8. SEISMICITY

8.1 Outline

From the viewpoints of the plate tectonics, major Himalayan tectonics that are located in the western part of the Kingdom of Bhutan were formed primarily by subduction of the Indian continent below the Eurasian plate since the Eocene period (ca. 40Ma). After colliding, the Indian continent has continued to move northward at a rate of about 5cm/year until the present, and this movement has caused remarkable mountain-building and high seismicity in central and eastern Asia.

Though the current seismicity in the Kingdom of Bhutan is not so active as compared with other regions of the Himalayas, there is found considerable seismic activity around the country, especially in eastern borderlands, western Sikkim and eastern Nepal. There is found also in this country a tendency to epicentral concentration in the vicinity of the Main Central Thrust (MCT).

An available seismic risk map for the Indian area was prepared in 1986 by the Bureau of Indian Standards (IS 1893-1984). The seismic risk map for the Indian area shows the five zones relating to the degree of risk. The Kingdom of Bhutan is located in IV~V zone (strong earthquake area).

According to the Modified Mercalli (MM) intensity scale, inferred seismic intensity in the region is VIII~IX (approximately corresponding to intensity a little less than V~VI).

8.2 Design Seismic Coefficient

Estimation of the maximum ground acceleration at the Punatsangchhu damsite by statistical probability analysis was performed to determine the design seismic coefficient.

Estimations were made with the data, taking an equal time interval of one year.

The maximum accelerations at the ground surface assumed for the damsite can be put together in the Table below from the previously-mentioned seismic risk analysis, and 158 gal (1,000 years probability) is to be taken as the maximum acceleration at the ground surface during earthquake for the damsite.

Maximum Accelerations expected at the Punatsangchhu Damsite

(Gal)

Attenuation Equation	Return Period (Year)				
	50	100	200	500	1,000
Oliveira's Equation	10	12	13	14	14
McGuire's Equation	44	47	49	51	52
Esteva & Rosenblueth's Equation	8	9	9	9	9
Katayama's Equation	23	25	27	28	29
Okamoto's Equation	166	259	374	548	688
Average	50	70	94	130	158
Probability	0.98	0.99	0.995	0.998	0.999

9. DEVELOPMENT PLAN

9.1 Review of Existing Development Plan

The Bhutan Power System Master Plan (hereinafter referred to as the Master Plan) was formulated during years 1990 to 1993.

In this Master Plan, development plans for 25 projects in the whole country were formulated, and the four most attractive projects, including Punatsangchhu Project (Project 3.120) and Project 3.230B, Pre F/S studies were carried out as part of the Master Plan. (see Fig. 9.1)

① Punatsangchhu Project stage 1 (760 MW Project 3.120)
② Punatsangchhu Project stage 2 (650 MW Project 3.230B)
③ Mangdechhu Project (265 MW Project 4.020)
④ Kholongchhu Project (290 Mw Project 5.150B)

In the river basin, seven projects (total capacity 1,894 MW) are proposed in the Master Plan, and Project 3.120 (760 MW) and Project 3.230B (650 MW) in Pre F/S. Both projects are located midstream in the Punatsangchhu. The generation method of Project 3.120 is a dam and waterway type and the damsite is proposed at a point about 10 km downstream from Wangdue Phodrang located downstream of the conjunction point of the two rivers, with the powerhouse site at a point about 8 km further downstream.

The midstream of the Punatsangchhu, where Project 3.120 and Project 3.230B is planned, has a relatively steep riverbed gradient. The damsite of Project 3.120 coincides with the marginal point of the riverbed gradient, and provides good topographical conditions for planning a dam and waterway type hydro power project, having a regulating reservoir upstream of the dam and a waterway downstream for headrace.

Therefore, the layouts for the dam and powerhouse are reasonable from the point of view of using headrace, because both projects are planned in an area where we can make use of the steep riverbed gradient. The daily regulations of river flow would enable peak generation with a small capacity reservoir in the dry season, and are also reasonable from the point of view of effective use of river flow.

Peak generation by daily regulation coincides with the change of electric demand, and this benefit would contribute to increase the worth of electricity for export. So, their daily regulations are also reasonable from the point of view of operations.

9.2 Comparative Study of Alternative Development Plan

Alternative plans for the optimization study of the development plan were made based on the method of comparative study below.

(1) Study of Generation Method・layout

- Dam and waterway type with daily regulating reservoir is the reasonable generation method suitable to the characteristics of the river.
- Proposed damsite is located in a reasonable position from a topographical and geological point of view.
- Therefore, the dam axis was fixed at the development plan study stage, and the comparative study of dam axis was made at the feasibility design stage.
- Proposed headrace tunnel (L=6,400m) is long and its construction cost seems to occupy a high percentage of the total cost. Therefore, it is necessary to check the economy of an alternative layout case in which the powerhouse is shifted upstream to lower tunnel construction cost.

(2) Study of Generation Scale

- Maximum discharge is set based on the peak discharge for firm discharge assuming the required peaking time for demand is 4 hours. However, it is necessary to check the economy of an alternative generation scale by changing Qmax.
- Dam height is set to guarantee the least reservoir capacity for daily regulation, set as more than 70 m from the existing river bed by Area Capacity Curve considering sedimentation level. ·
- It is, then, not necessary to check the economy of an alternative generation scale by changing dam height, because the steep river bed gradient would give enough headrace.

(3) Method of Comparative Study

1) Economic Comparison by BC method

- The method used for a comparative study of alternative development plans is the benefit cost method (BC method), considering an alternative thermal power plant built without the Punatsangchhu Project and taking the cost of a thermal power plant as the benefit of the project.
- An alternative thermal power plant was assumed constructed in the eastern part of India, supposed to mainly transmit the electricity of the Punatsangchhu Project.

- A combination of coal-fired thermal power and gas turbine was selected as an alternative thermal power plant. B-C was used as the fundamental index for judging the economy of the project. C is the equalized annual cost for hydro power and B is considered the equalized cost of alternative thermal power that has the same power ability as hydro power.

2) Estimation of Construction Cost

The condition for cost estimation is described below.

- Investment cost for project construction consists of preparatory works (relocation of existing road, access road, camp facility), civil works, hydraulic equipment, electro-mechanical equipment, transmission line, contingency, engineering-administration cost, land acquisition and interest during construction.

- Unit price for civil works, hydraulic equipment and cost of electro-mechanical equipment was roughly estimated based on the actual cost of other similar projects in the Kingdom of Bhutan. However, a part of the cost was estimated using costs in foreign countries including Japan. (cost estimation base in 2000)

3) Energy Calculation

- Operation method of reservoir is to have a daily peak regulation for desired peaking time using effective reservoir capacity. The capacity is based on firm discharge that is expected to arise with at least 95% probability. Daily energy calculation was made for it.

(4) Comparative Study of Alternative Development Plan

1) Study of Generation Scale and Layout

- Generation type (dam and waterway type), dam axis position, dam height and peaking time (6 hr) were fixed for all cases. Meanwhile, three powerhouse positions were checked (upstream, middle, downstream) and comparative studies of maximum discharge (Qmax : 200~375 m^3/s) were made for each powerhouse position.

Study Cases for Comparative Study

	HWL (EL m)	Qmax (m^3/s)	Power House Position
Case 1~5	1,161	375,348,300,250,200	Down stream
Case 6~10	〃	〃	Middle Stream
Case 11-15	〃	〃	Up Stream

Table 9.1 and Fig. 9.2 shows the comparative study results

- As to the powerhouse position, Cases 1~5 are more economical than the others.

  It seems to be more advantageous to make use of full headrace as much as possible by putting the powerhouse downstream.

- It seems to be more advantageous to increase maximum discharge against the given reservoir capacity. Study cases in which maximum discharge is greater than 348 m^3/s (Case 2) have less benefits because firm peak output for required peaking time would drop in the dry season and kW benefit decreases.

(5) Optimum Development Plan (Selection of Development Plan)

From the overall point of view, the development plan that shows in the Table below (Case 2: Qmax=348 m^3/s, Pmax=884 MW) was selected as the optimum one from the result of the comparative study above.

Punatsangchhu Hydro Power Project

Reservoir and Structures		
Reservoir effective volume		$4.24 \times 10^6 m^3$
Reservoir area		0.53 km^2
Dam height (from foundation)		140 m
Dam volume		924,000 m^3
Headrace tunnel length		6,860 m × 2
Headrace inner diameter		7.40 m
Underground powerhouse (B×H×L)		20 m × 38 m × 114 m
Development Plan		
Maximum discharge	Qmax	348 m^3/s
Effective head	He	291.3 m
Installed capacity	Pmax	884 MW (147 MW × 6)
Annual Average Energy	E	4,395 GWh

Table.9.1 Comparison Table for Alternative Development Plan

Item	Unit	Case1	Case2	Case3	Case4	Case5	Case6	Case7	Case8	Case9	Case10	Case11	Case12	Case13	Case14	Case15
Reservoir																
HWL	ELm	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161	1,161
LWL	ELm	1,147	1,147	1,151	1,153	1,153	1,147	1,147	1,151	1,153	1,153	1,147	1,147	1,151	1,153	1,153
Available drawdown depth hd	m	14	14	10	8	8	14	14	10	8	8	14	14	10	8	8
Sedimentation level SWL	ELm	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142	1,142
Gross storage capacity Vg	10^6m^3	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59	12.59
Effective storage capcity Ve	10^6m^3	4.24	4.24	3.46	2.91	2.91	4.24	4.24	3.46	2.91	2.91	4.24	4.24	3.46	2.91	2.91
Dam																
Type	-	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G	C.G
Crest length Bcrest	m	260	260	260	260	260	260	260	260	260	260	260	260	260	260	260
Dam height from thalweg hdam	m	74	74	74	74	74	74	74	74	74	74	74	74	74	74	74
Dam height from foundation Hdam	m	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Dam volume Vdam	10^3m^3	924	924	924	924	924	924	924	924	924	924	924	924	924	924	924
Headrace																
Type	-	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular
Inner diameter D(v=4m/s)	m	7.7	7.4	6.9	5.6 , 6.9	5.6	7.7	7.4	6.2 , 7.6	6.3	4.6 , 6.5	6.9 , 8.5	6.7 , 8.2	6.9	6.3	4.6 , 6.5
Tunnel length L	m	2x6840	2x6860	2x6900	2x6950	2x7110	2x6100	2x6120	2x6160	2x6190	2x6410	2x3870	2x3860	2x3920	2x3960	2x4150
Penstock(main part)																
Type	-	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft	shaft
Inner diameter D(v=7m/s)	m	5.8	5.6	5.2	4.2 , 5.2	4.2	5.8	5.6	4.6 , 5.7	4.7	3.4 , 4.9	5.2 , 6.3	5.0 , 6.1	5.2	4.7	3.4 , 4.9
Penstock length L	m	2x451	2x453	2x459	2x455	2x452	2x389	2x391	2x399	2x385	2x398	2x350	2x350	2x359	2x363	2x366
Power house																
Position	-	downstream	downstream	downstream	downstream	downstream	middle	middle	middle	middle	middle	upstream	upstream	upstream	upstream	upstream
Number of unit	unit	6	6	6	5	4	6	6	5	4	3	5	5	4	4	3
Tailrace(main part)																
Type	-	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular	circular
Inner diameter D(v=4m/s)	m	7.7	7.4	6.9	5.6 , 6.9	5.6	7.7	7.4	6.2 , 7.6	6.3	4.6 , 6.5	6.9 , 8.5	6.7 , 8.2	6.9	6.3	4.6 , 6.5
Tunnel length L	m	2x381	2x381	2x381	2x361	2x342	2x224	2x224	2x204	2x184	2x182	2x717	2x717	2x698	2x698	2x695
Development plan																
NWL	ELm	1,154	1,154	1,156	1,157	1,157	1,154	1,154	1,156	1,157	1,157	1,154	1,154	1,156	1,157	1,157
TWL	ELm	845	845	845	845	845	890	890	890	890	890	935	935	935	935	935
Gross head Hg	m	309	309	311	312	312	264	264	266	267	267	219	219	221	222	222
Effective head He	m	291.8	291.3	292.6	292.4	290.3	248.7	248.3	249.6	249.5	247.6	207.7	207.4	209.0	209.3	208.0
Loss of head hl	m	17.2	17.7	18.4	19.6	21.7	15.3	15.7	16.4	17.5	19.4	11.3	11.6	12.0	12.7	14.0
Peaking time Tp	hr	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Maximum discharge Qmax	m^3/s	375	348	300	250	200	375	348	300	250	200	375	348	300	250	200
Installed capacity Pmax	MW	954	884	766	638	506	813	754	653	544	432	679	630	547	456	363
Firm peak output Pf	MW	887	871	766	638	506	756	743	653	544	432	631	620	547	456	363
Firm energy Ef	Gwh	1,383	1,288	1,118	931	739	1,179	1,098	954	794	631	984	917	798	666	530
Secondary energy Es	Gwh	3,201	3,107	2,951	2,731	2,441	2,728	2,648	2,517	2,330	2,082	2,278	2,212	2,108	1,955	1,749
Total energy Etotal	Gwh	4,584	4,395	4,069	3,662	3,180	3,907	3,746	3,471	3,124	2,713	3,262	3,129	2,906	2,621	2,279
Economic evaluation																
Project cost (price in 2000 year)	$10^6$$	974	932	858	777	705	897	864	795	726	659	804	779	723	666	610
Unit construction cost per kw (*1)	$/kw	1,021	1,054	1,120	1,219	1,393	1,103	1,146	1,218	1,334	1,525	1,184	1,236	1,322	1,461	1,680
	Nu/kw	40,843	42,171	44,802	48,741	55,706	44,114	45,822	48,724	53,350	61,007	47,375	49,453	52,867	58,425	67,208
Unit construction cost per kwh (*2)	$/kwh	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
	Nu/kwh	1.07	1.07	1.06	1.07	1.11	1.15	1.16	1.15	1.17	1.22	1.24	1.25	1.25	1.28	1.35
B1(kw value)	$10^6$$	123.58	121.35	106.72	88.89	70.50	105.33	103.52	90.98	75.79	60.19	87.91	86.38	76.21	63.53	50.58
B2(kwh value)	$10^6$$	65.23	62.43	57.58	51.61	44.62	55.59	53.21	49.12	44.03	38.07	46.41	44.45	41.12	36.94	31.98
B/C	-	1.62	1.64	1.60	1.51	1.36	1.50	1.51	1.47	1.38	1.24	1.39	1.40	1.35	1.26	1.13
B-C	$10^6$$	71.92	71.94	61.35	47.21	30.56	53.33	53.08	44.65	32.75	19.19	37.83	37.36	30.58	20.54	9.36

