A-3 TANK MODEL METHOD FOR RIVERFLOW ANALYSIS

1. BASIC CONCEPT OF THE TANK MODEL

1-1 Structure of the tank model

Tank model is a simple model composed of several tanks laid vertically in series as shown in Fig.1. Rain water is put into the top tank. Water in each tanks partly discharges through side outlets and partly infiltrates to the next lower tank through bottom outlets. River discharge can be simulated by the sum of output from side outlets. We can image that the tank model corresponds to zonal structure of groundwater as shown schematically in Fig.2.

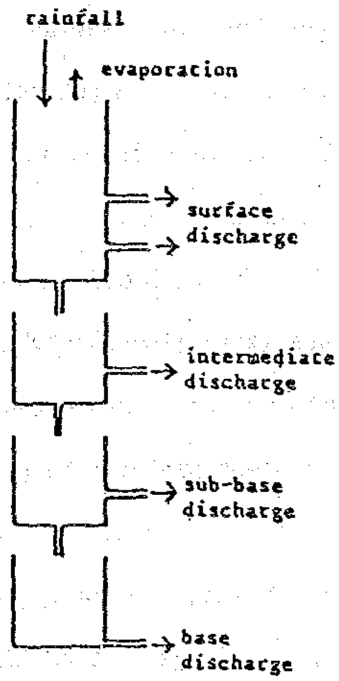


Fig.1

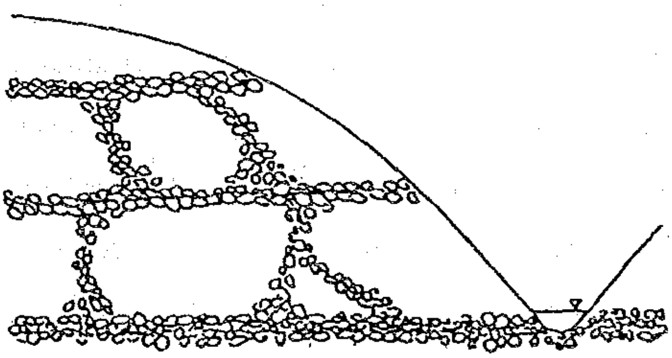


Fig.2

1-2 Behaviour of the tank model

In spite of its simple structure, response of the tank model is not so simple showing various response corresponding to types of input rainfall. In the case of the tank model composed of three tanks, where the top tank corresponds to surface flow, the second tank to intermediate flow and the third tank to base flow.

If amount of rainfall or its intensity is small, water storage in the top tank and the second tank does not rise up to the level of side outlet and input water goes to the third tank without any discharge from the top and the second tanks as shown in Fig.3 a). As the base flow is very stationary because of the large amount of groundwater strorage, it shows scarce change in river discharge by small supply of rain water. Accordingly, there appears scarce change in river discharge by such rainfall with small intensity.

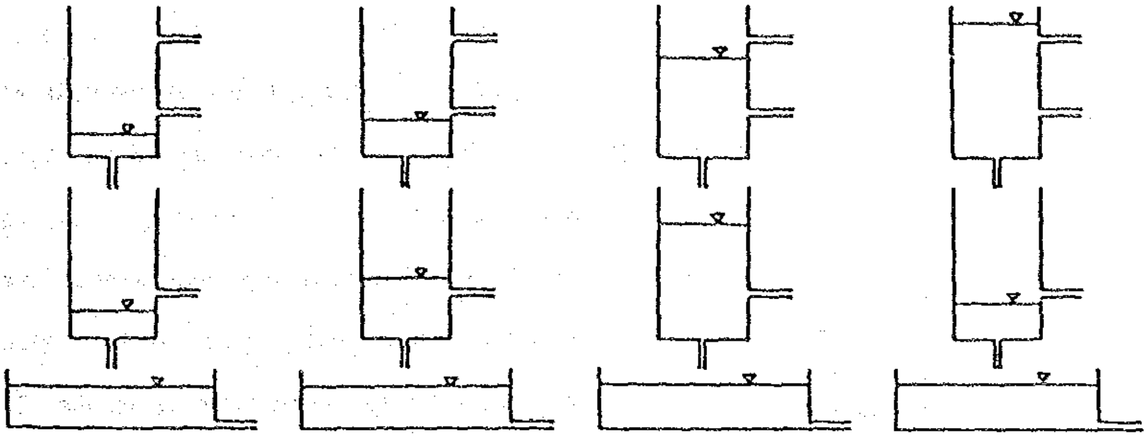
If there is some amount of rainfall with small intensity, water storage in the top tank does not rise up to the level of side outlet, but water storage in the second tank rises up to the level higher than the side outlet, from which intermediate flow discharges, as shown in Fig.3 b). In this case, river discharge slowly increases a little and disappears gradually.

In the case of heavy rainfall with large intensity, the tank model shows the state shown in Fig.3 c). In this case, there appears large discharge which is mainly composed of surface flow. The surface flow decreases quickly and there remains intermediate flow which is related to the slope part of the peak discharge.

In the case of very heavy rainfall with short time duration, the tank model shows the state shown in Fig.3 d) for a while. In this case, large surface flow appears without intermediate flow. After that, the state changes to the one shown in Fig.3 c) and intermediate discharge appears.

In some case of not so large rainfall with short duration, there appears only surface flow without any intermediate flow.

The tank model shows such various response corresponding to the character of input rainfall.



a) b) c) d)

Fig.3

1-3 Time constants of the tank model

Each tank of the tank model can be regarded as a linear tank by moving the side outlet or outlets to the bottom as shown in Fig.4. This linear tank model is called an incomplete integral or a first order lag system with the time constant of $[1/(\alpha + \beta)]$, where both storage and outputs decrease exponentially in the form $[\, C \times e^{-(\alpha+\beta)t} \,]$ when there is no input supply.

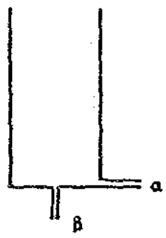
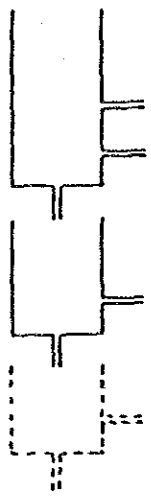


Fig. 4

By such a linear approximation, computed discharge by the tank model is composed of several exponential components each having their own time constants. For analysis of daily discharge by daily input data, the model with four tanks as shown in Fig.1 is often appllied, where time constants of each components are a day or a few days, several days or about ten days, a few months and years respectively.

1-4 The tank model for flood analysis

On the other hand, the tank model with two or three tanks as shown in Fig.5 is usually used for flood analysis. More two or three tanks should be required under this structure if wishing to represent the total discharge components completely, however, these lower tanks can be neglected because of their long time constants. These components are stationary and they show only small change during flood and moreover they are very small values campared with flood components. It can be assumed that these components are constant during the flood and a constant discharge can be applied instead of these stational components.



constant discharge

Fig. 5

For flood analysis, the time constant of the top tank changes relating with catchment area in rough approximation. That relation is given by following formula from various analyses about Japanese river basins:

$$T \fallingdotseq 0.15 \sqrt{S}$$

where T (hour) is the time constant and S (km²) is the catchment area. The time constant of the second tank is usually estimated to be about five times of that of the top tank.

2. CALIBRATION OF THE COEFFICIENTS

In spite of the long term research, no mathematical or objective method for coefficient calibration has developed because of variety and complexity of soil mechanism. Nevertheless the automatic calibration method was developed recently, final adjustment had to be done by human judgement, and trial and error method is still the most effective way.

In general, coefficients of upper, first and second, tanks have relation to amount and shape of flood peak, and coefficients of lower tanks have relation to base flow. Primary calibration methods and its effects are as follows:

a) If some runoff component is too large, decrease the runoff coefficient of the corresponding tank and increase the infiltration coefficient of the same tank, and vice versa.

b) If some runoff component decrease too fast, decrease both runoff and infiltration coefficients of the corresponding tank, and vice versa.

c) If peaks of calculated hydrograph are smaller than the observed one, increase the runoff coefficient of the upper outlet of the top tank, and vice versa.

d) If the base flow component is too large, decrease the infiltration coefficient of the third tank, and vice versa.

Besides the above factors, the influence by evapo-transpiration may be not negligible in the runoff analysis of the basin with considerable evaporation as tropical region. Modification of evapo-transpiration coefficients can be often an effective way to adjust total amount of runoff.

3. APPLICATION TO THE HYDROLOGICAL ANALYSIS OF THE NAM YUAM PROJECT

3-1 Genaral flow of the analysis

Runoff data from Sop Han and Ban Tha Rua were adopted for the hydrological analysis of the Nam Yuam Project, however, the periods of both existing data were judged to be not sufficient for the analysis. Tank model method was applied to extend these runoff data using precipitation data from Mae Sariang and Khun Yuam.

General flow of the analyzing process is shown in Fig.6. The tank model used in this study was composed of a series of four tanks having the soil moisture structure in the first tank, which is evaluated to be suitable for runoff analysis of the region with a long dry season.

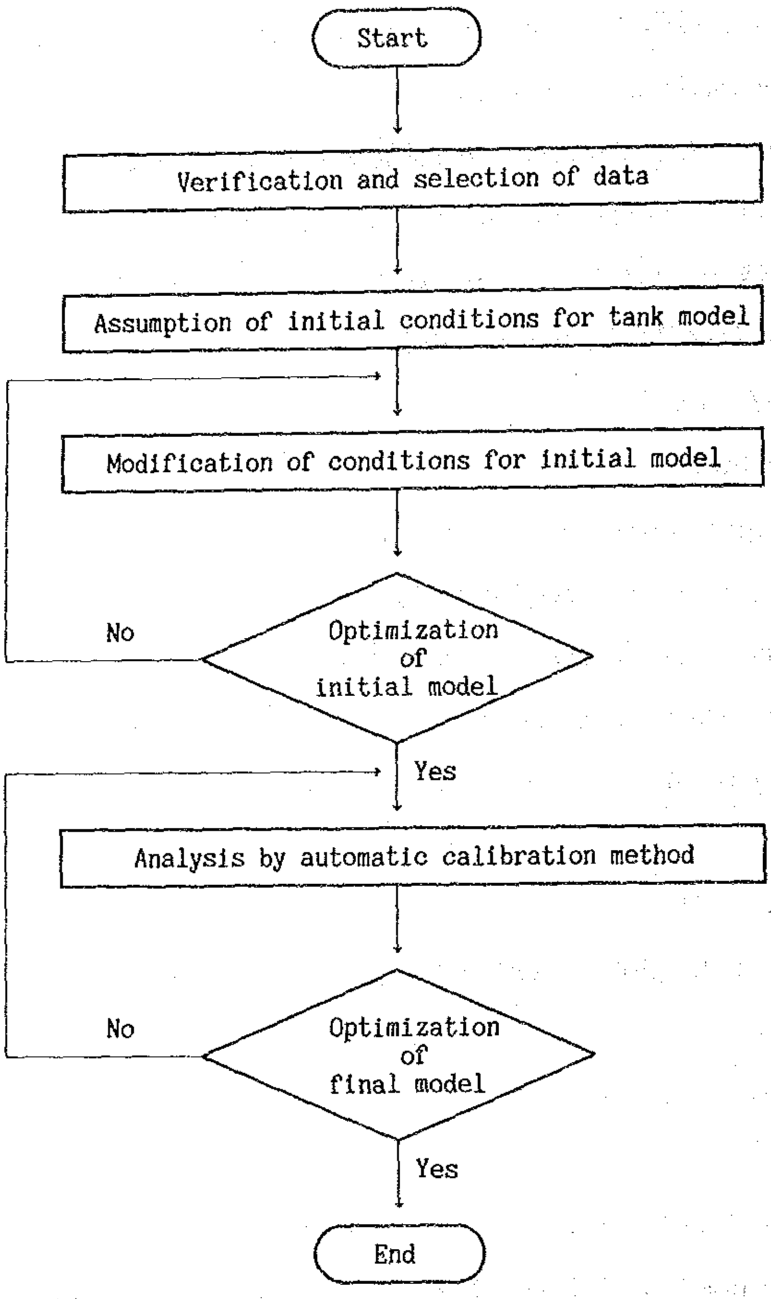


Fig.6 Analyzing flow of establishment of tank model

3-2 Calculation of Ban Tha Rua runoff data

(1) Used data

a) Verification period: 13 years (1969 ~1981)

b) Precipitation data :

Daily data from Mae Sariang and Khun Yuam, 1969~1981

c) Evaporation data :

Monthly average data of 14 years (1970~1980, 1984~1986) from Ban Tha Rua

(2) Assumption of initial conditions

a) Weight of precipitation (WE)

Considering the difference of two stations' assigned areas, weights of both data were assumed as follows:

$WE_{MAE\ SARIANG} = 0.7 \times S$

$WE_{KHUN\ YUAM} = 0.3 \times S$

where S is the catchment area of 5,770 km^2.

b) Adjustment coefficient of precipitation (CPM)

CPM = 1.0 (for all months)

c) Evapo-transpiration

Assumed as 70% of monthly evaporation data.

d) Adjustment coefficient of evapo-transpiration (CE)

CE = 1.0 (for all months)

(3) Runoff and infiltration coefficients of initial tank model

In the case that the catchment area is less than 10,000 km^2, standard values of runoff and infiltration coefficients are obtained by following formula:

$$A_0 = A_1 = A_2 = 1 / (0.3 \times \sqrt{s})$$

$$B_0 = B_1 = A_0 / 5$$

$$C_0 = C_1 = B_0 / 5$$

where A_0, B_0 and C_0 are infiltration coefficients, A_1, A_2, B_1 and C_1 are runoff coefficients, and S is the catchment area. All the coefficients were obtained as follows with the figure of 5,770 km² for S:

$$A_0 = A_1 = A_2 \fallingdotseq 0.05$$

$$B_0 = B_1 \fallingdotseq 0.01$$

$$C_0 = C_1 \fallingdotseq 0.002$$

$$D_0 = 0.0 \quad \text{(const.)}$$

$$D_1 = 0.0003 \text{ (const.)}$$

(4) Optimization of initial tank model

Through several trial calculations, some coeffficients were modified.

a) Increasing and decreasing rates of calculated hydrograghs were larger than those observed hydrographs, then runoff coefficients of each tank were modified about a half of standard values.

b) Calculated runoff were smaller than observed runoff through all the calibrating period, and this tendency was found obviously in rainy season (from April to September), then adjustment coefficients of evapo-transpiration were modified as follows:

From April to September	CE = 0.81
From October to March	CE = 0.94

(5) Analysis by automatic calibration method

After the above modifications, initial tank model was established. Automatic calibration analysis was performed using this initial model with a limit of nine iterations.

Final model showed a better result than initial model, and final model was adopted for expansion of Ban Tha Rua runoff data.

3-3 Calculation of Sop Han runoff data

(1) Used data

a) Verification period: 15 years (1967 ~1981)

b) Precipitation data :

Daily data from Mae Sariang and Khun Yuam, 1969~1981

c) Evaporation data :

Monthly average data of 17 years (1967~1980, 1984~1986) from Sop Han

(2) Assumption of initial conditions

a) Weight of precipitation (WE)

Considering two stations' assigned areas, weights of both data were assumed as follows:

$WE_{MAE\ SARIANG} = 0.5 \times S$

$WE_{KHUN\ YUAM} = 0.5 \times S$

where S is the catchment area of 2,496 km^2

b) Adjustment coefficient of precipitation (CPM)

CPM = 1.0 (for all months)

c) Evapo-transpiration

Assumed as 70% of monthly evaporation data.

d) Adjustment coefficient of evapo-transpiration (CE)

CE = 1.0 (for all months)

(3) Runoff and infiltration coefficients of initial tank model

Standard values of runoff and infiltration coefficients are obtained by following formula:

$$A_0 = A_1 = A_2 = 1 / (0.3 \times \sqrt{s})$$

$$B_0 = B_1 = A_0 / 5$$

$$C_0 = C_1 = B_0 / 5$$

where A_0, B_0 and C_0 are infiltration coefficients, A_1, A_2, B_1 and C_1 are runoff coefficients, and S is the catchment area. All the coefficients were obtained as follows with the figure of 2,496 km^2 for S:

$$A_0 = A_1 = A_2 \fallingdotseq 0.07$$

$$B_0 = B_1 \fallingdotseq 0.014$$

$$C_0 = C_1 \fallingdotseq 0.0028$$

$$D_0 = 0.0 \quad \text{(const.)}$$

$$D_1 = 0.0003 \text{ (const.)}$$

(4) Optimization of initial tank model

Through several trial calculations, some coeffficients were modified.

a) Increasing and decreasing rates of calculated hydrograghs were larger than those of observed hydrographs, then runoff coefficients of each tank were modified about a half of standard values.

b) Calculated runoff was smaller than observed hydrographs during rainy season (from April to September) and it was oppositely larger than observed hydrographs in dry season (from October to March), then adjustment coefficients of evapo-transpiration were modified as follows:

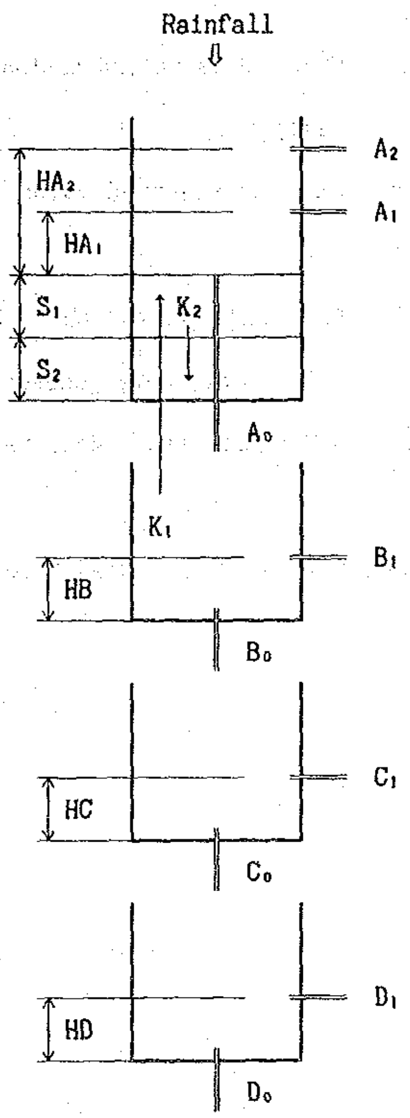
From April to September	CE = 0.85
From October to March	CE = 1.23

(5) Analysis by automatic calibration method

After the above modifications, initial tank model was established. Automatic calibration analysis was performed using this initial model with a limit of nine iterations.

Final model showed a better result than initial model, and final model was adopted for expansion of Sop Han runoff data.

Final values of major coefficients applied for the runoff data generation are shown in Fig.7 on next page.



Coefficient	for Ban Tha Rua	for Sop Han
A_0	0.0416	0.110
A_1	0.0262	0.030
A_2	0.0262	0.0424
B_0	0.0094	0.0176
B_1	0.0050	0.0066
C_0	0.0022	0.0048
C_1	0.0011	0.0013
D_0	0.0	0.0
D_1	0.0003	0.0003
HA_1 (mm)	10	10
HA_2 (mm)	60	60
HB (mm)	10	10
HC (mm)	10	10
HD (mm)	0	0
S_1 (mm)	50	50
S_2 (mm)	250	250
K_1	3	15
K_2	3	15

Fig.7 Adopted tank model and coefficients

3-4 Final result

In this study, following conditions were assumed for the culculated results in order to perform the accurate analysis:

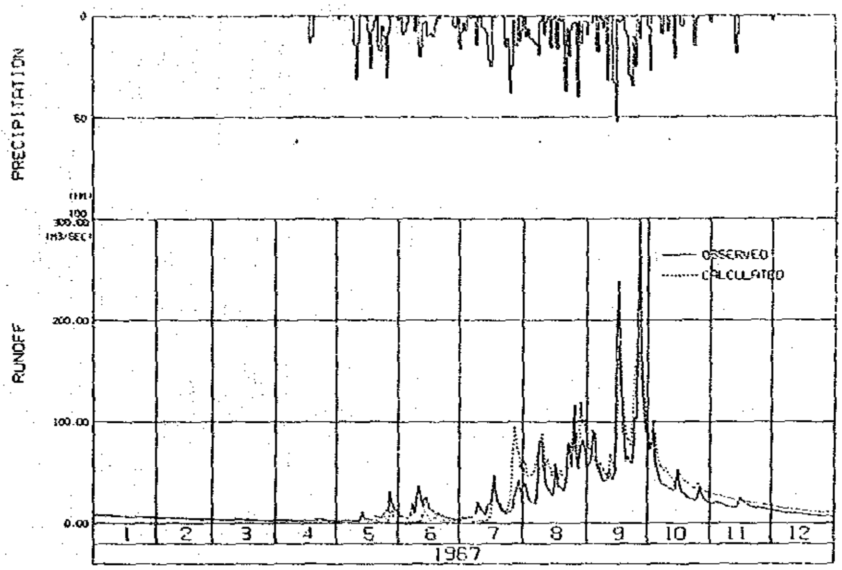
a) The absolute accumulated difference between measured value and estimated of the annual total runoff shall be zero or negligible.

b) Average ratios of the difference between actually measured value and estimated of monthly runoff shall be within 20%.

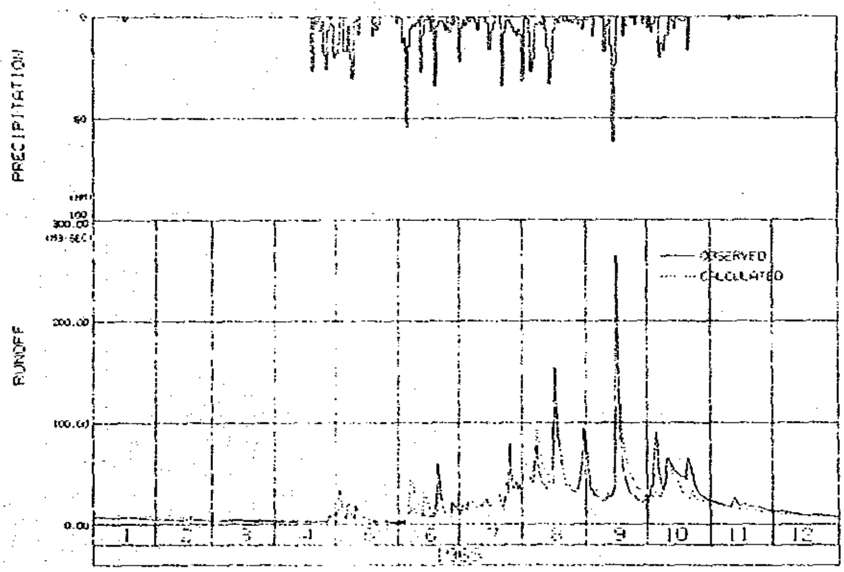
The results calculated by respective final tank models showed that they were sufficient to satisfy the above conditions and after that, data generation was made for required periods of both Ban Tha Rua and Sop Han runoff data using final models.

Hydrographs of both sites calculated by final models are attached hereinafter in this appendix.

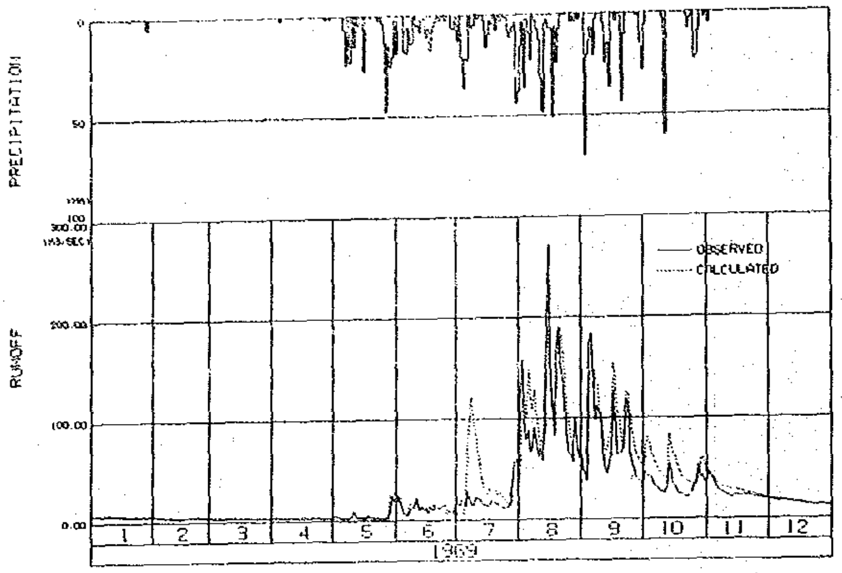
CALCULATION OF SOP HAI RUNOFF DATA (FINAL CASE, 1967)



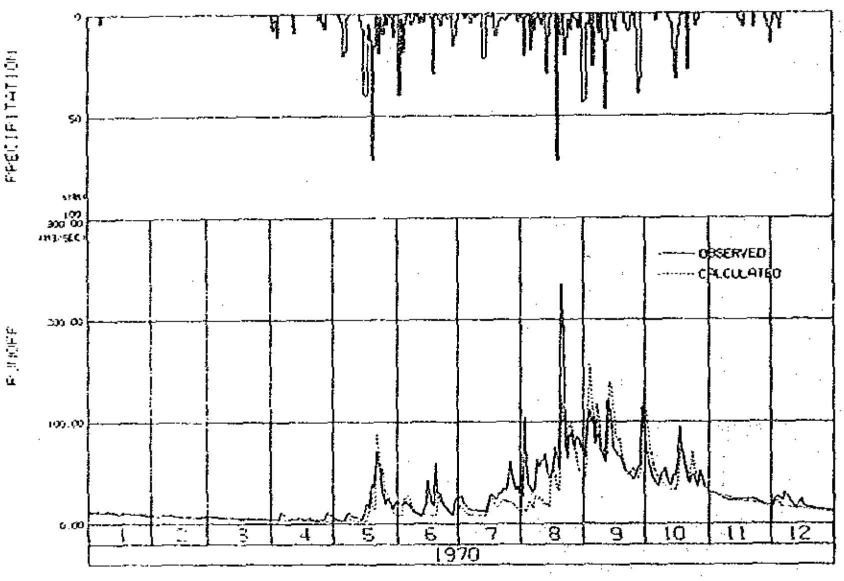
CALCULATION OF SOP HAI RUNOFF DATA (FINAL CASE, 1968)



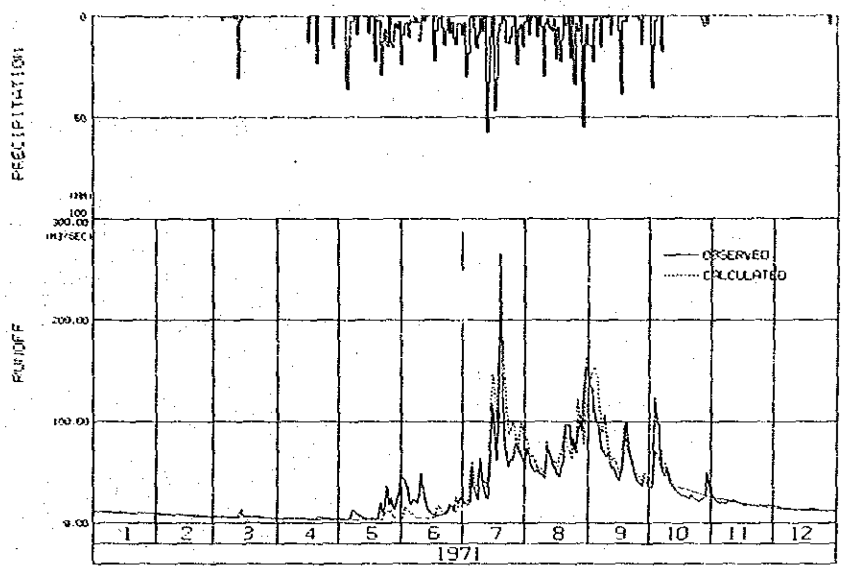
CALCULATION OF SOP HAU RUNOFF DATA (FINAL CASE, 1969)



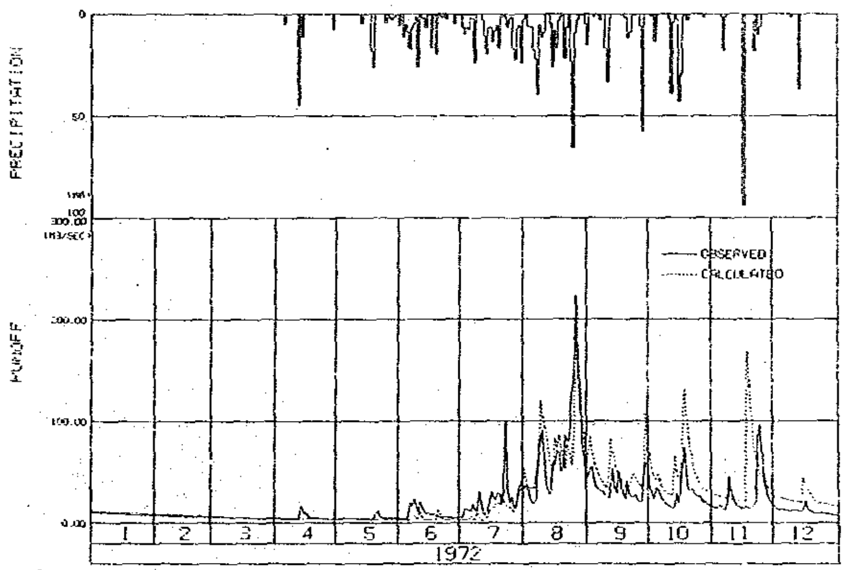
CALCULATION OF SOP HAU RUNOFF DATA (FINAL CASE, 1970)



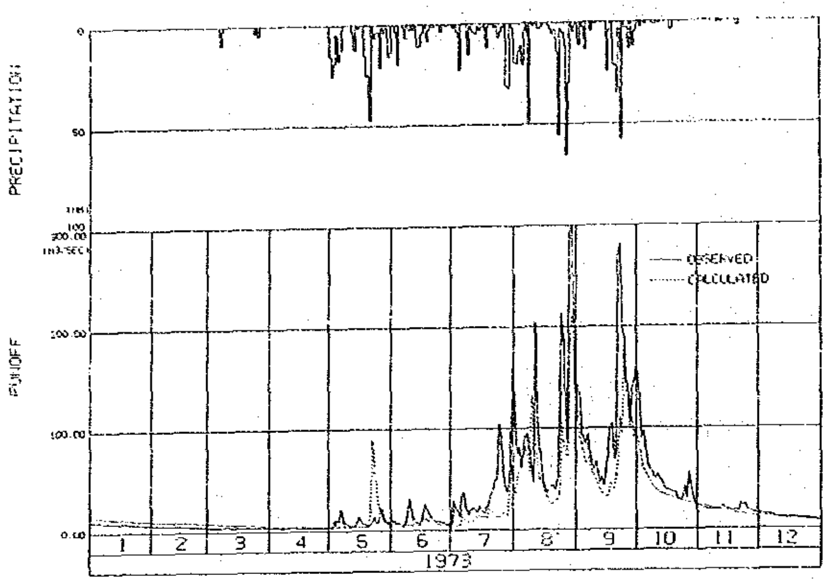
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE. 1971)



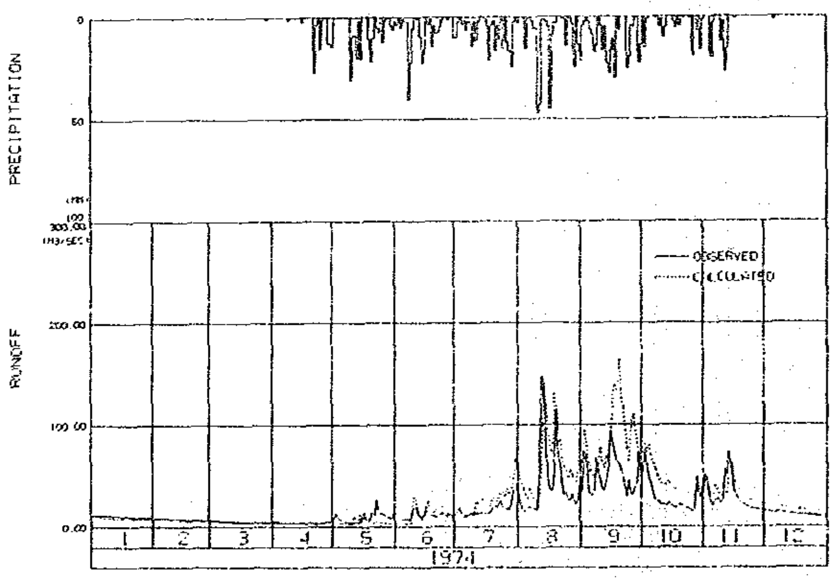
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE. 1972)



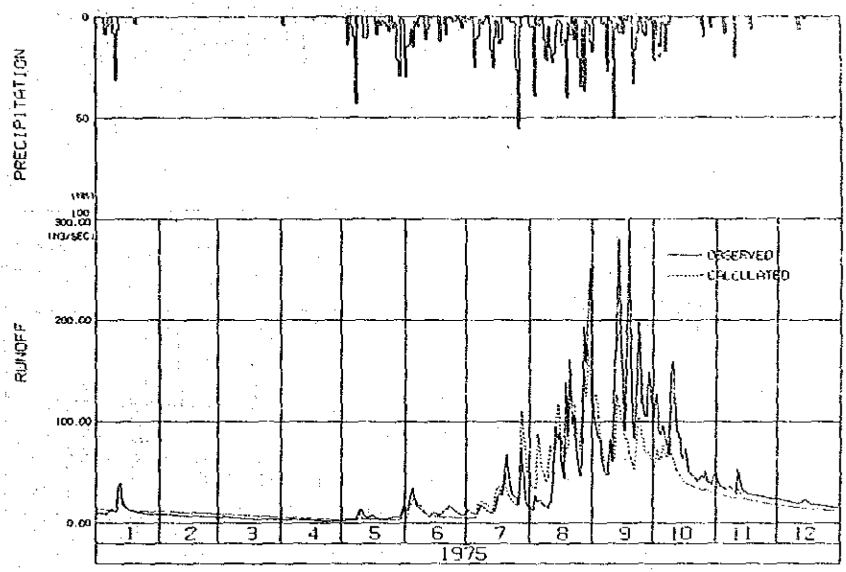
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1973)



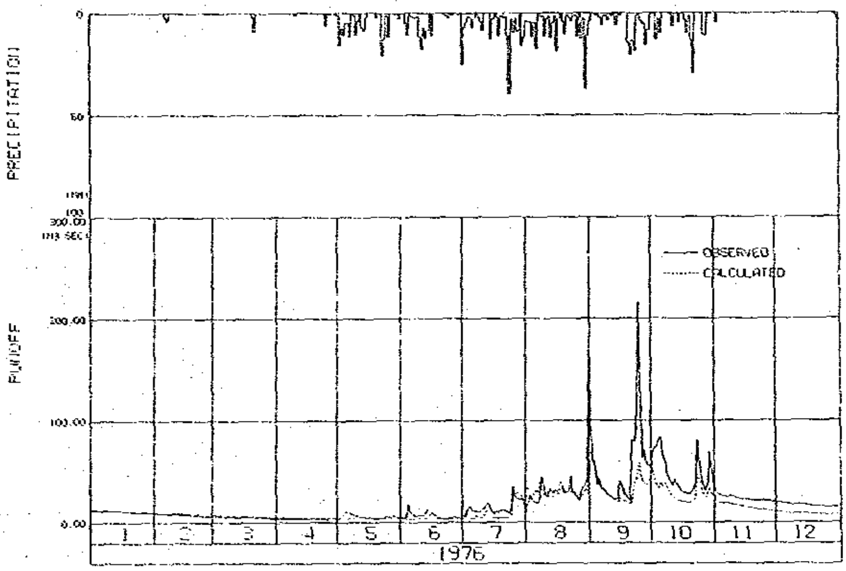
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1974)



