CHAPTER 8 GENERATION PLAN

The generation plan is made based on the planned maximum available discharge at Lagunilla P/P of 0.50 m^3/s.

The maximum available discharge can be changed if the facility utilization factor does not exceed 50% in the typical flow-duration curves at the intake site, and generating output and annual generating energy are calculated. The generation plan is conceived from technological and economical aspects.

8.1 Study of the Alternative Plans

When the generating facilities for Lagunilla P/P are rehabilitated, comparative studies will be made for the generation-optimizing plan as well as the rehabilitation plan of the existing generating facilities in consideration of the following conditions.

(1) Full use will be made of a 300-meter waterfall head. Since the right bank side slope is too steep, and the existing powerhouse building is half-built in the ground, the Study Team abandons the generation plan described above.

(2) According to survey, debris flow occurs once in 70 years. The layout of structures and facilities, except for intake facilities, will be planned to prevent debris flow.

Alternative plans under consideration as the rehabilitation plan for the Lagunilla P/P, with consideration given to the above conditions are shown in Table 8.1. The layout of alternative plans on a photogrammetric map (scale: 1/5,000) are shown in Fig. 8.1.

Table 8.1 Alternative Plans for Lagunilla Power Plant Rehabilitation

Item	Alternative Plans				
	Alternative-1	Alternative-2	Alternative-3		
Elevation at the intake (m)	1,782.5	1,821			
Headrace route	Right-bank route		Left-bank route		
Location of power plant	Existing power plant site (Elev = 1,650)		Left bank (Elev = 1,500 m)		
Net head, He (m)	125.9	161.5	309.0		
Discharge, Q (m^3/s)	2.0	2.0	2.0	3.0	4.0
Max. output, P (MW)	2.0	2.6	5.0	7.7	10.2
Facility utilization coefficient (%)	99	99	99	85	71

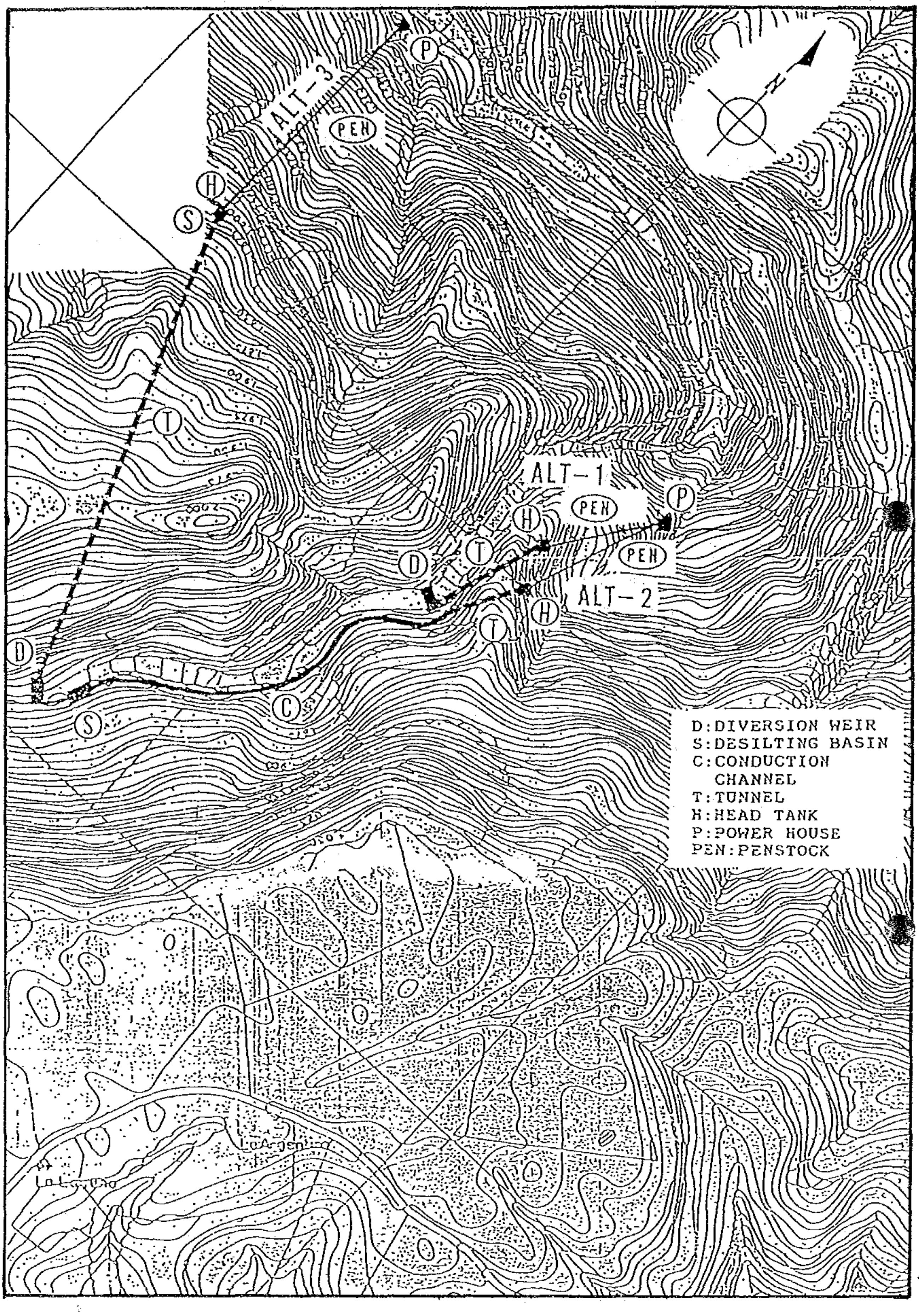


Fig. 8.1 Layout for the Alternative Plans.

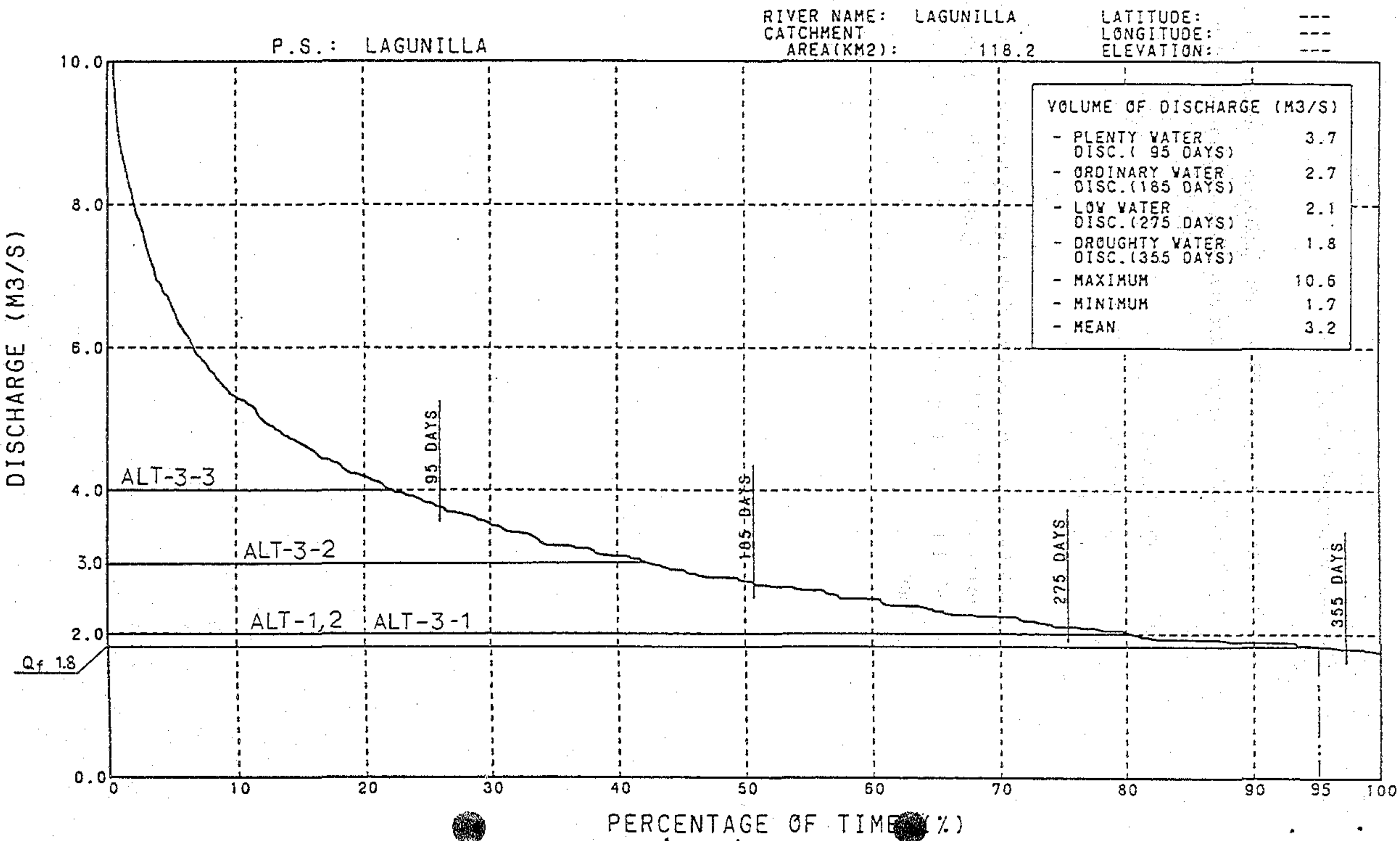
(1) Maximum available discharge

The annual guaranteed 95% of the maximum available discharge (refer to Fig. 8.2) is 1.8 m^3. Three alternative plans under the conditions

$Q = 2.0\ m^3/s$
$Q = 3.0\ m^3/s$
$Q = 4.0\ m^3/s$

are set up, and their respective generating output and annual generated energy are calculated. Both ALT-1 and ALT-2, at a maximum discharge of 2.0 m3/s and ALT-3 at discharges of 2.0 m3/s, 3.0 ms/s and 4.0 m3/s are compared in Table 8.1.

Fig-8.2 TYPICAL FLOW DURATION CURVE AT INTAKE SITE



(2) Standard net head

The standard net head, calculated as follows, is used to determine the turbine output and calculate the annual generated energy

The net head (He) can be obtained by the following formula.

$$He = Hg - \Sigma\Delta H$$

where:

Hg = gross head
(Intake water level - tailrace water level)

	Intake water level	Tailrace water level	Hg
ALT-1	1,782.5	1,650.0	132.5
ALT-2	1,821.0	1,650.0	170.0
ALT-3	1,821.0	1,500.5	320.5

$\Sigma\Delta H = \Delta H_1 + \Delta H_2 + \Delta H_3$

$\Sigma\Delta H$ = total loss of head (m)

ΔH_1 = head loss at the intake (m)

ΔH_2 = head loss at the headrace (m)

ΔH_3 = head loss at the penstock (m)

1) head loss at the intake

$$\Delta H_1 = \frac{V^2}{2g} \times (1 + f_1) + \Delta h_1$$

$V^2/2g$ = velocity head (m)

f_1 = coefficient of inflow loss; 0.1

Δh_1 = margin (m)

Head Loss at the Intake

	Q (m/s)	V (m/s)	$V^2/2g$ (m)	$V^2/2g(1+0.1)$ (m)	Δh_1 (m)	ΔH_1 (m)
ALT-1	2.0	1.0	0.051	0.056	0.014	0.070
ALT-2	2.0	1.0	0.051	0.056	0.014	0.070
ALT-3	2.0	1.0	0.051	0.056	0.014	0.070
"	3.0	1.0	0.051	0.056	0.014	0.070
"	4.0	1.0	0.051	0.056	0.014	0.076

2) head loss at the headrace

ΔH_2 = $i \times L_1 + \Delta h_2$
i = headrace gradient: 1.8 ‰
L_1 = headrace length (m)
Δh_2 = margin (m)

	Q (m^3/s)	i ‰	L_1 (m)	$i \times L_1$ (m)	Δh_2 (m)	ΔH_2 (m)
ALT-1	2.0	1.8	115	0.207	0.023	0.23
ALT-2	2.0	1.8	580	1.046	0.024	1.07
ALT-3	2.0	1.8	590	1.062	0.018	1.08
"	3.0	1.8	590	1.062	0.018	1.08
"	4.0	1.8	590	1.062	0.018	1.08

3) head loss at the penstock

$\Delta H_3 = V^2/2g\ (1+f_2 + f_2 + f_3\ L/D + fm) + \Delta h_3 = V^2/2g\ (1.85 + f_3\ L/D) + \Delta h_3$

where:

$V^2/2g$ = velocity head (m)
f_2 = coefficient of inflow loss; 0.1
f_3 = coefficient of frictional loss; $124.6\ n^2/D^{1/3}$

L = penstock length (m)
D = penstock diameter (m)
fm = loss coefficient at the branched part; 0.75
Δh_3 = margin (m)
n = coefficient of roughness; 0.012

	Q (m^3/s)	D (m)	L (m)	V (m/s)	$V^2/2g$ (m)	f_3 x L/D	$V^2/2g$ (m)	Δh_3 (m)	ΔH_3 (m)
ALT-1	2	0.8	220	3.98	0.808	5.315	5.789	0.501	6.29
2	2	0.8	270	3.98	0.808	6.523	6.765	0.505	7.27
3-1	2	0.8	470.6	3.98	0.808	11.370	10.682	0.498	11.18
3-2	3	0.95	470.6	4.23	0.913	9.040	9.943	0.497	10.44
3-3	4	1.10	470.6	4.21	0.904	7.433	8.392	0.498	8.89

4) Standard net head

	Q (m^3/s)	Hg (m)	ΔH_1 (m)	ΔH_2 (m)	ΔH_3 (m)	$\sum_{i=1}^{3} \Delta Hi$ (m)	He (m)
ALT-1	2	132.5	0.07	0.23	6.29	6.59	125.9
2	2	170.0	0.07	1.07	7.27	8.41	161.5
3-1	2	320.5	0.07	1.08	11.18	12.33	308.1
3-2	3	320.5	0.07	1.08	10.44	11.59	308.9
3-3	4	320.5	0.07	1.08	8.89	10.04	310.4

From the above calculations, the standard available head is 309 meters for ALT-3.

8.2 Generated Output

Theoretical output obtained from available discharge (Q) and the standard net head (He) is multiplied as resultant efficiency of the equipment, and the generated output is calculated as follows:

$$P = 9.8 \times Q \times He \times \eta$$

where:

P	=	generated output (kW)
Q	=	arbitrary available discharge (m^3/s)
He	=	standard net head (m)
η	=	resultant efficiency of turbine and generator (resultant efficiency of the single unit capacity)
9.8	=	constant (acceleration of gravity, m/s^2)

Resultant efficiency (η) is the value representing total efficiency, and this value is obtained by the following formula.

$$\eta = \eta t \times \eta g$$

where:

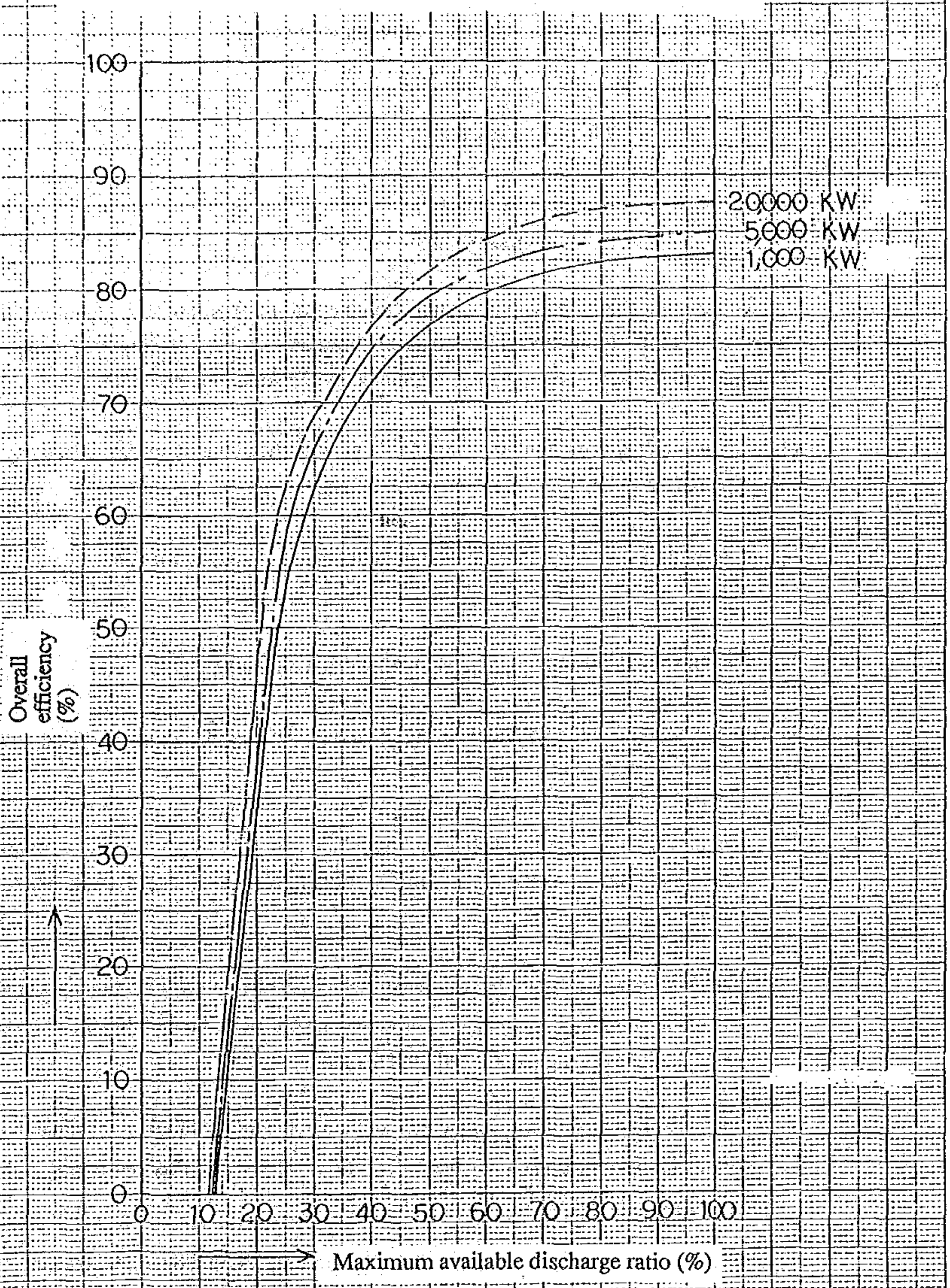
ηt	=	turbine efficiency
ηg	=	generator efficiency

Resultant efficiency corresponds to the value of the maximum available discharge ratio 100% in the resultant efficiency curve as shown in Fig. 8.2. Table 8.2 shows the calculation result of the generated output for the alternative plans.

Table 8.2 Calculation of Generated Output

Item / Alternative plan	① Available discharge Q (m^3/s)	② Standard net head H (m)	③ 9.8 x ① x ② Theoretical output (kW)	④ Resultant efficiency η	⑤ ③ x ④ Generated output ρ (kW)
ALT-1	2.0	125.9	2,467	0.830	2,000
ALT-2	2.0	161.5	3,165	0.830	2,600
ALT-3-1	2.0	309.0	6,056	0.830	5,000
ALT-3-2	3.0	309.0	9,084	0.850	7,700
ALT-3-3	4.0	309.0	12,112	0.850	10,200

Fig. 8.2 Resultant Efficiency Curve of Pelton Turbine and Generator



(Source: The above curves are drawn according to the Study Standard for Formulation of Hydroelectric Development Plan (March, 1981)

8.3 Annual Potential Generated Energy

Generated energy is calculated by the following formula.

$$E = P \times t \ (kWh)$$
$$= 9.8 \times Q \times He \times \eta \times t$$

where, P = generated output (kW)
t = operation time (hour)

Assuming that the power plant operation is not interrupted by accident, nor suspended for maintenance, inspection and repair purposes during the year, the Annual potential generated energy is calculated by the following methods.