*1: Unit construction cost per kw = Project cost/Pmax

*2: Unit construction cost per kwh = Project cost*Annual cost ratio / (Effective annual average energy)

= Project cost * 12% / (Annual average energy *(1-0.02)*(1-0.003)*(1-0.003)*(1-0.02))

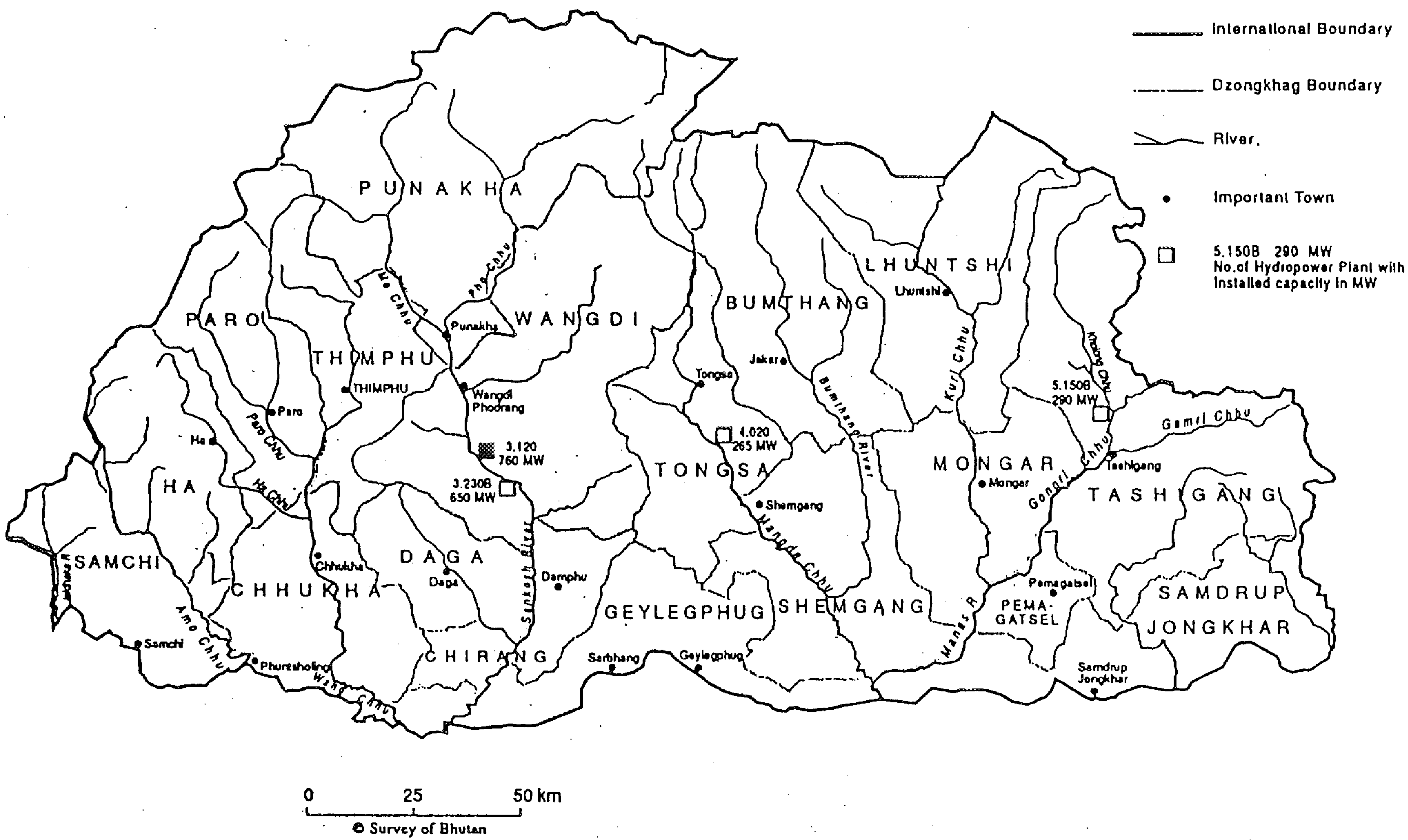

Fig. 9.1 Power System Master Plan in the Kingdom of Bhutan

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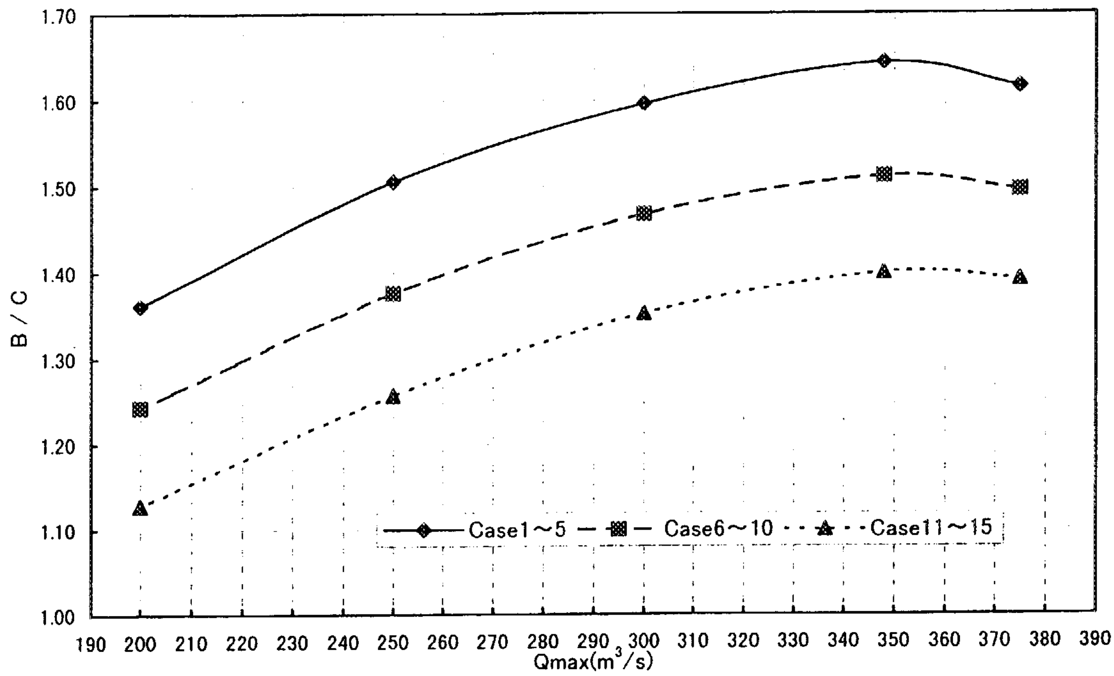


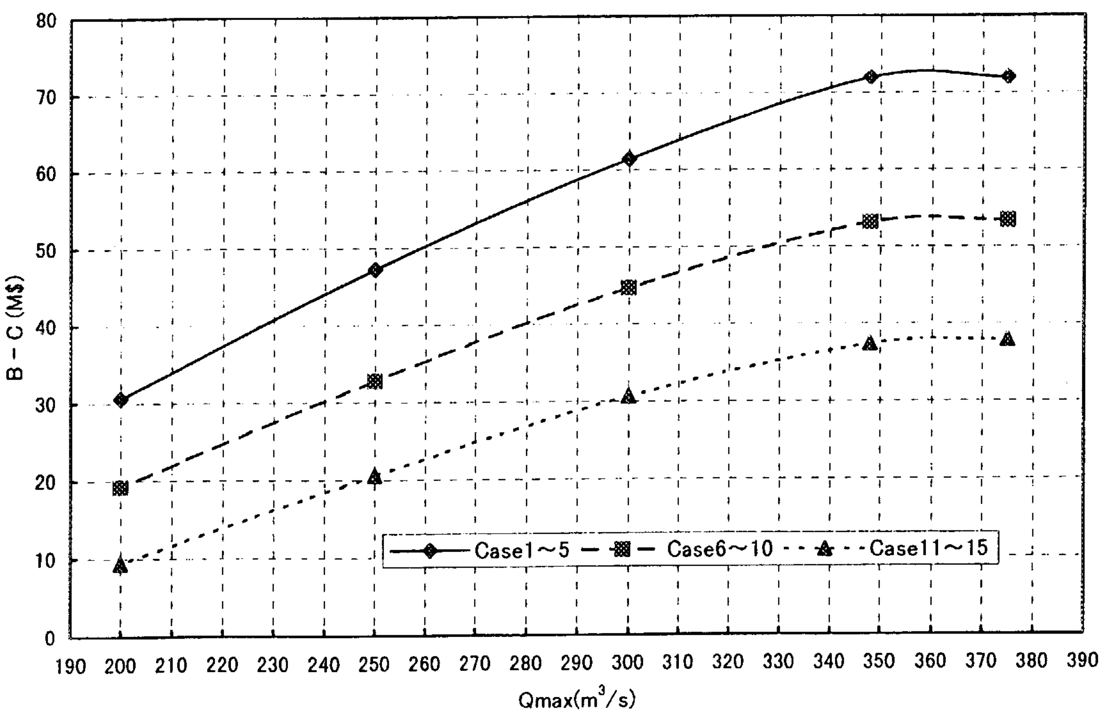


Fig. 9. 2 Comparative Study of Development Scale Examination (Qmax for Case 1～15) (1/2)

10. TRANSMISSION LINE PLAN AND POWER SYSTEM ANALYSIS

10.1 Transmission Line Planning

Candidate routes for transmission lines were surveyed based on the topographic map (scale 1/25,000 and 1/50,000). As a result of discussion with DoP regarding the two alternative route plans, Plan A and B, DoP/JICA study team surveyed Plan A (Punatsngchhu power station – Sarbhang (Sapang) - Bongaigaon substation) which is the most promising candidate route according to the master plan and Pre-feasibility study. On the other hand, DoP has a future scheme for Plan B (Punatsangchhu Switchyard - Kerabari Substation - via Devitar - Coach Bihar Substation).The JICA study team, however, recommends selection of Plan A. Plan B is an alternative for future development at the detailed design stage, for the following reasons:

The length of Transmission Lines are;

Plan A: approx. 140 km (.Within Bhutan 80 km – Borderline – Within India 60 km)

Plan B: approx. 125 km (Within Bhutan 108 km – Borderline – Within India 17 km)

The economic comparison for selecting optimum voltage was made comparing a 400 kV line and a 220 kV line. In addition, the power system stability studies were made to clarify a different characteristic of the two voltages, and finally the most suitable transmission line was suggested.

As a result of preconditions, the following transmission lines are selected for the studies.

a. 220 kV line: Punatsangchu ~ Bongaigaon (140 km), 3-circuits*1, 1-bundle
b. 400 kV line: Punatsangchu ~ Bongaigaon (140 km), 2-circuits, 2-bundles
c. Conductor: Martin (equivalent to ACSR 700mm^2)

Note) *1: 220 kV line with 2 circuits can not maintain its system stability and 3 circuits is suggested.

Comparing the annual costs of the two transmission lines, that of the 220 kV line is lower than the 400kV line by $558.6 thousand, inversely that of the 220 kV related equipment is higher by $201 thousand. On the other hand, the transmission losses (i.e. lost benefit) of the 220kV line increases by $2,260 thousand compared to the 400 kV line. Raising of the annual costs of the 220 kV line is caused by the addition of 220/400 kV transformers for the Bongaigaon substation. Total annual costs show that the 400 kV line makes a decrease of $1,902 thousand compared to the 220 kV line, and has very economical advantages.

10.2 Power System Analysis

Transmission lines connecting the Punatsangchhu power station with the Bongaigaon substation are classified into the following three patterns with a combination of voltage and the number of circuits and conductors.

a.	220 kV line:	2 circuits with 2 bundles
b.	220 kV line:	3 circuits with 1 bundle
c.	400 kV line:	2 circuits with 2 bundles

Power flow and stability studies about these three patterns are made to discover network problems and to select the optimum transmission line.

The year 2010, when the Punatsangchhu power station is proposed to be commissioned, is set for the power system studies. Power demand scale of West Bengal and its border states are as follows.

Assm state:	1,320 MW
West Bengal state:	6,350
Bihar state:	5,240
Orissa state:	5,180

In Bhutan only a local power demand supplied from the Chhukha power station is counted for the studies.

The table below shows the results of power stability calculations. Stability of the Punatsangchhu power station is maintained under the 220 kV line or the 400 kV line, but the 220 kV line requires 3 circuits.

Simulation studies with disturbance on the Siliguri~Malda line connecting two grids of Assam and West Bengal were made for verifying the stability of the major generators in Bhutan and observing the level of power flow in said line as the system stability limit. Operating stability limit of the Siliguri~Malda line is 810 MW for maintaining the stability of the generators in Bhutan under the 220 kV-3circuits and 970 MW is obtained under the 400 kV-2circuits.

Comparison of Transmission Line Alternatives and Stability

T. lines 3-ϕGF line	220kV-2cct (2-bundles)	220kV-3cct (1-bundle)	400kV-2cct (2-bundles)
1. Punatsangchhu line (Power flow=870MW) Siliguri~Malda line (MW)	Unstable 1,230	Stable 1,230	Stable 1,260
2. Siliguri~Malda line (Operating stability limit) (MW)	—	810	970

(4) Results of Analysis

It is recommended that introduction of a 400 kV-2circuits line for the Punatsangchhu power station be made, and that its connecting substation be Bongaigaon, for the following reasons:

The study for an expansion program of Assam~West Bengal line is required with a progress of power development plan in Bhutan. This study should be made under the power demand and supply program and the network expansion program of India.

10.3 Design of the Transmission Line Components

As a result of Item 10.2, a 400 kV-2 circuit of overhead transmission lines is to be applied in this project and the preliminary design is to be as follows.

(1) Conductor and Ground Wire

The corona effect is strongly influenced by the altitude. At 400 kV, only bundled conductors seem practical. Several of the Rights-of-Ways evaluated crossing areas in the mountain where the altitude is more than 1,000 m.

The twin bundle Moose conductor (ACSR 500 mm^2) used in India will be feasible only for lower altitudes, as corona losses and radio interference will be high at altitudes above 1000 m. A twin bundle Martin (ACSR 700 mm^2) would be needed at an altitude of about 2000 m for this transmission line.