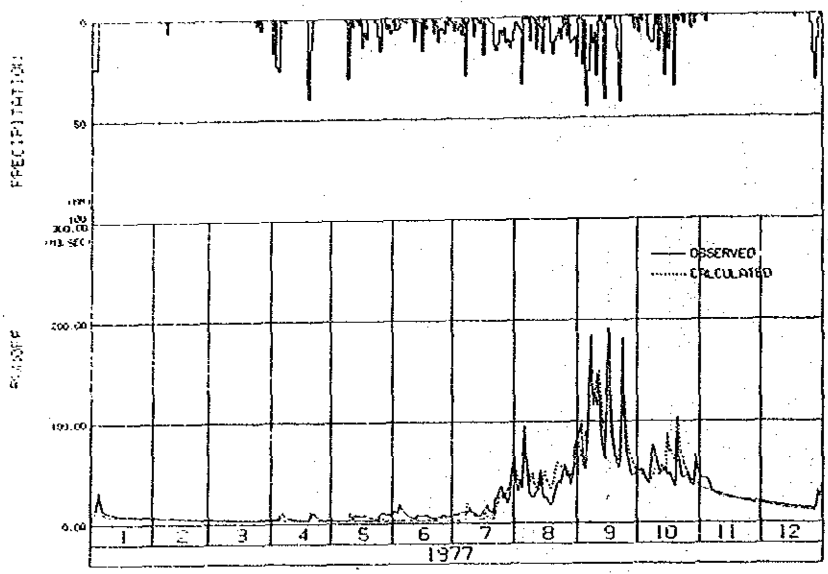
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE: 1975)



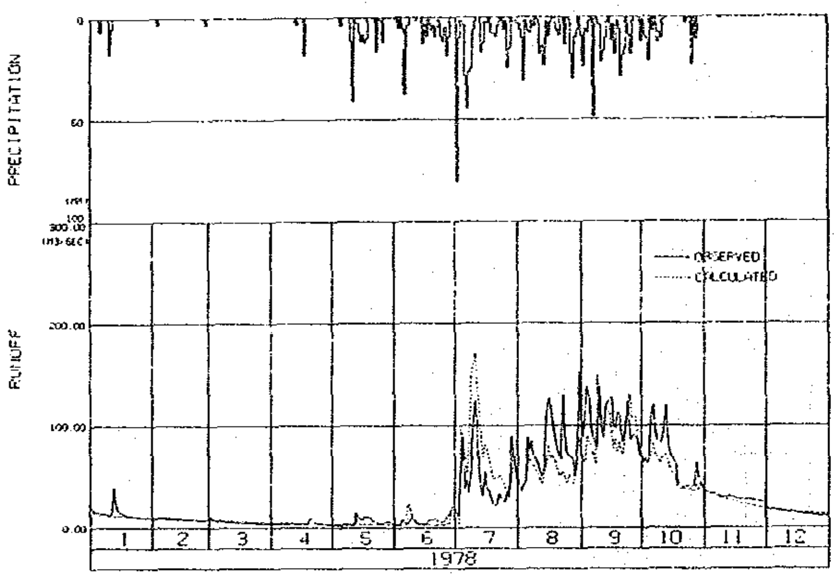
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1976)



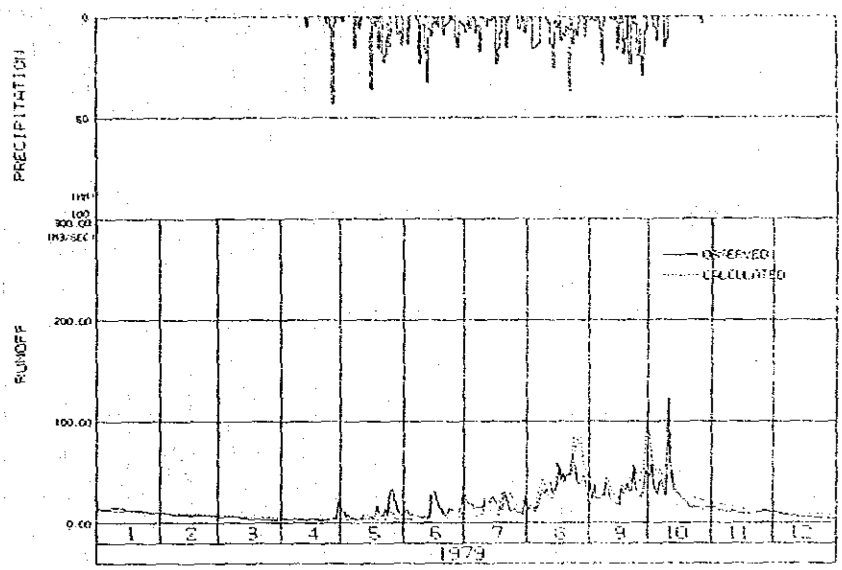
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1977)



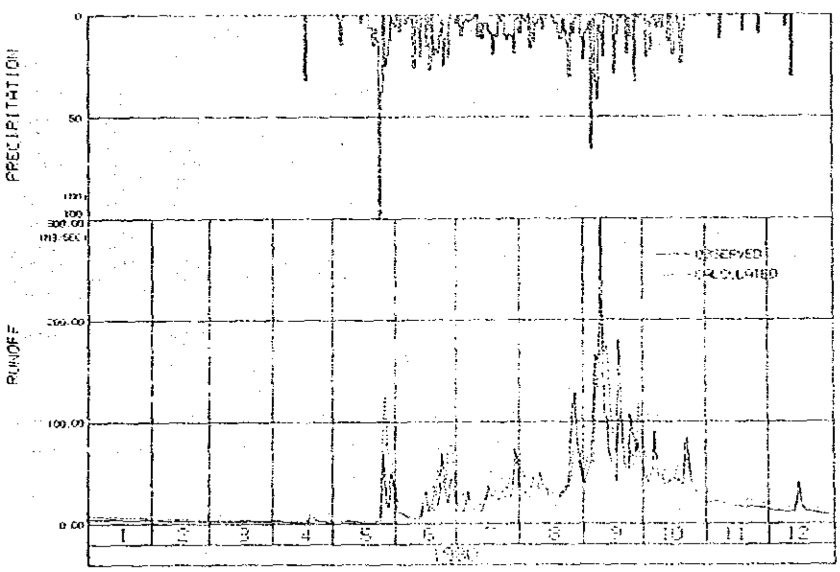
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1978)



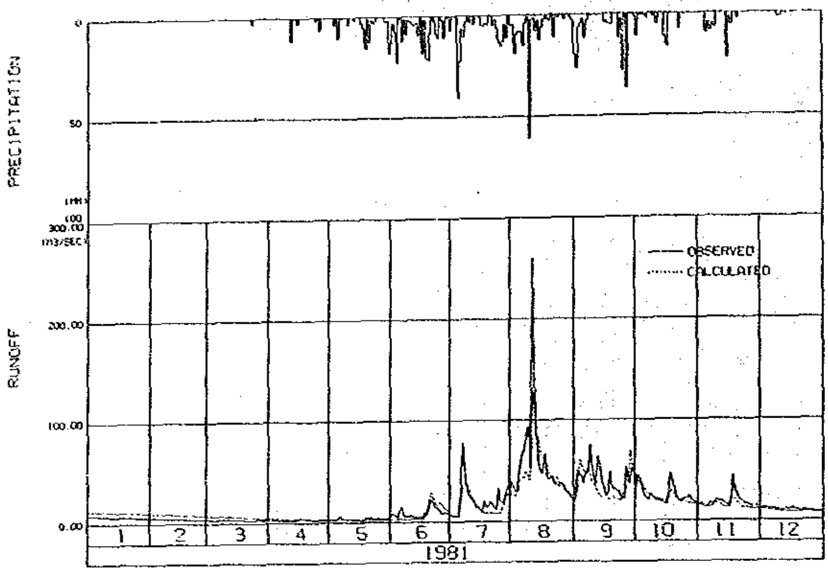
CALCULATION OF SOP HAI RUNOFF DATA (FINAL CASE, 1979)



CALCULATION OF SOP HAI RUNOFF DATA (FINAL CASE, 1980)



CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1981)



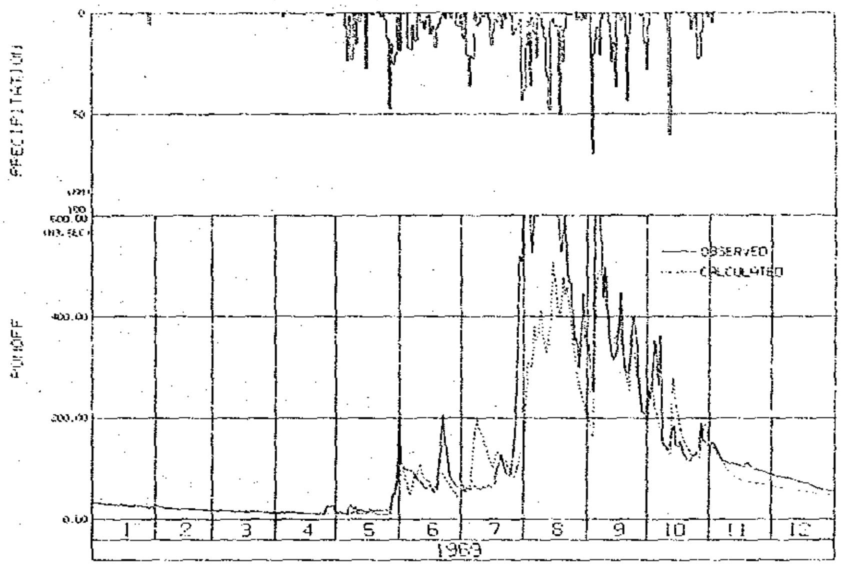
CALCULATION OF SOP HAN RUNOFF DATA (FINAL CASE, 1967-81)

< OO-GE >

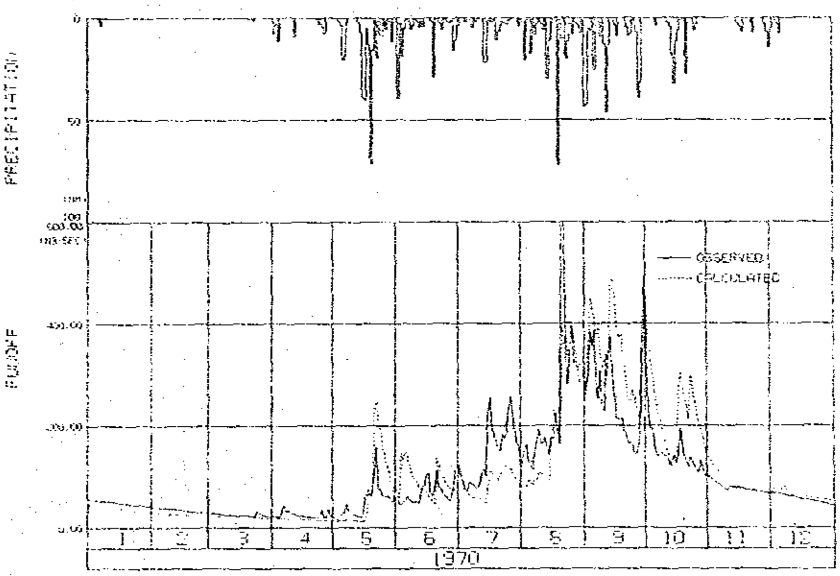
YY	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	TOTAL
67	19500	14993	14358	19644	117173	240904	-153631	-480249	12913	-334880	-167038	-120409	-814720
68	-95536	-76180	-20540	41802	140600	-140891	152909	-148373	-88342	427411	86811	14156	293827
69	-27213	-1849	26722	32876	17333	24613	-510496	-227298	-439111	-560531	-95940	-13924	-1774818
70	-43391	-44113	-10429	61360	80369	191051	319193	785373	-217476	-30911	7569	106167	1205542
71	-11527	-21378	-2744	13722	205978	298827	-598896	-77480	-325442	47320	-8291	14387	-465344
72	-45038	-37238	-6060	31373	35540	134449	288947	-222916	-490273	-662942	-499171	-358482	-1834011
73	-129971	-105964	-81004	-39896	-146033	105358	743369	1008078	1095929	411869	68676	-6269	2922142
74	57576	41427	20858	16438	131098	-40762	-232160	-565529	-1054791	-519711	-124827	-166827	-2434430
75	-33338	-91058	-92069	-50729	49978	103827	-162673	-290044	1363093	779827	817909	145640	1941363
76	-347	-26693	-29467	-19962	61360	74822	88284	134507	580187	551027	835964	252807	1890489
77	39953	9504	4564	43882	80080	144618	104578	-235329	47869	-114342	47927	43333	216637
78	63816	-20944	-36811	-4940	44047	47002	-724618	851027	251073	357671	105880	-23178	735570
79	33829	-28022	-51740	2918	181018	137458	85533	-230560	-512549	-168191	-106947	-83858	-542216
80	-75024	-68562	-40502	-23776	-271353	-279991	-271989	-3062	-173073	-248147	-218102	-92676	-1734257
81	-138726	-114256	-84124	-30536	13058	8580	162529	276784	175933	27502	100707	50527	447980
TO	-385435	-550333	-388988	94176	759866	1050660	-710641	379109	415920	-31228	-344731	-236301	69374
AV	-25696	-36689	-25933	6278	50658	70044	-47389	25274	27595	-2088	-22982	-15787	3292
AD	-829	-1298	-837	209	1634	2335	-1529	815	920	-47	-746	-509	9
MA	63816	41427	26722	61360	205978	298827	763369	1008078	1363093	779827	835964	852807	1363093
MI	-138726	-114256	-92069	-50729	-271353	-279991	-724618	-565529	-1054791	-662942	-499171	-358482	-1054791

** KOMOKU NO. : 5 ** POINT : 3 **

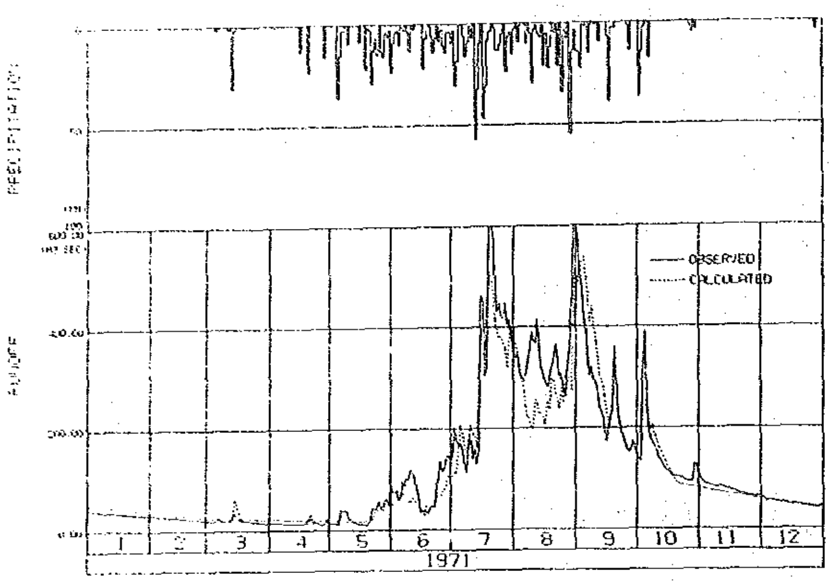
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1969)



CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1970)



CALCULATION OF BAN THA PUA RUNOFF DATA (FINAL CASE, 1971)



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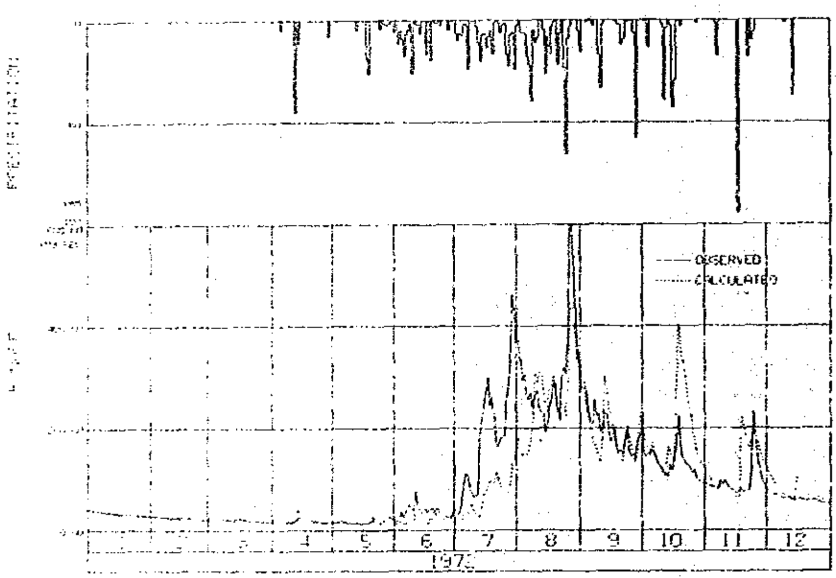
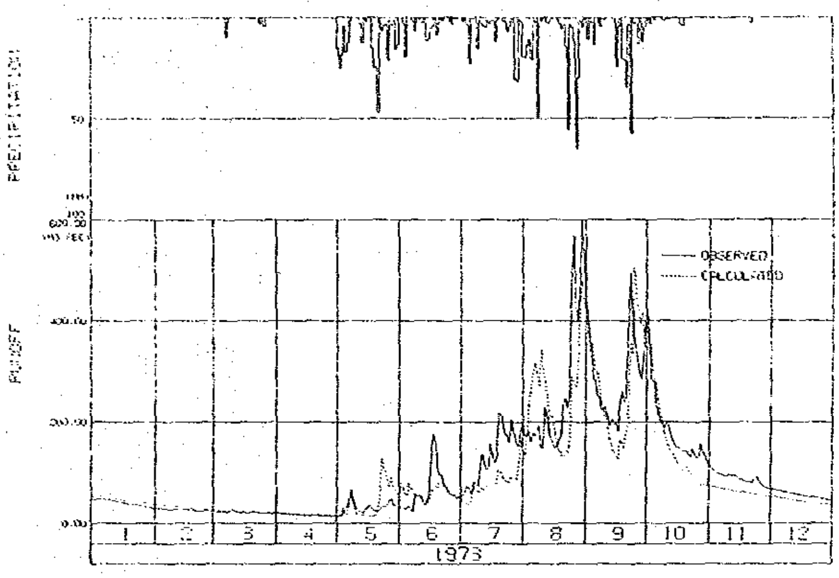
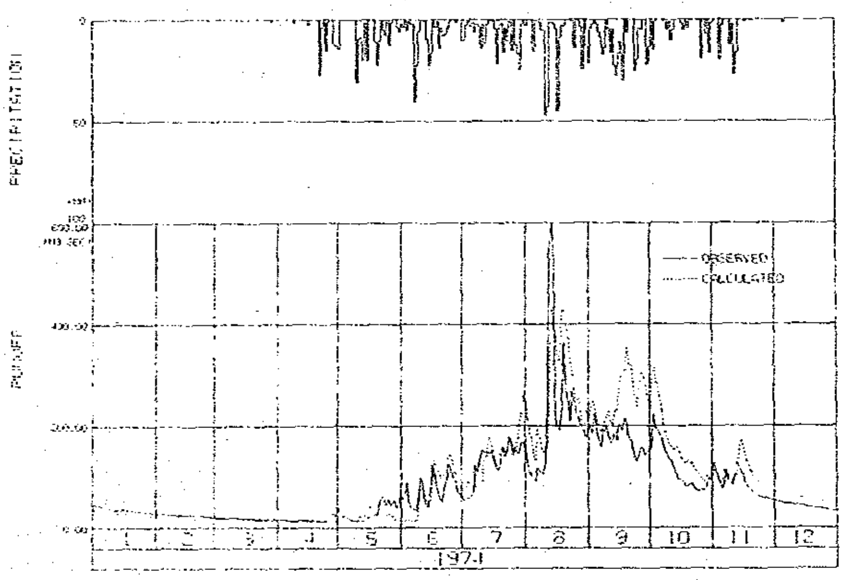


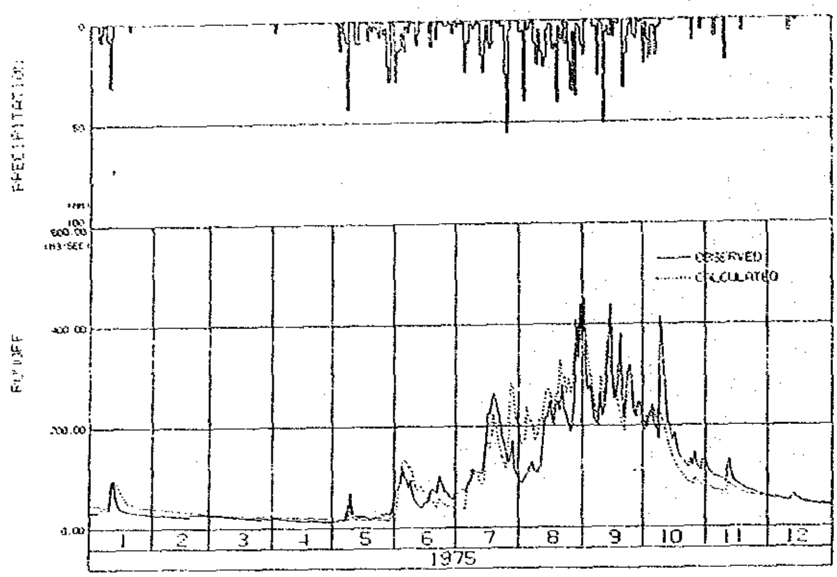
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1973)



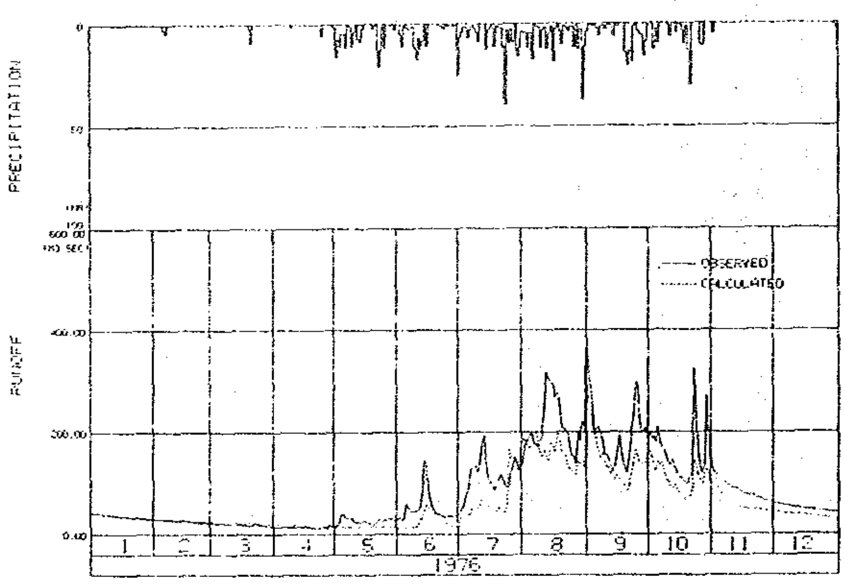
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1974)



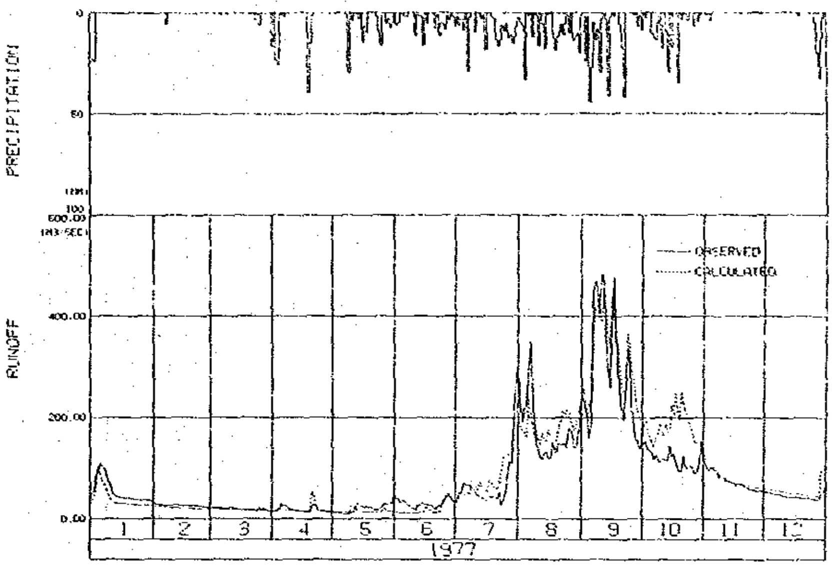
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1975)



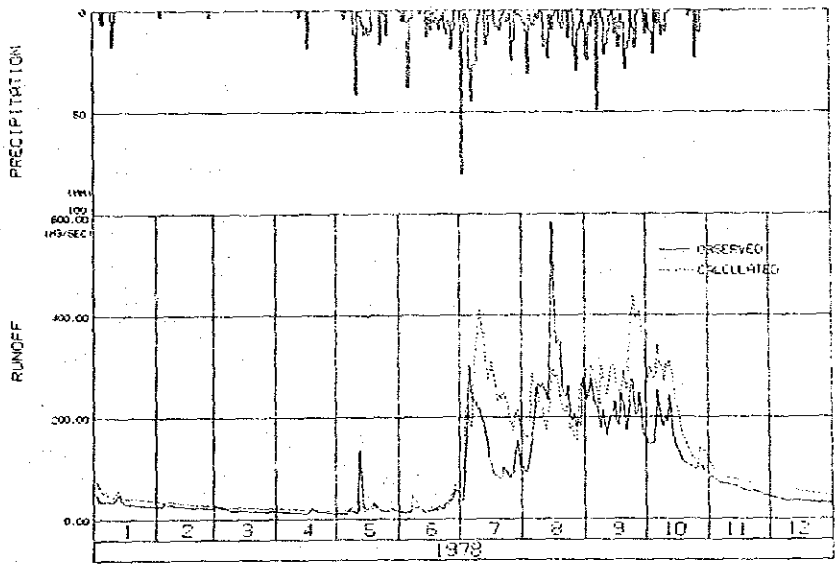
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1976)

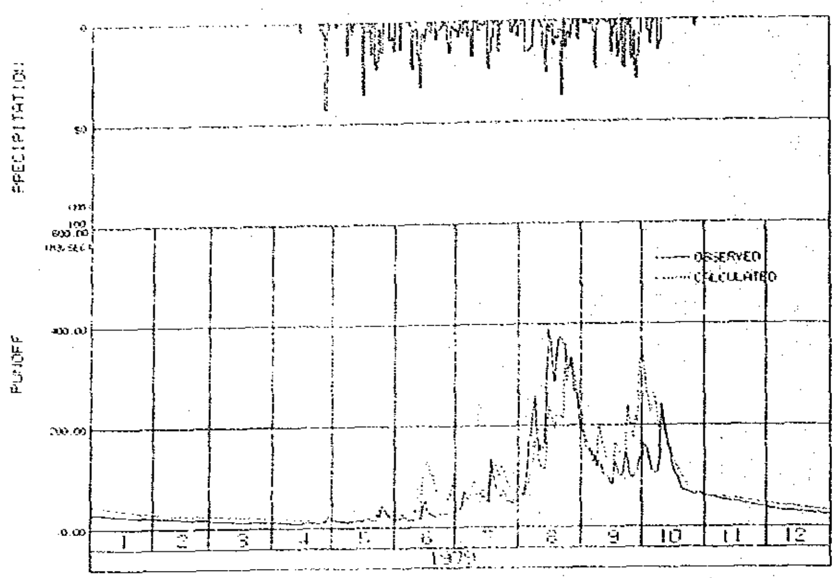


CALCULATION OF BAN THA ROA RUNOFF DATA (FINAL CASE, 1977)



CALCULATION OF BAN THA ROA RUNOFF DATA (FINAL CASE, 1978)




PRECIPITATION
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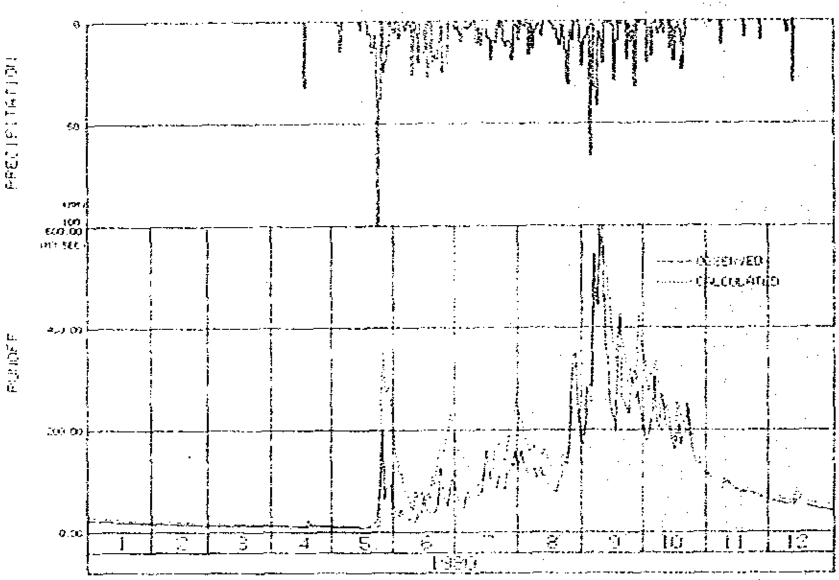
PRECIPITATION
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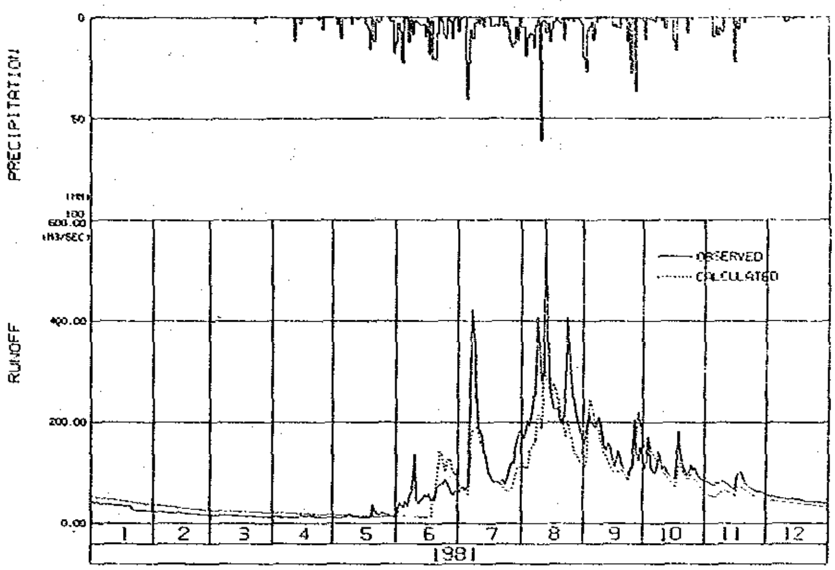
CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1981)



CALCULATION OF BAN THA RUA RUNOFF DATA (FINAL CASE, 1969-81) < GO-QE >

YY	JAN.	FEB.	MAR.	APR.	MAY.	JUN.	JUL.	AUG.	SEP.	OCT.	NOV.	DEC.	TOTAL
69	55363	23040	-53693	34393	243088	472685	704354	8359287	1701281	58234	595966	477494	12671493
70	321891	247896	137037	252838	-375664	-629892	1863697	1277881	-2361493	-2503539	-303860	-232403	-2505611
71	-258515	-134166	-191398	-173768	85153.	623347	769467	2520969	-984039	266761	223721	-30433	2700079
72	-9550	-62108	-86216	40003	99038	475758	3885400	1298851	140377	-1758247	-779417	-422733	2821156
73	-175237	-133698	-30386	-65180	-362361	74796	1648991	350207	305196	805863	777347	358555	3554093
74	193068	66716	-48685	55830	276813	-23173	-336717	-1071924	-2385267	-1343729	-629758	-479698	-5726724
75	-435555	-238343	-100708	-145852	369761	42206	135635	-1635501	296847	1130438	489248	12136	-271672
76	29852	7146	-96701	-100240	386737	781287	1199879	1723186	1448978	1488246	810671	402030	8081071
77	427608	118672	32924	-18566	169951	297231	-270135	-255910	-606565	-1979497	-81207	-335582	-2511086
78	-412381	-176372	-166018	-148791	168292	-161814	-3304126	771270	-2642313	-2151863	-513022	-605649	-9340787
79	-363786	-194404	-288929	-151195	29785	-1031655	-760718	1640376	-1629891	-1211566	-189528	-283491	-4412980
80	-153466	-135234	-85415	-43275	-1280152	-1920061	-1607586	-744490	-1765927	-1070989	1603	-296113	-9101105
81	-355750	-304595	-276813	-184186	25511	178042	1053626	2296714	144250	210899	526045	231067	3544810
TO	-1136438	-913450	-1231201	-647789	-561038	-831242	4981767	16530916	-8338766	-8072991	927809	-1204822	-497263
AV	-87418	-70265	-94708	-49830	-43157	-63942	383213	1271609	-641445	-620999	71370	-92679	-38251
AD	-2820	-2489	-3055	-1661	-1392	-2131	12362	41020	-21382	-20032	2379	-2990	-105
MA	427608	247896	137037	252838	386737	781287	3885400	8359287	1701281	1488246	810671	477494	8359287
MI	-435555	-304595	-276813	-184186	-1280152	-1920061	-3304126	-1635501	-2642313	-2503539	-779417	-605649	-3304126

** KOMOKU NO. : 5 ** POINT : 3 **

A-4 PROBABLE MAXIMUM FLOOD

A-4 PROBABLE MAXIMUM FLOOD

1. Preparation of Tank Model Parameters in Basin

(1) Sub-basin No. 1 (upstream basin of the Sop Hon G.S.)

Data used: runoff - hourly staff gauge heights during floods and rating curves at the Sop Han G.S.

rainfall - daily rainfall at the Khun Yuam, Mae Lama Luang and Sop Han St.

Floods concerned : July 17 - July 23, 1971
Sep. 14 - Sep. 21, 1977
Aug. 22 - Aug. 31, 1980

Area covered by rainfall station : 832 km^2 for each station (total catchment area = 2,496 km^2)

Rainfall coefficient:	Khun Yuam St.	0.3
	Mae Lama Luang St.	0.3
	Sop Han St.	0.6

Results of floods' simulation by tank model analysis are shown on Figs. 1-(1), 1-(2) and 1-(3).

(2) Sub-basin No. 2 (the Rit river basin)

Data used: runoff - hourly staff gauge heights during floods and rating curves at the Ban Mae Suat G.S.

rainfall - daily rainfall at the Ban Mae Suat St.

Floods concerned : Aug. 12 - Aug. 19, 1984
Sep. 16 - Sep. 23, 1985

Area covered by rainfall station : 1,376 km^2 for the Ban Mae Suat St.

Rainfall coefficient: Ban Mae Suat St. 0.5

Results of floods' simulation by tank model analysis are shown on Figs. 2-(1) and 2-(2).

