7.13 Rock Evaluation

The rock classification of drill cores was performed on the basis of Table 7-19. Furthermore a rock mass was synthetically evaluated as shown in Table 7-20 on the basis of the rock classification data. The bedrocks of this project area were roughly divided into that of the rock stiffly consolidated which is mainly composed of sandstone and that of the rock a little softly consolidated which is mainly composed of siltstone. Each bedrock was furthermore divided into fine classes due to the differences of the original consolidation degree, the weathering degree and the shearing degree.

Table 7-21 shows the relation between the rock evaluation and the physical properties obtained by in situ test and laboratory test. As mentioned in Section 7.11, the representative value of uniaxial compressive strength of the whole rock mass of rock evaluation S2 may be smaller than that in Table 7-21.

Table 7-19 Standard of Rock Classification for Drill Core

WAETHERING	
Classification	Description
1	Very fresh. No weathering of mineral component.
2	Fresh. Some minerals are weatherd slightly. Usually no brown crack.
3	Fairly fresh. Some minerals are weathered. Cracks are stained and with weathered material.
4	Weathered. Fresh portions still remain partially.
5	Strongly weathered. Most minerals are weathered and altered to second minerals.

HARDNESS	
Classification	Description
1	Very hard. Broken into knife-edged pieces by strong hammer blow.
2	Hard. Broken into pieces by strong hammer blow.
3	Brittle. Broken into pieces by medium hammer blow.
4	Very brittle. Easily broken into piecesby slight hammer blow.
5	Soft. Able to dig with hammer.

CRACK SPACING	
Classification	Spacing
1	Over 30 cm
2	10 ～ 30 cm
3	3 ～ 10 cm
4	1 ～ 3 cm
5	Under 1 cm

Table 7-20 Standard of Rock Evaluation

		HARDNESS*								
		1	1-2	2	2-3	3	3-4	4	4-5	5
CRACK SPACING*	1	H 1	H 1	H 1	H 2	H 2				
	1-2	H 1	H 1	H 1	H 2	H 2	H 3			
	2	H 1	H 1	H 1	H 2	H 2	H 3			
	2-3	H 1	H 1	H 1	H 2	H 2	H 3			
	3	H 2	H 2	H 2	H 2	H 2	H 3			
	3-4				H 3	H 3	H 3			
	4				H 3	H 3	H 3	H 3		
	4-5							H 3		
	5									

S 1 S 2 S 3 * see Table 7 - 19

Rock Type	Rock Evaluation	Suitability for Structures		
		Upper Dam	Tunnel	Powerhouse
<u>Hardrock</u>	H 1	○	○	○
· coarse-grained sandstone · fine-grained sandstone	H 2	○	○	○
	H 3	○	△	△~×
<u>Softrock</u>	S 1	○	○	○
· siltstone · sandy siltstone	S 2	○	○~△	△
· claystone	S 3	△	△	×

○: good △: not good ×: bad

Table 7 - 21 Rock Evaluation and Physical Properties

Rock Evaluation	In situ Deformation Modulus (kgf/cm²)		Dry Density (core) (g/cm³)	P-Wave Velocity (core) (m/s)	Compressive Strength (kgf/cm²)	Geology	
	Range	Mean				Rock Name	Description
H1	46,000~ 300,000<	100,000 <	2.39	3,510	729	c-ss, f-ss	fresh and slightly weathered part
H2	8,900~ 61,000	36,000	2.34	2,940	646	c-ss, f-ss alt. silty f-ss	wethered part fresh part
H3	9,300~ 23,000	15,000	2.10	3,830	275	c-ss silty f-ss	including cls patch soft part
S1	—	—	2.59	3,370	678	sandy sts	small part in fresh part
S2	6,300~ 25,000	17,000	2.55	2,610	343	sandy sts sts	fresh or weathered part fresh part
S3	1,500~ 19,000	10,000	2.01	1,150	21	sts cls	weathered or sheared fresh or weathered part

ss : sandstone c- : coarse-grained f- : fine-grained
sts: siltstone cls: claystone alt: alternation of sandstone and siltstone
W : weathering H : hardness C : crack spacing RE : rock valuation

7.14 Engineering Geological Evaluation of Main Structure Sites

7.14.1 Upper Reservoir Site

(1) The foundation rock of upper reservoir dam consists of weathered coarse-grained sandstone (rock evaluation: H1-3) and claystone (S3). There are small amount of joints in coarse-grained sandstone and its average RQD is about 66%. The deformation modulus of the coarse-grained sandstone including many claystone patches (the rock evaluation of the part is H3) is not less than 9,000 kgf/cm^2. The shear strength and deformation modulus of the coarse-grained sandstone is enough for the foundation of the dam. The fresh claystone also can be used for the foundation except for the part where the dam will be high judging from the result of standard penetration test and drill core test. The residual soil distributed at the ground surface with the thickness under about 5 m is necessary to be removed by excavation.

(2) The dam has a large height on the northern side and reaches its maximum height of about 50 m at the northwest corner. The foundation rock of the part with a large dam height will be coarse-grained sandstone by excavation and does not present any problem to the project concerning strength, deformation and compaction.

(3) However, it will be necessary to evaluate the differential settlement due to the difference of deformation property between coarse-grained sandstone and claystone.

(4) As for the permeability of the foundation rock of upper reservoir, although the permeability of claystone is mainly under the order of 10^{-5} cm/s which may be enough low, that of coarse-grained sandstone is frequently over 10 Lu due to the joints, so that it is difficult to use this bedrock as the foundation of the upper reservoir without a surface membrane.

The ground water level in the upper reservoir site is located in the depth of 20 ~ 50 m under the ground surface.

(5) Blasting will be necessary for the fair part of the excavation of the upper reservoir since the coarse-grained sandstone is stiff and has few cracks.

(6) The soil and rocks excavated for the upper reservoir can be used as the construction materials for the dam as mentioned later.

7.14.2 Intake and Headrace Tunnel Site

(1) The foundation rock of the intake consists of coarse-grained sandstone (H1-3). Although some part of the bedrock is strongly weathered and friable, the deformation modulus obtained by drill hole deformation test is about 20,000 kgf/cm^2, and so there will be no problem about the construction of the structure.

(2) The bedrock of the headrace tunnel consists of alternation of fine-grained sandstone and siltsone (mainly H1 and S2-3, siltstone is dominant). As the foundation rock may be partly weathered and there is a shear zone with an apparent width of 4.4 m, attention must be paid for the construction.

(3) The geologic conditions of the headrace tunnel are a little bad due to the sallow depth of the site, however there is no problems about the excavation of the tunnel as the deformation moduli are between 10,000 - 20,000 kgf/cm^2, enough large for the depth. The headrace tunnel is planned about 15 m under the ground water table.

(4) Care for stability of the bedrock near the crown of the tunnel must be necessary because the layers of the site are nearly horizontal and many low-angle joints are distributed in the bedrock.

7.14.3 Penstock Site

(1) The bedrock of the upper part of the penstock consists of alternation of fine-grained sandstone and siltstone (mainly H1-2 and S2, siltstone is dominant) and coarse-grained sandstone (H1) and is not weathered. There are few faults in the site and the geologic conditions are good.

(2) The bedrock of the lower part of the penstock consists of siltstone (S2, including sandy siltstone). The geologic conditions are inferred to be almost homogeneous with few faults. Although the conditions of siltstone observed in drill cores look bad due to slaking and shrinkage cracks, the geologic conditions of bedrock are not so bad judging from the fact that the wall of the drill holes in siltstone dose not collapse and the results of drill hole deformation tests. Siltsone is judged to be capable of the construction of tunnel, however, it will be necessary to spray concrete as soon as possible after the excavation in order to prevent the deterioration of bedrock.

(3) As the site is located 20 ~ 320 m under the ground water table and some part of sandstone is highly permeable (more than 20 Lu), water may spring at the time of excavation.

7.14.4 Underground Powerhouse Site

(1) According to the result of drilling DHW-2, the bedrock of the underground powerhouse site consists of siltsone (S2) and fine-grained sandstone (H1-2), and it is inferred that there are few faults.

(2) The fine-grained sandstone is mainly distributed in the lower part of the proposed underground powerhouse cavern and the thickness of the layer is about 20 m. This bedrock has few cracks and its RQD values are mostly 100%. As the average deformation modulus and uniaxial compressive strength of the

similar bedrock is about 63,000 kgf/cm^2 and 900 kgf/cm^2 respectively, the bedrock is very good for the underground powerhouse from the view point of strength and deformation property. The treatment for spring, however, may be necessary since the site is located about 270 m under the ground water table and there are many highly permeable parts (lugeon values are more than 20 Lu).

(3) As for the siltstone, the average deformation modulus is about 17,000 kgf/cm^2, the average uniaxial compressive strength about 300 kgf/cm^2. Considering the powerhouse is located at the depth of about 300 m from the ground surface, the in situ stress is roughly estimated to be 100 kgf/cm^2 with the assumption of wet density about 2.7 g/cm^3 (see Table 7-15 (3)). Consequently, the ratio of the average uniaxial compressive strength to the in situ stress is about 3. According to these test results, the siltstone is judged to be capable of the construction of underground powerhouse, however, the average uniaxial compressive strength may be overestimated and the cavern will not be sufficiently stable under these condition.

(4) The siltsone shows slaking, therefore it will be necessary to treat adequately, for example by spraying concrete, immediately after the excavation in order to keep the original conditions of the bedrock as much as possible.

(5) Care for stability of the bedrock near the arch of the cavern must be necessary as geologic boundaries of the siltstone and the fine-grained sandstone are nearly horizontal and many low-angle joints are distributed in the siltstone.

(6) The geologic condition of the underground powerhouse site has been grasped in outlines by the investigations conducted this time. However, since there is no drill hole directly to the site, there may be some difference in the thickness of the fine-grained sandstone beds, the distribution of faults and joints and the degree of consolidation of rock. Consequently, it is

thought to be necessary to investigate the site directly by drilling and/or exploratory tunnel.

7.14.5 Tailrace Tunnel and Outlet Site

(1) The bedrock of the tailrace tunnel and outlet site is as similar as that of the underground powerhouse site although it is weathered near the outlet site since the depth from the ground surface is shallow.

(2) The colluvial and talus deposit of the slope over the tailrace tunnel is highly likely to have been formed by the landslide acted in the past. At present no particular phenomenon indicating current activities can be observed and a large-scaled landslide is unlikely to occur in the future. Only, attention should be paid to the point that the excavation for switchyard and access road in the slope may eventually cause a damage to the stability of the slope.

(3) The tailrace tunnel near the outlet is planned to be excavated in a layer of siltstone. The weathering influences only as far as the layer of fine-grained sandstone above the said layer of siltstone. Therefore excavation itself of this siltstone layer is thought to be unlikely to present any particular problem. However, above this part of the tailrace tunnel there is a bedrock with large porosity and high permeability due to weathering and the ground water level near the lower reservoir is high, therefore any eventual faults, or joints may cause spring water.

(4) Taking future works for the outlet below the water surface of the lower reservoir into consideration, it will be necessary to grasp the geologic condition in and around the outlet in the reservoir in the future.

7.15 Construction Materials

7.15.1 Embankment Materials for Upper Dam

As for embankment materials for the upper dam, it will be possible to utilize adequate mixture of residual soil and claystone obtained by excavation of the upper reservoir. The physical properties of these materials are rather different each other. The disturbed samples of residual soil and claystone had been collected from pits and were tested. The results of the tests are described below. Although the material tests of coarse-grained sandstone have not been carried out, there will be no problem about the utilization of coarse-grained sandstone for the embankment material judging from the results of the drill core test and the concrete aggregate test described later.

(1) Test Samples

The disturbed samples of residual soil and highly weathered claystone, which total 10, were collected from test pits PU-1, 2, 3 and 4. The geologic name and Unified Soil Classification of samples are given in Table 7-22.

(2) Test Items, Quantity and Methods

Test Item	Quantity	Method
Specific Gravity Test	9	ASTM Standard C-127
Moisture Test	10	ASTM Standard D-2216
Liquid Limit and Plastic Limit Test	10	ASTM Standard D-4318
Particle Size Analysis Test	10	ASTM Standard D-422
Compaction Test	9	ASTM Standard D-698
Permeability Test	9	ASTM Standard D-2434
Triaxial Compression Test	2	ASTM Standard D-2850

(3) Test Results

The results are shown in Table 7-22. The detailed test data are attached in Appendix-A. The results are summarized as follows.

- Liquid limit is between 31 ~ 56% and Plastic limit between 9 ~ 20%.

- Maximum dry density by compaction is between 1.7 ~ 1.9 g/cm^3, optimum water content between 14 ~ 21% and minimum permeability coefficient between 1.1 x 10^{-6} ~ 1.8 x 10^{-8} cm/s.

- The variation of the content of grains under 75 μm is large, 10 ~ 77% because the particle size of the residual soil in the area where claystone is distributed is smaller than that in the area where coarse-grained sandstone is distributed and the upper part of residual soil containing lateritic crust is coarser than the lower part.

- The highly weathered claystone has a little smaller maximum dry density and is rich in the fine particle under 75 μm than residual soil.

- The shear strength of disturbed samples is relatively large and nearly as same as that of undisturbed ones given in Table 7-17.

According to the above mentioned results, these samples are suitable for impervious material, however, it is sufficiently possible to use them for the embankment materials after adequate mixing with coarse-grained sandstone. Furthermore the results of mineralogical analysis of residual soil and claystone indicate that they do not contain the minerals making troubles to the material.

7.15.2 Concrete Aggregate

Since the river bed deposit in the area around the project site mainly consists of silt, it is hard to collect river bed gravel so that it is necessary to collect aggregate at quarries. As a quarry may be proposed a site where coarse-grained sandstone is distributed about 1.5 km to the northeast of the upper reservoir (DWG. 7-1). At this site coarse-grained sandstone forms a steep cliff of the east end of the plateau. The bedrock contains intercalated layers of claystone and joints in relatively small quantities. Residual soil at this site is little, too. The thickness of the layer of coarse-grained sandstone is inferred to be over about 25 m, therefore it is thought to be possible to secure aggregate in necessary quantities by excavating along the top of the plateau.

In addition, the existing quarry located at a site where limestone of the Ratburi group is distributed about 12 km to the southwest of Pak Chong (about 30 km to the southwest of the project site) may also be proposed (DWG. 7-1). There are a number of quarries around this site, so it is thought to be quite possible to secure necessary quantities except that there may be problems concerning the equipment of the existing plant.

(1) Items of Tests and Analyses and Methods

The following tests and analyses were carried out for each sample of limestone and coarse-grained sandstone.

Item of Tests and Analyses	Method
Specific Gravity, Absorption Test	ASTM Standard C-127
Abrasion Test (Los Angeles Machine)	ASTM Standard C-131, C-535
Soundness Test	ASTM Standard C-88
Crushing Value Test*	British Standard 812
Mineralogical Analysis	Thin Section, X-ray Diffraction
Chemical Analysis	Flourescent X-ray Analysis

* The test was carried out only for coarse-grained sandstone. As for the limestone the test was not carried out because the sample was crushed stone produced in a factory.

(2) Results of Tests and Analyses

The results of tests and analyses are shown in Table 7-23, 7-24. The detailed data of tests and analyses are attached in Appendix-A.

Limestone sample is judged to be applicable for concrete aggregate on the bases of the criteria in ASTM and JIS (Japan Industrial Standards) which are given in Table 7-23. As for the constituent minerals, the noxious minerals for concrete such as montmorillonite, silica minerals, glass, zeolite and gypsum are not contained in the sample. Strictly speaking, this sample should be called dolomitic limestone (calcite : dolomite (mole ratio) = 2 : 1). Though it is rare case, dolomite is reported to be noxious for concrete because of alkali-carbonate reaction. Therefore the detailed tests such as concrete prism test should be carried out hereafter to clarify the suitability.

As for the coarse-grained sandstone, the value of dry density, 2.35 g/cm^3, is under the standard value of JIS and the other test results satisfy the standards. The dry density of coarse-grained sandstone is about 2.4 g/cm^3 even in fresh part because of the large porosity as shown in Table 7-15(3). As the standard value of density is considered not to be absolute, synthetic examination considering design condition, economics and so forth is necessary for the selection of concrete aggregate.

