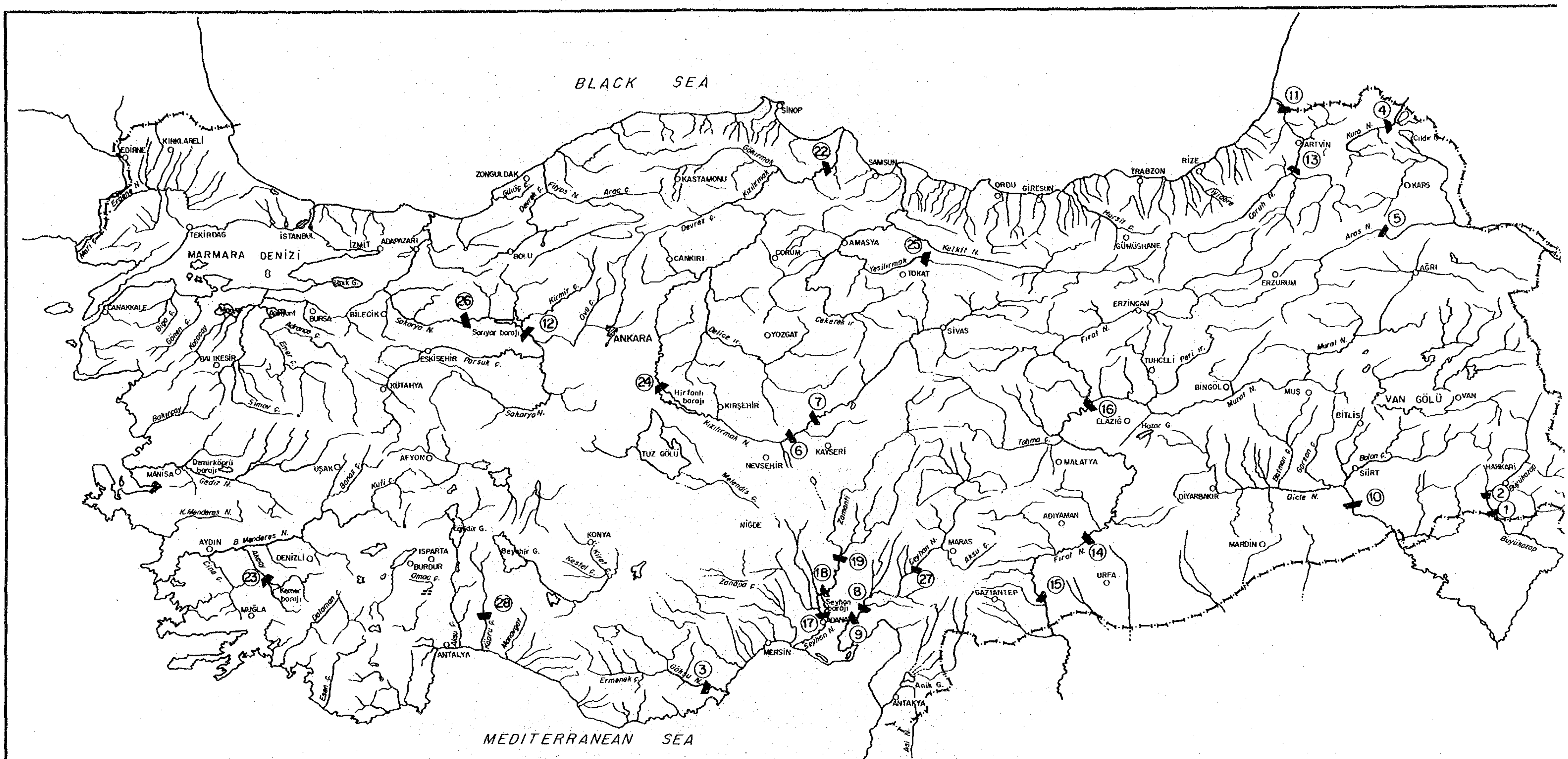


Fig. 6–24 Probable Maximum Floods in Turkey

Table 6–24 Maximum Snowmelt Runoff at Yusufeli Damsite

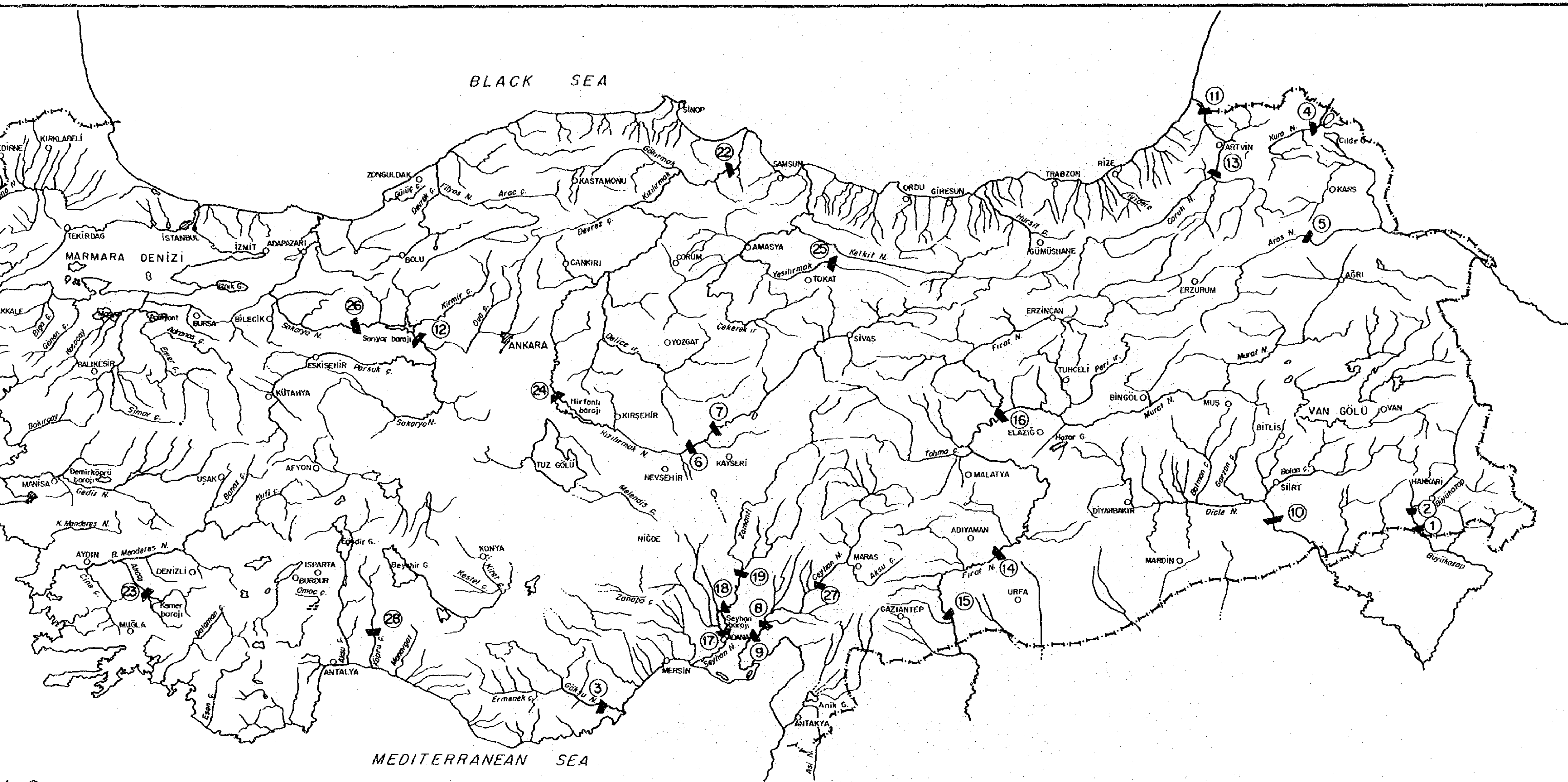
Days	Max. Daily Temperature Duration (°C)	Temperature at Mean Elevation of Snow Cover (°C)	Temperature Arranged in Design Pattern (°C)	Product of Temp. with Max. Snowmelt Ratio (cm)	Daily Snowmelt (10^6 m^3)	Daily Snowmelt Discharge (m^3/sec)
1	15.4	11.2	4.0	0.632	76.1	881
2	14.2	10.0	7.3	1.153	139.0	1,609
3	14.2	10.0	9.7	1.533	184.6	2,137
4	13.9	9.7	10.0	1.580	190.4	2,204
5	12.7	8.5	11.2	1.770	213.2	2,470
6	14.0	9.8	10.0	1.580	190.4	2,204
7	11.2	7.0	9.8	1.548	186.6	2,160
8	11.5	7.3	8.5	1.343	161.8	1,873
9	8.2	4.0	7.0	1.106	133.3	1,543
10	8.2	4.0	4.0	0.632	76.1	881



Name of Dam

(1) Cukurca	(8) Sır	(15) Fındıklı	(22) Altinkaya
(2) Doğanla	(9) Düzkesme	(16) Keban	(23) Kemer
(3) Kayraktepe	(10) Ilısu	(17) Seyhan	(24) Hirfanlı
(4) Sevimli	(11) Muratlı	(18) Asağıçatalan	(25) Almus
(5) Karakurt	(12) Kargı	(19) Yedigöze	(26) Gökçekaya
(6) Bayramhacılı	(13) Yusufeli	(20) Köprü	(27) Aşlantas
(7) Yamula	(14) Atatürk	(21) Menge	(28) Beşkonak

Fig. 6-25 Location Map of Existing and Planned Dams



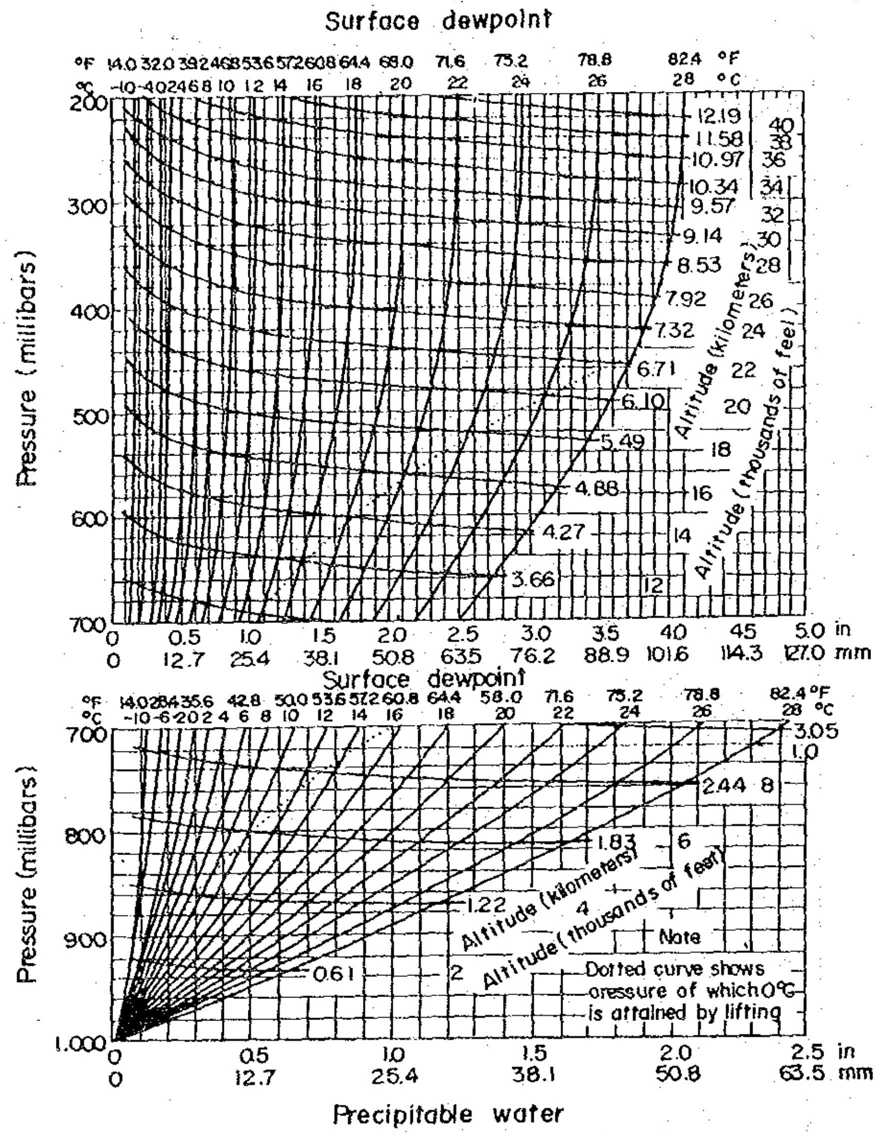
of Dam

rca	(8) Sır	(15) Fındıklı	(22) Altinkaya
ale	(9) Düzkesme	(16) Keban	(23) Kemer
ıktepe	(10) Ilısu	(17) Seyhan	(24) Hirfanlı
ılı	(11) Muratlı	(18) Asağıçatalan	(25) Almus
urt	(12) Kargı	(19) Yedigöze	(26) Gökçekaya
mhacılı	(13) Yusufeli	(20) Köprü	(27) Aşlantaş
la	(14) Atatürk.	(21) Menge	(28) Beşkonak

Fig. 6–25 Location Map of Existing and Planned Dams

Table 6–25 Probable Maximum Flood of Planned Dams in Turkey

Name of Dam	Catchment Area (Km^2)	Mean Annual Rainfall (mm)	Observed Daily Max. Rainfall (mm)	Probable Max Precipitation (mm/hr.)	Peak Discharge for 100 years (m^3/sec)	Probable Max. Flood (m^3/sec)	Stage
Cukurca	6,715	708	167.5	201/24	1,512	6,660	Reconnaissance
Doganli	5,977	640	-	-	1,394	5,774	ditto
Kayraktepe	9,867	662	-	202/48	2,383	9,875	Final Design
Sevimli	3,703	537	59.4	107/24	562	3,042	Reconnaissance
Karakurt	7,505	425	81.9	270/30	870	4,669	ditto
Bayramhacili	18,930	452	68.5	106/24	1,149	6,804	Feasibility
Yamula	15,582	465	68.5	106/24	1,001	6,233	ditto
Sir	12,950	612	106.4	104/24	2,520	7,876	Final Design
Duzkesme	13,061	612	106.4	104/24	2,562	7,972	ditto
Ilisu	35,509	787	130.0	137/36	10,096	25,774	ditto
Muratli	19,748	503	140.0	157/32	2,342	13,333	Master Plan
Kargi	33,847	402	91.5	107/30	485	3,704	Final Design
Yusufeli	15,250	443	64.6	122/32	1,679	9,000	Feasibility



Depths of precipitable water in a column of air of any height above the 1000-millibar level as a function of the 1000-millibar dewpoint, assuming saturation and pseuda-adiabatic lapse rate.
(U.S National Weather Service.)

Fig. 6–26 Depths of Precipitable Water in a Column of Air

CHAPTER 7 GEOLOGY AND MATERIAL

CHAPTER 7. GEOLOGY AND MATERIAL

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CHAPTER 7. GEOLOGY AND MATERIAL

7.1 Introduction

The geological investigation works for Yusufeli and Artvin projects were carried out by EIE since 1975 and up to March, 1986, the works listed on Table 7-3, 4, 5, 6 were completed. In the meantime, JICA team carried out site reconnaissances two times (1st,; May, 28 to July, 26, 1985. 2nd; January, 30 to February, 28, 1986).

Geological analysis presented in this report is based on the results of field survey by the JICA team and of geological investigations carried out by the EIE.

As a result of these analysis, the JICA team found that the Yusufeli dam site planned by the EIE was suitable for the project. On the other hand, Artvin dam site planned by the EIE was found not suitable because of Havuzlu landslide which is located on the left bank, approximately 1 km upstream of the original dam site, which will have the following problems:

- If the dam is to be constructed at the original dam site, detailed geological investigations need to be conducted on a large scale for Havuzlu landslide.

- Even if such geological investigations conducted, it is very difficult to guarantee the stability of the Havuzlu landslide at this stage when considering long period involved (dam's service life of 50 or more years, for instance) and various natural conditions to occur in and around the site (torrential rain and earthquake).

- Furthermore, it is reasonable to expect that the stability of the landslide will deteriorate since the tongue of the landslide will be under water after the filling of the reservoir.

- Because of these unfaborable conditions, an alternative dam site should be selected at a location outside or far from the landslide as far as construction requirements are satisfied.

The JICA team selected alternative dam sites to the original one, as described in Chapter 7.4.2.

7.2 Regional Geology

7.2.1 Topography

The Coruh River which has about 410 km total length is located on the north-eastern area of Turkey and the river basin is surrounded by Aras river basin at the east, by Kelkit stream basin at the west, by Firat river basin at the south and by Eastern Black Sea tributaries basins at the north respectively.

The Coruh River originates from the Mescit mountains and flows through north-eastern area of Anatolia. After joinning Cengit, Barhal, Oltu and Tortum tributalies, the Coruh River reaches Black Sea soon after crossing the Russian border.

The elevations of the mountains surrounded the Coruh River basin are very high (generally more than 3000 m) and topographies along main tributaries originated from high mountains are also very steep. Accordingly, the Coruh River forms steep river topagraphies until passing Artvin and flat plains are seen scarcely.

7.2.2 Geology

The Coruh river basin is the area which suffered Hercinian orogeny in Palaeozoic and Alpine orogeny from Mesozoic to Cenozoic. Sediments in Quaternary, sedimentary rocks and volcanic rocks in Tertiary and in Mesozoic (Jurassic - Cretaceous), and regional metamorphic rocks in Palaeozoic (Pre-Permian - Permo-Carboniferous) are found in this region.