(3) Sub-basin No. 4 (the Ngao river basin)

Data used:	runoff	- hourly staff gauge height and rating curves at the Ban Mae Ngao G.S.
	rainfall	- hourly rainfall at the Ban Mae Ngao St.

Floods concerned : Aug. 13 - Aug. 23, 1984
Aug. 25 - Sep. 8, 1985

Area covered by rainfall station : 935 km^2 for the Ban Mae Ngao St.

Rainfall coefficient: Ban Mae Ngao St. 1.0

Results of floods' simulation by tank model analysis are shown on Figs. 3-(1) and 3-(2).

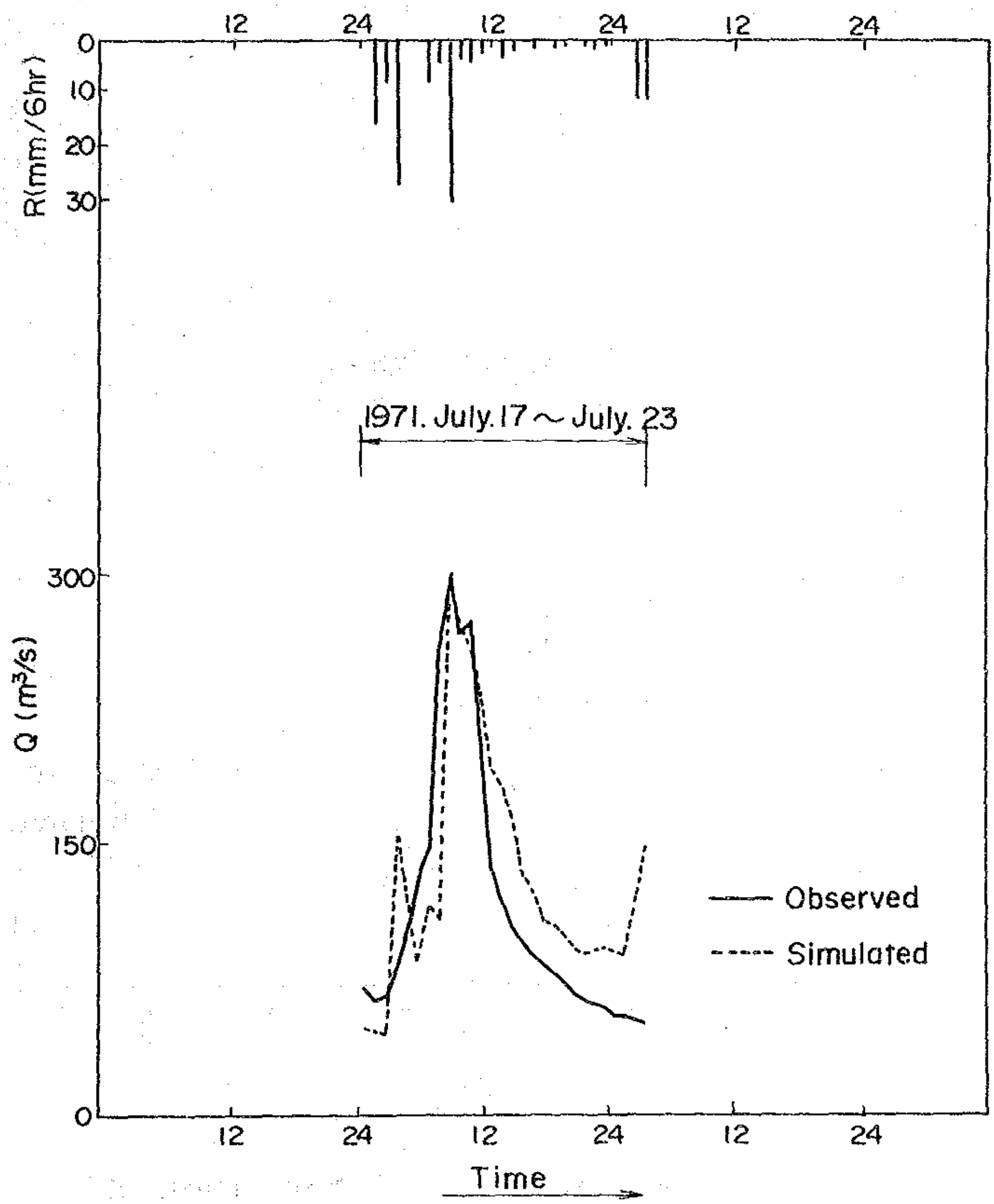


Fig. 1-(1) Result of Flood Simulation at the Sop Han G.S

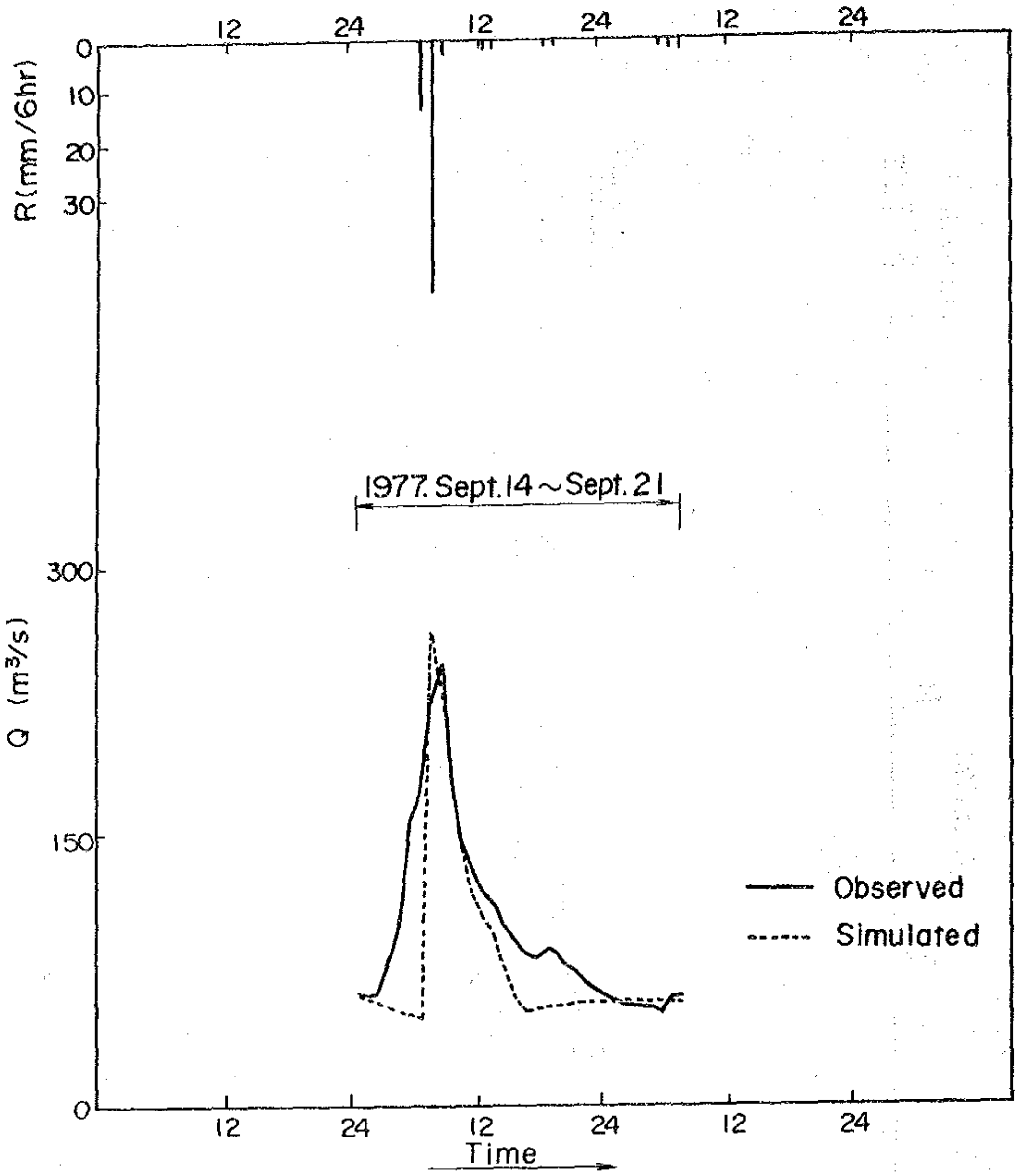


Fig. 1-(2) Result of Flood Simulation at the Sop Han G.S

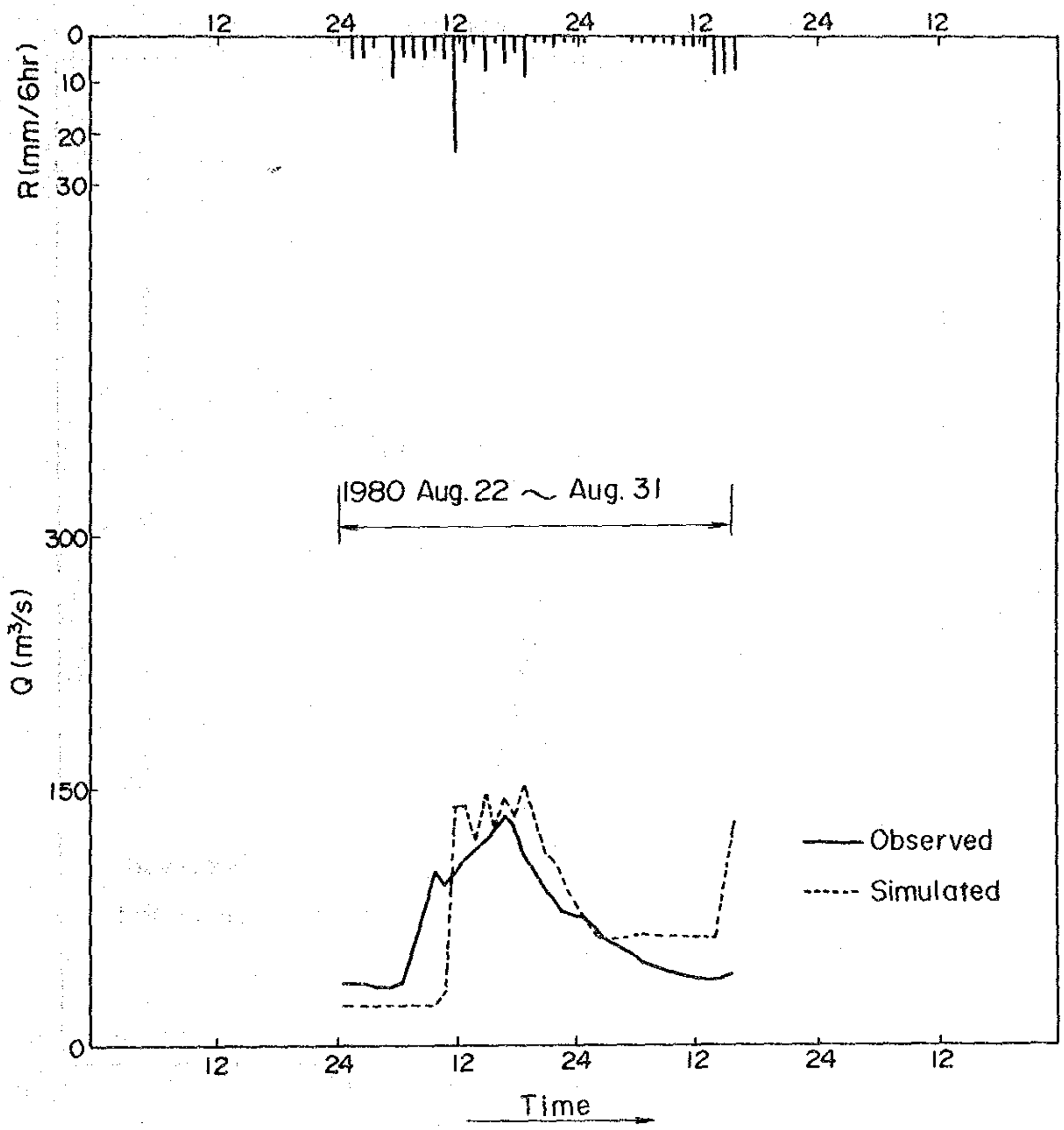


Fig. 1 -(3) Result of Flood Simulation at the Sop Han G.S

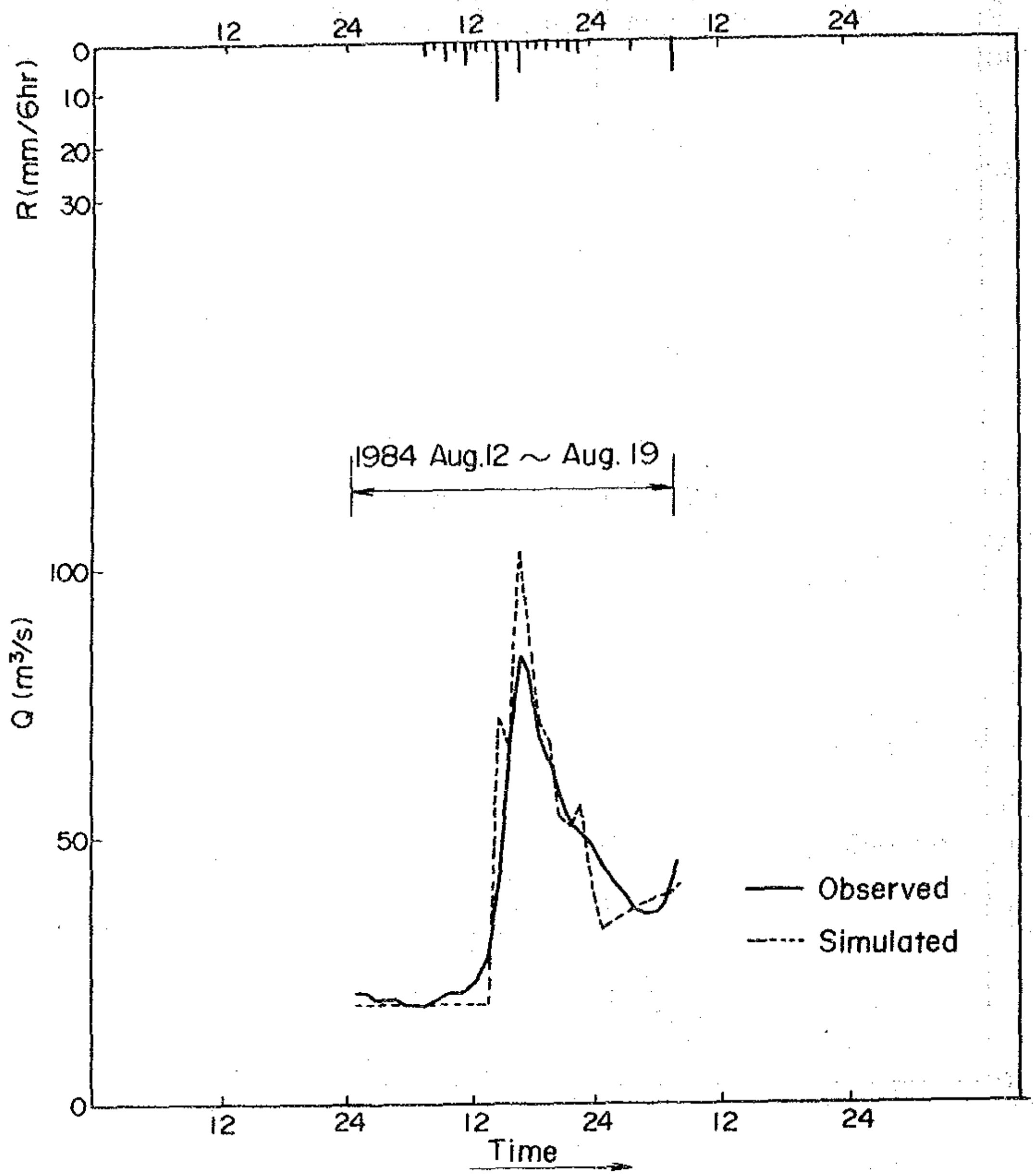


Fig. 2-(1) Result of Flood Simulation at the Ban Mae Suat G.S

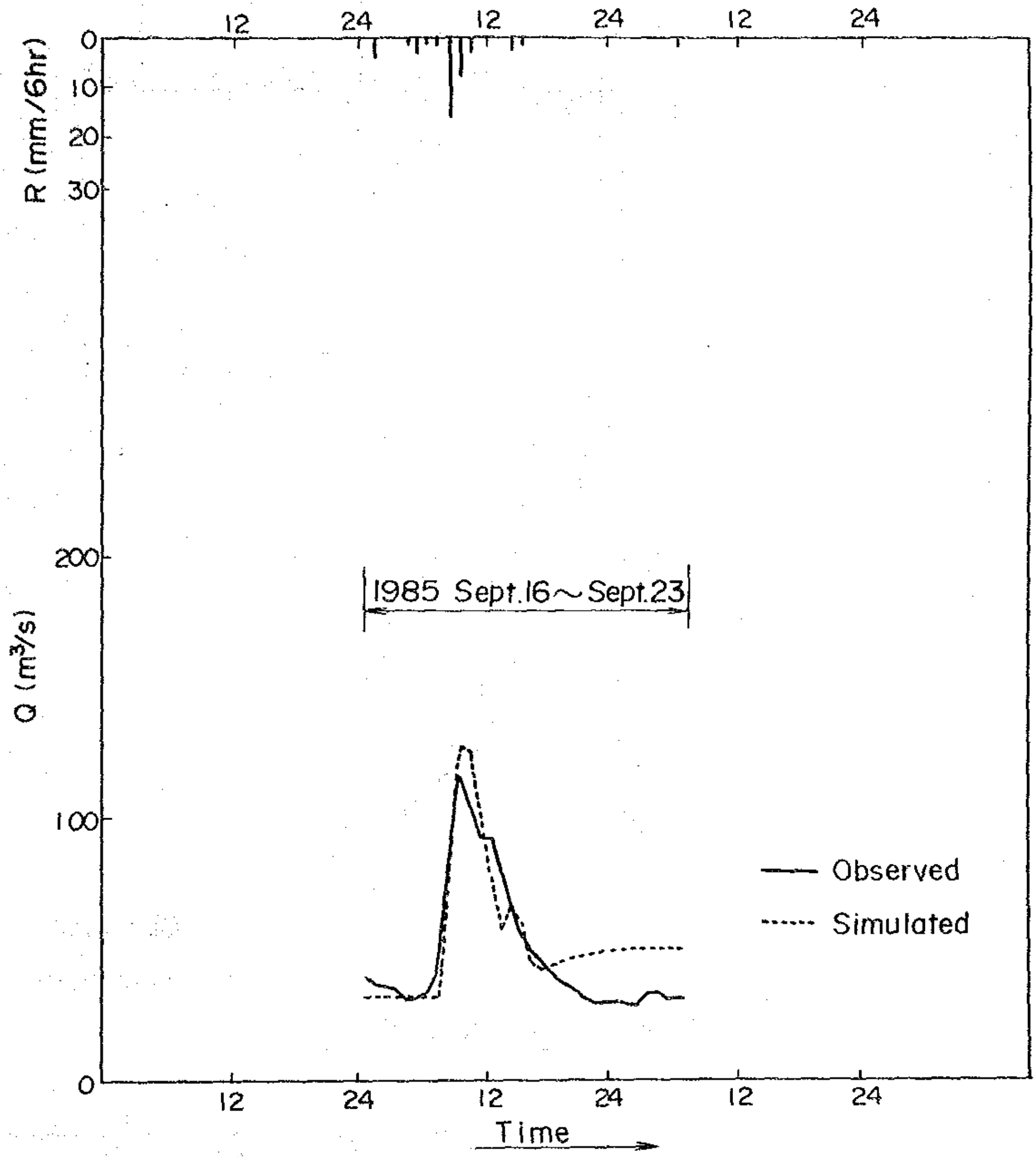


Fig. 2-(2) Result of Flood Simulation at the Ban Mae Suat G.S

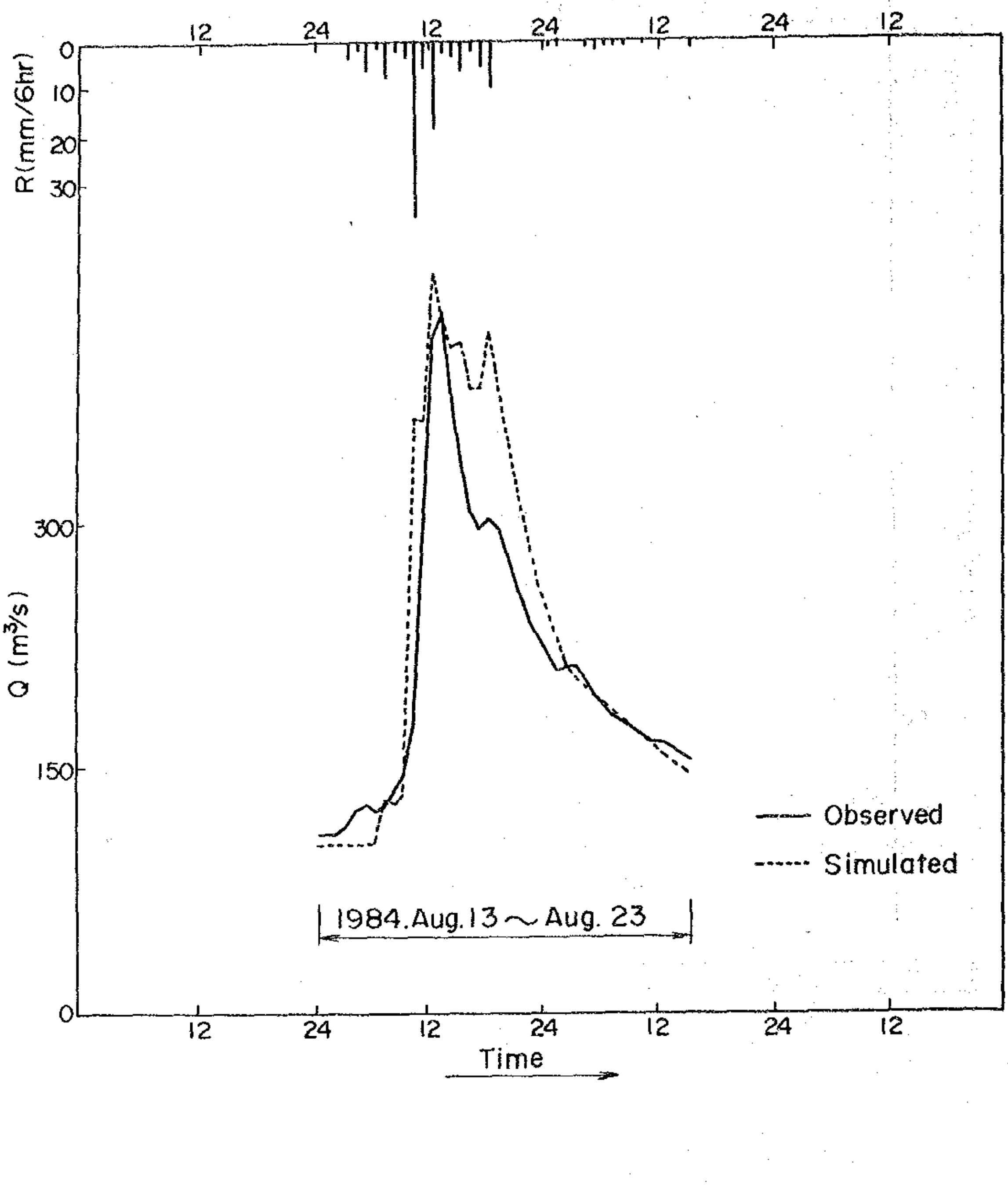


Fig. 3-(1) Result of Flood Simulation at the Ngao G.S

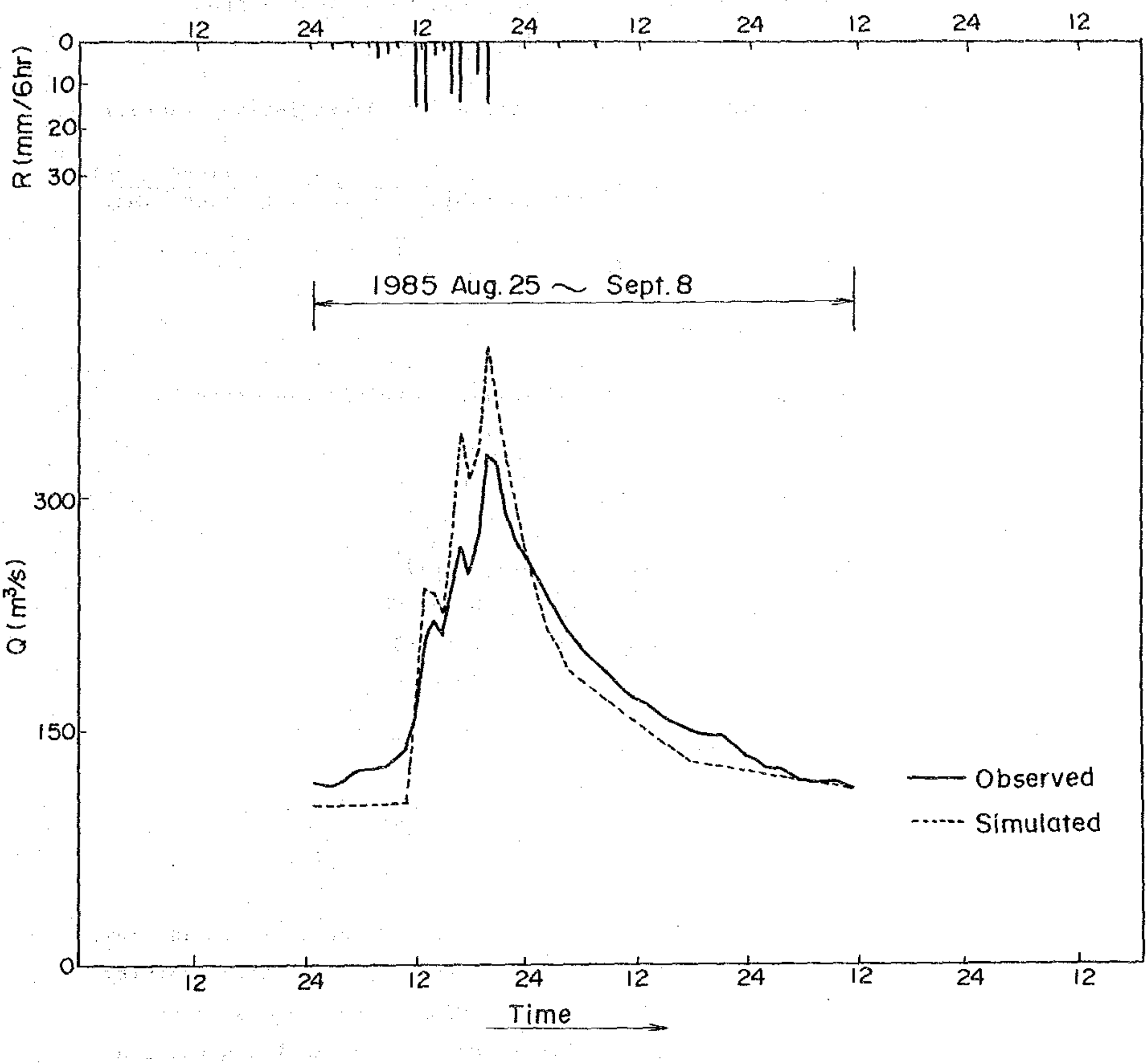


Fig. 3-(2) Result of Flood Simulation at the Ngao G.S

2. Estimation of Probable Maximum Precipitation

(1) General

Probable maximum precipitation (PMP) can be estimated from equations below.

PMP = (actual rainfall amount during a flood)*(maximizing factor)

$$\text{Maximizing factor} = \frac{\text{(maximum precipitable water during flood time)}}{\text{(actual precipitable water during flood time)}}$$

(2) Maximum Precipitable Water

1) Estimating Procedure

The estimating procedure of maximum precipitable water is shown on the following flow chart.

2) Maximum Precipitable Water

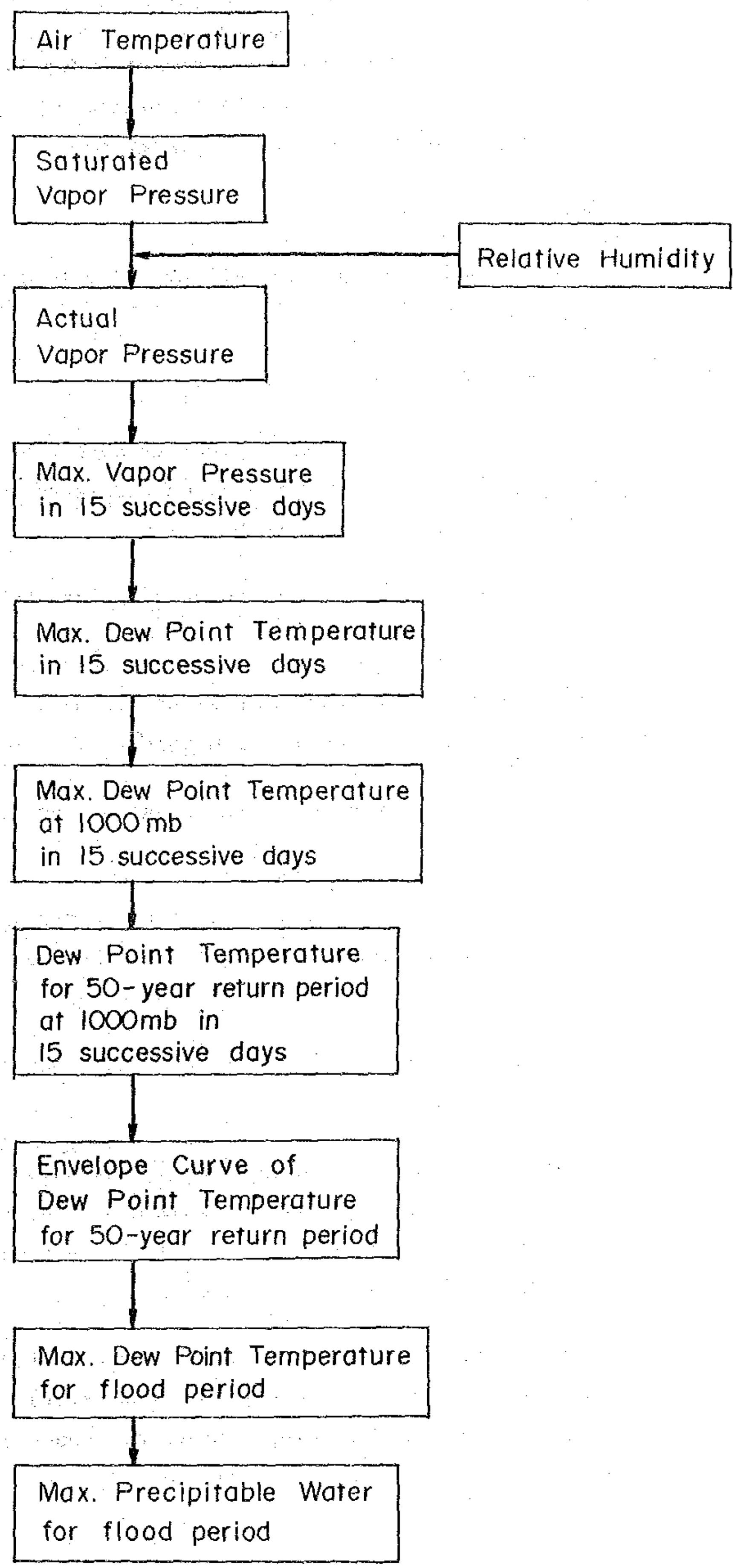
- Data used: Temperature (max., min.)*

Sop Han St.	1967 - 1985
Ban Tha Rua	1971 - 1985
Salawin	1970 - 1980

Relative Humidity

Sop Han St.	1971 - 1985
Ban Tha Rua	1971 - 1985
Salawin	1971 - 1981, 1985

* Temperature data for some periods are lacking, for which period there were relative humidity data. Hence, lacking temperature data are supplemented by correlation analysis between stations.


Air Temperature
Saturated Vapor Pressure
Relative Humidity
Actual Vapor Pressure
Max. Vapor Pressure in 15 successive days
Max. Dew Point Temperature in 15 successive days
Max. Dew Point Temperature at 1000 mb in 15 successive days
Dew Point Temperature for 50-year return period at 1000mb in 15 successive days
Envelope Curve of Dew Point Temperature for 50-year return period
Max. Dew Point Temperature for flood period
Max. Precipitable Water for flood period

- Saturated vapour pressure (es)

Saturated vapour pressure (es mb) of a day is derived from Fig. 4 (Variation of Vapour Pressure with Temperature at Percentages of Saturation).

- Actual vapour pressure (e)

Actual vapour pressure (e, mb) of a day is derived by a equation below.

$$e = es * R.H/100$$

where, e : actual vapour pressure (mb)
es : saturated vapour pressure (mb)
R.H: relative humidity

- Max. vapour pressure in 15 successive days (e max.)

In order to estimate the maximum precipitable water during flood time, maximum vapour pressure (e max.) in 15 successive days is found for each month.

- Max. Dew point temperature in 15 successive days

Maximum dew point temperature in 15 successive days is derived from maximum vapour pressure (e max.) in 15 successive days by using Fig. 4, and further be reducted at 1,000 mb.

- Dew point temperature for 50-year return period at 1,000 mb in 15 successive days

In order to draw envelope curves of dew point temperature for 50-year return period, maximum dew point temperatures at 1,000 mb in 15 successive days for observation periods are analysed with a normal distribution.

Plots of maximum dew point temperatures at 1,000 mb in 15 successive days and of dew point temperatures for 50-year return period, and envelope curves are shown on Figs. 5, 6 and 7.

- Max. precipitable water during the flood period concerned (May 20 - May 25, 1980)

The maximum precipitable water during the flood period concerned is estimated to be 116.2 mm as shown below.

Max. Precipitable Water

Item	Unit	Description
1. Flood period concerned	-	May 20 - May 25, 1980
2. Max. dew point temperature at 1,000 mb according to envelope curve	°C	31.7 (Sop Han) 33.0 (Ban Tha Rua) 32.6 (Salawin) 32.4 (average)
3. Precipitable water (200 mb - 1,000 mb)	mm	150.7
4. Precipitable water (200 mb - EL. 1,200 m*)	mm	34.5
5. Precipitable water (EL. 1,200 m* - 1,000 mb)	mm	116.2

*): EL. 1,200 m - topographic barrier

The precipitable water corresponding to a dew point temperature is estimated from Table 1.

(3) Actual Precipitable Water

The actual precipitable water during the flood period concerned (May 20 - May 25, 1980) is estimated 78.5 mm as shown below.

Actual Precipitable Water

Item	Unit	Description
1. Flood period concerned	-	May 20 - May 25, 1980
2. Max. dew point temperature at 1,000 mb during the flood concerned	°C	27.2 (Sop Han) 29.0 (Ban Tha Rua) 29.4 (Salawin) 28.5 (average)
3. Precipitable water (200 mb - 1,000 mb)	mm	108.5
4. Precipitable water (200 mb - EL. 1,200 m*)	mm	30.0
5. Precipitable water (EL. 1,200 m* - 1,000 mb)	mm	78.5

*): EL. 1,200 m - topographic barrier

(4) Maximizing Factor

A maximizing factor is estimated as below.