An overhead ground wire will be installed to protect conductors against lightning all over the transmission line. Zinc-coated steel wire strand (Sectional area: 74.5 mm^2) is appropriate for the overhead ground wire of this transmission line.

(2) Insulation Design

In the insulation design of this transmission line, we must consider the decrease of air insulation strength in high-altitude regions. The length of the insulator strings and arcing horn gaps should be about 10% longer than those in the lower regions.

The line should be constructed on double circuit type self-supporting latticed steel towers designed to carry the line conductors with the necessary insulators, ground wires and fittings under loading conditions. The three phases of each circuit should be in vertical formation on both sides of the tower. Each phase should be constituted with a bundle of two sub-conductors in horizontal formation. Two continuous ground wires should be provided over each circuit offering effective shielding against lightning.

11. FEASIBILITY DESIGN

11.1 Dam and Auxiliary Structures

The damsite proposed in the comparative study of the development plan is located about 10 km downstream from Wangdue Phodrang. Topographical condition at the damsite is what is called V type valley, having about 50 m valley width at riverbed level, and about 200 m at dam crest level. (HWL = EL. 1,161 m)

The characteristic of rock condition is estimated to have at least CM~CH class foundation rock whose shearing strength is enough for constructing a high concrete gravity dam (approximate dam height 140 m, HWL = EL. 1,161 m).

Adoption of gravity type concrete proposed in the development plan study is reasonable considering the topographical and geological conditions at the damsite.

The shape of the dam body (upstream face: vertical with fillet, downstream face: 1:0.8) was decided based on the stability analysis estimating design conditions like rock shearing strength.

Spillway type is center overflow with gate, and design flood discharge is 13,900 m^3/s (PMF).

In addition to these main spillway gates, four flap gates were set as sub gates for emergency flood by GLOF. In this case, Qf (4,600 m^3/s) would be supposed to overtop all gates including the main spillway gates, supposing the crest gates are all closed when GLOF occurred.

The temporary river closing and change of river flow would be made by a coffer dam and bypass tunnel (2 lines, Horseshoe type D=7.8m) before starting the riverbed dam excavation work.

Crest gate operation and bottom flushing system were proposed for the control of sediment level.

Crest gate operation would permit the rise of sedimentation level until at the sill level of the crest gate, and the inflow of earth and soil would escape when flushed from the crest gate.

Discharge facility (6 m^3/s) would be installed for releasing river maintenance water.

11.2 Waterway and Power House

Four sets of chamber type underground settling basins would be constructed subsequent to intake. A settling basin has a cavern 130 m long, 20 m wide, and 37~41 m high. In addition to this main cavern, a flushing tunnel and access tunnel would be constructed.

Dimension of settling basin was decided assuming the target size of sand that should be removed as d $\geq$0.3 mm.

Twin tunnels were adopted for the reasons below:

- Inner diameter for a single tunnel would be 10.5m (excavation diameter 11.9~12.3m) and the difficulty of constructing a large sized tunnel excavation would increase. Especially in the area of bad geological conditions, there is a possibility that extra construction costs would be necessary according to the degree of difficulty of construction.

- In the case of twin tunnels, there is convenience in its operation, and even if some accident occurred in one tunnel, electric generation would continue using the other tunnel. The single tunnel plan is inferior to the twin tunnel plan in its reliability of operation.

The headrace tunnel has two lines of about 7 km in length of tunnel, and the inner diameter is planned as D= 7.4 m (A= 43 m^2, V=4 m/s) for maximum discharge Q=348 m^3/s. The optimum diameter was decided so that the total of annual expenditure by capital cost and loss of annual benefit by head loss be at a minimum.

The headrace tunnel would have inner pressure and fundamentally, would be concrete lined. Three types of lining pattern were prepared and adopted according to the geological condition based on the present geological information from field reconnaissance and geological investigation.

The type of surge tank proposed was the orifice type surge tank considering its compactness. The diameter of the surge tank would be decided by stability conditions, but this time it was chosen to be D=15m by only statistical stability conditions.

The surge tank and powerhouse would be connected by penstock. Two lines of penstock would be required, each penstock with two parts of line, one for the vertical shaft and the other for the horizontal connection to the turbine.

A branch tube is installed at the end of the horizontal penstock, dividing into three branch tubes. The penstock tunnel has two lines of about 453 m in length of tunnel, and the inner diameter is to be D= 5.6 m (A= 24.6 m^2, V=7 m/s) for maximum discharge Q=348 m^3/s.

The position of the powerhouse would be selected for enough ground covered depth and it was judged appropriate to shift the position of the power house toward the mountain side with the adoption of a vertical shaft penstock.

The cross section of the cavern was proposed to be bullet style (H= 38 m, B= 20 m, L= 114 m).

As related facilities of the powerhouse, access tunnel for transporting electric equipment, cable tunnel for connecting cable to switchyard and the facility for draft gate would be constructed.

The main transformer was proposed to be installed in another cavern, just downstream of the powerhouse cavern.

Two lines of tailrace tunnel (circular shape, D= 7.4 m) would be constructed subsequent to the draft tube. The tunnel would be designed as a pressure tunnel and all lines of the tunnel are assumed to be concrete lined.

The type of outlet is horizontal with outlet gate. The site for the switchyard is located at the gentle slope area on the left side just upstream of the powerhouse. This area is now used as cultivated land and is covered with talus deposit material. According to the construction program, that area is scheduled to be used for the disposal area, so the switchyard would be constructed after banking of deposit materials. The power plant control building is also scheduled to be constructed next to the switchyard area.

11.3 Electrical and Mechanical Equipment

It has been decided that an appropriate unit size of turbine-generator will be determined in relation to influence of power system, year of development and limitation of transportation. It is a general practice to set a unit capacity as large as possible for the entire project considering the economic scale merit.

From the study, it is obvious that the condition of transportation limitation is an important factor in this project. In civil design, two penstocks are balanced which have distributing three-pronged inlet pipes for each three units. Therefore, principle design of unit capacity is to be approximately 150 MW, and then the number of units is to be six (6).

(1) Hydraulic Turbine

- Output and Number of Units

  The turbine-generator is designed for a full-gate output of not less than 148.5 MW operating under a rated effective head of 286.30 m. Number of units is six.

- Turbine Type

  The turbine is of the vertical-shaft, single-runner Francis type with steel spiral case and elbow type draft tube according to our practice.

- Material of Runner and Spare

It is specified that the Francis runner components be 13-4 Cr. Ni stainless steel having high abrasion resistance to silt.

One spare runner will be provided for repair work.

- Revolving Speeds and Runaway Speeds

The specific speed of a Francis type turbine, generally, is between Ns: 70 and 300 m-kW. It is determined to be Ns: 96.9 m-kW in relation to an "effective head- specific speed curve" by computer calculation and our practice. Then, turbine rated speed is obtained, 300 rpm corresponding to a specific speed of Ns: 96.9 m-kW units.

(2) Generator

The generator will be a vertical shaft, synchronous brush-less machine with AVR, rated continuous output of 161.7 MVA, three-phases, 0.9 lagging power factor. The generator stator and rotor windings will be provided with epoxy insulation of class F type. The generator ventilation will be an enclosed hood, air cooled type with rim-duct fan system.

(3) Main Transformer

A six unit power transformer will be installed at the transformer room in the underground powerhouse. Power transformer type is designed as single-phase, three-phases and special-three-phases type to consider the transportation limitation of the weight, efficiency and installed spaces of underground type, etc. Single and special three-phase types are feasible in this project, but three-phases type is not feasible due to transportation limitation. A special three-phase transformer would be, 1) economic, 2) high efficiency, and 3) require less space than a single type transformer. This transformer can be divided into three or six limbs and assembled on site after transportation. Each package will be weigh less than 60 tons against an assumed total weight of approximately 160 tons. Therefore, a special three-phase type is selected.

(4) Switchyard Equipment

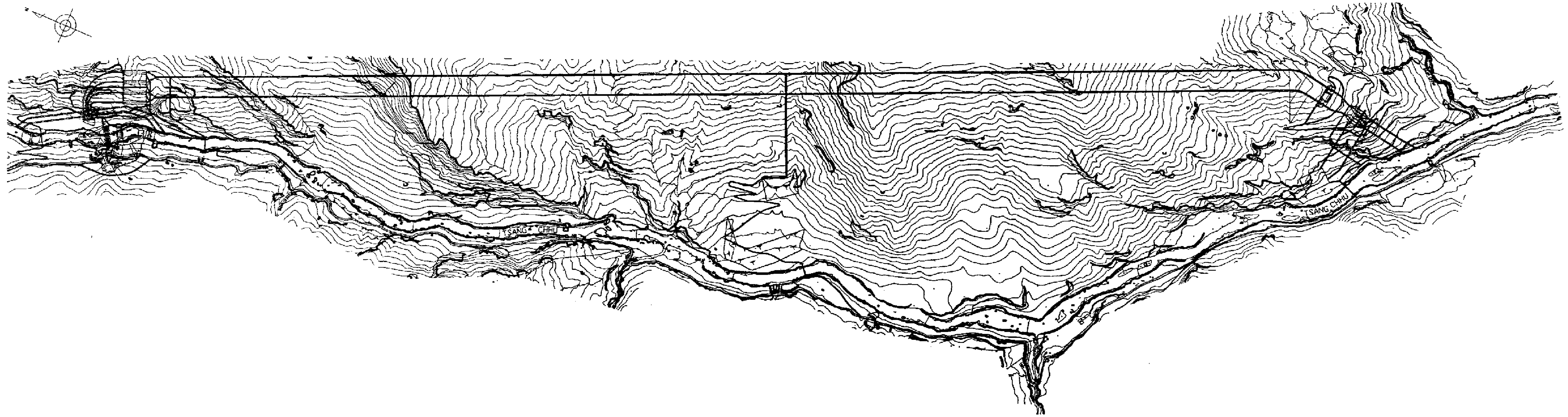
The switchyard is located outdoors at El. 895 m, to connect 400 kV power cables approximately 300 m in length from the main transformer secondary terminal in the transformer room underground. The outdoor fenced area of the switchyard has a dimension of 100 m by 150 m, and the control room and administration office will be located in this building.

A connection cable tunnel is provided between the switchyard and powerhouse for power cables, control cables, etc. Cargo and maintenance personnel are accessible from the access tunnel road that leads to the powerhouse from the switchyard.

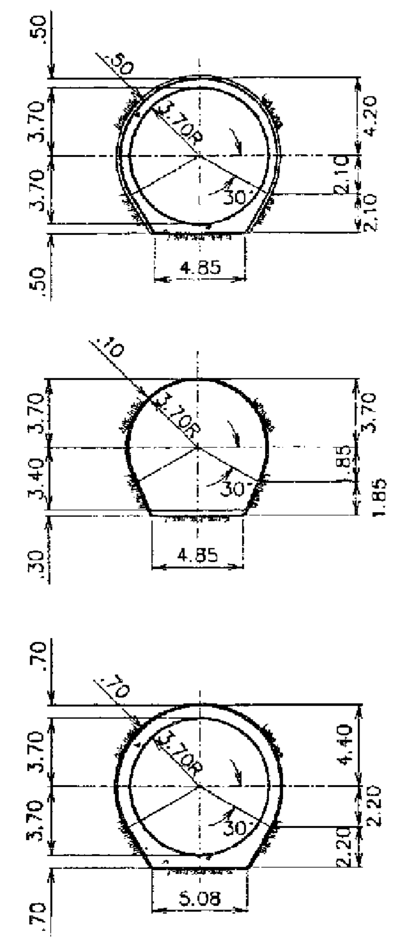
An outdoor conventional type (air insulated) switchyard consists of a 400 kV double bus system including gas circuit breakers, disconnecting switches and necessary apparatus. The outgoing lines of the switchyard are to be connected to the first transmission tower of 400 kV transmission lines to evacuate the Indian power system.

Maximum short circuit capacity for 400 kV main buses of the switchyard is calculated at approximately 5,200 MVA.