The regional geologic units are characterized by zonal distribution extending southwest- northeast direction as shown in Fig. 7-1 and they are partly intruded by plutonic rocks such as granite.

Moreover, allochthonous geologic units resulted from Alpine orogeny are also seen in this region.

The geologic sequence in regional area and in Yusufeli-Artvin project area is shown on Table 7-1.

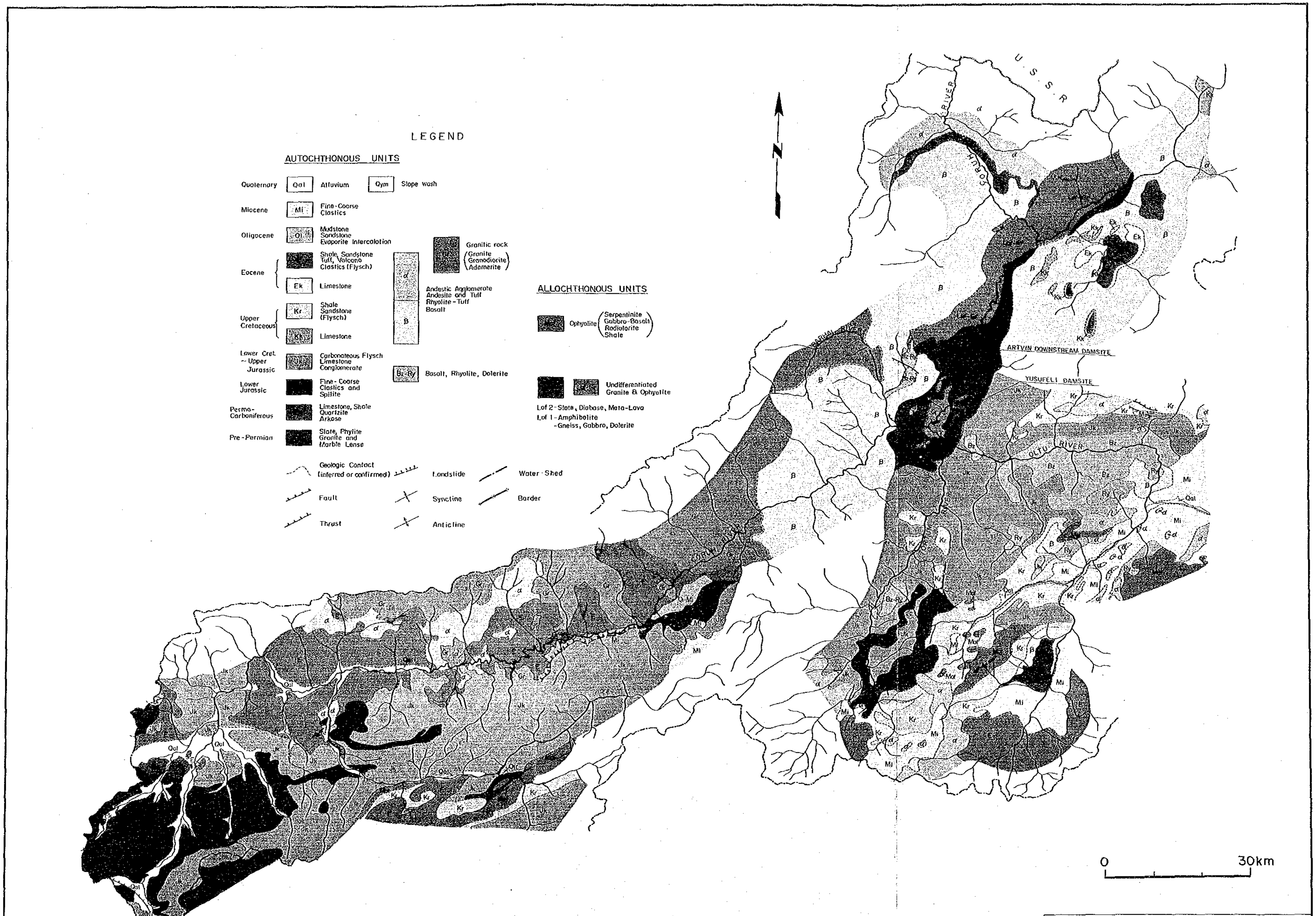

Fig. 7–1 REGIONAL GEOLOGY

Table 7-1 Geologic Sequence

GEOLOGIC TIME			REGIONAL GEOLOGY OF ÇORUH BASIN (EIE Sept, 1979)		GEOLOGY OF YUSUFELI – INANLI RESERVOIR AREA (EIE Sept, 1980)		
Era	Period		Lithology	Magmatic Activity, etc.	Formation	Lithology	Distribution
	Quaternary		Alluvium Slope wash Terrace		Quaternary System	Landslide Recent Alluvium Slope wash Old Alluvium (20~30m above the recent river level)	
CENOZOIC	Eocene	Late	Andesitic agglomerate, Tuff	Alpine orogeny (Mid. ~ Late Eocene)	IKIZDERE Granitic Rocks	Up. Eocene ~ Oligocene · Granodiorite – Tonalite Group · Adamellite Group · Porphyritic microgranite Group · Granite – Gneiss Group	Yusufeli damsite
		Mid.	Clayey-silty limestone, Sandstone	· (Dykes of Diabase & Tonalite			
		Early	Conglomerate, Mudstone, Claystone	· (Acidic intrusions Three different granodiorites			
M E S O Z O I C	Cretaceous	Late	Alternation of Calcarenite & Sandstone Alternation of Sandstone & Limestone Limestone Alternation of Mudstone, Shale & Limestone (Gravelly sandstone intercalated)	Alpine orogeny (Late Cret. ~ Eocene)	Berta F. (Kb)	Mudstone Marl Limestone Sandstone, Conglomerate Alternation of Spilitic Basalt, Rhyolite & Dacite IKIZDERE Granitic Rocks intruded	Upstream part of Yususeli Reservoir Area
		Early	Limestone with Silexite nodule Clayey limestone		Pügey F. (J-Kp)	Up ; Alternation of Limestone & Marl with Silexite Low; Basal conglomerate, Alternation of Sandstone & Marl	Oltu River
	Jurassic	Late (Malm)	(intercalated) Alternation of Clayey Limestone & Sandstone Alternation of Conglomerate & Sandstone				
		Mid. (Dogger)	Marl, Limestone, Sandstone Alternation of Siltstone & Limestone Mudstone Alternation of Sandstone & Siltstone Conglomerate			Angular Unconformity	
		Early (Lias)	Complex of Spilite, Spilitic agglomerate, Diabase, Shale, Tuff & Siltstone		Yusufeli F. (Jy)	Up. : Greywacke, Slate, Phyllite Mid.: Spilite (pillow lava), Metalava, Green Schist Low: Gabbro, Amphibolite IKIZDERE Granitic Rocks intruded	Downstream part of Yusufeli Reservoir Area. Inanli Reservoir Area
PALEO-ZOIC	Permo-Carboniferous Pre-Permian		Gneiss Mica schist Amphibolite gneiss	Hercinian Orogeny (Carboniferous) Gabbro dyke (altered to Amphibolite			

7.3 Reference Data and Investigation Work

7.3.1 Reference Data

Reference data to prepare this report are shown in Table 7-2.

7.3.2 Investigation Work

The summaries of the geological investigation works executed at Yusufeli and Artvin project sites are as follows and their details are shown in Table 7-3, 4, 5, 6.

<u>Yusufeli Project Site</u>

• Drillholes including permeability test at dam & powerhause sites	18 holes, 2120.75 m
• Adits at damsite	4 adits, 454.55 m
• Plate bearing tests	8 points in 3 adits
• Block shear test	12 blocks in 3 adits
• Seismic prospecting in adits	1212 m for 15 lines
• Impervious core material test	6 samples from 6 pits
• Concrete aggregate test	4 samples from 3 pits and 1 adit
• Surface geological investigations	As shown in Table 7-3

<u>Artvin project site (upstream plan)</u>

• Drillhole including permeability test at tunnel route	1 hole 102 m
• Surface geological investigation	As shown in Table 7-5

<u>Artvin project site (downstream plan)</u>

• Drillhole including permeability test	1 hole 100 m
• Surface geological investigation	As shown in Table 7-5

Havuzlu Landslide site

• Drillholes at landslide mass	3 holes	133 m
• Electric prospecting	41 points on 15 lines	
• Surface geological investigation		

Table 7-2 Reference Data

Items	Notes
1. Engineering Geological Report of the Çoruh-Yusufeli Damsite	EIE, September 1979
2. Çoruh Basin Engineering Geological Investigations of Dam Possibilities, Reservoirs and Tunnel Alignments	EIE, September 1980
3. Çoruh River Basin Master Plan Report —Geology—	Temelus, April 1982
4. Geological Map of Yusufeli Reservoir (1:25000)	EIE, July 1985
5. Geological Map of Yusufeli Damsite (1:1000) (plan & profile)	" "
6. Logs of Drillholes & Adits at Yusufeli Damsite (1:100)	" "
7. Groundwater Measurement Record at Yusufeli Damsite	" "
8. Geological Map of Inanli Reservoir (1:25000)	" "
9. Geological Map of Inanli Tunnel (1:5000) (plan & profile)	" "
10. Logs of Drillholes & Adit at Inanli Damsite (original site)	" "
11. Report of Seismic Prospecting at Havuzlu Landslide	" October, 1985
12. Geological Map of Inanli Downstream Damsite (1:2000)	" February, 1986
13. Log of Drillholes of ST–1 & SID–1 for Inanli Project	" "
14. Log of Extension Adit of LA–2 at Yusufeli Damsite	" "
15. Log of Drillhole of RSI–16 at Yusufeli Damsite	" "
16. Laboratory Test Data of Impervious Core & Aggregate for Yusufeli Dam	" "

Table 7-3 List of Geological Investigation at Yusufeli Damsite

(Drillhole)

Hole No.	Coordination X	Coordination Y	Length (m)	Elevation (m)	Direction (m)	Dip	Permeability test Stage	Permeability test Length (m)
LS - 1	470,204.37	4520,512.47	150	498.62	—	90°	66	132
LSI - 2	"	"	100	"	N45°W	45°	32	94
LS - 3	470,181.31	4520,567.65	150	547.28	—	90°	47	118
LSI - 4	"	"	100	"	N40°W	43°	33	96
RS - 5	470,257.61	4520,469.93	125	518.60	—	90°	15	75
RSI - 6	470,267.80	4520,455.74	100	524.23	S60°E	45°	31	89
RSH-7	"	"	75	"	"	0	5	25
RS - 8	470,222.78	4520,498.29	100	498.37	—	90°	12	54
LS - 9	470,170.81	4520,631.53	100	597.24	—	90°	31	92
LSI - 10	"	"	150	"	N55°W	52°	41	139
RSI-11/A	470,276.	4520,422.5	40.75	534.09	N42°W	45°	14	28
RSI - 11	"	"	200	"	"	48°	51	187
LSI - 12	470,173.13	4520,536.07	150	506.75	S37°E	45°	42	144
LS - 13	470,041.01	4520,638.34	100	685.73	—	90°	32	94
LSI - 14	"	"	150	"	N60°W	48°	41	142
RSI - 15	470,353.	4520,465.	100	600.06	S55°E	45°	33	96
RSI - 16	470,335	4520,546	100	520	N80°E	10°	48	96
LSI - 17	470,111.31	4520,712.08	130	613.25	N35°W	65°	63	126
Total 18 Holes			2120.75	—	—	—	637	1,827

(Adit)

Adit No.	Coordination X	Coordination Y	Length (m)	Elevation (m)	Direction
RA - 1	470,267.17	4520,434.40	50	534.82	S35°E
LA - 2	470,183.42	4520,521.30	126.75	506.68	N37°W
LA-3(I)	470,211.99	4520,696.03	103	609.62	N80°W
LA-3(II)	470,086.02	4520,591.21	125	618.47	N10°E
RA - 4	470,337.11	4520,476.51	49.80	599.03	S50°E
Total	4 Adits	454.55 m			

(In-situ rock test)

Adit No.	Test section (m)	Plate bearing test Test No.	Plate bearing test Location (m)	Block shear test Test No.	Block shear test Location (m)
RA - 1	41 ~ 47	B - 1 B - 2	41.6 46.0	S - 1 S - 2 S - 3	43.1 44.55 46.95
LA - 2	27 ~ 35	B - 3 B - 4	29.0 34.2	S - 4 S - 5 S - 6	28.5 30.4 33.4
LA-3(II)	29 ~ 39	B - 5 B - 6	29.55 32.6	S - 7 S - 8 S - 9	31.8 34.6 37.25
LA-3(II)	72 ~ 80	B - 7 B - 8	72.2 77.1	S - 10 S - 11 S - 12	73.9 76.15 77.8
Total		8 Tests		12 Tests	

(Seismic prospecting in adits)

(1) 3 lines (at floor, right wall and left wall) in each adit (RA-1: 50m×3 lines = 150m, LA-2: 76×3 = 228m, LA-3(I): 125×3 = 375m, LA-3(II): 103×3 = 309m, RA-4: 50×3 = 150m)
(2) Seismic prospecting between adit RA-1 and RA-2, and between LA-2 and LA-3.

(Construction Material Test)

(1) Quantities and items are shown on Table 7-4.

(Surface geological investigation)

(1) Damsite 1/1000, (2) Reservoir area 1/25000
(3) Görgülü landslide area 1/5000.

Table 7–4 Laboratory Test of Dam Construction Material

Subject	Location	Test Items	Test Quantities	Remarks
Soil material	Görgülü landslide area on the left bank of Turtum River	· Specific gravity and ASTM C 127 · Moisture test · Grain size analysis · Liquid limit and plastic limit · Compaction test · Permeability test · Direct shear test (Consolidated-Undrained)	Six (6) test pits	
Concrete aggregate	Just upstream of the confluence of Oltu and Tortum Rivers	· Grain Size analysis · Specific gravity, absorption · Organic impurities test · Test for clay lumps in aggregate · Unit weight · Soundness test · Abrasion test · Test for quantity of soft particles in coarse aggragate · Alkali-aggragates reaction test	Three (3) test pits	River deposits
	Extension adit of LA–2, Yusufeli damsite	· Specific gravity · Absorption · Alkali-aggregates reaction test		Excavated rock

Table 7-5 List of Geological Investigations at Artvin Site

(Drillhole)

Hole No.	Location	Length (m)	Elevation (m)	Dip	Permeability test	
					Stage	Length (m)
ST-1	Around Esenkaya Village for tunnel	102	—	90°	46	92
SID-1	Bottom of river at Inanli downstream dam	100	—	90°	32	64

(Surface geological investigation)

(1) Reservoir areas of up and downstream Inanli dams 1/25000

(2) Upstream damsite 1/2000

(3) Downstream damsite 1/2000

(4) Tunnel area of Inanli upstream dam 1/25000

Table 7-6 List of Geological Investigations at Havuzlu Landslide

(Drillhole)

Hole No.	Location	Length (m)	Elevation (m)	Dip	Permeability test
HS-1	Landslide area	46	about 625	90°	—
HS-2	"	45	about 560	"	—
HS-3	"	42	"	"	—

(Electric prospecting)

(1) Interval of measurement stations 100 - 200 m

(2) 15 measurement lines and 41 measurement stations

7.4 Site Geology

7.4.1 Yusufeli Project

(1) Reservoir

(a) Topography

The Coruh River, along which the Yusufeli reservoir is located, flows in the north-east end of Turkey and ends in Soviet Union. It is approximately 410 km long and is bounded by 2,000 - 3,000 m high mountains such as Tatos (3,937 m), Kop (2,953 m) and Cam (3,850m).

The Yusufeli dam site is located approximately 45 km upstream of Soviet boundary, and the reservoir contains the Coruh river and its major tributaries of Barhal, Oltu and Tortum. The reservoir along the Coruh river ends in vicinity of Cinler village, approximately 27 km upstream of the dam site. Up to 2.5 km upstream of the dam site where granitic rocks are found, the river forms a very steep valley (typical slope at the dam site is 50 - 70 degrees from the horizontal). In further upstream where Yusufeli and Berta formations are found, both sides of the river are relatively eroded. In particular, significant erosion is observed in the area where Berta formation is found.

The reservoir along the Barhal river which joins the Coruh river (on the left bank) around Yusufeli village, approximately 9 km upstream of the dam site, ends at around Dutdere village located 9 km upstream of the confluence. As the reservoir is mainly situated in Berta formation, the valley is wide and has many flood plains, terraces and alluvial fans like other Berta formation areas along the Coruh river. Also, a large Vecanket landslide, at immediate upstream of Yusufeli village, is found in the reservair area.

A major tributary of Oltu River joins the Coruh River (right bank) at approximately 1 km upstream of the dam site, and another major tributary of Tortum river joins the Oltu River (left bank) at approximately 7 km upstream of the confluence. The reservoir along the Oltu River ends at around 15.5 km upstream of the confluence. It forms a narrow valley up to approximately 4.5 km upstream of the confluence where granitic rocks occur. On the other hand, a portion of the Oltu River and the Tortum River upstream of granitic rock area is located in Yusufeli and Pugey formations and thus is wide and has many flood plains and terraces. The reservoir along the Tortum River ends at approximately 6.5 km upstream of the confluence with the Oltu River, nearby which large Gorgulu landslide exists in Gorgulu village. Further upstream, there is a natural lake formed by a large scale landslide (used as a reservoir for Tortum No.1 Power Plant).