Maximizing Factor

$$= \frac{\text{maximum precipitable water during flood time}}{\text{actual precipitable water during flood time}}$$

$= 116.2/78.5$

$= 1.48$

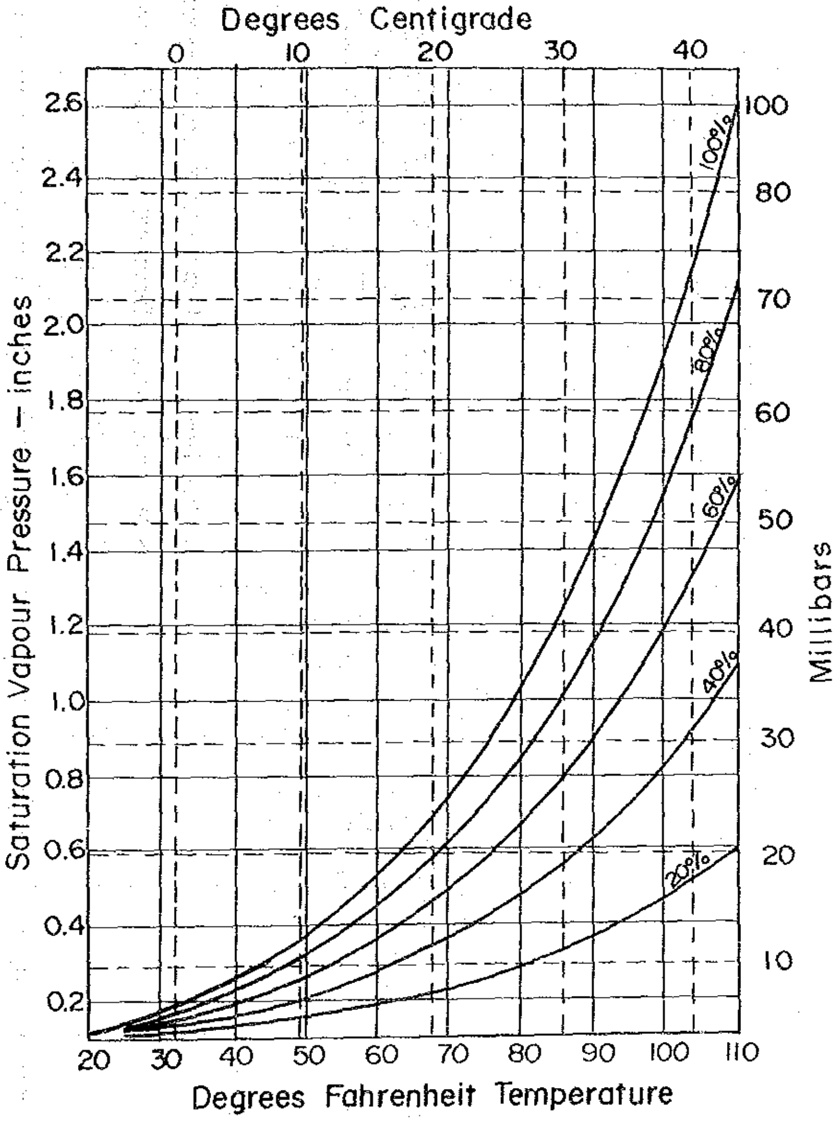


Fig. 4 Variation of Vapor Pressure with Temperature at Percentages of Saturation

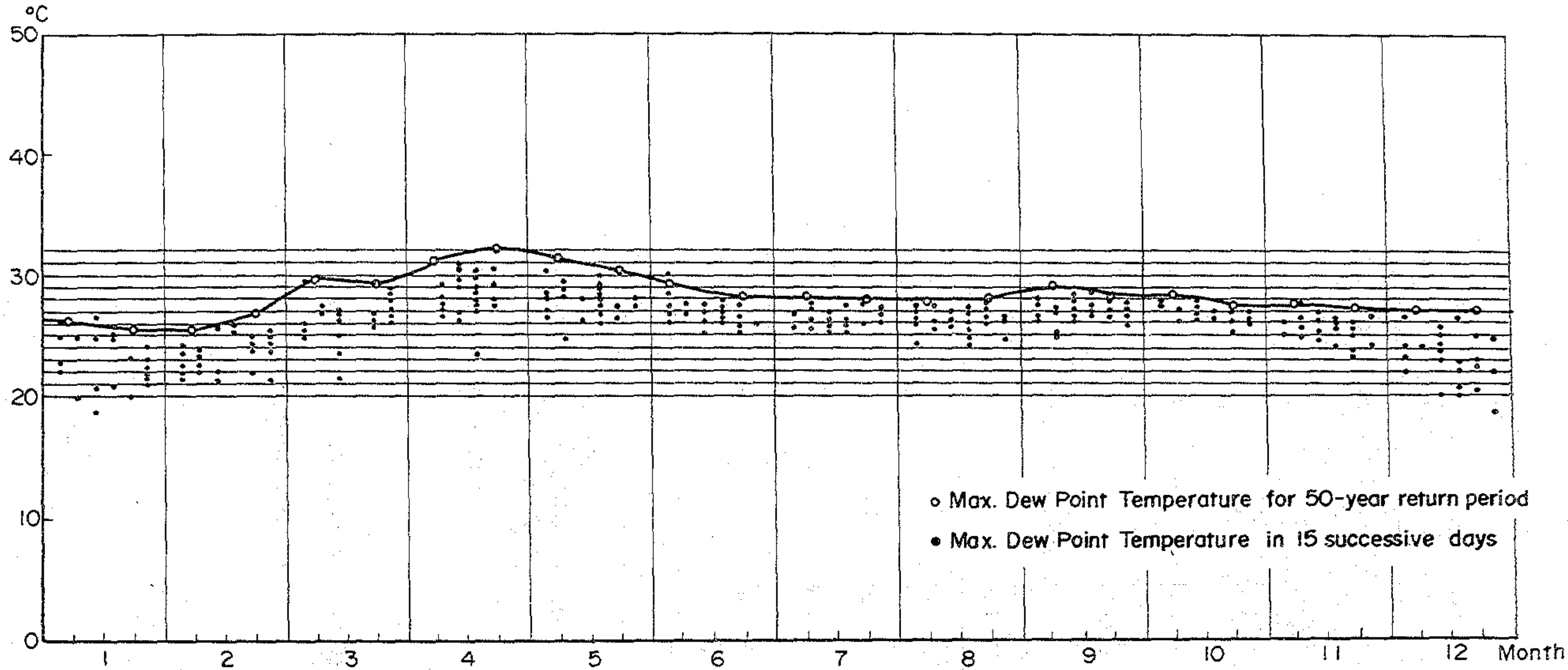


Fig. 5 Envelope Curve of Max. Dew Point Temperature at Sop Han St.

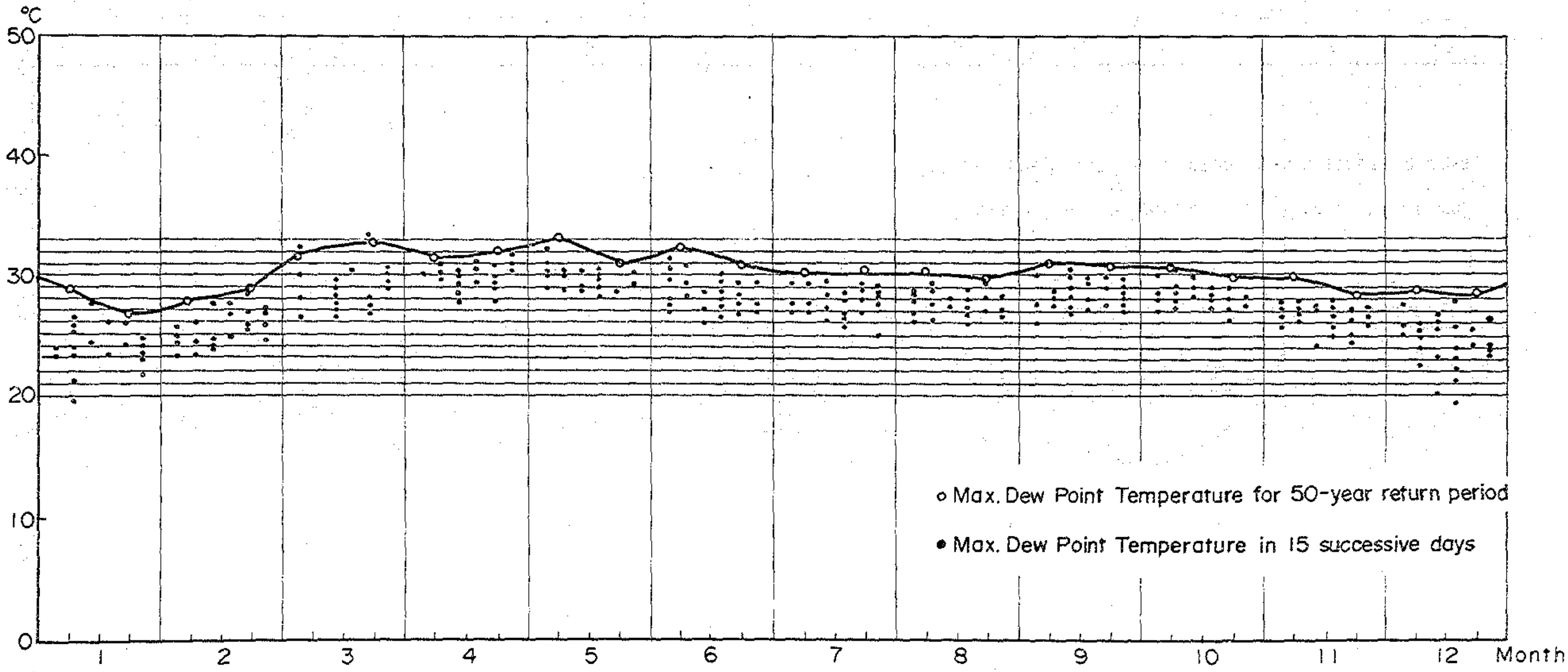


Fig. 6 Envelope Curve of Max. Dew Point Temperature at Ban Tha Rua St.

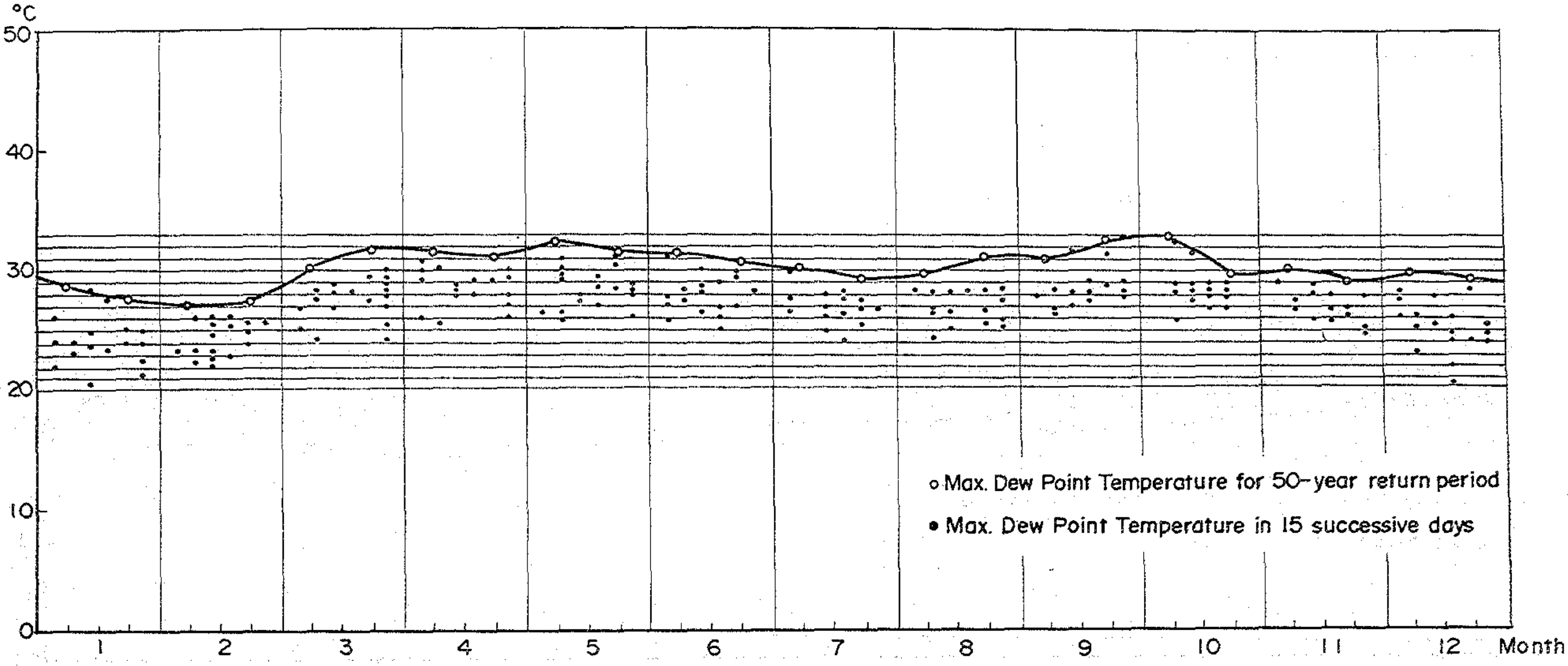


Fig. 7 Envelope Curve of Max. Dew Point Temperature at Salawin St.

Table 1 Dew Point Temperature and precipitable Water

Dew Point Tempreature (°C)	Precipitable Water (mm)	Dew Point Temperature (°C)	Precipitable Water (mm)	Dew Point Temperature (°C)	Precipitable Water (mm)	Dew Point Temperature (°C)	Precipitable Water (mm)
15.0	34.3	18.0	44.4	21.0	58.4	24.0	74.4
1	34.6	1	44.6	1	58.9	1	74.9
2	34.9	2	44.8	2	59.4	2	75.9
3	35.1	3	44.9	3	59.9	3	76.2
4	35.4	4	45.1	4	60.2	4	77.0
5	35.7	5	45.3	5	60.7	5	78.0
6	36.0	6	45.5	6	61.0	6	78.5
7	36.3	7	45.7	7	61.5	7	79.5
8	36.5	8	45.8	8	62.0	8	80.0
9	36.8	9	46.0	9	62.5	9	80.5
16.0	37.1	19.0	46.2	22.0	63.0	25.0	81.5
1	37.5	1	46.7	1	63.8	1	82.0
2	37.9	2	47.1	2	64.3	2	82.8
3	38.3	3	47.6	3	64.8	3	83.3
4	38.6	4	48.0	4	65.3	4	84.1
5	39.0	5	48.5	5	65.7	5	84.8
6	39.4	6	49.0	6	66.1	6	85.3
7	39.8	7	49.4	7	66.5	7	86.1
8	40.2	8	49.9	8	67.3	8	86.9
9	40.5	9	50.3	9	68.1	9	87.9
17.0	40.9	20.0	50.8	23.0	68.6	26.0	88.9
1	41.3	1	51.6	1	69.3	1	90.2
2	41.6	2	52.3	2	70.0	2	90.9
3	42.0	3	53.1	3	70.6	3	91.7
4	42.3	4	53.8	4	71.1	4	92.7
5	42.7	5	54.6	5	71.6	5	93.0
6	43.0	6	55.4	6	72.1	6	94.0
7	43.4	7	56.1	7	72.9	7	94.7
8	43.7	8	56.9	8	73.2	8	95.3
9	44.1	9	57.6	9	73.7	9	96.0

Dew Point Tempreature (°C)	Precipitable Water (mm)	Dew Point Temperature (°C)	Precipitable Water (mm)	Dew Point Temperature (°C)	Precipitable Water (mm)
27.0	97.0	30.0	123.2	33.0	157.5
1	97.8	1	124.3	1	158.7
2	98.6	2	125.5	2	159.9
3	99.6	3	126.6	3	161.2
4	100.3	4	127.8	4	162.4
5	101.1	5	128.9	5	163.6
6	101.9	6	130.0	6	164.8
7	102.4	7	131.2	7	166.0
8	102.9	8	132.3	8	167.3
9	103.6	9	133.5	9	168.5
28.0	104.4	31.0	134.6	34.0	169.7
1	105.4	1	135.8		
2	106.7	2	136.9		
3	108.0	3	138.1		
4	109.0	4	139.2		
5	109.7	5	140.4		
6	110.5	6	141.5		
7	111.3	7	142.7		
8	112.3	8	143.8		
9	113.0	9	145.0		
29.0	114.0	32.0	146.1		
1	115.1	1	147.2		
2	115.8	2	148.4		
3	116.3	3	149.5		
4	117.1	4	150.7		
5	118.1	5	151.8		
6	119.1	6	152.9		
7	120.0	7	154.1		
8	120.9	8	155.2		
9	122.0	9	156.4		

A-5 DAM BREACH ANALYSIS

A-5 DAM BREACH ANALYSIS

1. Nam Ngao Dam Breach

In order to obtain hydrographs of the river discharge and the river water level at Ban Mae Kha Tuan approximately 17 km upstream of the conjunction of the Nam Ngao river and the Yuam river when the Nam Ngao dam breaches, a calculation of flood wave propagation was carried out. Conditions of the calculation are shown below.

Nam Ngao Dam

Reservoir water level when breached:	270 m (N.H.W.L.)
Elevation of breach bottom :	160 m
Side slope of breach :	45°
Width of breach bottom :	80 m
Breach time :	1 h, 8 h

Mae Lama Luang Dam

Initial reservoir water level :	165 m (N.H.W.L.)
Reservoir water level when breached:	168.5 m
Elevation of breach bottom :	62 m
Side slope of breach :	45°
Width of breach bottom :	80 m
Breach time :	1 h, 8 h

	Nam Ngao Dam		Mae Lama Luang Dam		
	Width of Breach Bottom (m)	Breach Time (hrs)	Width of Breach Bottom (m)	Breach Time (hrs)	Manning n
1 (Max. breach)	80	1.0	80	1.0	0.04
2 (Min. breach)	80	8.0	80	8.0	0.04

The hydrographs of the river discharge and the river water level at Ban Mae Kha Tuan for the maximum breach case and the minimum breach case are indicated in Fig. 1 and Fig. 2 respectively.

2. PMF of Nam Ngao Dam

In order to obtain a hydrograph of the river water levels at Ban Mae Kha Tuan when the PMF discharge occurs in the Ngao river, a calculation of flood wave propagation was carried out.

The PMF hydrograph in Fig. 5-24 of the Final report was used in the calculation. The initial river discharge at Ban Mae Kha Tuan was set 1,100 m^3/sec - 1,500 m^3/sec which correspond to the river water level of EL. 164 m - 166 m at Ban Mae Kha Tuan.

The result of the calculation showed no change of the river water level at Ban Mae Kha Tuan.

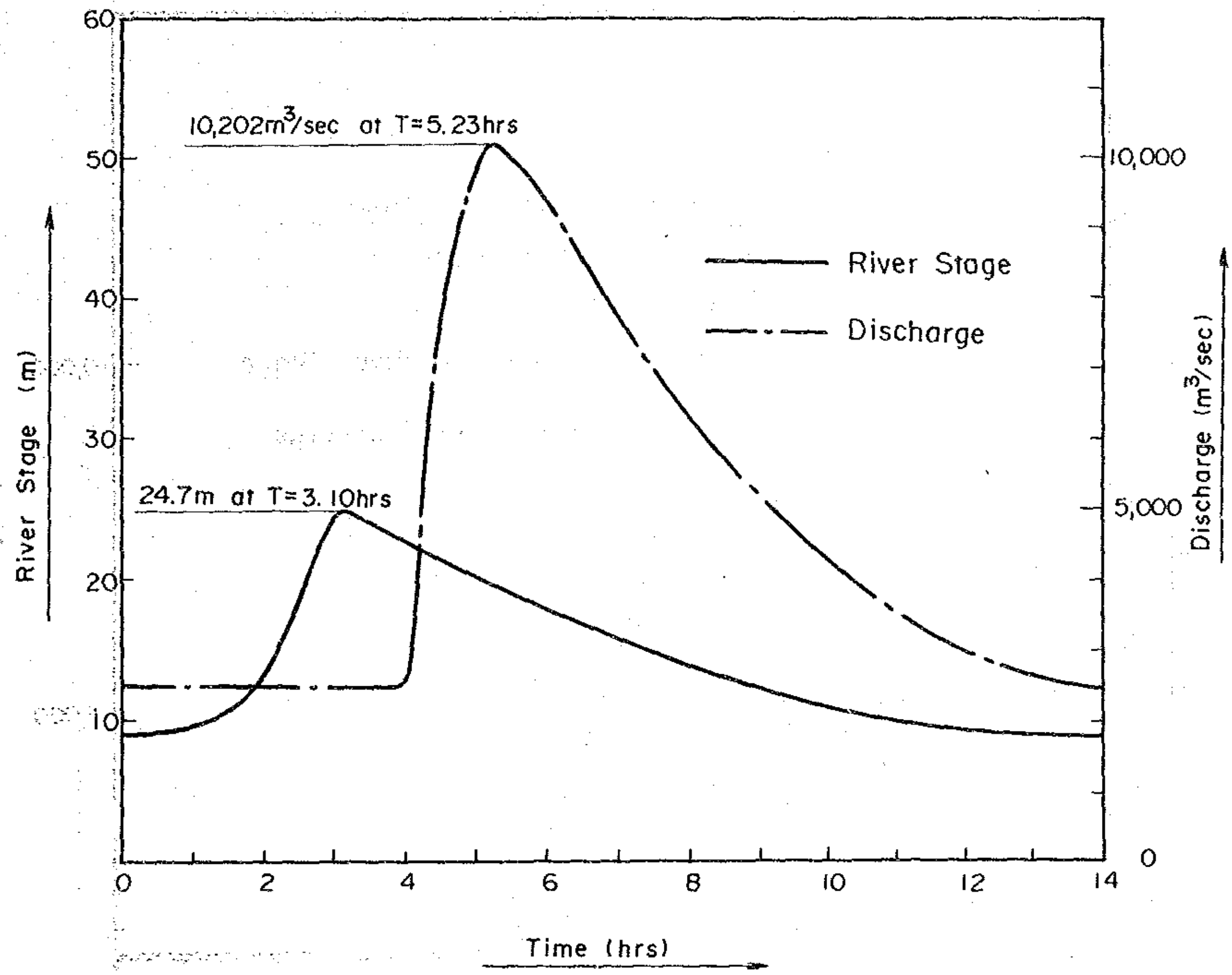


Fig. 1 Attenuation of Break Flood of Nam Ngao Dam at Ban Mae Kha Tuan (Max. Breach Case)

※ River stage zero = EL. 158.00m

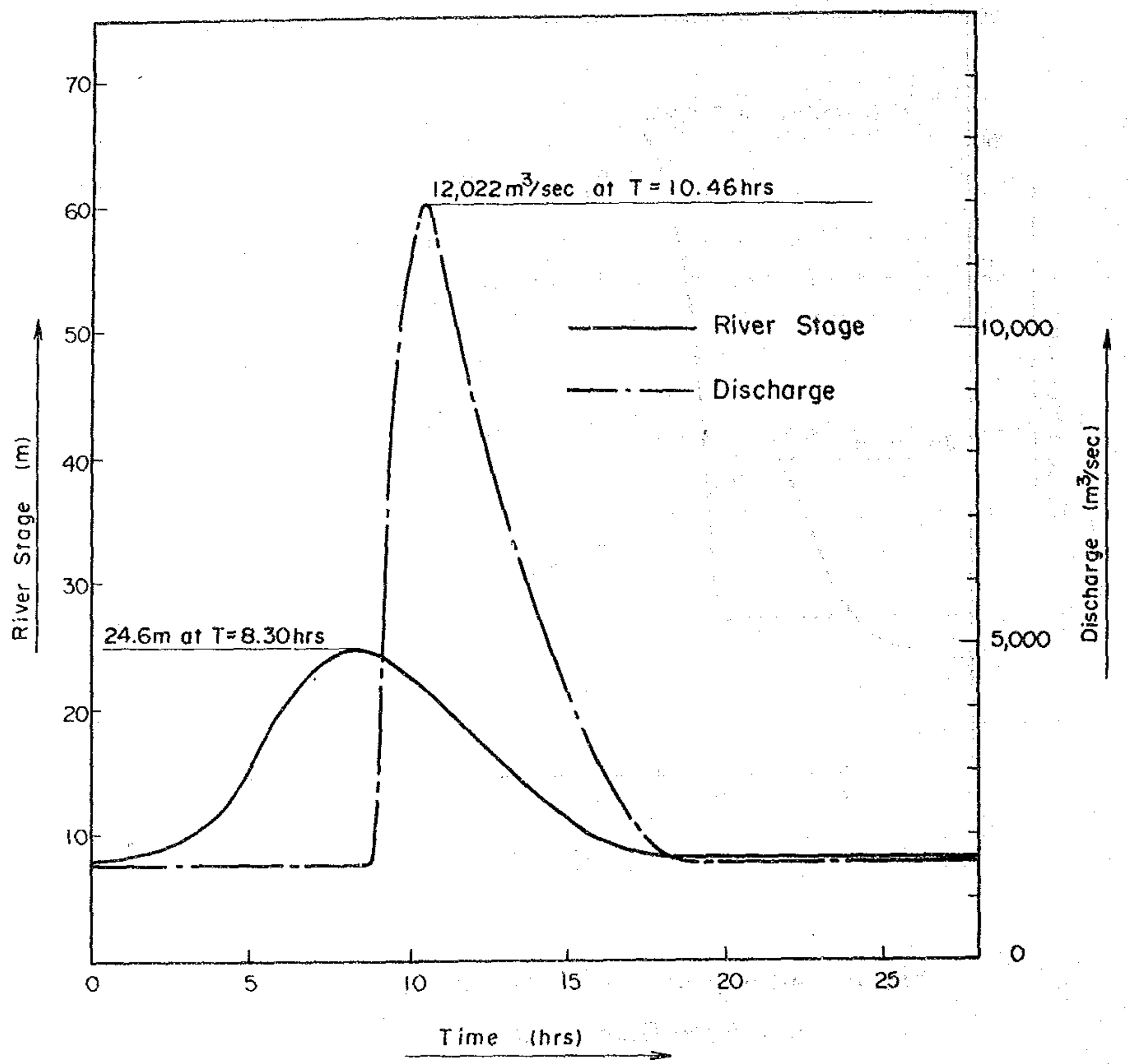


Fig. 2 Attenuation of Break Flood of Nam Ngao Dam at Ban Mae Kha Tuan (Min. Breach Case)

※ River stage zero = EL.158.00m

A-6 HYDROLOGICAL FORECASTING SYSTEM

A-6 HYDROLOGICAL FORECASTING SYSTEM

1. Hydrological Forecasting System (alternative)

An objective of establishing the alternative hydrological forecasting system in the Yuam river basin is to estimate future states of hydrological phenomena in real time, for example, to estimate the natural inflow into the reservoir 7-day ahead.

The forecasting system is composed of three different sub-systems below.

- Data collection
- Data transmission
- Hydrological modelling

(1) Data Collection

The collection of rainfall data is taken at the following five stations; Khun Yuam, Mae La Luang, Mae Sariang, Ban Mae Ngao (or upstream of the Ngao river), Ban Tha Rua.

(2) Data Transmission

The rainfall data collected at the above stations is transmitted to the Mae Lama Luang dam site through two relay stations by VHF radio wave at a required time interval. (See Fig. 5-40 in the Main Report)

Since the number and the location of relay stations are temporarily decided, they should be examined at the next stage.

(3) Hydrological Modelling

In order to estimate the reservoir inflow from the rainfall data, a hydrological forecasting model is established in development and operational mode.

The tank model is recommended as the hydrological forecasting model in the Yuam river basin by reason that the reliability of the tank model in this basin is already verified by this study.

(4) Installation Cost

The installation cost of the alternative hydrological forecasting system is roughly estimated 28 million Baht shown in a table below, which cost is not including the establishment cost of the hydrological forecasting model in development and operational mode.

Table 1 Installation Cost of Alternative Hydrological Forecasting System

(Million Baht)

Description	Unit	Quantity	Unit Price	Cost
1. Rainfall Station 1)	Station	5	2.0	10.0
2. VHF Relay St. 2)	Station	2	3.2	6.4
3. Main Terminal 3)	Station	1	3.0	3.0
4. CPU 4)	L.S.	1	--	5.0
5. Others 5)	L.S.	1	--	3.6
Total				28.0

Note 1) Installation cost of a rainfall station is listed for detailed items below.

Measuring equipment	0.30
Radio equipment	0.16
Solar battery	0.20
Rain guage & auxiliaries	0.14
House construction	0.60
Installation	0.60
Total	2.0 million Baht

The unit price of 2.0 million Baht is a rough estimate to install a new rainfall station. Detailed estimation should be carried out if existing facilities or equipments could be used or not by a detailed investigation of the existing rainfall station.

Note 2) Installation cost of a VHF relay station is listed for detailed items below.

Relay equipment	0.70
Radio equipment	0.64
Solar battery (2 units)	0.40
Auxiliaries	0.34
House construction	0.60
Installation	0.52
Total	3.20 million Baht

The unit price of 3.2 million Baht is a temporary estimate, and a detailed study should be carried out to determine the number of VHF relay stations and their location.

Note 3) Installation cost of the main terminal at the Mae Lama Luang power station is listed for detailed items below.

Observatory equipment	1.20
Printing device	0.24
Operation panel	0.44
Auxiliaries	0.52
Installation	0.60
Total	3.00 million Baht

Note 4) The cost CPU includes the cpu, on-line control program and CRT display.

Note 5) Other cost is roughly estimated for the inland transportation of equipments to the site.

2. Runoff Analysis (ARMA Model) Method

2.1 Outline of ARMA Model Method

The conditions required of a runoff model for predicting flood are as follows:

i) That the model is simple and calculations can be made rapidly,

ii) That the parameters of the prediction model are stable,

iii) That the accuracy of prediction is high, and

iv) That the calculation model has been structured on a physical basis

It may be considered that the ARMA Model Method is a run-off model which statisfies these conditions. There are two ways of predicting floods by the ARMA Model Method: (1) a method of predicting flood discharge from flood discharge data only, and (2) a method of predicting flood discharge from rainfall data.

The method of predicting flood discharge from discharge data only is according to the procedure below.

i) Discharge-time series obtained from time to time are passed through a numerical filter each time and are divided into groundwater runoff components and intermediate-surface runoff components.

ii) Effective component rainfall-time series are individually calculated inversely by the ARMA Model Method based on the individual component runoff-time series. Methods of inversely calculating available are the direct method, SLQ method, and LP method.

iii) Future rainfall is predicted from the time series of the individual component rainfalls (groundwater component rainfall, intermediate-surface component rainfall).

iv) The runoffs of the individual component systems are predicted from these rainfalls and the total flood discharge is predicted from these.

In the method of predicting flood discharge from rainfall data, the step of ii) above is altered as follows:

ii-a) The measured rainfall is separated into ground-water component rainfall and other components according to the nonlinear separation law.

ii-b) The other component rainfalls are separated into intermediate-surface component rainfall and loss component rainfall in accordance with the partial source area law.

2.1.1 Runoff Prediction from Flood Discharge Data

When discharge data can be obtained incessantly, the flood discharge until several hours later than the present is predicted. In such case, rather than simply applying the prediction theory to the discharge data, a high prediction accuracy can be expected by inversely calculating effective component rainfall by discharge-time series.

This method consists of repeatedly applying the discharge analysis technique according to the ARMA Model Method each time that flood discharge data are received, using the inversely estimated rainfall data obtained as a result to predict future rainfall, and predicting flood discharge from these rainfall data.

The procedure in concrete terms is as follows:

1) Discharge-time series data are passed through a numerical filter to separate into ground-water runoff components and intermediate-surface runoff components.

2) From the individual component runoff-time series, the individual effective component rainfall-time series are inversely calculated by the ARMA Model Method (inverse

estimation of rainfall). Methods of calculating available are the direct method, SLQ method, and LP method.

3) From these inversely estimated rainfalls the runoff amounts of the individual component systems are calculated using the AR equation, and the total flood discharge is obtained aggregating these runoffs.

(1) Component Separation of Discharge

It is widely known in concept that runoff is made up of a number of component systems. Accordingly, the discharge-time series yi up to the present time i is separated into momentary underground runoff component yi (1) and intermediate-surface runoff component yi (2) using a numerical filter whose characteristics are determined by the past gradual flood decrease curve.

$$yi^{(1)} = \alpha \Sigma w_j y_{i-j}$$
$$yi^{(2)} = yi - yi^{(1)} \qquad (2.1\text{-}1)$$

where, : weight coefficient

Here, if necessary, the second component $yi^{(2)}$ is further separated into two components.

(2) Inverse Calculation of Effective Rainfall

Actual rainfall changes form while infiltrating through soil to become effective rainfall components for a runoff system. The separation of the rainfall into each runoff system is nonlinear, but the runoff system itself can be handled as being linear. If one response system is linear and the dynamic characteristics (unit graph, AR coefficient, etc.) of the system are known, it will be possible to estimate output (discharge) from input (rainfall), of course, and conversely, to inversely calculate input (rainfall) from output (discharge).

With the ARMA Model Method, rainfall in units of an hour has the nature of white noise, and the characteristic of the systme is estimated using this nature. In effect, the component discharge $yi^{(1)}$ is expressed as follows by the AR equation:

$$yi^{(1)} = a_1 y_{i-1} + a_2 y_{i-2} + a_3 y_{i-3} + \ldots\ldots + \varepsilon \quad (2.1\text{-}2)$$

If discharge-time series $Yi^{(1)}$ ($i = 0, 1, 2, \ldots.$) is given, even though white noise ε is unknown, the AR coefficient can be estimated by methods such as the Yule-Walker method and the Barg method, and the characteristics of the system determined.

Regarding the characteristics (unit graph, AR coefficient) of the system, it will be necessary for them to be decided performing runoff analyses beforehand.

(3) Inverse Estimation of Effective Component Rainfall

Prediction of flood, in case the prediction time is short, can be done by discharge-time series, but to accurately predict flood for a prediction time which is of a certain length, it is necessary to predict rainfall which is the input.

However, it is necessary first to separate actual rainfall into individual component systems, or to estimate component rainfall by some method. Accordingly, since the white noise ε is Eq. (2.2-2) corresponds to rainfall, Eq. (2.1-2) is altered and the component rainfall is inversely calculated by the following equation.

$$xi\text{-}1^{(1)} = (yi^{(1)} - a_1 y_{i-1}{}^{(1)} - a_2 y_{i-2}{}^{(1)} \ldots)/\lambda b \quad (2.1\text{-}3)$$

where, $i = 1, 2 \ldots\ldots, n$
b = coefficient ($b - 1 - a_1 - a_2 \ldots\ldots$)
λ = unit transformation coefficient

For inversely estimating component rainfall from Eq. (2.1-3), there is 1 the direct method of solving Eq. (2.1-3) by each time step one by one, and the method of simultaneously setting up and solving the unit graph response function (h_i equation) for all ($i = 1, 2, \ldots., n$) up to this time and Eq. (2.1-4).

$$y_i = h_1 x_{i-1} + h_2 x_{i-2} + \ldots\ldots\ldots\ldots\ldots \quad (2.1\text{-}4)$$

where, hi: response function (unit graph)

There is further (3) the linear planning (LP) method in which solving is done with

$$x_i > 0 \; (i = 1, 2, \ldots.., n) \quad (2.1\text{-}5)$$
$$\Sigma|\varepsilon_i| \rightarrow \min$$

As the optimum problem which minimizes error based on (2) smoothing out method of least squares (SLQ) and with negative value not taken for rainfall.

(4) Prediction of Rainfall

The inversely estimated rainfall obtained in this manner is not actual rainfall itself, but is the effective component rainfall after lagging and alteration of actual rainfall in the process of infiltrating through soil. However, since this is prediction of flood, it would suffice if the effective component after lagging and being subjected to alteration can be predicted.