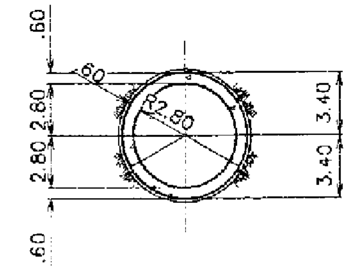
Plan



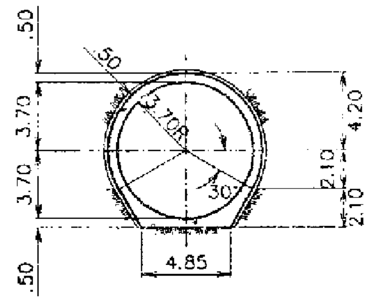
Headrace



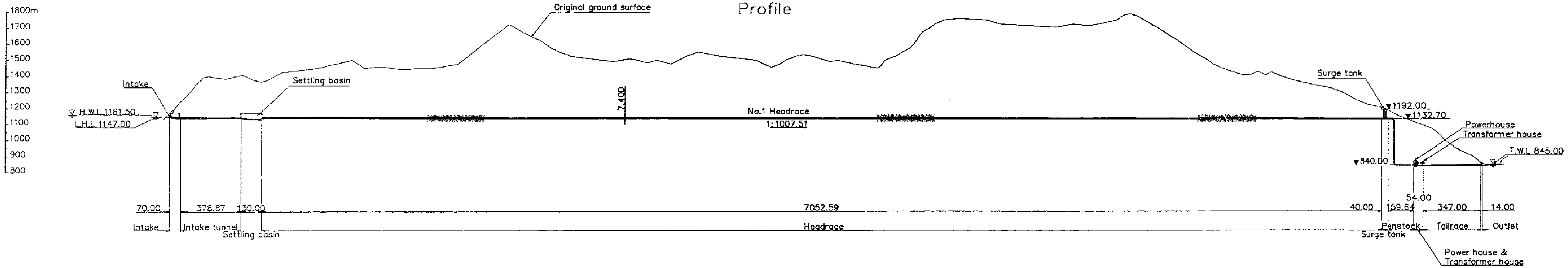
Penstock



Tailrace

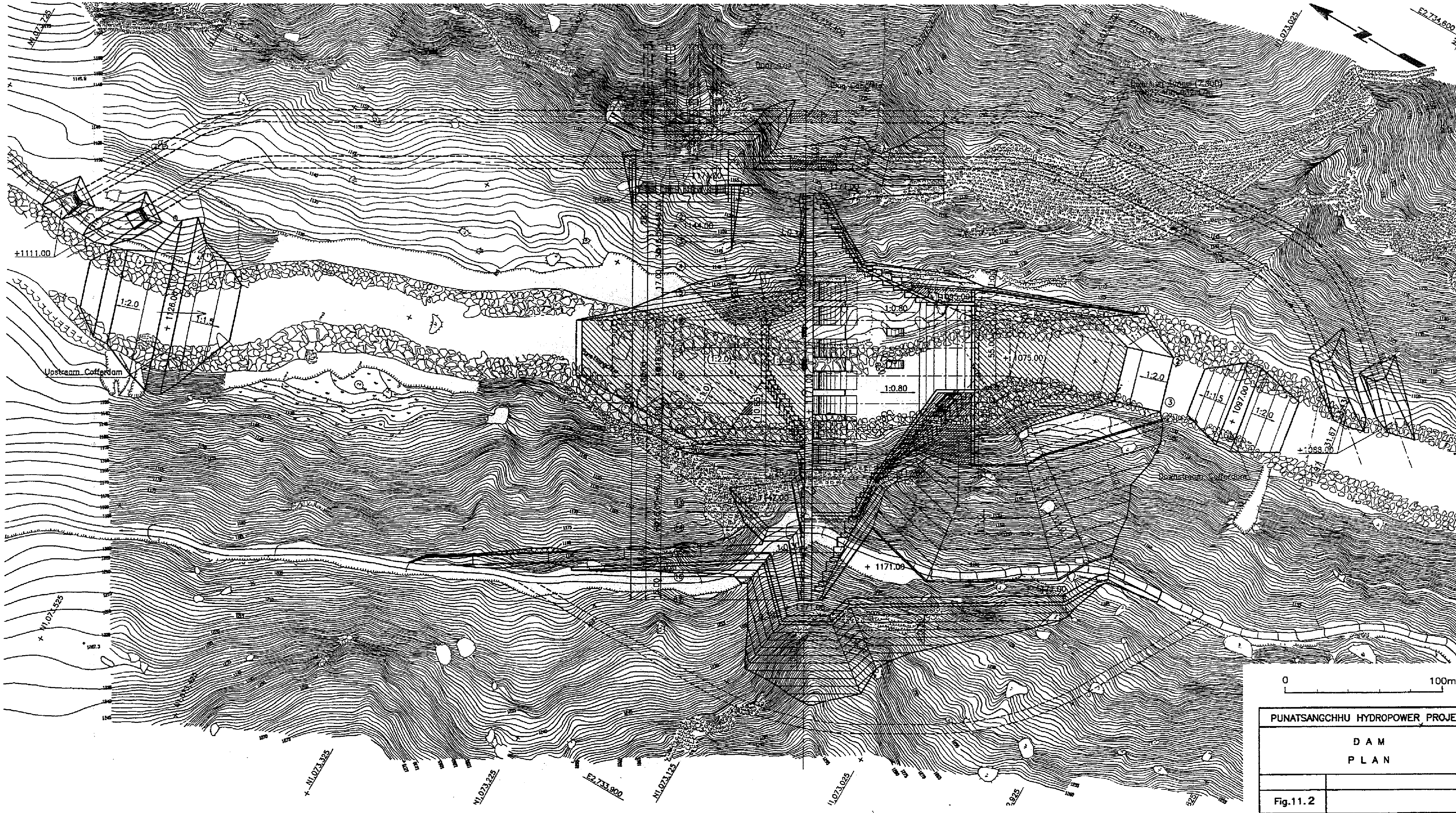


Profile

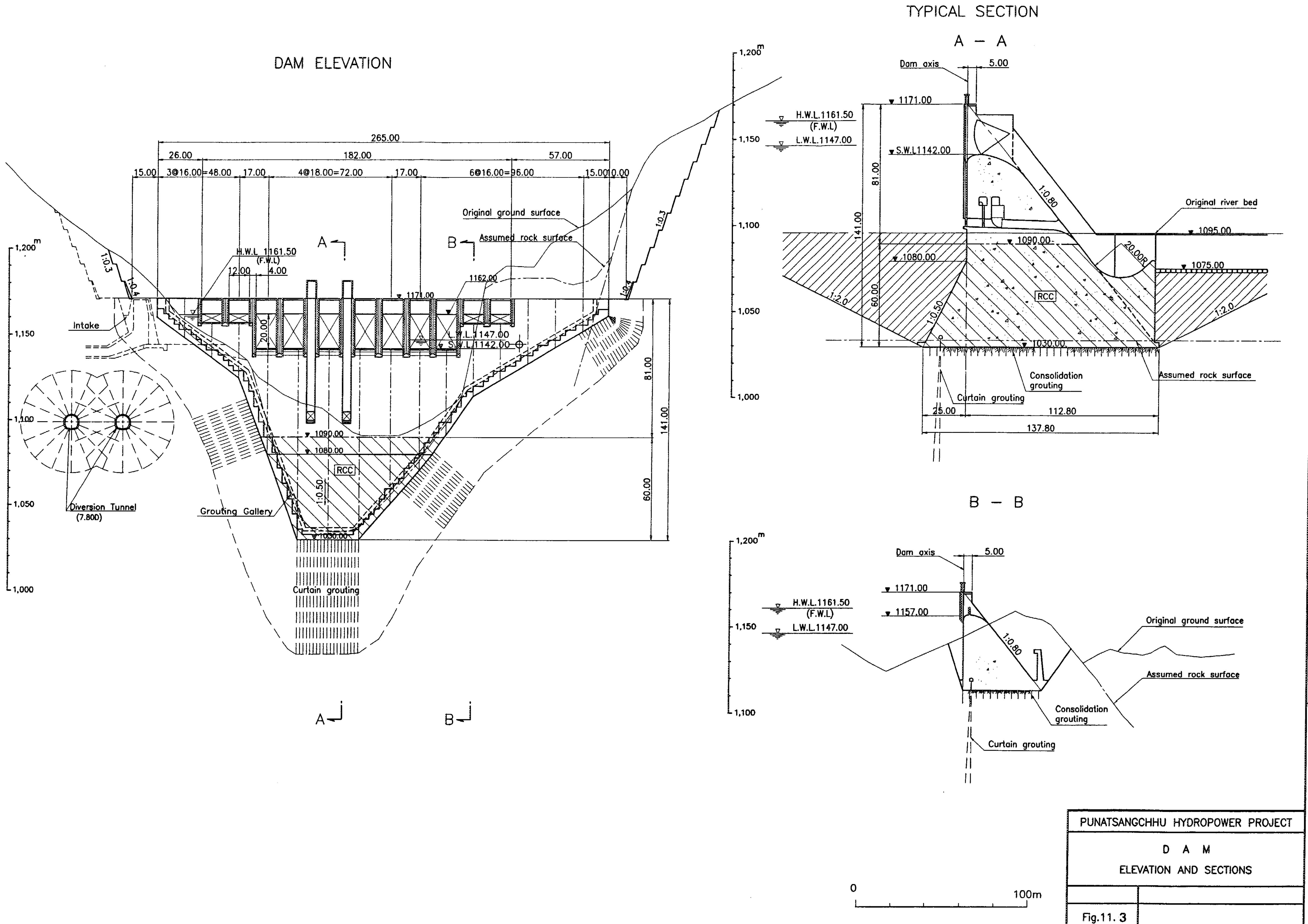


PUNATSANGCHHU HYDROPOWER PROJECT
WATERWAY GENERAL PLAN OF PROJECT
Fig.11. 1

PLAN



PUNATSANGCHHU HYDROPOWER PROJECT
DAM PLAN
Fig.11.2

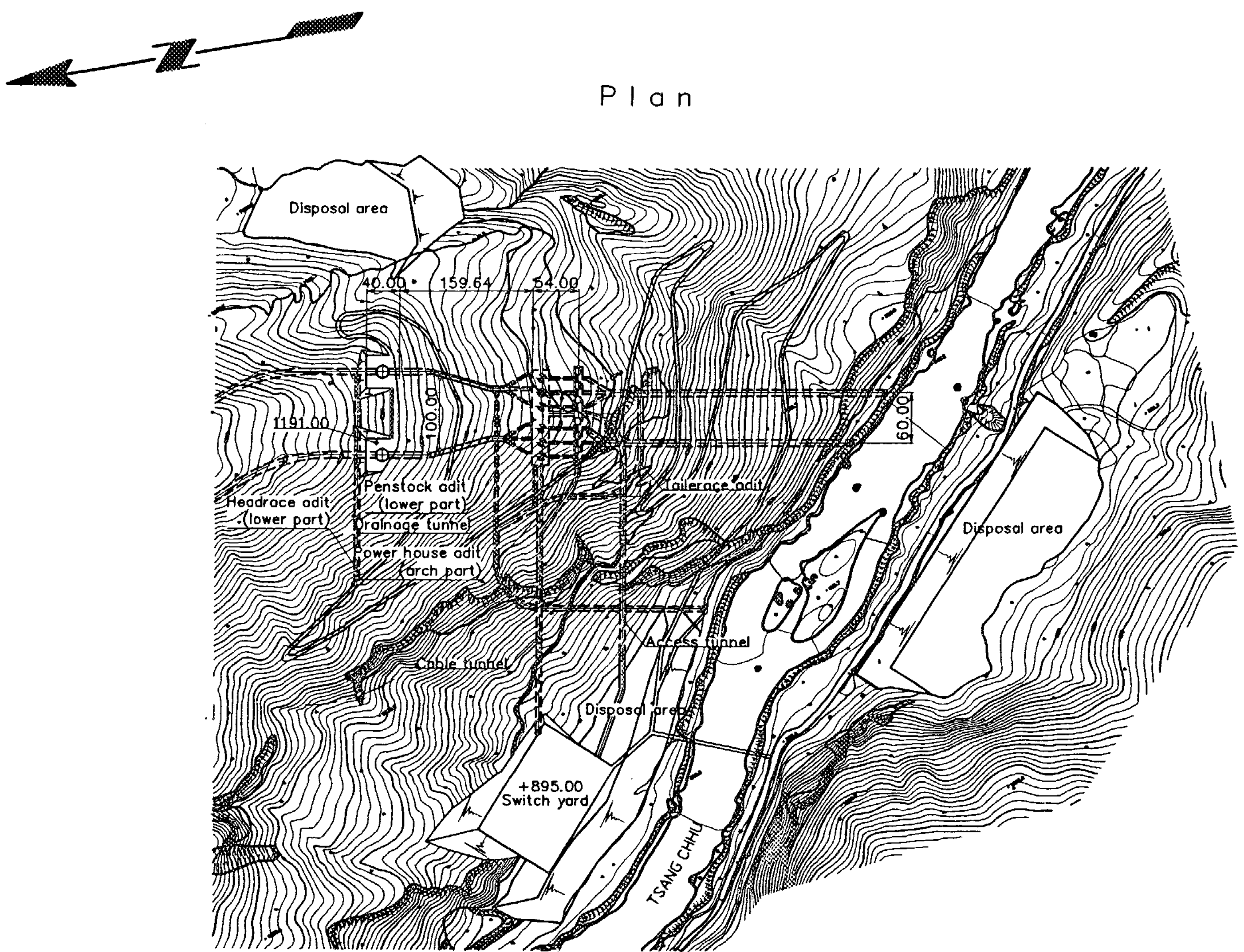


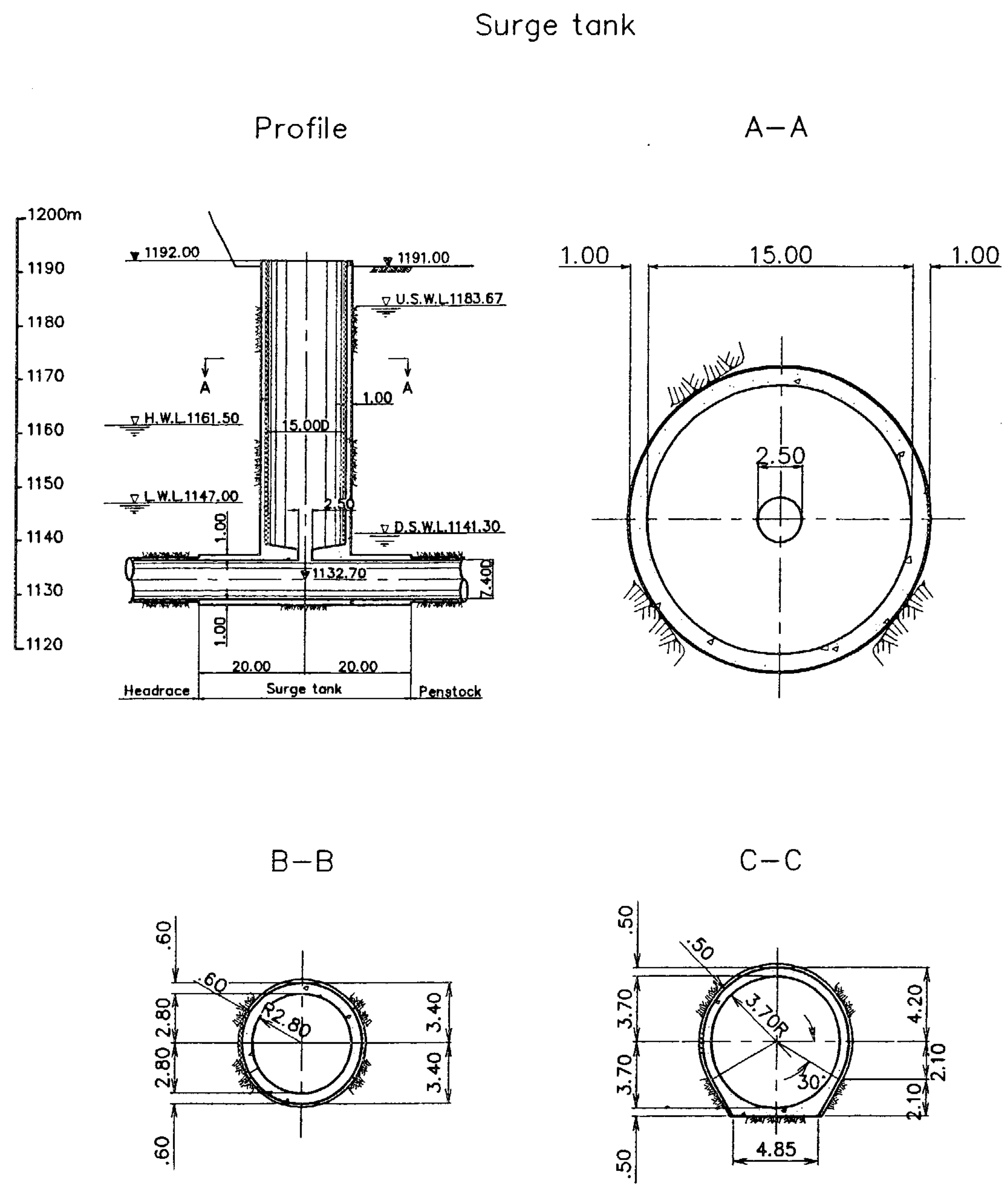
PUNATSANGCHHU HYDROPOWER PROJECT

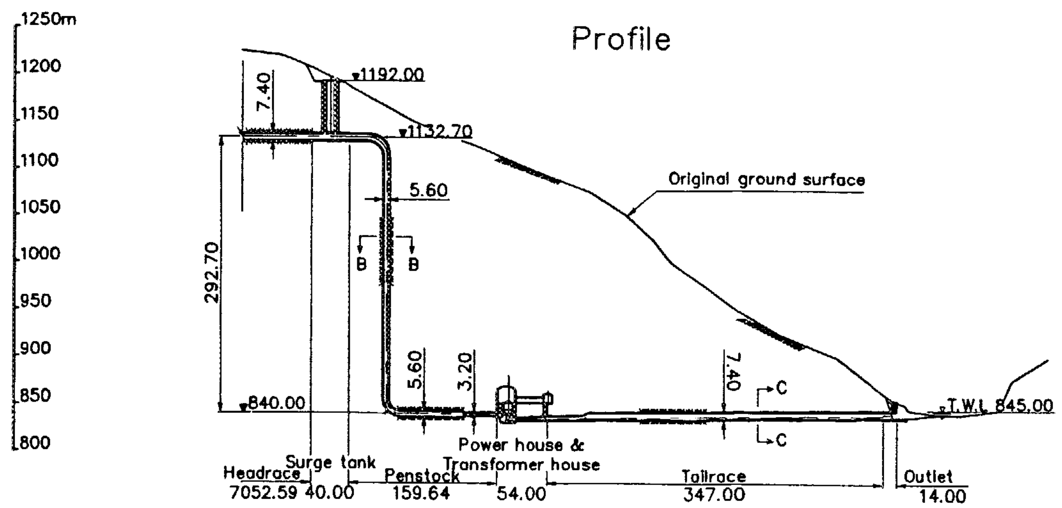
D A M

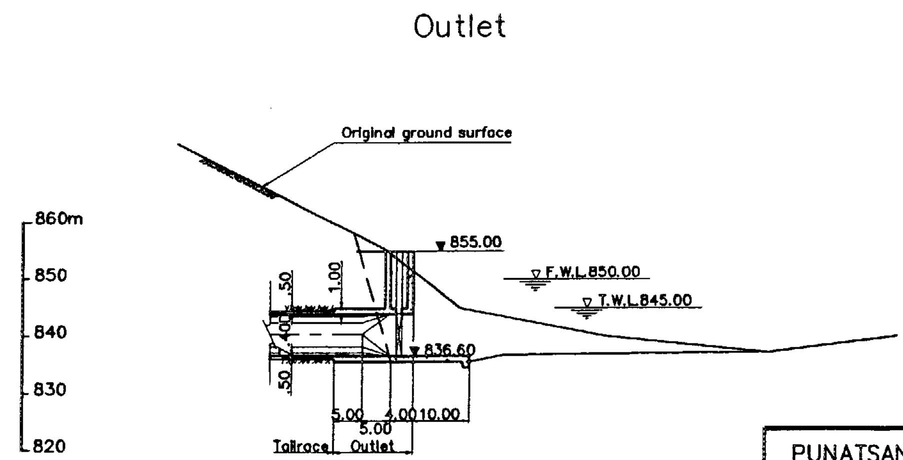
ELEVATION AND SECTIONS

Fig.11. 3









PUNATSANGCHHU HYDROPOWER PROJECT

SURGE TANK, PENSTOCK AND TAILRACE
PLAN, PROFILE AND SECTIONS

Fig.11. 4

12. CONSTRUCTION PLAN AND CONSTRUCTION COST ESTIMATE

12.1 General

The main structures to be established under the project comprise a 141m high gravity dam, two lines of waterways 7.40 m in diameter, and an underground powerhouse. The waterway includes four underground settling basins (20 m width × 39 m height × 130 m length).

The total volume of excavation required in constructing these structures is approximately 4,480,000 m^3. Concrete volume for the dam main-body is roughly 830,000 m^3 while that for other main structures totals roughly 460,000 m^3.

Dam construction works comprise the critical path in the Project construction schedule. In order to shorten the dam concreting period, the riverbed portion below EL 1090 (height: 60 m) is to be carried out by the RCC method.

There will be two headrace tunnels 7,023 m and 6,959 m in length, respectively. For the purpose of headrace tunnel construction, work adits will be established at three locations, upstream, midstream and downstream. Excavation length per one excavation face will be roughly 1,900 m.

The excavated surface of vertical shaft in the surge tank will be reinforced with concrete lining and shotcrete as the excavation progresses downward.

For excavation, steel pipe installation and concreting works, the vertical shaft segment will access from vertical adits established at the EL.1160 m, 60 m downstream of the surge tank shafts.

For excavation of the underground powerhouse, a work adit is connected from the cable tunnel to the top of the powerhouse cavern, and cavern excavation commenced.

Powerhouse excavation will be by bench-cut method, with cavern walls reinforced by rockbolt, shotcrete, etc.

A work adit is to be established from the lower penstock adit to the tailrace tunnel for tailrace tunnel excavation.

Draft tube installation for the first unit will begin in the 42nd month. Using the overhead travelling cranes, turbine and generator installation will be completed in the 58th month and commercial operation of the first unit is to commence in the 62nd month.

Following commercial operation of the first unit, the remaining units are to successively go on line at two-month intervals. The final unit will come on line in the 72nd month after the start of main civil works construction.

Construction of the 140 km long two circuits 400 kV-transmission line for the Project is begun in the second year, to be completed at the beginning of the fourth year.

12.2 Construction Schedule

Summalized construction schedule is shown in Fig. 12.1. The construction schedule for the Project is seven years, consisting six years for main activities and one year for preparatory works.

12.3 Construction Cost Estimate

- Unit prices of materials and equipment, labor costs, etc., are based on a price level in July. 2000.

  The exchange rates of currencies in July, 2000 were:

  US$1 = Nu. 44.682 = ¥ 105.900

- Administration and engineering cost is estimated at 10% of the total direct cost.
- The physical contingency is assumed at 10% of the estimated cost.
- All costs are given in local and foreign components and are expressed in US Dollars.