Typical slopes of various formations found in the Yusufeli reservoir area (between EL.750 m - 1,000 m) are as follows:

Ikizdere granitic rocks	1:0.9
Berta fromation	1:0.3
Yusufeli formation	1:0.7
Pugey formation	1:0.5

(b) Geology

The strata in the reservoir can be classified as follows:

Quaternary	Surface deposits	Slope wash Landslide material River bed deposits Terrace deposits
Tertiary	Basement rocks	Ikizdere granitic rocks
Mesozoic	"	Berta formation Pugey formation Yusufeli formation

i) Surface deposits

Slope wash

Slope wash is observed in many places of the reservoir area. This can be roughly classified into two types. One type consists of silt and rock fragments in mix, and another type consists of coarse grained sands and gravels in mix. The former is mainly found in gentle slopes of Berta, Pugey and Yusufeli formations. A typical distribution of this type is found in a slope where the EIE's camp is located. It is shallow in general. On the other hand, the latter forms so-called "alluvial cone" and is found at the foot of steep slopes in the reservoir, particularly in Ikizdere granitic rocks and Yusufeli formation. This type is not large in scale but distributing in many places, reaching relatively a great depth.

Landslide material

As mentioned previously, there are two large landslides in the Yusufeli reservoir; Vecanket and Gorgulu.

Vecanket landslide is located immediate upstream of Yusufeli town, made up of dacitic tuff which is subjected to hydrothermal alteration. Possible impact of water in the reservoir on the landslide is discussed in 7.4.1 (1)-(C)-ii).

Gorgulu landslide is located between Gorgulu village and Yardibi village along the Tortum River, consisting of material which seems to be slope wash containing gravels and clayey soils. However, it is probably spilite (or basalt) in Yusufeli formation which was weathered and sedimented. Possible impact of the reservoir on the landslide is described in 7.4.1 (1)-(C)-ii).

The above two landslides are well known because of large size and proximity to villages. In addition, some landscapes which were seemingly formed by past landslides are observed in upstreatm area of the reservoir, particularly in Berta formation area.

River bed deposits

This term is applied to deposits in present rivers. Thickness of river bed deposits in the reservoir was confirmed only in Yusufeli dam site; approximately 50 m. As mentioned previously, the river upstream of the dam site is wide in Berta or Pugey formation area, with sandbank being considerably wider than nearby the dam site. Especially, sandbanks (including flood plains) develop well in the Oltu River above the confluence with the Tortum River as well as in the Coruh River above Yusufeli village. Nevertheless, the thickness of the river bed deposits in the reservoir is estimated to be about 50 m judging from investigations on the Yusufeli dam site and other dam sites downstream of it. Also, the investigations revealed that gravels making up the deposits are granite, granodiorite, diabase, limestone, radiolarite, andesite, and basalt etc. The gravels are angular-subrounded-rounded with diameters of 1 - 40 cm and are generally not well sorted.

Terrace deposits

This is observed in many places of the reservoir. Elevations of terrace vary greatly; reaching 510 m around the dam site, at 630 m and 650 m around the confluence of the Barhal River and the Coruh River, and at 650 m along the Tortum River. The thickness of the sediments is generally a few meters in thin portions but 20 m or more in some places along the Tortum River. In general, the deposits are not well sorted. In some places (e.g., around Kazakura village near the confluence of the Barhal River and the Coruh River), however, gravel, sand and silt layers are well formed.

Pollen analysis was carried out for two samples which were collected from a terrace at EL.650 m on the left bank of the Coruh River near the confluence with Barhal River (higher terrace) and from a terrace at EL.510 m on the left bank of downstream of the dam site (lower terrace): the former is sample No.2 and the latter is sample No.3. The results indicate that the sample from higher terrace (Sample No.2) contains mainly nonarboreal pollen while the sample from lower terrace (Sample No.3) contains more arboreal pollen. In particular, Sample No.3 contains a lot of old fossils of Mesozoic (classopollis), which seemingly much re-sedimented as new pollens of later era sedimented. In any case, the pollen analysis suggests that the terrace deposits are young, probably in Alluvium.

Since the present river bed deposits are around 50 m thick, elevations of the basement rocks in river beds are estimated to be of 450 m (near the dam site) and of 550 m (near Yusufeli village). If the terraces were formed by old rivers, it should be assumed that the area upheaved or the sea level in Black Sea regressed in Alluvium (within the past 10,000 years). Since regression of sea level in Black Sea in the period of Alluvium cannot be assumed from geological viewpoint, upheaval of several ten meters should be assumed to occur in the Alluvium period, if the terraces were formed through erosion by the existing rivers.

Another hypothesis on terrace formation is that large landslides in the area downstream of the dam site blocked the rivers for a while to form a lake and deposits at that time, left as terrace deposits at present. Because sand and gravels of terrace deposits are found above landslide material (or talus) in some places of the area. If so, it is most probable that Demirkent landslide caused the river blockade.

ii) Basement rocks

Ikizdere granitic rocks

Ikezdere granitic rocks are batholith which cuts Berta formation and Yusufeli formation and are widely distributed in and around the Yusufeli dam site and Deriner dam site downstream. In the Yusufeli dam site, they are mainly distributed up to 3 - 4 km upstream of the dam site. They consist of a variety of rock types, such as granodiorite-tonalite group, adamellite group, porphyritic microgranite group and granite-gneiss group, according to the investigations by the EIE. It should be noted that in this report diabase which is dyke rock cutting granitic rocks is included in Ikezdere granitic rocks.

Berta formation

Berta formation in the Yusufeli reservoir is mainly found in an area along the Barhal River as well as the Coruh River upstream of the confluence with the Barhal River. It is bounded by a thrust fault with Yusufeli formation located immediately downstream of the confluence. Berta formation consists of spilite, basalt, dacite, rhyolite, tuff, mudstone, sandstone, conglomerate, marl and limestone. Although detailed distribution of these rocks is not known, yellowish brown - yellowish white outcrop was conspicuously observed during the field investigation. This suggests wide presence of the alteration of acidic volcanic rocks such as dacite, rhyolite and dacitic (or rhyolitic) tuff. Judging from the rocks distributed, Berta formation has sufficient watertightness as a reservoir foundation but its slope might have stability problems after filling water. Possible occurence of landslide in this formation is discussed in 7.4.1 (1)-(c)-ii).

Pugey formation

Pugey formation in the Yusufeli reservoir is mainly found in an area upstream of the confluence of Oltu and Tortum Rivers. It is bounded by angular unconformity with Yusufeli formation in the vicinity of the confluence.

Pugey formation consists of alternation of limestone and marl, marl, sandstone and conglomerate etc. In addition to the sedimentary rocks, intrusive rocks cutting them are found. Large stratified outcrop of Pugey formation is observed in an area upstream of Tortum River (upstream of the reservoir end) and an area along the Oltu River upstream of the confluence.

Although Pugey formation is mainly made up of calcareous rocks and is distributed in wide areas, noncalcareous rocks are intercalated in calcareous rocks. Because of these, Pugey formation is considered to have sufficient watertightness as a reservoir foundation. Its slope stability is discussed in 7.4.1 (1)-(c)-ii).

Yusufeli formation

Along the Coruh River, Yusufeli formation is found between Ikizdere granitic rocks and Berta formation, and around the EIE camp, while along the Oltu River it is found between Ikizdere granitic rocks and Pugey formation and around Dag yolu village. Berta formation and Yusufeli formation are bounded by thrust fault, and Pugey formation and Yusufeli formation are bounded by angular unconformity.

Yusufeli formation is consisted of serpentinized gabbro, amphibolite, spilite, green schist, greywacke [1], slate and phyllite etc. It has appropriate watertightness and its slope stability is discussed in 7.4.1 (1)-(c)-ii).

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1) Microscopic identification by the EIE revealed that some of the rocks previously called "greywacke" were basic tuff and/or diabase.

(c) Considerations from the viewpoint of engineering geology

i) Watertightness

The Yusufeli reservoir area is considered to be adequately watertight because:

- Ikizdere granitic rocks in the vicinity of the dam site have remarkably good watertightness.

- Yusufeli formation found in the midstream of the reservoir is made up of non-soluble rocks.

- Berta formation lies in the upstream of the Coruh River and along the Barhal River. It is not likely to have continuous caverns affecting the reservoir leakage as judged from topographical conditions, although it might contain soluble rocks (limestone) in part.

- Pugey formation in the upstream area of the reservoir along the Oltu River, made up of soluble rocks (limestone) is not likely to contain continuous and large caverns, as the limestone includes less-soluble and non-soluble rocks such as marl and sandstone in between. Furthermore, even if continuous caverns should exist, seepage of water from the reservoir will not occur because the formation in the area is surrounded by non-soluble strata.

- Also, no other topographical conditions (e.g., thin saddles) to cause water seepage are found in the reservoir area.

ii) Slope stability

In addition to watertightness, slope stability is the most important geological requirement for the reservoir. In the Yusufeli reservoir, the following problems are considered to affect the slope stability.

- Presense of two large landslides
- Possible occurence of landslides after the filling of the reservoir
- Possible collapses of alluvial cones after the filling of the reservoir
- Stability of rock forming steep cliffs

Presense of two large landslides

As mentioned previously, there are two large landslides in the Yusufeli reservoir area; Gorgulu landslide near the end of the reservoir along the Tortum River and Vecanket landslide at the immediate upstream of Yusufeli town along the Barhal Stream. These landslides are consisted of materials mentioned in (b).

Degraded area of Gorgulu landslide is estimated to be 1 km^2, with average thickness of 48 m (based on 1/5000 scaled topographical maps). On the other hand, Vecanket landslide has an area of 1 km^2 with average thickness of 40 m (based on 1/25000 scaled topographical maps).

At present, Gorgulu landslide is slowly active, while Vecanket landslide is not active. Nevertheless, the tongue of Vecanket landslide is steeper than that of Gorgulu landslide and it is not certain that it is really stable.

Both of landslides are expected to be inundated at their tongues after the filling of the reservoir (up-to elevation of 710 m). The elevation of lower end of sliding surfaces of the landslides is estimated to be around 750 m, although further investigation will be required at the detail design stage to determine whether main parts of the landslides (main sliding surfaces) will be inundated. It should be noted, however, that this does not necessarily mean that the landslides will not become active after the filling of the reservoir just because their sliding surfaces will not be under water; Gorgulu landslide is still active and Vecanket landslide is in topographically unstable conditions. Possible impacts of the landslides on dam and reservoir were considered and are summarized as follows:

Gorgulu landslide

- The landslide is located at the end of the reservoir along the Tortum River, approximately 10.5 km from the dam site. The reservoir in this part is characterized by T-shape at two confluences of the Tortum River and Oltu River as well as the Oltu River and the Coruh River. These conditions are considered to be useful in dissipating wave energy generated by Gorgulu landslide, if it slides into the reservoir.

- Average slope of the sliding surface is approximately 11 degrees. The landslide is made up of residual soil of weathered spilite (or basalt) and rock fragments (gravel), which are suitable for core materials of rock fill dams. Judging from the angle of the slope, the landslide moves very slowly. On the other hand, the materials suggest that flow type sliding will occur if becoming active due to torrential rain and other natural causes, instead of block type sliding.

- On the other hand, wide plain at elevations of 675 - 700 m is formed in front of Gorgulu landslide and the reservoir near the landslide has a water depth of 40 m on average and 60 m at deepest.

- Taking into account the slope and materials of the landslide as well as water depths, the landslide will not generate large waves to affect the dam stability even if it slides rapidly into the reservoir.

- The volume of Gorgulu landslide is estimated to be approximately 50 x 10^6 m^3. On the other hand, the storage capacity of the reservoir in front of the landslide is roughly estimated to be 19 x 10^6 m^3 (calculated from difference in elevations of 650 m and 710 m). Based on these data, it is safely said that, the rise in water level in the reservoir caused by sliding of the entire landslide will be accomodated within the freeboard (capacity of 170 x 10^6 m^3) of the reservoir.

- At the same time, however, the volume of the landslide is three times the capacity of the reservoir in front of it, so that the entire landslide will block up the reservoir completely.

Naturally, the above case is not likely to occur as the landslide has already developed and is now maintaining the stable slope in comparison to active period although being slightly active. Nevertheless, there are a natural dam and reservoir about 15 km upstream of the landslide which were formed by a large landslide. The power plant using the lake and a village near it are estimated to be located at elevation of 800 m. Thus, impacts of blockade of reservoir by Gorgulu landslide on the upstream area should be studied at later stages.

Vecanket landslide

- The landslide is located immediate upstream of Yusufeli town along the Barhal River, approximately 11 km from the dam site. The reservoir in this area is also T-shaped at two confluences of the Barhal River and the Coruh River as well as the Coruh River and the Oltu River. Like Gorgulu landslide, this topography will help dissipate wave energy generated by the landslide, if flowing into the reservoir.

- The average slope of the landslide on surface is approximately 23 degrees. The landslide is made up of dacitic tuffs which were subjected to hydrothermal alteration, with less clayey materials in comparison to Gorgulu landslide. However, it is not certain for lack of data if the entire landslide has the above components. In any case, the landslide of block type caused by hard bed rocks on the sliding surface is not likely to occur, judging from the fact that the rapid sliding occured at the time of intensive rain in 1968 and flowing materials filled up the Barhal River and that the filling materials were carried away by subsequent river erosion.

- The reservoir in front of Vecanket landslide is relatively a narrow valley (about 500 m wide at elevation of 700 m) and its water depth is estimated to be 110 m assuming that the highest water level of the reservoir is at EL.710 m. On the other hand, the volume of the landslide is estimated to be 40×10^6 m^3. Thus, if the entire landslide flows down to the reservoir rapidly, a significant high wave will be generated.

- In this case, however, it is likely that the wave having destructive energy will not reach the dam site because (1) the landslide is about 11 km from the dam site, (2) the reservoir is well meandering, and (3) materials making up the landslide are not in lump. Nevertheless, further investigations are required in this connection.

- The landslide is in stable condition at present. Furthermore, water in the reservoir will not seep into the landslide, because lower end of the landslide is at elevation (about 750 m) higher than the high water level (EL.710 m). For this reason, rapid sliding is not likely to occur by impounding the water of the reservoir.

- The volume of Vecanket landslide is estimated to be 40×10^6 m^3, whereas the capacity of the reservoir in front of the landslide is roughly 47×10^6 m^3 (calculated from the difference in elevations of 650 m and 710 m). Thus, the rise in water level by sliding of the entire landslide can be accommodated within the freeboard of the reservoir as in case of Gorgulu landslide.

- However, since the volume of the landslide is smaller than the capacity of the reservoir in front of the landslide, the entire landslide, once occured, is not likely to block up the reservoir.

<u>Possible occurrence of landslides after the filling of the reservoir</u>

As mentioned previously, there are Ikizdere granitic rocks, Berta formation, Pugey formation and Yusufeli formation in the Yusufeli reservoir area. Of these, Berta formation is most likely to cause landslides after the filling of the reservoir.

Berta formation is found on both banks of the Brahal River and the Coruh River at the upstream of the confluence of these rivers, and it is made up of spilite, basalt, dacite, rhyolite, tuff, mudstone and sandstone. Many of these rocks were subjected to hydrothermal alterations to have high risk of landsliding. One example of this is Vecanket landslide.

On the other hand, Pugey formation is made up of stratified calcareous rocks and clastic rocks. In this type of formation, large block type sliding will occur if the sliding surface exist along the stratum. A typical example of this is a natural dam created by the landslide at the upstream of the Tortum River.

Yusufeli formation is made up of, among other rocks, weathered serpentinized gabbro and spilite which require special attention on landslide potential. Gorgulu landslide is a primary example of landslide caused by weathered spilite (or basalt). Also, phyllite belonging to this formation has a high landsliding hazard. Example of this is Havuzlu landslide at the downstream of the Yusufeli dam site. However, as far as the formation in the Yusufeli reservoir is concerned, no potential landslide is found except for Gorgulu landslide.

In summary, Berta formation in the Yusufeli reservoir has a high risk of new landslides after the filling of the reservoir. Consequently, to avoid the risks of new landslides, the following points shall be carefully considered;

- Detailed geological maps (namely lithofacies map) in the Berta formation area should be prepared to pinpoint areas with landslide hazard.

- Judging from a risk of new landslides in the Berta formation area, it can be said that the lower water level of the reservoir is better and has less influence on new landslides.

At present, such hazard is only limited to the upstream area of the reservoir, so that no problem is foreseen for the construction of the dam when considering water depths of the reservoir and distance to the dam.

Possible collapses of alluvial cones after the filling of the reservoir

At feet of steep cliffs formed by Ikizdere granitic rocks and Yusufeli formation in the reservoir, alluvial cones are well developed. As these slope washes are made up of unconsolidated sand, silt and gravel, they have a high risk of collapse after the filling of the reservoir. However, the tops of alluvial cones are generally below the highest water level of the reservoir, so that it is considered that no damage to the dam or reservoir will occur due to collapse of the alluvial cones, i.e., sand or gravel in the alluvial cones will sediment in dead water capacity of the reservoir.

Stability of rock forming steep cliffs

As mentioned previously, the topography in the Yusufeli reservoir is generally steep, especially in areas where Ikizdere granitic rocks or Yusufeli formation occur. Generally speaking, steep rock slopes in this area which are under little rain and dry conditions lose their stability sometimes if water is permanently supplied into the foundation after the filling of the reservoir.