(1) Using daily discharge in discharge data plus net head and resultant efficiency at that daily discharge

(2) Combining hydrological regime and resultant efficiency from the flow-duration curve

(3) Using the generating output-to-available discharge ratio

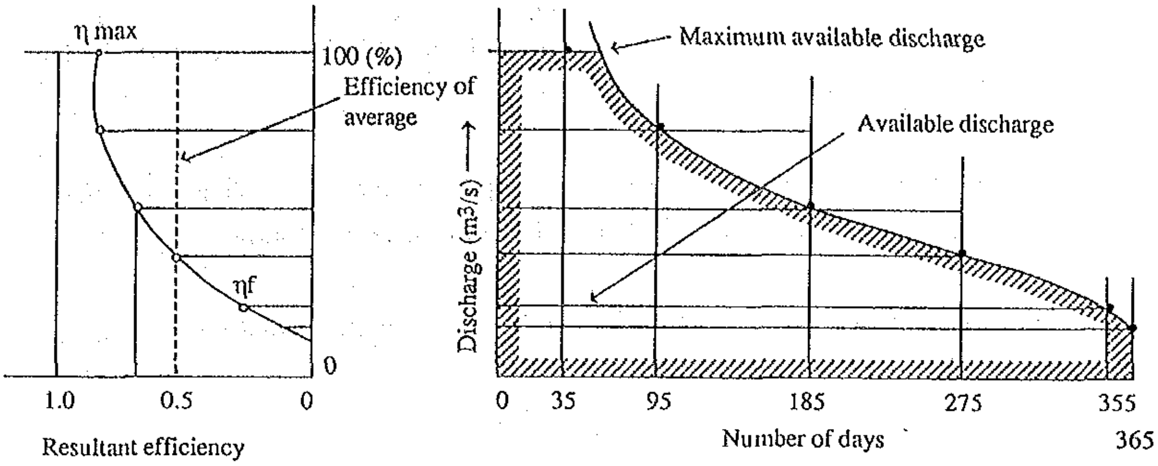
For the calculation of the annual potential generated energy at Lagunilla P/P, item (2) is used for the following reasons.

① Instead of recorded observations at the intake site of this power plant, converted data from the El Bosque gauging station operated by HIMAT is used as discharge data.

② Since there are no recorded observations at the El Bosque gauging station and the intake site, discharge data is converted according to the catchment area ratio at the above gauging station and intake site.

③ The average generating output-to-available discharge ratio of (3) and flow-duration curve are used for the calculation. However, this method is not as accurate as method (2).

Hydrological regime and resultant efficiency are combined from the flow-duration curve, and the hydrological regime-efficiency method, to roughly calculate the annual potential generated energy, as shown below.



Max. available discharge = m³/s Net head = m

① Day	② Number of days	③ Available discharge (m^3/s)	④ Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	⑤ Resultant efficiency η	⑥ Generating power (kW)	⑦ Average power (kW)	⑧ Generated energy (kWh)
Max.							
95	95-						
185	185-95 = 90						
275	275-185 = 90						
355	355-275 =80						
365	365-355 = 10						
Total	365					( )	

① Possible intake-water days of maximum available discharge are inserted for the day order ①.
② Represents the difference of the day order of calculation stage and right above stage. This example employed hydrological regime representative days as a matter of convenience.
③ The discharge of the day order topped out by maximum available discharge shall be an available discharge.
④ Available discharge divided by maximum available discharge shall be input load factor, and the resultant efficiency ⑤ shall be read and entered.
⑥ $9.8 \times Q \times He \times \eta$
⑦ Mean value of generated output of calculation stage and right above stage.
⑧ ⑦ x ② x 24 is the generated energy for calculated days, and the total value becomes yearly possible generated energy.

Fig. 8.3 Calculation of Annual Potential Generated Energy According to the Hydrological Regime-Efficiency Method

8.3.1 Calculation Procedure of Annual Potential Generated Energy by Hydrological Regime-Efficiency Method.

The Annual potential generated energy for respective alternative plans is calculated according to the hydrological regime and efficiency method as follows.

(1) Annual generated energy of ALT-1 (max. available discharge = 1.0 m^3/s x 2 units):

17.6 GWh (99%)

(2) Annual generated energy of ALT-2 (max. available discharge = 1.0 m^3/s x 2 units):

22.6 GWh (99%)

(3) Annual generated energy of ALT-3-1 (max. available discharge = 1.0 m^3/s x 2 units)

43.2 GWh (99%)

(4) Annual generated energy of ALT-3-2 (max. available discharge = 1.5 m^3/s x 2 units):

56.7 GWh (85%)

(5) Annual generated energy of ALT-3-3 (max. available discharge = 2.0 m^3/s x 2 units):

62.4 GWh (71%)

Table 8.3 Calculation of annual potential generated energy

(1) Alternative 1 (ALT-1)

Max. available discharge Q = 1.0 m^3/s x 2 units
Standard net head He: 125.9 m
Turbine type: Pelton turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	285	2.0	1.00	0.830	2,047	2,047	14,001
299	14	1.9	0.95	0.830	1,945	1,996	670
341	42	1.8	0.90	0.828	1,838	1,891	1,906
365	24	1.7	0.85	0.825	1,730	1,784	1,027
Total	365					(1,929)	17,604

(2) Alternative plan 1 (ALT-2)

Max. available discharge: Q = 1.0 m^3/s x 2 units
Standard net head He: 161.5 m
Turbine type: Pelton turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	285	2.0	1.00	0.830	2,627	2,627	17,968
299	14	1.9	0.95	0.830	2,495	2,561	860
341	42	1.8	0.90	0.828	2,358	2,426	2,445
365	24	1.7	0.85	0.825	2,219	2,288	1,317
Total	365					(2,475)	22,590

(3) Alternative plan 3-1 (ALT-3-1)

Max. available discharge: Q = 1.0 m^3/s x 2 units
Standard net head He: 309.0 m

Turbine type: Pelton turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	285	2.0	1.00	0.830	5,026	5,026	34,377
299	14	1.9	0.95	0.830	4,775	4,900	1,646
341	42	1.8	0.90	0.828	4,513	4,644	4,681
365	24	1.7	0.85	0.825	4,247	4,380	2,522
Total	365					(4,735)	43,226

(4) Alternative plan 3-2 (ALT-3-2)

Max. available discharge: Q = 1.5 m^3/s x 2 units
Standard net head He: 309.0 m
Turbine type: Pelton turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio Available discharge / Max. available discharge	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	150	3.0	1.000	0.850	7,721	7,721	27,795
159	9	2.9	0.966	0.848	7,446	7,583	1,637
166	7	2.8	0.933	0.846	7,173	7,309	1,227
181	15	2.7	0.900	0.845	6,908	7,040	2,534
193	12	2.6	0.866	0.844	6,645	6,776	1,951
207	14	2.5	0.833	0.843	6,381	6,513	2,188
222	15	2.4	0.800	0.842	6,119	6,250	2,250
235	13	2.3	0.766	0.840	5,850	5,984	1,867
249	14	2.2	0.733	0.837	5,576	5,713	1,919
267	18	2.1	0.700	0.835	5,309	5,442	2,350
285	18	2.0	0.666	0.828	5,014	5,169	2,229
299	14	1.9	0.633	0.827	4,758	4,886	1,641
341	42	1.8	0.600	0.817	4,453	4,605	4,641
365	24	1.7	0.566	0.810	4,169	4,311	2,483
Total	365					(6,092)	56,712

(5) Alternative plan 3-3 (ALT-3-3)

Max. available discharge: Q = 2.0 m^3/s x 2 units
Standard net head He: 309.0 m
Turbine type: Pelton turbine

Day	Number of days	Available discharge (m^3/s)	Burden ratio $\frac{\text{Available discharge}}{\text{Max. available discharge}}$	Resultant efficiency η	Generating power (kW)	Average power (kW)	Generated energy (MWh)
Max.	79	4.0	1.000	0.850	10,295	10,295	19,519
85	6	3.9	0.975	0.849	10,026	10,160	1,463
90	5	3.8	0.950	0.848	9,758	10,392	1,247
95	5	3.7	0.925	0.847	9,490	9,624	1,154
102	7	3.6	0.900	0.846	9,222	9,356	1,571
109	7	3.5	0.875	0.845	8,955	9,088	1,526
114	5	3.4	0.850	0.844	8,689	8,822	1,058
122	8	3.3	0.825	0.823	8,224	8,456	1,623
125	3	3.2	0.800	0.842	8,159	8,191	589
140	15	3.1	0.775	0.840	7,885	8,022	2,887
150	10	3.0	0.750	0.838	7,612	7,748	1,859
159	9	2.9	0.725	0.826	7,253	7,432	1,605
166	7	2.8	0.700	0.835	7,079	7,166	1,203
181	15	2.7	0.675	0.830	6,786	6,932	2,495
193	12	2.6	0.650	0.827	6,511	6,648	1,914
207	14	2.5	0.625	0.823	6,230	6,370	2,140
222	15	2.4	0.600	0.817	5,937	6,083	2,189
235	13	2.3	0.575	0.813	5,662	5,799	1,809
249	14	2.2	0.550	0.807	5,376	5,519	1,854
267	18	2.1	0.525	0.802	5,100	5,238	2,262
285	18	2.0	0.500	0.793	4,802	4,951	2,138
299	14	1.9	0.475	0.785	4,516	4,659	1,565
341	42	1.8	0.450	0.773	4,213	4,364	4,398
365	24	1.7	0.425	0.760	3,912	4,062	2,339
Total	365					(7,307)	62,407

CHAPTER 9 REHABILITATION PLAN

The JICA study team's FS to increase output recommends the use of existing facilities by increasing their power generation capacity through rehabilitation. However, the river water utilization coefficient of these facilities is extremely low, as they were built 50 years ago and have been left unattended for over 16 years. Thus, this plan calls for the abandoning of existing facilities.

The rehabilitation plan will be formulated according to standards established by ISA (Interconexion Electrica SA) in June, 1987.

9.1 Formulation of Rehabilitation Plans

As stated, all of these power generation facilities will be newly installed. This requires the procurement or parts or replacement of transformers and generator equipment and machinery facilities. In comparing maximum discharge capacity, the following five rehabilitation proposal plans are shown in Table 9.1.

ALT-1, ALT-2, ALT-3-1	$Q = 2.00\ m^3/s$
ALT-3-2	$Q = 3.00\ m^3/s$
ALT-3-3	$Q = 4.00\ m^3/s$

For each rehabilitation plan the total construction cost is calculated and the construction cost per kW output and the generating cost are calculated and compared. The optimum rehabilitation plan is then chosen.

Table 9.1 Comparison of Alternative Rehabilitation Plans for the Lagunilla Hydroelectric Power Plant

Item	Alternative Plans				
	Alternative-1	Alternative-2	Alternative-3		
Elevation at the intake (m)	1,782.5	1,821			
Headrace route	Right-bank route		Left-bank route		
Location of power plant	Existing power plant site (Elev = 1,650 m)		Left bank (Elev = 1,500 m)		
Net head, He (m)	125.9	161.5	309.0		
Discharge, Q (m^3/s)	2.0	2.0	2.0	3.0	4.0
Max. output, P (MW)	2.0	2.6	5.0	7.7	10.2
Facility utilization coefficient (%)	99	99	99	85	71

9.2 Estimation of Construction Costs of Rehabilitation

The construction costs can be divided into the estimate for generating equipment and the cost of civil works, and calculated. This can then be divided into the foreign currency portion and the local currency portion and calculated at the present exchange rates (September 1989) based on the U.S. dollar.

9.2.1 Estimation of Generating Equipment Costs

According to the ISA valuation standard, CIF cost of generating equipment are calculated based on the FOB of Japan base. The generating equipment specifications and FOB costs are shown in Table 9.2.

The CIF/FOB ratio for CIF costs is 1.12, as shown in Table 9.3.

Table 9.2 Generating Equipment Specifications and FOB Costs

Item	Alternative Plans				
	ATL-1	ALT-2	ALT-3		
			1	2	3
1. Specifications					
Design discharge (m^3/s)	1.0	1.0	1.0	1.5	2.0
Net head (m)	125.9	161.5	309.0	309.0	309.0
Theoretical output (kW)	1,233	1,582	3,028	4,542	6,056
Turbine type	Pelton	Pelton	Pelton	Pelton	Pelton
Turbine output (kW)	1,070	1,380	2,640	4,060	5,420
Generator power factor	0.9	0.9	0.9	0.9	0.9
Generator output (kVA)	1,200	1,500	2,800	4,300	5,800
Main transformer capacity (kVA)	2,400	3,000	5,600	8,600	11,600
2. FOB costs (U.S.$1,000)					
Generating Equipment					
(1) Water turbine etc.	394.6	504.3	837.85	1,250.7	1,670
(2) Generator etc.	182.1	212.8	358.55	510	662.1
(3) ((1)+(2)) Sub-total:	576.1	717.1	1,196.4	1,760.7	2,332.1
(4) Number of units	2	2	2	2	2
(5) ((3)x(4)) Total:	1,153.4	1,434.2	2,392.8	3,521.4	4,664.2
(6) 4.16 kV switchgear etc.	97.9	97.9	97.9	97.9	97.9
(7) Substation	132.2	140.8	180.8	288.6	328.6
(8)=(5)+(6)+(7) Total:	1,383.6	1,673	2,671.5	3,907.9	5,090.7

Table 9.3 Implementation Cost of Generating Equipment

(units: US$10^3)

Item	ALT-1 A	ALT-1 B	ALT-2 A	ALT-2 B	ALT-3 1 A	ALT-3 1 B	ALT-3 2 A	ALT-3 2 B	ALT-3 3 A	ALT-3 3 B
1) FOB cost	1,383.6	-	1,673	-	2,671.5	-	3,907.9	-	5,090.7	-
2) Transport costs insurance 1) x 0.12	166	-	200.8	-	320.6	-	469	-	610.9	-
3) Tax 1) x 0.223	-	308.6	-	373.1	-	595.8	-	871.5	-	1,135.2
4) Value-added tax 1) x 0.134	-	185.4	-	224.2	-	358	-	523.7	-	682.2
5) Others 1) x 0.22	-	304.4	-	368.1	-	587.4	-	859.8	-	1,120
6) Subtotal	1,549.6	798.4	1,873.8	965.4	2,992.1	1,541.2	4,376.9	2,255	5,701.6	2,937.4
7) Contingency 1) x 0.17	235.2	-	284.4	-	454.2	-	664.3	-	865.4	-
8) Engineering fee 1) x 0.149	206.2	-	249.3	-	398.1	-	582.3	-	758.6	-
9) Subotal 6) + 7) + 8)	1,991	798.4	2,407.5	965.4	3,844.4	1,541.2	5,623.5	2,255	7,325.6	2,937.4
10) Total	2,789.4		3,372.9		5,385.6		7,878.5		10,263	

Note: A = foreign currency portion
B = local currency portion

9.2.2 Estimation of Civil Work Cost

The work volume for the rehabilitation or improvement of the main structures is multiplied by the unit costs (as shown in Table 5.2) as decided by ELECTROLIMA and the civil work costs are estimated in the local currency base.

The civil work costs estimated for each rehabilitation plan are compared as shown in Table 9.4.

Table 9.4 Estimation of Civil Work Cost

(unit: 10^6 pesos)

Item	Alternative				
	ALT-1	ALT-2	ALT-3		
			1	2	3
Diversion weir and intake work	27.0	23.5	23.5	25.9	28.2
Desilting basin work	19.6	38.0	19.6	28.4	37.2
Conduction channel work	11.2	46.9	77.4	85.1	92.9
Head tank work	27.9	27.9	27.9	36.3	44.6
Penstock work	32.7	43.7	91.8	133.1	170.3
Foundation of equipment work	28.1	32.9	51.7	75.7	99.7
Powerhouse building work	52.3	52.3	154.8	154.8	154.8
Temporary works	4.9	6.8	11.7	11.7	11.7
Other works	2.9	2.9	5.0	5.0	5.0
① Total	206.6	274.9	463.4	556.0	644.4
② Contingency (① x 0.15)	31.0	41.2	69.5	83.4	96.7
③ Engineering fee ((① + ②) x 0.10)	23.8	31.6	53.3	63.9	74.1
④ Total (① + ② + ③)	261.4	347.7	586.2	703.3	815.2
⑤ Output loss	0	0	0	0	0
⑥ Grand total (④ + ⑤)	261.4	347.7	586.2	703.3	815.2

9.3 Comparison of Economic Indices

For a comparison of the two economic indices, the construction cost per kW and the generating cost per kW, the basic conditions common to all alternative plans are as follows.

(1) Exchange rate for September, 1989 is adopted as follows.

US$ 1 = ¥140
US$ 1 = 369.4 pesos
1 peso = ¥0.379

(2) The design life of new generating equipment and the repaired and reconstructed structures is 25 years.

(3) The interest rate is divided between the foreign currency portion and the local currency portion under the following conditions.

- The foreign currency portion is based on an annual interest rate of 10% (unredeemable for 4 years) with a repayment of the principal in equal annual amounts over 25 years.

- The local currency portion is based on an annual interest rate of 21% (unredeemable for 1 year) with a repayment of the principal in equal annual amounts over 8 years.

(4) The operation, maintenance and management costs of hydroelectric power plants per year is US$4 per installed capacity (kW).

9.3.1 Comparison of Construction Cost per kW

A comparison of the construction cost per kW is shown in Table 9.5. The ALT-3-3 plan is US$ 1,200/kW per increase in power output and this is the lowest costs.

Table 9.5 Comparison of Construction Costs per kW

Item	Alternative Plans				
	ALT-1	ALT-2	ALT-3		
			1	2	3
Existing equipment output (kW)					
Rated output Po	392	392	392	392	392
Available output Pe	0	0	0	0	0
Post-rehabilitation output P_1 (kW)	2,000	2,600	5,000	7,700	10,200
Recovered/increased output $\Delta P = P_1 - Pe$ (kW)	2,000	2,600	5,000	7,700	10,200
Rehabilitation work cost (US$1,000)					
Foreign currency portion Cf	2,000	2,400	3,800	5,600	7,300
Local currency portion C	1,500	1,900	3,100	4,200	5,100
Total C = Cf + C	3,500	4,300	6,900	9,800	12,400
Construction cost per kW (US$/kW)					
C/P_1	1,750	1,650	1,400	1,300	1,200
$C/\Delta P$	1,750	1,650	1,400	1,300	1,200

9.3.2 Comparison of Generating Cost per kWh

The generating cost per kWh is calculated from the following equations:

$$\text{Generating cost} = \frac{\text{Total cost at generating terminal}}{\text{Supplied output per year}}$$

where the supplied output per year = annual potential generated energy (E) x utilization factor

= 0.95 E

The annual total cost at generating terminal is shown in Figure 9.1. On condition that service life of hydroelectric power plants is 25 years, the operation, maintenance and management costs (AOM per year = US$4 per kW) plus the amount to be paid as interest for the construction work and construction fund are totalized and divided by 25 years.