The method of predicting rainfall necessary for flood prediction will be described below.

(a) Extrapolation of Inversely Calculated Effective rainfall

It is only up to the present time that inversely calculated rainfall can be estimated and the future rainfall-time series required for flood prediction cannot be known. However, the groundwater component rainfall is smoothed out during the process of infiltrating through soil, and a gradual alteration occurs. Consequently, future effective rainfall can be determined by simple extrapolation.

$$x_{i+ip}^{(1)} = (p^{(1)})^{LP} \, x_i^{(1)} \quad (2.1\text{-}6)$$

where, $p^{(1)}$: extrapolated load (p= 0.8)

On the other hand, the effective component rainfall for intermediate and surface runoff varies irregularly in accordance with the irregularity of actual rainfall. Because of this, since simple extrapolation would be meaningless, the rainfall $x^{(2)}(t)$ smoothed out over the past several hours is extrapolated.

(b) Rainfall Prediction from Rainfall Data (Estimate)

Even in the case that rainfall data up to the present time $t = i\Delta t$ can be obtained, it is not that those rainfall data will directly become effective component rainfalls, so that the value according to inverse calculation from actual discharge data will be used as effective component rainfall up to the present time.

Beyond the present tie, inversely calculated effective rainfall cannot be determined since measured discharge data are not available. However, in case there are rain-fall data, there is generally a time lag (lag 2) until rainfall acts effectively on runoff, and there would be rainfall in advance by the amount of this time. Therefore, component rainfall is predicted by simple runoff ratio, or using the conception of the law of separation of rainfall described in 2.6 and P.S.A. (Partial Source Area).

However, in case the predicted time exceeds the time lag until runoff, component rainfall is predicted by the method of smoothed out extrapolation previously described.

Prediction of the intermediate-surface runoff component is done by the following equation i view of the facts that rainfall for several hours corresponding to the time lag has not yet acted on the runoff system and that change in the groundwater component rainfall is extremely gradual.

$$S^{(2)}{}_{i+ip} = f.X_{i+ip-lag\ 2} - x_i^{(1)} \qquad (2.1\text{-}7)$$

where, (ip = 0, 1, ..., lag 2)

or

$$X^{(2)}{}_{i+ip} = al(s)\{X_{i+ip} - x_i^{(1)}\} \qquad (2.1\text{-}8)$$

where, ip: prediction time step

lag 2: time lag in action of rainfall

f: runoff ratio

al(s): P.S.A. ratio to princial catchment area

The method of (a) is used for a predictiontime exceeding this range.

In general, lag 2 is from 2 to 3 hours, so that this method can be used for prediction 2 to 3 hours ahead of time.

(5) Prediction of Flood Discharge

If rainfall can be predicted, it is a simple matter to predict flood discharge. This is done by Eq. (2.1-9) using the predicted values of these component rainfalls, or Eq. (2.1-10) the component unit graph hi equation obtained by conversion of the AR coefficient.

$$y_{i+ip} = a_1 y_{i+ip-1} + a_s y_{i+ip-2} + \ldots + b x_{i+ip-1} \qquad (2.1\text{-}9)$$

or

$$y_{i+ip-1} = h_1 x_{i+ip-1} + h_2 x_{i+ip=2} + \ldots.. \qquad (2.1\text{-}10)$$

When substituting predicted values in y of the AR equation of Eq. (2.1-9) one after another, the predicted value according to the AR equation of Eq. (2.1-9) one after another, the predicted value according to the AR equation will exhibit an unstable behavior so that a better result is obtained with the hi equation of Eq. (2.1-10), namely, the unit graph method. However, an AR equation expression generally requires a small number of terms, but when this is transformed to the hi equation, the number of terms will be increased.

2.1.2 Prediction of Runoff from Measured Rainfall

A case of determining flood discharge from rainfall data will be considered. As is well known, rainfall can be divided into loss rainfall consisting of initial loss, tree canopy obstruction, evapotranspiration, etc., and effective rainfall contributing to runoff into streams. Effective rainfall is further divided into the runoff component rainfalls of intermediate-surface and groundwater inside ground strata. Here, the point of separation of rainfall observed into effective components will be discussed. The procedure in concrete terms is as follows:

(1) The observed rainfall is separated by the nonlinear law of separation into groundwater component and other components.

(2) The other components are separated into intermediate-surface components and loss component rainfall according to the partial source area law.

(3) The runoff quantities of the individual component systems are calculated from these separated rainfalls using the AR equation, and the total flood discharge is obtained by aggregating these quantities.

1) Effective Component Rainfall According to the Law of Separation of Rainfall

Rainfall is separated into groundwater compoennt rainfall $xi^{(1)}$ and intermediate-surface component rainfall $xi^{(2)}$ by the law of separation below.

(a) Initial Loss

There is no contribution to runoff until the quantity of initial loss (L_0) is reached by the cumulative quantity (Σx) of observed rainfall.

$Xi^{(1)} = 0 \quad (\ell = 1, 2) \; (\Sigma xi < Lo)$ (2.1-11)

where, xi: observed rainfall (mm)

Lo: initial loss (mm)

(b) Groundwater Component Rainfall

When the cumulative quantity (x) of observed rainfall reaches the initial loss L_o, the subsequent rainfall first becomes groundwater component rainfall.

$$Xi(1)\begin{cases} = xi^{(1)} & (xi \leqq xG) \\ = xG & (xi > xG) \end{cases} \qquad (2.1\text{-}12)$$

(c) Intermediate-Surface Runoff Component Rainfall

When the groundwater component rainfall reaches a saturated condition, part of the surplus rainfall becomes diect rnoff (surface-intermediate runoff component) from P.S.A (partial source area, see 2.6) and the remainder of the rainfall is stored in soil.

$$Xi(2)\begin{cases} = 0 & (xi \leqq xG) \\ = ap(s)(xi - xG) & (xi > xG) \end{cases} \qquad (2.1\text{-}13)$$

where, $a_{p(s)}$: partial source area ratio to total catchment area

This $a_{p(s)}$ is a function of catchment area storage quantity S.

$$S(t) = \int_o^t (x_{(t)} - y_{(t)})dt$$

where, the form of function $a_{p(s)}$ is

$$a_{p(s)} = \frac{S}{So} \quad (S \leqq So)$$

$$ap(s) = 0 \quad (S > So)$$

where, S_o: saturated storage quantity or, $a_{p(s)} = 1 - \exp(-S/S_o)$

2) Prediction of Rainfall

Rainfall is predicted in the same manner as in 2.1.4 (4).

3) Prediction of Flood Discharge

The individual component rainfalls having been obtained according to the foregoing, flood idscharge is predicted by the method of 2.1.1 (5).

2.1.3 Preparation of Parameters

In order to predict flood discharge by the ARMA Model Method, it is necessary to make known the characteristics (AR coefficient, unit graph, etc.) of the rainfall-runoff system performing runoff characteristics analyses beforehand.

The procedure is explained in brief below.

(i) Several cases of flood data (rainfall, discharge, etc.) required for runoff analysis are selected. In selecting data, it is desirable for rainfall data to have small spatial and temporal dispersion, discharge data to have a single peak of a clean line, discharge data with the gradual decrease portion long, and the scale of the flood medium.

(ii) The discharge-time series data yl are divided into groundwater runoff component Yi(1) and intermediate-surface runoff component yi(2) using a numerical filter w_1. If necessary, the second component $yi^{(2)}$ is further divided into two components.

At this time, it is necessary for the time constant Tc of component division to be calculated beforehand and the damping-parameter of filter selected.

(iii) The individual component AR coefficients are calculated by the AR equation which is an autoregressive equation using the separated runoff components yi(1) and yi(2).

Methods available for calculations are the Yule-Walker method and the Barg method.

(iv) The optimum degrees of the AR coefficients for the individual components are selected. As judgement criteria for optimum degrees, there are the method of least squares, the FPE method, and the AIC method.

Actually, however, AR coefficients are decided referring to unit graphs obtained at the stage of (v).

(v) The AR coefficient is transformed to a unit graph.

* As characteristics (AR coefficient, unit graph) of the rainfall-runoff system have been calculated to an extent, the phenomena of rainfall-runoff separated into components can be handled as linear systems.

(vi) Inverse estimation of the component rainfall-time series is done. The ARX equation considering the error term of the AR equation as rainfall is solved with regard to rainfall quantity, and the component rainfall solution series is obtained.

$$\overline{xi}^{(1)} = \{yi^{(1)} - a1^{(1)}yi\text{-}1^{(1)} - a2^{(1)}yi\text{-}2^{(1)} \; \ldots\ldots \; ap^{(1)}yi\text{-}p\}/\lambda b$$

Methods available for calculation are the direct method, smoothed-out method of least squares (SLQ), and the linear planning method (LP).

(vii) Considerations are given to parameters such as those below from the component effective rainfall-time series inversely estimated.

a) Runoff ratio (RATIO)

b) Initial loss rainfall (X_{loss})

c) Time lag for start of effective rainfall
(lag 1, lag 2)

d) Elongation magnification of rainfall (ELG)

e) Ultimate infiltration capability of ground water (R-ground)

f) Maximum value of basin storage quantity (So)

(viii) By calculating the steps from (i) to (vi) for individual cases of flood, the AR coefficient on average is determined for each component.

For AR coefficient, an average value or a representative value is taken.

The same applies for the parameters listed in (vii).

(ix) Studies are made of reproduceabilities performing runoff analyses for the individual cases of flood (see 2.1.2) using AR coefficients or unit graphs obtained by system identification.

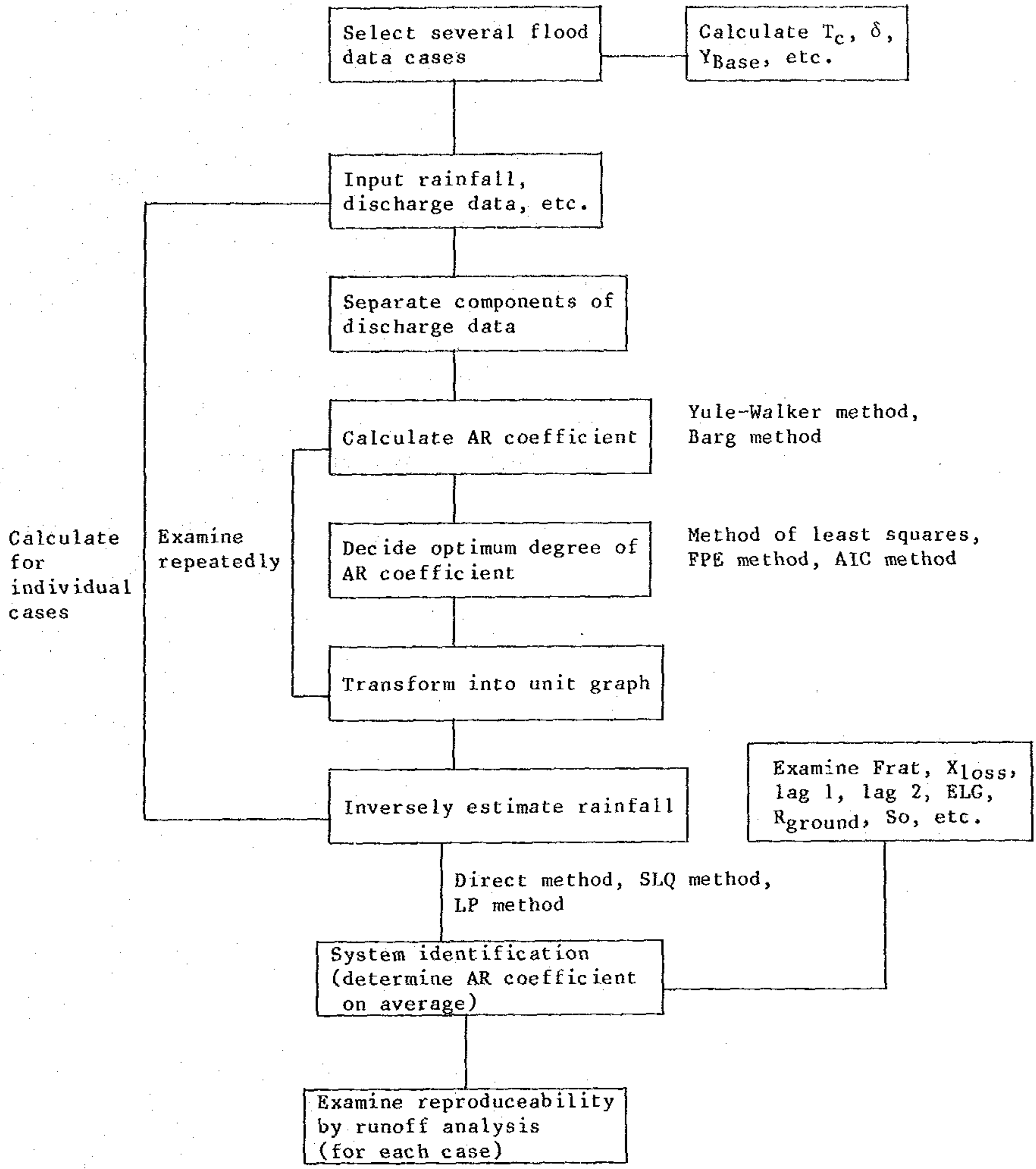


Fig. 2.1-2 System Identification Procedure

APPENDIX—B

GEOLOGY AND CONSTRUCTION MATERIALS

APPENDIX-B GEOLOGY AND CONSTRUCTION MATERIAL

CONTENTS

B-1 SEISMIC PROSPECTING

B-1-(1) HAGIWARA'S ANALYSIS METHOD

B-1-(2) SEISMIC PROFILE AND TIME DISTANCE CURVE

B-1-(1) HAGIWARA'S ANALYSIS METHOD

*** Hagiwara's analysis method:**

As shown in Fig. A, this method considers the ground to be a two layered structure, with velocity in the upper layer V_1 and velocity in the lower layer, V_2. T_{AP} is travel time of refracted wave from shot point A, received at P; T_{BP} is travel time of the refracted wave from B to P; and T_{AB} is travel time of the refracted wave from A to B (The white circles in the figure represent travel times of refracted waves received at P. The X marks represent travel times of direct waves–those waves received at P that are propagated in the first layer only.) Here, T_{AP}, T_{BP} and T_{AB} are quantities obtainable through direct observation. The quantity t_0, where

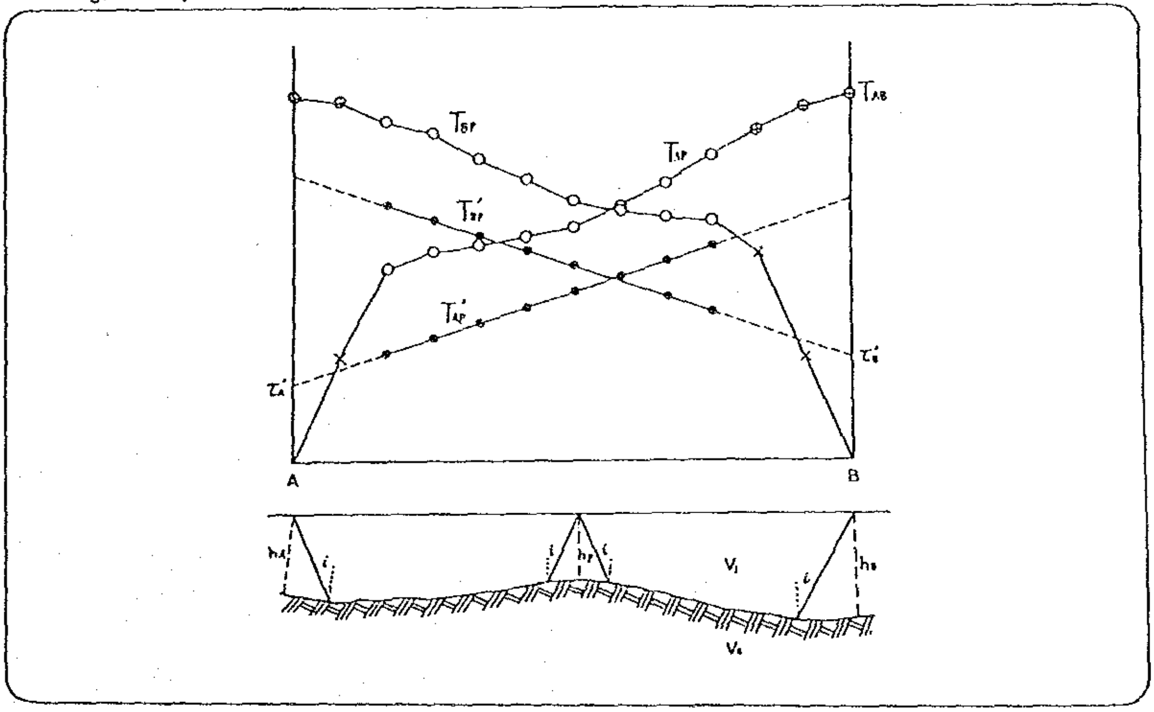
$$t_0 = T_{AP} + T_{BP} - T_{AB} \qquad \text{(a)}$$

is called zero travel time. The quantities T_{AP}' and T_{BP}', where

$$\left.\begin{aligned} T_{AP}' &= T_{AP} - t_0/2 = (T_{AP} - T_{BP} + T_{AB})/2 \\ T_{BP}' &= T_{BP} - t_0/2 = (T_{BP} - T_{AP} + T_{AB})/2 \end{aligned}\right\} \qquad \text{(b)}$$

are called velocity travel time (the black circles in the figure indicate velocity travel time). The curve that successively joins the velocity travel times determined for each receiving point is called the velocity travel time curve. Theoretically, this is a straight line, and its slope indicates velocity V_2 of the lower layer. Velocity V_1 of the upper layer is determined from the travel time of the direct wave mentioned above.

Fig. A Explanation of Hagiwara's analysis method



If we designate the length of a perpendicular line drawn from receiving point P to the surface of the lower layer (depth of the lower layer) h_P,

$$h_P = \frac{V_1(T_{AP}+T_{BP}-T_{AB})}{2\cos i} \qquad \text{(c)}$$

where $\sin i = V_1/V_2$, meaning that h_P may be determined.

We have seen that where T_{AP} and T_{BP} are both known for the receiving point, depth of the lower layer can be determined using Formula (c). However, for the points marked ⊕ in the figure, only one of the values, T_{AP} or T_{BP} is known. For these receiving points, Formula (b) is substituted into Formula (c), giving us:

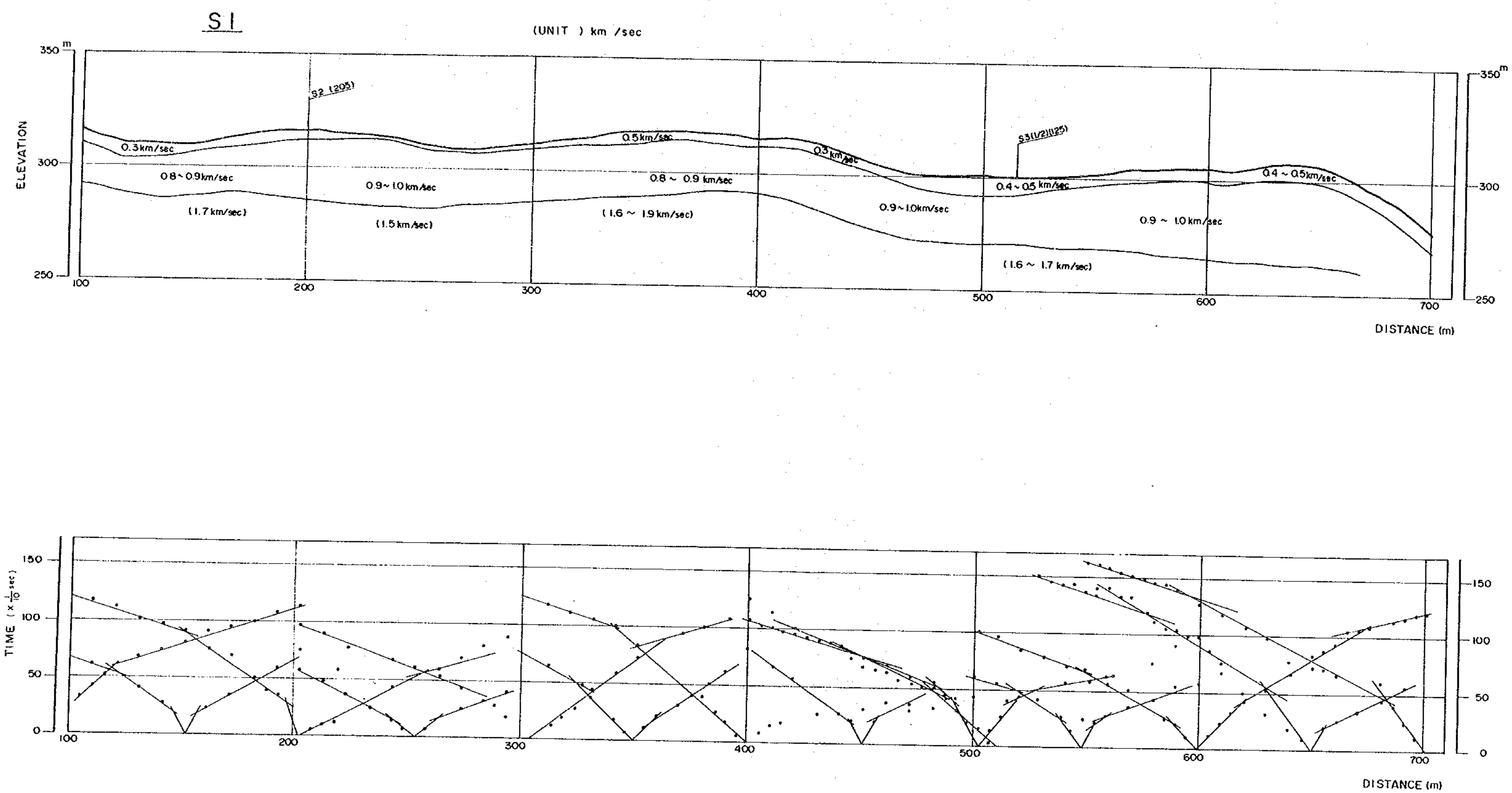
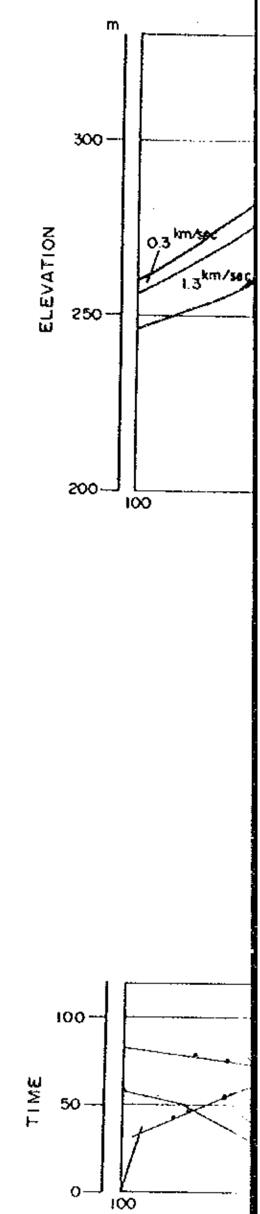
$$\left.\begin{aligned} h_P &= \frac{V_1(T_{AP}-T_{AP}')}{\cos i} \\ h_P &= \frac{V_1(T_{BP}-T_{BP}')}{\cos i} \end{aligned}\right\}$$

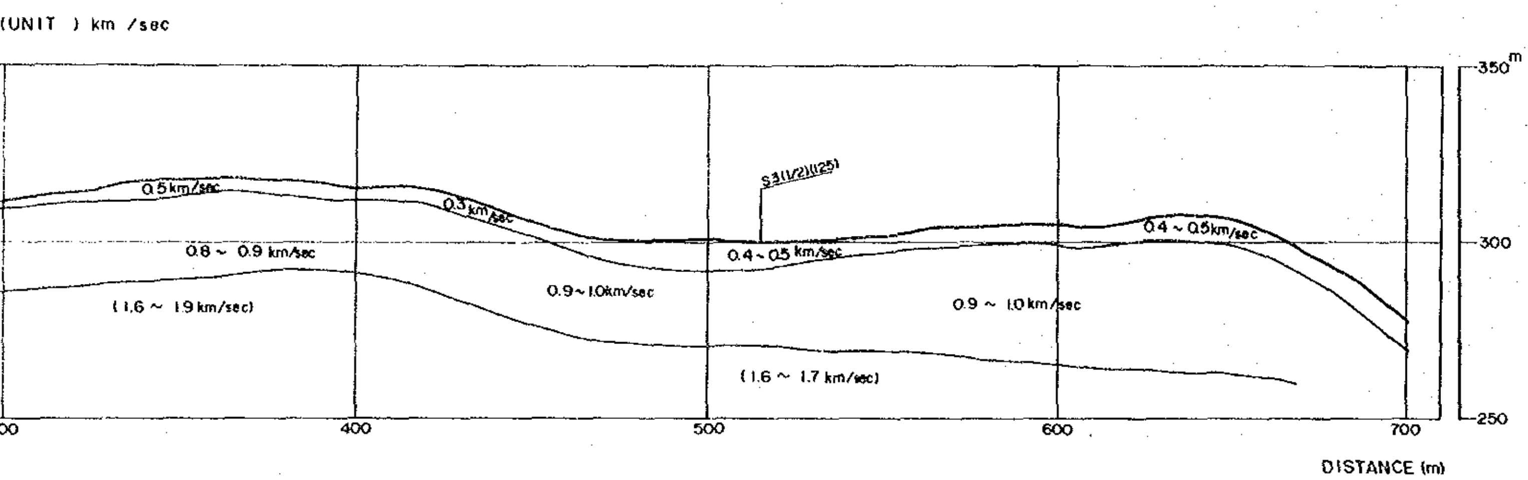
Here, the values T_{AP}' or T_{BP}' extend the velocity travel time curve. The values at P read off from this extended curve may be used.

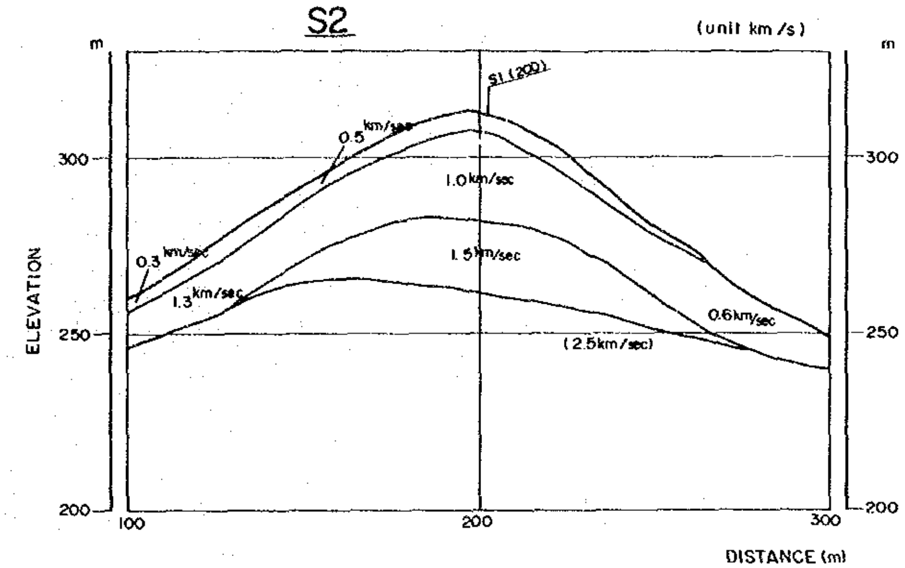
Also, if we designate the value of the point where velocity travel time curve T_{AP}' intersects the vertical axis at shot point A as τ_A' and the point where T_{BP}' intersects the vertical axis at shot point B as τ_B', the following formulas are obtained:

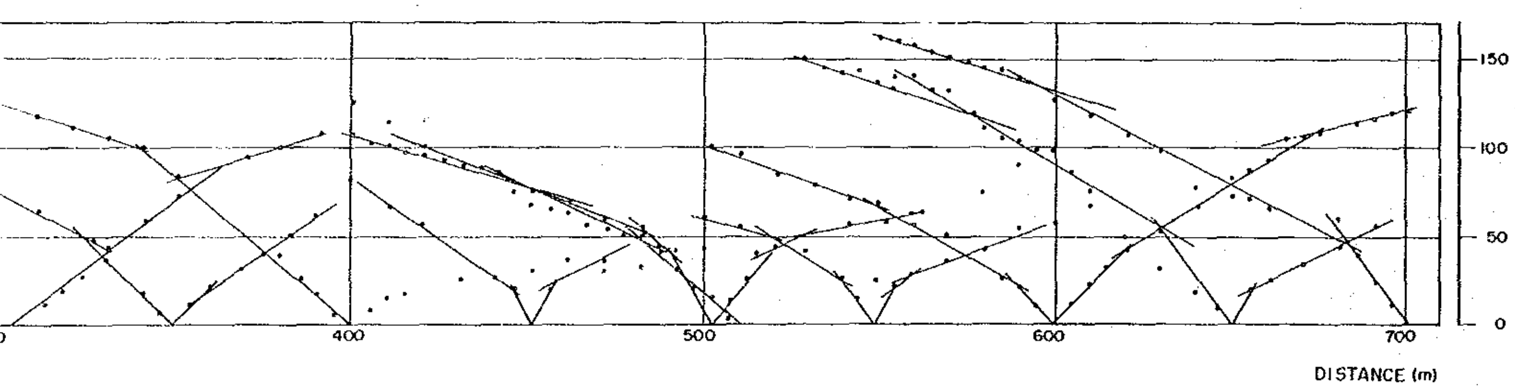
$$\left.\begin{aligned} h_A &= \frac{V_1\tau_A'}{\cos i} \\ h_B &= \frac{V_1\tau_B'}{\cos i} \end{aligned}\right\} \qquad \text{(d)}$$

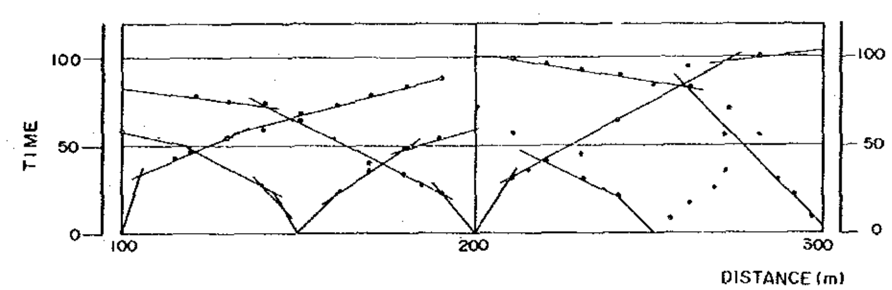
B-1-(2) SEISMIC PROFILE AND TIME DISTANCE CURVE


S I
(UNIT) km /sec
ELEVATION
S2 (205)
S3(1/2)(125)
0.3km/sec
0.5km/sec
0.3km/sec
0.4 ~ 0.5km/sec
0.8 ~ 0.9km/sec
0.9 ~ 1.0 km/sec
0.8 ~ 0.9 km/sec
0.4 ~ 0.5 km/sec
0.9 ~ 1.0km/sec
0.9 ~ 1.0 km/sec
(1.7 km/sec)
(1.5 km/sec)
(1.6 ~ 1.9 km/sec)
(1.6 ~ 1.7 km/sec)
DISTANCE (m)
TIME (× 1/10 sec)
DISTANCE (m)

ELEVATION
0.3 km/sec
1.3 km/sec
TIME





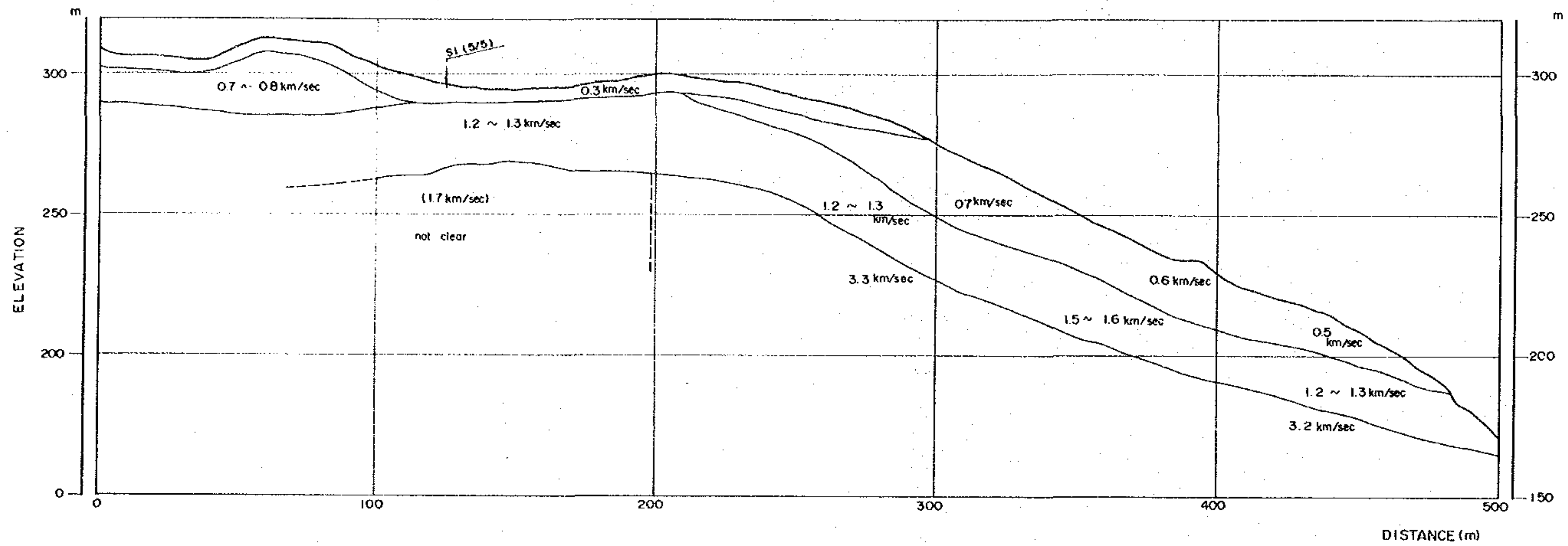




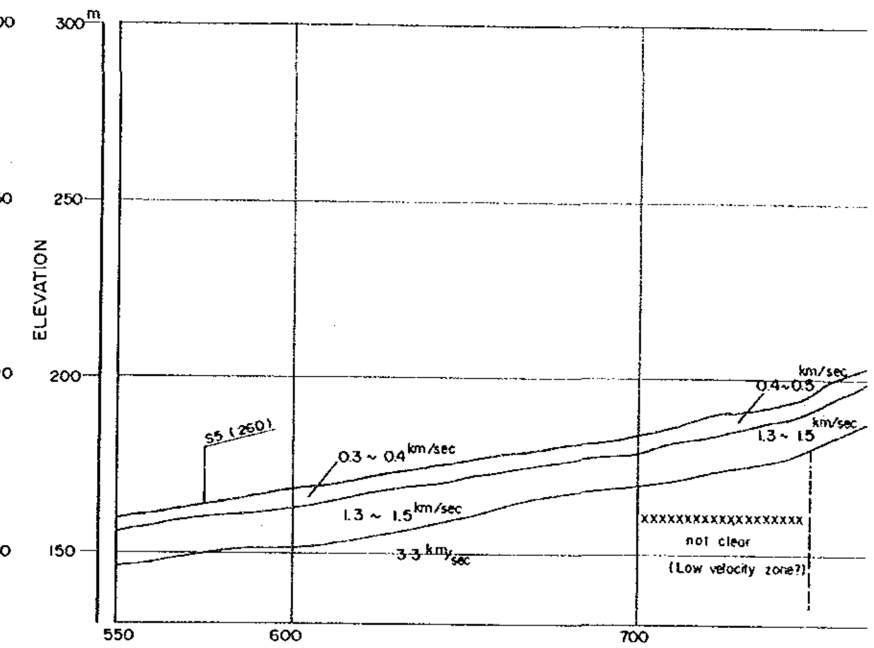
NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT
GEOLOGY
NAM NGAO DAM SITE NO.2 SEISMIC PROFILE and TIME DISTANCE CURVE S1. S2 lines
Fig. 6-2(1-6) Appendix