Table 7-22 Laboratory Test Results of Disturbed Samples of Test Pits

Pit No.	Sample Depth (m)	Geology [Unified Soil Classification]	Water Content at Received (%)	Specific Gravity	Atterberg Limits		Gradation (wt%)							Compaction and Permeability			
					LL. (%)	PI. (%)	-3/4" (19mm)	-# 4 (4.75mm)	-#10 (2.00mm)	-#40 (425 μm)	-#200 (75 μm)	-10 μ (10 μm)	- 2 μ (2 μm)	Max. dry Density (g/cm³)	Optimum Water Content(%)	minimum Permeability (cm/s)	Molded Water Content(%)
PU-1	0.5-3.0	Re [GM]	4.03	2.72	56.00	20.04	91.51	66.15	57.43	52.99	49.64	39.00	31.98	1.71	21.3	1.8×10^{-8}	22.0
PU-1	3.0-5.0	w-cls [ML]	6.19	2.67	44.00	16.71	96.71	81.65	79.23	78.20	76.37	50.23	29.12	1.72	18.6	7.0×10^{-8}	21.0
PU-2	0.3-1.2	Re [ML-CL]	4.78	2.63	31.40	9.38	100.00	98.77	97.06	94.71	55.96	39.51	31.43	1.77	15.5	9.0×10^{-8}	16.9
PU-2	1.2-1.8	Re [GM]	5.14	—	41.20	12.59	100.00	38.41	15.64	14.42	10.30	7.96	6.62	—	—	—	—
PU-3	0.7-3.1	Re [GM]	10.95	2.78	53.30	17.18	87.80	42.70	30.28	27.50	24.67	20.41	16.88	1.90	16.4	1.1×10^{-6}	17.0
PU-3	3.1-5.0	w-cls [GM]	6.62	2.67	47.00	17.65	83.42	56.64	51.14	47.52	43.26	30.29	22.03	1.77	17.7	1.6×10^{-7}	18.9
PU-4	0.6-3.1	Re [GM]	5.06	2.81	45.00	13.43	77.71	48.89	34.39	31.55	27.26	20.44	16.05	1.91	16.5	1.1×10^{-7}	17.1
PU-4	3.1-4.4	Re [GM]	5.13	2.72	45.80	17.84	75.70	53.12	47.61	45.30	40.97	28.07	20.82	1.90	15.1	1.0×10^{-7}	16.6
PU-4	4.4-5.0	w-cls [ML-CL]	3.99	2.80	45.90	20.00	100.00	85.68	81.57	80.33	76.65	51.51	35.57	1.77	17.1	1.0×10^{-7}	19.0
PU-4	0.6-5.0	Re and w-cls[GM]	3.14	2.79	46.40	17.30	100.00	57.56	44.56	42.12	37.59	26.50	16.50	1.92	14.2	1.3×10^{-7}	16.2

Re: Residual soil w-cls: weathered claystone

Pit No.	Sample Depth (m)	Geology [Unified Soil Classification]	Water Content (%)	Dry Density (g/cm³)	Shear Strength (CU test)	
					Cohesion $\overline{C}$ (kgf/cm²)	Friction Angle $\overline{\phi}$(°)
PU-3	3.1-5.0	weathered claystone [GM]	18.81 -19.64	1.671 -1.683	0.30	33.12
PU-4	0.6-5.0	weathered claystone [GM]	16.68 -17.03	1.792 -1.797	0.24	32.21

Table 7-23 Laboratory Test Results for Concrete Aggregate

Sample Name	SA-1	SA-2	Allowance for Concrete Aggregate	
Sample Location	Sila Sakol Patana quarry (existing)	Proposed site of sandstone quarry	ASTM C-33	JIS A-5005
Rock Name	Dolomitic limestone	Coarse-graind sandstone		
Bulk Specific Gravity	2.67 (dry) 2.69 (saturated) 2.73 (apparent)	2.35 (dry) 2.41 (saturated) 2.51 (apparent)	— — —	more than 2.5 — —
Absorption (%)	0.84	2.76	—	less than 3.0
Abrasion Loss * (%)	24.52	34.46	less than 50	less than 40
Uniform Hardness Factor	0.22	0.21	—	—
Weight Loss in Soundness Test ** (%)	3.27	0.27	less than 18	less than 12
Crushing Value (%)	—	23.22	—	—
Elongation Index (%) [Nominal particle size (mm)]	—	1.00[7.125] 1.00[12.75] 0.83[17.46] 0.83[22.22] 0.43[28.45] 0.37[34.8] 0.23[44.45]	—	—
Flakiness Index (%) [Nominal particle size (mm)]	—	0.33[7.125] 0.27[12.75] 0.33[17.46] 0.27[22.22] 0.50[28.45] 0.53[34.8] 0.63[44.45]	—	—

* by the Los Angeles Machine. after 500 cycle
** by sodium sulfate

Table 7-24 Results of Mineralogical and Chemical Analyses for Concrete Aggregate

(a) Items of Analyses

Sample No.	Sample Location	Rock Name	Items of Analyses: Thin Section	X-ray Diffraction	Chemical Composition	Purpose of Analyses
SA-1	Sila Sakol Pattana quarry	Dolomitic limestone	○	○#	○*	to egxamine alkali reactivity of aggregate by petrographic methods
SA-2	Proposed site of sandstone quarry	Coarse-grained sandstone	○	○#, ##	○*	

bulk analysis
clay fraction analysis

* analysis for SiO_2, TiO_2, Al_2O_3, Fe_2O_3, FeO, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, H_2O^-, H_2O^+

(b) Constituent Minerals

Sample No.	Sample Name	Constituent Minerals: Calcite	Quartz	Kaoline	Sericite	Remarks
SA-1	Dolomitic limestone	◎	++			Zeolites, Smectite and amorphous material are not included.
SA-2	Coarse-grained sandstone		◎	+	+	moderately weathered

relative quantity : abundant ⇦ ◎, ○, ++++, +++, ++ , + ⇨ trace

(c) Chemical Composition

Sample	Oxides (wt%): SiO_2	TiO_2	Al_2O_3	Fe_2O_3*	FeO*	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	H_2O^-	H_2O^+
SA-1	3.38	<0.01	0.30	<0.01	0.16	<0.01	10.42#	42.04#	0.88	0.04	<0.01	0.06	0.06
SA-2	93.45	0.11	2.46	0.01	0.06	<0.01	0.91	0.43	1.35	0.16	0.02	0.04	0.82

* Fe^{2+} , Fe^{3+} : wet process chemical analysis , the others : flourescent X-ray analysis
# calcite : dolomite = 65.5 : 34.5 (mole ratio)

CHAPTER 8

SEISMICITY

CHAPTER 8 SEISMICITY

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Fig. 8-17 Return Period for Maximum Acceleration Estimated by Eq.-(4) [Katayama]

Chapter 8 Earthquakes

8.1 General

The project site is located on the southwest edge of the Khorat Plateau which is about 180 km northeast of Bangkok. This area's geological structure is simple with gently-sloping strata, no remarkable fold and no big tectonic line.

The project area's geological structure, seismicity, earthquake risk and seismic intensity required for anti-earthquake design are mentioned here in this chapter.

8.2 Geological Structure

8.2.1 Geological Outline in the Indochina Peninsula Region

The oldest rock in the Indochina Peninsula region is the metamorphic rocks which were produced by orogenic movement in the Late Precambrian or Early Paleozoic. The orogenic movement took place three times as described below, in the period from the Late Paleozoic to the present.

Orogenic Movement		Period
1st:	Hercynian	(Carboniferous)
2nd:	Indochina	(Permian - Jurassic, mainly Triassic)
3rd:	Himalayan	(Cretaceous - Quaternary)

The new orogenic belt was formed in the concentric circle shape surrounding the old orogenic belt. The present land paleo-geographically called "Annamia" is considered to have been formed by the Hercynian orogenic movement. After that, the Indochina orogenic belt was formed around the Hercynian orogenic belt.

The craton which was formed in this region by the Indochina orogenic movement is called "Indochina". The Indochina continent was surrounded later by the Himalayan orogenic belt, but great part of the Indochina continent has remained as a stable region up to present. The existing circumference of the continent was always surrounded by one new orogenic movement after another, and most part of the new orogenic belt was formed on the ocean floor around the existing circumference of the continent. Therefore, the craton started growing in the outside direction. The outline of the Indochina Peninsula region's geological structure is shown in Fig. 8-1.

8.2.2 Geological Structure in Thailand

On the bases of topography, geology and tectonic history, Thailand can be divided into the following three parts.

1) Eastern Thailand represented by the Khorat Plateau

2) The Gulf of Thailand and lowlands in the central valley north of this Gulf

3) The western and northwestern mountain belt that continues southward into the mountains of Malaysia.

The project area belongs in 1).

The outline of geological structure in Thailand and its neighbor areas is shown in Fig. 8-2.

The ocean floor on the western side of the Indochina Peninsular started subsiding along the eastern edge of the Shan-Thai craton in the Silurian Period. Subsidence to the west continued until the Early Mesozoic, with the production of volcanic arches, as represented by volcanic rocks made of andesite and rhyolite in central Thailand. After that, collision of the Shan-thai craton with the Indochina craton took place during the Triassic and Early Jurassic periods, producing the main geologic features of central Thailand as deformation belts running nearly north and south. Indo-Burna mountain range was formed as a result of subsidence of the indian Plate under the Eurasian Plate in the Cenozoic period.

Late Mesozoic sediment which is widely distributed in the eastern part of Thailand is continental or shallow-sea sediment. Jurassic folds and the influence of metamorphism are seen on the western side of the Shan Plateau, but the red clay layer which is distributed in the table shape in the Khorat Plateau basically has no folds or no influence of metamorphism.

There is no volcano in Thailand, and volcanic activities such as volcanic earthquakes, etc., are not seen as well.

8.2.3 Main Faults in Thailand and in Surrounding Area of the Project

As shown in Fig. 8-2, main faults in Thailand are located side by side, running from northeast to southwest or from northwest to southeast. There are large-sized faults such as Three Pagoda Fault which continuously runs from northwest to southeast, Moei-Uthai Thani Fault, etc., in the western part of Thailand.

As shown in Fig. 8-3, a lot of faults about 10 km or less in length are seen in an area with Paleozoic strata on the western side of the project area, and faults about 60 km in length are seen in an area with Paleozoic strata on the northern side of the project area.

Besides, those, there are small-sized faults in its neighbor countries, but no active faults are seen in epicenter areas (EGAT, 1985). There are no faults reported as active ones in Thailand. Therefore, even though seismic energy is omitted, it seems to have no direct relationship with the movement of faults appearing on the surface of the ground.

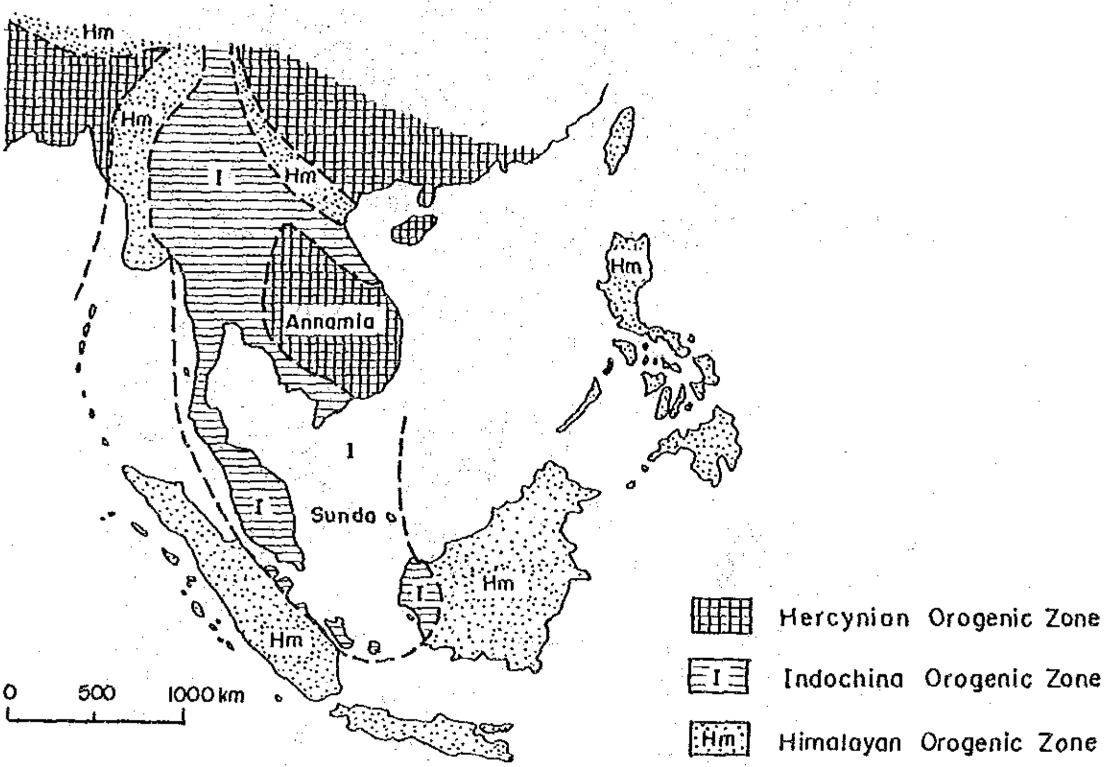


Fig. 8-1 General Geological Structure of Southeast Asia

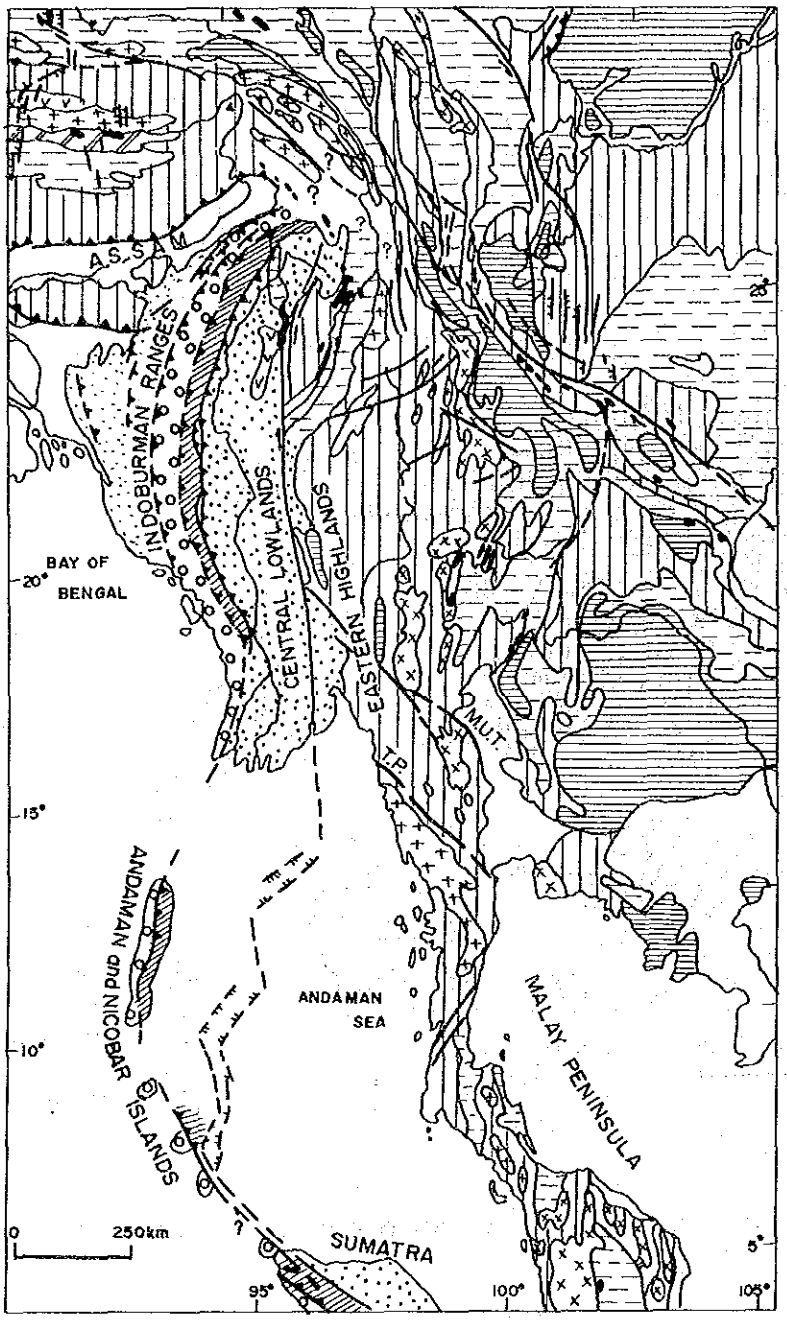
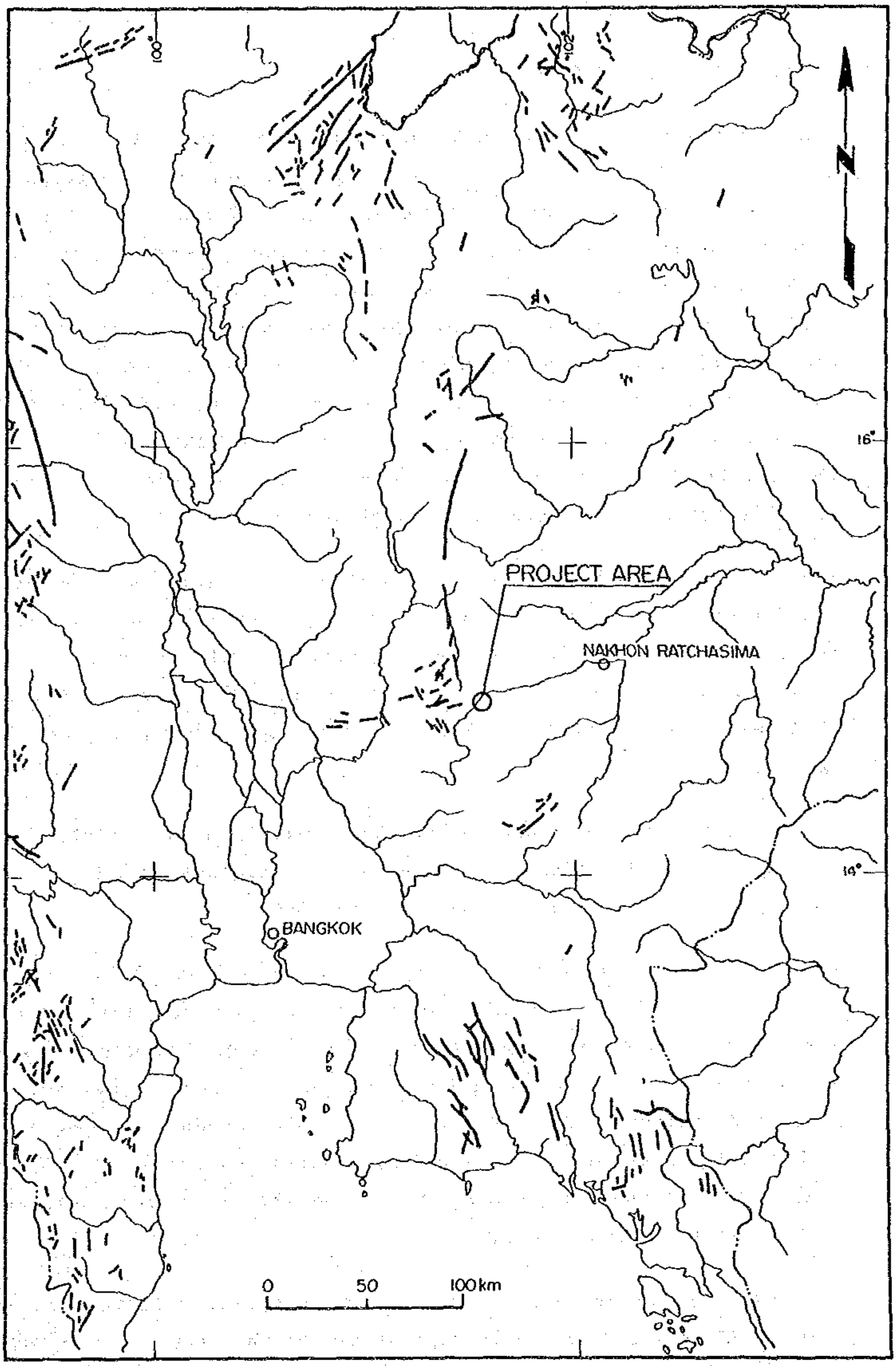