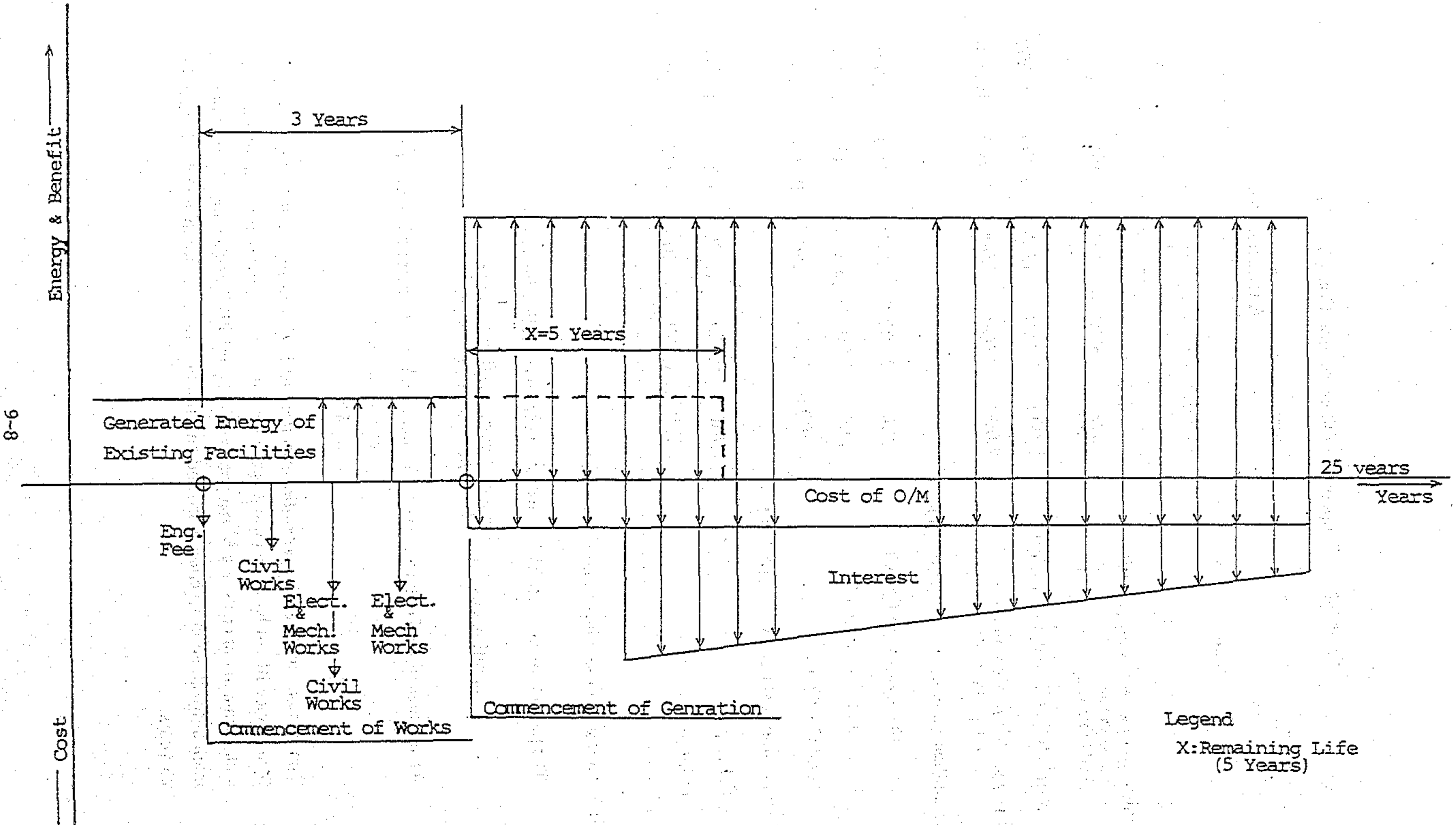


Fig- 9.1 Cost and Benefit of Rehabilitation Plan for Hydroelectric Power Plant

The results of calculation of generating costs per kWh are shown in Table 9.6. Since the generating potential of Lagunilla P/P was lost in 1972, a plan for new generation at the existing location is being considered. The generating cost per annually supplied energy is 16 mills/kWh, according to ALT-3-1 and the lowest costs is shown.

Table 9.6 Comparison of Generating Cost per kWh

Item		Alternative Plans				
		ALT-1	ALT-2	ALT-3		
				1	2	3
Existing equipment capacity:						
Power output	Pe (kW)	0	0	0	0	0
Energy	Ee (GWh)	0	0	0	0	0
Rehabilitation plan:						
Power output	P_1 (kW)	2,000	2,600	5,000	7,700	10,200
Generated Energy	E_1 (GWh)	17.6	22.6	43.2	56.7	62.4
Recovered/increased power						
Output	$\Delta P = P_1 - Pe$ (kW)	2,000	2,600	5,000	7,700	10,200
Energy	$\Delta E = E_1 - Ee$ (GWh)	17.6	22.6	43.2	56.7	62.4
Total espenses at generating terminals: (US$1,000)						
Construction work cost						
Foreign currency portion Cf_1		2,000	2,400	3,800	5,600	7,300
Local currency portion $C\ell_1$		1,500	1,900	3,100	4,200	5,100
Total $C_1 = Cf_1 + C\ell_1$		3,500	4,300	6,900	9,800	12,400
Interest payment C_2						
Foreign currency portion Cf_2		3,220	3,864	6,118	9,016	11,753
Local currency portion $C\ell_2$		1,524	1,930	3,150	4,267	5,182
Total $C_2 = Cf_2 + C\ell_2$		4,744	5,794	9,268	13,283	16,935
AOM C_3 = US$4 x PI x 25 years		200	260	500	770	1,020
Total $\Sigma Ci = C_1 + C_2 + C_3$		8,444	10,354	16,668	23,853	30,355
Average annual cost $C = \Sigma Ci/25$		336	415	673	953	1,219
Generating cost per annually supplied energy (mills/kWh)						
Per E_1	$C/(E_1 \times 0.95)$	20	19	16	18	21
Per ΔE	$C/(\Delta E \times 0.95)$	20	19	16	18	21

9.3.3 Overall Evaluation

ALT-3-1 plan is thus selected as the optimum plan taking the generating costs per kWh.

CHAPTER 10 FINANCIAL ANALYSIS

To evaluate the profitability of rehabilitation plans, a cost-benefit analysis is adopted. The difference between revenue after the existing facilities are rehabilitated and the revenue when the existing facilities are not rehabilitated is regarded as the profitability of the investment. Then the financial analysis of the selected rehabilitation plan is made for the planning of the balance of revenue and expenditure in accordance with the cash balance. For the evaluation of the investment propriety within the national economy, refer to the economic analysis described in the main report.

10.1 Preconditions for the Financial Analysis

Preconditions set up for the financial analysis are summarized below:

(1) Residual life of existing power plant

In case of unchanging the existing facilities with new ones, residual life of the existing power plant is tentatively set at five years after the installation of new equipment.

(2) Estimation of construction cost

The construction cost is estimated in both foreign and local currency portion according to the market price as of September, 1989. Currency exchange rate between foreign currency (US$) and local currency (Col.$) is set at US$1.00 = Col.$369.4, as determined by DNP.

The construction cost includes the contingency and technical management expense. The land acquisition cost is not accounted because the plan is for rehabilitating the existing power plant. The FOB price of the generating facilities is taken from Japanese market price. The CIF price is calculated in the ratio of CIF price to FOB price which ISA usually applies to a hydroelectric power generation project. The ratio of CIF price to FOB price is 1.00 : 1.12.

(3) Service life

The service life of the project is set at 25 years after rehabilitation for evaluating the profitability.

The annual depreciation of facilities will be based on the fixed amount method adopted by ICEL. The service life, as described below, is determined according to the facility. The residual price will be set at zero.

1) Service life of civil structure : 50 years
2) Service life of generating facilities : 25 years

(4) Operation and maintenance costs

Operation and maintenance costs consist of the fixed cost which depends upon the scale invested in the facilities, and the variable cost which fluctuates in proportion to generated electric power. This study adopts the average cost, i.e., US$4.0 per installed capacity (kW) per year, which ISA usually applies to make an estimate of operation and maintenance costs of a hydroelectric power plant.

(5) Estimation of revenue

ICEL's electricity-selling unit price of US$13.36/MWh (Col $4,936.18/MWh) and US$2,942.36/MW (Col$1,086,909.69/MW) in December, 1988 is adopted as the financial unit price. The estimation of annual revenue can be made by multiplying the rated capacity and the annual supplied power at generating terminal.

(6) Discount rate

The discount rate which is used to calculate the net present value (NPV) and the cost-benefit ratio (C/B Ratio) is set at 7.6% per year. It is determined by the real interest rate in Colombia.

(7) Conditions for borrowing capital on investment

The loan conditions for borrowing capital in foreign and local currency are as follows:

1) Loan conditions of foreign currency

- Annual interest	:	10%
- Period for principal repayment	:	25 years (including a 4-year grace period)
- Terms of payment	:	Repayment of the principle in equal, annual amounts

2) Loan conditions of local currency

- Annual interest	:	21%
- Period for principal repayment	:	8 years (including a 1-year grace period)
- Terms of payment	:	Repayment of the principal in equal, annual amounts

(8) Constant price

The annual inflation rate in Colombia varied from 24 to 30%, but the prices used in the cost and benefit stream are set at the constant price in 1989.

(9) Evaluation index

For evaluating profitability, the following three indices, which are commonly used, are adopted.

(1) Cost-benefit ratio (C/B ratio)
(2) Net present value (NPV)
(3) Internal rate of return (IRR)

These indices are calculated by using "with" and "without" the project.

10.2 Comparison of Profitability

The profitability of the generating plans are calculated using the cash flow for each alternative plan, as shown in Table 10.1.

Table 10.1 Profitability Index of Alternative Plans

Alternative	C/B	NPV (US$1,000)	IRR (%)
ALT-1	1.28	- 413	5.5
ALT-2	1.24	- 450	5.3
ALT-3-1	1.06	- 202	7.0
ALT-3-2	0.96	- 188	8.1
ALT-3-3	1.29	- 1,502	4.9

From the results of the financial analysis according to cash generation of the project, ALT-3-2 is determined to be the most profitable plan.

The rehabilitation plan, ALT-3-1 is selected as the optimum plan, which is described in Section 9.3.3, since it has a high profitability amongst the alternatives.

10.3 Financial Planning

The cash balance of the selected rehabilitation plan is prepared as a projected financial statement. The projected Profit-Loss Statement and Fund Flows Statement are shown in Table 10.2. According to the financial plan, the selected rehabilitation plan will show a profit from the year 2002, though there will be a projected aggregate deficit of US$221,000 at the end of service life.

Table - 10.2 PROJECTED FINANCIAL STATEMENTS

(1) PROJECTED REVENUE AND EXPENDITURE STATEMENT (at 1989 Price)

== Lagunilla : ALT-3-1 ==

Year	Year in Order	(A) Total Operating Revenue	(B) Operating Expenditure (US$:1000) O/M Cost	Depreci-ation	Interest on Investment	Total	(C) Net Benefit (A)-(B)
1989	-6	0.0	0.0	0.0	0.0	0.0	0.0
1990	-5	0.0	0.0	0.0	0.0	0.0	0.0
1991	-4	0.0	0.0	0.0	0.0	0.0	0.0
1992	-3	0.0	0.0	0.0	20.5	20.5	-20.5
1993	-2	0.0	0.0	0.0	41.0	41.0	-41.0
1994	-1	0.0	0.0	0.0	51.3	51.3	-51.3
1995	0	0.0	0.0	0.0	245.4	245.4	-245.4
1996	1	281.7	10.0	218.9	709.5	938.4	-656.7
1997	2	563.4	20.0	218.9	1002.7	1241.6	-678.2
1998	3	563.4	20.0	218.9	917.3	1156.2	-592.8
1999	4	563.4	20.0	218.9	812.6	1051.5	-488.1
2000	5	563.4	20.0	218.9	708.0	946.9	-383.4
2001	6	563.4	20.0	218.9	603.3	842.2	-278.8
2002	7	563.4	20.0	218.9	327.8	566.7	-3.3
2003	8	563.4	20.0	218.9	308.5	547.5	16.0
2004	9	563.4	20.0	218.9	289.3	528.2	35.3
2005	10	563.4	20.0	218.9	270.0	508.9	54.6
2006	11	563.4	20.0	218.9	250.7	489.6	73.8
2007	12	563.4	20.0	218.9	231.4	470.3	93.1
2008	13	563.4	20.0	218.9	212.1	451.0	112.4
2009	14	563.4	20.0	218.9	192.8	431.8	131.7
2010	15	563.4	20.0	218.9	173.6	412.5	151.0
2011	16	563.4	20.0	218.9	154.3	393.2	170.3
2012	17	563.4	20.0	218.9	135.0	373.9	189.5
2013	18	563.4	20.0	218.9	115.7	354.6	208.8
2014	19	563.4	20.0	218.9	96.4	335.3	228.1
2015	20	563.4	20.0	218.9	77.1	316.1	247.4
2016	21	563.4	20.0	218.9	57.9	296.8	266.7
2017	22	563.4	20.0	218.9	38.6	277.5	286.0
2018	23	563.4	20.0	218.9	19.3	258.2	305.2
2019	24	563.4	20.0	218.9	0.0	238.9	324.5
2020	25	563.4	20.0	218.9	0.0	238.9	324.5
TOTAL		13804.5				14025.1	-220.6
						C/B	1.02

(2) PROJECTED FUNDS FLOW STATEMENT (Constant Price at 1989)

== Lagunilla : ALT-3-1 ==

Year	Year in Order	(A) Source Benefit before Interest	Depreci-ation	Balance Brought Forward	Long/Short Term Borrowing	Total	(B) Application (US$:1000) Construc-tion Progress	Debt Service Interest	Debt Service Principal	Total	Cash Balance (A)-(B)
1989	-6	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
1990	-5	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0
1991	-4	0.0	0.0		205.2	205.2	205.2	0.0	0.0	205.2	0.0
1992	-3	0.0	0.0		205.2	205.2	205.2	20.5	0.0	225.7	-20.5
1993	-2	0.0	0.0		102.6	102.6	102.6	41.0	0.0	143.6	-41.0
1994	-1	0.0	0.0		1109.6	1109.6	1109.6	51.3	0.0	1160.9	-51.3
1995	0	0.0	0.0		3043.8	3043.8	3043.8	245.4	0.0	3289.2	-245.4
1996	1	52.8	218.9		2229.7	2501.4	2229.7	709.5	406.6	3345.8	-844.4
1997	2	324.5	218.9			543.4		1002.7	406.6	1409.3	-865.9
1998	3	324.5	218.9			543.4		917.3	599.5	1516.8	-973.3
1999	4	324.5	218.9			543.4		812.6	599.5	1412.1	-868.6
2000	5	324.5	218.9			543.4		708.0	599.5	1307.4	-764.0
2001	6	324.5	218.9			543.4		603.3	599.5	1202.7	-659.3
2002	7	324.5	218.9			543.4		327.8	599.5	927.3	-383.8
2003	8	324.5	218.9			543.4		308.5	192.8	501.4	42.1
2004	9	324.5	218.9	42.1		585.5		289.3	192.8	482.1	103.4
2005	10	324.5	218.9	103.4		646.8		270.0	192.8	462.8	184.0
2006	11	324.5	218.9	184.0		727.5		250.7	192.8	443.5	283.9
2007	12	324.5	218.9	283.9		827.4		231.4	192.8	424.3	403.1
2008	13	324.5	218.9	403.1		946.6		212.1	192.8	405.0	541.6
2009	14	324.5	218.9	541.6		1085.0		192.8	192.8	385.7	699.4
2010	15	324.5	218.9	699.4		1242.8		173.6	192.8	366.4	876.4
2011	16	324.5	218.9	876.4		1419.8		154.3	192.8	347.1	1072.7
2012	17	324.5	218.9	1072.7		1616.2		135.0	192.8	327.8	1288.3
2013	18	324.5	218.9	1288.3		1831.8		115.7	192.8	308.5	1523.2
2014	19	324.5	218.9	1523.2		2066.7		96.4	192.8	289.3	1777.4
2015	20	324.5	218.9	1777.4		2320.9		77.1	192.8	270.0	2050.9
2016	21	324.5	218.9	2050.9		2594.3		57.9	192.8	250.7	2343.6
2017	22	324.5	218.9	2343.6		2887.1		38.6	192.8	231.4	2655.7
2018	23	324.5	218.9	2655.7		3199.1		19.3	192.8	212.1	2987.0
2019	24	324.5	218.9	2987.0		3530.4		0.0	0.0	0.0	3530.4
2020	25	324.5	218.9	3530.4		4073.9		0.0	0.0	0.0	4073.9

CHAPTER 11 BASIC DESIGN

11.1 Facilities Design

ALT-3-1 has been selected based on an economic comparison. The basic design for ALT-3-1 is described below.

11.1.1 Design Standards of Civil Structures

The following standards shall apply to the design of facilities.

(1) Tyrolean type concrete dam will be constructed as the diversion weir. The design flood discharge can safely flow over the overflow crest.

(2) The flow rate at the intake and the screen is 0.6 - 1.0 m/s.

(3) The effective area percentage of the intake screen is 30%.

(4) The desilting basin has sufficient desilting capacity by expanding the tunnel section, because of the tunnel type conduction channel..

(5) The desilting basin has a capacity to remove all particles greater than 0.075 mm in size.

(6) The size of the head tank is designed to have a capacity equivalent to a 2-minute period of the design flow.

(7) The practicality of the penstock is most important and pipe diameter shall be determined with reference to the best practical examples for dimensions.

11.1.2 Design of Improvement for the Main Structure

(1) Intake facilities

An outline of a new diversion weir is as follows:

Type	Tyrolean type concrete dam
Crest elevation	1,823.0 m
Dam height	3.0 m
Crest length	20.5 m
Design flood	60.0 m^3/sec
Height of head water (when design flood rate flows)	1.4 m
Intake size	2.5 (W) x 20.0 (L) m
Intake water level	1,821.0 m

(2) Conduction channels

The conduction channel is tunnel-type because of topographical restriction. Tunnel cross-section will be determined considering the workability, economical aspect, and durability, so that the design discharge rate can be secured.

Because the design discharge at the Lagunilla P/P site is 2.0 m^3/s, the following minimum cross section is determined considering the workability.

W = 1.8 m, H = 2.0 m

Velocity of 2.0 m/sec is appropriate.

(a) Equation

The flow in the conduction channel can be calculated from the following equation.

$$Q = A \times \frac{1}{n} \times R^{2/3} \times I^{1/2}$$

(b) Coefficient of roughness (n)

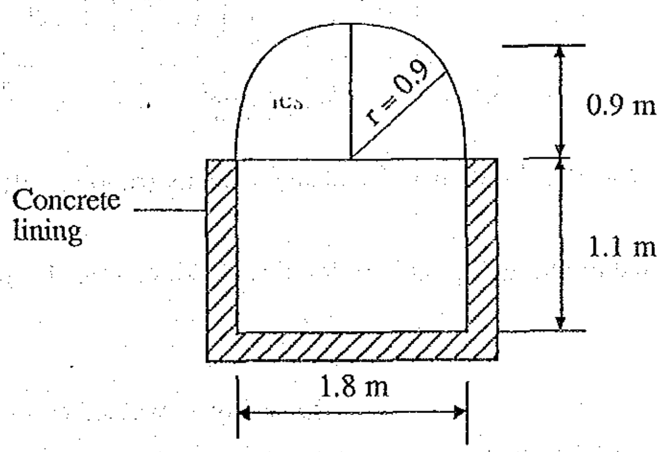
The coefficient of roughness for concrete is shown in Table 11.1. The coefficient of roughness to be used is 0.013.

Table 11.1 Manning's Coefficient of Roughness

	Least	Average	Most
Concrete			
1. Culvert - straight, no impediments	0.010	0.011	0.013
2. Culvert - curved, jointed and impediments	0.011	0.013	0.014
3. Well finished	0.011	0.012	0.014
4. Not finished, smooth wood form	0.012	0.014	0.016
5. Aggregate visible at the surface	0.015	0.016	0.018

Accordingly, if the longitudinal gradient is 1.8 $^o/_{oo}$, the velocity becomes 2.0 m/s.

Type	non-pressure tunnel
Length	590 m (35 m for desilting basin)
Inside diameter	1.8 (W) x 2.0 (H) m
Cross section	as shown in the following figure
Gradient	1.8 $^o/_{oo}$
Max. water-flowing rate	2.0 m^3/sec
Concrete lining	(at the water-flowing part only)



(4) Head tank

The size of the head tank shall be designed to be equivalent to a 2-minute capacity at the designed flow. A spillway, detailed below, corresponding to the design flow during non-operation shall be provided.

Shape	:	circular
Diameter	:	13.0 m
Average water depth	:	2.5 m

A sluice gate and air valves shall be installed at the entrance to the penstock.

(5) Penstock

The penstock diameter obtained from the curve shown in Fig. 11.1 is 0.8 m. The construction of an access road along the penstock is impossible, because of a steep slope. Temporary incline equipment (capacity: 5 ton) will be provided. RC steps (width: 1.0 m) will be included along the penstocks.

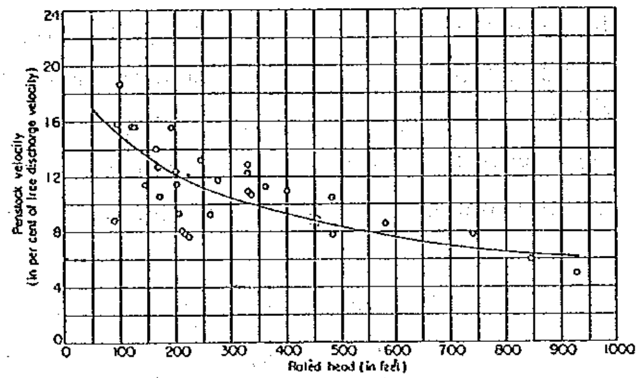


Fig. 11.1 Existing Equipment Head and Velocity (ratio to velocity at free drop)*

* <u>Handbook of Applied Hydraulics</u> Editor DAVIS and SORENSEN

Type	Exposed type, welded connection
Number of penstocks	one penstock, two penstocks after fork
Max. water-flowing rate	2.0 m^3/sec
Penstock inside diameter	800 mm

Pipe wall thickness	6 ~ 18 mm
Pipe length	470.6 m

(6) Powerhouse

Type	Powerhouse building - RC above-ground	
Building size	Width	45.0 m
	Depth	22.5 m
	Eaves height	7.0 m

11.1.3 Gate and Screen Specifications and Types

A summary of gates and screens is shown in Table 11.2.