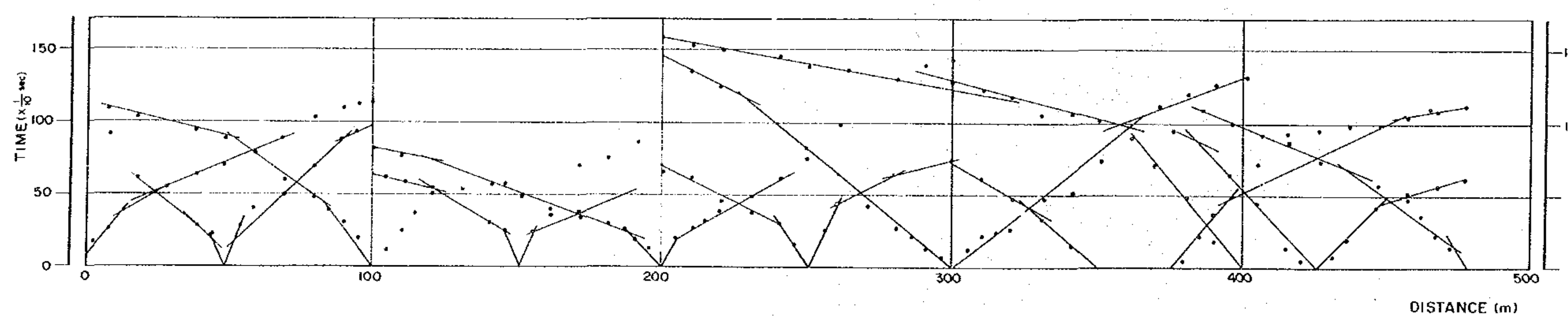
S3 (1/2)

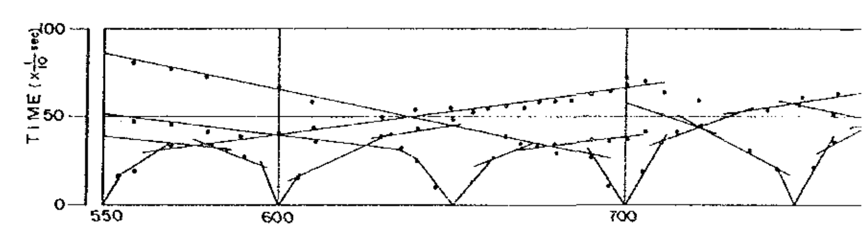
(UNIT) km / sec

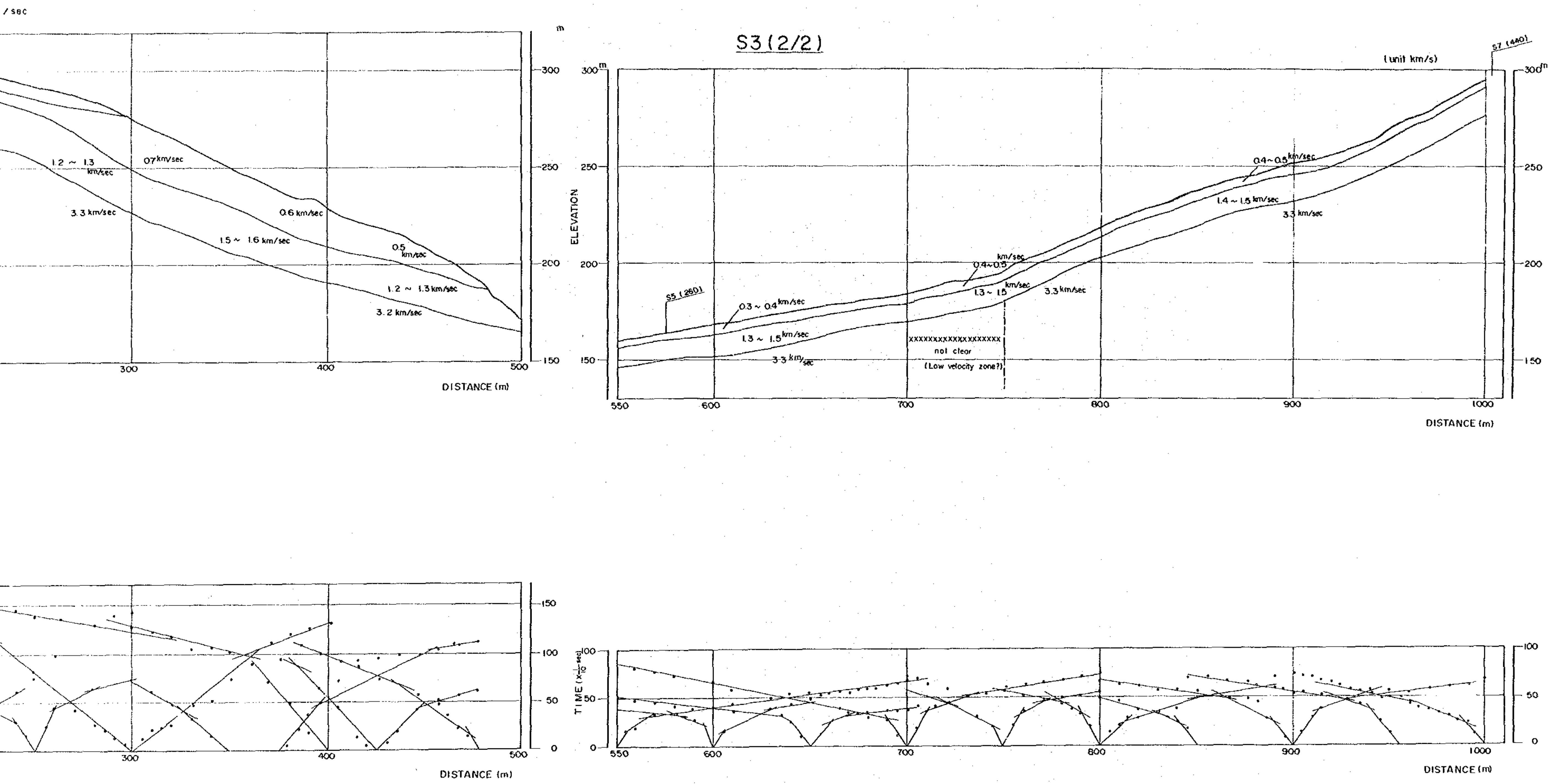


S3 (2/2)



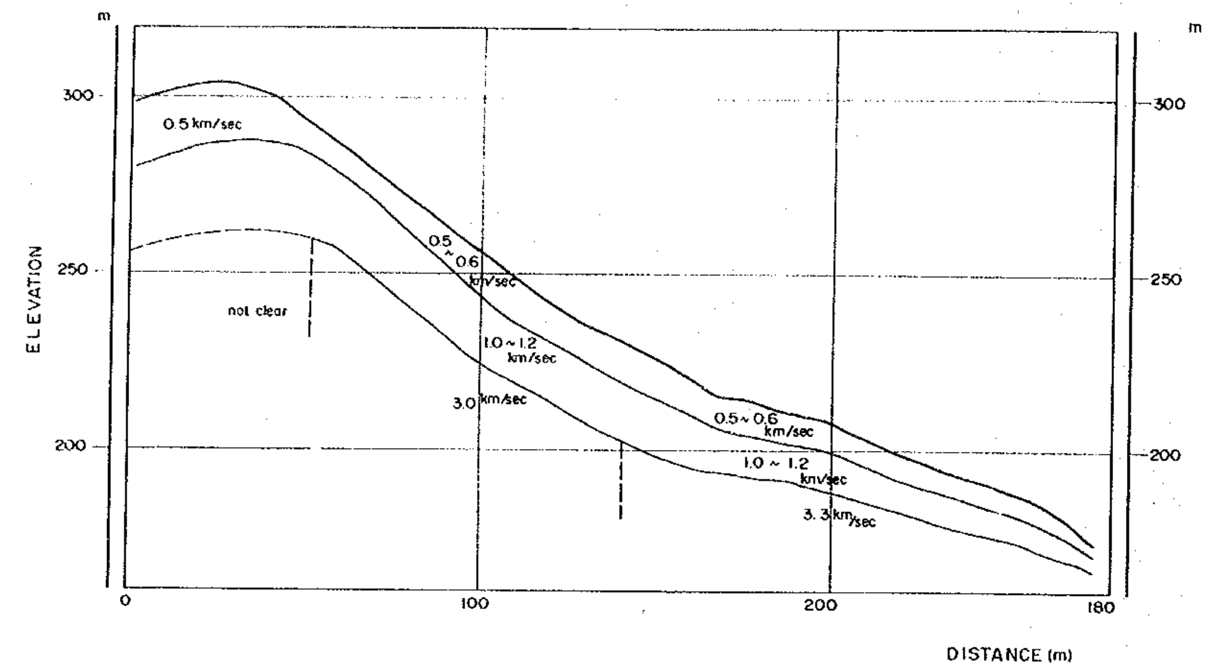




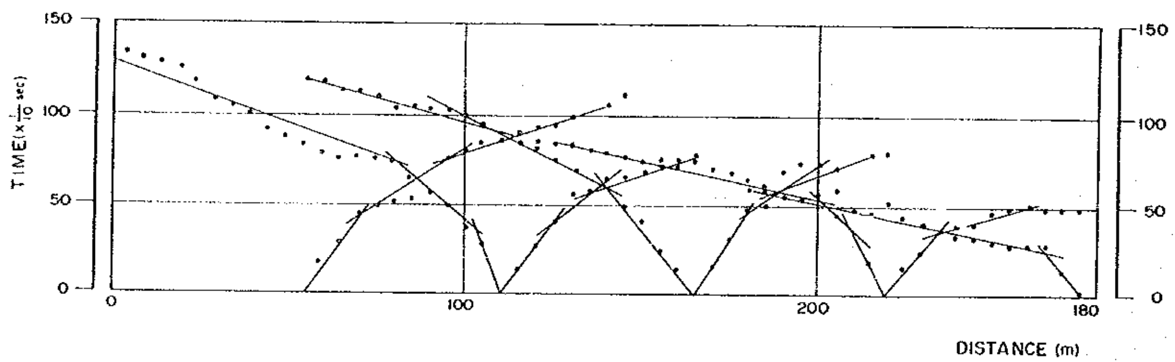


NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT	
GEOLOGY	
SEISMIC PROFILE and TIME DISTANCE CURVE	
S3(1/2), S3(2/2) lines	
Fig. 6 - 2(2-6)	Appendix

S 4

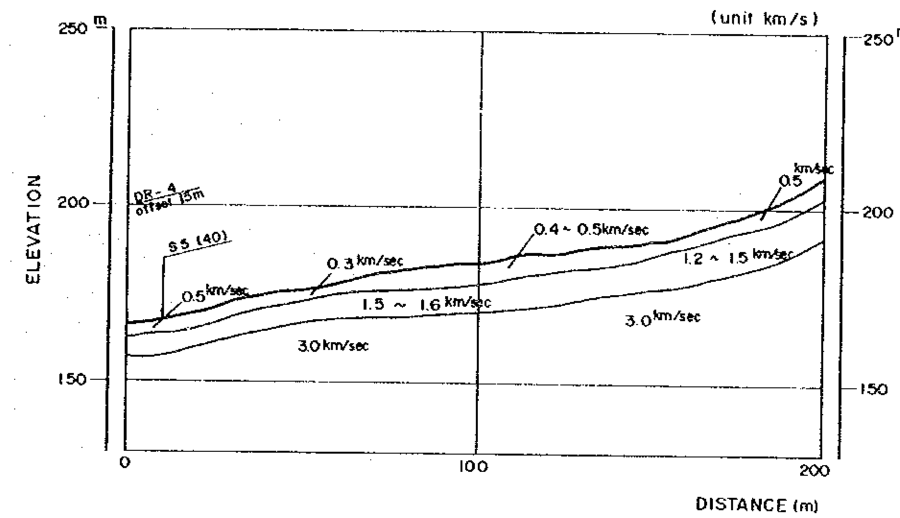


(UNIT) km / sec
ELEVATION
m
0.5 km/sec
0.5 ~ 0.6 km/sec
not clear
1.0 ~ 1.2 km/sec
3.0 km/sec
0.5 ~ 0.6 km/sec
1.0 ~ 1.2 km/sec
3.3 km/sec
DISTANCE (m)

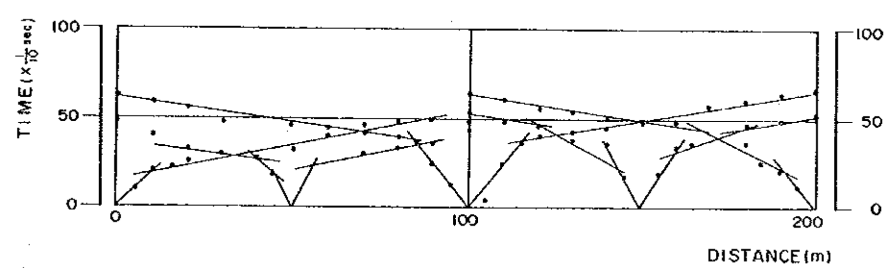


TIME (x 1/10 sec)
DISTANCE (m)

S4a

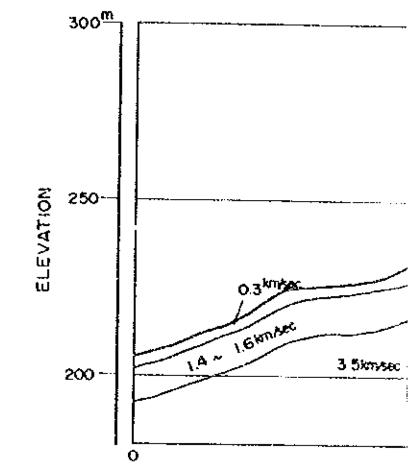


(unit km/s)
ELEVATION
DR-4 offset 15m
S5 (40)
0.5 km/sec
0.3 km/sec
0.4 ~ 0.5 km/sec
0.5 km/sec
1.5 ~ 1.6 km/sec
1.2 ~ 1.5 km/sec
3.0 km/sec
DISTANCE (m)

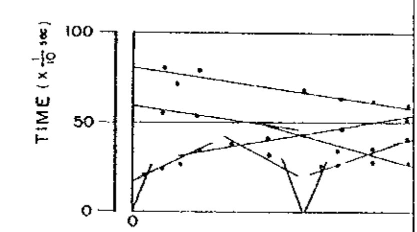


TIME (x 1/10 sec)
DISTANCE (m)

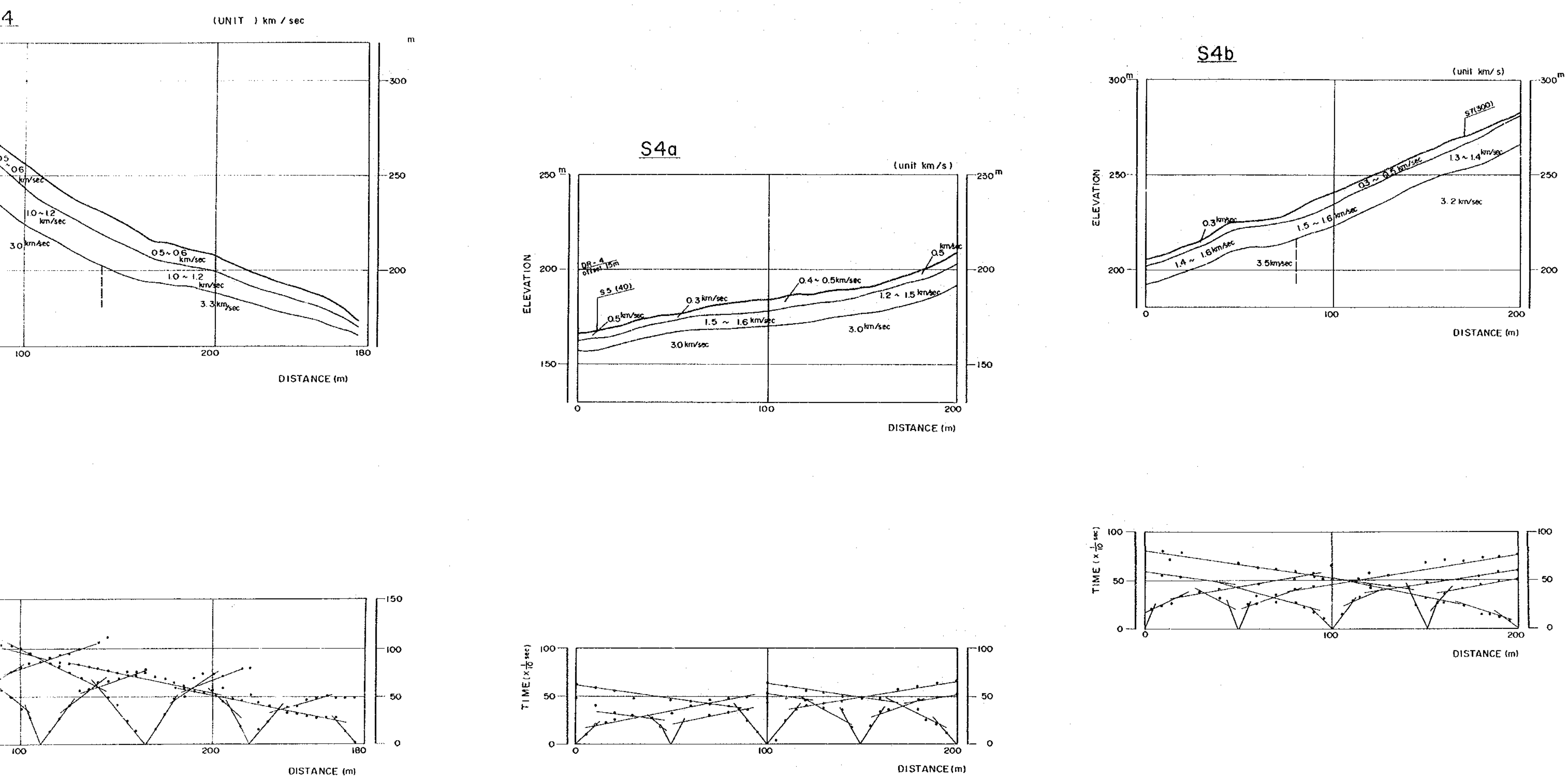
S4b



ELEVATION
0.3 km/sec
1.4 ~ 1.6 km/sec
3.5 km/sec



TIME (x 1/10 sec)



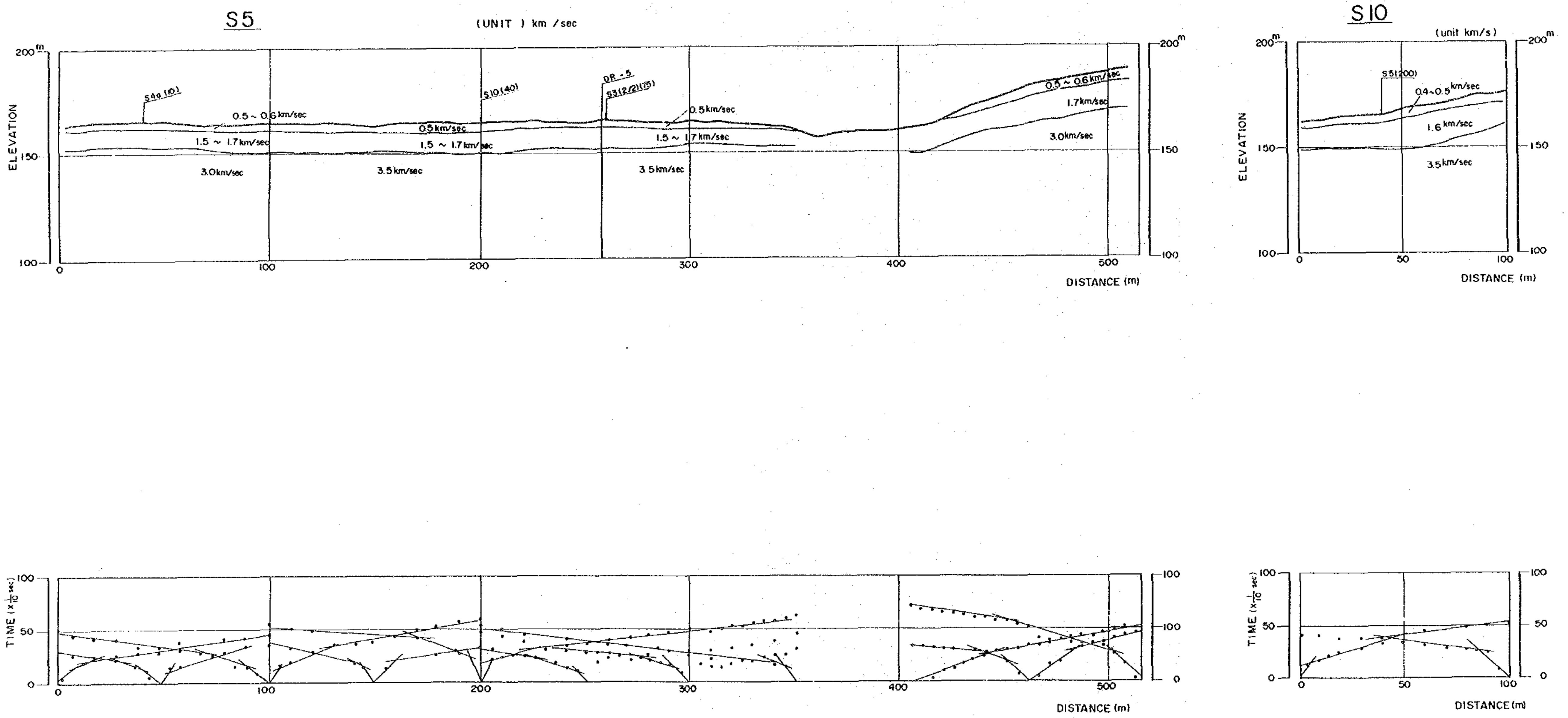
NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT

GEOLOGY

SEISMIC PROFILE and TIME DISTANCE CURVE

S4. S4a. S4b lines

Fig. 6-2(3-6) | Appendix



NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT

GEOLOGY

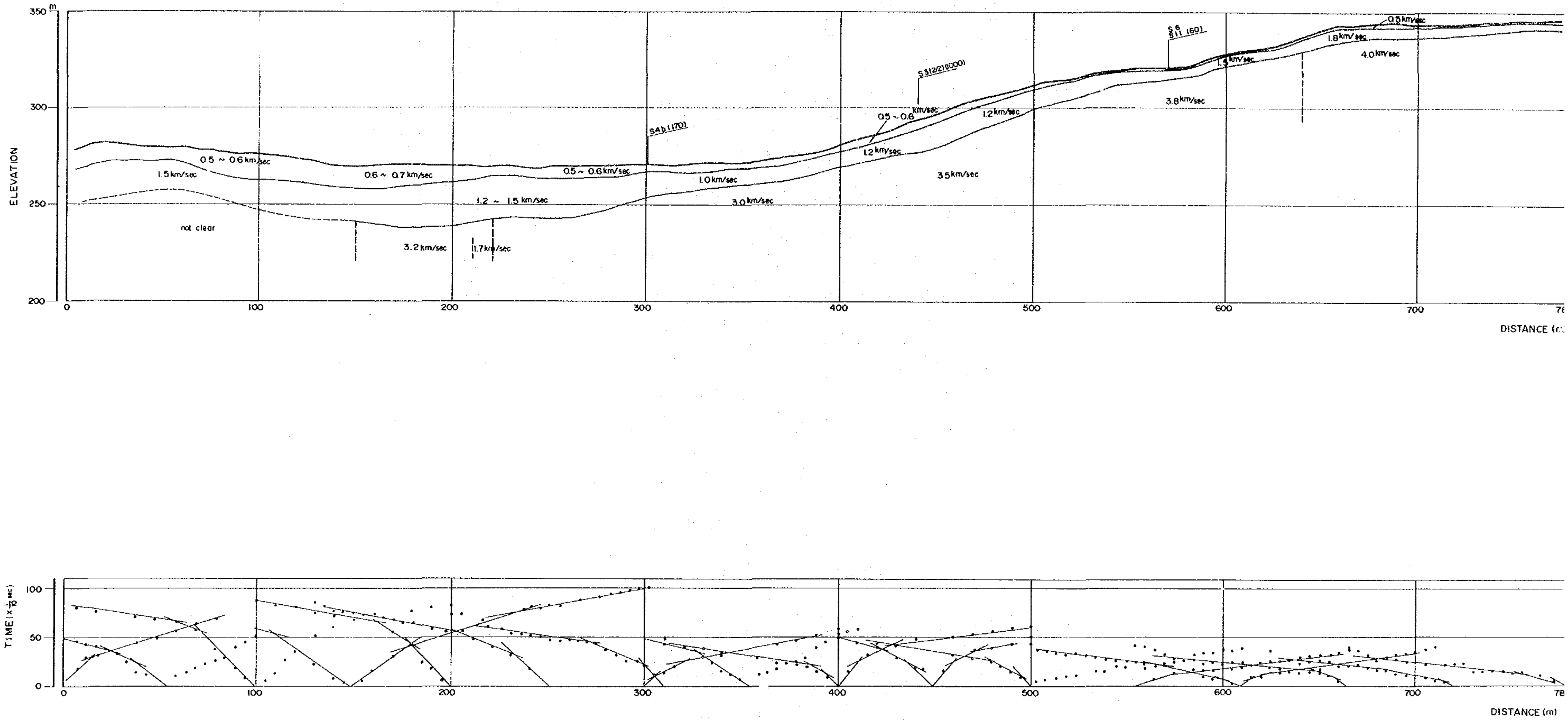
SEISMIC PROFILE and TIME DISTANCE CURVE

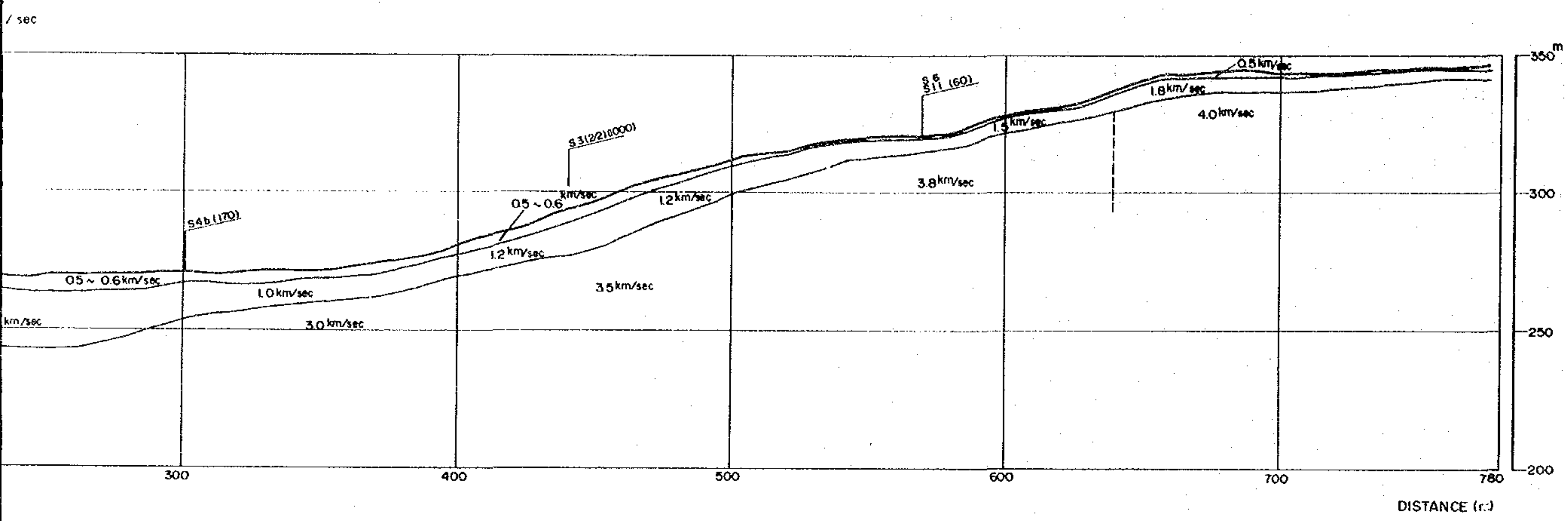
S5. S10 lines

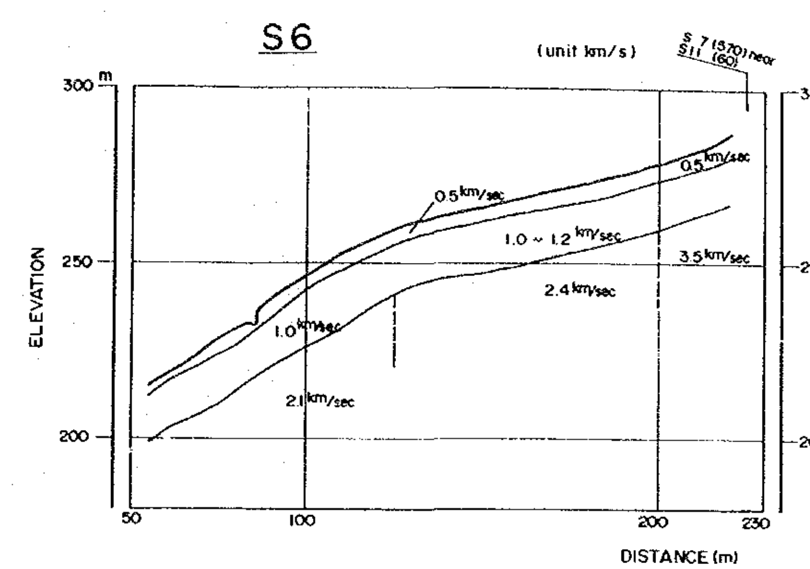
Fig. 6-2(4-6) | Appendix

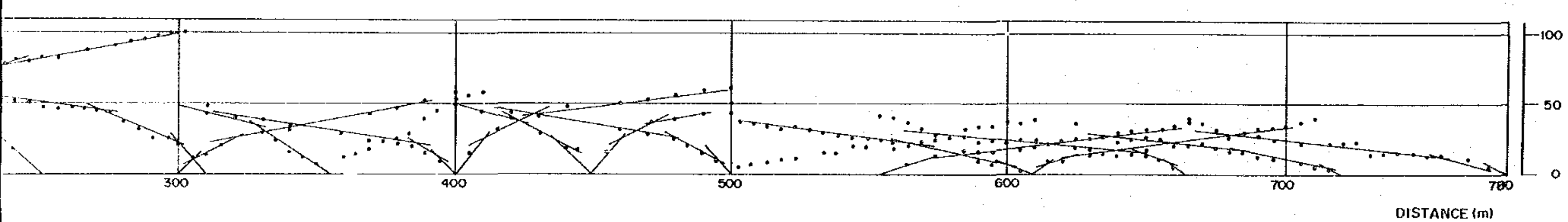
S7

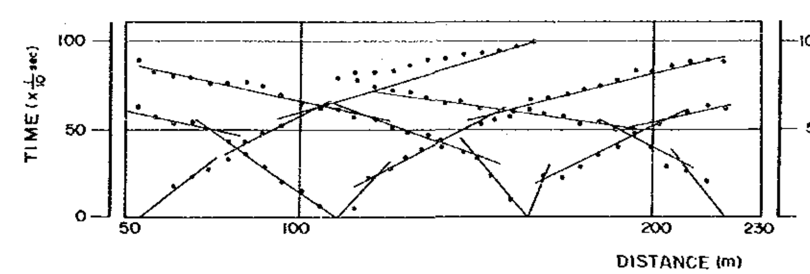
(UNIT) km / sec



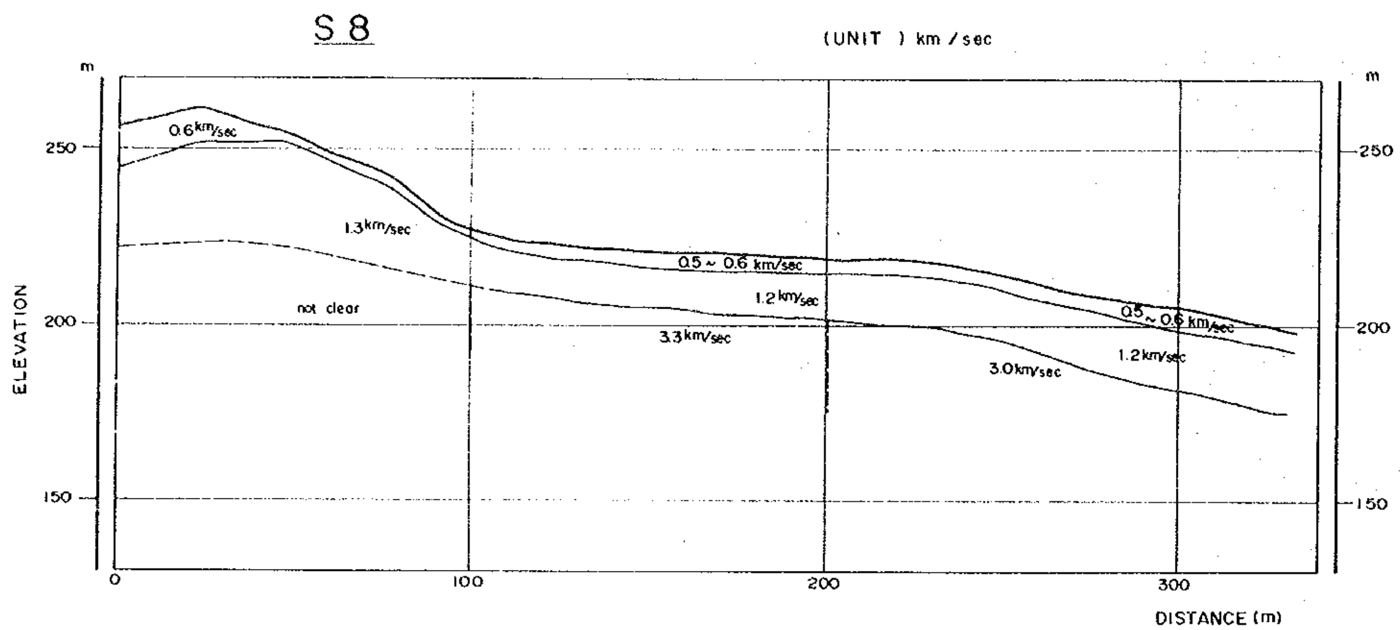




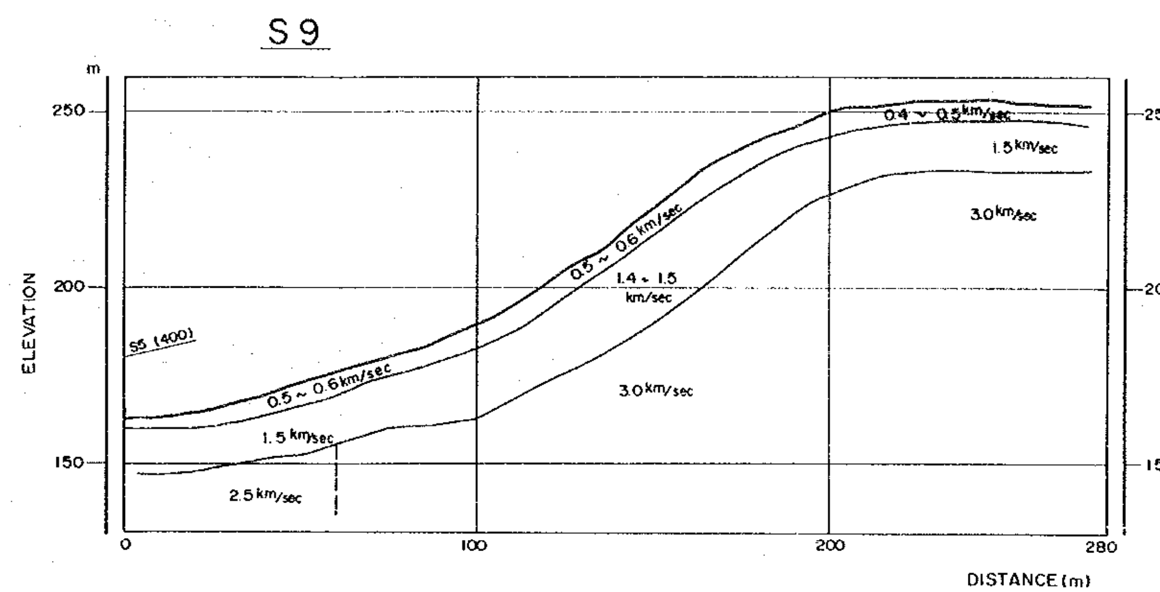




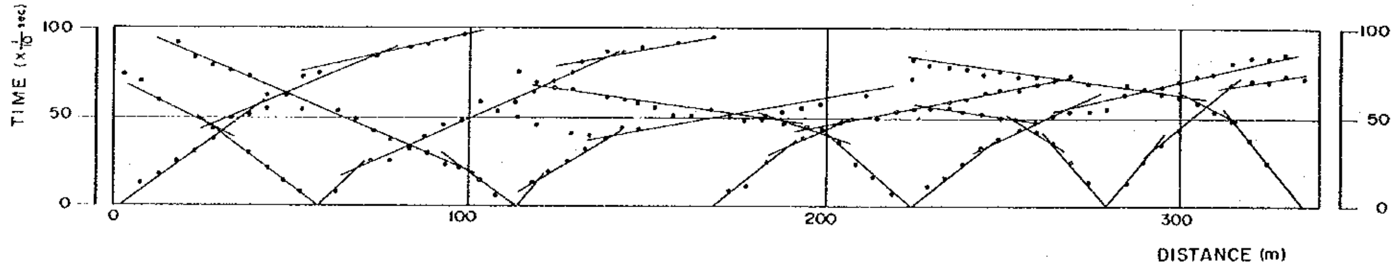
NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT	
GEOLOGY SEISMIC PROFILE and TIME DISTANCE CURVE S6 S7 lines	
Fig. 6-2(5-6)	Appendix