- The unit prices and lump sum items include taxes incurred in the country of origin. For imported materials and equipment, local taxes and customs duties are not included.
- Price escalation and interest during the construction period is not included in the project cost.

Project cost as estimated based on the above criteria is as follows:

Project cost: US$ 812,892,000.－

The breakdown of project cost is shown in Table 12.1. Annual required funding (disbursement schedule) is indicated in Table 12.2.

Table 12.1 Project Cost

Punatsangchhu Hydropower Project

Unit: US$ thousand

Item	Local Currency	Foreign Currency	Total
1 Preparatory Works	33,849	3,761	37,610
2 Civil Works	23,594	313,464	337,058
3 Hydromechanical Equipment	9,650	86,848	96,498
4 Electromechanical Equipment	15,410	138,690	154,100
5 Transmission Line	4,200	37,800	42,000
Total Direct Cost (A)	86,703	580,562	667,266
6 Engineering & Administration Cost	13,345	53,381	66,727
7 Land Acquisition & Compensation	5,000	0	5,000
8 Physical Contingency	10,505	63,394	73,899
Total Indirect Cost (B)	28,850	116,776	145,626
Total Construction Cost (A+B)	115,553	697,339	812,892
9 Interest during Construction	0	0	0
Total Project Cost (A+B+9)	115,553	697,339	812,892
Percentage (%)	14.2	85.8	100

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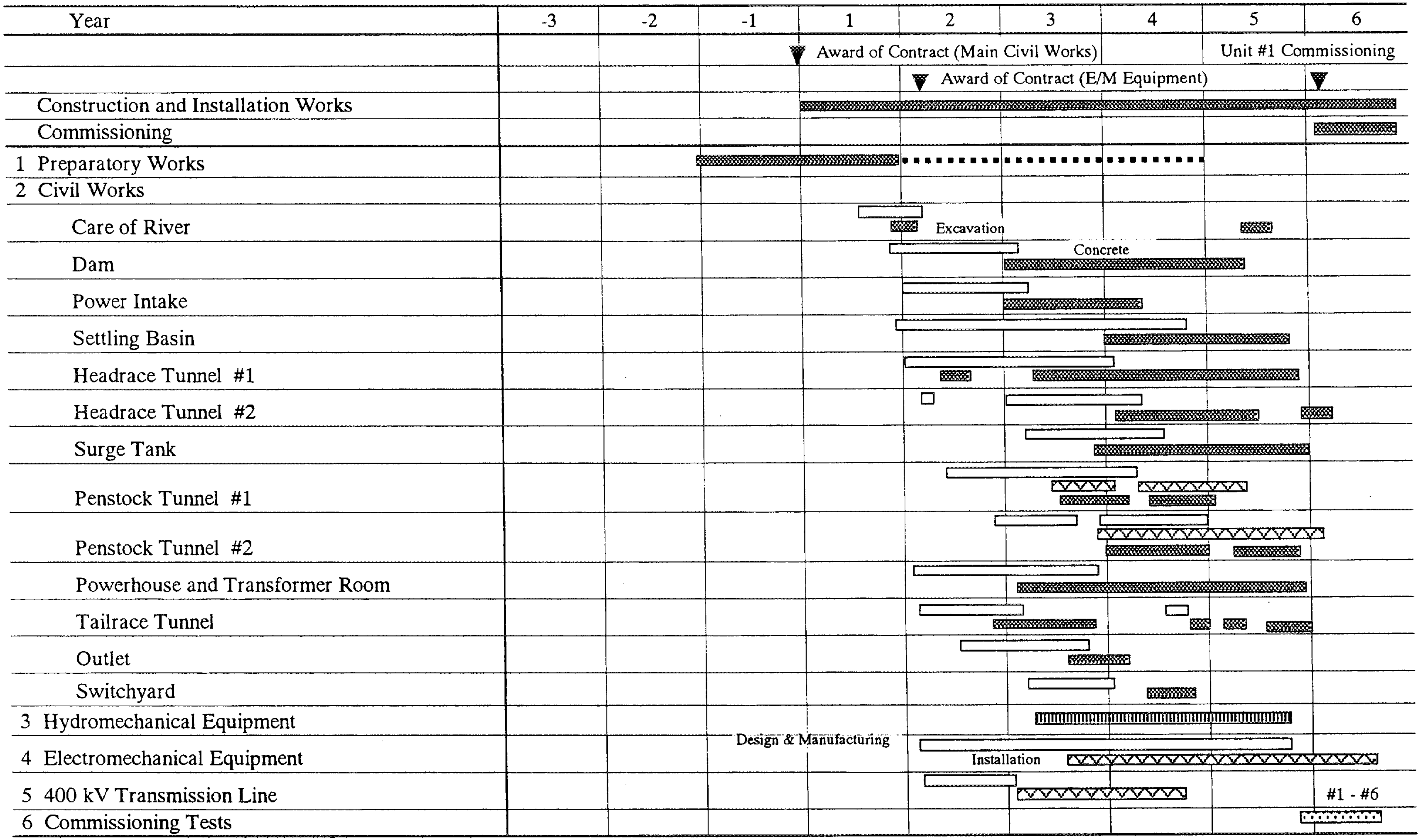
Table 12.2 Disbursement Schedule

Unit : US$ thousand

Year	-3	-2	-1	1	2	3	4	5	6	7	Total
			▼ Award of Contract (Main Civil Works)								
Preparatory Works	0	0	7,000	26,699	3,181	430	300	0	0	0	37,610
Civil Works	0	0	0	45,466	43,760	95,061	78,359	39,601	1,105	33,706	337,058
Hydromechanical Equipment	0	0	0	0	9,650	480	21,778	36,293	18,648	9,650	96,498
Electromechanical Equipment	0	0	0	0	23,115	2,937	37,282	45,825	29,532	15,410	154,100
400 kV Transmission Line	0	0	0	0	6,300	16,000	15,500	0	0	4,200	42,000
Total Direct Cost	0	0	7,000	72,165	86,006	114,908	153,218	121,719	49,285	62,966	667,266
Engineering & Administration Cost	0	0	700	8,007	10,009	12,678	16,682	13,345	5,305	0	66,727
Land Acquisition & Compensation (LC)	0	0	5,000	0	0	0	0	0	0	0	5,000
Physical Contingency	0	0	1,270	8,017	9,601	12,759	16,990	13,506	5,459	6,297	73,899
Total Construction Cost	0	0	13,970	88,189	105,616	140,344	186,890	148,570	60,050	69,262	812,892
LC	0	0	12,584	31,694	13,018	12,670	18,202	15,018	6,552	5,814	115,553
FC	0	0	1,386	56,495	92,598	127,674	168,688	133,552	53,498	63,448	697,339

Fig. 12. 1 Project Construction Schedule



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1
3

13. ENVIRONMENTAL IMPACT ASSESSMENT

13.1 Preparation of Environmental Impact Assessment Report

The environmental impact assessment report of this project was prepared by the Department of Power (DoP) of Bhutan and Japan International Cooperation Agency (JICA). The report is prepared in detail on the basis of the results of Initial Environmental Examination (IEE) and pursuant to Terms Of Reference (TOR) (Table 13.1) agreed by DoP and National Environment Commission (NEC) through consultation.

For the purpose to investigate impacts from the project implementation and to prepare an environmental impact assessment report, the JICA study team surveyed the natural and social environment around the project site from May, 1999 to March, 2000. An Indian consulting firm, WAPCOS is conducting and co-ordinating surveys including field surveys under contract, and its subcontractor in Bhutan is in charge of surveys on social environment.

The Study Team completed filled survey of environmental impact assessment by March, 2000, and submitted draft report of all results of this filled survey after compilation.

Then, the study team submitted "Punatsangchhu Hydropower Project in the Kingdom of Bhutan, Draft Final Report, Environmental Impact Assessment" to DoP as attached Appendix, on July, 2000.

DoP carried out public consultation for people living in the project area and the surrounding area. Outline of these explanations and opinions of people in the areas related to are contained in Annex 2 as attached.