Table 11.2 Summary of Gate and Valve Types

	Regulating gate	Sand-flush gate	Screen	Sand-flush gate	Regulating gate	Screen	Sand-flush gate
Use	Water intake	Sand trap sand removal	Silt removal	Desilting basin sand removal	Penstock intake	Head tank sand removal	Head tank sand flushing
Type	Steel, sluice gate	Wooden, sluice gate	Fixed type	Steel, sluice gate	Steel, sluice gate	Fixed type	Wooden, sluice gate
Width x height	1.50x2.00m	2.00x3.00m	2.5mx20.0m 1.5mx19.0m	1.50x2.00m	0.90x0.90m	2.0mx1.50m	0.90x0.90m
Design depth	10 m	10 m	-	10 m	5 m	-	5 m
Stopwater method	Reverse 4 direct.	Reverse 4 direct.	Rack spacing	Reverse 4 direct.	Reverse 4 direct.	Rack spacing	Reverse 4 direct.
Starting method	Spindle	Spindle		Spindle	Spindle		Spindle
Hoisting device	Engine or manual	Engine or manual		Manual	Engine or manual		Manual
Lifting speed	0.1 m/min.				0.1 m/s	Gradient 1:0.3	
Lifting torque	10 kg				10kg		
Lift	3 m	4 m	-	3 m	2 m	-	2 m

11.1.4 Standard Specifications for Generating Equipment

For the generating equipment the specifications for the generators and water turbines are shown below.

(1) Number of water turbines and generators

There are two water turbines and generators since water turbines and generators can be inspected and repaired alternately, since when the generating equipment is stopped revenue is reduced.

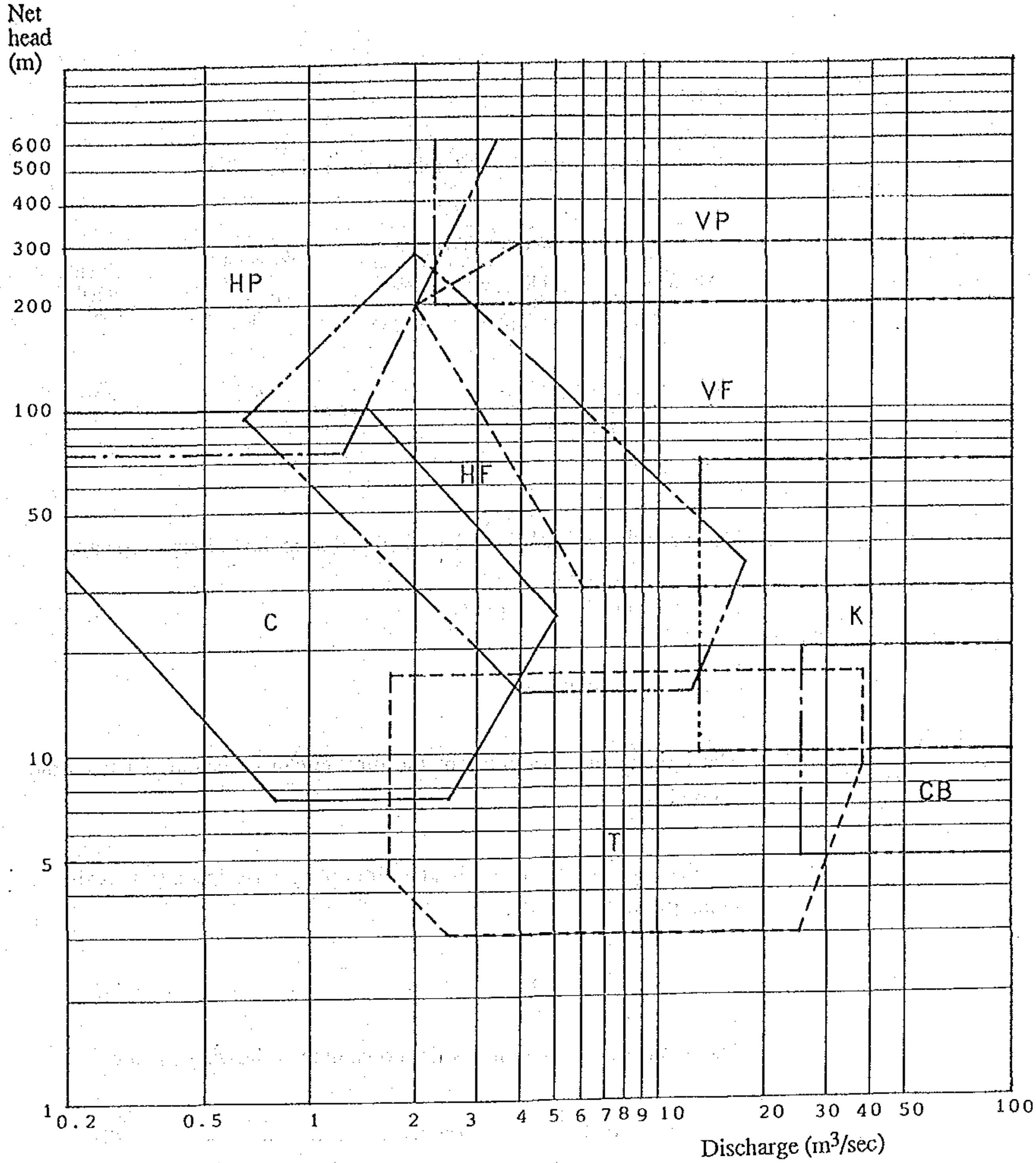
(2) Water turbine specifications

1) Machine type

After deciding on the turbine's net head and flow the water turbine type can be selected from Fig. 11.2.

The choice for the optimum plan for generation rehabilitation is made as follows:

Alternative	Rehabilitation plan		Chosen machine type
	Flow per water turb. (m^3/s)	Net head (m)	
ALT-3-1	1.0	309	horiz. Pelton



KEY

H = horizontal shaft type
V = vertical shaft type
P = Pelton turbine
F = Francis turbine
K = Kaplan turbine
C = cross flow turbine
T = tubular turbine
CB = conduit type bulb turbine

(Source: Enterprise Bureau, Gunma Prefectural Government)

Fig. 11.2 Turbine Type Selection Table

2) Output

The output per turbine for the optimum plan is as follows:

Alternative	Rehabilitation plan		Water turb. estimated efficiency η_T	Water turb. output P_T (kW)
	Flow per water turb. Q (m^3/s)	Net head He (m)		
ALT-3-1	1.0	309	0.87	2.640

The water turbine (kW) may be calculated from the following equation.

$P_T = 9.8 \times Q \times He \times \eta_T$ (kW)

3) Number of revolutions

The number of revolutions of the turbine can be calculated from the following.

For the case of a Pelton turbine the limit of specific speed (Ns) is shown in the following equation.

$$12 \leqq Ns \leqq 23 \quad \text{.......} \quad (1)$$

The number of revolutions (N) is shown in the following equation.

$$N = Ns \times \frac{He^{5/4}}{(\frac{P}{Z})^{1/2}} \quad \text{(rpm)} \quad \text{.......} \quad (2)$$

where N_s is the specific speed (m-kW) taken from eq. (1)
He is the net head (m)
P is the water turbine output (kW)
Z is the number of nozzles

The generator's synchronous speed (N) is shown in the following equation:

$$N = \frac{120f}{pole} = \frac{120 \times 60}{pole} = \frac{7200}{pole} \text{ (rpm)} \quad \cdots\cdots\cdots\cdots\cdots \quad (3)$$

where
f = frequency
pole = number of poles

A value for the pole is chosen such that the value of N in eq. (3) is less than but close to the value of N in eq. (2).

The value of N from eq. (3) is then substituted into eq. (2) to obtain a value for Ns.

The results for the optimum rehabilitation plan are shown in the following table.

Alternative	Net head He (m)	Turbine output, P (kW)	Number of poles	Specific speed, Ns (m-kW)	Number of revolution N (rpm)
ALT-3-1	309	2,640	12	18	600

Note: Ns represents the output per one nozzle (total: two nozzles).

(3) Generator specifications

1) Cooling system

The generator cooling system will be designed to evacuate air from the powerhouse and blow it into the powerhouse.

2) Rated voltage

For standardization of voltage, the rated voltage will be 4.16 kV.

3) Power factor

Large-capacity generators, aiming to supply reactive power to the power system network, have a power factor of 0.8-0.85. However, since this factor is not as important in small-capacity generators, an economical power factor of 0.9 is available.

4) Pole

In deciding the turbine speed, the number of poles for the generator pole is decided and reference is made to the water turbine specifications, as described previously.

5) Generator capacity

The capacity per generator for the optimum plan is as follows:

Alternative	Rehabilitation plan		Estimated turbine effic. η_T	Estimated generator effic. η_G	Generator capacity P_G (kW)	Power factor	Generator capacity (kVA)
	Discharge per turbine Q (m^3/s)	Net head He (m)					
ALT-3-1	1.0	309	0.87	0.95	2,500	0.9	2,800

The generator capacity (kW) may be calculated from the following equation:

$$P_G = 9.8 \times Q \times He \times \eta T \times \eta G \text{ (kW)}$$

11.1.5 Standard Specifications for Electrical Equipment

The machine specifications for the electrical equipment attached to the generator and the substation electrical equipment are explained in the following.

(1) Excitation equipment

A brushless excitation method is used for the generator excitation method so that maintenance inspection is quick and easy.

(2) Grounding method

In order to protect the generator when the value of the generator's current flow to the ground is small, the transformer uses a high resistance grounding method.

(3) Switchgear

With the generator circuit the switchgear contains the following electrical items.

- circuit breaker
- lightning arrester
- current transformer and voltage transformer
- excitation transformer
- auxiliary transformer
- low-voltage distribution board

(4) Direct current equipment

The direct current supply for the initial excitation for the generator's excitation circuit and the control panel is supplied by a charger and lead batteries.

(5) Control and protective relay panels

The simultaneous start, stop and generator circuit breakers, for the turbine and generators, emergency and all essential controls are contained in a water turbine/generator control panel. Thus, one operator can control the system.

Furthermore, the protective relay for the generator circuit is contained in the protective relay board. If an accident occurs the relay is put into action, simultaneously stopping the water turbine and generator, as a buzzer and flickering light warn the operator.

(6) Substation equipment

Outdoor equipment shall be installed for the purposes of simplifying substation equipment and reducing the construction cost. The rated voltage for the substation equipment will be 33 kV, matching voltage for the interconnected Libano Substation.

The specifications for main equipment are described in Table 11.3

Table 11.3 Main Equipment Specifications

Item	Specifications
1. Main transformer	
1) Number of transformers	3 ø x 1
2) Type	ONAN
3) Voltage	4.16/33KV
4) Capacity	5,600 KVA
5) Connection	Δ/⅄
2. Circuit break	
1) Number of circuit breakers	3 ø x 1
2) Type	ABB
3) Voltage	33 KV
4) Current	600 A
5) Capacity	12.5 KA
3. Disconnecting switch	
1) Number of disconnecting switches	3 ø x 1
2) type	Horizontal
3) Voltage	33 KV
4) Current	600 A
4. Current transformer	
1) Number of current transformers	1 ø x 3
2) Current	150/5 A
5. Transformer	
1) Number of transformers	1 ø x 3
2) Voltage	33 KV/110 V

Fig. 11.3 shows the main circuit connection diagram for a substation. Fig. 11.4 indicates the substation equipment layout plan.

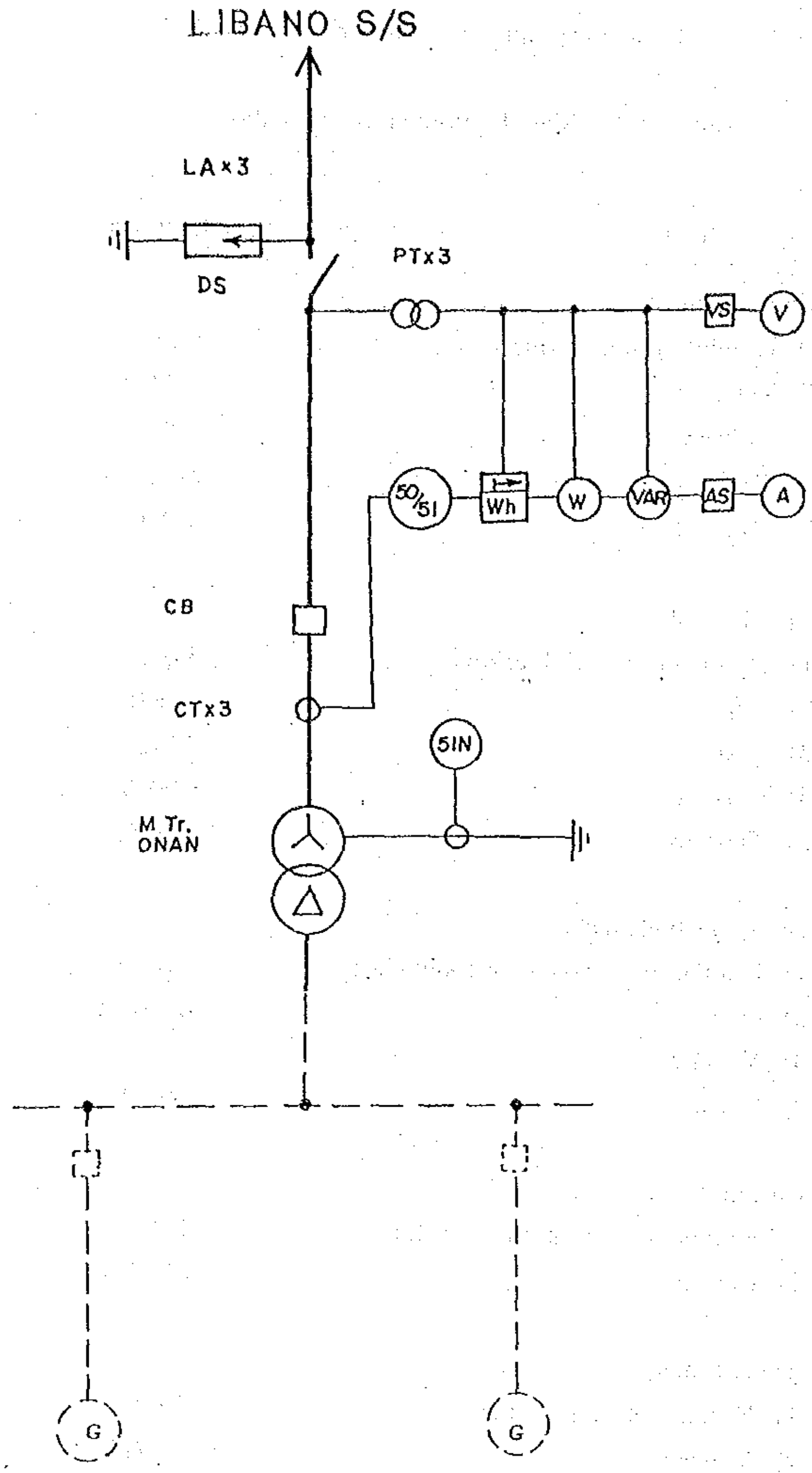


Fig. 11.3 Main Circuit Connection Diagram for Substation

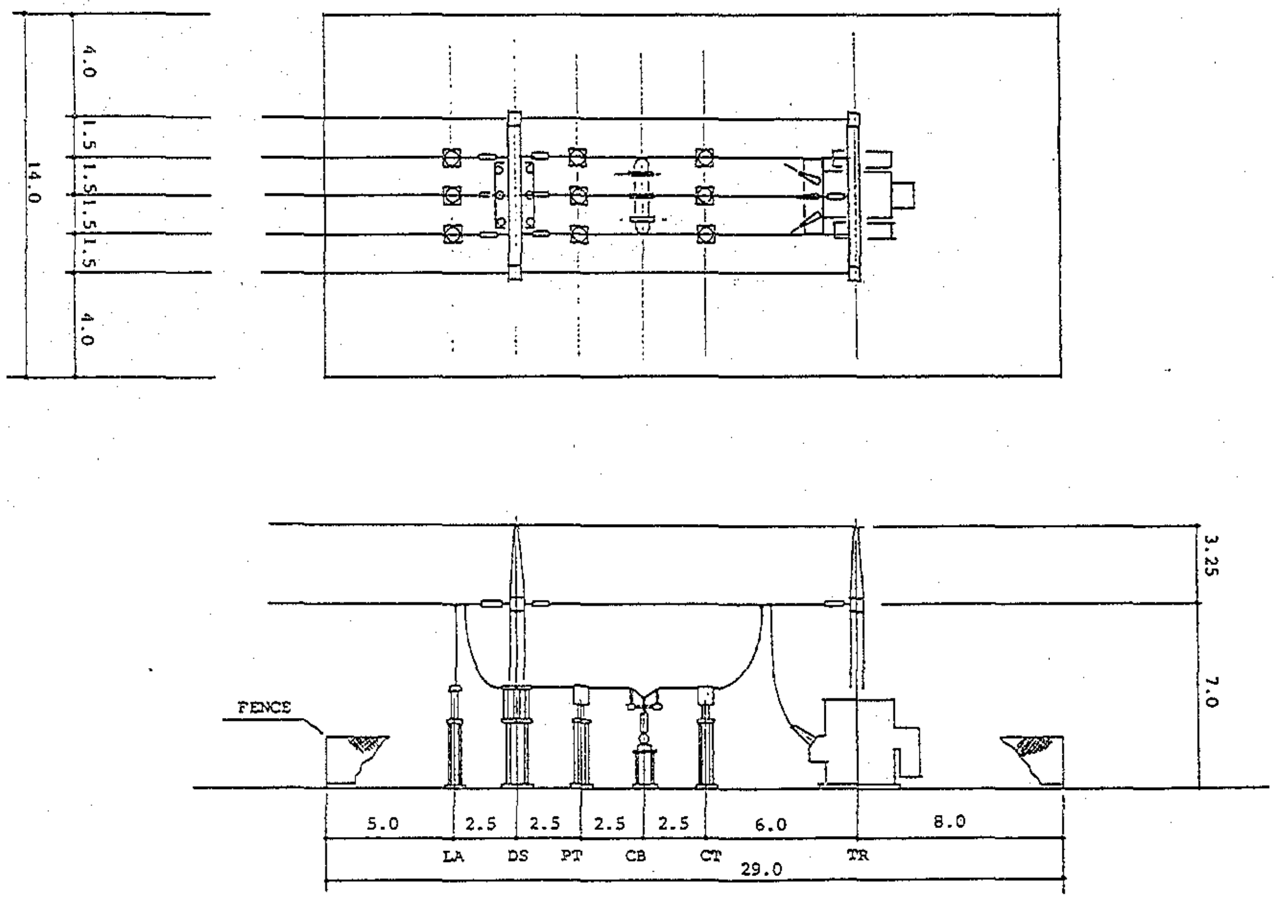


Fig. 11.4 Substation Equipment Layout Plan

(7) Transmission lines

The Libano substation, situated about 5 km east of the Lagunilla P/P, is the nearest place for connecting transmission lines. 33 kV transmission lines will be interconnected from the Lagunilla P/P's substation to the Libano substation.

Power that will be generated at this power plant is shown in Fig. 11.5. The power will be supplied to the surrounding area through substations of Libano, Tiestos, Lerida and Recio substations. The construction cost of transmission lines is not included at this stage of the study.