Geological factors relating to such problem are as follows:

* Degree of discontinuity developed on the slope (size, number, and continuity) and properties (presense of infilling material, dip, direction, etc.)
* State of ground water in the foundation rock

It is difficult to investigate the aboves on steep cliffs in the dam site and reservoir area due to a lack of access. Nevertheless, the following conclusions can be drawn from observations on adits excavated in the dam site:

Discontinuities which might affect the stability of slope are faults and joints. The faults are fractured and often contain clay to suggest poor shearing strength, thus having a risk of sliding due to rise in pore pressure after the filling of the reservoir. On the other hand, the joints are generally tight and do not show significant attitudes as mentioned in 7.4.1 (2)-(c)-iii) to suggest very low possibility of affecting the slope stability. Therefore, when observing attitudes of faults as weak layers affecting the slope stability, they are concentrated in attitudes of N70 - 80°E, 40 - 50°NW, N40 - 50°E, 65 - 70°NW, and N10 - 20°W, 65 - 80°SW (see Fig. 7-6). This indicates that many faults are pallalel or crossing at 0 - 60 degrees to the course of the Coruh River (N50°E) and dipping to the left bank, so far as foundation rocks of the dam site are concerned. The frequency of faults is more on the left bank and less on the right bank. Also, ground water level implying presense of cracks is relatively low on the left bank and high on the right bank.

Therefore, if water seeps into faults and other cracks in the foundation rocks after the filling of the reservoir and pore pressure rises, slopes on the both banks are not likely to lose their stability since many faults on the left bank are dipping mountain-side while not many faults exist on the right bank.

(2) Dam

(a) Topography

The dam site is located approximately 800 m downstream of the confluence of the Coruh River and the Oltu Tributary. The Coruh River flows mostly straight in the dam site in NE direction. The river width is about 25 - 30 m, with river bed at elevation approximately of 500 m. The valley width at the design high water level of 710 m is 350 - 420 m. On the left bank, a two-lane paved road (National Road 20) with side slope is extending.

The dam site has generally a steep topography both on upstream and downstream. On the mountainside, outcrops of foundation rocks are observed entirely except for surface deposits in part, with very little fertile soil and vegetation.

The topography of rock fill type dam axis can be characterized as follows. The left bank is gentle slope of about 30 degrees which runs parallel to the river in the form of band at elevation of 530 - 580 m. Above these elevations, the bank forms steep slope of 50 degrees. On the right bank, there is a slope wash with slope of 30 degrees, peaking at a elevation of 545 m, above which steep slope of 60 degrees is observed (see Fig. 7-3). The valley width at elevation of the highest water level is about 420 m.

As to arch dam axis and its vicinity, the left bank has little ups and downs except for a small stream at the immediate upstream of the dam axis, with slope of around 45 degrees throughout the area. On the other hand, the right bank is relatively steep, average slope of 55 degrees. On section, it shows staged topography as crossing small ups and downs on the mountainside diagonally (see Fig. 7-4). The dam crest is approximately 500 m long.

(b) Geology distributed

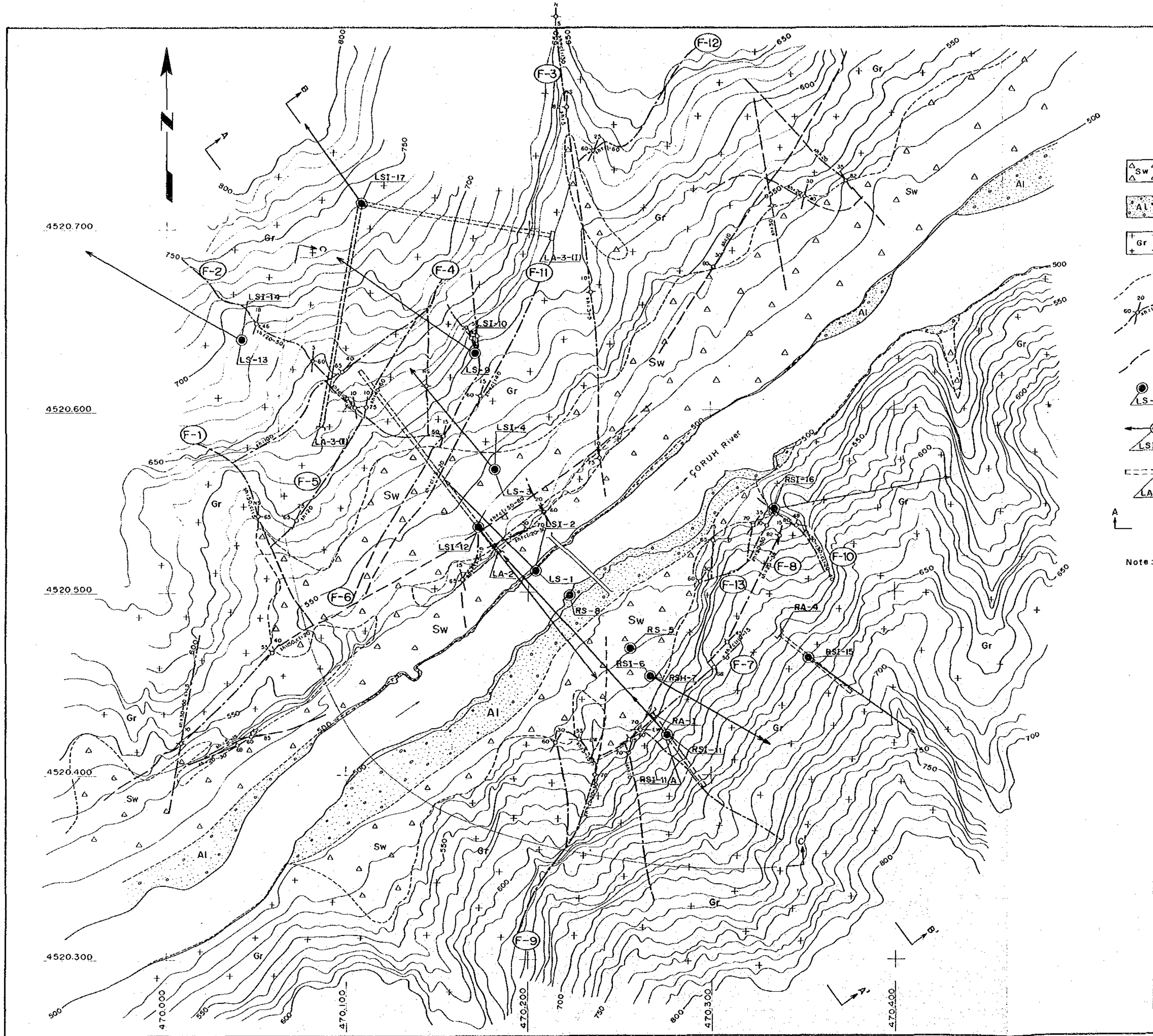
Base rocks in the dam site are Ikizdere granitic rocks which were active from late Eocene to Oligocene. Rock types are granite, granodiorite, granophyre and diabase, each of which cut another with width of a few centimeters to several ten meters to form a complex of granitic rocks. Each rock is generally very hard and does not have significant variation in quality from others, so that the base rocks can be recognized as a mass having uniform property of very hard with many cracks.

The foundation rocks are covered by surface deposits that is, alluvium and slope wash in the dam site. Alluvium is made up of gravels and is 41.8 m or more in thickness in the river bed (drillhole RS-8). Gravels are mainly rounded with angular ones in part. Also, silt and sand are contained. According to drillhole data, they are generally not well stratified.

Slope wash of 3 - 4 m thick is observed in the band parallel to the river, on the left bank at elevations of 530 - 580 m. The slope wash tends to get thicker toward the downstream, with well compacted structure in part.

The slope wash along the road on the left bank (shown on a geological map Fig. 7-2) is a fill materials for the road, with estimated depth to the foundation rock being about 2 m.

On the right bank, slope wash with maximum width of 120 m occurs around the rock fill dam axis, peaking at elevation of 545 m. It covers the alluvium, with maximum thickness of 25 m.



ÇORUH RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

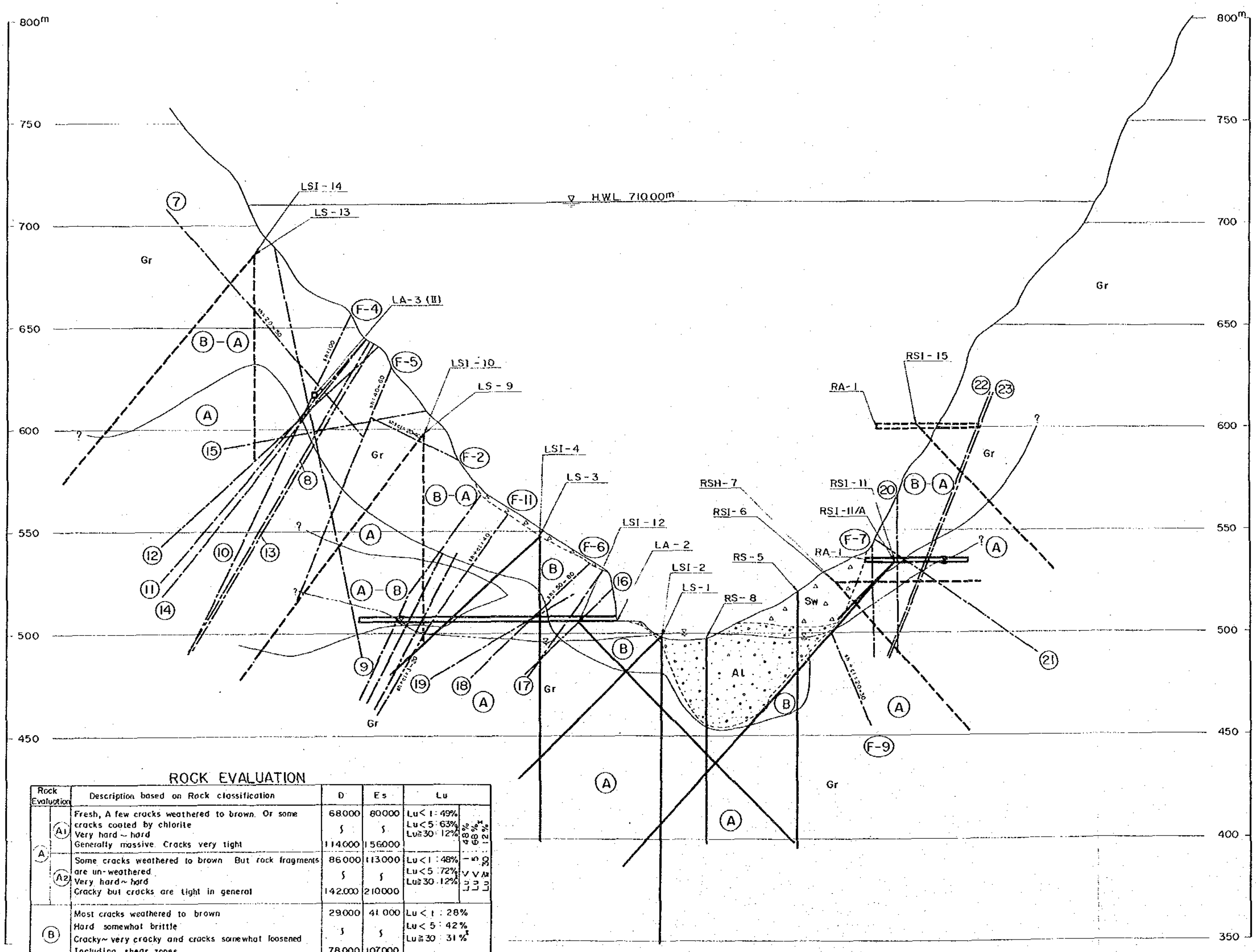
YUSUFELİ PROJECT

GEOLOGY

DAM PLAN

Fig. 7–2 DECEMBER 1986

Section A - A'



LEGEND

- Sw — Slope wash
- AL — Alluvium
- Gr — Granophyre, diabase, granite granodiorite complex
- Geologic boundary
- Fault (thickness is not less than 10 cm) confirmed by surface geological survey where
  - (F-6) : Fault name corresponding to geologic plan
  - sh : Thickness of shear in cm
  - cl : Thickness of clay in cm
- Fault (thickness is less than 10cm) confirmed by surface geological survey, where the description of fault is eliminated.
- (18) Fault (thickness is not less than 10cm) confirmed in adits
  - (18) : Fault number corresponding to logs of adits
- (B)/(A) Rock evaluation and its boundary
- LA-2 Adit
- RA-4 Adit (projected)
- LA-3 Drillhole
- LS-9 Drillhole (projected)
- Ground-water table

0 — 100m

ROCK EVALUATION

Rock Evaluation		Description based on Rock classification	D	Es	Lu	
(A)	(A1)	Fresh, A few cracks weathered to brown. Or some cracks coated by chlorite Very hard ~ hard Generally massive. Cracks very tight	68000 ~ 114000	80000 ~ 156000	Lu< 1 : 49% Lu< 5 : 63% Lu≧30 : 12%	Lu< 1 : 48% Lu< 5 : 68%* Lu≧30 : 12%
	(A2)	Some cracks weathered to brown But rock fragments are un-weathered Very hard ~ hard Cracky but cracks are tight in general	86000 ~ 142000	113000 ~ 210000	Lu< 1 : 48% Lu< 5 : 72%* Lu≧30 : 12%	
(B)		Most cracks weathered to brown Hard somewhat brittle Cracky ~ very cracky and cracks somewhat loosened Including shear zones	29000 ~ 78000	41000 ~ 107000	Lu< 1 : 28% Lu< 5 : 42% Lu≧30 : 31%*	

Note D : Modulus of deformation (kgf/cm²)
Es Secant modulus of elasticity (kgf/cm²)
Lu Lugeon value (ℓ/m/min/10kgf/cm²)
* marked values include the percentages of water leakage

ÇORUH RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

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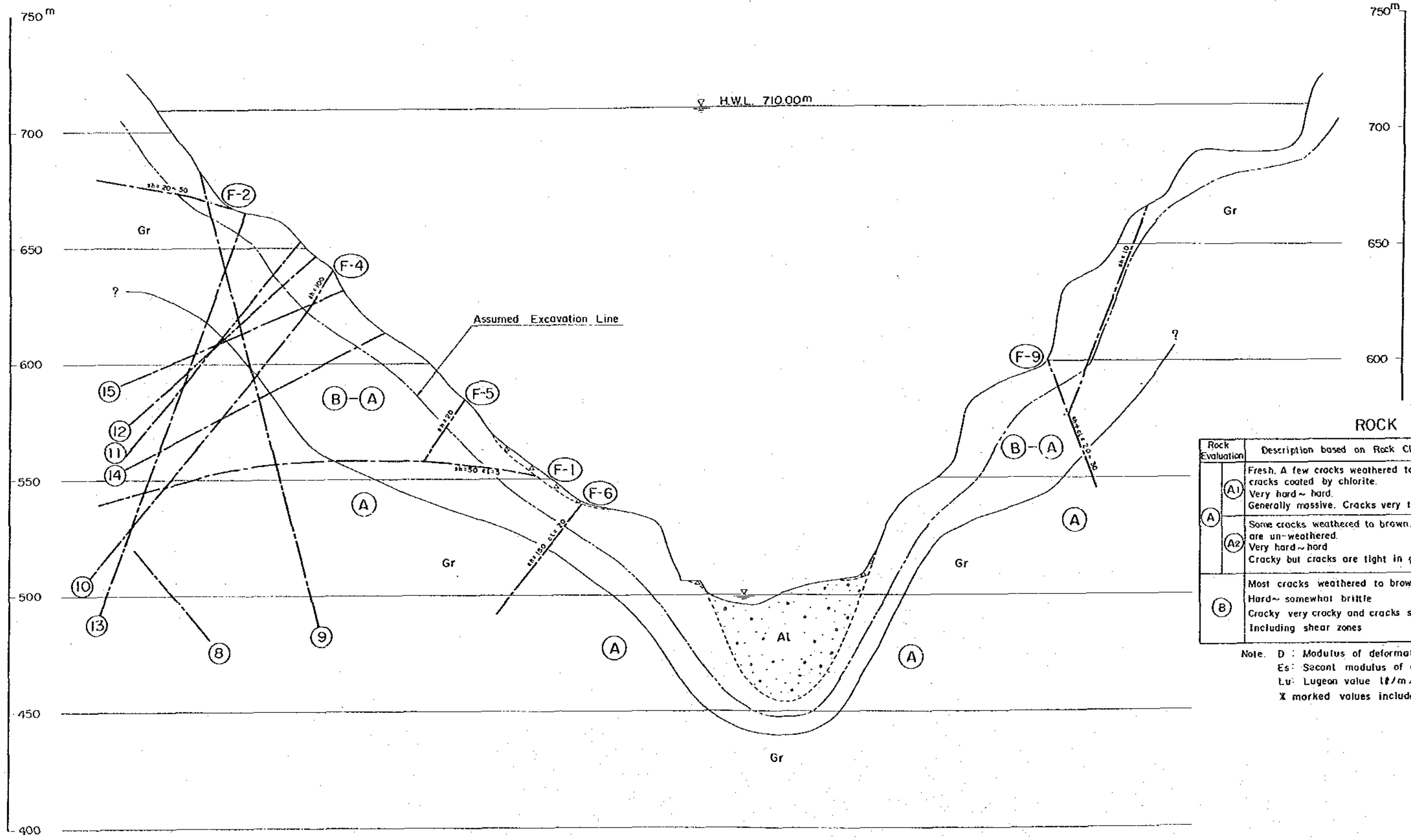
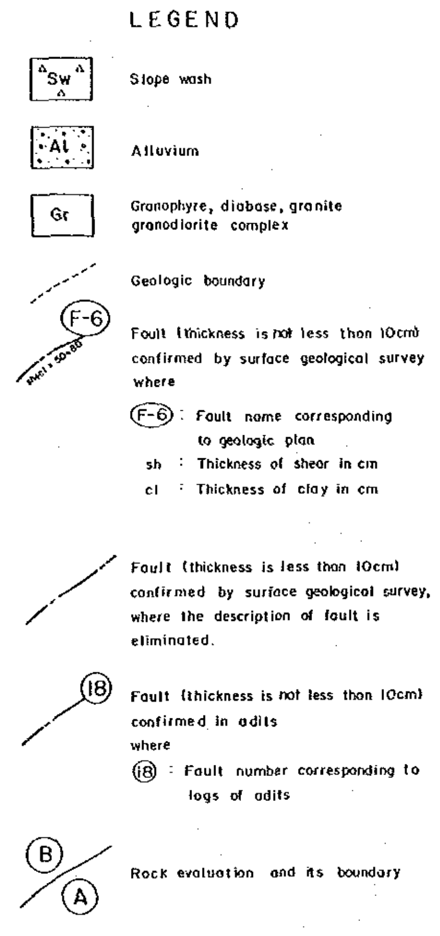
GEOLOGY
DAM SECTION A-A'