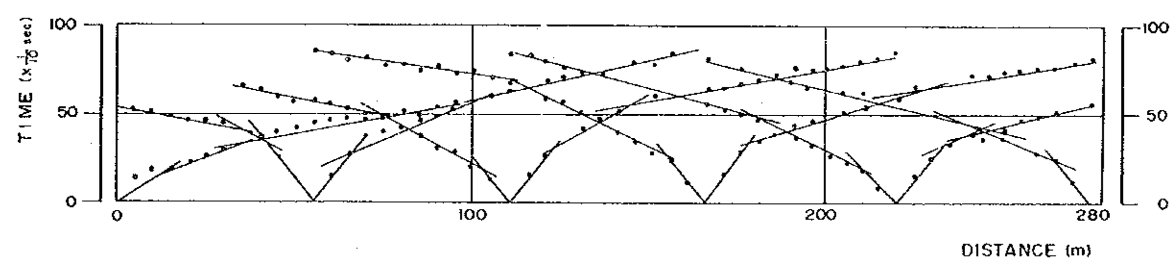
S 8
(UNIT) km / sec
ELEVATION
0.6 km/sec
1.3 km/sec
not clear
0.5 ~ 0.6 km/sec
1.2 km/sec
3.3 km/sec
3.0 km/sec
DISTANCE (m)



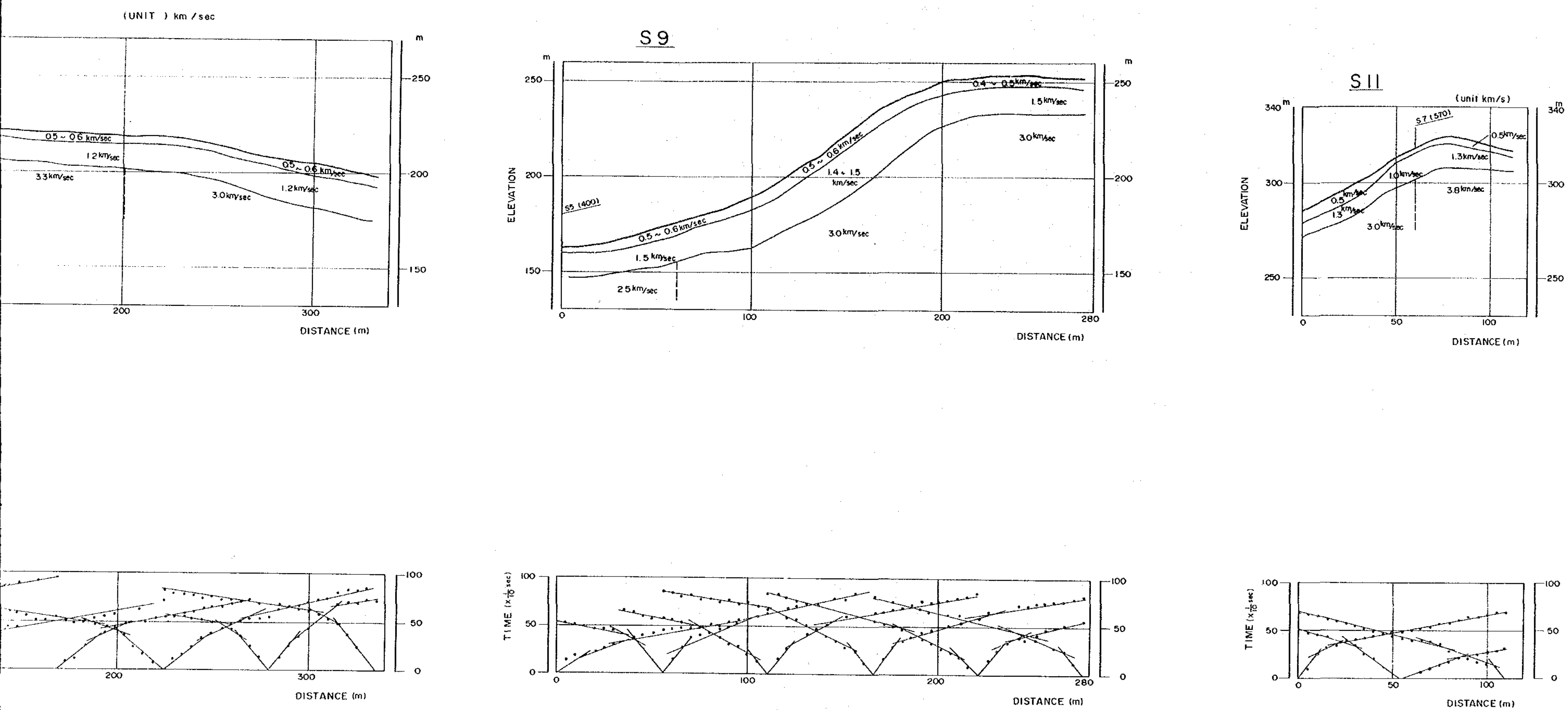
S 9
ELEVATION
0.4 ~ 0.5 km/sec
1.5 km/sec
3.0 km/sec
1.4 ~ 1.5 km/sec
0.5 ~ 0.6 km/sec
S5 (400)
2.5 km/sec
DISTANCE (m)



TIME (x 1/10 sec)
DISTANCE (m)



TIME (x 1/10 sec)
DISTANCE (m)



NAM YUAM RIVERBASIN INTEGRATED HYDROELECTRIC DEVELOPMENT PROJECT

GEOLOGY

SEISMIC PROFILE and TIME DISTANCE CURVE

S8, S9, S11 lines

Fig. 6 - 2(6-6) | Appendix

B-2 EVALUATION OF DRILLED CORE

Evaluation of Drilled Core

The logs of core boring give evaluations of drilled cores. The evaluations comprise three elements -- degree of weathering, hardness, and crack spacing.

Each element is further classified according to five levels based on the criteria given below.

Degree of Weathering (W)

- W = 1 : Very fresh. No weathering of rock mineral component.
- W = 2 : Fresh. Some rock minerals are slightly weathered. Usually, no brown cracks.
- W = 3 : Fairly fresh. Some rock minerals are weathered. Cracks are stained and contain weathered materials.
- W = 4 : Weathered. Fresh portions still remain partially.
- W = 5 : Strongly weathered. Most of rock minerals are weathered and altered into secondary minerals.

Hardness (H)

- H = 1 : Very hard. Broken to knife-edged pieces by strong hammer blow.
- H = 2 : Hard. Broken to pieces by strong hammer blow.
- H = 3 : Somewhat brittle. Broken to pieces by medium hammer blow.
- H = 4 : Brittle. Easily broken to pieces by medium hammer blow.
- H = 5 : Soft. Able to dig with hammer.

Crack Spacing (C)

- C = 1 : $C \geqq 50$ cm
- C = 2 : $50 \text{ cm} > C \geqq 20$ cm
- C = 3 : $20 \text{ cm} > C \geqq 5$ cm
- C = 4 : $5 \text{ cm} > C \geqq 1$ cm
- C = 5 : $1 \text{ cm} > C$

B-3 LOG OF BORING

B-3-(1) NAM NGAO SITE

B-3-(2) MAE LAMA LUANG SITE

B-3-(1) NAM NGAO SITE

LOG OF BORING

Project: NAM MAE NGAO NO. 2	Location: Dam Axis (Left Bank)	Boring No.: DL-3	Log No. 1 of 3
Co-ordinates: N1966,936.917 E393,509.365	Elevation: 202.043m MSL	Depth of Hole: 75.00m	Commenced: 24/10/88
Angle from Horizontal: 90°	Core Recovery: 75.6%	Depth of Overburden: 10.30m	Completed: 14/11/88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 56.75m	Logged by: V. Vichorn. K. Takeda

Column headings: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit Ø of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | Water Pressure Test, Lugeon Value ○, Water Table | Drill | Pressure (Kg) (0, 50, 100) | Time (min) | Depth (M) | Elevation

Dates: 24/10/88 (0–9 m); 25/10/88 (9–15 m); 26/10/88 (15–22 m); 27/10/88 (22–26 m); 28/10/88 (26–30 m)

R.Q.D: 16 (10.30–12 m); 0 (12–30 m)

Geology: Overburden (0–10.30 m); Alternation of Sandstone and Shale (10.30–30 m)

Colour of rock: Raddish Brown (0–3.5 m); Brown (3.5–11.1 m); Gray (11.1–30 m)

Description

0.00 – 10.30m.

Overburden

0.00 – 4.00m. Clayey silt with rock fragments Detritus deposit.

4.00 – 5.90m. Clayey silt with quartz. sandstone fragments rounded to subrounded gravels

5.90 – 10.30m. gravel bed.

4.00 — 10.30m Terrace deposit

Core loss at 6.00–8.90m, 9.00–10.30m

10.30 – 30.00m.

Non-Calcareous sandstone, fine to medium grains broken rock, shale at core loss must be sheared zone at 11.10 – 14.00 m. 17.45 – 18.00m. 24.70 – 26.30m.

Water Pressure Test

$K = 2.4 \times 10^{-6}$

S PT. N = 5-5-8

$K = 3.7 \times 10^{-5}$

S.PT. N = 16-23-40

$K = 7.3 \times 10^{-5}$

$K = 7.95 \times 10^{-5}$

$K = 4.3 \times 10^{-4}$

$K = 3.4 \times 10^{-4}$

$K = 7.5 \times 10^{-4}$

$K = 3.4 \times 10^{-4}$

$K = 3.1 \times 10^{-4}$

$K = 7.2 \times 10^{-6}$

Water table: 14/11/88 (at about 27.8 m)

$K = 7.2 \times 10^{-4}$

Pressure (Kg) values written on the graph, from top to bottom: 80, 30, 50, 25, 40, 30, 30, 35, 50, 45, 30, 20, 15, 25, 30, 45

Core loss [symbol] — Weathering 1 (fresh) – 5 (decomposed) — Hardness 1 (hard) – 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50cm, 20 cm), 3 (20 cm, 5cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM MAE NGAO SITE NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-3
Log No.	2 of 3	Co-ordinates	N1,966,936.917 E393,509.365	Elevation	202.043m MSL.
Depth of Hole	75.00m	Commenced	24/10/88	Angle from Horizontal	90°
Core Recovery	75.6 %	Depth of Overburden	10.30m	Completed	14/11/88
Bearing of Angle Hole	—	Company	EGAT.	Total length of core	65.75m
Logged by	V. Vicharn, K. Takeda				

Columns: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (← 100% →) | Kind of Bit, ⌀ of Core (mm) | Casing, Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | Water Pressure Test: Lugeon Value ○, Water Table —⋀⋁— | Drill: Pressure (Kg) 0, 50, 100; Time (min) | Depth (M) | Elevation

Date: 29/10/88 (31–2 m); 31/10/88 (2–4 m); 1/11/88 (4–6 m); 5/11/88 (6–10 m); 6/11/88 (40–42 m); 7/11/88 (42–45 m); 8/11/88 (45–54 m); 11/11/88 (55–60 m)

Depth: 30 – 60 M

R.Q.D (%): 33 (43–44 m); — ; 29 (45–46 m); 31 (48–49 m); 31 (50–51 m); 40 (59–60 m)

Geology: Alternation of Sandstone and Shale

Colour of rock: Gray

Description:

30.00–75.00m

Calcareous sandstone, medium grains brittle, hard. Shale interlaminar with sandstone at 33.00–35.00m, 43.00–48.00m, 56.00–67.00m

Sheared zone at 47.00–47.90m Joints dip 10°, 45°, 60°, 80° rough joints, slickenside and smooth Joints at 42.00–47.00m 52.00–53.80m

Bedding 70° at 33.00–56.00m

Bedding 60° at 56.00–75.00m

Core loss at 30.00–30.80m, 30.85–31.00m, 32.00–32.80m, 33.40–33.90m, 35.60–36.85m, 37.30–37.70m, 37.80–39.00m

44.00–75.00m Fresh and hard rock

Water Pressure Test:

- $K = 2.5 \times 10^{-5}$
- Water table: 24/2/89, 31.30m
- $K = 2.2 \times 10^{-4}$
- $K = 2.3 \times 10^{-4}$
- $K = 2.6 \times 10^{-4}$
- $K = 1.5 \times 10^{-4}$
- $K = 1.9 \times 10^{-4}$
- $K = 9.1 \times 10^{-5}$
- Lugeon value (0.7)
- Lugeon value (0.2)

Drill time (min): 20, 20, 25, 35, 15, 65, 30, 40, 15, 65, 13, 30, 20, 30, 55, 20, 40, 5, 40, 20, 50, 80, 55, 70, 35, 40, 15, 40, 35, 35, 40

Core loss [⊠] — Weathering 1 (fresh) – 5 (decomposed) — Hardness 1 (hard) – 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM MAE NGAO SITE NO.2 | Location: Dam Axis (Left Bank) | Boring No.: DL-3 | Log No. 3 of 3

Co-ordinates: N1,966,936.917 E 393,509.365 | Elevation: 202.043m | Depth of Hole: 75.00m | Commenced: 24/10/88

Angle from Horizontal: 90° | Core Recovery: 75.6 % | Depth of Overburden: 10.30m | Completed: 14/11/88

Bearing of Angle Hole: — | Company: EGAT. | Total length of core: 56.75m | Logged by: V. Vicharn, K. TAKEDA

Columns: Date | Depth M | R.Q.D % | Geology | Symbol of geology | Core recovery (← 100% →) | Kind of Bit, ø of Core (mm) | Casing, Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 —— 5) | Description | WATER PRESSURE TEST, LUGEON VALUE ○, WATER TABLE | Drill (0, 50 Pressure Kg, 100 Time min) | Depth M | Elevation

Date	Depth (M)	R.Q.D (%)
11/11/88	60–61	0
11/11/88	61–63	29
12/11/88	63–64	44
12/11/88	64–64.5	33
12/11/88	64.5–65	53
12/11/88	65–65.5	100
12/11/88	65.5–68	8
14/11/88	68–69	27
14/11/88	69–70	23
14/11/88	70–71	14
14/11/88	71–72.5	25
14/11/88	72.5–73.5	25
14/11/88	73.5–75	67

Geology: Alternation of Sandstone and Shale

Colour of rock: Gray

Description:
As above
Fresh and hard rock
Partialy cracky
Clcite veinlets are found at some parts.

Bottom of Hole (75 M)

Lugeon values: 0.7, 0.4, 0.4

Drill time (min): 60, 65, 25, 25, 60, 20, 30, 65, 25, 35, 50, 25, 25, 55

Core loss —— ⊠ | Weathering: 1 (fresh) – 5 (decomposed) | Hardness: 1 (hard) – 5 (soft) | Average length of Core: 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM NGAO SITE NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-4
Co-ordinates	N1,966,909.798 E 393,377.688	Elevation	254.454m MSL.	Depth of Hole	92.60m
Angle from Horizontal	90°	Core Recovery	69.6 %	Depth of Overburden	4.00m
Bearing of Angle Hole	—	Company	EGAT	Total length of core	64.45m

Commenced 8/9/88
Completed 24/9/88
Logged by V. Vichorn, K. Takeda

Columns: Date | Depth (M) | R Q D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit, ø of Core (mm) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core | Description | Water pressure test, Lugeon value, Water table | Drill, Pressure (Kg), Time (min) | Depth | Elevation

Dates: 8/9/88 (0–12 m); 9/9/88 (12–20 m); 10/9/88 (20–24 m); 12/9/88 (24–30 m)

RQD: 0 %

Geology: Overburden (0–4 m); Alternation of Sandstone and Shale (4–30 m)

Colour of rock: Reddish Brown (0–4 m); Brown (4–30 m)

Description

0.00 – 4.00m
Overburden, clayey silt with sandstone fragments.
Detritus deposit.

4.00 – 23.00m
Sandstone, medium grains, soft and poor cement, easy to break by hand.
Strongly weathered zone
Core loss at
4.10 – 4.90m, 5.00 – 5.90 m
6.00 – 6.70m, 7.50 – 8.60m
9.00 – 11.85m, 12.50 – 13.20m
15.20 – 17.50m, 18.00 – 19.50m
20.10 – 20.75m, 21.00 – 22.20m
22.55 – 23.00m
The section of core loss must be filled by silt and clay with fragments.

23.00 – 29.00m
Sandstone interbedded with shale, bedding 45°.
Weathered zone
Core loss at
25.05 – 27.45m

Water pressure test / SPT

Test interval	Result
0 – 4 m	K=1.8x10^-3; SPT. N=11-7-6
4 – 6 m	K=1.0x10^-3; SPT. N=12-10-12
6 – 12 m	K=2.5x10^-4; SPT. N=16-19-31; K=2.1x10^-4
12 – 15 m	SPT. N=14-16-19; K=5.7x10^-5
15 – 18 m	SPT. N=18-24-40; K=6.6x10^-5
18 – 21 m	SPT. N=18-39-40; K=1.2x10^-4
21 – 24 m	SPT. N=40; K=8.95x10^-5
24 – 30 m	K=7.5x10^-5

Drill time values (min): 10, 10, 20, 15, 35, 15, 20, 65, 20, 15, 50, 20, 120, 45, 125

Core loss [⊠]
Weathering 1 (fresh) – 5 (decomposed)
Hardness 1 (hard) 5 (soft)
Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM NGAO SITE NO.2	Location	DamAxis (Left Bank)	Boring No.	DL-4	Log No	2 of 4
Co-ordinates	N 1,966,909.788 E 393,377.688	Elevation	254.454m MSL	Depth of Hole	92.60m	Commenced	8/9/88
Angle from Horizontal	90°	Core Recovery	69.6 %	Depth of Overburden	4.00m	Completed	24/9/88
Bearing of Angle Hole	—	Company	EGAT.	Total length of core	64.45m	Logged by	V. Vichorn, K. Takedo

Columns: Date | Depth (M) | R Q D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit / ∅ of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST LUGEON VALUE ○ / WATER TABLE | Drill (Pressure Kg 0 50 100, Time min) | Depth (M) | Elevation

Date: 12/9/88, 13/9/88, 14/9/88, 15/9/88

Geology: Alternation of Sandstone and Shale

Colour of rock: Brown (29.00–41.40 m), Gray (41.40–60 m)

RQD (%): 0 (30–41.9 m); 16.5; 0; 20.6; 0; 47; 0; 29; 40; 31; 0; 20; 46; 67

Depth (m)	Description	Water pressure test	Drill time (min)
30–33	29.00 - 41.40m Weathered. Sandstone, medium grains, Iron oxide fill in joints. Core loss at 29.45-29.80m, 31.00-32.90m, 34.45-35.30m, 37.60-39.00m, 40.25-41.40m	$K=1.1\times10^{-4}$	90
33–41.4		$K=5.7\times10^{-5}$; Water table 36.00m (24/2/89)	25, 25, 15, 105, 70, 60
41.4–51.0	41.40 - 83.30m Shale interbedded with sandstone joints dip 30°, 45°, 80°, smooth to rough joints and fill with clay bedding 60° - 70°. Fresh and hard rock. Core loss at 44.40-45.00m, 48.00-49.90m, 51.00-52.80m	$K=1.9\times10^{-5}$	15, 45, 75, 55, 45, 30
51.0–54.0	47.70 - 53.50m The rock is patially altered to porous tuff by hydro thermal.	$K=1.8\times10^{-5}$	95
54.0–57.0		$K=4.2\times10^{-5}$	20, 20, 25, 20, 35, 30
57.0–60.0		$K=3.3\times10^{-5}$	30, 35, 25, 20

Core loss — ☒ ; Weathering 1 (fresh) - 5 (decomposed) ; Hardness 1 (hard) - 5 (soft) ; Average length of Core 1 (more than 50 cm), 2 (50cm, 20 cm), 3 (20 cm, 5cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM NGAO SITE NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-4
Log No.	3 of 4	Co-ordinates	N1,966,909.768 E393,377.688	Elevation	234.454 m MSL
Depth of Hole	92.60 m	Commenced	8/9/88	Angle from Horizontal	90°
Core Recovery	69.6 %	Depth of Overburden	4.00 m	Completed	24/9/88
Bearing of Angle Hole	—	Company	EGAT.	Total length of core	64.45 m
Logged by	V. Vicharn, K. Takeda				

Columns: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit of Core (mm) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 – 5) | Description | Water Pressure Test (Lugeon Value ○, Water Table) | Drill (0 – 50 Pressure Kg – 100 Time min) | Depth (M) | Elevation

Geology: Alternation of Sandstone and Shale

Colour of rock: Gray

Date	Depth (m)	R.Q.D (%)
	60 – 61	0
16/9/88	61 – 64	77
	64 – 65	46
20/9/88	65 – 68	77
	68 – 69	31
21/9/88	69 – 71	72
	71 – 74	50
	74 – 77	90
	77 – 80	83
	80 – 82	100
22/9/88	82 – 83	90
	83 – 84	62
	84 – 87	0
	87 – 88	26
	88 – 90	0

Description:

As above.
61.00 – 83.30m
Fresh, hard and massive sandstone, shale.
Bedding 70° – 80°

83.30 – 92.60m
sandstone, coarse grains, interbedded with shale.
Bedding 80°

Water pressure test (Lugeon value):

Depth (m)	Lugeon value
65 – 71	0.3
71 – 74	No Test
74 – 77	1.3
77 – 82	0.3
83 – 89	0.3, 0.6

Drill time values (min): 20, 40, 40, 50, 35, 40, 50, 70, 30, 20, 20, 10, 10, 55, 15, 25, 25, 25

Core loss ——→ [⊠]
Weathering 1 (fresh) – 5 (decomposed)
Hardness 1 (hard) – 5 (soft)
Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM NGAO SITE NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-4	Log No.	4 of 4
Co-ordinates	N1,966,909.788 E 393,377.688	Elevation	254.454m MSL	Depth of Hole	92.60m	Commenced	8/9/88
Angle from Horizontal	90°	Core Recovery	69.6 %	Depth of Overburden	4.00m	Completed	24/9/88
Bearing of Angle Hole	—	Company	E G A T.	Total length of core	64.45m	Logged by	V. Vichorn K. Takeda

Date	Depth (M)	R.Q.D (%)	Geology	Symbol of geology	Core recovery (100%)	Kind of Bit Ø of Core (mm)	Casing Cementation	Colour of rock	Weathering (1–5)	Hardness	Average length of core	Description	Water Pressure Test (Lugeon value ○, Water table)	Drill Pressure Kg (0–50–100) / Time min	Depth (M)	Elevation
23-24/9/88	90–92.60	—	Alternation of Sand. & Sh.					Gray				As above	0.3	35, 30, 30, 30	90–92.60	
												Bottom of Hole				

Core loss ☒ — Weathering 1 (fresh) – 5 (decomposed) — Hardness 1 (hard) – 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM NGAO SITE NO.2	Location	Dam Axis(Left Bank)	Boring No.	DL-4A	Log No.	1 of 1
Co-ordinates	N1,966,808.131 E393,380.854	Elevation	223.973	Depth of Hole	9.00m	Commenced	18/8/88
Angle from Horizontal	90°	Core Recovery	69.44 %	Depth of Overburden	9.00m	Completed	20/8/88
Bearing of Angle Hole	—	Company	EGAT	Total length of core	6.25m	Logged by	V. Vichorn K. Takedo

Date	Depth (M)	R Q D (%)	Geology	Symbol of geology	Core recovery (100%)	Kind of Bit ϕ of Core (mm.)	Casing Cementation	Colour of rock	Weathering (1–5)	Hardness (1–5)	Average length of core (1–5)	Description	WATER PRESSURE TEST / LUGEON VALUE ○ / WATER TABLE	Drill (0)	Pressure __ Kg (50)	Time __ min (100)	Depth (M)	Elevation
18/8/88	0–3		Overburden					Brown				0.00–9.00m Overburden 0.00–5.50m Clayey silt with sandstone fragments, residual soil and detritus deposit, low plasticity	SPT N=9-13-24				0–3	
19/8/88	3–7.5											5.50–9.00m Sandstone, strongly weathering	SPT N=6-40-40				3–7.5	
20/8/88	7.5–9											Core loss at 3.75–4.50m, 5.25–5.50m, 6.00–7.05m, 7.50–8.05m, 8.25–8.40m	S PT N=24-40				7.5–9	
	9											Bottom of Hole					9	

Core loss [⊠] Weathering 1 (fresh) – 5 (decomposed) Hardness 1 (hard) – 5 (soft) Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm) 5 (grained)

LOG OF BORING

Project	NAM MAE NGAO NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-6	Log No.	1 of 3
Co-ordinates	N1,966,683 E 393,014	Elevation	309.496 m MSL	Depth of Hole	76.40 m	Commenced	24/5/88
Angle from Horizontal	90°	Core Recovery	63.6 %	Depth of Overburden	2.35 m	Completed	23/7/88
Bearing of Angle Hole	—	Company	EGAT.	Total length of core	48.60 m	Logged by	V. Vichorn K. Takeda

Date	Depth M	R.Q.D %	Geology	Description	Water Pressure Test / Lugeon Value / Water Table
24/5/88	0–2.35		Overburden	0.00 - 2.35m Overburden Silty clay with siltstone fragment.	
24/5/88 – 29/5/88	2.35–12.00		Alternation of Sandstone and Shall	2.35-12.00m Siltstone interbedded with shale core broken strongly weathered Core loss at 1.10 - 2.35m, 3.00-3.80m 4.40-5.40m, 6.00-6.65m 9.00-9.85m	SPT. N=30-28-32 90/45cm SPT. N=5-24-53 82/45cm Can Not Set Packer
30/5/88 – 2/6/88	12.00–30.00	0 (at 14), 31 (at 29–30)	Alternation of Sandstone and Shall	12.00-30.00m Siltstone interbedded with sandstone joints 20°, 45°, 60°, 80° Clay and iron oxide coated at joints, Bedding 30° Weathered and cracky rock Core loss at 12.00-12.15m, 15.00-16.00m 16.45-16.90m, 19.00-19.20m 19.35-23.65m, 24.00-24.80m 27.75-28.40m	SPT. N=65-43 108/18cm SPT. N=35-70-60 165/38cm SPT.N=8-35-43 86/45cm SPT. N=23-25-41 SPT.N=20-80 S PT. N=50

Colour of rock: Gray to Brown

Column headings: Date; Depth (M); R.Q.D (%); Geology; Symbol of geology; Core recovery (100%); Kind of Bit / Ø of Core (mm.); Casing Cementation; Colour of rock; Weathering; Hardness; Average length of core (1 — 5); Description; Water Pressure Test Lugeon Value ○ / Water Table; Drill 0 – 50 – 100 (Pressure Kg, Time mm); Depth M; Elevation

Drill time values (Depth, top to bottom): 65, 40, 30, 35, 15, 5, 25, 25, 5, 30, 30, 25, 35, 25, 40, 33, 25, 60, 25, 60, 30

Core loss [⊠]; Weathering 1 (fresh) – 5 (decomposed); Hardness 1 (hard) – 5 (soft); Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm) 5 (grained)

LOG OF BORING

Project	NAM MAE NGAO NO.2	Location	Dam Axis (Left Bank)	Boring No.	DL-6
Log No.	2 of 3	Co-ordinates	N 1,966,683 E 393,014	Elevation	309.496 m MSL
Depth of Hole	76.40 m	Commenced	24/5/88	Angle from Horizontal	90°
Core Recovery	63.6 %	Depth of Overburden	2.35 m	Completed	23/7/88
Bearing of Angle Hole	—	Company	EGAT	Total length of core	48.60 m
Logged by	V. Vicharn, K. Takeda				

Columns: Date | Depth M | R Q D % | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit / Ø of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 – 5) | Description | WATER PRESSURE TEST, LUGEON VALUE ○, WATER TABLE | Drill Pressure (0–50–100) Kg, Time min | Depth M | Elevation

Depth: 30–60 m

Dates: 2/6/88, 3/6/88, 4/6/88, 10/6/88, 11/6/88, 13/6/88, 5/7/88, 8/7/88, 9/7/88, 11/7/88

RQD %: 0 (30.0–31.5 m), 29 (31.5–32.8 m), 0 (below)

Geology: Alternation of Sandstone and Shale

Colour of rock: Gray; Pale Gray; Gray

Description:

30.00-41.65m
Sandstone, fine grained, brittle a few calcite veins joints filled with sulpher and clay
30.00-33.60m iron oxide coated at joints, 45°, 20°
The rock must be altered by hydrothermal alteration.
Core loss at 31.00-31.55m, 34.10-34.75m 40.45-41.65m

41.65-49.00m Sheared zone of sandstone, core broken, black clay, gouge
Core loss at 42.00-43.15m, 43.45-44.30m 45.70-46.30m, 46.70-47.00m 47.30-47.80m, 48.00-48.50m

49.00-52.50m Sandstone dense calcite veinlets, slickenside at 49.00-50.00m joints 10°, 45°
Fresh and hard rock

52.50-76.40m Sheared zone with some dense sandstone, core broken.
Core loss at 55.20-55.40m, 55.70-56.00m 57.20-57.90m, 59.50-60.70m

Water pressure test: Can Not Set Packer

Water table: 23/7/88; 24/2/89

Drill pressure (Kg): 45, 25, 40, 25, 20, 20, 40, 15, 20, 25, 35, 30, 20, 10, 15, 25, 20, 10, 45, 30, 35, 45, 50, 20, 20, 15, 15, 20, 20, 15, 45

Core loss [⊠]; Weathering 1 (fresh) – 5 (decomposed); Hardness 1 (hard) – 5 (soft); Average length of Core 1 (more than 60 cm), 2 (60 cm 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM MAE NGAO NO.2	Location: Dam Axis (Left Bank)	Boring No.: DL - 6	Log No.: 3 of 3
Co-ordinates: N1,966,663 E 393,014	Elevation: 309.496m MSL	Depth of Hole: 76.40m	Commenced: 24/5/88
Angle from Horizontal: 90°	Core Recovery: 63.6 %	Depth of Overburden: 2.35m	Completed: 23/7/88
Bearing of Angle Hole: —	Company: EGAT.	Total length of core: 48.60m	Logged by: V.Vicharm, K.Takeda

Columns: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit of Core (mm) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | Water Pressure Test: Lugeon Value ○, Water Table | Drill 0, Pressure 50 Kg, Time 100 min | Depth (M) | Elevation

Dates: 11/7/88, 14/7/88, 15/7/88, 16/7/88, 17/7/88, 18/7/88, 19/7/88, 23/7/88

Geology (60.00–76.40 m): Alternation of Sandstone and Shale

Colour of rock: Gray

Description:

60.00-76.40m Joints 20°, 30°, 30°, 45°, 60°

Dense Sandstone at
61.40 – 62.00m
64.80 – 67.90m

Quartz in broken core.

Core loss at
60.90-61.00m, 61.10-61.40m
62.30-62.50m, 63.10-63.20m
63.50-63.60m, 64.40-64.60m
68.15-68.50m, 69.00-69.40m
69.80-70.00m

Water pressure test: Can Not Set Packer.

Drill time values (min): 55, 55, 65, 10, 20, 25, 25, 20, 56, 60, 40, 55, 25, 65, 35, 35, 50, 25

Elevation: 76.40m

Bottom of Hole

Core loss [⊠] — Weathering 1 (fresh) – 5 (decomposed) — Hardness 1 (hard) – 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50cm, 20 cm), 3 (20 cm, 5cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project	NAM MAE NGAO No. 2	Location	Dam Axis (Right Bank)	Boring No.	DR-5	Log No.	1 of 2
Co-ordinates	N 1,967,000 E 393,600	Elevation	166.11m MSL	Depth of Hole	56.20m	Commenced	19/5/88
Angle from Horizontal	60°	Core Recovery	83.45%	Depth of Overburden	7.50m	Completed	14/6/88
Bearing of Angle Hole	S 70° W	Company	EGAT	Total length of core	46.9 m	Logged by	V. Vichan, K. Takeda

Columns: Date | Depth (M) | R Q D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit & of Core (mm) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST, LUGEON VALUE ○, WATER TABLE | Drill 0 50 Pressure ___ Kg 100 Time ___ min | Depth (M) | Elevation

Date	Geology	Colour of rock	Description
19/5/88, 20/5/88	OVERBURDEN	Brown	0.00 - 7.50 m. Overburden (Terrace deposit, River depsit) 0.00-2.50m. Clayey silt. 2.50 - 4.00 m. Gravel of quartz rounded gravel. 4.00 - 7.50 m. Clayey silt, fine to medium sand with gravel.
21/5/88, 28/5/88, 29/5/88, 30/5/88, 31/5/88	Alternation of SANDSTONE and SHALE	Gray	7.50-21.10m. Sandstone medium grained. Calcareous, calcite veinlets, interbedded with sheared zone, Bedding 50° with core axis (dip 70°) joints 10°, 45°, 80° with core axis. 12.30 - 21.10 m. Slightly sheared. 14.70 - 14.80 m Slickenside are found. Core loss at 8.00-9.00m, 9.90-10.50m, 10.75-11.00m, 13.20-13.80m, 15.90-16.50m, 16.70-17.20m, 17.40-18.00m, 18.40-18.80m, 19.70-20.40m, 21.20-21.55m. 21.10-39.65m. Sheared zoned, clay and sandstone fragments, some slickenside. Core loss at 29.75 - 30.00m.