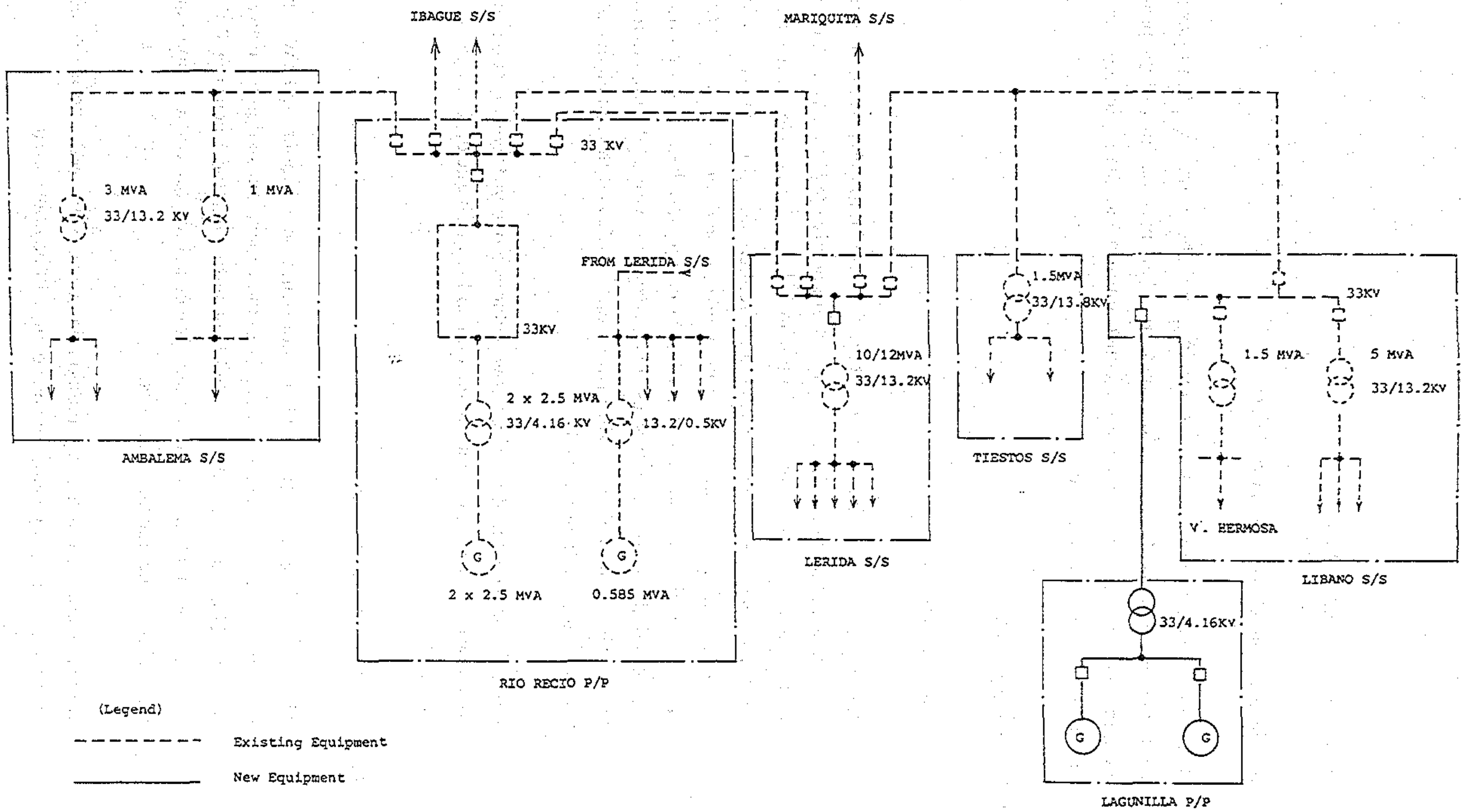


Fig. 11.5 Power Schematic Diagram

11.2 Construction Execution Plan

11.2.1 Investigation into Construction Conditions

This power plant is not presently operating, and there are no conditions for restricting the progress of the rehabilitation work. The inaccessibility of the project site and the lack of a power source for construction becomes a problem, as the topography of the site is very steep.

11.2.2 Preparatory Work

(1) Shutoff and water diversion

Before installing the intake equipment, river diversion construction will be undertaken in the river, the main channel will be diverted to the right bank and the left bank will be closed off. Sediment is heaped up to close off the area, and gabions and sand bags are used to prevent erosion of the surface. Within the closed off area of the left bank the intake, a sand trap and one part of the diversion weir will be constructed. After the left bank construction is completed, the sand trap will be used and river flow will be diverted to the left bank. The right bank area will then be closed off and the remainder of the diversion weir will be finished.

Further management of the river flow includes a one year construction period for a low concrete dam and using the probability discharge of times per year of 10 m^3/s.

(2) Construction power source

The required power estimated for construction is about 600 kW. New transmission lines will be provided from the Libano substation to secure this power. Thus, a new substation will be built near the Lagunilla P/P and transmission lines will be provided, power source for construction can be secured from the transmission lines.

If the construction of the transmission line work is delayed, alternative power sources, e.g., diesel generation and so on, will be considered.

11.2.3 Construction Access Road Work

There is no access road near the Lagunilla P/P site. The construction of an access road will be planned from the existing road at an elevation of 1,960 m on the channel route to the plant and intake sites.

The outline of the access road is as follows:

Width	:	7.0 m	
Average longitudinal gradient	:	10%	
Length	:	1.5 km	between the existing road and the diversion weir
		5.0 km	between the existing road and the power plant site
Total length	:	6.5 km	

11.2.4 Temporary Construction Equipment

The main temporary construction equipment are as follows:

Incline equipment for penstock installation is needed for the main temporary construction.

Incline equipment shall be capable of carrying 1.0 m^3 concrete or 12-meter-long conduit pipe. The incline equipment loadage is determined in consideration of the flat car, etc.

The outline of the incline equipment is as follows:

Rail length	:	500 m
Rail distance	:	480 m
Gradient	:	45°
Max. loadage	:	5 ton

11.2.5 Work Schedule

The work schedule is shown in Table 11.4.

Table 11.4 Lagunilla Hydroelectric Power Plant Rehabilitation Plan Work Schedule

Year	1989				1990				1991				1992				1993				1994				1995				1996			
Item / Month	3	6	9	12	3	6	9	12	3	6	9	12	3	6	9	12	3	6	9	12	3	6	9	12	3	6	9	12	3	6	9	12
Study for rehabilitation plan	■	■	■	■	■																											
Examination of rehabilitation plan						■	■	■																								
Main civil structures design and drawing up of documents									■	■	■	■	■	■	■	■																
Tender and award																	■	■	■													
Negotiations and conclusion of contract																				■												
Negotiating period for financing											■	■	■	■	■	■	■	■	■													
Ordering																				▼												
Construction work																					■	■	■	■	■	■	■	■	■	■	■	■
Compilation of discharge observation data			■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■												

Note) The details of the construction period are in Table 11.5.

Table 11.5 Construction Period

		1st Year												2nd Year												3rd Year											
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
Intake Facilities	Groundwork					Right	Bank			Left Bank																											
	Concrete							200 m³				400 m³																									
	Gate, screen								M			Tr	I																								
	Slope protection work																																				
Desilting Basin	Groundwork																																				
	Concrete																500 m³																				
	Gate								M			Tr						I																			
Conduction Channel	Groundwork																																				
	Concrete																			400 m³																	
Head Tank	Groundwork																																				
	Concrete													800 m³			20 m³																				
	Gate, screen								M			Tr					I																				
	Slope protection work																																				
Penstock	Groundwork																																				
	Concrete														500 m³																						
	Penstock										M					Tr			I																		
Powerhouse	Site grading work																																				
	Groundwork for foundation																																				
	Concrete for foundation											1,000 m³												30 m³													
	Building																																				
	Equipment No.1											M						Te		Tr			I		Te												
	Equipment No.2																										M			Te		Tr			I		Te
	Slope protection work																																				
Tailrace	Groundwork																																				
	Concrete																	40 m³																			
Substation	Groundwork																																				
	Concrete																		100 m³																		
	Equipment														M			Te		Tr			I		Te												
Preparatory Work	Access road																																				
	Incline		M			Tr			I																												
	Other																																				

Note: M = Manufacturing, Te = Testing, Tr = Transportation, I = Installation

11.3 Construction Costs

11.3.1 Basic Conditions of Estimates

(1) Estimate method

(a) Estimate of construction content

Project-related approximate construction costs include the following items:

Civil construction costs
Direct construction costs + contingency + engineering costs

Equipment costs
FOB + sea transport costs (inc. insurance) + land transport costs (inc. insurance) + various taxes + installation costs + testing costs + contingency + engineering costs

(b) Civil construction cost calculation

- Direct costs are calculated as the work quantity x unit price

- The work quantity is estimated based on attached Drawing. No. LA-C-01 ~ No.LA-C-05.

- Within the unit direct temporary work costs (AIU) are taken as 30% in Columbia.

- The contingency and engineering costs are based on the ISA hydro-electric power project's construction costs as follows:

Contingency	direct construction costs x 15%
Engineering costs	(direct cost + contingency) x 10%

(c) Estimate of equipment and construction costs

Using the FOB and the ISA hydroelectric power plant project direct construction costs and equipment and construction cost may be calculated as follows:

- FOB	100%	
- sea transport costs	FOB x 10%	
- sea transport insurance	FOB x 2%	
- taxes	FOB x 22.3%	3.15 x 1.105
- law 68		2.0 x 1.105
- law 50		8.0 x 1.105
- proexpo		5.0 x 1.105
- value-added tax	FOB x 13.4%	10% of above
- land transport/insurance	FOB x 6%	
- installation	FOB x 10%	
- test, connection	FOB x 6%	
- direct construction costs	FOB x 169.7%	
- contingency	FOB x 17%	10% of direct costs
- engineering costs	FOB x 14.9%	8% of (direct work costs + contingency)

(d) Division of work

The cost estimate for the Lagunilla hydroelectric power plant is divided as follows:

Intake dam/intake	:	groundwork, concrete, cobble concrete, reinforcing bars, gate, screen, slope protection
Headrace/desilting	:	tunnel excavation, tunnel concrete, screen, gate
Head tank	:	groundwork, concrete, reinforcing bars, screen, gate, slope protection, cobble concrete, valves
Powerhouse	:	groundwork, concrete, reinforcing bars, building, crane, slope protection

Spillway : groundwork, concrete

Substation : groundwork, concrete, reinforcing bars

Furthermore, the generating equipment is divided as follows:

turbine and ancillary equipment
generator and ancillary equipment
turbine/generator control panel
generator switchgear
auxiliary transformer, distribution board, battery, charger
substation

(e) Year for estimate

From a meeting with ICEL the costs are estimated on an average rate of September, 1989.

(2) Civil construction units

As shown in 5.4 the units prepared by ELECTROLIMA in September, 1989 were used. The cost of temporary work camps, electricity sources, communication facilities etc., have been included within the present estimates.

(3) Equipment FOB costs

Quotes were taken from two domestic Japanese companies, and 90% of the lowest cost is determined as FOB cost.

11.3.2 Breakdown of Civil Construction Costs

The breakdown of the civil construction costs for ALT-3-1 is shown on the following pages.

No.	Description	Unit	Quantity	Rate	Estimated Amount	Remarks
	Lagunilla		ALT-3-1			
1.	Diversion Weir & Intake					
1.1	Earthwork	m^3	250	2,800	700,000	
1.2	Concrete Work	"	600	17,900	10,740,000	
1.3	Reinforcing Bar	ton	10	215,000	2,150,000	
1.4	Gate	"	4.6	480,000	2,208,000	
1.5	Screen	"	1.7	650,000	1,105,000	
1.6	Shotcrete	m^3	3.0	40,000	1,200,000	t = 10 cm
	Sub Total	-	-	-	18,103,000	
2.	Desilting Basin					
2.1	Earthwork	m^3	1,600	2,800	4,480,000	
2.2	Concrete Work	"	200	17,900	3,580,000	
2.3	Reinforcing Bar	ton	15	215,000	3,225,000	
2.4	Gate	ton	2.7	480,000	1,296,000	
2.5	Spillway	ton	6.0	420,000	2,520,000	
	Sub Total	-	-	-	15,101,000	
3.	Conduction Channel					
3.1	Earthwork	m^3	2,400	19,600	47,040,000	
3.2	Concrete Work	"	500	25,000	12,500,000	
	Sub Total	-	-	-	59,540,000	

No.	Description	Unit	Quantity	Rate	Estimated Amount	Remarks
4.	Head Tank					
4.1	Earthwork	m^3	2,700	2,800	7,560,000	
4.2	Concrete Work	"	400	17,900	7,160,000	
4.3	Reinforcing Bar	ton	10	215,000	2,150,000	
4.4	Gate	ton	3	480,000	1,440,000	
4.5	Screen	ton	3	650,000	1,950,000	
4.6	Shotcrete	m^3	30	40,000	1,200,000	
	Sub Total				21,460,000	
5.	Penstock					
5.1	Earthwork	m^3	960	2,800	2,688,000	
5.2	Concrete Work	"	580	17,900	10,382,000	
5.3	Reinforcing Bar	ton	5.8	215,000	1,247,000	
5.4	Penstock	ton	134.0	420,000	56,280,000	
	Sub Total				70,597,000	

No.	Description	Unit	Quantity	Rate	Estimated Amount	Remarks
6.	Foundation of Equip.					
6.1	Earthwork	m^3	2,800	2,800	7,840,000	
6.2	Concrete Work	"	1,100	17,900	19,690,000	
6.3	Reinforcing Bar	ton	57	215,000	12,255,000	
	Sub Total	-	-	-	39,785,000	
7.	Powerhouse					
7.1	Building	m^3	900	55,000	49,500,000	
7.2	Excavation	m^3	23,000	2,800	64,400,000	
7.3	Concrete	m^3		17,900		
7.4	Shotcrete	m^3	13.0	40,000	5,200,000	t = 0.1 m
	Sub Total	-	-	-	119,100,000	
8.	Temporary Facilities					
8.1	Incline	lot	1	-	9,000,000	CAP: 5.0 t = 480 m
	Sub Total				9,000,000	
9.	Substation	lot	1		3,813,000	
10.	Grand Total				355,899,000	

11.3.3 Breakdown of Generating Equipment Costs

The breakdown of generating equipment costs for ALT3-1 is shown on the following table.

FOB COST OF ELECTRICAL &MECHANICAL EQUIPMENT (ALT-3-1)		
No.	Description	FOB cost (US$1,000)
1	Water Turbine and Auxiliary Equipment	1,675.7
2	Generator and Auxiliary Equipment	620.0
3	Turbine and Generator Control Panel	97.1
4	Switchgear for Generator	72.9
5	Auxiliary Service Transformer, Distribution Board, Battery and Charger	25.0
6	Main Transformer	82.9
7	33 kV Substation	97.9
	Total	2,671.5

11.3.4 Annual Construction Work Costs

The annual construction costs calculated according to the total cost and the construction schedule are shown in the following table.

Item	Alternative Plans									
	ALT-1		ALT-2		ALT-3					
					1		2		3	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
Diversion weir and intake work	27.0	0	23.5	0	23.5	0	25.9	0	28.2	0
Desilting basin work	0	19.6	0	38.0	0	19.6	0	28.4	0	37.2
Conduction channel work	5.6	5.6	23.4	23.5	38.7	38.7	42.5	42.6	46.4	46.5
Head Tank work	13.9	14.0	13.9	14.0	13.9	14.0	18.1	18.2	22.3	22.3
Penstock work	10.9	21.8	14.5	29.2	30.6	61.2	44.3	88.8	56.7	113.6
Equipment foundation work	14.0	14.1	16.4	16.5	25.8	25.9	37.8	37.9	49.8	49.9
Powerhouse building work	26.1	26.2	26.1	26.2	77.4	77.4	77.4	77.4	77.4	77.4
Temporary facilities work	4.9	0	6.8	0	11.7	0	11.7	0	11.7	0
Miscellaneous work	0	2.9	0	2.9	0	5.0	0	5.0	0	5.0
① Total	102.4	104.2	124.6	150.3	221.6	241.8	257.7	298.3	292.5	351.9
② Contingency (① x 0.15)	15.4	15.6	18.7	22.5	33.2	36.3	48.7	44.7	43.9	52.8
③ Engineering fee (①+②) x 0.10	11.8	12.0	14.3	17.3	25.5	27.8	29.6	34.3	33.6	40.5
④ Grand total ① + ② + ③	129.6	131.8	157.6	190.1	280.3	305.9	326.0	377.3	370.0	445.2

CHAPTER 12 CONCLUSION AND RECOMMENDATIONS

This chapter describes JICA study team's conclusion of the feasibility study for the *rehabilitation of the Lagunilla hydroelectric P/P* (for 17 months from November 1988 to March 1990), which was conducted following the pre-feasibility study (for 8 months from November 1987 to June 1988).

12.1 Most Feasible Rehabilitation Plan

The Lagunilla P/P operation has been suspended since 1972. The intake facilities were washed away by debris flow caused by the eruption of Mt. Nevado del Luiz in 1985. The rehabilitation plan for the Lagunilla P/P which is most likely to be implemented from the technical and financial point of view is summarized below.

Table 12.1 Summary of Post-rehabilitation Optimum Generating Facilities

Item				Unit	Content
(1) Generation plan requirements	Max. available discharge		Q	m^3/s	2.0
	Standard net head		H	m	309
	Theoretical output			kW	6,056
	Max. output		P	kW	5,000
	No. of generating equipment				2
	Annual potential generated energy		E_1	GWh	43.2
	Plant utilization factor			%	99
(2) Civil structure specification	Diversion weir	Type			Tyrolean type concrete dam
		Dimensions		m	3.5 (height), 20.5 (crest length)
	Sand flush gate	Type			Wooden sluice gate
		No. of gates			One gate
		Dimensions		m	2.00 (width), 3.00 (height)
	Intake	Type			Non-pressure type, rectangular
		Dimensions		m	2.50 (width), 20.0 (height)
	Intake gate	Type			Steel sluice gate
		Dimensions		m	0.90 (width), 0.90 (height)
	Desilting basin	Type			Sand trap in open channel floor, tunnel expansion
		Dimensions		m	7.00 (width), 2.70 (average depth), 35.00 (length)
	Sand trap gate	Type			Steel sluice gate
		No. of gates			One gate
		Dimensions		m	0.90 (width), 0.90 (height)
	Conduction channel	Type			Tunnel
		Length		m	555
		Dimensions		m	1.5 (width), 2.00 (height)
	Head tank	Shape			Circular
		Dimensions		m	13.0 (diameter), 2.50 (average depth)
	Head tank gate	Type			Steel sluice gate
		Dimensions		m	0.90 (width), 0.90 (height)
	Penstock	No. of penstocks			One
		Diameter		m	ø0.80
		Length		m	470
	Powerhouse	Shape			Rectangular, RC structure
		Dimensions		m	45.00 (width), 22.50 (depth)
	Tailrace	Shape			Rectangular
		Dimensions		m	1.50 (width), 1.20 (height)

Table 12.1 Summary of Post-rehabilitation Optimum Generating Facilities (cont'd)

Item			Unit	Content
(3) Generating equipment specifications	Turbine	Type		Pelton
		No. of turbines		2
		Output	kW	2,640
		Revolution	rpm	600
	Generator	Type		Synchronous
		No. of generators		2
		Output	kVA	2,800
		No. of poles		12
		Revolution	rpm	600
	Main transformer	Type		ONAN
		No.of transformer		1
		Voltage	kV	4.16/33
		Capacity	kVA	5,600
(4) Rehabilitation work cost	Generating equipment	Foreign currency portion	US$	3,800,000
		Local currency portion	US$	1,500,000
	Civil and building work cost	Foreign currency portion	US$	0
		Local currency portion	US$	1,600,000
	Project cost		US$	6,900,000
	Construction cost	per kW	US$/kW	1,400
		per kWh	mills/kWh	160

12.2 Economic Indices

As general indices to evaluate the feasibility, the construction cost per kW and the average generating cost per kWh are explained in the General Criteria Vol.1 issued by ISA in June, 1987. The result of the economic indices study is described in Section 9. Economic indices in the case of the optimum rehabilitation plan shown in Table 12.1 are as follows:

Construction cost per kw: US$ 1,400/kW
Average generating cost for annual supplied electric power: 16 mills/kWh

12.3 Operation and Maintenance Manual

The maintenance manual contains the regulations to secure stable power supply and to maintain the installed facilities in the normal condition. Each electric power company shall establish such regulations based on its managerial policy.