Fig. 7-3 | DECEMBER 1986

Section C - C'





ROCK EVALUATION

Rock Evaluation		Description based on Rock Classification	D	Es	Lu	
A	A1	Fresh. A few cracks weathered to brown. Or some cracks coated by chlorite. Very hard ~ hard. Generally massive. Cracks very tight	68000 ~ 114000	80000 ~ 156000	Lu<1: 49% Lu<5: 63% Lu≧30: 12%*	Lu<1: 48% Lu<5: 68% Lu≧30: 12%*
	A2	Some cracks weathered to brown. But rock fragments are un-weathered. Very hard ~ hard. Cracky but cracks are tight in general	86000 ~ 142000	113000 ~ 210000	Lu<1: 48% Lu<5: 72% Lu≧30: 12%*	
B		Most cracks weathered to brown. Hard ~ somewhat brittle. Cracky very cracky and cracks somewhat loosened. Including shear zones	29000 ~ 78000	41000 ~ 107000	Lu<1: 28% Lu<5: 42% Lu≧30: 31%*	

Note. D : Modulus of deformation (kgf/cm^2)
Es : Secant modulus of elasticity (kgf/cm^2)
Lu : Lugeon value ($\ell/m/min/10kgf/cm^2$)
X marked values include the percentages of water leakage

0 — 100m

ÇORUH RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

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GEOLOGY

DAM SECTION C - C'

Fig. 7–4 | DECEMBER 1986

(c) Considerations from the viewpoint of engineering geology

i) Weathering

Foundation rocks in the Yusufeli dam site can be characterized as follows:

- The rocks are generally fresh and are not much altered or deteriorated by weathering. Weathering characteristics vary little among rock types.

- In high-rain areas with warm to hot climate, granitic rocks are weathered and decomposed into fine particles of minerals in general. In the dam site, however, this phenomenon can not be seen excepting small part in the sidewall at TD. 17 m of adit RA-4. One reason for this is found in the fact that most of foundation rocks in the area are hypabyssal rocks in which rock-forming minerals bind each other firmly, instead of plutonic rocks which are easily decomposed into mineral particles when strongly weathered.

- The most common type of weathering in the site is oxidation which develops along discontinuities (crack, joint and fault) in the rocks to turn them into brown color, caused by water seeping through the discontinuities.

  This type of weathering extends only to the discontinuities which become slightly separable and rarely reaches inside of the rocks.

- In addition, a different type of alteration is observed in the discontinuities; chlorite film lies in between to make the discontinuities separable relatively. This alteration sometimes reaches inside of the rocks. For instance, significant degree of alteration of this type is observed at TD.10 m of adit RA-4 for maximum width of 1 m, and it can be easily excavated by hammer pick. It should be noted, however, that such alteration is localized and of little continuous.

. Weathering of cracks accompanied by oxidation is more developed on the left bank abutment and becomes less from the river bed to the right bank.

. Weathering which causes brown discoloration of most cracks (weathering rank 3 in Rock Classification; see 7.4.1 (2)-(c)-vi)) has reached the following depths (measured vertically from rock surface):

On the left bank abutment, 16 m at high elevations (Drillhole LS-13), 39.5 m at middle elevations (Drillhole LS-9), 18.8 m at low elevations (Drillhole LS-3).

In the river bed area, 14.7 m on the left bank (Drillhole LS-1), 2.35 m in the thickest alluvium where the foundation rock is most deeply eroded (Drillhole RS-8), and 21.3 m on the right bank (Drillhole RS-5).

On the right bank abutment, rank 3 weathering is rarely observed and rocks are generally fresh.

Below the above depths, foundation rocks are generally fresh except for local weathering along discontinuities such as faults and major joints.

. The graph of Fig. 7-5 shows the correlation between the depth from the top of each hole and the weathering (Degrees of weathering are shown in Table 7-9, 10). The following tendency can be read from this graph.

* The weathering stronger than degree 3 (fair class) is very scarce in general.

* Degree 3 is mainly developed within 50 m from the ground surface.

* The prominent weathering grades are degree 2 to 1.5 (fresh) and they are mainly seen within 100 m from the ground surface.

* As a whole, the weathering grade on this damsite is very weak, especially below 50 m from the ground surface.

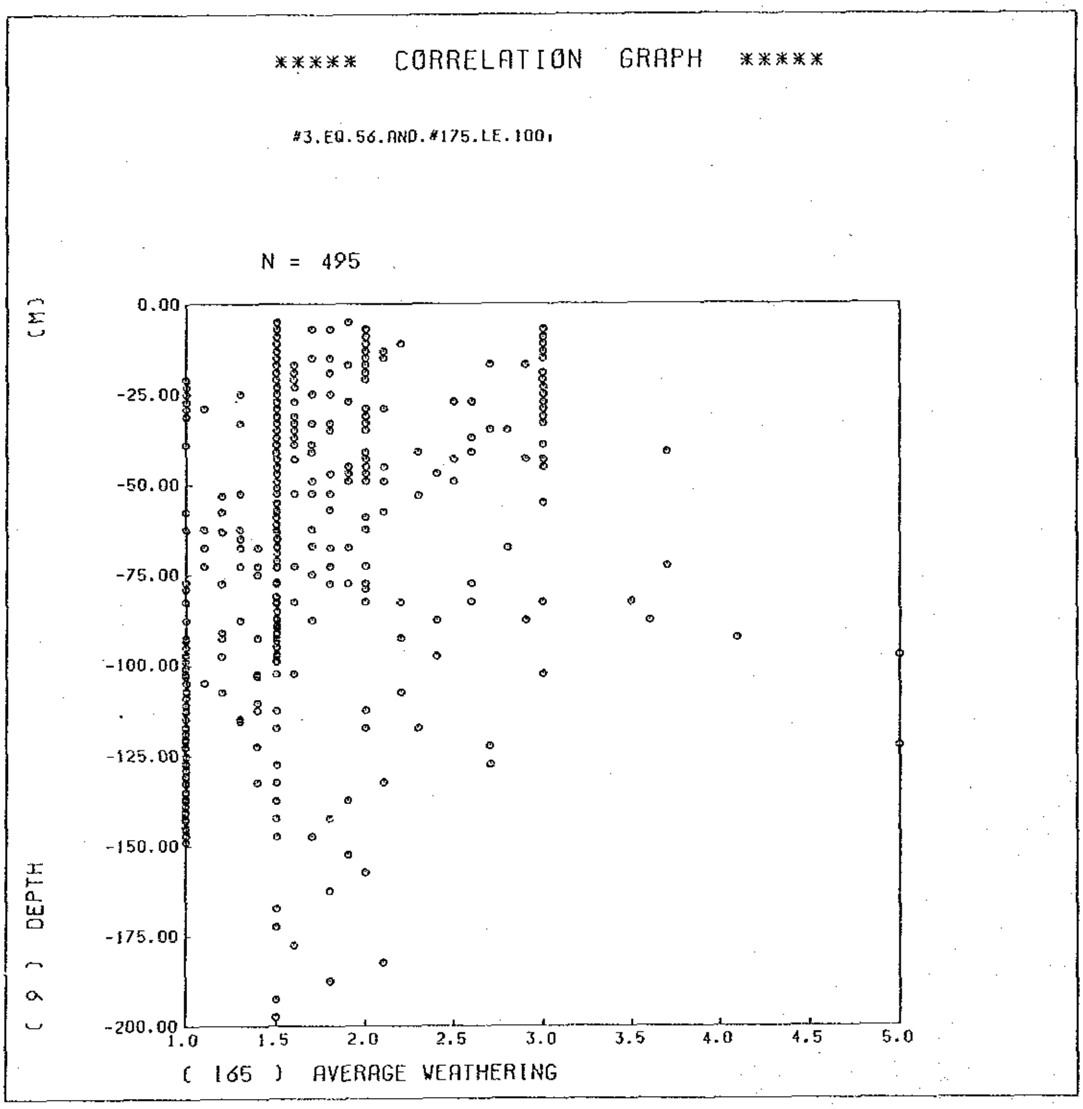


Fig. 7-5 Correlation graph, Depth – Weathering

ii) Hardness

All rock types found in the damsite are very hard without significant variation in hardness. Foundation rocks with less hardness are found in shear zones of fault and local spots subjected to remarkable chloritization as mentioned in the previous section.

Accordingly, except for the localized soft portions mentioned-above, foundation rocks in the damsite have sufficient hardness.

iii) Discontinuities

Discontinuities in the foundation rocks found in the dam site are taking the form of fault, joint, crack and igneous contact. Each type can be generally described as follows:

Fault

Faults with attitudes identified by surface investigations or adit observations are named as follows: those having the width of 10 cm or more as identified by surface investigations are named F-1 - 13, while those having the width of less than 10 cm are not named. On the other hand, those having the width of 10 cm or more as identified by adit observations are numbered from ① to ㉔ , but no number for those with the width of less than 10 cm. Faults named or numbered are listed in Table 7-7. Same names or numbers are indicated in geological plan, sections and logs of adits. General properties of the faults are as follows:

- Although the faults are generally crushed into small pieces with clay, the shear zones, when they are located above the ground water level, are binding together firmly and well compacted. However, when the shear zones are located below the ground water level

Table 7-7 List of Remarkable Fault

Name or No.	Strike and dip	Width (cm) sh : shear cl : clay br : breccia	Location, continuity and other features
F – 1	NS, 65°E	Sh=50, cl=5	On the left bank, at the immediate upstream of the arch dam axis Dipped downstreamly, eroded to form a valley Continues at least 100 m
F – 2	N5~18°E, 46~60°SE N10°W, 62°NE	sh=20~50 sh=20~40	On the left bank, at the immediate downstream of the arch dam axis Dipped downstreamly, eroded to form a valley Continues at least 200 m
F – 3	N0~10°W 75~90°W	max. sh+cl=130	On the left bank, 200 m downstream of the arch dam axis Eroded to form a steep valley Continues at least 250 m
F – 4	N40°E, 65°NW	sh=100	On the left bank, crossing the arch dam axis Dipped toward the mountain, continues at least 150 m
F – 5	N10~25°E, 65~75°NW	sh=20~60	On the left bank, roughly parallel to F–3 Continues at least 150 m
F – 6	N40~68°E 55~68°NW	max. sh=150 cl=20	On the left bank, parallel to the river, dipped to the mountain side Continues at least 250 m, corresponding to Fault 18 of LA–2
F – 7	N50~60°E 88~90°SE	sh+cl=10~15	On the right bank, parallel to the river Continues at least 90 m
F – 8	N15~45°E 82~92°NW	sh=20~30	On the right bank Continues at least 80 m
F – 9	N5°E, 70°SE	sh+cl=20~30	On the right bank, crossing the arch dam axis Dipped toward the mountain Eroded to form a steep valley Continues at least 200 m
F – 10	N80°W, 48°N	sh=50~130 cl=20~40	On the right bank, 200 m downstream of the arch dam axis Continues at least 50 m
F – 11	N15°E, 60°NW	sh+cl=40	On the left bank, sloped toward the mountain Continues at least 100 m
F – 12	N25°E, 60°NW	sh+cl=60	On the left bank, 200 m downstream of the arch dam axis Eroded to form a steep valley
F – 13	N30°E, 60~70°NW	sh=20~30	On the right bank, dipped toward the river Continues at least 60 m
1	N24°E, 55°NW	sh=5~40	LA–3(I) The following is faults which are identified in the adits as having relatively good continuity
2	N20°W, 62°W	sh=10~25	LA–3(I)
3	N18°E, 53°W	sh+cl=20	LA–3(I)
4	N40°E, 52°W	sh+cl=10~20	LA–3(I)
5	N3°W, 70°W	sh=20~30	LA–3(I)
6	N30°W, 40°E	sh+cl=5~20	LA–3(I)
7	N15°W, 55°E	sh=15~30	LA–3(II)
8	N10°W, 75°W	sh+cl=5~15	LA–3(II)
9	N60°E, 78°SE	br+cl=5~15	LA–3(II)
10	N40°E, 65°NW	sh+cl=15~30	LA–3(II)
11	N75°E, 52°N	cl+sh=20~30	LA–3(II)
12	N75°E, 45°N	cl+sh=15~20	LA–3(II)
13	N75°W, 68°N	sh+cl=1~3	LA–3(II), fracture zone is formed between 10 to 13 (10 m in width)
14	N20~25°E, 55°~78°W	sh+cl=5~30	LA–3(II)
15	N60~65°W 15~25°NE	sh=2~30	LA–3(II)
16	N73°W, 64°N	sh=5~30 cl=1~2	LA–2
17	N17°W, 60°W	cl=1~3 sh=5~15	LA–2
18	N68°E, 50°NW	cl+sh=50~80	LA–2, corresponding to F–6 fault
19	N84°E, 39°N	sh=1~20 cl=1~3	LA–2
20	N35°E, 89°W	sh+cl=5~25	RA–1
21	N43°E, 35°E	sh+cl=10~20	RA–1
22	N50°E, 68°N	sh=10~15	RA–1
23	N55°E, 68°N	sh=5~20	RA–1
24	N50°E, 72°N	sh=10	RA–4

as seen at TD 92 m - TD 102 m of Adit LA-2, the shear zones and the clay films of the slickensides are softened to a degree that can be excavated by hammer pick.

The above mentioned informations shall be carefully considered.

- The width of the faults varies greatly from 1 cm of small faults to 150 cm of F-6 fault, for instance.

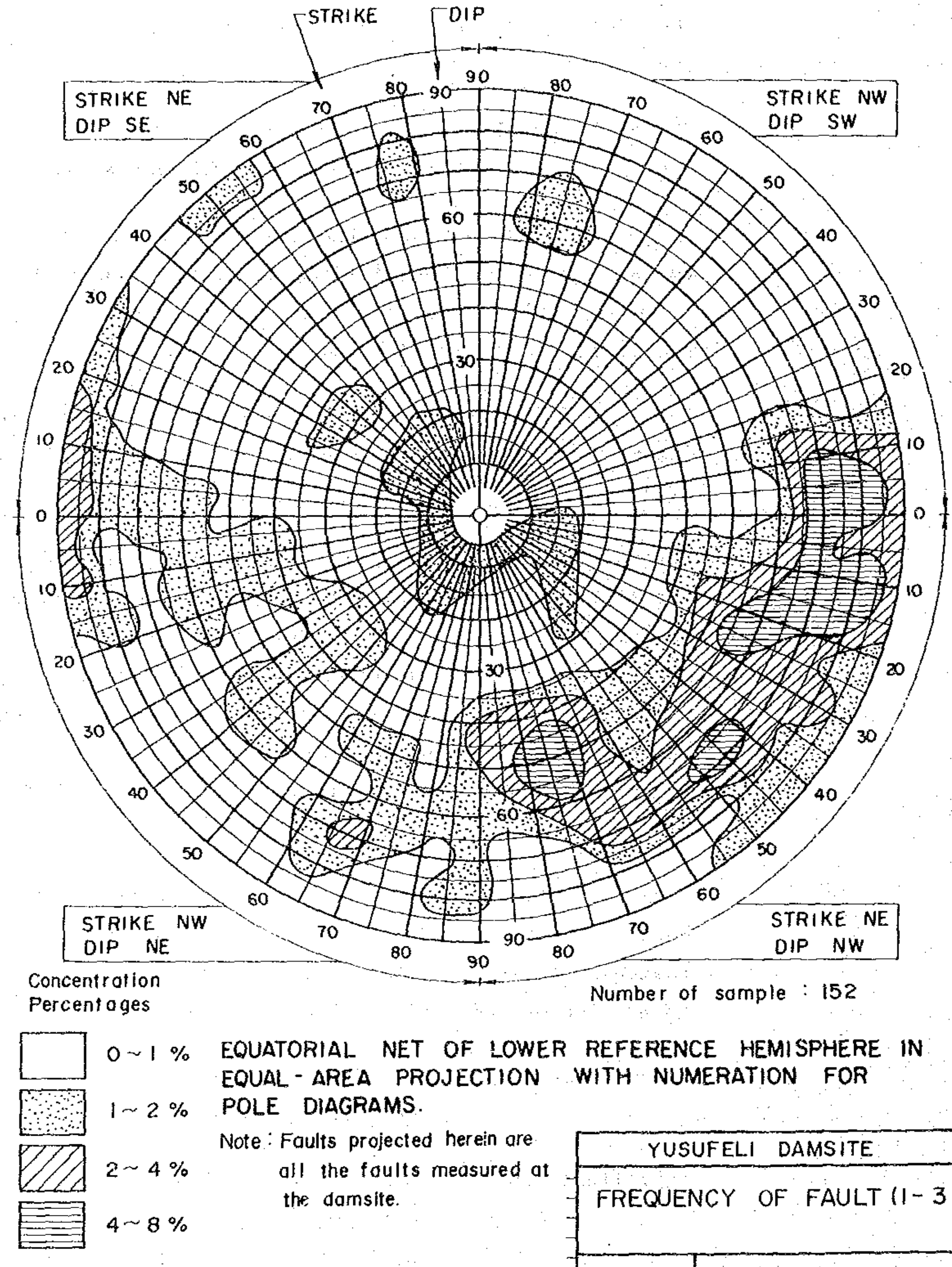
- On the ground surface, the faults are eroded and valleys are often formed along the fault lines; F-1, 2, 3, and 12 on the left bank of the dam site, and F-8, 9 and 10 on the right bank.