Fig. 8-2 Schematic Structural Map of Thailand and Surrounding Regions
(after Le Dain et al (1984))

(Legend)

- Oligomiocene Molasses
- Eocene to Pleistocene molasses of the Burma Lowlands
- Eocene flysch (with exotic blocks at places)
- Flysch and melanges with exotic blocks
- Indus Triassic flysch
- Mesozoic, including Lower Mesozoic flysch
- Paleozoic and Proterozoic
- Ophiolites
- Metamorphic complex (Naga Hills in particular)
- Upper Mesozoic platform sediments
- Late Paleozoic to Early Mesozoic granites
- Middle to late Mesozoic granites
- Tertiary volcanics
- Strike slip
- Major Fault Overthrusts
- Normal
- M.U.T Moei - Uthai Thani Fault
- T.P. Three Pagoda Fault



(Compiled from S. Vimuktanandana, 1984)

Fig. 8-3 Major Faults around the Project Area

8.3 Seismicity of Thailand

8.3.1 Tectonic Plates and Seismicity

The earthquake phenomena has not only the physical side as a destruction phenomena of rock but also the physical geographical side as a result of tectonic movement. The individual great earthquakes are the exact results of the tectonic movement, and the moderate-small earthquakes concentrated at a certain limited area reflect the characteristics of the mobil belt. Accordingly, in order to clarify the earthquake phenomena, it is necessary to study about the characteristics of the rock destruction, the mechanism of the earthquake fault movement, the statistical characteristics of the earthquake occurrence, and finally to make clear the relationship between the tectonic movement and seismic activity.

The distribution of major tectonic plates on the earth and the plate boundaries is shown in Fig. 8-4. And the epicenters of the earthquakes of magnitude 4 or over which occurred in the world during the period from 1964 to 1982 are shown in Fig. 8-5 for focal depth shallower than 100 km and Fig. 8-6 for focal depth deeper than 100 km.

It is clear that the earthquakes occur mainly at the plate boundaries as a result of tectonic movement, or interaction between tectonic plates as seen in Fig. 8-4, 8-5 and 8-6.

The lithospheric plates and microplates around Thailand and the direction of the microplate movements relative to the India - Eurasia collision are shown in Fig. 8-7. And the epicenters of earthquakes occurred in Asia is shown in Fig. 8-8. High seismic zone is distributed limitedly along the plate boundaries. While the stable and low seismic zone is widely distributed inside of the plates. Most of the continental shield and the ocean floor form the stable and low seismic zone.

The most typical features of the plate tectonics evolution in the considered area are generally represented by the results of interaction between three major plates: the Eurasian, Pacific and Indo-Australian. The Eurasian plate is believed to be still, while the Indo-Australian plate moves northward with a clockwise component and the Pacific plate moves essentially westward. Under the influence of this interaction the boundary of these plates and most of tectonic faults in the area are of trench and strike-slip fault types. Furthermore, two spreading centres situated in the Indian Ocean and in the East Sea, and two parallel oposing subduction zones were active at the same time, migrating towards the East Sea (from Trias to the present time). These features are reflected in the mechanism of earthquakes in the area.

The strike-slip motion is the main form of fault movement for shallow earthquakes. This is also a main type of tectonic faults in the area. For intermediate earthquakes the oblique-slip motion is a dominant form of movement in the focus.

8.3.2 Regional Stress Field around Thailand

The pressure axes and the tension axes of the earthquakes in south east Asia are shown in Fig. 8-9 and Fig. 8-10, respectively.

In southeast Asia, almost all structures and fault systems are directed to the northwest-southeast.

The area is divided into four smaller regions in Fig. 8-9. The first one contains the north Vietnam Mesozoic folding zone with the great Red River fault. All earthquakes in this region were in the Earth's crust. The second region is the western Myanmar Cenozoic folding zone with the chain of great faults which have direction either meridianal or nothwest-southeast. In this region a number of earthquakes occurred with depth reaching the upper mantle. The third region is the Cenozoic folding zone in the Andaman sea with meridianal faults, where earthquakes occur in narrow bands in the Earth's crust or below. The fourth region is the part of the Cenozoic folding zone of Sumatra (Indonesia), belonging to the Asiatic earthquake belt of the Cenozoic tectonic belt of the Pacific Ocean. Most of earthquakes in this area occur in the subduction zone with depth reaching the upper mantle.

8.3.3 Seismicity in and around Thailand

With the development and spread of the modern earthquake observation network, the earthquakes of magnitude 5 or over which occurred all over the world can be observed without omission. Seismicity in Asia since 1900 can be drawn as shown in Fig. 8-11 by selecting the earthquakes of magnitude larger than 6 from the earthquake data file of the National Oceanic and Atomospheric Administration Environmental Data Service, USA (hereinafter NOAA).

As mentioned before, there exist two kinds of region classified according to the seismic activity, namely high seismic region and low seismic region. Aseismic region in Asia is shown in Fig. 8-12. Generally speaking, the earthquakes are not frequent in Indochina region, and Thailand can be considered to be a stable aseismic region, except its northern part.

Furthermore, the epicenters of the earthquakes of magnitude larger than 6 since 1500 and the main geological structures in Asia is shown in Fig. 8-13. Judging from the wide standpoint of view, it can be clearly said that Thailand is an aseismic country. Seismic activity of Thailand is remarkably low compared with the adjacent countries, or Myanmar, India, China, Nepal, Japan and so forth.

8.3.4 Seismicity of Project Area

On retrieval from the earthquake data files of NOAA (National Oceanic and Atmospheric Administration) with regard to earthquakes in which tremors were felt in the project area, the results obtained were zero times within a radius of 200 km from the Lam Ta Khong upper reservoir site, 8 times within 500 km, and 543 times within 1,000 km.

As is clearly indicated by this, it may be considered that there has been no historical earthquake at this project site from 1959 to 1987 which should be considered in design of the dam and other structures.

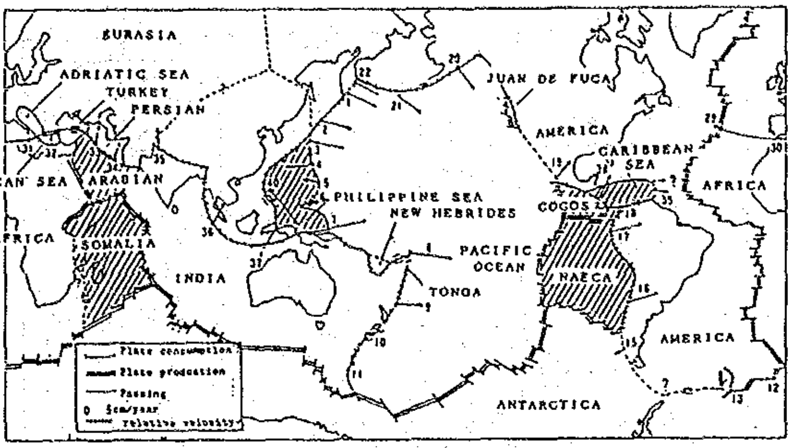


Fig. 8-4 Distribution of Major Tectonic Plates on the Earth and Plate Boundaries

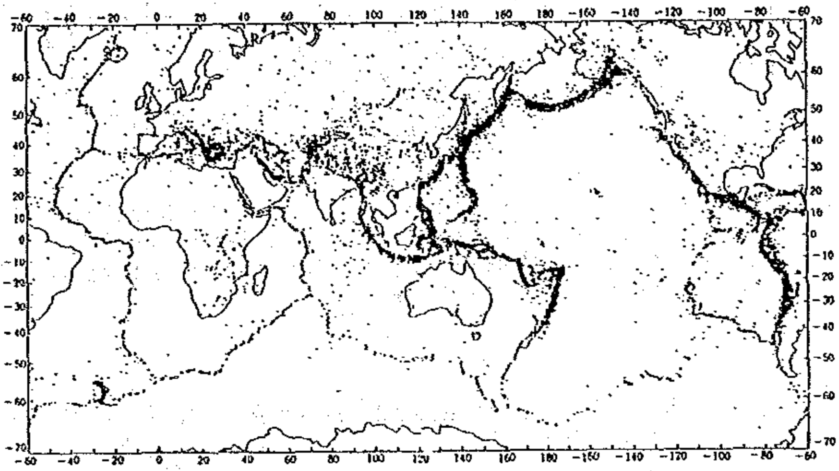


Fig. 8-5 Epicenters of Earthquakes of Magnitude : M ≧ 4 and Focal Depth : H ≦ 100 km which Occurred during the Period from 1964 to 1982 in the World

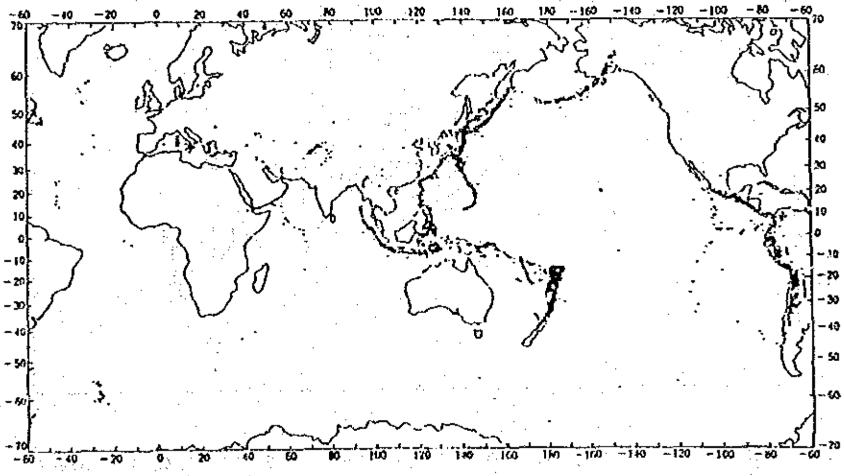


Fig. 8-6 Epicenters of Earthquakes of Magnitude: M ≧ 4 and Focal Depth : H ≧ 100 km which Occurred during the Period from 1964 to 1982 in the World

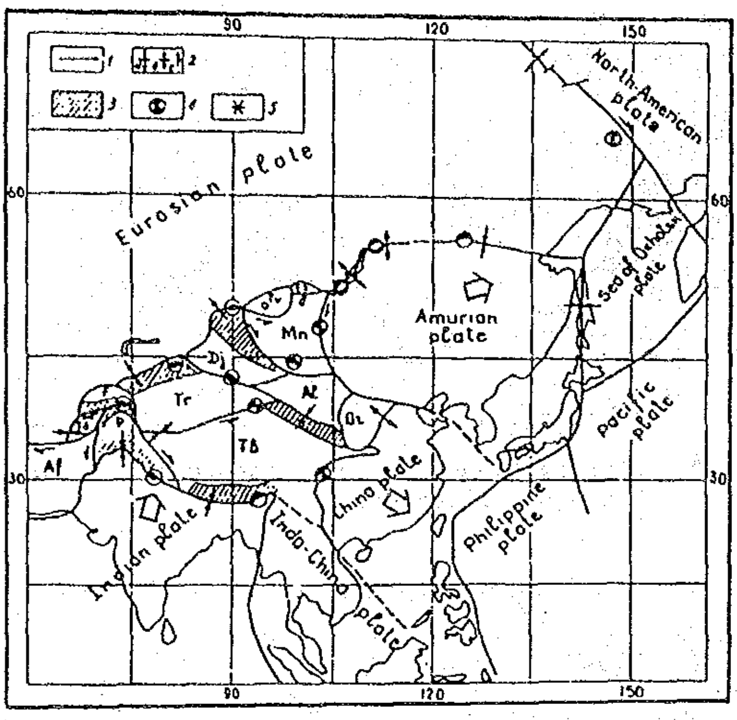


Fig. 8-7 Lithospheric Plates and Microplates in North-eastern to Middle Asia [after Zonenshain and Savostin (1981)] and the Direction of Micro Plate Movements relative to the India-Eurasia Collision

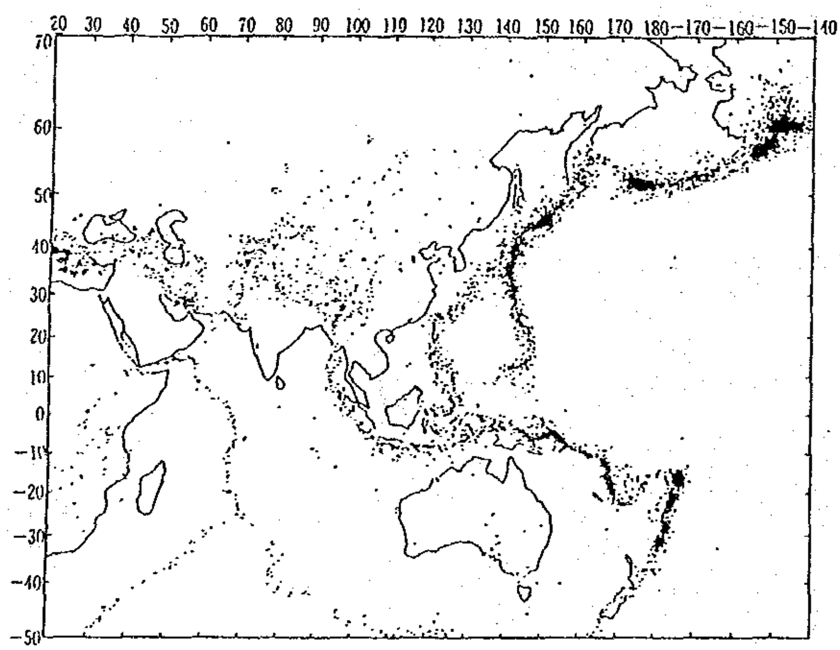


Fig. 8-8 Epicenters of Earthquakes Occurred in Asia

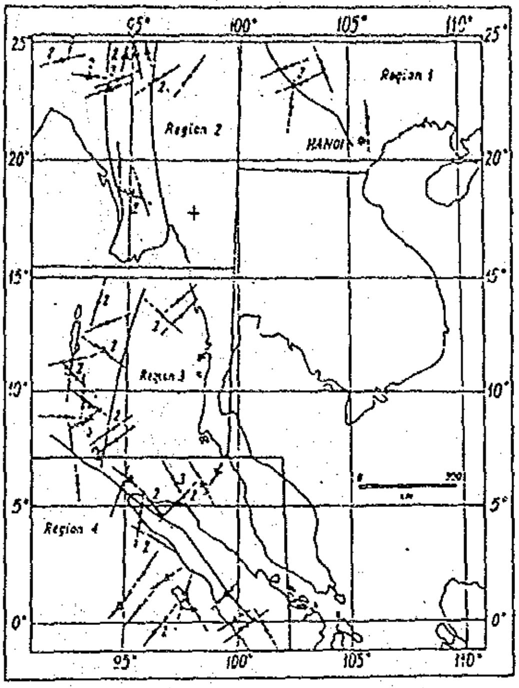


Fig. 8-9 Average Positions of Pressure Axes in Southeast Asia
Black dots and triangles show the location of single epicenters for shallow and intermediate earthquakes, respectively. The earthquakes with almost identical mechanism are shown by the numbers next to their average positions. The longest arrows indicate the plunge from 0 to 30°, the medium arrows from 31 to 60°, and the shortest from 61 to 90°. The solid lines show the main geological faults.