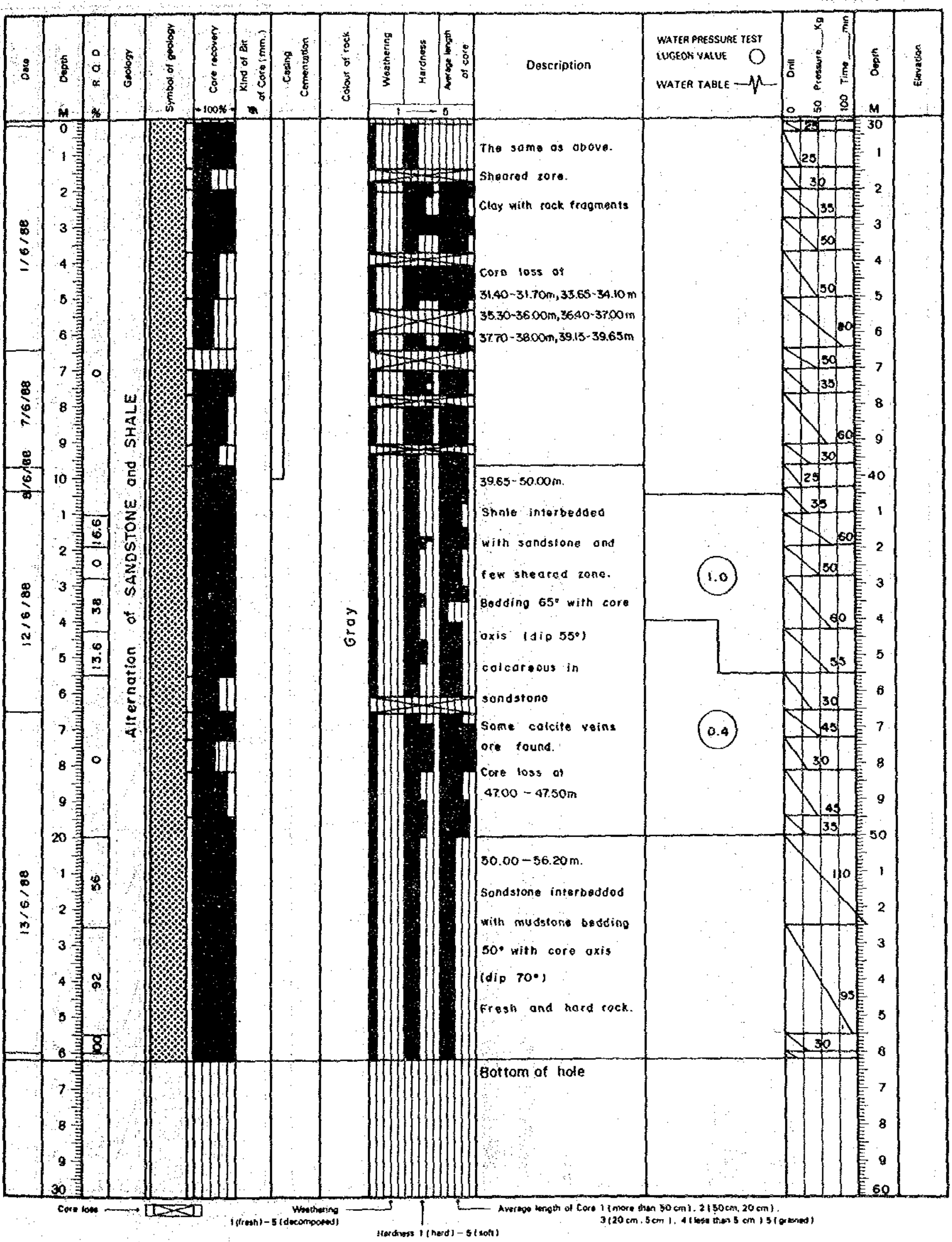
Water table: 12/6/88, 9.30m

Pressure values (0–30 m): 10, 5, 10, 10, 30, 35, 65, 30, 10, 25, 20, 18, 20, 35, 40, 5, 45, 80, 35, 70, 15, 20, 35, 50, 60, 26, 85, 30

Core loss ——→ [⊠]
Weathering 1 (fresh) - 5 (decomposed)
Hardness 1 (hard) - 5 (soft)
Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

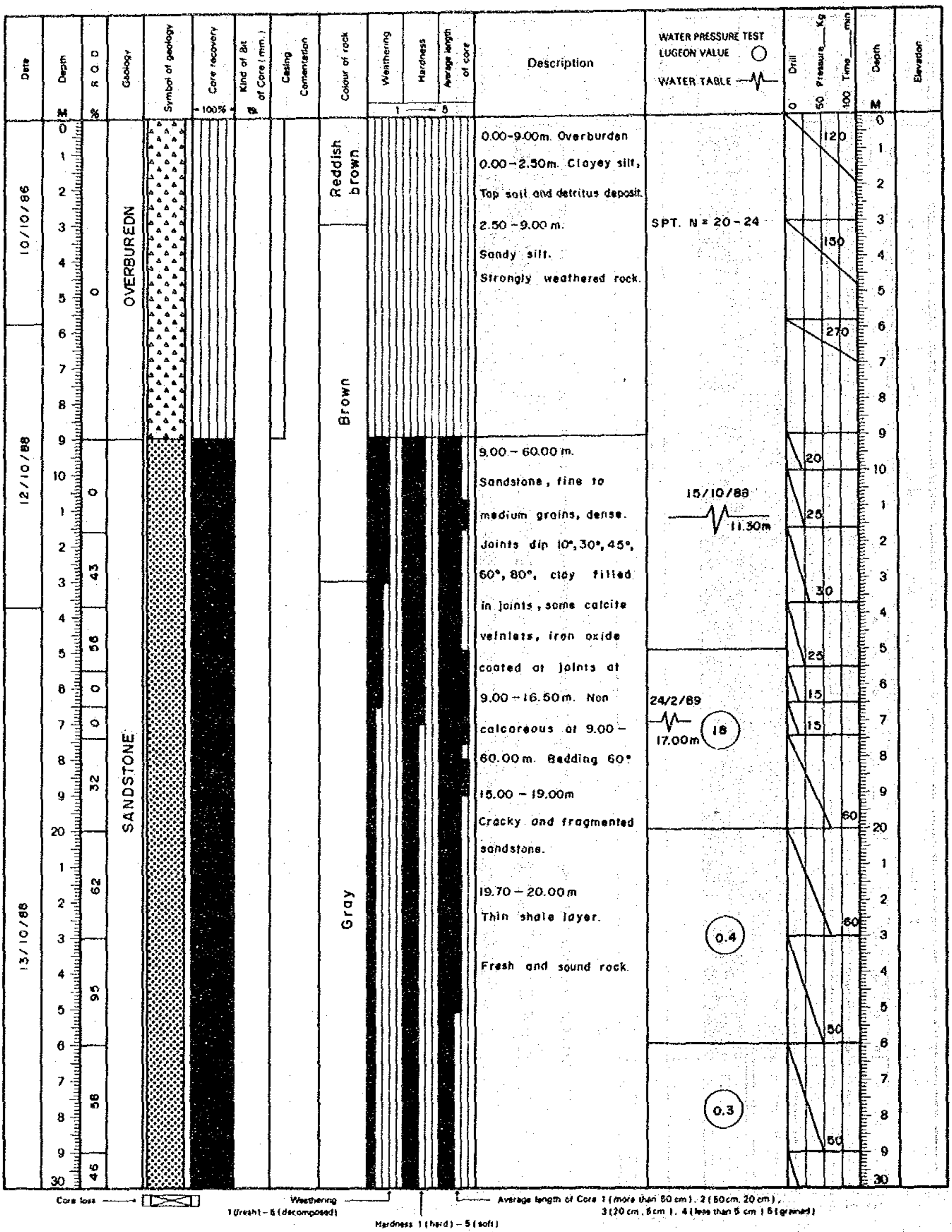
LOG OF BORING

Project	NAM MAE NGAO No. 2	Location	Dam Axis (Right Bank)	Boring No.	DR-5	Log No.	2 of 2
Co-ordinates	N1,967,000 E 393,600	Elevation	166.11m MSL	Depth of Hole	56.20m	Commenced	19/5/88
Angle from Horizontal	60°	Core Recovery	83.45%	Depth of Overburden	7.50m	Completed	14/6/88
Bearing of Angle Hole	S70°W	Company	E G A T	Total length of core	46.90m	Logged by	V. Vicharn K. Takeda



LOG OF BORING

Project: NAM NGAO SITE No.2	Location: Dam Axis (Right Bank)	Boring No.: DR-6	Log No.: 1 of 2
Co-ordinates: N1,967,049.189 E393,773.682	Elevation: 201.725m MSL	Depth of Hole: 60.00m	Commenced: 10/10/88
Angle from Horizontal: 90°	Core Recovery: 100%	Depth of Overburden: 9.00m	Completed: 15/10/88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 60.00m	Logged by: V. Vichorn, K. Takeda



LOG OF BORING

Project: NAM NGAO SITE No.2	Location: Dam Axis (Right Bank)	Boring No.: DR-6	Log No.: 2 of 2
Co-ordinates: N1,987,049.189 E 393,773.682	Elevation: 201.725m MSL	Depth of Hole: 60.00m	Commenced: 10/10/88
Angle from Horizontal: 90°	Core Recovery: 100%	Depth of Overburden: 9.00m	Completed: 15/10/88
Bearing of Angle Hole: —	Company: E G A T	Total length of core: 60.00m	Logged by: V. Vichorn, K. Takeda

Date	Depth (M)	R.Q.D. (%)	Geology	Colour of rock	Description	Water pressure test: Lugeon value	Pressure (Kg)
14/10/88	30 – 32	62.5	SANDSTONE	Gray	As above. 30.20–30.60 m. Limestone lense, dense, at contact dip 40° Fresh and sound rock Some calcite veins are found, the width of calcite veins are 5 to 10 mm.	0.3	25, 25
	32 – 34	62				0.6	
	34 – 35.5	73					25
	35.5 – 37	54					30
	37 – 38.8	42					25
	38.8 – 41.8	83				2.5	40
	41.8 – 43	100					20
	43 – 47	93				0.4	55
15/10/88	47 – 50	100					60
	50 – 53	93				1.4	50
	53 – 55	60					30
	55 – 57	0				2.1	30
	57 – 60	90			Bottom of hole		40

Core loss ⊠ — Weathering 1 (fresh) – 5 (decomposed) — Hardness 1 (hard) – 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm) 5 (grained)

LOG OF BORING

Project: NAM NGAO SITE No. 2	Location: Dam Axis (Right Bank)	Boring No.: DR-7	Log No.: 1 of 4
Co-ordinates: N1,967,107.734 E393,974.110	Elevation: 279.969 m MSL	Depth of Hole: 100 m	Commenced: 14/9/88
Angle from Horizontal: 90°	Core Recovery: 88.9 %	Depth of Overburden: 6.70 m	Completed: 30/9/88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 88.90 m	Logged by: V. Vicharm, K. Takeda

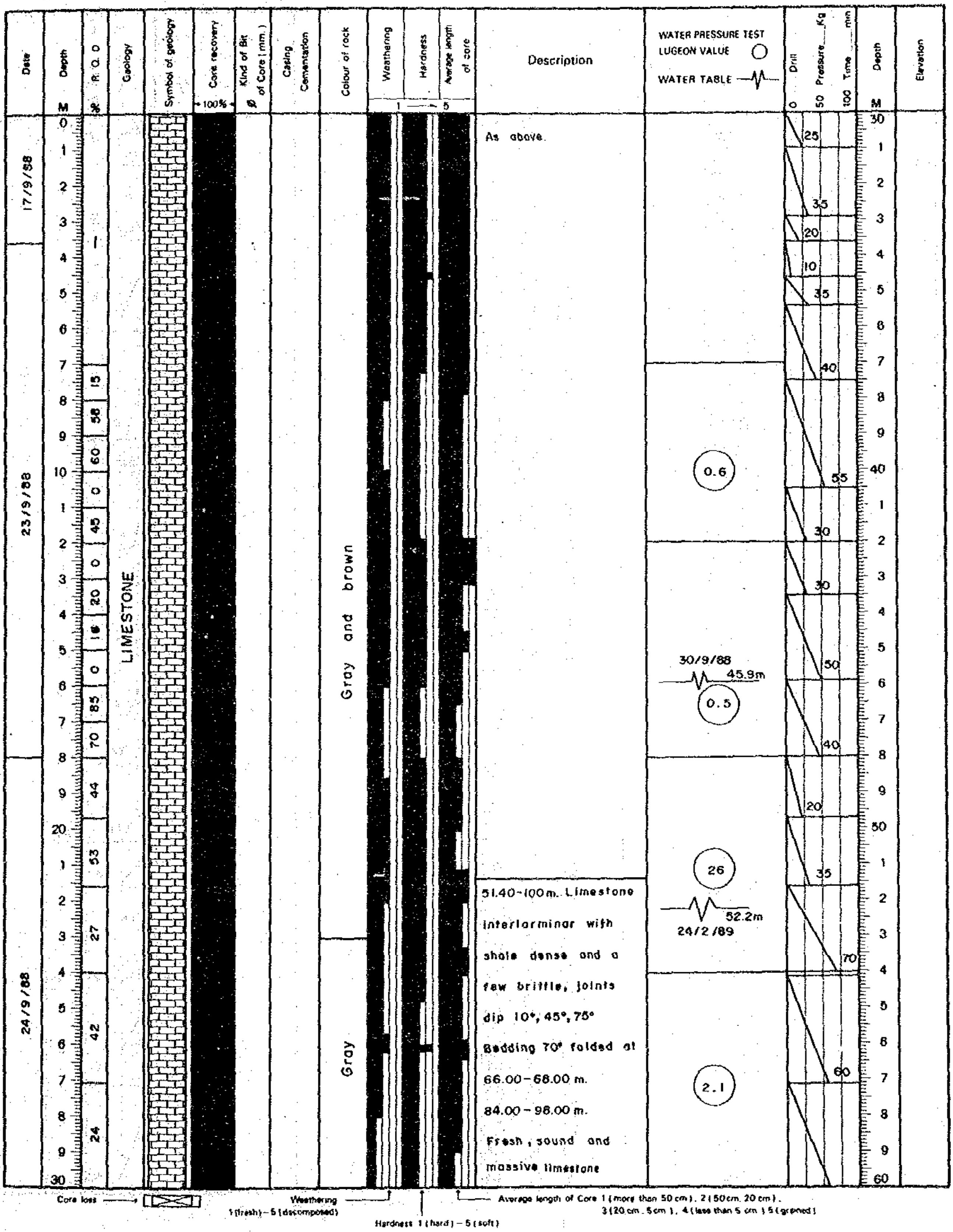
Columns: Date | Depth (M) | R.Q.D. (%) | Geology | Symbol of geology | Core recovery (←100%→) | Kind of Bit, ø of Core (mm.) | Casing, Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST, LUGEON VALUE ○, WATER TABLE | Drill, Pressure (Kg), Time (min) (0, 50, 100) | Depth (M) | Elevation

Date	Depth (M)	R.Q.D. (%)	Geology	Colour of rock	Description	Water pressure test	Lugeon value
14/9/88	0–6.70		OVERBURDEN	Reddish brown	0.00-6.70m. Overburden Residual Soil with fragments. 0.00-2.00m. Silty Clay. 2.00-5.00 m. Silty Clay with sandstone fragments. 5.00-6.70m. Silty clay with limestone fragments. 5.90-6.70m. Strongly weathered	SPT. N = 7-9-13; SPT. N = 17-39-70	70, 95, 10
15/9/88	6.70–20.40	0, 23	LIMESTONE	Gray and brown	6.70-51.40m. Limestone with reddish clay in crack, iron oxide coated at joints. Joints dip 10°, 30°, 45°. Bedding 45°, 70°. Core loss at 7.75-9.40m, 9.50-12.10m, 12.50-14.50m, 15.50-16.00m, 18.40-18.90m, 19.70-20.00m, 21.00-21.05m, 24.05-24.25m, 25.70-26.35m, 27.40-27.80m, 29.00-29.20m.	No test	50, 50, 25, 10, 25, 20, 30, 10
16/9/88	20.40–30	43, 45, 23	LIMESTONE	Gray and brown			20, 35, 20, 40, 30, 20

Core loss —— [⊠] Weathering 1 (fresh) - 5 (decomposed) Hardness 1 (hard) - 5 (soft) Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM NGAO SITE No. 2	Location: Dam Axis (Right Bank)	Boring No.: DR - 7	Log No.: 2 of 4
Co-ordinates: N1,967,107.734 E 393,974.110	Elevation: 279.969 m MSL	Depth of Hole: 100 m	Commenced: 14 / 9 / 88
Angle from Horizontal: 90°	Core Recovery: 98.9 %	Depth of Overburden: 6.70 m	Completed: 30 / 9 / 88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 88.90 m	Logged by: V. Vichorn, K. Takeda



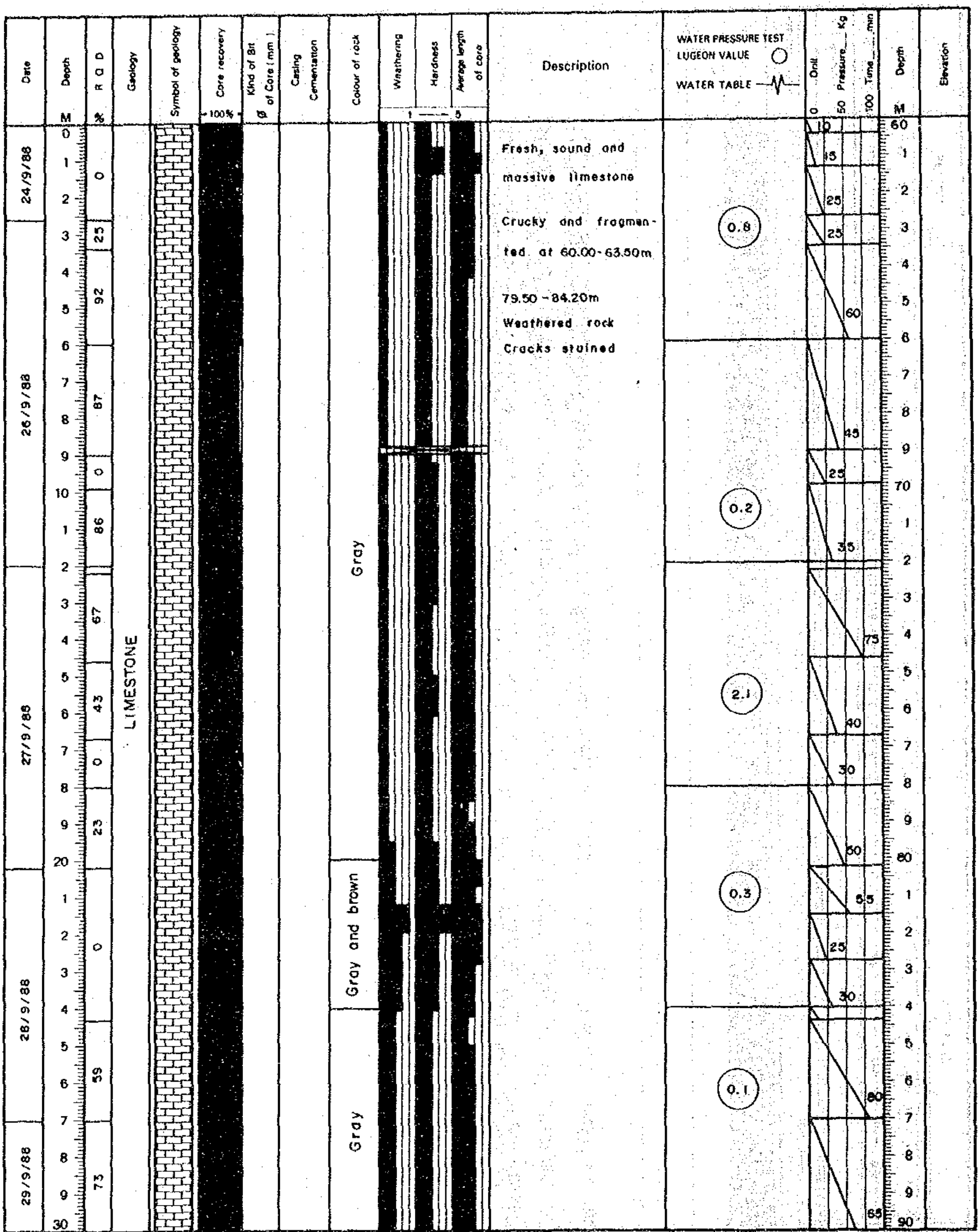
LOG OF BORING

Project NAM NGAO SITE No.2 — Location Dam Axis (Right Bank) — Boring No. DR - 7 — Log No. 3 of 4

Co-ordinates N1,967,107.734 E393,974.110 — Elevation 279.969 m MSL — Depth of Hole 100 m — Commenced 14/9/88

Angle from Horizontal 90° — Core Recovery 88.9 % — Depth of Overburden 6.70 m — Completed 03/9/88

Bearing of Angle Hole — — Company EGAT — Total length of core 88.90 m — Logged by V. Vichorn, K. Takeda



Core loss — Weathering 1 (fresh) - 5 (decomposed) — Hardness 1 (hard) - 5 (soft) — Average length of Core 1 (more than 50 cm), 2 (50cm, 20 cm), 3 (20 cm, 5cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM NGAO SITE No. 2	Location: Dam Axis (Right Bank)	Boring No.: DR - 7	Log No.: 4 of 4
Co-ordinates: N 1,967,107.734 E 393,974.110	Elevation: 279.969 m MSL	Depth of Hole: 100 m	Commenced: 14/9/88
Angle from Horizontal: 90°	Core Recovery: 88.9 %	Depth of Overburden: 6.70 m	Completed: 30/9/88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 88.90 m	Logged by: V. Vichorn, K. Tokedo

Columns: Date | Depth (M) | R.Q.D. (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST LUGEON VALUE ○, WATER TABLE | Drill / Pressure (Kg) / Time (min) (0, 50, 100) | Depth (M) | Elevation

Date	Depth (M)	R.Q.D. (%)	Geology	Colour of rock	Description	Lugeon value	Pressure (Kg)	Depth (M)
29/9/88	0 – 1	92	LIMESTONE	Gray	Fresh, sound and massive limestone	0.2	30	90 – 91
29/9/88	1 – 4	80	LIMESTONE	Gray		0.2	60	91 – 94
29/9/88	4 – 6	39	LIMESTONE	Gray		0.2	25	94 – 96
30/9/88	6 – 8	60	LIMESTONE	Gray		1.0	65	96 – 98
30/9/88	8 – 10	46	LIMESTONE	Gray		1.0	35	98 – 100
	10				Bottom of hole			100

Core loss ——→ [⊠]   Weathering 1 (fresh) – 5 (decomposed)   Hardness 1 (hard) – 5 (soft)   Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM MAE NGAO No. 2	Location: Intake	Boring No.: DR-7A	Log No. 1 of 1
Co-ordinates: N1,966,964.636 E393,945.956	Elevation: 258.802 m MSL	Depth of Hole: 27.00 m	Commenced: 12/8/88
Angle from Horizontal: 90°	Core Recovery:	Depth of Overburden: 3.95 m	Completed: 24/8/88
Bearing of Angle Hole: –	Company: EGAT	Total length of core:	Logged by: V. Vichorn, K. Tokeda

Columns: Date | Depth (M) | R Q D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit / ø of Core (mm.) | Casing | Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST LUGEON VALUE ○, WATER TABLE | Drill | Pressure ___ Kg (0, 50, 100) | Time ___ min | Depth (M) | Elevation

Dates: 12/8/88 (0–7 m), 13/8/88, 16/8/88, 17/8/88, 18/8/88, 19/8/88, 20/8/88, 21/8/88, 22/8/88, 23/8/88, 24/8/88

RQD: 0

Geology: Overburedn (0.00–3.95 m); Alternation of sandstone and shale (3.95–27.00 m)

Colour of rock: Brown; Gray

Drill (pressure readings, top to bottom): 40, 35, 40, 30, 40, 60, 20, 30, 45, 20, 30, 45, 55, 30, 20, 20, 30, 45, 25, 20, 15, 20, 10, 15, 15, 25, 25, 40, 30, 20, 15, 23, 25, 65, 25, 20, 25, 33

Description:

0.00-3.95m. Overburden Detritus deposits
0.00-2.00m. Silty clay with sandstone fragments.
2.00-3.95m. Silty sand with sandstone fragments.

3.95-10.20m. Sandstone interbedded with shale brittle, iron oxide coated at joints.
Core loss at 4.15-4.60m, 5.70-7.00m, 8.10-8.70m, 9.00-9.40m

10.20-27.00m. Shale interbedded with sandstone, few calcite veins, broken rock joints 30°, 60°, 85° rough, clay and iron oxide coated at joints, calcareus in sandstone, Bedding 60°
10.80m. Slicken side
12.70-13.30m Sheared zone, clay with breccia
Core loss at 11.00-12.00m, 12.35-12.65m, 13.30-16.60m, 17.40-17.65m, 18.30-18.40m, 20.40-21.50m, 22.25-22.45m, 22.70-22.95m, 23.25-23.65m, 24.40-24.60m, 26.60-26.75m.

Bottom of hole

Water pressure test: No ground water

Core loss [⊠]; Weathering 1 (fresh) - 5 (decomposed); Hardness 1 (hard) - 5 (soft); Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 6 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project: NAM MAE NAGO No. 2	Location: Dam Axis (Right Bank)	Boring No. DR - 8	Log No. 1 of 3
Co-ordinates: N 1,966,999 E 394,032	Elevation: 293.682 m MSL	Depth of Hole: 90.00 m	Commenced: 5/7/88
Angle from Horizontal: 90°	Core Recovery: 87.2 %	Depth of Overburden: 2.70 m	Completed: 30/7/88
Bearing of Angle Hole: —	Company: EGAT	Total length of core: 78.50 m	Logged by: V. Vicharn, K. Takeda

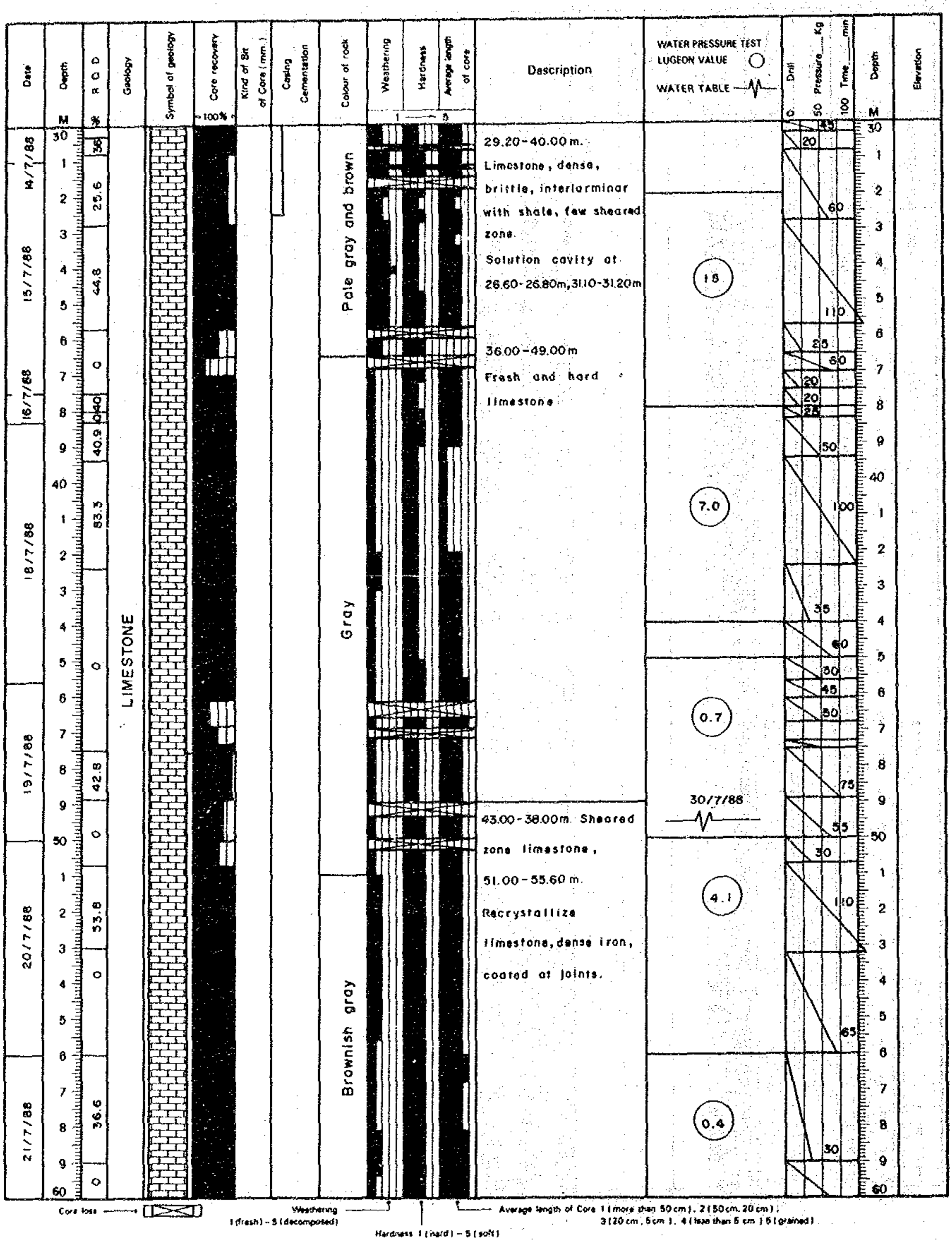
Columns: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | Water pressure test: Lugeon value ○, Water table | Drill: Pressure Kg (0, 50, 100), Time mm | Depth (M) | Elevation

Date	Depth (M)	R.Q.D (%)	Geology	Colour of rock	Description	Water pressure test / Lugeon value / Water table	Drill time (mm)
5/7/88, 6/7/88	0–2.70			Brown	0.00-2.70m. Overburden 0.00-0.50m. Top soil 0.5-2.30m. Clayey silt 2.30-2.70m. Fragments weathered limestone.	SPT. N = 6 - 9 - 16 SPT. N = 50	
7/7/88	2.70–6	52	LIMESTONE	Pale gray	2.70-11.00m. Limestone dense cavity at 4.30 - 4.60 m, 5.15 - 5.30 m, 8.40-8.70 m. Joints 40°-60° Clay and iron oxide fill at joints calcite veinlets. Core loss at 10.95 - 12.35m.		70
8/7/88	6–9	58.3				18	60
	9–10	9.2					30, 20
11/7/88	10–11	13					25
	11–13.5	24			12.10-17.10m. Limestone interlaminar with shale, fold at 12.30 - 12.40 m. bedding 25° cavity at 13.50 - 13.95 m, 14.10 - 15.55 m, 16.10 - 16.30 m.	No test	85
12/7/88	13.5–14	0					25
	14–17	10					50
	17–20	0		Pale gray and brown	17.10 - 24.00m. Limestone, cavity fill with clay. Sandy Limestone at 21.50 - 22.00 m. Core loss at 17.10-17.50m, 17.75-19.00m, 19.55-21.40m, 22.20-22.44m	Water table 17.65m 21/2/89	35, 45
	20–22	8.7					60
13/7/88	22–24	22.1					55, 40
	24–29	0			24.00 - 29.20 m. Limestone interlaminar with shale, brittle, bedding 80° nearly vertical.		60, 40, 30
14/7/88	29–30	27, 51					45

Core loss: ⊠   Weathering 1 (fresh) - 5 (decomposed)   Hardness 1 (hard) - 5 (soft)   Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)

LOG OF BORING

Project NAM MAE NGAO No. 2	Location Dam Axis (Right Bank)	Boring No. DR – 8	Log No. 2 of 3
Co-ordinates N 1,966.999 E 394.032	Elevation 293.682 m MSL	Depth of Hole 90.00 m	Commenced 3/7/88
Angle from Horizontal 90°	Core Recovery 87.2 %	Depth of Overburden 2.70 m	Completed 30/7/88
Bearing of Angle Hole —	Company EGAT	Total length of core 78.50 m	Logged by V. Vichorn



LOG OF BORING

Project	NAM MAE NAGO No. 2	Location	Dam Axis (Right Bank)	Boring No.	DR – 8	Log No.	3 of 3
Co-ordinates	N 1,966.999 E 394.032	Elevation	293.682 m MSL	Depth of Hole	90.00 m	Commenced	5 / 7 / 88
Angle from Horizontal	90°	Core Recovery	87.2 %	Depth of Overburden	2.70 m	Completed	30 / 7 / 88
Bearing of Angle Hole	—	Company	EGAT	Total length of core	78.50 m	Logged by	V. Vichorn, K. Takeda

Column headings: Date | Depth (M) | R.Q.D (%) | Geology | Symbol of geology | Core recovery (100%) | Kind of Bit of Core (mm.) | Casing Cementation | Colour of rock | Weathering | Hardness | Average length of core (1 — 5) | Description | WATER PRESSURE TEST LUGEON VALUE ○ / WATER TABLE | Drill – Pressure (Kg) – Time (min) (0 – 50 – 100) | Depth (M) | Elevation

Dates: 21/7/88; 22/7/88; 23/7/88; 25/7/88; 29/7/88; 30/7/88

R.Q.D (%) (from top to bottom): 0; 9.7; 0; 22; 38.3; 66.6; 83; 66.6; 93; 0; 73.3; 86.5; 40; 92.8

Geology: LIMESTONE INTERLARMINAR with SHALE

Colour of rock: Brownkish gray; Gray to dark gray

Description:

58.00 – 90.00 m.
Limestone, interlarminar with shale bedding 30° – 80° sheared zone at 63.80 – 64.30 m.
65.30 – 66.90 m. calcite veinlets dense
Joints 20°, 45°, 60°, 80° clean and rough.
61.30 – 64.00 m Weathered, cracks are stained

Bottom of hole

Lugeon values (from top to bottom): 0.4; 0.4; 0; 0.1; 0.1; 0

Drilling time (min) (from top to bottom): 60; 40; 30; 70; 35; 80; 80; 105; 55; 60; 85; 20; 80; 40; 30; 55

Depth scale: 60, 1, 2, 3, 4, 5, 6, 7, 8, 9, 70, 1, 2, 3, 4, 5, 6, 7, 8, 9, 80, 1, 2, 3, 4, 5, 6, 7, 8, 9, 90

Core loss —— [⊠] Weathering 1 (fresh) – 5 (decomposed) Hardness 1 (hard) – 5 (soft) Average length of Core 1 (more than 50 cm), 2 (50 cm, 20 cm), 3 (20 cm, 5 cm), 4 (less than 5 cm), 5 (grained)