In the rehabilitation of the Lagunilla hydroelectric P/P, the generating equipment such as the turbines, generators and main transformers will be replaced with new ones. Therefore the maker of each equipment shall provide the operation and maintenance manual which conforms to the specification.

Accordingly the attached data in the Main Report contain the general management manual for the maintenance and inspection of the main civil structures and generating equipment.

12.4 Technical Recommendations on the Rehabilitation Plan

When the rehabilitation plan of the Lagunilla hydroelectric P/P is realized, the following points should be carefully considered at the stage shifting from the feasibility study to the basic design and detailed design.

(1) Topographic, geologic and biological incrustation survey of the watershed

The topographic map will be drawn on a scale of 1:10,000 ~ 1:5,000 from the aerial photographs. A survey of the present condition of the topography, geology and biological incrustation of the watershed is recommended. The catchment area of the intake area and the hydrological gauging station will be confirmed. In addition, it is desirable to conduct the present-condition survey of the access road route.

(2) Works to conform river hydrological regime

The Study Team obtained observations recorded at the gauging stations of Quinta Cobra and El Bosque. Such data is not reliable, because of short observation period and many non-observed dates.

Thus, a simple hydrological gauging station will be built immediately for obtaining a complete set of discharge data. A program for simultaneous observation of discharge at the Pte Sanfrancisco and Nueva La gauging stations will be set up. Discharge will be observed upstream from the proposed intake site or downstream from the proposed power plant site. A cross section of the river reveals a favorable slight gradient, therefore discharge will be observed at this site.

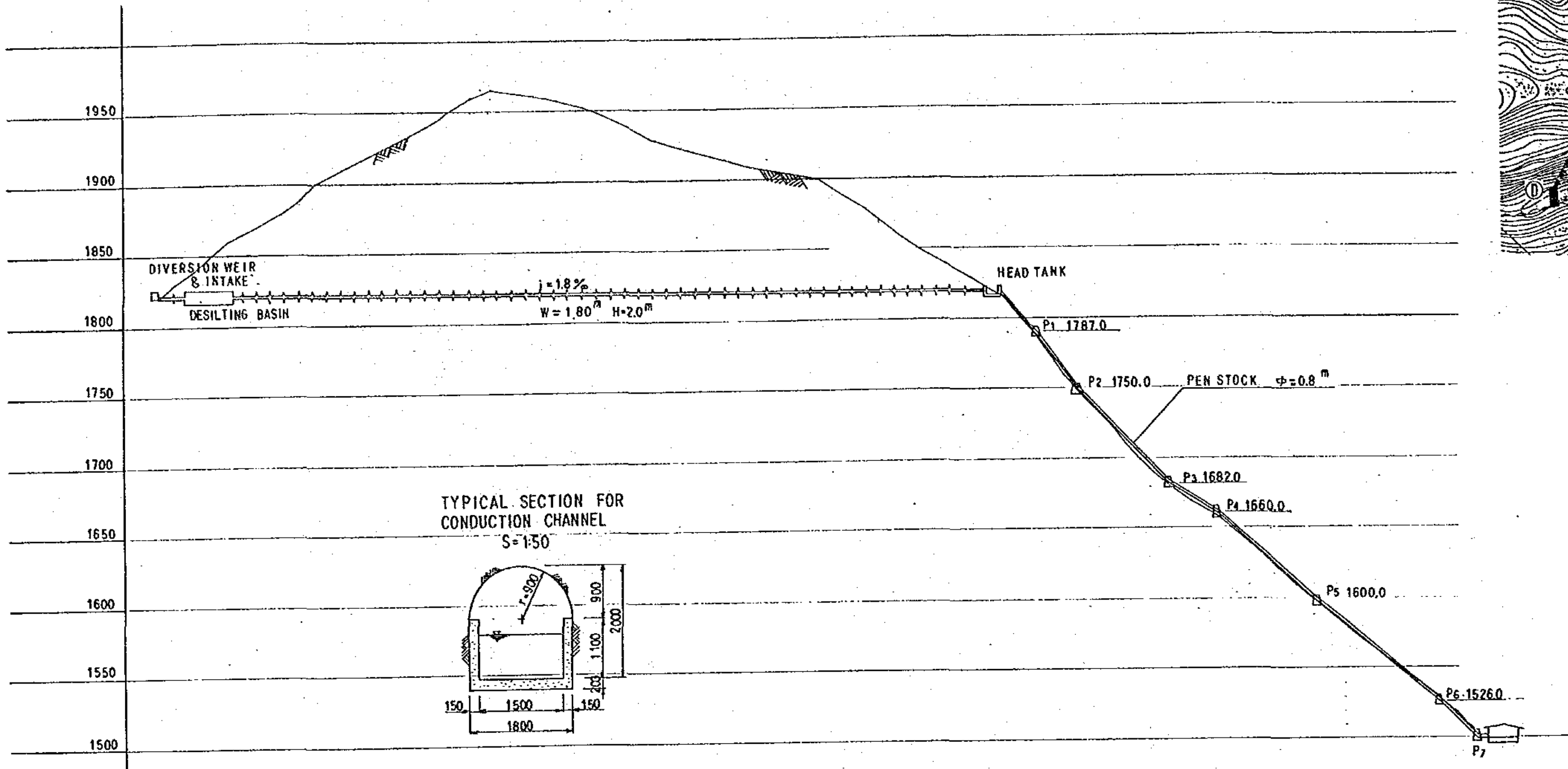
Drawings

Attached Data

1. Facility Register for the Existing Power Plant

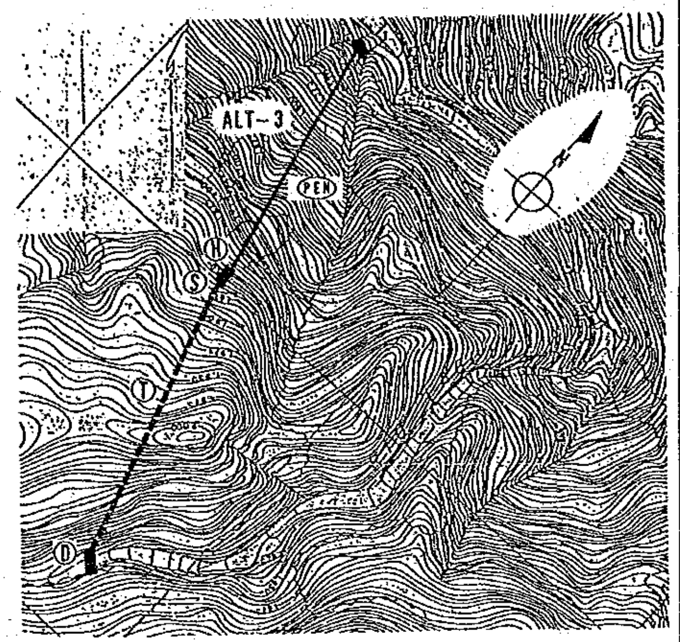
2. Survey Record

PROFILE (S = 1/2000)



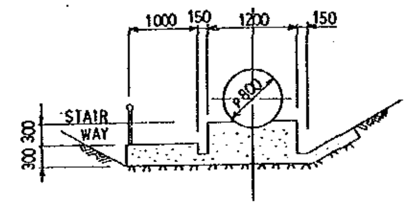
GROUND HEIGHT	1822	1860	1889	1920	1940		1953	1930	1915	1900	1879	1840	1814	1750	1694	1660	1613	1570	1532	1500
FORMATION LEVEL	1920.36	1920.27	1920.18	1920.09	1920.00	1919.94	1819.82	1819.73	1819.64	1819.52	1819.45	1819.36	1819.30 1817.5							
ACCUMULATED DISTANCE	0	49.0	100	150	200	235.5	300	348.5	400	466	500	557	590 600	649	700	745.5	800	850	900	934.5
DISTANCE	0	49.0	51.0	50.0	50.0	35.5	64.5	48.5	51.5	66.0	34.0	57.0	9.00 43.0	49.0	51.0	45.5	54.5	50.0	50.0	34.5
STATION	0		1+0		2+0		3+0		4+0		5+0		6+0		7+0		8+0		9+0	

GENERAL PLAN

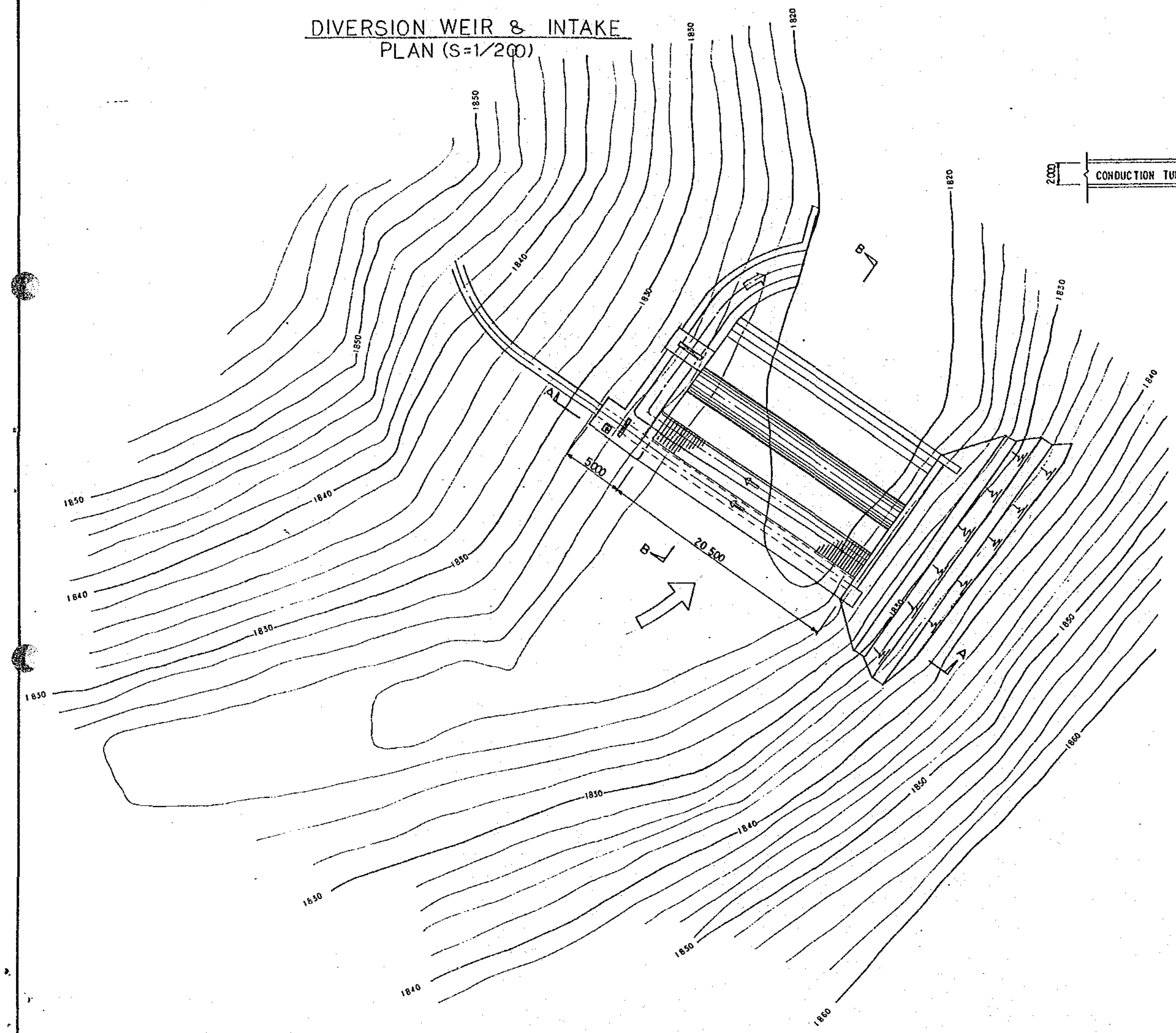


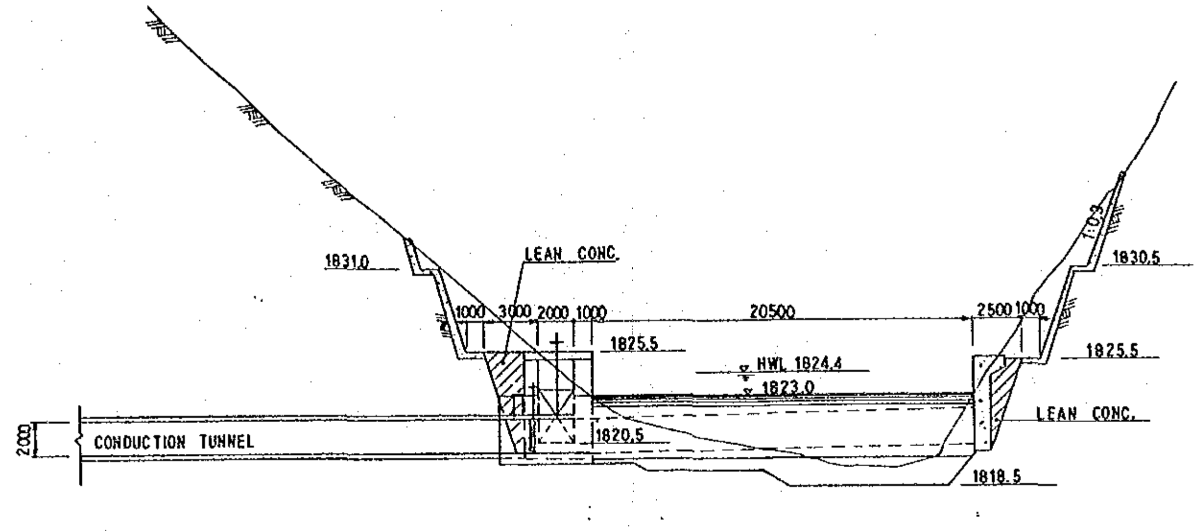
D: DIVERSION WEIR
S: DESILTING BASIN
C: CONDUCTION CHANNEL
T: TUNNEL
H: HEAD TANK
P: POWER HOUSE
PEN: PENSTOCK

TYPICAL SECTION FOR PENSTOCK
S=1:50

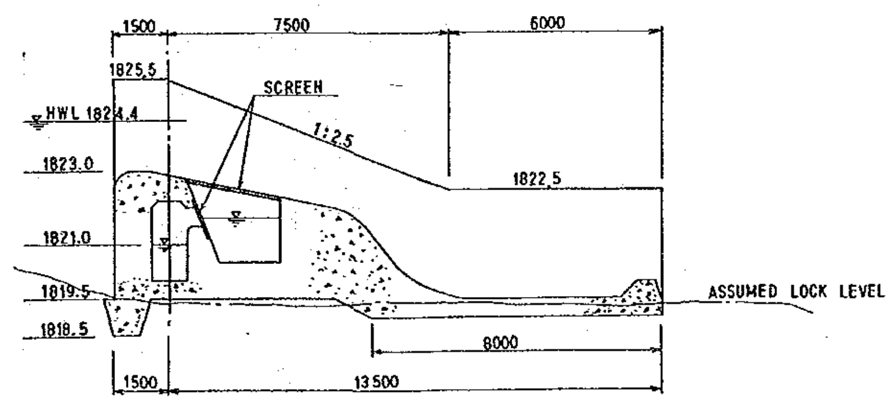


JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
GENERAL PLAN AND PROFILE (ALT 3-1)	
DRAWING NO.	LA-C-01
SCALE 1/2000	DATE





A — A

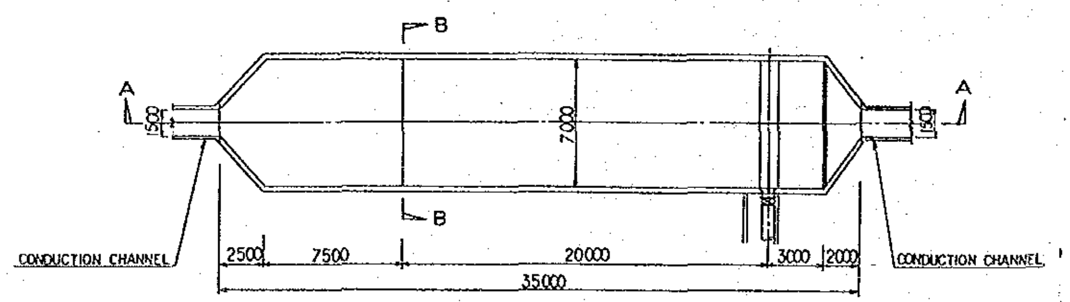


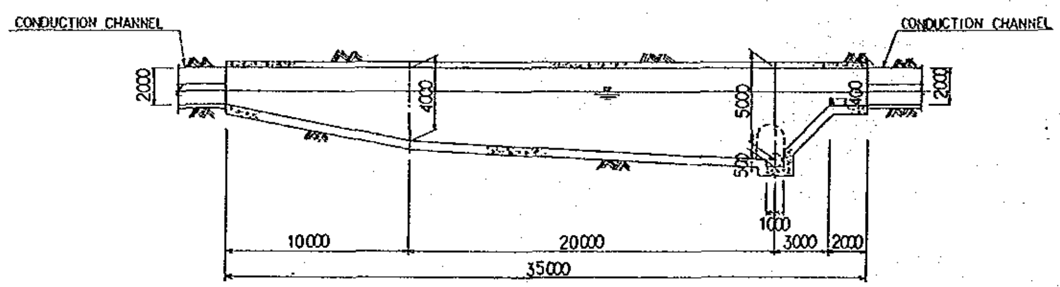
B — B

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
DIVERSION WEIR AND INTAKE (ALT 3-1)	
DRAWING NO.	LA-C-02
SCALE 1/200	DATE

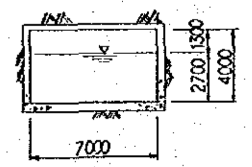
DESILTING BASIN

PLAN (S=1/200)