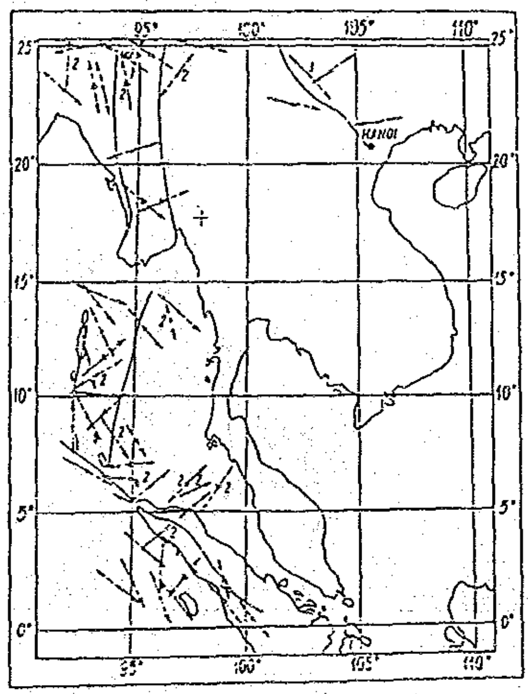


Fig. 8-10 Average Positions of Tension Axes in Southeast Asia
The symbols are the same as in Fig. 7-9.

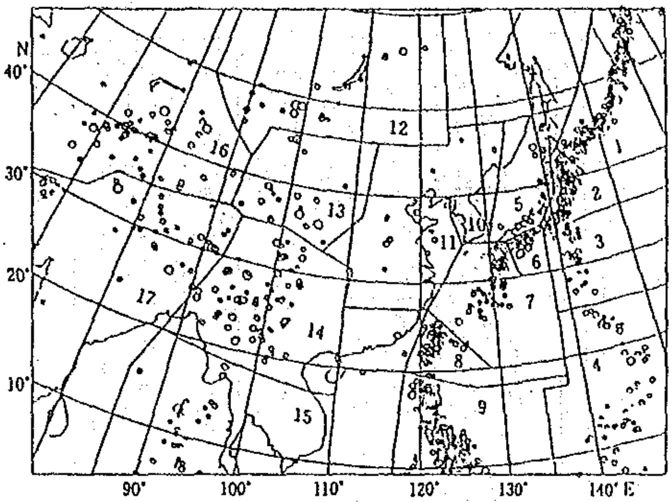


Fig. 8-11 Distribution of Shallow Earthquakes (M $\geq$ 6) since 1900

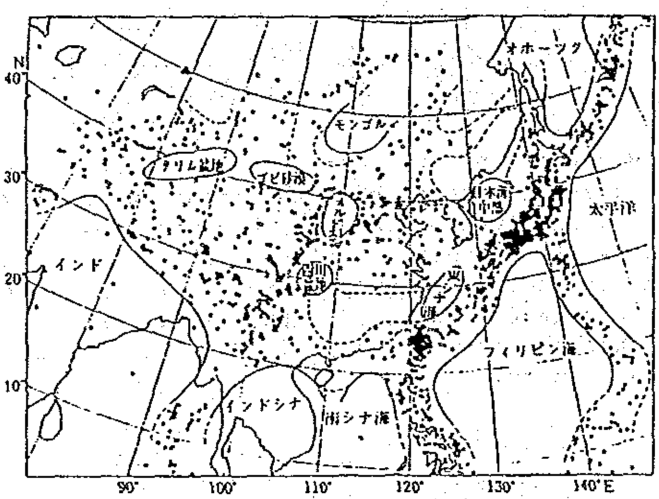
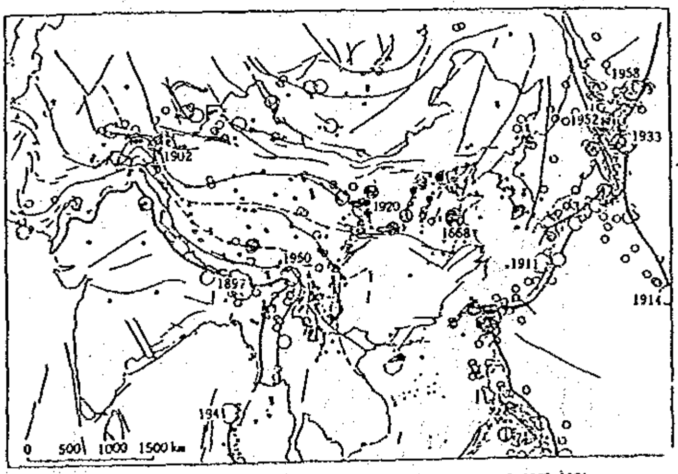


Fig. 8-12 Asismic Area in Asia



○ M≥8½ ○ M=8–8.4 ○ M=7–7.9 • M=6–6.9 ○ 1500–1739 ○ 1830–1971 • 1740–1829

Plate Boundaries — Large Fracture Zone

Quaternary Graben Zone

Fig. 8-13 Distribution of Epicenters of Strong Earthquake and Structural Lines in Asia

8.4 Seismic Risk Analysis

8.4.1 Estimation of Maximum Acceleration

(1) Seismicity Data

Seismicity data used in this study are based on those retrieved from "The Earthquake Data File" released from National Geophysical Data Center, National Oceanic and Atmospheric Administration. United States Department of Commerce. Regarding earthquake events having their epicenters within 1,000 km in radius from the project site, total number compiled in the file is 543 during the period from 1959 to 1987.

Taking the attenuation characteristics of the peak amplitude of the earthquake ground motion into account, it can be judged that the range of 1,000 km in radius from the site is enough for estimation.

(2) Attenuation Models

Of previously proposed attenuation models which express peak ground acceleration A (gal), in terms of earthquake magnitude M, and hypocentral distance R (km), or epicentral distance D (km), the following four models are used in this study.

$$\text{Log } A = 3.090 + 0.347 M = 2 \text{ Log } (R + 25) \quad (1)$$

proposed by C. Oliveira

$$\text{Log } A = 2.674 + 0.278 M - 1.301 \text{ Log } (R + 25) \quad (2)$$

proposed by R. K. McGuire

$$\text{Log } A = 2.041 + 0.347 M - 1.6 \text{ Log } R \quad (3)$$

proposed by L. Esteva and E. Rosenblueth

$$\text{Log } A = 2.308 + 0.411 M - 1.637 \text{ Log } (R + 30) \quad (4)$$

proposed by T. Katayama

(3) Gumbel's Extreme Value Theory

If the probability variable : x obeys the probability function G (x),

$$G(x) = Q\ (X \leqq x)$$

The probability that x is larger than each of X1, X2, ..., Xn is defined by:

$$Pn(x) = Q\ (X1 \leqq x,\ X2 \leqq x,\ \ldots,\ Xn \leqq x) = Gn(x)$$

And, the return period : T(x) and the transform variable Z are expressed by the following equation.

$$T(x) = 1/\{\ 1 - Pn(x)\ \}$$
$$Z \quad = -\ln\{-\ln Pn(x)\ \}$$

Use of Gumbel's theory (1958) does not require knowledge of the parent distribution. When applied to deal with the seismological problems, it gives the estimates of the frequency of occurrence of events on the extreme of a statistical distribution, and also given an estimate of recurrent times for these events, if the following main conditions involved in the development of theory are met :

1) The conditions prevailing in the past will definitely be valid in the future.

2) The observed largest events in a given interval are independent.

3) The behaviour of the largest earthquake in a given interval in the future will be similar to that of the past.

According to Gumbel, there are three types of asymptotic distributions of extremes, each corresponding to a specific type of behavior of large values of the variable.

The first type asymptotic distribution

$$Pn(x) = \exp [- \exp (-\alpha n)(x - V)]$$

The second type asymptotic distribution

$$Pn(x) = \exp [- (V - \varepsilon)/(x - \varepsilon)^k]$$

The third type asymptotic distribution

$$Pn(x) = \exp [- (W - x)/(W - V)^k]$$

In the first type asymptotic distribution, the variable is unlimited. The second type introduces a lower limit for the variable. And the third type introduces an upper limit. In this study, a probability function of the maximum acceleration expected at the project site is not known. However, it is reasonable to suppose that the function should be associated with the third type asymptotic distribution, because the maximum amplitude of earthquake ground motion for the arbitrary site should have an upper limit.

In the equation for the third type asymptotic distribution, W is an upper limit of a variable, k is a shape parameter, V is a characteristic value, and x is a random variable taken as logarithm of the maximum acceleration during a year-long interval, express as:

$$x = \log Amax$$

Plotting position of the ordered series is calculated by:

$$p(m) = (N - m + 1) / (N + 1)$$

where, N is the total years of record, and m is the order of the value from the largest one.

(4) Statistical Analysis Results

The seismicity data are used for 29 years from 1959 to 1987. Hence, a probabilistic model based on the "Gumbel's Extreme Values Theory" can be established by setting an equal time interval to one year.

Although a probability function of the maximum acceleration at the project site is not known, it is reasonable to suppose that the function should be associated with the third type asymptotic distribution.

The previously mentioned maximum acceleration values are plotted in Fig. 8-14 to Fig. 8-17. In these figures, two kinds of regression curves estimated for the third asymptotic distribution function are also shown by solid lines, from which the maximum acceleration for any return period can be evaluated.

The curve "B" is a result evaluated by method of least squares for all the annual maximum acceleration points, and regression curve "A" is a result evaluated to cross the annual maximum acceleration point.

Table 8-1 shows the maximum accelerations expected at the site for different three return periods of 50, 100 and 200 years.

According to the results of the statistical analysis based on the earthquake date from 1959 to 1987, the maximum acceleration by McGuire's equation are very large compared with the other equations, i.e. Oliveira's equation, Esteva & Rosenblueth's equation and Katayama's equation.

Table 8-1 Maximum Accelerations Expected at the Project Site for 4 Return Periods (gal)

Attenuation Model	Return Period (Year)		
	50	100	200
(1) by C. Oliveira	1.4	1.6	1.8
(2) by R.K. McGuire	12.0	13.0	14.0
(3) by Est. & Rosen	1.4	1.6	1.7
(4) by T. Katayama	4.4	5.0	6.0

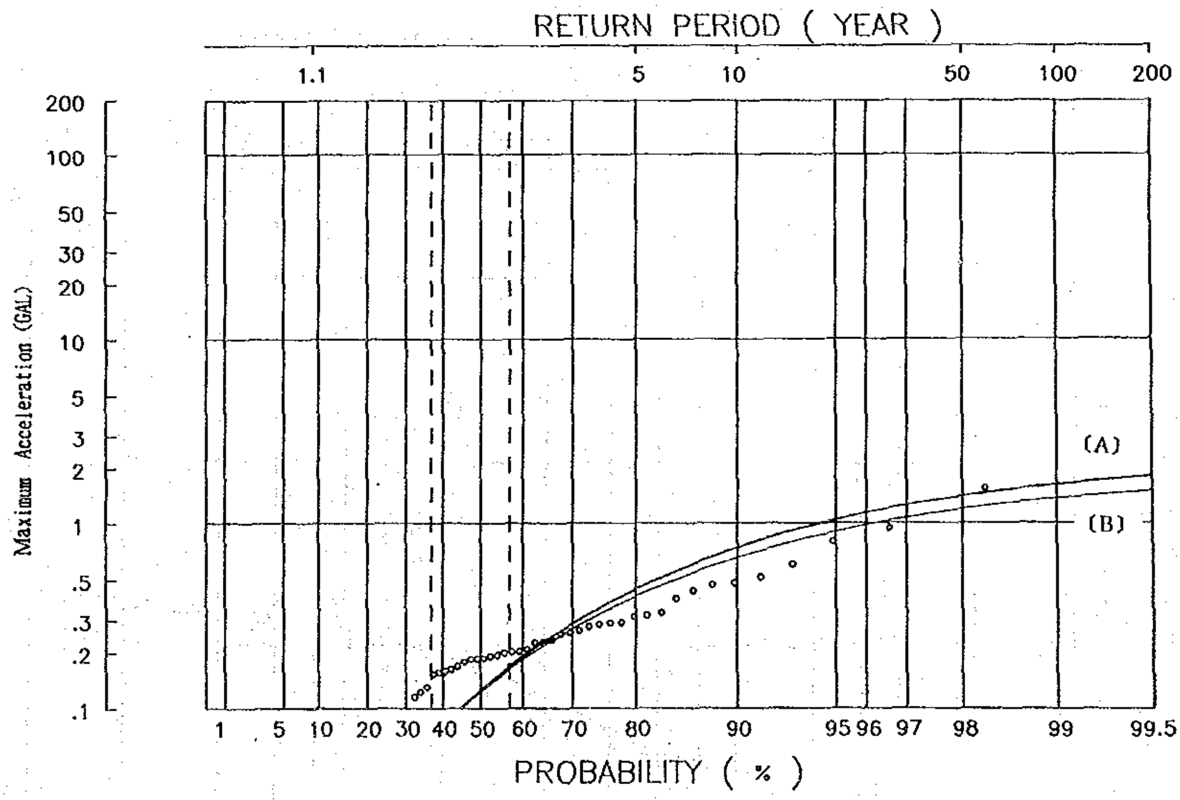


Fig. 8-14 Return Period for Maximum Acceleration Estimated by Eq.-(1)[Oliveira]

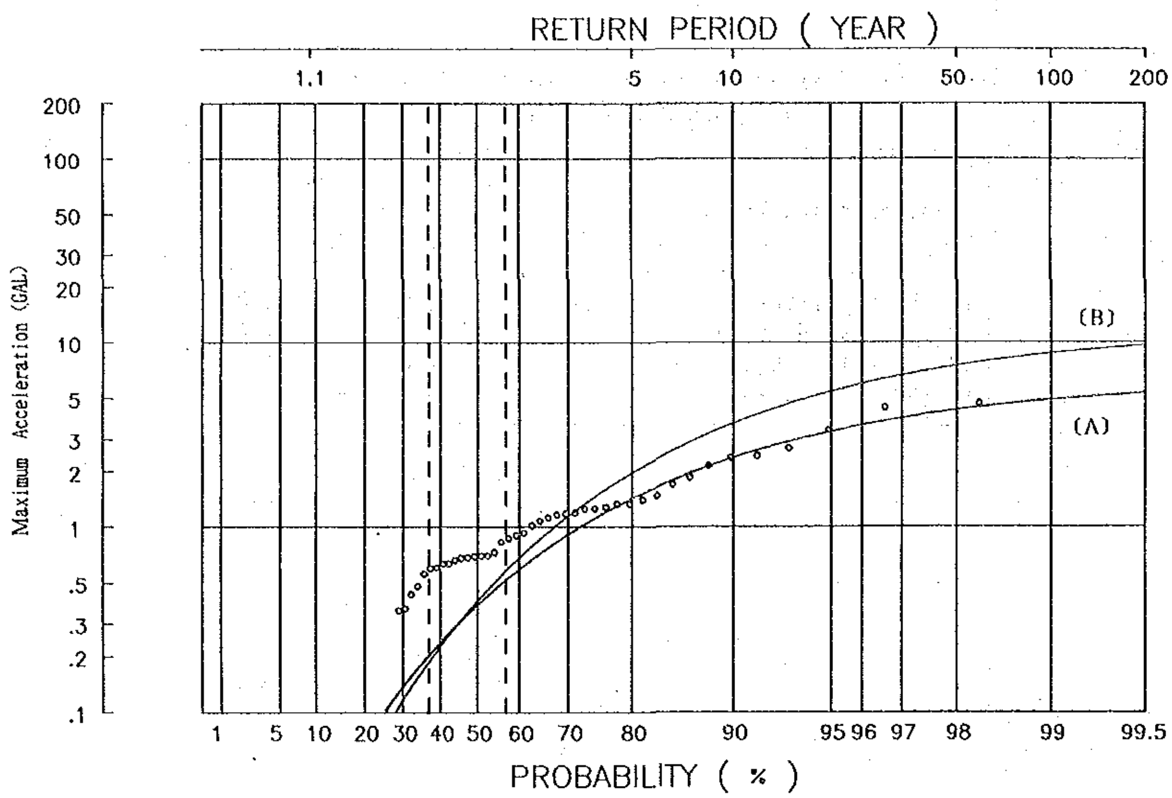


Fig. 8-15 Return Period for Maximum Acceleration Estimated

by Eq.-(2)[McGuire]