13.2 Outline of the Project

It is essential to develop energy sources through abundant hydro power in order to vitalize industry, and improve the socio-economic standard of living in the Kingdom of Bhutan. The government of this country has decided to adopt a policy of reducing its dependency on oil and giving priority to the development of hydroelectric power generation. In addition, one important measure for Bhutan is to acquire foreign currencies by exporting electric power to neighboring countries.

This project is to construct facilities for run-of-river type hydropower, which include dam, headrace tunnel, penstock, underground powerhouse and tailrace outlet, that can generate power at a peak load midstream in the Punatsangchhu, which runs through the Wangdue Phodrang in the middle west of Bhutan. The location of the proposed site is shown in Fig. 13.1. Its planned maximum output and annual plant capacity are 870 MW and 4,330 GWh, respectively. This will contribute to the improvement of the socio-economic standard of living in the Kingdom of Bhutan.

An 80-m high (from riverbed) concrete gravity type dam body is planned. Because it's a run-of-river type, the reservoir area at high water level is 53 ha. Water is carried about 8 km downstream through a headrace tunnel and power is generated by six generators installed in the underground powerhouse.

Since generated power is for export, it is to be transmitted to India through transmission lines on a route having minimum impact on the environment (Fig. 13.2).

13.3 Current Environmental Condition

The proposed site is located midstream in the Punatsangchhu. It is approximately 10 to 18 km south of Wangdue Phodrang, a town in Wangdue Phodrang region.

The proposed dam site is about 1,090 m above sea level while the proposed tailrace outlet site of the powerhouse is approximately 840 m above sea level. The distance between these two sites is about 8 km. The site of this project and its surroundings, which include relatively high mountains, have steep topographic features. As for climate, the annual rainfall is about 550 to 800 mm and the monthly average temperature ranges from 6℃ to 28℃.

The survey area on nature characteristics for the environmental impact assessment stretches from 10 km upstream of the proposed dam site to 20 km downstream of the proposed powerhouse site and extends to 2.5 km each side of the banks of the Punatsangchhu. According to the survey results, because of no large pollution source exists, air around the proposed site and water in the river are in good condition. As for terrestrial flora, existence of a broadleaf forest is noted along the river sides near the riverbed. Pine groves are dominant halfway up the mountain. Many kinds and peculiar species of terrestrial fauna are reported and, according to visual survey, footprint survey and hearing survey results, it is felt that several species designated as endangered and protected species live around the proposed site. Three fish species are found in the river and Asala, a member of the Carp family, is the dominant species.

The survey on the social characteristics extends to 2.5 km each side of the banks of the river from a point about 2 km south of the Wangdue Bridge to a point near Pinsa Village about 38 km to the south. The survey area has 35 small villages and a population of about 4,200. Almost all the inhabitants are Bhutanese who speak Dzongkha, and many of them are engaged in agriculture.

13.4 Predicted Environmental Impact

13.4.1 Geophysical Environment

When the powerhouse and related facilities are constructed, soil erosion and slope collapse may occur due to the collection of ballast and the site preparation. It is necessary to stabilize the soil by reclamation and afforestation.

Since there is no big air pollution source around the proposed project site, the air is clean. The environment may be affected by the generation of dust from the construction work during construction. In order to minimize this impact, various measures, including the installation of a cyclone filter and the sprinkling of water, will be taken. After the powerhouse is put into operation, nothing will generate air pollutants.

Water may become muddy due to the construction. The impact can be reduced by taking action, including the installation of a settling basin. After the powerhouse is put into operation, there will be about 8km long river sections affected by river diversion. This impact can be reduced by providing an appropriate minimum flow for river condition conservation. Also, since water circulates relatively quickly in the proposed reservoir, there is little possibility that the water quality will deteriorate.

The noise from construction needs to be minimized by taking measures such as the use of low-noise type machines and standard-conforming vehicles, regulation of traffic, etc. Nighttime construction should be avoided wherever possible.

13.4.2 Biological Environment

Deforestation and submergence involved in the construction and operation of the powerhouse and reservoir were planned so that the area is affected is as little as possible. A muck disposal site and other construction sites, which are reinstated as a vacant lot after the completion of the work, will be afforested with trees of the same type as that of the neighborhood.

Although the noise from the construction work may affect animals living near the project this is a temporary impact and may not be a menace to the preservation of species. Nevertheless, great care should be taken during construction.

After the powerhouse is put into operation, there will be about 8-km long river sections affected by river diversion. This impact can be reduced by providing an appropriate minimum flow for river condition conservation.

13.4.3 Economic, Social, and Cultural Characteristics

The resettlement of inhabitants, and the acquisition of a construction site are required to construct the dam and the powerhouse. In order to reduce inhabitants' antipathy, it is advisable to make appropriate compensation for the resettlement and land acquisition, and to move inhabitants based on a carefully thought-out resettlement plan.

13.5 Impact Mitigation Measures

The main mitigation measures to remove, reduce, or lessen the impact of this project on the environment are shown below.

Item	Impact mitigation measures
Physiography, geology and soil	Reclamation of slopes and afforestation for stabilization.
Air quality	Reduce dust from the construction work by installing a cyclone filter and frequently sprinkling water.
Water quality	Carry out proper water treatment such as the installation of a settling basin.
Noise	In order to reduce the noise generated from the construction, employ low-noise type machines whenever possible and at the same time use standard-conforming vehicles and regulate traffic. Avoid nighttime construction.
Biology	Afforest a vacant lot after the completion of the work with trees of the same type as that of the neighborhood. Secure an appropriate minimum flow for river condition conservation in the river sections affected by river diversion. Set up an observation station to prevent trees from illegal deforestation and watch out for poaching and other offenses.
Social characteristics	Make appropriate compensation for the resettlement and at the same time resettle inhabitants based on a carefully thought-out resettlement plan.

13.6 Cost for Environmental Mitigation

Cost for environmental mitigation is included the cost required for implementation of the measures for environmental impact mitigation and the cost required for implementation of the environmental monitoring program.

The total cost required for implementation of the measures (Table 13.2) will be Nu 211.56 million (approx. US$ 5.04 mil.) which includes measures for flora and fauna, air, water and soil and costs for resettlement and rehabilitation.

The cost required for implementation of the environmental monitoring program (Table 13.3) will be Nu 1.92 million / year (approx. US$ 0.046 mil. / yr) which includes a monitoring program for water, ecology and public health.

13.7 Conclusion

If the project is carried out, it will be possible to develop an energy source through abundant hydro power, which is essential to the improvement of the socio-economic standard of living that Bhutan is aiming at by vitalizing the domestic industry. It is estimated that the implementation of this project will generate annual electric power of 4,330 GWh and bring in revenues of approximately 6,900,000,000 Nu/year (in terms of 1.5 Nu/kwh) from the sales of electric power. In addition, it will contribute to the local economy by creating employment, roads maintenance, and stimulating the growth of other sectors such as manufacturing industry.

On the other hand, if this project is not carried out, Bhutan can neither break dependence on petroleum nor acquire foreign currencies from export of electric power to India. This will be a telling blow to the socio-economic trend of this country, which depends on imports for various agricultural products and quotidian goods.

In addition, environmental impact caused by this project will be minimized and mitigated by state-of-the-art technology. The impact in the process of construction is estimated at a minimum. All the required mitigation measures will be taken.

Therefore, hydro power, a renewable energy, generated from this run-of-river type hydro-powerhouse will contribute to the socio-economic status of this country. Since the positive impact is greater than the negative, it is desired that this project be carried out.

Table 13.1 Final TOR for the Environmental Impact Assessment on Punatsangchhu Hydropower Project

Final TOR	Remarks
1. Executive Summary The summary will be a concise non-technical description of the salient features of the project, its alternatives if any, existing environment, anticipated environmental impacts and mitigation measures adequately and accurately covered.	An alternative of "doing nothing" will be compared with the proposed to see the merits and demerits between the two cases.
2. Policy, Legal and Administrative Framework - Government policy regarding power development - Legal and administrative framework for environmental assessment of a hydropower project	The item "Government policy regarding power development" may be omitted, if the same subject will have been covered by other part of the Feasibility Study.
3. Description of the Proposed Project Provide information on the following: a. Location of project-related development sites b. General layout of facilities at project-related development sites c. Main design specifications of the project d. Pre-construction activities e. Construction activities f. Project schedule g. Staffing and support system for construction and operation h. Facilities and services	To provide maps at appropriate scales to illustrate the general setting of project-related development sites, as well as surrounding areas likely to be environmentally affected. These maps will include topographic contours, as available, as well as locations of major surface waters, roads, town center and concerned villages, parks and preserves, and political boundaries, if any. Also to provide, as available, maps to illustrate existing land use, including industrial, residential, commercial and institutional development, agriculture, etc. The facility and services will mean those required for project staff members and workers during construction and operation. Examples are the dwellings, health services, etc. The access road(s) will also be described, if it would be constructed.

45-2

Final TOR	Remarks
4. Description of the Environment a. Physical Environment (a) Geology, Topography and Soils (b) Meteorology (c) Hydrology (d) Air Quality (e) Water Quality (f) Noise (g) Sediments b. Biological Environment (a) Terrestrial Flora and Fauna (b) Aquatic Flora and Fauna (c) Rare, endangered or protected species in the project areas and its vicinity c. Socioeconomic and Cultural Environment (a) Population Characteristics and Demographics (b) Occupation/Economic Activities (c) Land Use Pattern (d) Community structure (e) Employment and labor market (f) Recreation (g) Public health (h) Education (i) Cultural properties (j) Indigenous or ethnic peoples	To present, evaluate and assemble the baseline data on the environmental characteristics of the study area. The study area will include the project site area and its vicinity. The power transmission line route will also be covered to the extent meaningful and possible. It is noted that the area to be covered by each item listed in the left column will be defined on the required and meaningful basis. Therefore, the area for one item will be different from that of other item. The details will be clarified in the detailed scope of work for the EIA.

Final TOR	Remarks
5. Anticipated Environmental Impacts Potential environmental impacts will be identified for both of construction and operation phase3s. Also to be covered will be the potential impacts in connection with the power transmission line. a. Construction Phase a) Physical Environment (a) Geology, Topography and Soils (b) Air Quality (c) Hydrology and Water Quality (d) Noise b) Biological Environment (a) Terrestrial and aquatic flora/fauna c) Socioeconomic and Cultural Environment (a) Concerned Villages (b) Employment Issue (c) Economic Activities (d) Land Use (e) Public Health (f) Recreation/Cultural Properties b. Operation Phase a) Physical Environment (a) Geology, Topography and Soils (b) Hydrology (c) Water Quality (d) Sediment b) Biological Environment (a) Terrestrial and aquatic flora/fauna	Identify all significant changes which the project would incur. These would include changes in the following : employment opportunities, wastewater effluents, air emissions, land use, infrastructure, exposure to potential water-borne diseases, noise, traffic, socio-cultural behavior. Assess the impacts from changes brought about by the project on baseline environmental conditions as described above under section 4. In this analysis, distinguish between significant positive and negative impacts, direct and indirect impacts and immediate and long-term impacts. Also identify potential impacts which may occur in connection with the followings : (1) Potential impacts in connection with quarrying activity, construction of access road(s) and power transmission line (2) Potential impacts in connection with construction and operation of dwellings for project staff members and workers (3) Potential issues in connection with occupational health and safety (4) Potential air pollution during construction (5) Potential soil erosion (6) Potential impact analysis in connection with hypothetical dam failure or overflow due to extreme flooding

Final TOR	Remarks
c) Socioeconomic and Cultural Environment (a) Local Communities (b) Employment Issue (c) Economic Activities (d) Land Use (e) Public Health (f) Recreation/Cultural Properties c. Other Impacts During Construction and Operation Phase (a) Transmission Line (b) Dwellings and access road(s) (c) Hypothetical dam failure or overflow due to extreme flooding	
6. Mitigation Measures and Plans a. Measures and plans for potential physical impacts b. Measures and plans for potential biological impacts c. Measures and plans for potential socioeconomic and cultural impacts 1) People resettlement plan when deemed necessary 2) Compensations 3) Others	For the proposed project, will recommend feasible and cost-effective measures to prevent or mitigate potential significant negative impacts. Will also include the measures to address emergency response requirements for potential accidental events, if any. It must be noted that the "People resettlement and compensation plans" shall be prepared by the project proponent, i.e. the Hydrology Unit, Division of Power, Ministry of Trade & Industry, the Government of Bhutan. The JICA Study Team will assist the DOP for the preparation of the plans. It should also be noted that the plan(s) will usually become a key issue of the EIA which will be paid attention by potential funding organization(s) in future.
7. Environmental Monitoring Plan Prepare a basic plan to monitor the implementation of mitigation measures and the potential impacts of the project during construction and operation.	

Final TOR	Remarks
8. Cost-Benefit Analyses for taking certain measures which would require balance between cost and benefit	
9. Comparison between the Project and the "doing nothing" cases for their merits and demerits	
10. Conclusion and Recommendations	
11. List of References	

Table 13.2 Cost for implementing Environmental Management Plan

S. No.	Item	Cost (Nu million)
1	Sanitary facilities in labour camps	5.25
2	Solid waste collection & disposal system	3.00
3	Environmental Management in road construction	10.00
4	Compensatory afforestation	20.35
5	Construction of settling tanks	0.50
6	Wildlife conservation	38.58
7	Control of water-related diseases	61.00
8	Control of air pollution	2.00
9	Stabilization of muck disposal sites	25.00
10	Sustenance of riverine fisheries	8.00
11	Maintenance of Environmental Cell	31.08
12	Area development activity (ADA)	4.60
13	R&R	2.20
	Total	211.56

Table 13.3 Cost for implementing Environmental Monitoring Program

S. No.	Item	Cost (Nu million/year)
1	Water quality	0.08
2	Soil quality	0.10
3	Ecology	0.50
4	Riverine fisheries and aquatic ecology	0.50
5	Public health	0.50
6	Scholarship to students (as part of ADA)	0.24
	Total	1.92

14. ECONOMIC AND FINANCIAL EVALUATION

14.1 Economic Evaluation

Economic evaluation aims at measuring the "economic" impact brought about in a country by implementing a project from a viewpoint of national economy. Here a comparison of costs and benefits expressed at economic prices will be made, applying Discount Cash Flow Method, which is widely adopted for such purposes.

Economic cost of the Project consists of Initial Investment cost, Operation & Maintenance cost and Replacement cost (including Engineering and Administration Cost, Physical Contingency).