  In addition, F-6 on the left bank forms kern col (saddle) at the immediate upstream of the arch dam axis.

- Attitudes of total 152 faults which are observed at the damsite were analyzed using Schmidt net as shown on Fig. 7-6, 7 and 8. Although their directions are scattered in all quadrants, relatively high concentration is observed in the quadrant of strike NE and dip NW, indicating that relatively many faults run roughly parallel to the course of the river (N50°E) with dipping to the left bank.

- Geographically, more faults are observed on the left bank and less on the right bank. In addition, the following faults were found on the river bed according to drillholes and their attitudes are unknown.

Drillhole RS-5:	Depth 36.75 - 46.8 m and 51.0 - 58.05 m
Drillhole RSI-11:	Depth 45.7 - 50.7 m, 62.9 - 81.55 m, 83.05 - 84.0 m, 89.0 - 90.8 m, 102.8 - 106.4m, and 123.0 - 131.0 m



EQUATORIAL NET OF LOWER REFERENCE HEMISPHERE IN EQUAL - AREA PROJECTION WITH NUMERATION FOR POLE DIAGRAMS.

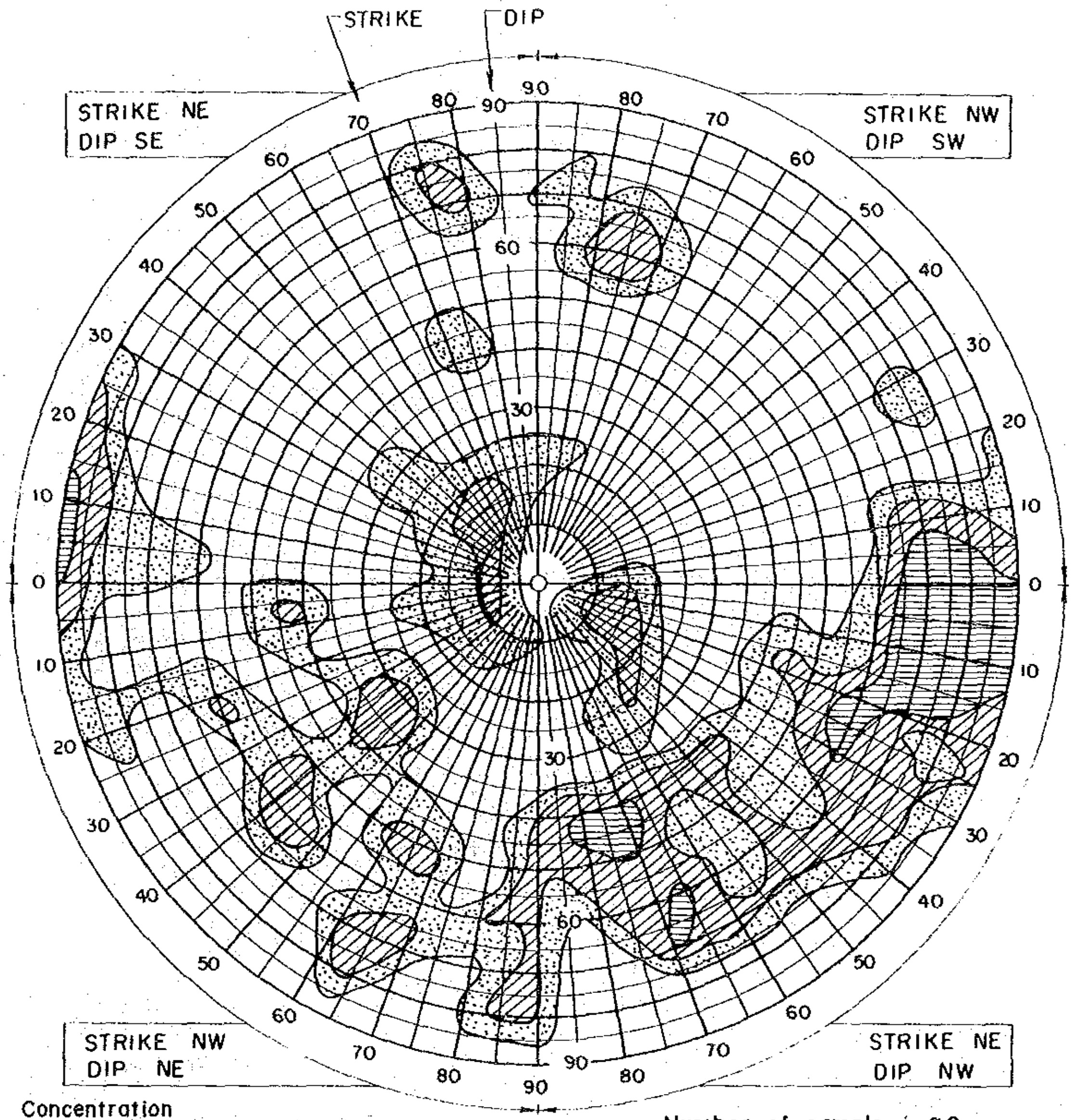
Note : Faults projected herein are all the faults measured at the damsite.

YUSUFELI DAMSITE

FREQUENCY OF FAULT (I - 3)

Fig. 7-6

LOCATION	DATE	DESCRIPTION	BY
REVISION			



Concentration Percentages

- 0 ~ 1 %
- 1 ~ 2 %
- 2 ~ 4 %
- 4 ~ 8 %

Number of sample : 96

EQUATORIAL NET OF LOWER REFERENCE HEMISPHERE IN EQUAL - AREA PROJECTION WITH NUMERATION FOR POLE DIAGRAMS.

Note : The thicknesses of faults projected herein are less than 10 cm.

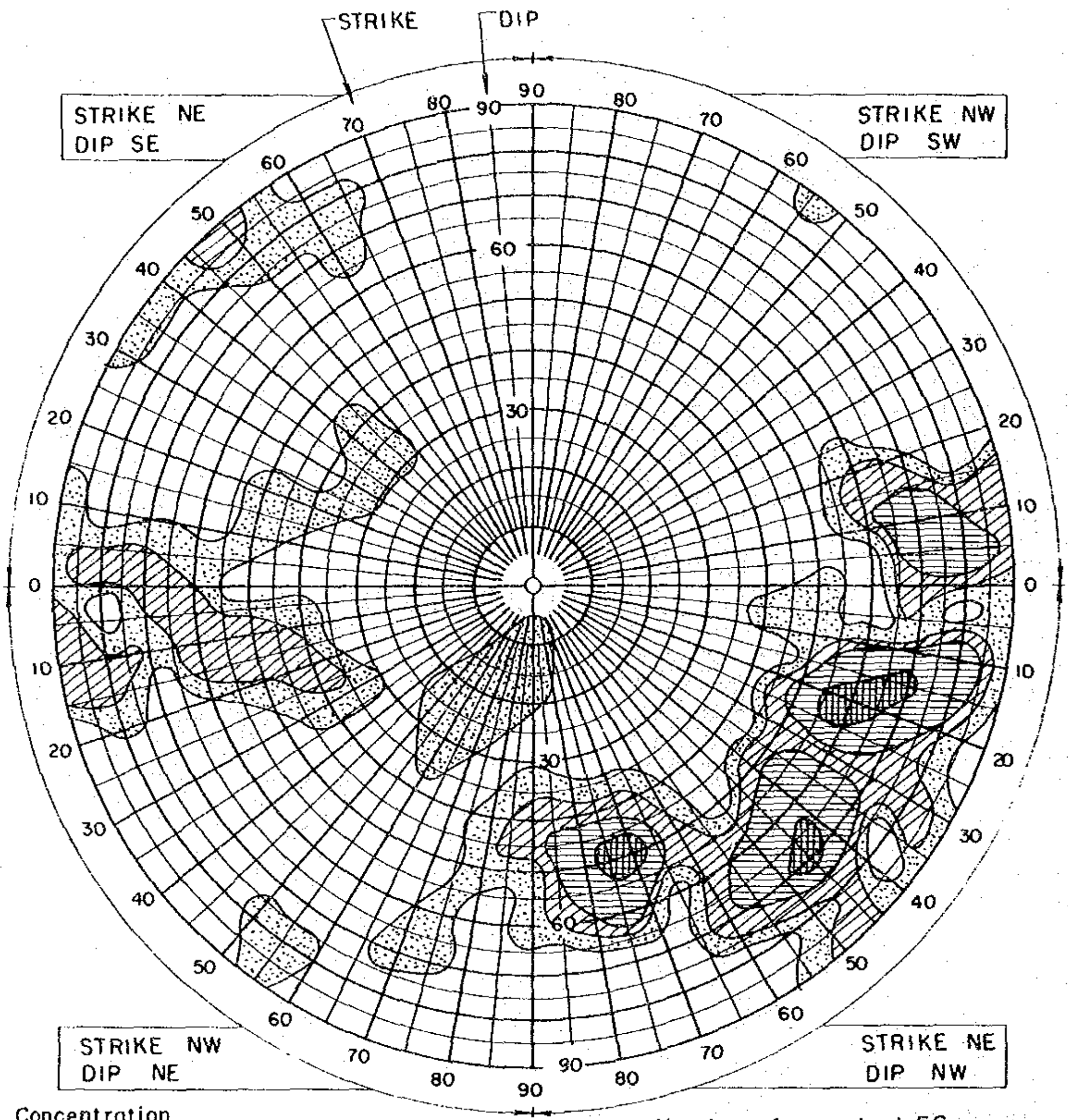
YUSUFELI DAMSITE

FREQUENCY OF FAULT (2 - 3)

LOCATION	DATE	DESCRIPTION	BY

REVISION

Fig. 7-7



Number of sample : 56

Concentration Percentages

- 0 ~ 1 %
- 1 ~ 2 %
- 2 ~ 4 %
- 4 ~ 8 %
- 8 ~ %

EQUATORIAL NET OF LOWER REFERENCE HEMISPHERE IN EQUAL - AREA PROJECTION WITH NUMERATION FOR POLE DIAGRAMS.

Note : The thicknesses of faults projected herein are not less than 10cm.

LOCATION	DATE	DESCRIPTION	BY
REVISION			

YUSUFELI DAMSITE

FREQUENCY OF FAULT (3-3)

Fig. 7-8

- The informations of the faults in and around the arch dam axis are not known because of few drillholes or adits available. If the arch dam is to be adopted, detailed investigations should be required to identify attitudes and sizes of faults at the detail design stage, since large shearing stress will be applied to the foundation of the arch dam.

Joint and crack

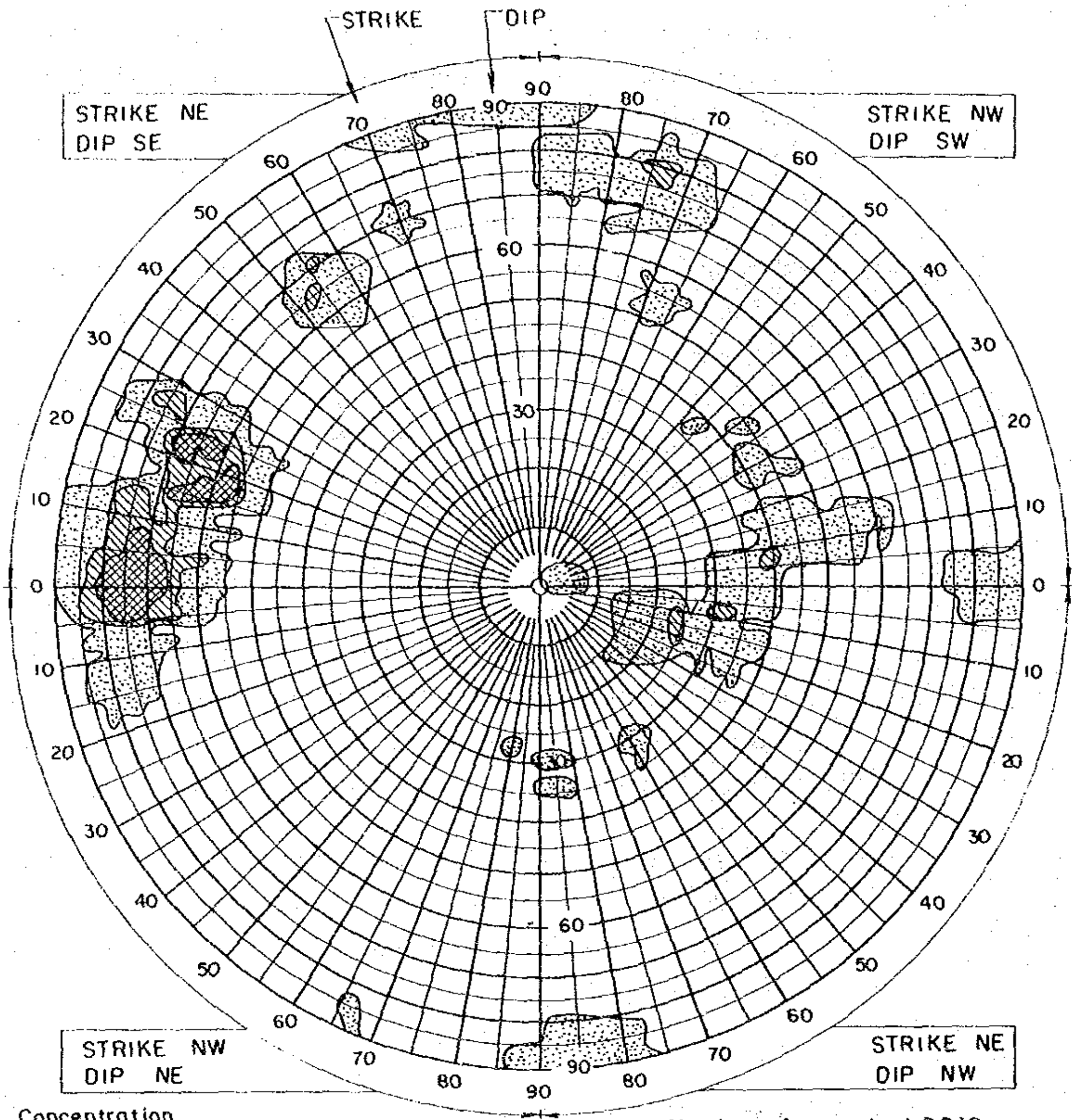
- The joints and cracks are discolored to brown in weathered parts and are separable relatively, but are well tightened in other parts.

- Attitudes of 2,910 joints were measured by EIE's investigations and the results are summarized in Fig.7-9. According to this, although relative concentration is observed in attitude of NS with steep dip to east at 60 - 80 degrees, general distribution is scattered in all quadrants to indicate that joints are developing in all directions. Thus, it can be safely said that foundation rocks in the dam site are overall isotoropic so far as joints are concerned.

- The graph of Fig. 7-10 shows the correlation between the depth from the top of each hole and the intervals of cracks (degrees of crack interverls are shown in Table 7-9, 10).
  The following tendency can be read from this graph.

* The degree of crack interval is generally less then 3.5.

* The remarkable tendency can not be seen in between the depth of 0 m (ground surface) and the depth of 100 m. However, below 100 m, the crack intervals decrease in accordance with the depth.



Number of sample : 2910

Concentration Percentages

- 0 ~ 2 %
- 2 ~ 4 %
- 4 ~ 6 %
- ≧ 6 %

EQUATORIAL NET OF LOWER REFERENCE HEMISPHERE IN EQUAL - AREA PROJECTION WITH NUMERATION FOR POLE DIAGRAMS.

Note : Measurement results were based on the investigation performed by EIE.