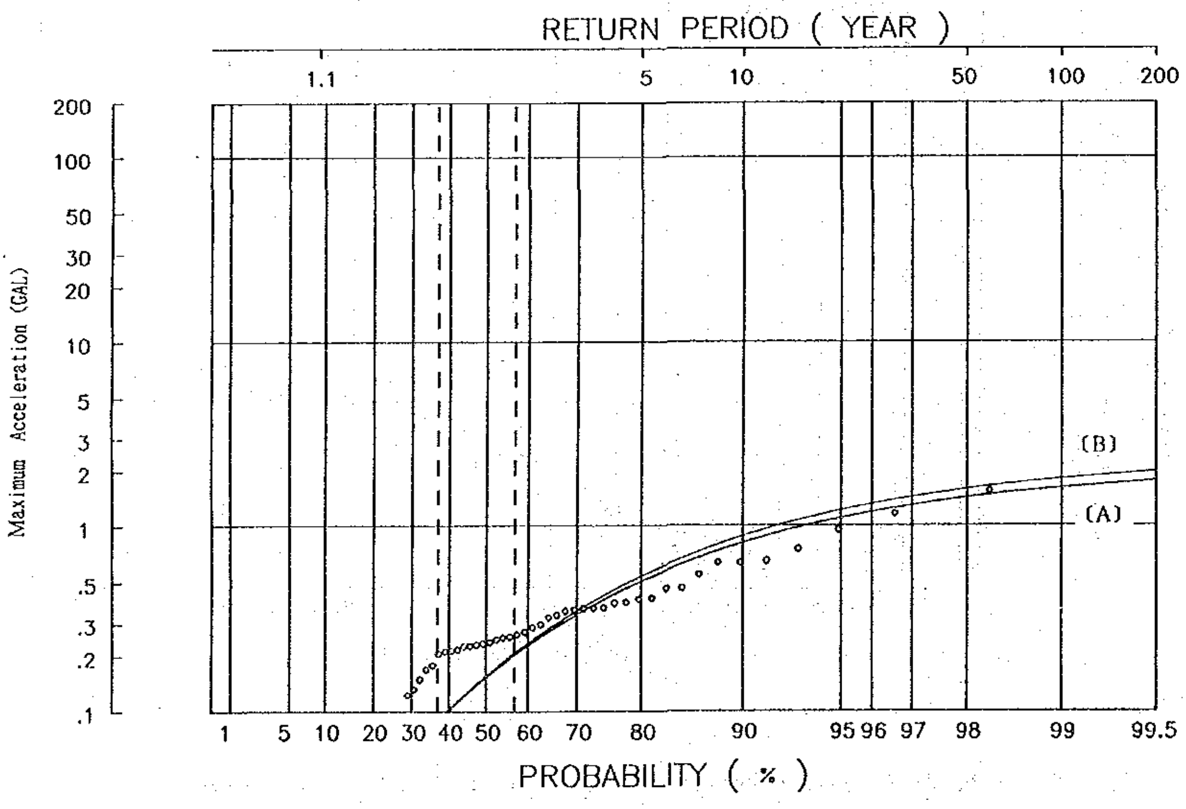


Fig. 8-16 Return Period for Maximum Acceleration Estimated

by Eq.-(3)[Esteva & Rosenblueth]

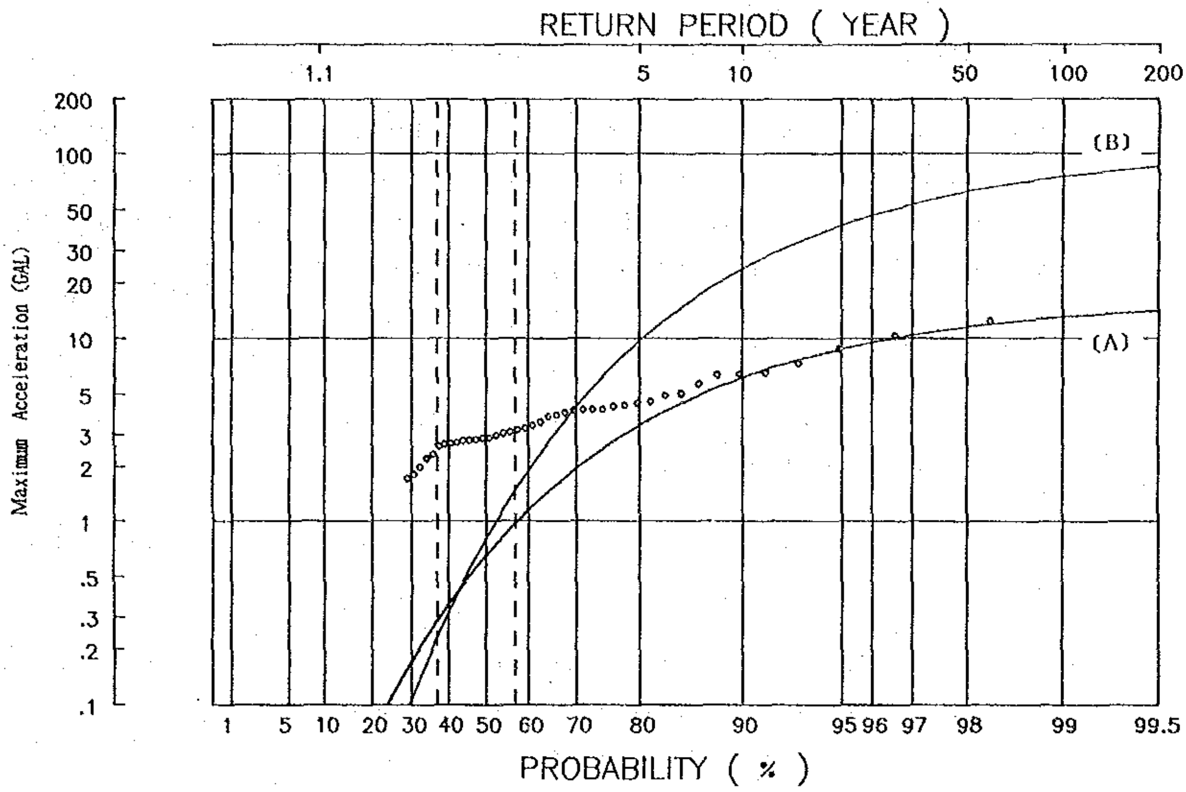


Fig. 8-17 Return Period for Maximum Acceleration Estimated

by Eq.-(4)[Katayama]

8.5 Design Seismic Intensity at the Project Site

There is now no established theory of relationship between seismic oscillations' maximum acceleration and design seismic intensity, but the following formula is used here. This formula has been proposed based on experienced information, and regarded as practical.

$$\alpha\ eff = R \times \alpha\ Amax/980$$

α eff: Effective design seismic coefficient
R: Reduction factor

(The values 0.5 to 0.65 are used as the coefficient of reduction according to experience.)

α : Design seismic coefficient
Amax: Maximum acceleration of the motion (gal)
980: Gravitational acceleration (gal)

The maximum acceleration of seismic oscillation was estimated at 20gal at most at the project site, according to the results of earthquake risk evaluated based on earthquakes in history.

The design seismic intensity is estimated in the following way.

$$\alpha\ eff = (0.5 \text{ to } 0.65) \times 20/980$$
$$= 0.01$$

According to the estimated value, the design seismic intensity at the project site has been adopted 0.05 in consideration of importance of the key structrues.

Since the clear locations of active faults near the project site have never been reported, the design seismic intensity (0.05) is regarded as appropriate.

CHAPTER 9

ENVIRONMENTAL IMPACT

CHAPTER 9 ENVIRONMENTAL IMPACT

CONTENTS

List of Drawing

CHAPTER 9 ENVIRONMENTAL IMPACT

9.1 Objective and Scope

The objective of environmental study is to recommend appropriate environmental/development measures in order to avoid or minimize adverse impacts.

This study is based on the investigation and findings conducted by the EGAT and the Khon Kaen University.

9.2 Watershed Classification

9.2.1 Background

Forest area in Thailand has been greatly reduced in the past two decades. In 1961, 57 percent of the country (29.12 million hectares) was covered by forests. Forest area declined to 37 percent in 1974 (19.04 million hectares) and 32 percent (16.33 million hectares) in 1982. Largest declines in forest area have occurred in northern portions of Thailand where forest area has declined from 67 percent in 1973 to 56 percent in 1978, a loss of 1.87 million hectares.

Forests have been converted to cultivated lands to provide food for a rapidly increasing population. Also export of agricultural products is very important economically, providing slightly less than 70 percent of Thailand's total export income per year. Currently, about 43 percent of the land area of Thailand is dedicated to permanent agricultural production.

The rapid agronomic expansion and population growth, which are causing changes in land use patterns, are of national concern. The Thai government has had a policy of managing forests for the benefit and welfare of the public.

The Fourth National Economic Development Plan (NESDB, 1977) has the following goals for conserving Thailand's forests:

(1) Maintain at least 37 percent of the total land area in forests.

(2) Reduce the present rate of deforestation (7600 square kilometers per year) to a rate not exceeding 800 square kilometers per year.

(3) Increase the rate of reforestation to 80,000 hectares annually.

(4) Increase wildlife conservation areas from 12 to 22 zones by increasing the number of national reserves (national parks) from 13 to 20.

(5) Implement reforestation programs in all significant watershed areas of the country with priority given to the north and northeast regions.

The above briefly highlights the critical need for a watershed classification method which will properly allocate land areas for various uses. The need for such classification in Thailand has been recognized for over 20 years, but only in recent years has a vigorous project been pursued.

A new committee was formed for the Watershed Classification Project in October 1979. The National Economic and Social Development Board provided funds to Kasetsart University through the National Environmental Board for conduct of the project. The National Environmental Board retained a technical panel of experts (the Watershed Classification Committee) for advice on technical aspects of the project.

9.2.2 Watershed Classification

The Watershed Classification process requires a system for establishing potential uses of land based on physical and/or environmental characteristics of landscape units. Physical characteristics of landscape units are stable features such as long-term average climate, elevation, slope, landform, geology, and soils. Environmental features of landscape units are less stable and interact with short-term climatic trends, human uses, and certain physical features which influence plant and animal populations.

A decision has been made to have five major watershed classes, ranging from 1 to 5, and watershed class 1 will be divided in two with 1A as protection forest and 1B as commercial forest or certain restricted agricultural uses. Watershed classes 2 to 5 are lower elevation lands with a broad range of agricultural uses. These are briefly described as:

WSC1. Class 1A are areas of protection forest and headwater source areas usually at higher elevation with very steep slopes. These areas should remain in permanent forest cover.

Class 1B are areas of similar physical features and environment to WSC 1A but portions of the area have been cleared for agricultural use or occupied by villages. These areas require special soil conservation protection measures and where possible should be replanted to forest or maintained in permanent agro-forestry.

WSC2. Class 2 are areas of protection and/or commercial forests (usually commercial forests). Usually at higher elevations with steep to very steep slopes. Landforms are less erosive than WSC 1A or 1B. Areas may be used for grazing or certain crops with soil protection measures.

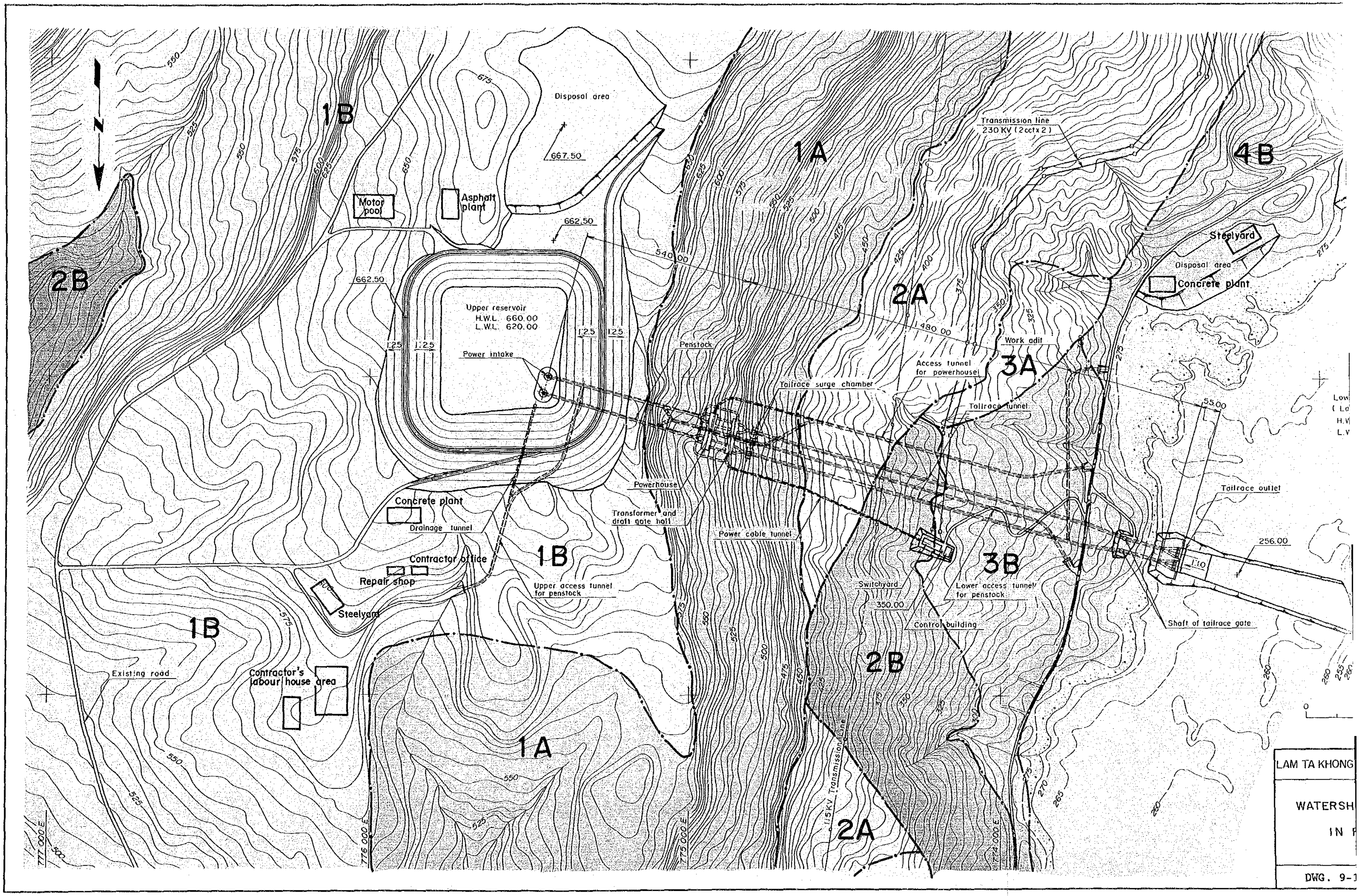
WSC3. Class 3 are areas of uplands with steep slopes and less erosive landforms. Areas may be used for commercial forests, grazing, fruit trees, or certain agricultural crops with need for soil conservation measures.

WSC4. Class 4 are areas of gently sloping lands suitable for row crops, fruit trees, and grazing with a moderate need for a few soil conservation measures.

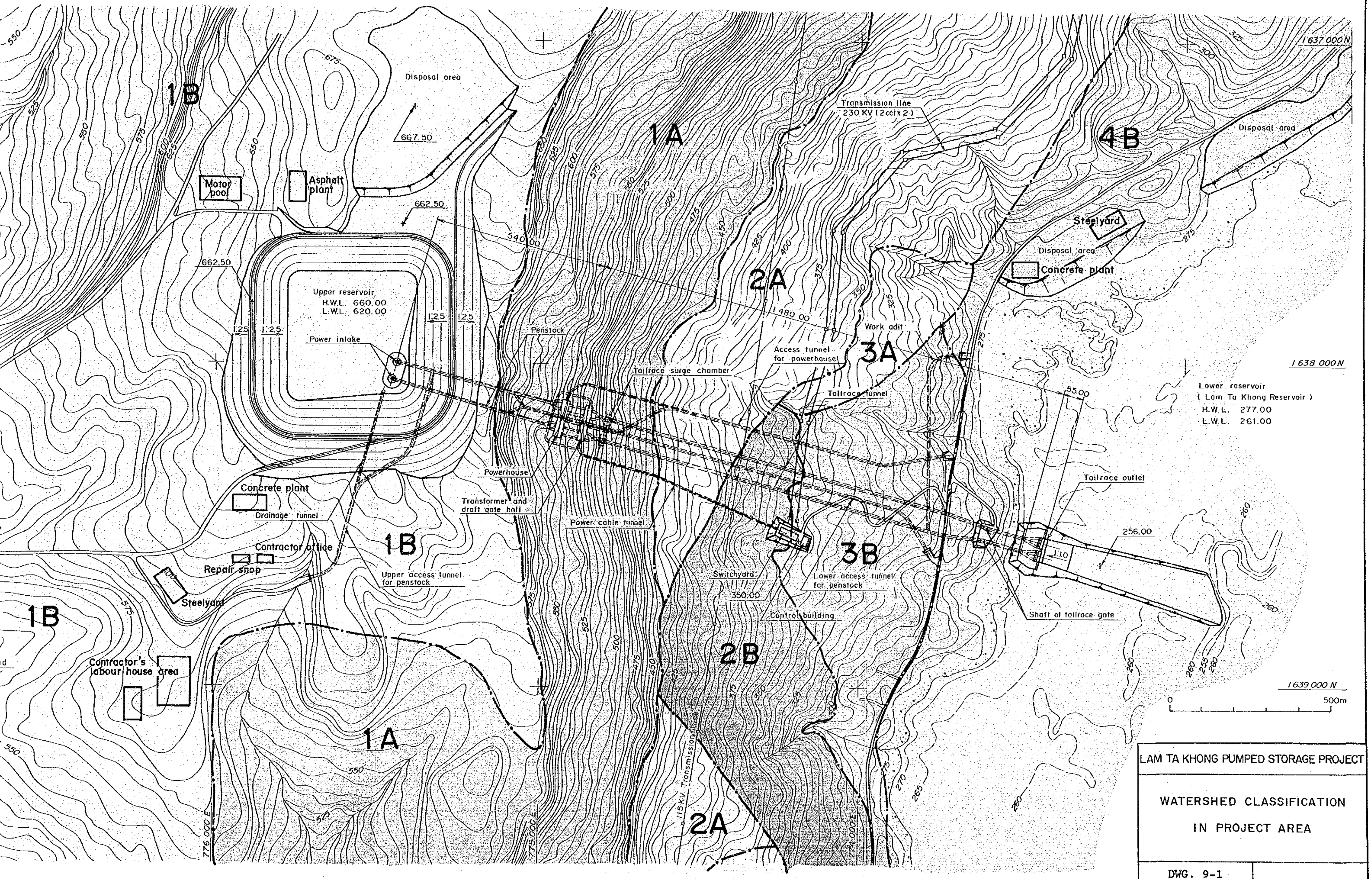
WSC5. Class 5 are gentle to flat areas used for paddy fields or other agricultural uses with few restrictions.