For the purpose of this study, the following two benefits conceivable for such a Project are adopted: one is income from electricity sale to India, and the other is the saved cost of an alternative thermal power project.

(1) Power Sale Revenue

The main purpose of the Punatsangchhu Hydropower Project is to generate electricity for export to India. The major benefit of the Project will be to obtain foreign exchange by electricity export. Thus the revenue of electricity sale will be attributed to the direct benefit of the Project.

A unit price of power sale per kilowatt-hour (Nu.1.5/kWh = US3.482 cents/kWh) used by Chhukha Hydropower Station is adopted as an export price to India. Annual power sale of US$143,933 thousand, obtained from the unit rate of Nu.1.5/kWh multiplied by annual salable energy (4,133.6 GWh), will be used as the financial benefit of the Project.

(2) Cost for Alternative Thermal

Instead of constructing a hydropower station, it is possible to set up a thermal power station within Bhutan, near the Indian border, to generate energy with equivalent quality and quantity to the Punatsangchhu Project for power export to India. The cost required for such an alternative (construction cost and O&M cost including fuel) can be considered as the cost saved by implementing the Punatsangchhu Project. In order to reflect the power supply pattern of the Punatsangchhu Project, a combination of a coal-fired thermal power and a gas turbine power plant were selected as the alternative thermal plant.

14.2 Evaluation Result

If any evaluation index, including those lower values, surpasses the evaluation criteria, the Project can be judged as sound from an economic point of view.

Total present value of the economic cost at the initial year of the project amounts to US$571,421 thousand (with a discount rate of 10%: the same is applied for the following calculations). Total present value of the economic benefit with the power sale revenue is US$769,240 thousand. Net present value (B-C) is calculated as US$197,819 thousand, and Benefit cost ratio (B/C) as 1.35. Economic Internal Rate of Return (EIRR) has been worked out as 13.1%. (See Table 14.3 for details.)

On the other hand, total present value of the economic benefit with the alternative thermal plant is US$1,131,015 thousand. Net present value (B-C) is calculated as US$571,421 thousand, and Benefit cost ratio (B/C) as 1.98. Economic Internal Rate of Return (EIRR) has been calculated as 29.8%. (See Table 14.4 for details.)

Evaluation indices like Net Present Value (B-C) and Benefit Cost Ratio (B/C) at various discount rates, as well as EIRR are summarized below:

	Benefit		Criteria	Discount rate
	Power sale revenue	Alternative thermal		
NPV	430,542	812,385	> 0	8%
	197,819	559,594	> 0	10%
	55,789	395,264	> 0	12%
B/C	1.67	2.27	> 1	8%
	1.35	1.98	> 1	10%
	1.11	1.76	> 1	12%
EIRR	13.1%	29.8%	> opportunity cost of capital	

14.3 Financial Evaluation

Financial analysis aims at measuring the expected return on investment from the viewpoint of the implementing body. Here the Discounted Cash Flow method was adopted. Evaluation index to be obtained will be Financial Internal Rate of Return (FIRR) on investment, which will not be affected by financing conditions.

(1) Financial Cost

Financial cost of the Project includes the initial investment cost, cost for replacement of equipment, and Operation and Maintenance cost expressed at the market price. The cost for initial investment and equipment replacement was taken from the estimation in Chapter 12.

(2) Financial Benefit

Financial benefit of the Project is the revenue to be earned by the electricity sale. Current unit power rate by Chhukha Hydropower Project of Nu.1.5/kWh = US3.482 cents/kWh is adopted as an export price to India. Annual power sale of US$143,933 thousand, obtained from the unit rate multiplied by annual salable energy (4,133.6 GWh), will be used as financial benefit of the Project.

FIRR on investment was calculated based on financial revenue. (See Table 14.5 for details.) Thus, the Project can be judged as feasible from the financial point of view.

Item	Result	Criteria
FIRR	13.1%	> interest rate

14.4 Sensitivity Analysis

Sensitivity of economic and financial evaluation indices is analyzed for the cases where basic conditions have worsened. Items for analysis are shown below. The Project has been proved to be sound, in adverse conditions, from the economic and financial point of view.

(1) Benefit (Power sale revenue)

The following assumptions were made as to the economic/financial evaluation using power sale revenue as benefit (Discount rate of 10% is used):

1) 10% decrease in annual available energy
2) 20% decrease in annual available energy
3) 10% increase in construction cost
4) 20% increase in construction cost
5) 10% decrease in annual available energy and 10% increase in construction cost
6) 10% decrease in annual available energy and 20% increase in construction cost

Item	NPV	B/C	EIRR	FIRR
Case 1	120,895	1.21	12.0%	12.0%
Case 2	43,971	1.08	10.7%	10.7%
Case 3	141,203	1.22	12.1%	12.1%
Case 4	84,587	1.12	11.2%	11.2%
Case 5	64,279	1.10	11.0%	11.0%
Case 6	7,663	1.01	10.1%	10.1%

(2) Benefit (Alternative thermal)

The following assumptions were made as to the economic/financial evaluation using alternative thermal as benefit (Discount rate of 10% is used):

1) 10% decrease in alternative thermal cost
2) 20% decrease in alternative thermal cost
3) 10% increase in construction cost
4) 20% increase in construction cost
5) 10% decrease in alternative thermal cost and 10% increase in construction cost
6) 10% decrease in alternative thermal cost and 20% increase in construction cost

Item	NPV	B/C	EIRR
Case 1	303,975	1.59	25.1%
Case 2	212,677	1.41	20.8%
Case 3	345,068	1.61	25.7%
Case 4	294,872	1.48	22.4%
Case 5	253,644	1.45	21.7%
Case 6	203,317	1.33	18.9%

With these results, the Project has been proved to be sound, in adverse conditions, from an economic and financial point of view.

Table 14.1 Economic Evaluation (Tariff)

(Unit: 1000 US dollars)

No.	COST				BENEFIT			B - C
	Construction Cost	T/L Cost	O & M Cost	Total	Energy Generation (MWh) Firm	Energy Generation (MWh) Secondary	Total	
-7	13,970	0		13,970			0	-13,970
-6	87,635	554		88,189			0	-88,189
-5	98,224	7,392		105,616			0	-105,616
-4	122,286	18,058		140,344			0	-140,344
-3	169,458	17,432		186,890			0	-186,890
-2	148,571	0		148,571			0	-148,571
-1	60,050	0	3,789	63,839	605,246	1,461,563	71,966	8,128
1	64,600	4,662	7,578	76,840	1,210,491	2,923,127	143,933	67,093
2			7,578	7,578	1,210,491	2,923,127	143,933	136,355
3			7,578	7,578	1,210,491	2,923,127	143,933	136,355
4			7,578	7,578	1,210,491	2,923,127	143,933	136,355
5			7,578	7,578	1,210,491	2,923,127	143,933	136,355
6			7,578	7,578	1,210,491	2,923,127	143,933	136,355
7			7,578	7,578	1,210,491	2,923,127	143,933	136,355
8			7,578	7,578	1,210,491	2,923,127	143,933	136,355
9			7,578	7,578	1,210,491	2,923,127	143,933	136,355
10			7,578	7,578	1,210,491	2,923,127	143,933	136,355
11			7,578	7,578	1,210,491	2,923,127	143,933	136,355
12			7,578	7,578	1,210,491	2,923,127	143,933	136,355
13			7,578	7,578	1,210,491	2,923,127	143,933	136,355
14			7,578	7,578	1,210,491	2,923,127	143,933	136,355
15			7,578	7,578	1,210,491	2,923,127	143,933	136,355
16			7,578	7,578	1,210,491	2,923,127	143,933	136,355
17			7,578	7,578	1,210,491	2,923,127	143,933	136,355
18			7,578	7,578	1,210,491	2,923,127	143,933	136,355
19			7,578	7,578	1,210,491	2,923,127	143,933	136,355
20			7,578	7,578	1,210,491	2,923,127	143,933	136,355
21			7,578	7,578	1,210,491	2,923,127	143,933	136,355
22			7,578	7,578	1,210,491	2,923,127	143,933	136,355
23			7,578	7,578	1,210,491	2,923,127	143,933	136,355
24		554	7,578	8,132	1,210,491	2,923,127	143,933	135,801
25		7,392	7,578	14,970	1,210,491	2,923,127	143,933	128,963
26		18,058	7,578	25,636	1,210,491	2,923,127	143,933	118,297
27		17,432	7,578	25,010	1,210,491	2,923,127	143,933	118,923
28		0	7,578	7,578	1,210,491	2,923,127	143,933	136,355
29	0	0	7,578	7,578	1,210,491	2,923,127	143,933	136,355
30	32,765	4,662	7,578	45,004	1,210,491	2,923,127	143,933	98,928
31	3,417		7,578	10,994	1,210,491	2,923,127	143,933	132,938
32	59,059		7,578	66,637	1,210,491	2,923,127	143,933	77,296
33	82,118		7,578	89,695	1,210,491	2,923,127	143,933	54,237
34	48,180		7,578	55,757	1,210,491	2,923,127	143,933	88,175
35	25,060		7,578	32,637	1,210,491	2,923,127	143,933	111,295
36			7,578	7,578	1,210,491	2,923,127	143,933	136,355
37			7,578	7,578	1,210,491	2,923,127	143,933	136,355
38			7,578	7,578	1,210,491	2,923,127	143,933	136,355
39			7,578	7,578	1,210,491	2,923,127	143,933	136,355
40			7,578	7,578	1,210,491	2,923,127	143,933	136,355
41			7,578	7,578	1,210,491	2,923,127	143,933	136,355
42			7,578	7,578	1,210,491	2,923,127	143,933	136,355
43			7,578	7,578	1,210,491	2,923,127	143,933	136,355
44			7,578	7,578	1,210,491	2,923,127	143,933	136,355
45			7,578	7,578	1,210,491	2,923,127	143,933	136,355
46			7,578	7,578	1,210,491	2,923,127	143,933	136,355
47			7,578	7,578	1,210,491	2,923,127	143,933	136,355
48			7,578	7,578	1,210,491	2,923,127	143,933	136,355
49			7,578	7,578	1,210,491	2,923,127	143,933	136,355
50	-107,399	-32,066	7,578	-131,887	1,210,491	2,923,127	143,933	275,820
Total	907,992	64,131	382,673	1,354,796	61,129,818	147,617,903	7,268,596	5,913,799

i = 10%	PV (Cost): 571,421	PV (Benefit):	769,240	197,819
			NPV	197,819
	Firm	Secondary	B/C	1.35
Tariff (US$/MWh):	34.82	34.82	EIRR	13.1%

Table 14.2 Economic Evaluation (Alternative Thermal)

(Unit: 1000 US dollars)

No.	Cost: Punatsangchhu Hydropower Construction Cost	T/L Cost	O & M Cost	Total Cost	Benefit: Alternative Thermal Power Project Gas Turbine Plant Construction Cost	O & M Cost	Fuel Cost	Coal fired Power Plant * Construction Cost	O & M Cost	Fuel Cost	Total	B - C
-7	13,970	0		13,970							0	-13,970
-6	87,635	554		88,189							0	-88,189
-5	98,224	7,392		105,616				42,826			42,826	-62,790
-4	122,286	18,058		140,344				86,580			86,580	-53,764
-3	169,458	17,432		186,890				165,152			165,152	-21,738
-2	148,571	0		148,571	20,101			236,522			256,623	108,052
-1	60,050	0	3,789	63,839	24,568	670	8,264	275,942	19,865	26,106	355,415	291,577
1	64,600	4,662	7,578	76,840		1,340	16,529	1,998	39,729	52,213	111,809	34,969
2			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
3			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
4			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
5			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
6			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
7			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
8			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
9			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
10			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
11			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
12			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
13			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
14			7,578	7,578	20,101	1,340	16,529		39,729	52,213	129,912	122,334
15			7,578	7,578	24,568	1,340	16,529		39,729	52,213	134,379	126,801
16			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
17			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
18			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
19			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
20			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
21			7,578	7,578		1,340	16,529	39,420	39,729	52,213	149,231	141,653
22			7,578	7,578		1,340	16,529	78,841	39,729	52,213	188,651	181,073
23			7,578	7,578		1,340	16,529	157,681	39,729	52,213	267,492	259,914
24		554	7,578	8,132		1,340	16,529	236,522	39,729	52,213	346,332	338,200
25		7,392	7,578	14,970		1,340	16,529	279,348	39,729	52,213	389,158	374,188
26		18,058	7,578	25,636		1,340	16,529	7,739	39,729	52,213	117,550	91,914
27		17,432	7,578	25,010		1,340	16,529	7,471	39,729	52,213	117,281	92,272
28		0	7,578	7,578		1,340	16,529	0	39,729	52,213	109,811	102,233
29	0	0	7,578	7,578	20,101	1,340	16,529	0	39,729	52,213	129,912	122,334
30	32,765	4,662	7,578	45,004	24,568	1,340	16,529	1,998	39,729	52,213	136,377	91,372
31	3,417		7,578	10,994		1,340	16,529		39,729	52,213	109,811	98,816
32	59,059		7,578	66,637		1,340	16,529		39,729	52,213	109,811	43,174
33	82,118		7,578	89,695		1,340	16,529		39,729	52,213	109,811	20,115
34	48,180		7,578	55,757		1,340	16,529		39,729	52,213	109,811	54,053
35	25,060		7,578	32,637		1,340	16,529		39,729	52,213	109,811	77,173
36			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
37			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
38			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
39			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
40			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
41			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
42			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
43			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
44			7,578	7,578	20,101	1,340	16,529		39,729	52,213	129,912	122,334
45			7,578	7,578	24,568	1,340	16,529		39,729	52,213	134,379	126,801
46			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
47			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
48			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
49			7,578	7,578		1,340	16,529		39,729	52,213	109,811	102,233
50	-107,399	-32,066	7,578	-131,887	-29,779	1,340	16,529		39,729	52,213	80,031	211,918
Total	907,992	64,131	382,673	1,354,796	148,897	67,674	834,694	1,618,038	1,946,735	2,558,419	7,312,371	5,957,574

i = 10%	PV (Cost)	571,421	PV (Benefit):	1,131,015	559,594
				NPV	559,594
				B/C	1.98
				EIRR	29.8%

* Note: Coal fired plant cost includes transmission line cost.