A — A

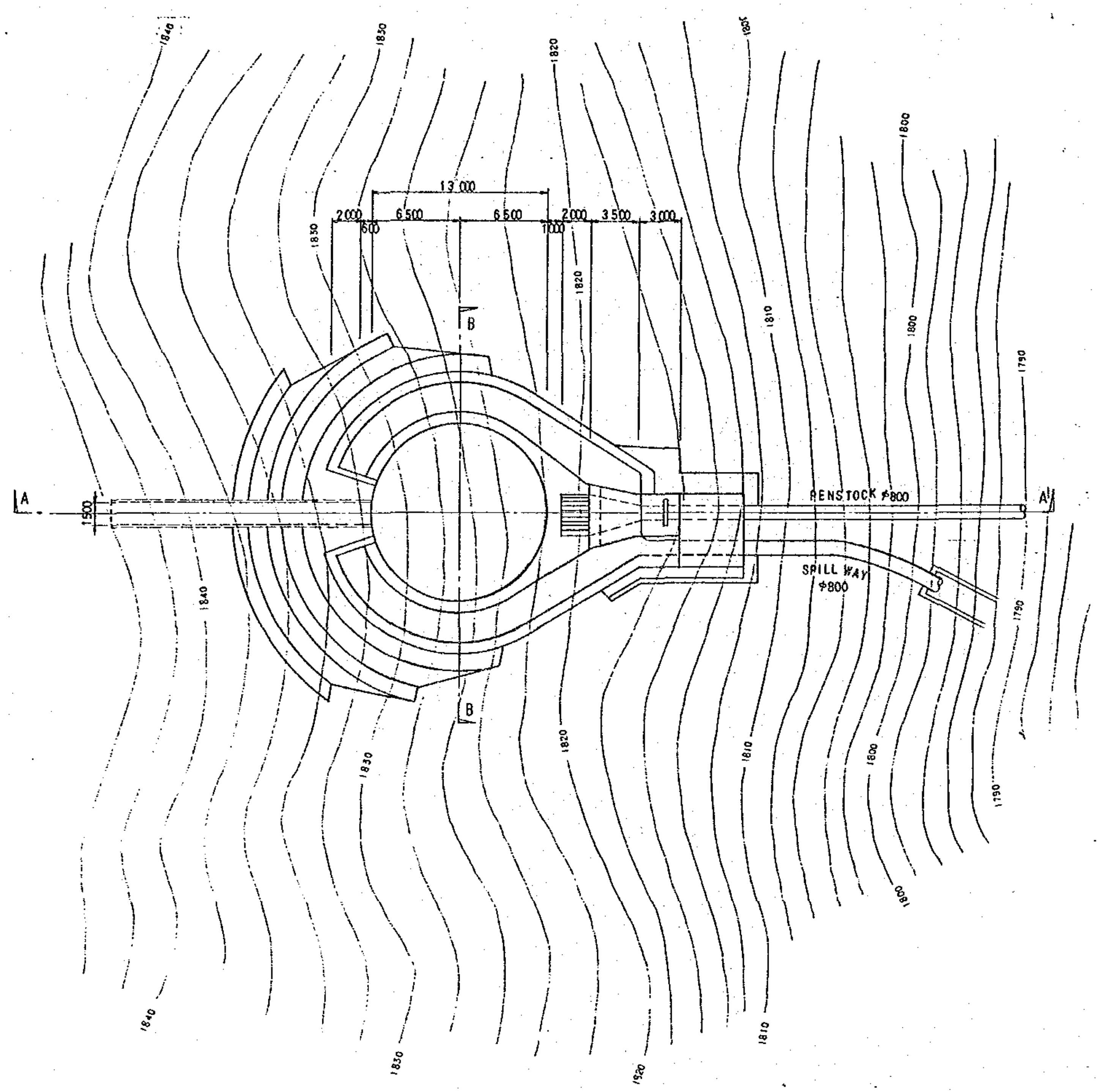


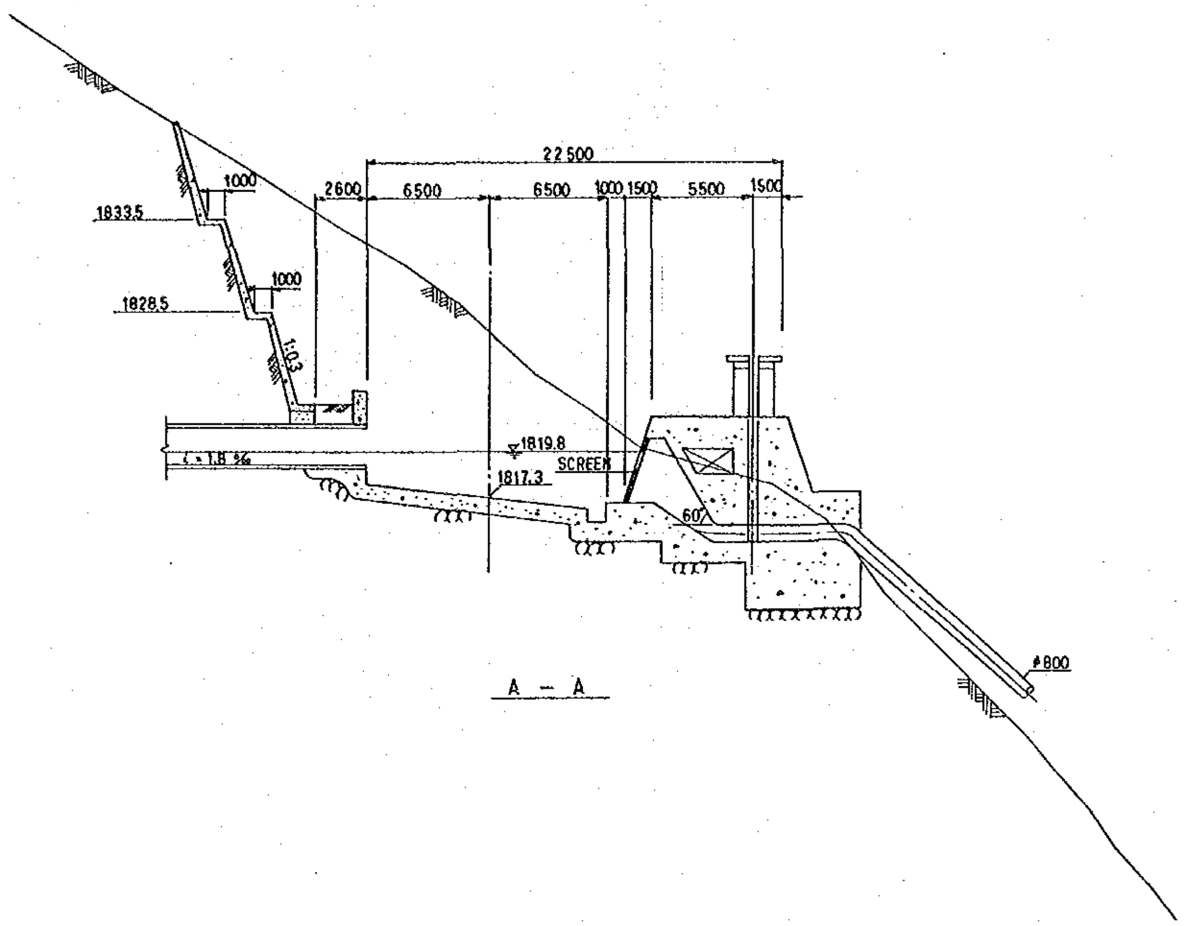
B — B

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)			
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)			
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA			
DESILTING BASIN (ALT 3-1)			
DRAWING NO.		LA-C-03	
SCALE	1/200	DATE	

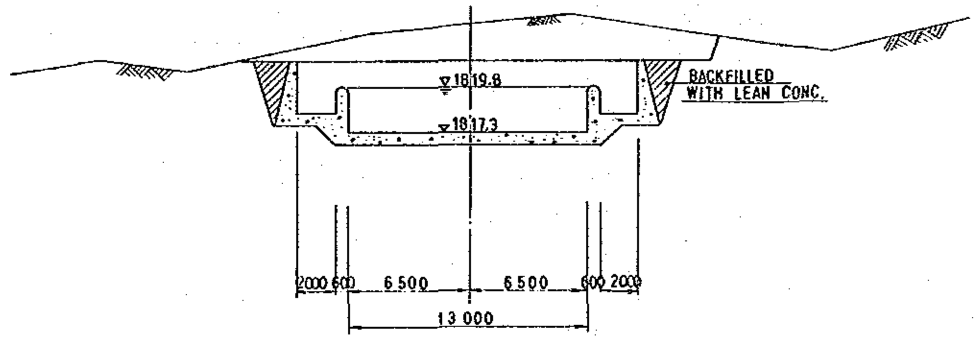
HEAD TANK

PLAN (S-1/200)





A — A

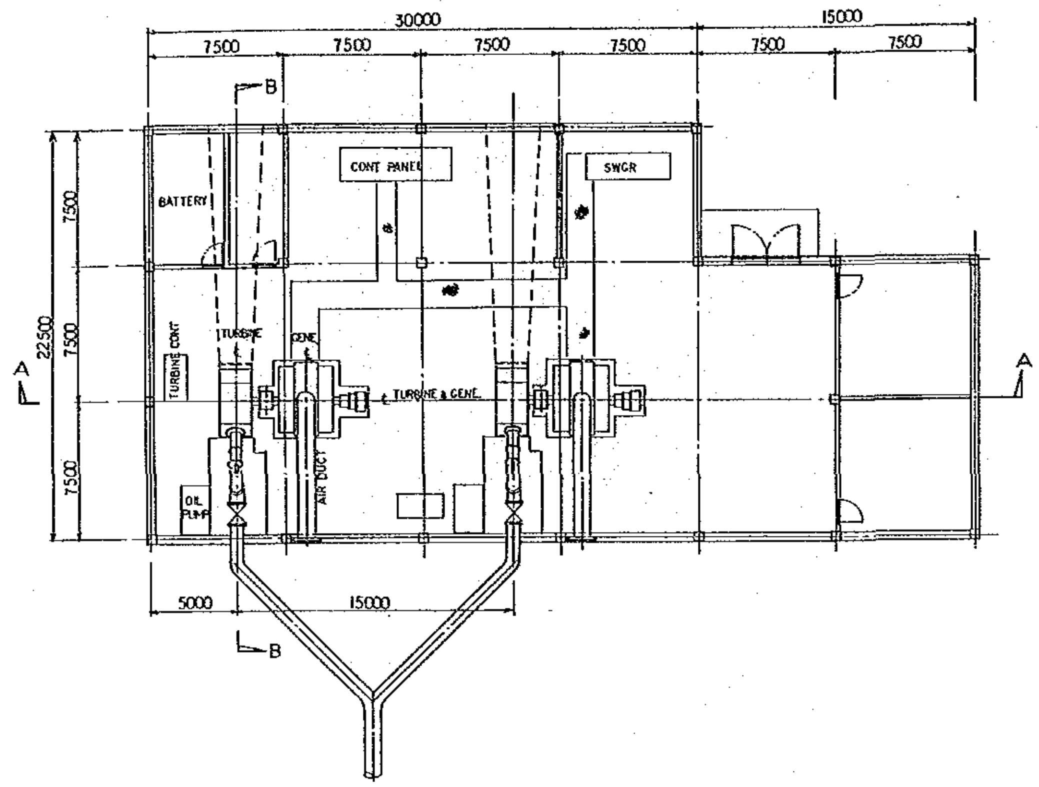


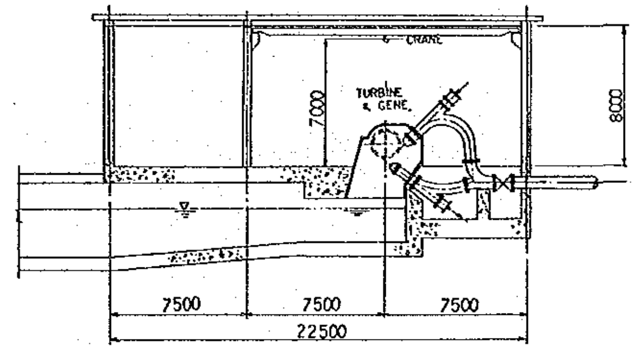
B — B

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
HEAD TANK (ALT 3-1)	
DRAWING NO.	LA-C-04
SCALE 1/200	DATE

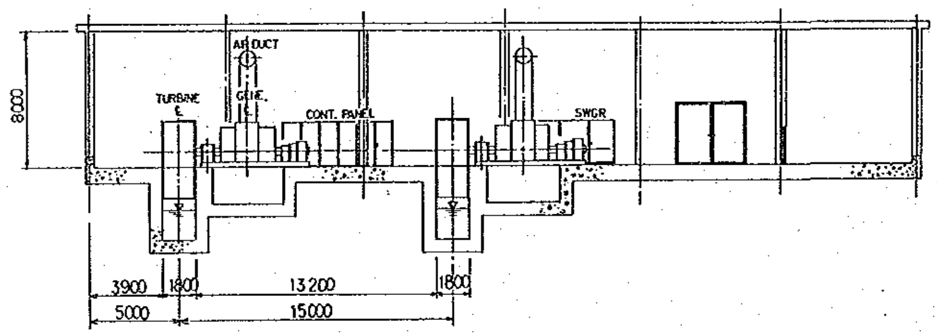
POWERHOUSE & TAILRACE

PLAN (S=1/200)





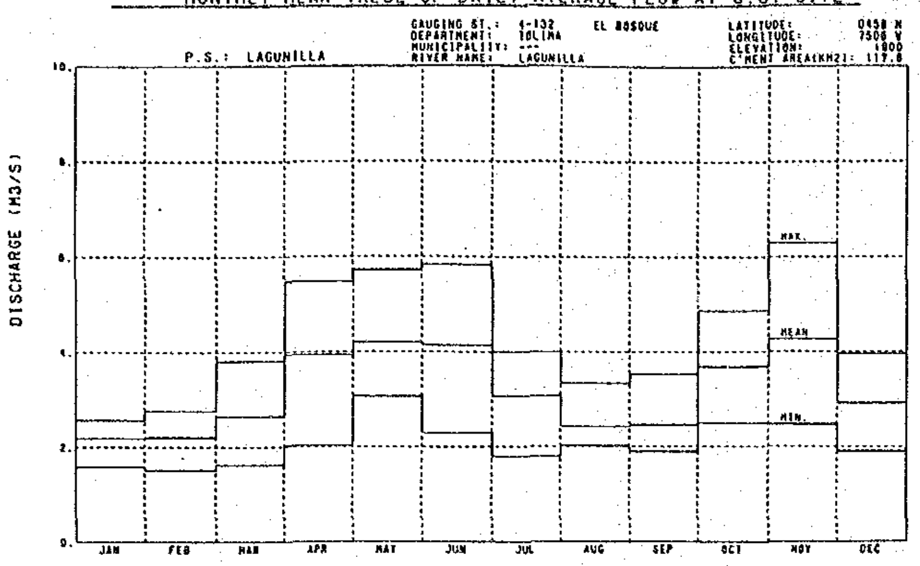
B – B



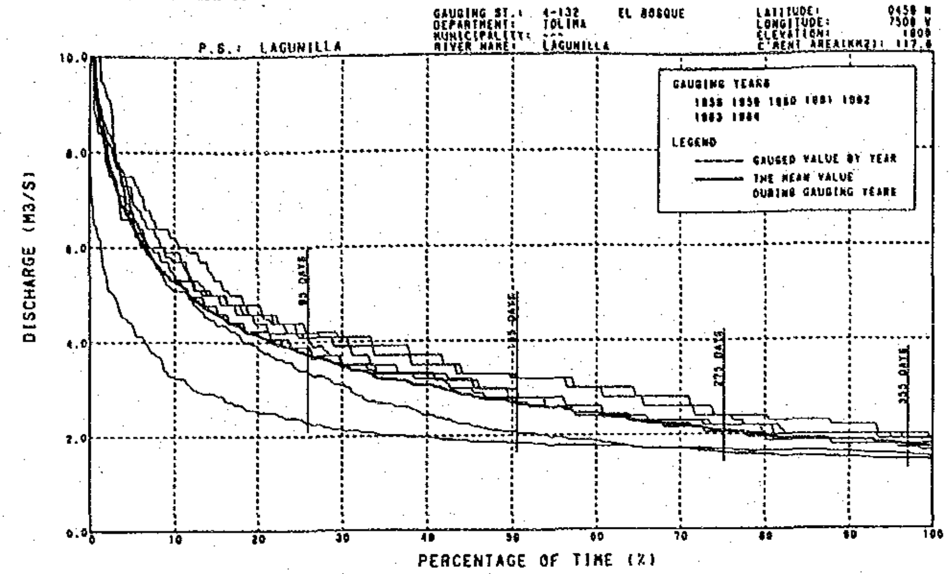
A – A

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
POWERHOUSE AND TAILRACE (ALT 3-1)	
DRAWING NO.	LA-C-05
SCALE 1/200	DATE

(1) MONTHLY MEAN VALUE OF DAILY AVERAGE FLOW AT G.S. SITE



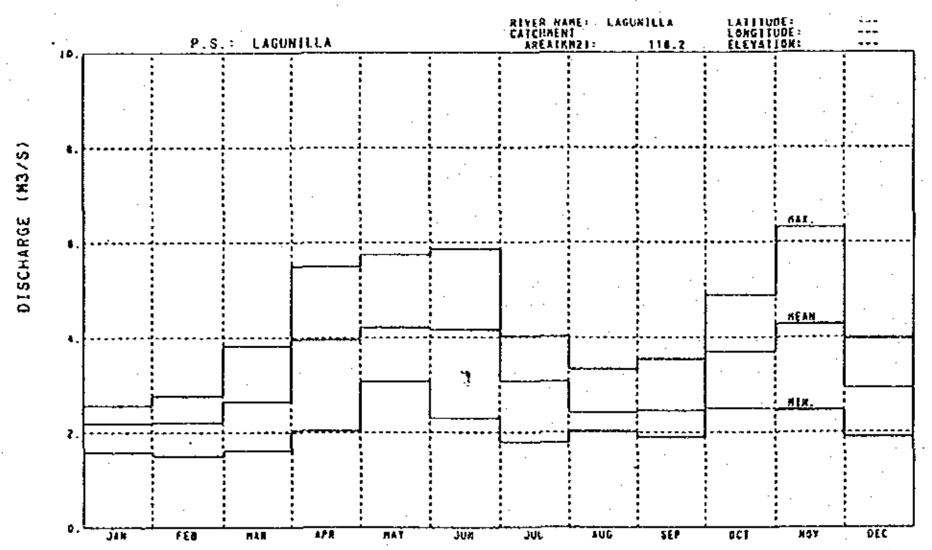
(3) FLOW DURATION CURVE AT GAUGING STATION SITE



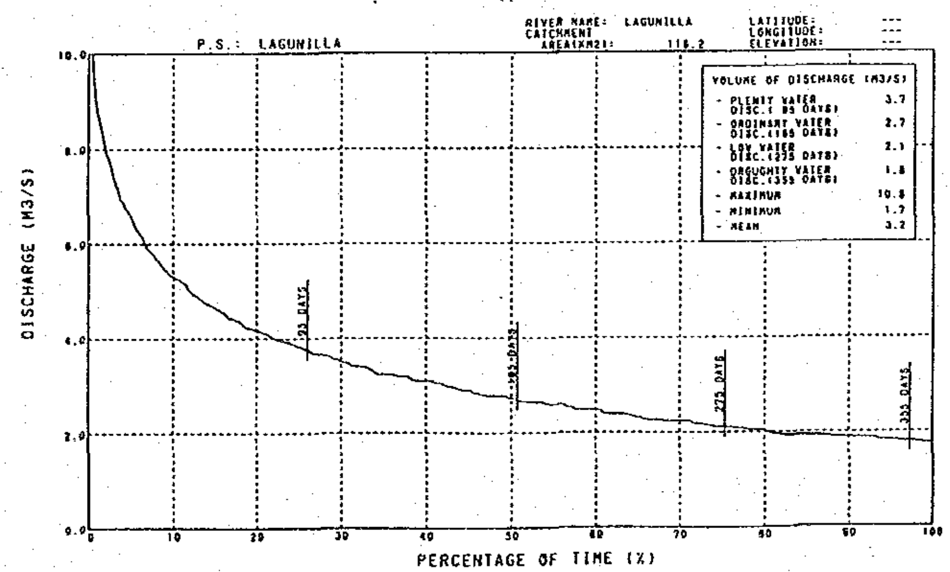
Data of Hydrological Gauging Station

No. of Station	4 −132
Name of Station	El Bosque
River	Lagunilla
Management	IAAFE
Installation Year − Month	1956 02
Coordinates (Deg. − Min.)	
Latitude	0455
Longitude	7506
Above Sea Level s.n.m. (m)	1900
Long River (km)	—— ——
Catchment Area (km²)	155
Water Shed (m)	—— ——
Observation Period	1957 − 1964

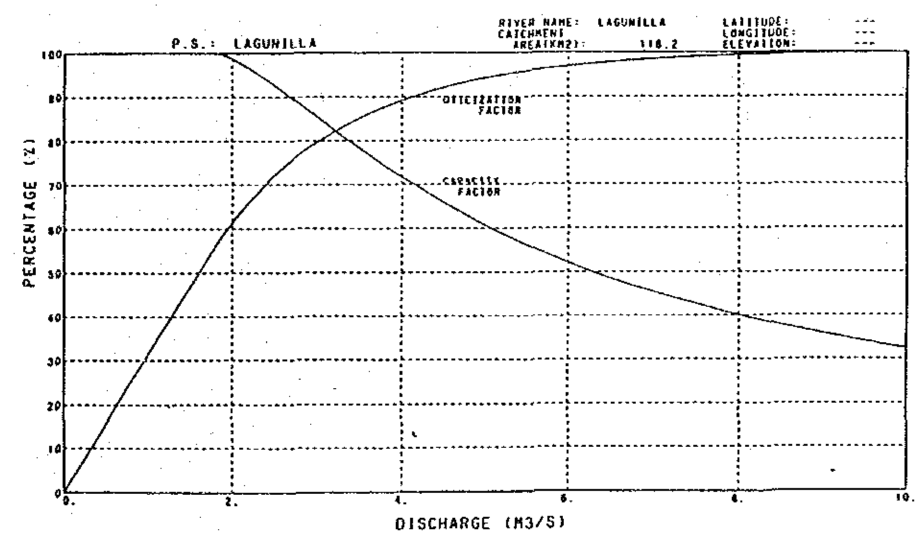
(2) MONTHLY MEAN VALUE OF DAILY AVERAGE FLOW AT INTAKE SITE