* WSC: Watershed Classification

Watershed classifications in the project area are shown on DWG. 9-1.



N
1B
1A
4B
2B
2A
3A
3B
Disposal area
667.50
Motor pool
Asphalt plant
662.50
540.00
Transmission line
230 KV (2cctx2)
Steelyard
Disposal area
Concrete plant
Upper reservoir
H.W.L. 660.00
L.W.L. 620.00
Power intake
Penstock
Tailrace surge chamber
Access tunnel for powerhouse
Work adit
1480.00
Tailrace tunnel
55.00
Powerhouse
Transformer and draft gate hall
Power cable tunnel
Concrete plant
Drainage tunnel
Contractor office
Repair shop
Steelyard
Upper access tunnel for penstock
Switchyard
350.00
Control building
Lower access tunnel for penstock
Tailrace outlet
256.00
Shaft of tailrace gate
Existing road
Contractor's labour house area
115 KV Transmission line
777 000 E
776 000 E
775 000 E
774 000 E
LAM TA KHONG
WATERSH
IN
DWG. 9-1



LAM TA KHONG PUMPED STORAGE PROJECT

WATERSHED CLASSIFICATION IN PROJECT AREA

DWG. 9-1

9.3 Physical Resources

9.3.1 Water Resources

<u>Surface Water Hydrology</u>

The length of the Lam Ta Khong River upstream from the reservoir to its origin is about 55 kilometers and the slope of the watershed area is about 1:360. The natural average annual reservoir inflow is 258.94 MCM. It was 110.00 MCM in the driest year (1968) and 495.00 MCM in the wettest year (1972). This will adequately support the Project development.

<u>Surface and Ground Water Quality</u>

For the existing Lam Ta Khong reservoir, the water quality in the upstream zone naturally fluctuates from season due to the fluctuation of flow and quality of inflowing water. The water quality in the downstream zone approaching the dam where the proposed intake/outlet site is located does not fluctuate, and there happens good mixing throughout the water body.

The anticipated impact from the Project implementation will be of two stages:

<u>Construction Stage.</u> The impact will be due to soil erosion and sedimentation resulting from the construction activities on land and the underwater works. This will increase turbidity in the reservoir water close to the construction sites.

<u>Operation Stage.</u> Pumping and discharge of water during the Project operation will influence the activities of aquatic animals, plants and benthal deposit in the vicinity of the intake/outlet site. This, in turn, may lead to dissolved oxygen depletion in the vicinity due to the decomposition of the death animals and plants. Algal bloom may also occur locally. However, these impacts depend on the degree of

mixing in the reservoir to transport the organic materials to the main water body, and the effectiveness of aquatic resource conservation measures.

For ground water quality, no impact is anticipated.

9.3.2 Land Resources

Soil

The soil in the area is unsuitable for crop production. Some erosion and sediment will occur during and after construction of the Project. To protect soil erosion, plantation at the disposal area must commence immediately after the construction activities have been completed.

Geology, Seismology, and Mineral Resources

Thailand can be considered a stable seismic region, except its northern part.

The results of Gammarays spectrometer survey and stream sediment samples analysis reveal that the area can be considered having low potentiality in mineral resources deposits.

9.4 Ecological Resources

9.4.1 Aquatic Resources

The concerned water body is the existing Lam Ta Khong reservoir which will be used as the lower reservoir. The aspects which have been covered in this study are: (1) Aquatic Biology, (2) Fisheries, and (3) Parasitology. The study has been carried out for two development stages: construction and operation.

Construction Stage. The anticipated impacts during the construction are:

- Increased erosion from the construction sites, i.e., intake-outlet and disposal sites and hauling routes, will increase sedimentation and turbidity in the vicinity along the shore line of the Lam Ta Khong reservoir which consequently disturb the activities of aquatic lives.

- Underwater work at the intake/outlet site will disturb the habitat of aquatic lives.

Operation Stage. The survey conducted on aquatic resources in the reservoir reveals the existence of high plankton density, various types of small fish, and fingerlings of some large fish at the proposed intake/outlet site. These fish have the habit of feeding at the area near the shore. Since the intake/outlet structure is designed to pump up or discharge the water at 1 m/sec, there will be few possibilities for the fishes to be pumped up. However, those fishes might happen to pass into the tailrace tunnel through the outlet.

9.4.2 Terrestrial Resources

The specific aspects covered in this study is forest/wildlife/rare species. The two areas of major impact to be anticipated from the Project are: the upper reservoir, and the switchyard/transmission line.

Naturally, the degree of impacts are high during the construction stage; and with proper mitigation and development, the impacts will lower to normal with time.

Upper Reservoir/Disposal Area. At present, the area is mostly occupied and is used for cassava and cashew plantation, and abandoned grassland. Only small number of timber trees were found.

No evidence of big mammal was found at the site. Only about 30 species of birds were found. Eventhough the area has been dedicated to be the watershed classification 1 B, from the ecological view point; the impact from the Project is very small. In fact, positive impact can be enhanced through proper development in conjunction with the Project implementation.

Transmission Line. The proposed area where the transmission line will be constructed is composed mainly of secondary bamboo clumps and Mimosa (Krathin) plantation. In terms of wildlife, there are some jungle fowls and birds utilizing this area as their habitats. During or after the construction of the transmission line, there would be moderate impacts on both the plantations and wildlife in the area. However, it is quite certain that the wildlife eco-system could be restored once the construction is completed.

9.5 Human Use Values

9.5.1 Water Management

The studies topics under water management are: (1) irrigation, (2) water supply, (3) water pollution and control, (4) flood control, and (5) water balance.

Minor impacts can be anticipated from the Project implementation during both construction and operation stages.

During the construction stage, slight deterioration of water quality in terms of turbidity is expected to occur due to erosion, underwater work, soil hauling, and disposal activities.

However, this will occur in the area far from the water supply intake site and the turbid water will be treated in the stilling basin, thus no disturbance is expected.

During the operation stage, it is estimated that the effective storage capacity of the Lam Ta Khong reservoir (the lower reservoir) will be decreased about 5 MCM or about 1.7% of the existing effective storage capacity upon utilizing the upper reservoir capacity of 8 hours. This might restrict the existing water use activities to some extent in dry years. The identified impacts are:

<u>Irrigation</u>

Water requirements in dry seasons (September - January) are 138 MCM and 8.9 MCM for irrigating paddy and mung bean respectively. In other words, the total is about 51% of the effective storage of the reservoir. Restriction of water availability may slightly affect the irrigation water requirement during drought periods.

Water Supply

At present, water from the Lam Ta Khong reservoir serves Nakhon Ratchasima municipality, sanitary districts, villages, and industries totalling about 22.4 MCM per year or about 7.7% of the effective storage of the reservoir. This demand is increasing with the growth of the communities and should be considered as top priority in water allocation. Nevertheless, this water requirement shares a small percentage of the overall water demand comparing to the irrigation requirement. Thus, small direct impact is anticipated, provided that water is appropriately allocated in the future.

Water Pollution and Control

At present, a serious water pollution condition occurs in the Lam Ta Khong river reach downstream from Nakhon Ratchasima municipal area. At present the allocation of water fails to maintain low flow in order to prevent water pollution. The Project impact on restricting water availability will consequently increase the water pollution problem to some extent. However, this may be considered as minor impact. The effective measures for the problem should be the improvement of sewage facilities of Nakhon Ratchasima municipality.

9.5.2 Land Use and Dedicated Area

The upper reservoir is on the most part of gently dipping plateau with field crops and fruit trees. The major vegetation covers with field crops and fruit trees. The major vegetation covers in this area are maize, cashew nut, mango, etc. Shrubs, small remands trees, woody weed and a limited varieties of grasses have been found. In the dry season, only grass and imperata with woody weeds are frequently observed.

Underlain access tunnel and other facilities passing through the scarp zone correspond to shrub/herbaceous and a small area of semidense forest. Care must be taken in the scarp zone which corresponds to 1A watershed classification.

9.5.3 Agricultural Development

Agricultural development activities under this study are: (1) Aquaculture, (2) Reforestation, and (3) Agriculture. In general, no direct impact from the Project implementation is anticipated. The summaries of existing condition are as follows:

Aquaculture

Since there were a lot of existing small-scale fish farming systems at downstream of the Lam Ta Khong reservoir, the amount of water released from the reservoir into the irrigation canals plays a very crucial role in these activities. Farmers draw water from these canals into their fish ponds.

Reforestation

So far there has been no reforestation activity in the proposed areas. The reforestation scheme being planned for the upper reservoir disposal site and its vicinity and the lower reservoir disposal site could have moderate positive impact upon both aesthetic value and wildlife especially birds in the areas.

Agriculture

In the irrigation area along the Lam Ta Khong river downstream from the dam, there are agricultural activities as follows:

- About 98,855 rai is used for growing rice during rainy reason.

- About 5,880 rai is used for growing vegetable.

- Less than 50,000 rai is used for dry season cropping.

- The farmers prefer to grow the crops with less water demand and short growing season.

9.5.4 Transportation

Assessment of the expected environmental impact of the Project implementation will be performed only on highway transportation system. This is because the construction will not affect the railway and navigation systems.

Main Highway. The annual average daily traffic (AADT) on Route 2 (at Station 181 + 800) was very high (11,604 vehicles per day). This coupled with the very high percentage of heavy vehicle composition (56-62%) and the relatively high annual traffic growth rate of approximately 11% can cause traffic congestion and accidents, and also accelerate pavement deterioration. However, this highway section under improvement can reduce traffic congestion, traffic accidents, and pavement deterioration. Consequently, the expected little traffic volume generated from the Project during construction and during early will not affect the traffic flow characteristics.

Access Road. The existing traffic volume on the main access road leading to the upper reservoir is very low. This is because the number of villagers living in the Project area is very small. The expected traffic volume during the construction will not bring about traffic congestion on this access road. However, the traffic volume generated during the construction period partly consists of heavy trucks. This coupled with the bad existing access road surface conditions will rapidly deteriorate the existing road surface particularly in rainy season, and will easily cause traffic accidents. Hence, the running surface is needed to be improved.

9.5.5 Recreation

From field investigation on the recreation area of the Lam Ta Khong reservoir, it was found that the upper reservoir site has high potential for recreation development because of its good accessibility and suitability regarding terrain development and good view for sightseeing. The popularity of the Lam Ta Khong area for recreation activities will then bring visitors to the Project site if appropriate facilities are provided. No adverse effect is found on the aspect of recreation development. In fact, the Project site will promote the recreation activities.

9.5.6 Socio-Economic

Socio-Economic

Socio-Economic overview of the people in the vicinity of the upper reservoir site can be described as follows:

- The majority of the heads of family are engaged in agriculture with a small proportion dealing with casual labour.

- Approximately 65% of these families have their own farm land (average holding = 23 rai.)

- About 78% of the farm land is used for growing upland crops, i.e., maize, baby corn; and a small section being used for trees and fruit trees.

- The average annual income of the families in this area is 86,555 Baht, 47% of this is from off-farm income. For the remaining on-farm income, 57% is derived from livestock and the rest comes from vegetables and upland crops.

The Project implementation will not directly affect the households, only part of their farm land will be inundated by the upper reservoir and the disposal area.

Compensation and Resettlement

No resettlement is needed for the Project.

The compensation is required for:

(1) Farm land of approximately 938 rai (150 ha.)
(2) Approximately 9,300 trees and fruit trees

Public Health/Public Safety

The households in the surrounding area which receive no impact from the Project were found to be in a good environmental sanitary condition. Most households have proper latrine. Boiling of drinking water is however, usually not practiced. Burning is a main method for patients who were of diarrhoea, pyrexia of unknown origin, dysentery, and conjunctivitis.

9.5.7 Culture

Neither archaeological artifacts nor trace of ancient settlement were found in the Project area. There is no archaeological or historical site on the top of Khao Yai Thiang (the upper reservoir site). The Lam Ta Khong Pumped Storage Project will not impact on archaeological or historical site.

9.6 Mitigation and Development Measures

9.6.1 Needs for Mitigation and Development

The Project impacts on environmental resources/values are of two types:

- Short-term impacts occurring during construction, and
- Long-term impacts occurring during operation.

The impacts of the first type are generally confined in specific areas and can be avoided or minimized by proper mitigation measures practicing in conjunction with the construction as follows:

- Measures for minimizing erosion/sedimentation
- Measures for minimizing dust, noise, and vibration
- Measures for traffic control
- Measures for health and safety.

The impacts of the second kind could be of both positive and negative impacts. The measures needed for enhancing positive impacts and/or for alleviating negative impacts are of both non-structure and structure types.

The measures needed are:

(1) Compensation and occupation development for the inundated land owners at the upper reservoir site.

(2) Fisheries resource conservation and development in the existing Lam Ta Khong reservoir.

(3) Land rehabilitation and development, for the disposal sites and vicinities.

(4) Tourism and recreation development to promote the use of tourism resource potential being enhanced by the Project.

(5) Water use planning to properly allocate the available water in the Lam Ta Khong reservoir to meet future requirements.

From the above five measures, the measures (1) to (4) are considered as structural type requiring capital cost for implementation; the measure (5) are non-structural.

9.6.2 Mitigation/Development Measures

(1) Compensation and Occupation Development

Based on the socio economic study, the only village to be affected directly from the Project is Ban Khao Yai Tiang Mu 6, Amphoe Si-khiu, Nakhon Ratchasima province. However, no household will be affected. The affected area at the upper reservoir site and the disposal area is currently used for cultivation of field crops (e.g., maize, cassava) and cashew planting.

The estimated direct impact to the people concerned will be:

- Approximately 9,300 trees and fruit trees of 18 different types will be cut down.
- Approximately 30 households will lose their farm lands totalling about 1.5 km^2.
- The affected people will consequently change their ways of life and/or career. Some may have to move to other places.

The recommended mitigation/development measures are to provide compensation to the affected people at reasonable rate, and to promote suitable occupation to these people.

(2) Fisheries Resource Conservation and Development

The survey conducted on fish species in the Lam Ta Khong reservoir reveals the existence of various types of small fish and fingerlings of large fish.

These fish feed at the area near the shore. Though the modes of life of fishes concerned has not been studied in detail, those fishes might happen to pass through the outlet into the tailrace tunnel.

The countermeasures of preventing fishes from passing through the outlet are generally classified into 4 methods.

- Sound-making method by loudspeaker in the water
- Coloured-lightening method
- Net-barrier method
- Low-voltage electrification method

(3) Land Rehabilitation and Development

The physical aspects of the project area will be changed after the construction. That means the aesthetic aspects and values of the site will be consequently changed. The changing environs of the physical aspects of the project area are much related to aesthetic aspects. So there must be much attention in improving and managing the environment in order to enhance the aesthetic values.

To fulfill the project goal, especially in aesthetic aspects and amenity for human use values, it is necessary to find out the proper development that suits the project sites.

To enhance the aesthetic values for recreation development in the project area, the natural beauty can be encouraged by reforestation and landscaping.

It is necessary to manage and improve the changed physical aspects of the project area in the proper ways, such as provide the proper activities to each site, create more attraction and more appreciation of environment both natural features and man-made features.

Another important development for aesthetic aspects achievement is providing and developing the proper and good accesses and routes to each sites.