YUSUFELI DAMSITE

FREQUENCY OF JOINT

Fig. 7-9

LOCATION	DATE	DESCRIPTION	BY
REVISION			

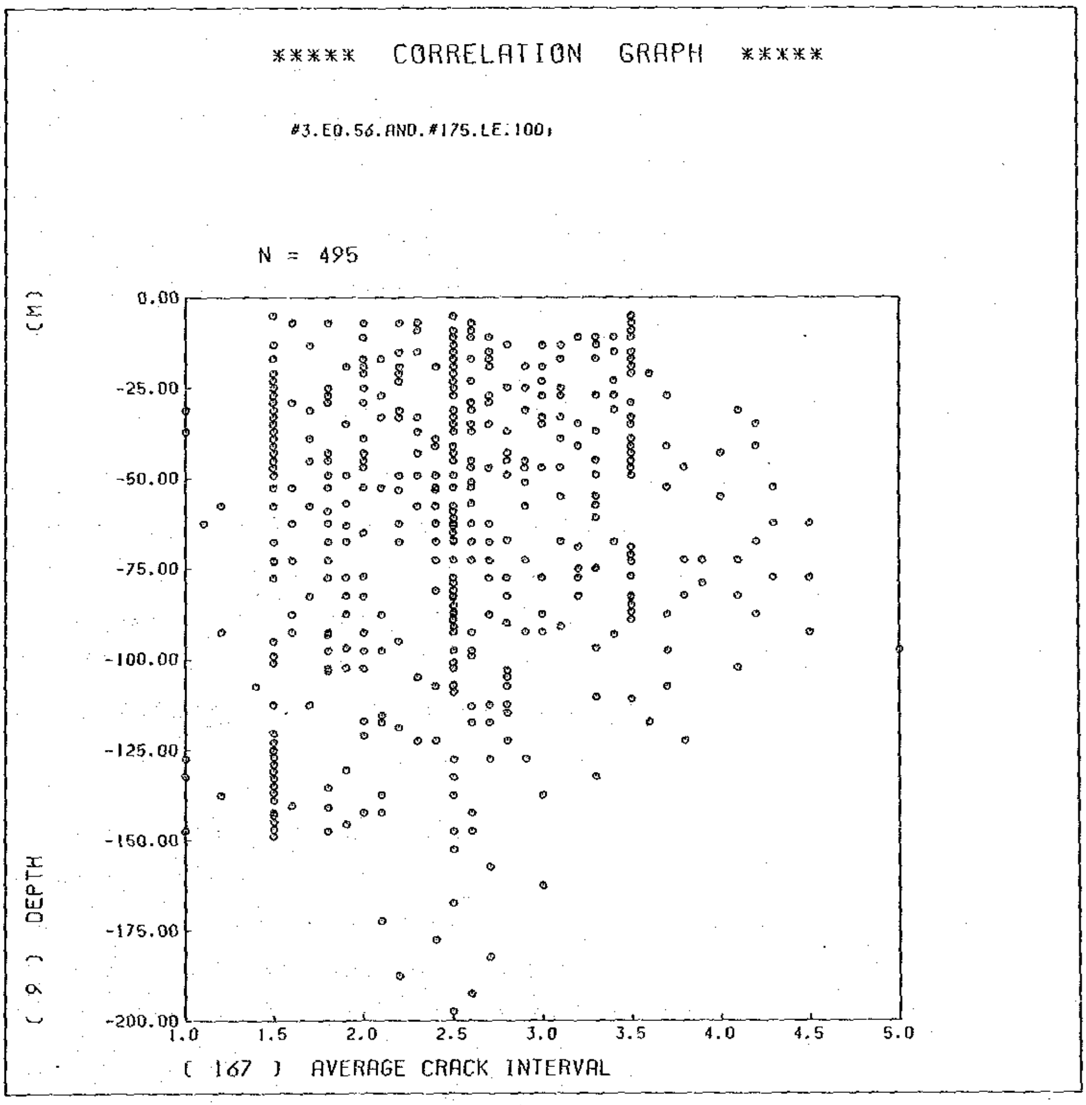


Fig. 7-10 Correlation graph, Depth – Crack Interval

Igneous contact

- As mentioned previously, all the foundation rocks in the dam site are igneous rocks of complex structure in which various rock types cut each other. Thus, boundaries between rocks are frequently igneous contacts as well as fault contacts. The rocks in igneous contact accompany fractured parts of a few centimeters wide in some cases and have completely tight contact plane in other cases. In the former case, though, the igneous contact is well compacted above the ground water level.

- Attitudes of igneous contact were not analyzed by Schmidt net since continuous igneous contacts are often flexed.

iv) Permeability

Permeability of the dam site was tested by Lugeon test using 16 drillholes, covering 526 stages and 1,607 m. The tests were conducted for foundation rocks, not including surface deposits made up of slope wash or alluvium, at 2 m section in shallow parts and at 5 m section in deep parts, respectively. Permeability data was analyzed by the following method:

- Lugeon value (Lu) is defined as an amount of injection under pressure of 10 kgf/cm^2 (unit l/m/min/10 kgf/cm^2). When the injection pressure could not be raised upto 10 kgf/cm^2 by any reasons, Lugeon value was determined using the following formula:

$$Lu = \frac{10 \cdot Q}{P \cdot l}$$

Whereas,

Q: amount of injection (l/min)
l: length of test section (m)
P: injection pressure (kgf/cm^2)

- When injection pressure could not be obtained (P=0 kgf/cm^2), it was considered as water leakage. However, amount of injection (l/m/min) under no pressure was deemed as tentative Lugeon value for the grouping below.

- Drillholes were projected on geological section of the dam (A - A' section) to prepare a Lugeon map (Fig.7-12). In this case, they were classified into the following four groups. Exceptional cases indicating significant difference between drilled core's condition and Lugeon value were neglected.

  1. $Lu < 1$
  2. $1 \leqq Lu < 5$
  3. $5 \leqq Lu < 30$
  4. $Lu \geqq 30$

Permeability of the dam site can be described as follows:

- Permeability is generally high in the left bank, both at low and high elevations. Permeability at this bank gets lower as going deeper; from $Lu \geqq 30$ zone, $5 \leqq Lu < 30$ zone, to $1 \leqq Lu < 5$ zone, but below $1 \leqq Lu < 5$ zone, $5 \leqq Lu < 30$ zone is again observed. The top of impervious zone ($Lu < 1$) is observed at elevation of 450 - 500 m.

- In the river bed, Lu $\geqq$ 5 zone is observed in 5 - 10 m below the surface of foundation rocks and impervious layer of Lu < 1 below it. On the right bank of the river bed, although fracture zones were identified by drillholes their permeabilities are very low (Lu < 1) because of intercalated clay seams and/or calcite veins in the zones.

- As to the right bank, permeability of high elevations is not known because of no drillhole data. In foundation rocks at middle or lower elevations, Lu $\geqq$ 30 zone is observed on the surface and then impervious layer below it.

- The graph of Fig. 7-11 shows the correlation between Lugeon value and the depth from the top of each hole. The following tendency can be read from this graph.

  * Generally, the large Lugeon value can not be seen so many and even the large values exist, they are located near the ground surface (within 50 m from the ground).

  * The Lugeon values within 50 m from the ground are scattered in wide range (between 0 Lu to 100 Lu), however, below 50 m, they are concentrated in accordance with the depth and the values more than 20 Lu are a few below 50 m.

The aboves describe the permeability of the foundation rock along the rock fill dam axis. On the other hand, no detail is available for the arch dam axis due to lack of drilling data. However, geological conditions in the arch dam axis are similar to those in the rock fill dam axis, so that similar trend in permeability between the two axis can be inferred. If the arch dam is to be adopted, permeability of its foundation is a very important factor and thus more detailed permeability test should be planned.

In any case, rock quality in the dam site suggests that permeability of foundation rocks is not a type to filtrate between particles but a type to seep between cracks. Thus, adequate groutability can be expected by an ordinary grouting.

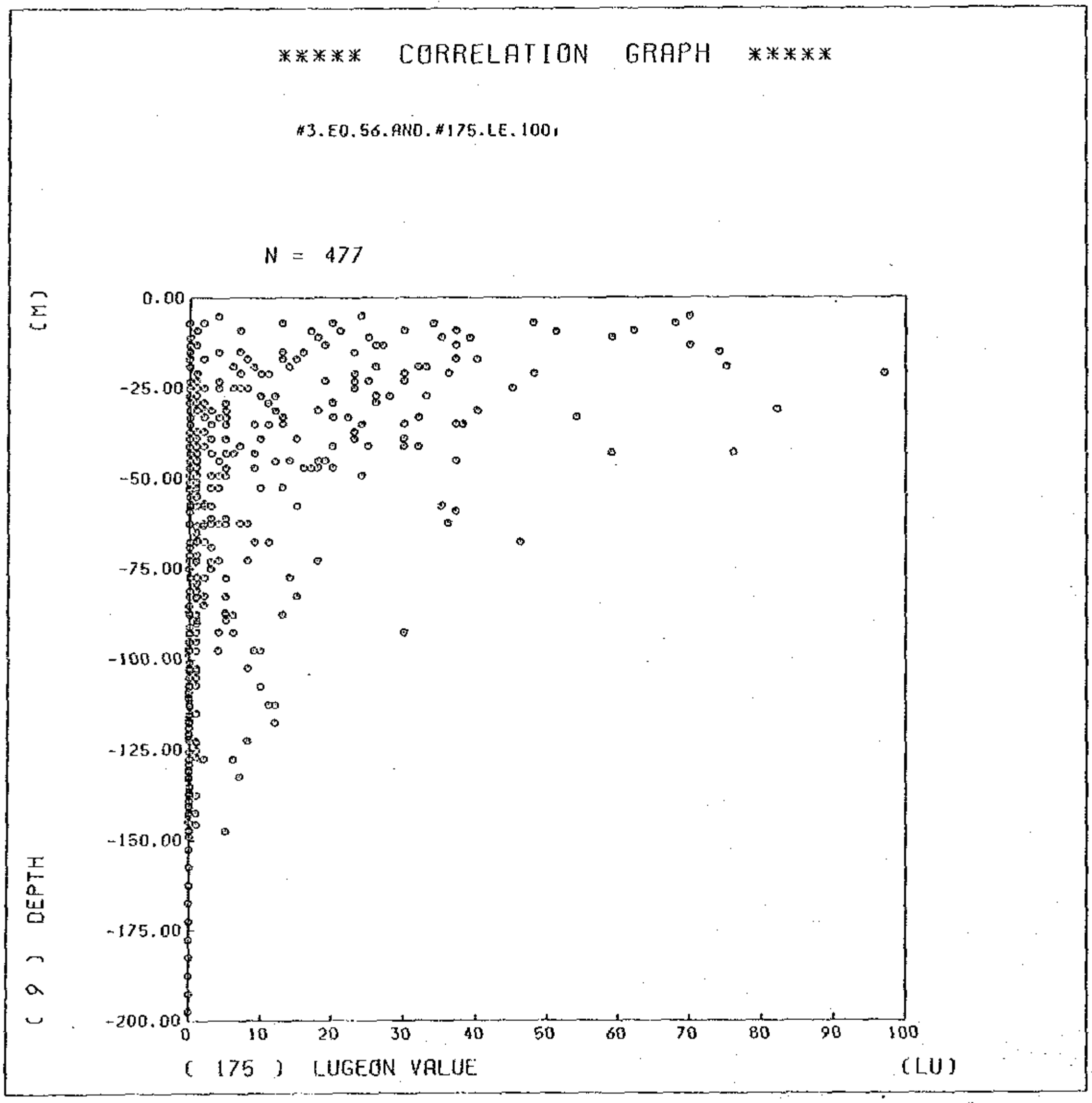
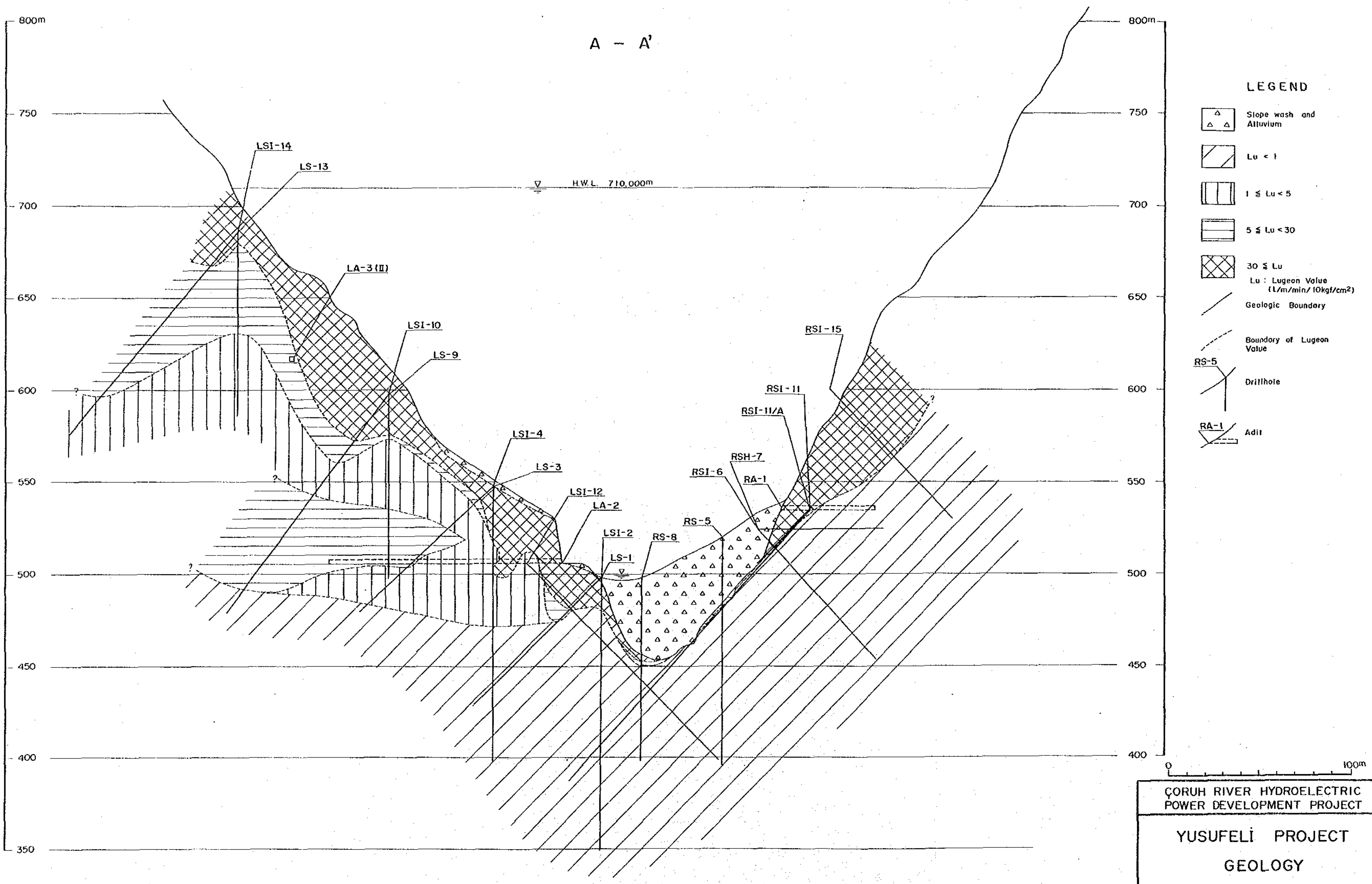


Fig. 7-11 Correlation graph, Depth — Lugeon Value



ÇORUH RIVER HYDROELECTRIC POWER DEVELOPMENT PROJECT

YUSUFELİ PROJECT

GEOLOGY

DAM LUGEON MAP

Fig. 7–12 | DECEMBER 1986

v) Ground water

Data on ground water in the dam site is summarized in Table 7-8.

Table 7-8 Elevation of Ground-water Level

Location	Elevation of ground-water	Depth
Left bank abutment Drillhole LS-9	499 m	98 m
Left bank abutment Drillhole LS-3	496 m	51.5 m
River bed, left bank Drillhole LS-1	497 m	2 m
River bed, right bank Drillhole RS-5	500 m	22 m
Right bank abutment Adit RA-1	535 m	TD. 42m or deeper
Left bank abutment Adit LA-2	506 m	TD. 92m or deeper

The above data recorded lowest ground water levels during the dry season, and it is slightly higher in other seasons. Nevertheless, as indicated in the data, ground water levels in the left bank are generally low and ground water levels in the right bank tend to rise in proportion to topography, as seen in adit RA-1.

Although it is possible to conclude that ground water supply in the dam site is relatively small since the area has relatively small precipitation, 350 - 400 mm per year, it is more plausible that the left bank has more cracks than the right bank considering that ground water levels are closely associated with frequency of cracks in foundation rocks in general.

vi) Rock classification and Rock evaluation

Basic understanding

In evaluating foundation rocks in the Yusufeli dam site as the proposed dam's foundation, this report defines rock classification and rock evaluation as follows.

First of all, rock classification is defined as classifying of geological and engineering properties of foundation rocks on the basis of certain standards. As a result, rock classification does not consider elements related to type and size of dam, tunnel, power plant and other structures. Thus, results of rock classification should be used as basic data to support rock evaluation.

Secondly, rock evaluation is defined as evaluating of foundation rocks on their appropriateness as a foundation of structure in consideration of type and size of structure to be constructed. In other words, rock evaluation is overall analysis of mechanical and hydrological properties of foundation rocks which are determined from rock classification, along with type and size of structure on them.

Rock classification

Hardness, weathering and discontinuity of foundation rocks are basic elements to determine their geological features and affect their engineering properties as a foundation of structure. Thus, if these elements can be expressed objectively by grade, geological and engineering features possessed by foundation rocks can be classified.

To do this, outcrop of foundation rocks, exploratory adits and drilled cores should be recorded and analyzed in detail. In addition, quantitative information collected from in-situ rock tests and laboratory tests can be used. It should be noted, however, that information on geological investigations, exploratory adits and drilled cores can be collected in any dam site in early stages of investigation while in-situ rock tests and laboratory tests are not performed in all the dam sites. Also, their numbers are limited even if they are carried out in a certain stage.

For these reasons, in rock classification for the Yusufeli dam site, information on three elements obtained from observations in exploratory adits and drilled cores was graded in accordance with Table 7-9 and 7-10, and permeability test data in drillholes, rock mechanical tests results in exploratory adits were used as a basis of rock evaluation. The flow chart from rock classification to rock evaluation is summarized in Fig. 7-13.