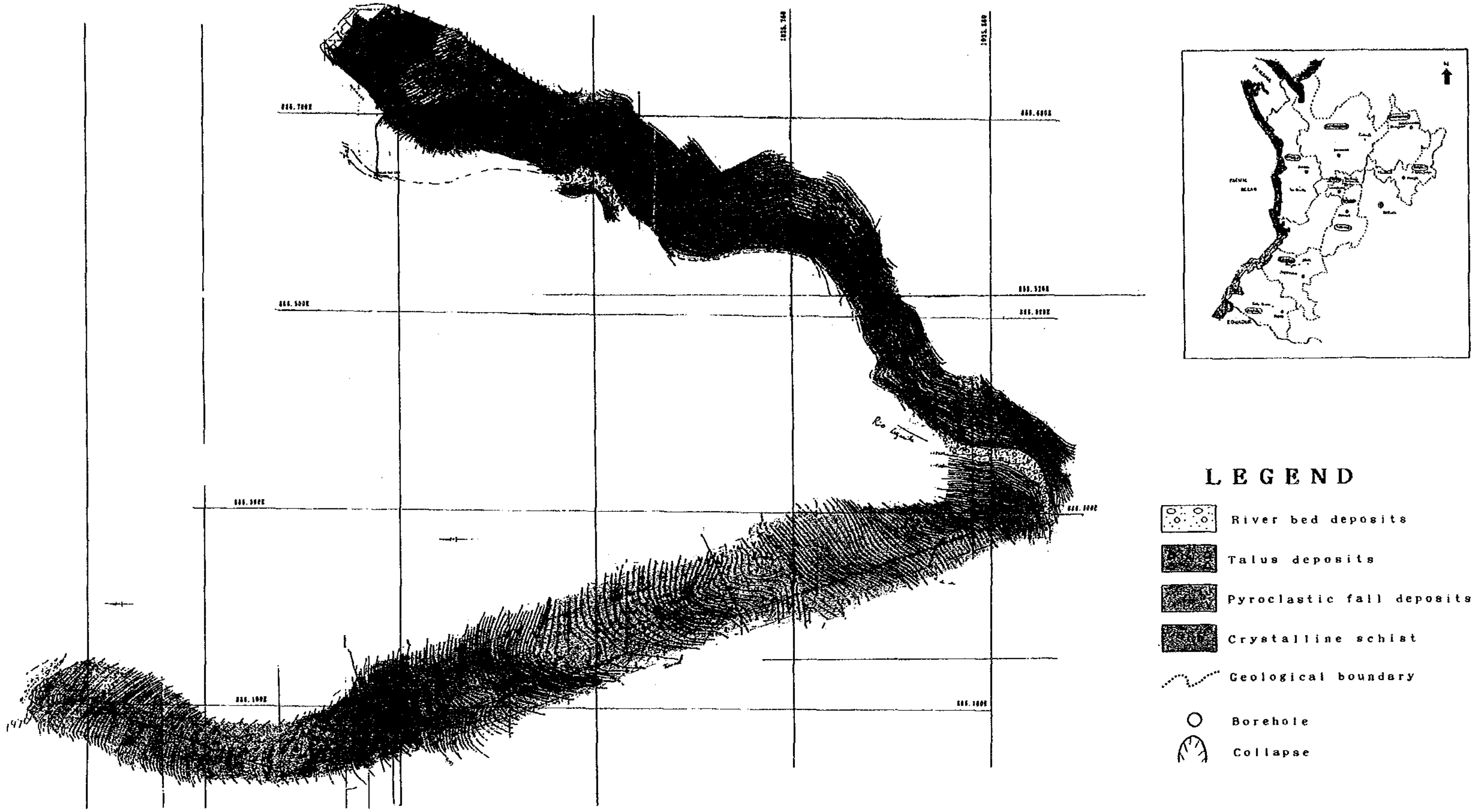
(4) TYPICAL FLOW DURATION CURVE AT INTAKE SITE



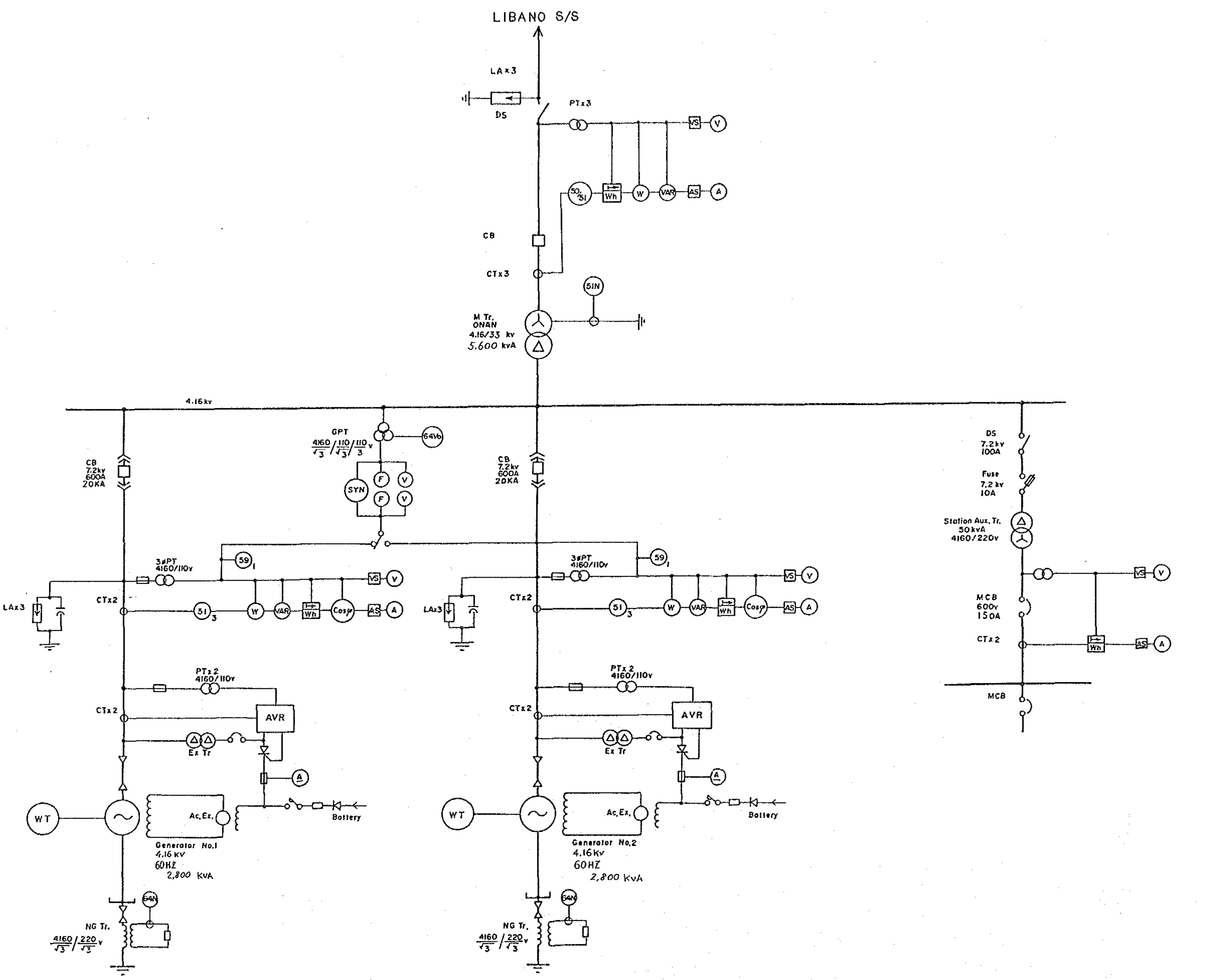
(5) UTILIZATION & CAPACITY FACTOR



JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)			
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)			
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA			
DURATION CURVES			
DRAWING NO.	L A − H − 0 1		
SCALE	———	DATE	



JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
Geological Plan Laguailla	
DRAWING NO.	LA-G-01
SCALE 1/4,650	DATE



JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)	
INSTITUTO COLOMBIANO DE ENERGIA ELECTRICA (ICEL)	
FEASIBILITY STUDY ON SMALL-SCALE POWER PLANTS REHABILITATION PROJECT IN THE REPUBLIC OF COLOMBIA	
ONE LINE DIAGRAM (ALT-3-1)	
DRAWING NO.	LA-E-01
SCALE —	DATE

Facility Register for the Existing Power Plant

Power Plant	Lagunilla
Electric Power Company	ELECTROLIMA
Location	Libano /Tolima
River	Lagunilla
Generating Method	Run-of-River
Year Installed	1940
Years in Service	1940
Installed Capacity	452 kW
Available Capacity	0

Civil	
Item	**Data**
1. Dam	
1) Type	DESTROYED
2) Height (m)	〃
3) Crest length (m)	〃
4) Height of overflowing crest (m)	〃
5) Width of overflowing crest (m)	〃
6) Depth of overflowing crest (m)	〃
2. Intake Gate	
1) Type	DESTROYED
2) Number of gates	〃
3) Dimensions (W x H)(m)	〃
3. Intake	
1) Intake sill height (m)	〃
2) Number of intake	〃
3) Dimensions (W x H)(m)	〃
4. Desilting Basin	
1) Dimensions (W x L x H)(m)	2.9 x 8.5 x 1.5
5. Sand Trap Gate	
1) Type	SLUICE
2) Number of gates	1
3) Dimensions (W x H)(m)	1.0 x 1.0
6. Headrace	
1) Type	RC COVERED CHANNEL
2) Dimensions (W x H)(m)	0.70 x 0.65
3) Length (m)	46.1

Civil	
Item	**Data**
7. Reservoir Tank	
1) Dimensions (W x L x H)(m)	1.87 x 3.5 x 1.35
8. Forebay	
1) Dimensions (W x H)(m)	N/A
9. Penstock	
1) Number of lines	2
2) Penstock diameter (d)(m)	φ0.5 ~ φ0.3
3) Penstock length (L)(m)	112.0 + 117.0
10. Tailrace	
1) Dimensions (W x H)(m)	1.05 x 1.6

Equipment

Item	Data #1	Data #2
1. Water Turbine		
1) Manufacturer's name	no data available	
2) Year manufactured	〃	
3) Type	Pelton	Pelton
4) Output (kW)	320	210
5) Revolution (rpm)	900	900
6) Ancillary equipment		
a) Type of governor	Mechanical	Mechanical
b) Inlet valve		
- Type		
- Diameter (mm)		
2. Generator and Exciter		
1) Manufacturer's name	no data available	
2) Year manufactured	〃	
3) Type	Synchro.	Synchro.
4) Capacity (kVA)	300	190
5) Power factor (%)	80	80
6) Voltage (V)	4,400	4,400
7) Frequency (Hz)	60	60
8) Revolution (rpm)	900	900
9) Method of neutral earthing	no data available	
10) Type of exciter	〃	

Equipment	
Item	**Data**
3. Transformer	N/A
1) Manufacturer's name	
2) Year manufactured	
3) Type	
4) Capacity (kVA)	
5) Primary voltage (kV)	
6) Secondary voltage (kV)	
7) Number of unit	
8) Vector-group symbol	
9) Impedance (%)	
10) Purpose for use	
4. Circuit Breaker	N/A
1) Manufacturer's name	
2) Year manufactured	
3) Type	
4) Voltage (kV)	
5) Rated current (A)	
6) Rupturing capacity (kA)	
7) Purpose for use	
5. Transmission Line	N/A
1) Destination	
2) Length (m)	
3) Voltage (kV)	
4) Number of circuit	
5) Number of pylons	
6) Size of conductors	
7) Materials of conductors	

Equipment	
Item	**Data**
6. Battery 1) Manufacturer's name	N/A
2) Year manufactured	
3) Capacity (AH/HR)	
4) DC voltage (V)	
5) Type	
7. Battery Charger 1) Manufacturer's name	N/A
2) Year manufactured	
3) Capacity	
4) Incoming voltage (V)	
8. Overhead Crane 1) Weight (ton)	N/A
2) Method of operation	
3) Span (m)	

Survey Records

Lagunilla Hydroelectric Power Plant

I. RECORDS BY VISUAL INSPECTION AND HEARING SURVEY

Unit No.: 1

Type of Turbine: Pelton

	Generating Facilities	Check item by visual inspection and hearing	Results
Pelton Turbine	Cover	1) Presence of vibration	1) No existing
	Bucket	1) Existence of corrosion	1) 〃
	Shaft	1) Shaking of shaft axis	1) Exists but it didn't function since 20 years approx.
	Bearing	1) Oil shortage on bearing surface	1) It is not operating
		2) Lack of oil viscosity	2) 〃
	Governor control	1) Control by belt-driven type	1) No existing
		2) Speed detection device	2) 〃
		3) Speed regulation system	3) 〃
		4) Installation of load limiter	4) 〃
		5) Accuracy of governor speed regulation	5) 〃

	Generating Facilities	Check item by visual inspection and hearing	Results
Pelton Turbine	Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) The equipments don't exist. 2) 〃
	Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) Out of service since 20 years approx. 2) 〃 3) The equipments don't exist.
	Nozzle and Needle	1) Existence of corrosion 2) Presence of water leakage from nozzle pipe when needle is closed	1) No existing 2) 〃
	Deflector	1) Smoothness of control	1) 〃
	Jet Brake	1) Smoothness of control	1) 〃

Unit No. /

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat	1) It is totally converted in scrap iron and it is abondoned.
		2) Existence of erosion for core	2) Useless
		3) Fitness of between rotor and shaft	3) Out of service
	Stator winding	1) Frequency of burning trouble or repair	1) 〃
		2) Reduction of insulation resistance	2) Useless
		3) Rust and erosion of core	3) 〃
	Bearing	1) Occurrence of deformation on metal surface	1) 〃
		2) Lack of oil lubrication	2) Out of service
		3) Occurrence of temperature rise	3) 〃
	Exciter	1) Exchange frequency of brushes worn out	1) 〃
		2) Sufficient stock of spare brush	2) 〃
	Voltage regulator	1) Operation method of voltage regulator	1) 〃
		2) Response of voltage detection for load variation	2) 〃

	Generating Facilities	Check item by visual inspection and hearing	Results
Pelton Turbine	Oil pressure equipment	1) Existence of oil leakage 2) Application of oil pressure pumping system	1) doesn't exist 2) 〃
	Inlet valve	1) Operation method 2) Locking condition 3) Smoothness of pressurized oil operation	1) Out of service since 20 years approx. 2) no function since 20 years 3) No existing
	Nozzle and Needle	1) Existence of corrosion 2) Presence of water leakage from nozzle pipe when needle is closed	1) No existing 2) 〃
	Deflector	1) Smoothness of control	1) 〃
	Jet Brake	1) Smoothness of control	1) 〃

Unit No.: 2

Type of Turbine: Pelton

	Generating Facilities	Check item by visual inspection and hearing	Results
Pelton Turbine	Cover	1) Presence of vibration	1) No existing
	Bucket	1) Existence of corrosion	1) 〃
	Shaft	1) Shaking of shaft axis	1) Exists but it is not function since 20 years approximately.
	Bearing	1) Oil shortage on bearing surface	1) It is not operating.
		2) Lack of oil viscosity	2) 〃
	Governor control	1) Control by belt-driven type 2) Speed detection device 3) Speed regulation system	1) No existing 2) 〃 3) 〃
		4) Installation of load limiter	4) 〃
		5) Accuracy of governor speed regulation	5) 〃

Unit No. 2

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat	1) It is totally converted in scrap iron and it is abondoned.
		2) Existence of erosion for core	2) Useless
		3) Fitness of between rotor and shaft	3) Out of service
	Stator winding	1) Frequency of burning trouble or repair	1) 〃
		2) Reduction of insulation resistance	2) Useless
		3) Rust and erosion of core	3) 〃
	Bearing	1) Occurrence of deformation on metal surface	1) 〃
		2) Lack of oil lubrication	2) Out of service
		3) Occurrence of temperature rise	3) 〃
	Exciter	1) Exchange frequency of brushes worn out	1) 〃
		2) Sufficient stock of spare brush	2) 〃
	Voltage regulator	1) Operation method of voltage regulator	1) 〃
		2) Response of voltage detection for load variation	2) 〃

Unit No. 2

	Generating Facilities	Check item by visual inspection and hearing	Results
Generator	Rotor	1) Discoloration of winding surface due to heat	1) It is totally converted in scrap iron and it is abondoned.
		2) Existence of erosion for core	2) Useless
		3) Fitness of between rotor and shaft	3) Out of service
	Stator winding	1) Frequency of burning trouble or repair	1) 〃
		2) Reduction of insulation resistance	2) Useless
		3) Rust and erosion of core	3) 〃
	Bearing	1) Occurrence of deformation on metal surface	1) 〃
		2) Lack of oil lubrication	2) Out of service
		3) Occurrence of temperature rise	3) 〃
	Exciter	1) Exchange frequency of brushes worn out	1) 〃
		2) Sufficient stock of spare brush	2) 〃
	Voltage regulator	1) Operation method of voltage regulator	1) 〃
		2) Response of voltage detection for load variation	2) 〃

Generating Facilities		Check item by visual inspection and hearing	Results
Control Board	Metering equipment	1) Sufficiency of accuracy for instruments 2) Lack of necessary instruments 3) Items constantly recorded	1) No existing 2) Out of service 3) No existing
	Protection equipment	1) Lack of relays to be installed 2) Operation method in case of accident in transmission lines	1) Out of service 2) No existing
	Remote control equipment	1) Control method for turbine and generator operation 2) Control method for voltage and speed control 3) Operation method of synchronized switching	1) 〃 2) 〃 3) 〃
	Power system	1) Power supply voltage (kV) after rehabilitation work	1) 〃

Generating Facilities		Check item by visual inspection and hearing	Results
Indoor Switchgear	Insulation level	1) Sufficiency of insulation level 2) Unification of insulation level 3) Reduction of insulation registance	1) No existing 2) 〃 3) 〃
	Accessi-bility and Safety	1) Accessibility to high voltage devices 2) Sufficiency of protection for high voltage cable terminals 3) Method and reliability of operation for synchronizing circuit breaker	1) 〃 2) 〃 3) 〃

	Generating Facilities	Check item by visual inspection and hearing	Results
Outdoor Equipment	Transformer	1) Presence of over load operation	1) No existing
	Circuit breaker	1) Situation of tripfor outgoing feeder breaker in case of accident on transmission line 2) Fitness of maintenance in case of oil circuit breaker	1) 〃 2) 〃
	Line switch	1) Operation method 2) Reliability of operation	1) 〃 2) 〃
	Insulator	1) Presence of damage and dusts	1) 〃
	Structural steel	1) Occurence of erosion due to rust 2) Presence of injury	1) 〃 2) 〃
	Line protection	1) Existence of adequate protection relays to connect to RED	1) 〃

II. ACTUAL GENERATED ENERGY AND OPERATION TIME

It can not state that the power plant doesn't operate since 20 years approximately.

III. REPAIR RECORDS

No.	Study Item	Results
	The past records concerning the following items shall be obtained to evaluate reliability of generating facilities.	The recod doesn't exist because the plant is outside of service since 20 years.
	1) Repaired locations and method for repairing	
	2) Causes for damage/defect	
	3) Duration of repairing and power supply stoppage	
	4) Repaired by;	
	a) staff in Power Plant	
	b) manufacturer	
	c) other	
	5) Repair cost	
	6) Operation life after the completion of repairing work	

III. REPAIR RECORDS

No.	Study Item	Results
	The past records concerning the following items shall be obtained to evaluate reliability of generating facilities.	The recod doesn't exist because the plant is outside of service since 20 years.
1)	Repaired locations and method for repairing	
2)	Causes for damage/defect	
3)	Duration of repairing and power supply stoppage	
4)	Repaired by;	
	a) staff in Power Plant	
	b) manufacturer	
	c) other	
5)	Repair cost	
6)	Operation life after the completion of repairing work	

V. E.TOLIMA's INTENTION FOR REHABILITATION

No.	Study Item	Leaving as it is	Repair work	Replacement	Notes
	Mark with ✓ in pertinent columns.				
	- Inlet valve				
	- Turbine, governor, auxiliary equipment				
	- Generator, exciter				
	- Control panel	It should be assembled by new ones because by abandonment of more 20 years, existing damage is totaly and moreover the project is for machine of major power.			
	- Switchgear				
	- Transformer				
	- Substation equipment (Circuit breaker, Isolator, etc.)				
	- Transmission tower, conductor and insulator				
	- Power House				

IV . SITUATION OF STOCK SPARE PARTS

No.	Study Item	Results
	Data on the situation of stock spare parts shall be obtained to evaluate maintainability of generating facilities.	No existing