(4) Recreation Development

The Project implementation will enhance recreation development potential for two reasons. First, the upper reservoir itself has many scientific attraction to public. Second, the disposal area nearby the lower reservoir along Route 2 provide a site for more interesting views with its broader vista.

So there must be some controls and guidelines about the activities and the changing environmental aspects caused by the project.

From the impacts that effect to the quality and potentiality of the area for recreation development as mentioned, there are two zones suited for recreation development; the upper reservoir area and the lower reservoir area.

In order to enhance the recreation activity development in this two zones, the development plans and measures have to be established.

To meet the project aims, the recreation activity development must be integrated with another developments i.e., the reforestation development and the transportation development.

CHAPTER 10

DEVELOPMENT PLAN

CHAPTER 10 DEVELOPMENT PLAN

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CHAPTER 10 DEVELOPMENT PLAN

10.1 Methodology and Basic Conditions

10.1.1 Methodology

The objective of this chapter is to determine the optimum development plan of the Lam Ta Khong Pumped Storage Project (hereinafter, the Lam Ta Khong Project), according to the methodology mentioned below.

(1) Layout of the project is studied from viewpoints of topography, geology, environmental regulations and economics to select the optimum layout.

(2) The development scale is studied from a viewpoint of demand-supply balance, unit capacity and power system's stability. The studies on demand-supply balance and power system's stability are carried out in Chapter 5 and 11, respectively. The study on unit capacity is carried out in this Chapter.

(3) Development scale is studied from the optimization study using benefit and cost of the project. This study consists of "Investigation Stage" and "Feasibility Design Stage". In the "Investigation Stage", an optimum development plan is selected from a viewpoint of the most effective utilizations of pumped storage resource of this site. In the "Feasibility Design" stage, the development plan is studied from a viewpoint of constraints of the development.

(4) The development plan is finalized taking into account the above-mentioned (1) to (3).

10.1.2 Basic Conditions

(1) Topographic Maps

The topographic maps listed below are available for the study of the Lam Ta Khong Project.

1:250,000	Entire project area
1: 50,000	Entire project area
1: 20,000	Reservoir area before the construction of the existing Lam Ta Khong Reservoir
1: 5,000	Vicinity of area covering the alternative (Alternative No. 1) of the right bank
1: 1,000	Area covering the main structure of the alternative (Alternative No. 1) the right bank

(2) Existing Lam Ta Khong Reservoir

The Lam Ta Khong Project uses the existing Lam Ta Khong Reservoir as the lower reservoir, which was constructed for irrigation by the Royal Irrigation Department (RID).

The storage capacity curves of the existing Lam Ta Khong Reservoir just after its completion (1968) and as of 1984 are available. The storage capacity curve as of 1984 as shown in Fig. 10-1 is used for this study.

The high water level (HWL), low water level (LWL) and effective storage capacity are 277 m, 261 m and 290×10^6 m^3 (as of 1984) respectively.

Since the Lam Ta Khong Power Plant is operated, the irrigation storage capacity of the existing Lam Ta Khong Reservoir is restricted unless the HWL is raised or the LWL is lowered. For example, the irrigation storage capacity of about 10 x 10^6 m^3 (5 x 10^6 m^3) decreases in case of the installed capacity of 1,000 MW (500 MW) and the reservoir capacity of 8 hours. It accounts for about 3% (1.7% for 500 MW) of the effective storage capacity. According to the past 20 years record of the Lam Ta Khong Reservoir's operation from 1968 to 1988, the lowest water level was 264.67 m (refer to Fig. 6-3) which corresponds to effective storage volume of 33 x 10^6 m^3. From the figure above, it can be said that even though the pumped storage project uses the storage capacity of 10 x 10^6 m^3, it does not cause shortage of the irrigation water in case the future condition of reservoir operation is same as the past condition. Therefore, this study is carried out under the condition that the pumped storage project can use its necessary capacity without changing the HWL (277 m) and LWL (261 m) of the existing Lam Ta Khong Reservoir.

The daily change of the water level is about 0.3 m/day (0.2 m/day) near the HWL and about 2.1 m/day (1.2 m/day) near LWL in case of the installed capacity of 1,000 MW (500 MW) and the reservoir storage capacity of 8 hours. It is considered that the daily change of the water level does not affect the stability of the existing Lam Ta Khong Dam and the land slope surrounding the reservoir.

(3) Intake Water Level and Tail Water Level

The intake water level for installed capacity of the Lam Ta Khong Power Plant is the water level corresponding to 2 hours operation from the HWL.

The tail water level is fixed at the water level of 10% exceeding probability obtained from the 19 years, records of monthly water level from 1969 to 1988 (see Fig. 6-3).

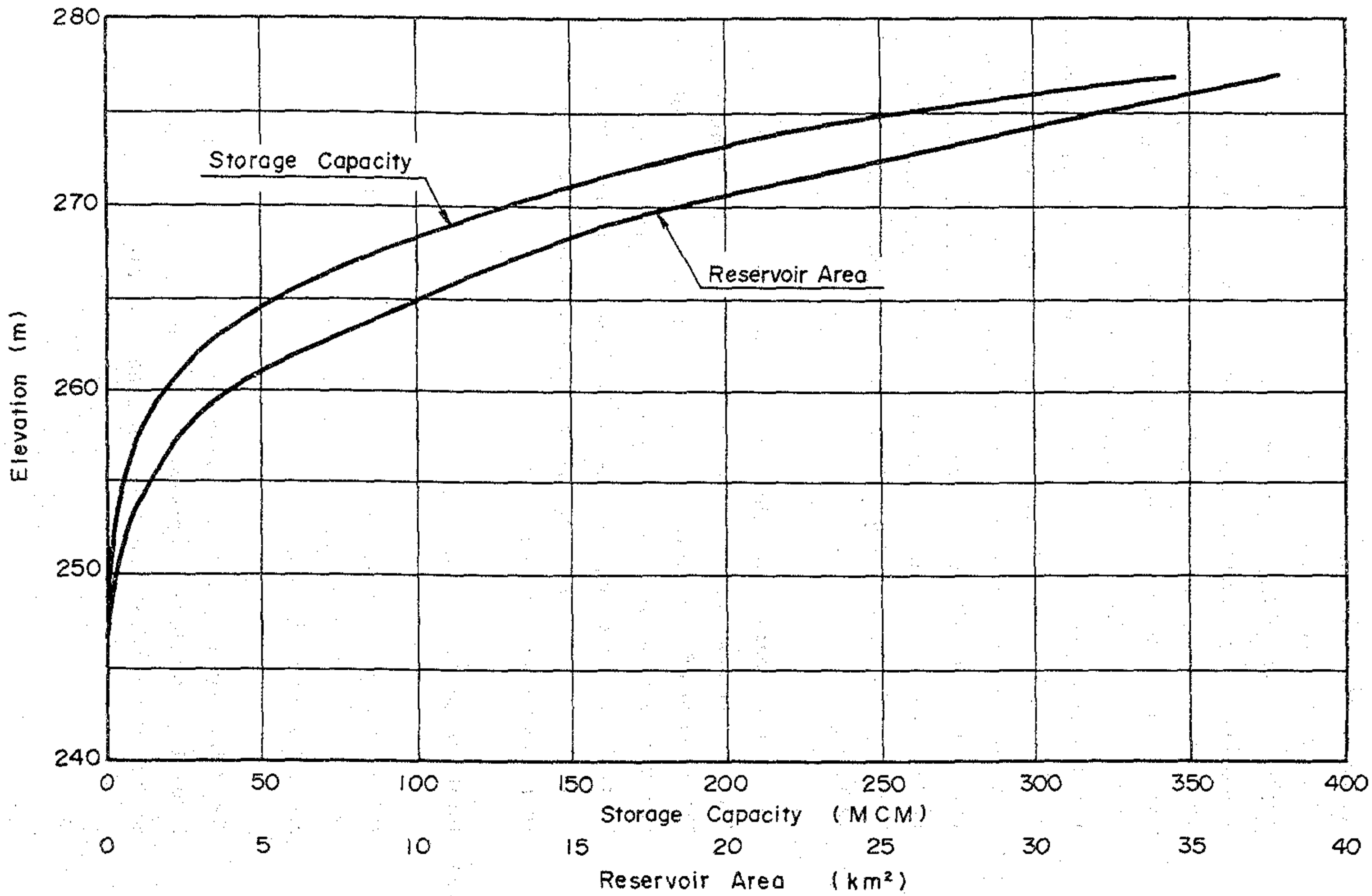


Fig.10—1 Reservoir Area and Storage Capacity Curve of Lam Ta Khong Reservoir

10.2 Selection of Optimum Layout

10.2.1 General

The objective of this section is to determine the optimum layout of the Lam Ta Khong Project.

Three alternative sites and five alternative routes shown in Fig. 10-2 were planned for the upper reservoir and the waterway respectively.

Site reconnaissance and preliminary study were carried out considering following points.

- Watershed Classification

  The watershed classification in the project area is shown in Fig. 10-2 in the Mum and Chi river basin, and the watershed classification is formulated as follows:

  - Class 1A area:

    In any case, the land use in this area is prohibited in order to protect the headwater of rivers.

  - Class 1B area:

    In case of public land use by government organization, the said organization should propose and report the environmental effect of the project to the National Environmental Board (NEB), and get the approval of NEB for the land use.

- Households Inundated

  The compensation and resettlement cost is not much, however social environmental matter caused by resettlement should be considered.

- Availability of Access Road, Length of Access Tunnel, Length of Transmission Line and Underwater Works

  These factors affect the construction cost of the project.

  Considering the factors mentioned above, characteristics of each alternative are described below and summarized in Table 10-1.

10.2.2 Characteristics of Upper Reservoir Site

(1) Alternative UR-1

The reservoir is created by a surface membrance type dam and is located on a terrace of right bank of the existing Lam Ta Khong reservoir.

Judging from the topography, HWL is about elevation of 640 m. An access road from National Highway No.2 to the site is available however it should be improved for construction of the reservoir.

The UR-1 area is classified to watershed class 1B.

(2) Alternative UR-2

The reservoir is an ordinary type dammed up by a rockfill dam at the upstream of a gully on the right bank.

The HWL is lower than about elevation of 590 m judging from the topography, and distance between the existing Lam Ta Khong reservoir and the upper reservoir is longer than UR-1. Accessibility to the project site is the same condition as UR-1.

The UR-2 area is classified to the watershed classification of Class 1B. This alternative has resettlement problem because there are about one hundred households in the upper reservoir area.

(3) Alternative UL-1

The reservoir is created by a surface membrance type dam and is located on a terrace of the left bank of the Lam Ta Khong reservoir.

The HWL is about elevation of 640 m similar to UR-1. Existing road from the Lam Ta Khong dam to the site is available, however it should be improved for construction of the Project. Present condition of the access road is worse than those of alternatives on the right bank. The most serious problem for this site is that this area is classified to watershed classification of Class 1A, in which land use is prohibited in any case in order to protect the headwaters of rivers.

10.2.3 Characteristics of Route of Waterway and Location of Powerhouse

(1) Alternative WR-1

This alternative connects the upper reservoir UR-1 and the Lam Ta Khong reservoir with the shortest waterway.

Accessibility to the powerhouse is good, since National Highway No.2 passes along right shore of the Lam Ta Khong reservoir. In case of a underground type powerhouse, the access tunnel to the powerhouse and the cable tunnel are about 1,000 m and 600 m long respectively.

(2) Alternative WR-2

This alternative connects the upper reservoir UR-1 and the Lam Ta Khong reservoir without passing the area of watershed classification of Class 1A. However, length of the waterway is about 2,000 m longer than that of WR-1.

Accessibility to the powerhouse is almost same condition as that of WR-1.

(3) Alternative WR-3

This alternative connects the upper reservoir UR-2 and the Lam Ta Khong reservoir. However, length of the waterway is about 1,000 m longer than that of WR-1.

The accessibility is same condition as WR-1.

(4) Alternative WL-1

This alternative connects the upper reservoir UL-1 and the Lam Ta Khong reservoir. Length of the waterway is about 300 m shorter than that of WR-1 and shortest in all alternatives, however quantity of underwater works in the Lam Ta Khong reservoir is much more than WR-1.

This alternative has the following two problems.

- Access road to the project site about 6 km long should be newly constructed, since existing road along the left bank of the Lam Ta Khong reservoir is not available.

- Length of the transmission line is about 25 km longer than the alternatives of WR-1, WR-2 and WR-3 located on the right bank of the Lam Ta Khong reservoir.

(5) Alternative WL-2

This alternative connects the upper reservoir UL-1 and the Lam Ta Khong reservoir. Quantity of underwater works in the Lam Ta Khong reservoir is less than WL-1, however a tunnel of the waterway is longer than WL-1.

Concerning the access road to the project site and the length of transmission line, this alternative has the same problems as WL-1.

10.2.4 Determination of Optimum Layout

(1) Upper Reservoir Site

Concerning the selection of the upper reservoir site, two important matters should be considered. One is watershed classification, and the other is resettlement.

Alternative UL-1 has a problem of the location in the area of watershed classification of Class 1A.

Alternative UR-2 has the resettlement problem. Besides, the effective head between upper and lower reservoirs of this alternative is smaller than other alternatives, since the HWL is lower than other alternatives.

On the other hand, Alternative UR-1 is located in watershed classification of Class 1B, in which the restriction on land use is not so strict as Class 1A, and this alternative does not have a resettlement problem.

As a result of the study above, Alternative UR-1 was selected as the upper reservoir site of Lam Ta Khong Project.

(2) Route of Waterway and Location of Powerhouse

Two alternatives, WR-1 and WR-2, were studied for the selected upper reservoir UR-1.

After consideration that the construction cost of WR-1 is about 12% smaller than that of WR-2, Alternative WR-1 was selected as the layout of the waterway and the location of the powerhouse of the Lam Ta Khong Project.

(3) Adopted Layout

As a result of study mentioned above, Layout No.1, the combination of the UR-1 and WR-1, was selected as the optimum layout of the Lam Ta Khong Project.

Table 10-1 Comparison of Alternative Layout

Layout / Description	No. 1	No. 2	No. 3	No. 4	No. 5
1. Upper Reservoir	UR-1		UR-2	UL-1	
1-1 Geology	Massive coarse sandstone and alternation of sandstone and siltstone of Phra Wihan formation. Coarse sandstone is hard and relatively solid, however the alternation is softened by weathering.		Alternation of sandstone and siltstone of Phra Wihan formation. Surface is softened and loosened by weathering.	Massive coarse sandstone and alternation of sandstone and siltstone of Phra Wihan formation. Coarse sandstone is hard and relatively solid, however the alternation is softened by weathering.	
1-2 Topography	Relatively flat terrace and appropriate topography for construction of surface membrance pond type reservoir. The Max. of HWL is about EL.640m.		U-shape vally and storage efficiency (storage volume /dam volume) is not good. The Max. of HWL is about EL.590m.	Relatively flat terrace and appropriate topography for construction of surface membrance pond type reservoir. The Max. of HWL is about EL.640m.	
1-3 Watershed Class	Class 1B.		Class 1B.	Class 1A.	
1-4 Compensation and Resettlement	———		About one hundred households.	———	
1-5 Accessibility	Existing road should be improved.		Existing road should be Improved.	Existing road should be improved. Present condition of existing road is worse than that of the right bank.	
2. Waterway and Powerhouse	WR-1	WR-2	WR-3	WL-1	WL-2
2-1 Geology	Waterway : Penstock is mainly located in alternation of sandstone and siltstone of Phra Wihan formation. Tailrace is located in siltstone, sandy siltstone and fine siltstone of Phu Kradung formation. Bedrock is assumed to be scarcely weathered, however silty part is assumed to be soft because of poor consolidation. Powerhouse : Bedrock is assumed to be composed of siltstone, sandy siltstone and fine siltstone of Phu Kradung formation. It is assumed to be fresh, however soft because of poor consolidation.				
2-2 Accessibility to Powerhouse	Good. Access tunnel and cable tunnel are about 1000m and 600m long, respectively.	Good. Access tunnel and cable tunnel are longer than WR-1.	Good. Access tunnel and cable tunnel are about 1000m and 600m long, respectively.	New road about 6km long should be constructed from exsisting Lam Ta Khong dam. The length of access tunnel and cable tunnel is similar to WR-1.	
3. Transmission Line*	About 11km			35 ~ 40km	
4. Construction Cost per kW (%)**	100	112	111	106	107

* : Length from powerhouse to existng transmission line.
** : Including construction cost of transmission line and excluding resettlement and compensation cost.