Table 14.3 Financial Evaluation

(Unit: 1000 US dollars)

No.	COST: Construction Cost	COST: T/L Cost	COST: O & M Cost	COST: Total	BENEFIT: Energy Generation (MWh) Firm	BENEFIT: Energy Generation (MWh) Secondary	BENEFIT: Total	B - C
-7	13,970	0		13,970			0	-13,970
-6	87,635	554		88,189			0	-88,189
-5	98,224	7,392		105,616			0	-105,616
-4	122,286	18,058		140,344			0	-140,344
-3	169,458	17,432		186,890			0	-186,890
-2	148,571	0		148,571			0	-148,571
-1	60,050	0	3,789	63,839	605,246	1,461,563	71,966	8,128
1	64,600	4,662	7,578	76,840	1,210,491	2,923,127	143,933	67,093
2			7,578	7,578	1,210,491	2,923,127	143,933	136,355
3			7,578	7,578	1,210,491	2,923,127	143,933	136,355
4			7,578	7,578	1,210,491	2,923,127	143,933	136,355
5			7,578	7,578	1,210,491	2,923,127	143,933	136,355
6			7,578	7,578	1,210,491	2,923,127	143,933	136,355
7			7,578	7,578	1,210,491	2,923,127	143,933	136,355
8			7,578	7,578	1,210,491	2,923,127	143,933	136,355
9			7,578	7,578	1,210,491	2,923,127	143,933	136,355
10			7,578	7,578	1,210,491	2,923,127	143,933	136,355
11			7,578	7,578	1,210,491	2,923,127	143,933	136,355
12			7,578	7,578	1,210,491	2,923,127	143,933	136,355
13			7,578	7,578	1,210,491	2,923,127	143,933	136,355
14			7,578	7,578	1,210,491	2,923,127	143,933	136,355
15			7,578	7,578	1,210,491	2,923,127	143,933	136,355
16			7,578	7,578	1,210,491	2,923,127	143,933	136,355
17			7,578	7,578	1,210,491	2,923,127	143,933	136,355
18			7,578	7,578	1,210,491	2,923,127	143,933	136,355
19			7,578	7,578	1,210,491	2,923,127	143,933	136,355
20			7,578	7,578	1,210,491	2,923,127	143,933	136,355
21			7,578	7,578	1,210,491	2,923,127	143,933	136,355
22			7,578	7,578	1,210,491	2,923,127	143,933	136,355
23			7,578	7,578	1,210,491	2,923,127	143,933	136,355
24		554	7,578	8,132	1,210,491	2,923,127	143,933	135,801
25		7,392	7,578	14,970	1,210,491	2,923,127	143,933	128,963
26		18,058	7,578	25,636	1,210,491	2,923,127	143,933	118,297
27		17,432	7,578	25,010	1,210,491	2,923,127	143,933	118,923
28		0	7,578	7,578	1,210,491	2,923,127	143,933	136,355
29	0	0	7,578	7,578	1,210,491	2,923,127	143,933	136,355
30	32,765	4,662	7,578	45,004	1,210,491	2,923,127	143,933	98,928
31	3,417		7,578	10,994	1,210,491	2,923,127	143,933	132,938
32	59,059		7,578	66,637	1,210,491	2,923,127	143,933	77,296
33	82,118		7,578	89,695	1,210,491	2,923,127	143,933	54,237
34	48,180		7,578	55,757	1,210,491	2,923,127	143,933	88,175
35	25,060		7,578	32,637	1,210,491	2,923,127	143,933	111,295
36			7,578	7,578	1,210,491	2,923,127	143,933	136,355
37			7,578	7,578	1,210,491	2,923,127	143,933	136,355
38			7,578	7,578	1,210,491	2,923,127	143,933	136,355
39			7,578	7,578	1,210,491	2,923,127	143,933	136,355
40			7,578	7,578	1,210,491	2,923,127	143,933	136,355
41			7,578	7,578	1,210,491	2,923,127	143,933	136,355
42			7,578	7,578	1,210,491	2,923,127	143,933	136,355
43			7,578	7,578	1,210,491	2,923,127	143,933	136,355
44			7,578	7,578	1,210,491	2,923,127	143,933	136,355
45			7,578	7,578	1,210,491	2,923,127	143,933	136,355
46			7,578	7,578	1,210,491	2,923,127	143,933	136,355
47			7,578	7,578	1,210,491	2,923,127	143,933	136,355
48			7,578	7,578	1,210,491	2,923,127	143,933	136,355
49			7,578	7,578	1,210,491	2,923,127	143,933	136,355
50	-107,399	-32,066	7,578	-131,887	1,210,491	2,923,127	143,933	275,820
Total	907,992	64,131	382,673	1,354,796	61,129,818	147,617,903	7,268,596	5,913,799
i = 10%		PV (Cost):		571,421		PV (Benefit):	769,240	197,819
					Firm	Secondary		
		Tariff (US$/MWh):			34.82	34.82	FIRR	13.1%

15. FINANCIAL ARRANGEMENT

15.1 Financial Arrangement

The construction cost for the Project is estimated to be US$813 million (as of 2000), including direct cost and indirect cost. The cost does not include price contingency for escalation and interest during construction.

Thus, important factors to consider are the possibility of financial arrangements through conventional financial cooperation and commercial loans, as well as new business models like BOT/IPP, determining what is necessary to make this possible, and examining the organizational reforms and government measures that should be effected.

(1) Scenario A: Conventional Aid Scheme

This scenario has been formulated referring to the cases of existing Chhukha Hydropower Project under operation and Tala Hydropower Project under construction: 40% of grant aid from the Indian Government, and 60% by supplier's credit and the like. The merits for this scheme are: there are a few cases in the past; there is no anxiety as to the power purchase due to grant aid being supplied by India; the past project has operated satisfactorily. This scheme is reliable and less uncertain. It is worried, however, that India could provide such a grant aid in the future, and that the initiative of Bhutan would not be less, due to a strong stand point of India in power purchase.

(2) Scenario B (BOT/IPP scheme)

This is a development scheme under Private Sector Financing. Here project cost is financed by Equity (own capital of the implementing entity, i.e. investment capital to the power generator) and Loan. Debt will be repaid from the project income. This is so called Project Financing.

This is the same scheme for a hydropower project under progress in Laos. The major issues are how to enhance the credibility of the project to raise equity, and how to procure the long and low rate project loan.

(3) Scenario C (Regional ODA)

This is a scheme to consider the project as a regional development project coming in sight in Eastern India and Bhutan. Thus the project may look for economy and rationality in development, as well as global environment.

Regional ODA is rare in the past and it could involve complicated formalities. However, there should be a development scheme with the initiative of regional development agencies such as thr Asian Development Bank from a global viewpoint.

15.2 Evaluation Result

The required amount for construction is large compared to the economic scale of Bhutan, therefore, cash flow analysis has been made for some cases, supposing various financial sources. The result confirmed that there will be no problems in profitability of the project in any cases. Any indices surpass the criteria value in terms of Debt Service Coverage Ratio (DSCR), Loan Life Coverage Ratio (LLCR) and Financial Generation Cost.

In any case, implementation of the Project requires Power Purchase Agreement (PPA) with India, as a prerequisite. Another condition is the physical condition such as the installation of an ultra high voltage transmission line in India.

In order to assure the power sale revenue, a bilateral agreement between the Royal Government of Bhutan and the Government of India, in addition to the PPA, is required. Inclusion of a clause regarding payment in part or in all in hard currencies will widen the options for financial procurement. Another important point to put forward for the project is to obtain the assurance of an international financing agency having a strong influence in both countries. It is considered that the credibility of the Project will become higherif the project is implemented under a cooperative scheme between the Government of Bhutan and the Government of India including financial support from international financing agencies.

Therefore, approaches and publicity work for the Indian Power Grid Corporation Limited (GOI/PGCIL) and West Bengal State Electricity Board (WBSEB) are important for the promotion of the project.

A Build-Operate-Transfer (BOT) scheme, which will enable lessening of the financial burden of the implementing entity (Royal Government of Bhutan) by participation of the private sector, should be considered as an option. For this purpose, it is important to reform the electric power sector as well as to arrange investment incentives by private investors, assurance of capital security and investment environment, through preparation of related laws.

Table 15.1 Financial Analysis (A-1): Summary

Scenario: AAA
Construction Cost 934.36 US$/kW

Finance Proportion	Bhutan	Others
Equity Share	100%	0%
Debt/Equity	Debt	Equity
	60%	40%

Installed Capacity 870.00 MW
Energy Generation 4,330.00 GWh
Salable energy 4,133.62 GWh
Firm 1,210.49 GWh
Secondary 2,923.13 GWh

Construction cost
Before price escalation 812.89 M.US$
After price escalation 876.26 M.US$
Financial Budget 945.13 M.US$

Financial Items	Bhutan	Private
Own Finance	350.50	0.00
Loan amount	525.75	0.00
IDC	68.88	0.00
Royalty	0.00	0.00
Total	945.13	0.00

Export/Domestic Ratio for salable energy
Export 100%
Domestic 0%

Initial Power Tariff
Firm 39.21 US$/MWh
Secondary 100% 39.21 US$/MWh

Power Tariff Escalation
Firm
Secondary

Inflation (in terms of US dollar)
Foreign 2.0%
Domestic 2.0%

Financial Condition (I)
Interest rate for IDC 10.0%
Interest after operation 10.0%
Repayment Period(net) 8
Grace Period (years) 4
Gov't Own finance 100.0%

Financial Condition (II)
Interest rate for IDC 0.0%
Interest after operation 0.0%
Repayment Period(net) 0
Grace Period (years) 0

Royalty for Construction Period 0%

Royalty from Operation onwards 0%

Financial Indices

Debt Service Coverage Ratio
Average for Finance (I) 2.68
Average for Finance (II) -

Loan Life Coverage Ratio
For Finance (I) 2.03
For Finance (II) -

Financial Generation Cost at Year 1
2.82 cent/kWh
(Discount rate= 10%)

Table 15.2 Financial Analysis (B-1): Summary

Scenario: BBB
Construction Cost 934.9 US$/kW

Finance Proportion / Equity Share / Debt/Equity

Bhutan	Others
33%	67%
Debt	Equity
70%	30%

Installed Capacity	870.00	MW
Energy Generation	4,330.00	GWh
Salable energy	4,133.62	GWh
Firm	1,210.49	GWh
Secondary	2,923.13	GWh

Construction cost

Before price escalation	813.40	M.US$
After price escalation	876.26	M.US$
Financial Budget	1,051.67	M.US$

Financial Items	Bhutan	Private
Own Finance	86.75	176.13
Loan amount	202.42	410.96
IDC	117.18	58.23
Royalty	0.00	0.00
Total	406.35	645.32

Export/Domestic Ratio for salable energy

Export	100%
Domestic	0%

Initial Power Tariff

Firm		39.21	US$/MWh
Secondary	100%	39.21	US$/MWh

Power Tariff Escalation
Firm
Secondary

Inflation (in terms of US dollar)

Foreign	2.0%
Domestic	2.0%

Financial Condition (I)

Interest rate for IDC	7.0%
Interest after operation	7.0%
Repayment Period (net)	25
Grace Period (years)	6
Gov't Own finance	100.0%

Financial Condition (II)

Interest rate for IDC	10.0%
Interest after operation	10.0%
Repayment Period (net)	12
Grace Period (years)	4

Royalty for Construction Period 0%

Royalty from Operation onwards 15%

Financial Indices

Debt Service Coverage Ratio

Average for Finance (I)	3.62
Average for Finance (II)	1.45

Loan Life Coverage Ratio

For Finance (I)	1.73
For Finance (II)	1.42

Financial Generation Cost at Yeat 1
3.07 cent/kWh
(Discout rate= 10%)

Table 15.3 Financial Analysis (C-1): Summary

Scenario	CCC
Construction Cost	934.9 US$/kW

Finance Proportion

	Bhutan	Others
Equity Share	100%	0%
Debt/Equity	Debt	Equity
	90%	10%

Installed Capacity	870.00	MW
Energy Generation	4,330.00	GWh
Salable energy	4,133.62	GWh
Firm	1,210.49	GWh
Secondary	2,923.13	GWh

Construction cost		
Before price escalation	813.40	M.US$
After price escalation	876.26	M.US$
Financial Budget	1,086.31	M.US$

Financial Items	Bhutan	Private
Own Finance	87.63	0.00
Loan amount	788.63	0.00
IDC	125.84	84.21
Royalty	0.00	0.00
Total	1002.10	84.21

Export/Domestic Ratio for salable energy

Export	100%
Domestic	0%

Power Tariff

Firm		39.21 US$/MWh
Secondary	100%	39.21 US$/MWh

Power Tariff Escalation

Firm

Secondary

Inflation (in terms of US dollar)	
Foreign	2.0%
Domestic	2.0%
Financial Conditions (I)	
Interest rate for IDC	7.0%
Interest after operation	7.0%
Repayment Period (years)	25
Grace Period (years)	6
Gov't Own finance	100.0%
Financial Conditions (II)	
Interest rate for IDC	10.0%
Interest after operation	10.0%
Repayment Period (years)	12
Grace Period (years)	4
Royalty for Construction Perio(	0%
Royalty from Operation onward	0%

Financial Indices

Debt Service Coverage Ratio	
Average for Finance (I)	3.87
Average for Finance (II)	1.51
Loan Life Coverage Ratio	
For Finance (I)	1.65
For Finance (II)	1.24
Financial Generation Cost at Year 1	2.44 cent/kWh
(Discount rate= 10%)	

16. ADDITIONAL INVESIGATION

It is essential for the Punatsangchhu hydropower project to carry out the following additional investigation program prior to the implementation of detail design.

(1) Hydrological Investigation

It is essential for predicting GLOFs to obtain data on them by observing glacier lakes and water leakage from moraine dams, as well as meteorological observation, including precipitation in the upper reach of the basin.

If possible, a trace study on the mass movement of debris should be conducted along the river in the basin.

(2) Geological Study

Dam Site: It is necessary to carry out further detailed investigations on permeability and groundwater table at rock foundation on the right abutment. Therefore, core drilling, permeability test and various in-situ tests after excavating exploratory adit should be carried out during the detail design stage.

Waterway Tunnel: It is considered that a seismic prospecting survey or other proper detecting method be conducted along the tunnel route.

Surge Tanks and Underground Powerhouse Site: It is necessary to carry out further investigation in detail of the distribution and characteristics of sheared zones along foliation by mainly core drilling 5 holes 1,000 m in total length.

(3) Route for Transmission Line:

Detail Site Survey for detail comparative study between A route (Powerhouse - Sarpang -Bongaigaon).