Rock evaluation

As mentioned previously, three elements of foundation rocks (hardness, weathering and discontinuity) can be graded in accordance with standards in Table 7-9 and 7-10. However, this classification does not take into consideration type and size of structure to be constructed on foundation rocks. Therefore, the results need to be grouped and evaluated on the basis of type and size of structure using the results of in-situ rock test. This work is defined as rock evaluation.

Rock evaluation on the Yusufeli dam site is shown in Table 7-11. Based on rock evaluation using visual observations, the rocks can be classified in qualitative terms to three sub-groups of A1, A2 and B as shown in

Table 7-11. Then, A1 and A2 sub-groups were reorganized into A group since overall evaluation including in-situ rock tests and permeability tests did not indicate any significant difference between these sub-groups, to have two groups of A and B. More detailed rock evaluation can be done as more tests are performed.

From Table 7-11, foundation rocks in the Yusufeli dam site can be evaluated as follows:

- They are appropriate for construction of 270 m high concrete arch dam as far as necessary foundation treatment is done.

- Results of in-situ rock tests (permeability and rock mechanics) did not show any significant difference between A1 and A2 sub-groups. The difference was made on the basis of visual observations on adits and drilled cores (in particular, the number of discontinuities and their weathering).

- Although rock fragment in B group is sufficiently hard, the number of discontinuities and their weathering are much more than those in A group to result in difference in in-situ rock tests.

- B group includes dyke of diabase which is considered as fractured zone (or cracky zone) in visual observations on adits and drilled cores. Results of in-situ rock tests in such area are not particularly poor. This is probably because conspicuous cracks in dyke rock are filled by calcite vein.

- In addition to fractured zones of above type, fractured zones accompanying clay seam were observed in the adits. When these having thickness of 10 cm or more are extended on horizontal or vertical sections, concentration occurs at a great depth of foundation. Since the concentration is not confirmed by drillholes, rock evaluation in this report does not consider such concentration. Generally, the fractured zones mentioned above are well compacted in the area above groundwater level as seen in the adit LA-3, however, when they are saturated by water such as groundwater or reservoir water (in future), they are soft as seen in the adit LA-2. Thus, geological conditions of the concentration mentioned-above should be carefully studies in detailed investigations to be conducted in the future.

- Results of rock evaluation are shown on cross sections along the rockfill dam axis and the arch dam axis (Fig. 7-3 and 7-4 respectively).

- In case of the rock fill dam (see Fig. 7-3): Sufficient bearing capacity is expected even in B group which is evaluated as being the poorest. At the same time, appropriate treatments should be provided for B and/or B - A2 zones near the rock surface from the viewpoint of permeability.
- In case of the arch dam (see Fig. 7-4): Since few subsurface investigations were conducted for the area, rock evaluation was inferred from geological conditions in the rock fill dam axis, so that the rock evaluation is rather simplified.

- From the viewpoint of deformation properties of foundation, the foundation rocks are hard enough to be a foundation of arch dam. Therefore, element of A2 subgroup in rock evaluation can be reasonably expected near the ground surface. However, a few permeable layers are expected both on right and left banks, sufficient cut-off works will be required for foundation rocks near the ground by grouting.

Table 7-9 Standard of Rock Classification for Adit

Weathering		Hardness		Interval of Cracks	
1	Very fresh. No weathering of mineral component.	A	Very hard. Broken into Knifeedged pieces by strong hammer blow.	I	Over 100 cm
2	Fresh. Some minerals are weathered slightly. Usually no brown crack.	B	Hard. Broken into pieces by strong hammer blow.	II	40 – 100 cm
3	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered material.	C	Brittle. Broken into pieces by medium hammer blow.	III	20 – 40 cm
4	Weathered. Fresh portions still remain partially.	D	Very brittle. Easy broken into pieces by medium hammer blow.	IV	5 – 20 cm
5	Strongly weathered. Most minerals are weathered and altered to second minerals.	E	Soft. Able to dig with hammer.	V	Under 5 cm

Table 7-10 Standard of Rock Classification for Drilled Core

Weathering		Hardness		Interval of Cracks	
1	Very fresh. No weathering of mineral component.	1	Very hard. Broken into Knifeedged pieces by strong hammer blow.	1	Over 30 cm
2	Fresh. Some minerals are weathered slightly. Usually no brown crack.	2	Hard. Broken into pieces by strong hammer blow.	2	10 – 30 cm
3	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered material.	3	Brittle. Broken into pieces by medium hammer blow.	3	3 – 10 cm
4	Weathered. Fresh portions still remain partially.	4	Very brittle. Easy broken into pieces by medium hammer blow.	4	1 – 3 cm
5	Strongly weathered. Most minerals are weathered and altered to second minerals.	5	Soft. Able to dig with hammer.	5	Under 1 cm

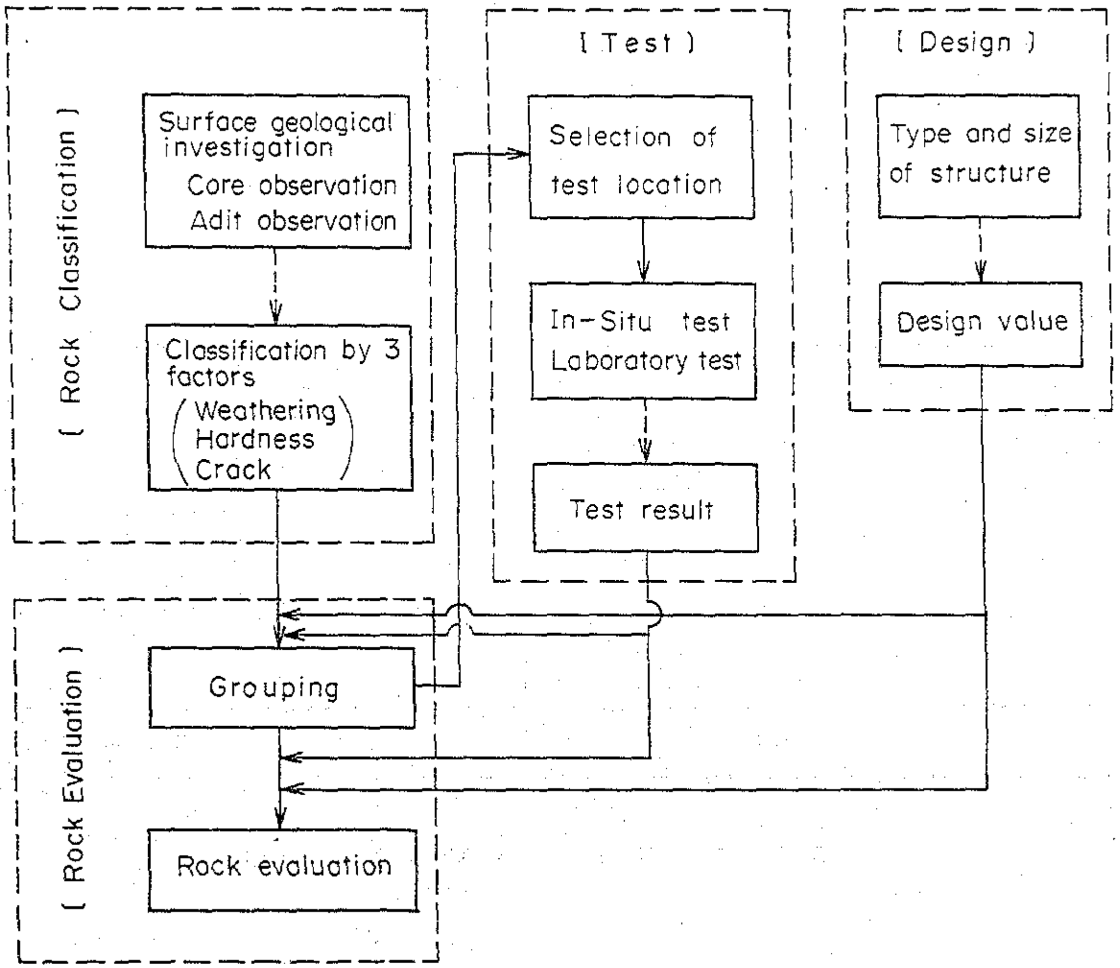


Fig. 7-13 Flow Chart of Rock Evaluation

Table 7-11 Rock Evaluation

Rock Evaluation		Description based on Rock Classification	Modulus of Deformation D (kgf/cm²)	Secant Modulus of Elasticity Es (kgf/cm²)	Lugeon Value Lu (ℓ/m/min/10kgf/cm²)		Remarks
Ⓐ	Ⓐ1	Fresh. A few cracks weathered to brown. Or some cracks coated by chlorite. Very hard ~ hard Generally massive Cracks very tight	68,000 ~ 114,000	80,000 ~ 156,000	Lu < 1 : 49% Lu < 5 : 63% Lu ≧ 30 : 12%*	Lu < 1 : 48% Lu < 5 : 68% Lu ≧ 30 : 12%*	
	Ⓐ2	Some cracks weathered to brown. But rock fragments are un-weathered. Very hard ~ hard Cracky but cracks are tight in general	86,000 ~ 142,000	113,000 ~ 210,000	Lu < 1 : 48% Lu < 5 : 72% Lu ≧ 30 : 12%*		
Ⓑ		Most cracks weathered to brown. Hard ~ somewhat brittle Cracky ~ very cracky and cracks somewhat loosened	29,000 ~ 78,000 Values may be lower at clayey shear zones	41,000 ~ 107,000	Lu < 1 : 28% Lu < 5 : 42% Lu ≧ 30 : 31%*	Tendency of low permeability in shear zones	This group includes shear zones of faults; Shear zone is generally altered to secondary minerals. Brittle ~ very brittle and very cracky.

Note: * marked values include the percentages of water leakage.

Table 7-12 Relation between Rock Evaluation and Lugeon Value

Rock Evaluation	Number of Test Stage / Percentages	Lu : Lugeon Value (ℓ/m/min/10kgf/cm^2)					
		Lu < 1	1 ≦ Lu < 5	5 ≦ Lu < 10	10 ≦ Lu < 30	30 ≦ Lu	Water Leakage*
(A1)	170	83	23	10	33	17	4
	32	49	14	6	19	10	2
(A2)	255	122	62	18	23	21	9
	49	48	24	7	9	8	4
Subtotal (A) ((A1) + (A2))	425	205	85	28	56	38	13
	81	48	20	7	13	9	3
(B)	101	28	14	11	16	30	2
	19	28	14	11	16	29	2
Total Average	526	233	99	39	72	68	15
	100	44	19	7	14	13	3

Note : * (Water Leakage) shows the test stage where the pressure did not rise during the permeability test.

Hardness (H) / Interval of Cracks (C) \ Weathering (W)		Fresh or a few cracks brown.	Some cracks coated by chlorite	Some cracks brown	Most cracks weathered to brown		Minerals weathered or altered to secondary minerals		
		1	1 – 2	2	2 – 3	3	4	5	
Very hard ~ hard Rather massive Cracks very tight	A II								H : A~B C : II~III
	A II-III	ⓐ							
	A-B II-III								
	A III	A1							
	A-B III								
	AIII-(IV)								
Very hard ~ hard Cracky in general Cracks are tight in general	AIII-IV		ⓒ						H : A~B C : III~V
	A-BIII-IV								
	A IV								
	AIV-V					ⓑ			
	A V		A2						
	A-B IV								
	A-B IV-V								
	A-B V								
	B III								
Hard ~ somewhat brittle Cracky ~ very cracky	BIII-IV								H : B~C C : III~V
	B IV								
	BIV-V								
	B V								
	B-C IV				B				
	B-C V								
Brittle ~ very brittle Very cracky	C IV								H : C~D C : IV~V
	CIV-V								
	C V								
	C-D V			ⓓ					
	D V								
		W : 1~(1–2)		W : 2	W : (2–3)~5				

Note :

	Best		Very Bad	
W :	1	~	5	
H :	A	~	E	
C :	I	~	V	(See Table 2–3–7)

◯ marks indicate the locations of In-situ Rock tests as follows:

ⓐ; RA–1 (41~47m), ⓑ; LA–2 (27~35m)

ⓒ; LA–3(II) (29~39m), ⓓ; LA–3(II) (72~80m)

Fig. 7–14 Rock Evaluation & Rock Classification for Adits

H	C \ W	1	1 – 2	2	2 – 3	3	3 – 4	4	4 – 5	5
1	1									
1	1 – 2									
1	2	A1								
1 – 2	1 – 2									
1 – 2	2									
1	2 – 3									
1 – 2	2 – 3									
1	3									
1 – 2	3									
1 – 2	3 – 4									
2 – 3	2			A2						
2	2 – 3									
2	3									
2	3 – 4									
2	4									
2 – 3	3									
2 – 3	3 – 4									
3	3 – 4									
3	4									
3 – 4	3 – 4				B					
3 – 4	4									
3	4 – 5									
3 – 4	4 – 5									
4	3 – 4									
4	4 – 5									
4 – 5	4 – 5									

Note:

	Best		Very Bad
Weathering (W) :	1	~	5
Hardness (H) :	1	~	5
Interval of Cracks (C) :	1	~	5

(See Table 7–10)

Fig. 7–15 Rock Evaluation & Rock Classification for Drilled Core

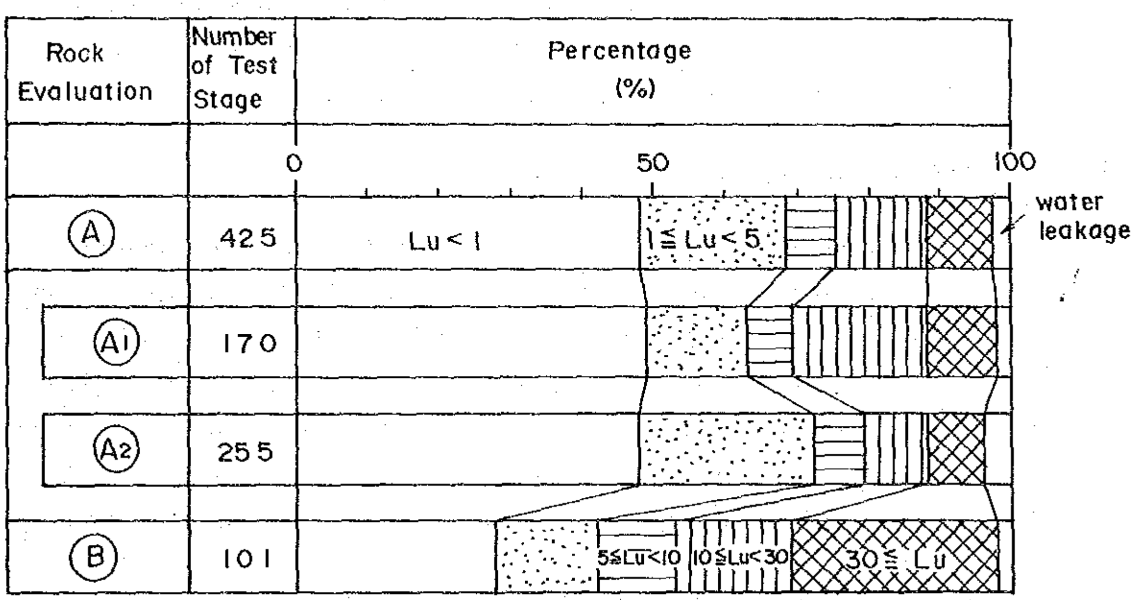


Fig. 7–16 Relation between Rock Evaluation and Lugeon Value

(3) Appurtenant Structures

The locations of spillway and underground powerhouse for the rockfill dam at Yusufeli site are proposed at the left bank and at the right bank respectively. The geological investigation works on the appurtenant structures sites are not so many, some investigations, however, near by the sites are available to evaluate the geological conditions of the appurtenant structures sites and the following comments are given;

(a) Spillway site

No drillhole is located on the site, however, judging from the data of drillholes and adits at the left bank, it can be assumed that the foundation rock conditions at the site are quite possible for the spillway. But, some unconsolidated materials mixing with terrace and slope wash are seen near the stilling basin. The thickness of this materials is not confirmed yet by drillhole (it seems to be several meters).

(b) Underground powerhouse and penstock sites

The underground powerhouse and the penstock sites are located at the right bank. One drillhole (RSI-16) was carried out at the powerhouse site. Based on the data of RSI-16 and adit RA-1, the following geological evaluations can be given for the powerhouse site.

- The foundation rocks at the site are quite sound and fresh.

- Discontinuities (cracks and joints) develop in ordinary grade, for example, average RQD of whole RSI-16 is about 58% and average RQD excepting 10 m from the top of the hole and 20 m from the bottom of the hole is about 68%. The figures of RQD are ordinary ones as compared with RQD of other completed underground powerhouse sites.

- Average RQD of 20 m from the bottom of the hole (80 m to 100 m of the hole depth) is about 35% and this figure is rather poor compared with RQD of other drillholes at Yusufeli site. The cores of this depth are somewhat sheared and the location of this depth is near the valley. These conditions seem to affect poor RQD. The mentioned informations shall be considered for the layout of the powerhouse.

- According to the analysis of joints and cracks by EIE, relative concentration is observed in attitude of NS with steep dip to east at 60 - 80 degrees, however, general distribution is scattered in all quadrants to indicate that joints are developing in all directions.

- The powerhouse will be located below the ground water level, however, judging from the results of the permeability tests, discontinuities seem to be tight, accordingly, seepage spring will be expected, but no troubles by spring water will be occured during the construction of the underground powerhouse.

- The geologic evaluations for tunnels of penstock and tailrace are the same with the powerhouse site.