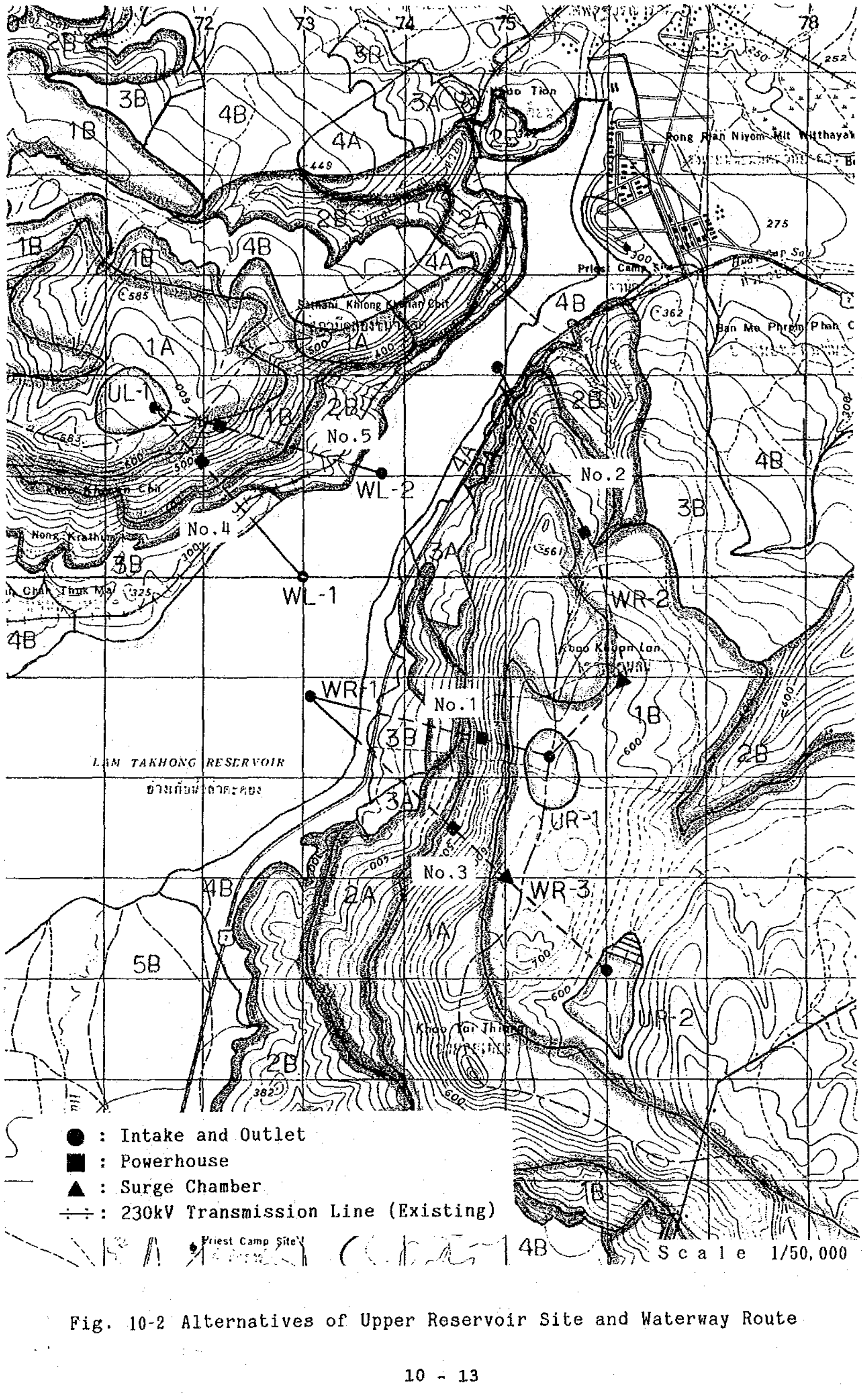


Fig. 10-2 Alternatives of Upper Reservoir Site and Waterway Route

10.3 Study on Unit Capacity

10.3.1 Necessity of Study on Unit Capacity from Power System

Generally, a power plant becomes economical in regard to machine cost and overall construction cost as the unit capacity of generating plant is larger. The unit capacity of Lam Ta Khong project should be chosen as large as possible in consideration of the reliability of the plant, manufacturing technique and means of transportation of equipment.

While the use of large capacity machines has the above economical advantage (scale-merit), it has a disadvantage of producing large frequency fluctuations in a power system at starting and stopping of pumping operation. Another disadvantage of using a large capacity unit is that it requires large operating reserve for its outages.

If the capacity of Lam Ta Khong pumped storage power plant is set at 600 MW or 800 MW, the unit capacity will be 150 MW or 200 MW. These are almost the same as the capacity of unit No. 4 and 5 (180 MW) of Srinagarind power plant and, therefore, the introduction of 200 MW unit does not cause any problems.

But if the capacity of the pumping power plant is set at 1,000 MW, the use of unit capacity of 250 MW is conceivable.

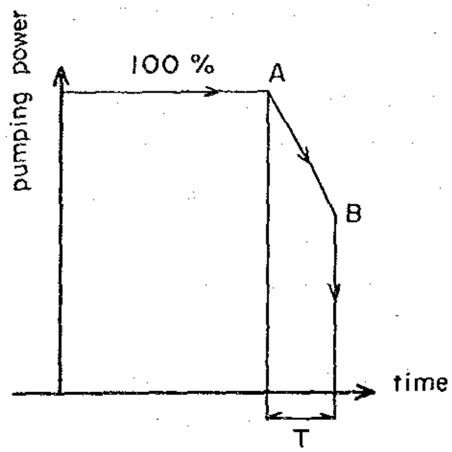
The third unit (600 MW) of Bang Pakong power plant will be the largest unit in Thailand power system in 1997 when Lam Ta Khong pumped storage is commissioned. Since the unit capacity of 250 MW is much smaller than this and, therefore, system disturbance caused by a failure of the unit during its generating operation is smaller than that caused by the thermal unit and no problems are likely to occur.

However, the introduction of a 250 MW unit to Lam Ta Khong project must be decided after examining frequency fluctuations during start and stop of pumping, because the system capacity of off-peak time falls to nearly one half of the level of the peak time, and power required for pumping increases by about 10% over generating output. Frequency fluctuations by pumping unit always occur at ordinary start and stop processes besides by unit failures.

10.3.2 Pumping Operation and Frequency Fluctuation

In normal operation of a pumped storage power plant, pumping stops cause very severe frequency fluctuations in a power system. It is clearly shown by the past records of EGAT power system as well. A frequency fluctuation by a pumping stop is a little larger than that by a pumping start.

Stopping of pumping operation is normally carried out by the process shown below.



A: A guide vane starts closing.

B: Pumping stops and the machine is disconnected from a power system.

T: Several tens of seconds

When the pumping stops, because of a sudden disconnection of load from a power system, the equilibrium condition between power supply and demand breaks. The imbalance between power supply and demand causes promptly rise of power system frequency from the level before pumping stop.

When pumping starts, an imbalance between power supply and demand also occurs. The power system frequency goes down at this instance.

The fluctuation of system frequency becomes larger as the amount of load change is larger, because the frequency control by power sources can not keep up with a rapid frequency change.

The deviation from the specified frequency causes numerous unfavorable influences to the facilities of suppliers and users of electric power. Especially, the resonace between the natural frequency of the turbine blades in the thermal power plants and power system frequency will cause a very serious damage to the machines. So, great care must be taken to avoid this condition and to safeguard the equipment.

10.3.3 Frequency Fluctuations at Pumping Start and Stop

The frequency fluctuation caused by a sudden change in system load can be estimated by the following equation.

$$\frac{\frac{\Delta P}{P}\times 100}{\Delta F}\times\frac{1}{10}=K$$

where Δ P = Power supply - demand imbalance (MW)
P = System capacity (MW)
Δ F = Amount of frequency fluctuation (Hz)
K = Power-frequency characteristic (%MW/0.1Hz)

Power frequency characteristic K varies for each power system and fluctuates depending on to the frequency characteristics of the load, kinds of power sources and their operating conditions. However, in general, 1 - 2 %MW/0.1Hz is used for K value.

K value for EGAT power system has been estimated from the past records of load change and frequency fluctuation.

Table 10-2 shows actual frequency fluctuations in EGAT power system which were caused by pumping starts and stops of the unit No.4 of Srinagrind power station (motor input : 200 MW).
From this table, the power-frequency characteristic K was estimated to be 1.47 (%MW/0.1Hz) at a pumping start with standard deviation 0.35(%MW/0.1Hz), when frequency is going down. K was also estimated to be 1.08(%MW/0.1Hz) at stop of pumping with standard deviation 0.24(%MW/0.1Hz), when frequency is going up.

Using these values, frequency fluctuation Δ F caused by pumping start and stop of a machine with capacity of 250 MW can be estimated in the power system of Thailand in 1997, when Lam Ta Khong pumped storage power plant will be commissioned.

At pumping start

$$\Delta F = \frac{1}{K} \times \frac{\Delta P}{P} \times 100 \frac{1}{10}$$

$$= \frac{1}{1.47 \pm 0.35} \times \frac{-250 \times 1.1}{13835 \times 0.5} \times 100 \times \frac{1}{10}$$

$$= -0.22 \text{ (min)}, -0.36 \text{ (max)}$$

At pumping stop

$$\Delta F = \frac{1}{K} \times \frac{\Delta P}{P} \times 100 \times \frac{1}{10}$$

$$= \frac{1}{1.08 \pm 0.24} \times \frac{250 \times 1.1}{13835 \times 0.5} \times 100 \times \frac{1}{10}$$

$$= +0.30 \text{ (min)}, +0.47 \text{ (max)}$$

In the above calculations, it is assumed that a start and stop of pumping occur at 50 percent load of the system's maximum demand with the motor input power of 110% of the unit generating capacity. These calculated values show the extent of frequency fluctuation which covers about 70% of probability.

The recorded frequency fluctuation caused by Srinagarind No. 4 unit at the start and stop of pumping ranges from 0.2 Hz to 0.6 Hz as shown in Table 10-2.

From the above calculations, the frequency fluctuations caused by the start and stop of pumping by a 250 MW unit will range between 0.22 Hz and 0.47 Hz with 70% probability in 1997, and this fluctuation level is smaller than the current level. Even in the most severe case, the power system frequency fluctuation will hardly go up to 0.6 Hz, as it did in the past.

After 1997, the frequency fluctuations is smaller, because the system capacity becomes larger. Therefore, there are no problems in view of the system frequency fluctuations for using a 250 MW unit.

In case the plant capacity is 600 MW, the use of a 300 MW unit is one alternative. However, the introduction of a 300 MW unit machine is not recommendable, because the frequency fluctuation caused by of the 300 MW unit is 20% larger than that of the 250 MW unit. The system frequency will go up very often to above 50.5 Hz, at which the thermal units must be disconnected from the power system.

Table 10-2 Record of Frequency Fluctuation by Star/Stop of Pumping Operation of Srinagarind No. 4 Unit

Start/Stop of Pumping	Date	System Capacity (MW)	Frequency Change		Power Imbalance (%MW)	Frequency Fluctuation (HZ)	K (%MW/0.1HZ)
			from (HZ)	to (HZ)			
Start	Nov 30, 1987	2900	50.00	49.54	6.90	0.46	1.50
	Jan 03, 1988	2188	50.17	49.57	9.14	0.60	1.52
	Apr 25, 1990	4500	50.00	49.63	4.44	0.37	1.20
	Apr 26, 1990	4300	50.00	49.80	4.65	0.20	2.33
	Apr 27, 1990	4500	50.12	49.84	4.44	0.28	1.59
	Apr 28, 1990	4200	50.00	49.60	4.76	0.40	1.19
	Apr 29, 1990	4500	50.00	49.72	4.44	0.28	1.59
	Apr 30, 1990	4400	50.01	49.58	4.55	0.43	1.06
	Apr 31, 1990	4500	50.04	49.69	4.44	0.35	1.27
						Average	1.47
						Standard Deviation	0.35
Stop	Dec 01, 1987	2950	49.91	50.45	6.78	0.54	1.26
	Jan 03, 1988	2400	49.90	50.50	8.33	0.60	1.39
	Apr 27, 1990	4500	49.89	50.49	4.44	0.60	0.74
	Apr 28, 1990	4200	49.91	50.28	4.76	0.37	1.29
	Apr 29, 1990	4700	50.00	50.50	4.26	0.50	0.85
	Apr 30, 1990	4800	49.85	50.36	4.17	0.51	0.82
	Apr 31, 1990	4800	50.00	50.35	4.17	0.35	1.19
						Average	1.08
						Standard Deviation	0.24

K: Power-frequency characteristic

10.4 Study on Optimum Development Plan (Investigation Stage)

10.4.1 Conditions of the Study

The objective of this section is to determine optimum development scale by varying the installed capacity and storage capacity of the upper reservoir from a viewpoint of the most effective utilization of the pumped storage resource of Lam Ta Khong site. The study is carried out on the basis of the following conditions.

(1) Layout

The layout No.1 was selected in section 10.2.

(2) Demand-Supply Balance and Available Energy for Pumping

As mentioned in Chapter 5, power supply of more than 700 to 900 MW would be required in 1997 or 1998 even though new generating facilities are implemented to the system in line with the EGAT's Power Development Plan (PDP 90-02 Sep. 1990).

Pumping energy for the Lam Ta Khong power plant (1000 MW) is shown in Fig. 10-3 and enough pumping energy can be supplied from thermal power plant.

(3) Unit Capacity

As mentioned in Section 10.3, unit capacity of 250 MW does not cause any harmful influence to the stability of power system.

(4) Transmission Line and Power System

For the transmission line expansion plan of EGAT up to year of 2006, pumping operation of the Lam Ta Khong Project is limited to a maximum of 500 MW in consideration of the stability of the power system due to the insufficient capacity of main transmission line between Mae Moh and Bangkok. However, it is assumed in this section that the main transmission line will be strengthened in future by appropriate measure and consequently more than 500 MW pumping operation of the Lam Ta Khong Project will be possible.

(5) Construction cost as of January 1991 is estimated for generating facility and transmission line between Lam Ta Khong site and Tha Tako which is a connecting point to the main transmission line.

10.4.2 Continuous Generating Capability and Reservoir Operation

(1) Continuous Generating Capability and Reservoir Classification

Capability of a pumped storage power plant can be expressed by using a concept of "Continuous Generating Capability" at the maximum power level as follows.

$$T = \frac{Ve}{Q \times 3600}$$

where, T : continuous generating capability of reservoir (hr)

Ve: effective storage capacity of reservoir ($10^6 m^3$)

Q : maximum power discharge (m^3/sec)

The concept "T" expresses the reservoir capacity. The reservoirs of pumped storage plants are generally classified to "daily regulating reservoir" and "weekly regulating reservoir" for "T=4~6 hours" and "T≥8 hours" respectively.

Appendix B-1 shows the example of the regulating reservoir in Japan.

(2) Power Plant having Daily Regulating Reservoir

Water level of the upper reservoir moves from HWL to LWL during peak time and from LWL to HWL during off-peak time in a day. The concept of operation of daily regulating reservoirs is shown in Fig. 10-4. The daily generating energy (Eo) is supplied from daily pumping energy (E_{p1}) as follows.

$$E_o = E_{p1} \times 0.7$$

(Note) 0.7: pumping efficiency (output energy/input energy, see Appendix B-2)

The possible daily generating hours (Td) is expressed to be smaller value of "J" and "T".

Td = J or Td = T

J : Possible daily generating hours at maximum output level related to possible daily pumping hours in daily load curve (hr)

(3) Power Plant having Weekly Regulating Reservoir

The water level of the upper reservoir does not move from HWL to LWL in a day but moves in a week. The concept of operation of the weekly regulating reservoir is shown in Fig. 10-5. The daily generating energy (E_o) is supplied with daily pumping energy (E_{p1}) and weekend pumping energy (E_{p2}) as follows.

$$E_o = (E_{p1} + E_{p2}/D) \times 0.7$$

where,

E_{p1}: daily pumping energy (kWh)
E_{p2}: weekend pumping energy (kWh)
D : number of days using E_{p2} in a week (day)

- The power plant generates by using the daily and weekly pumping energy from Monday to Friday, and by using the daily pumping energy only on Saturday.

- The generating operation of pumped storage power plant is not required from power system on Sunday because the load drops on Sunday. (See Fig. 10-6)

The possible daily generating hours is expressed as follows.

$$T_d = (T-J)/D+J$$

where,

- T_d : possible daily generating hours (maximum output level: hr)
- T : continuous generating capability of reservoir (hr)
- J : possible daily generating hours related to possible daily pumping hours (hr), (J = 5.6 hours; See Appendix B-3)
- D : Number of days using weekly regulating portion of reservoir capacity (D = 5 days)

10.4.3 Study on Installed Capacity and Reservoir Capacity

(1) Methodology

Economic comparison on development scale and reservoir capacity is carried out by using the technique of benefit-cost ratio (B/C) and annual surplus benefit (B - C). The cost (C) is annual cost of a pumped storage power project, and the benefit (B) is annual cost of an alternative thermal power project (= annual benefit of the pumped storage project). The construction costs of the pumped storage and the alternative thermal projects are expressed with economic cost which does not include taxes, interest during construction.

In this section, the cost and benefit are calculated as follows.

(a) Annual Cost.

The annual cost (C) of the pumped storage project consists of fixed cost (C_1: including O&M cost of facility) and variable cost (C_2). The fixed cost is estimated by using the construction cost and the annual conversion factor (13.7%). The variable cost is estimated by using the annual pumping energy and the unit cost for pumping energy (0.4084 Baht/kWh). The annual pumping energy is calculated from annual generating energy (assumed: annual operation of 800 hours) and pumping efficiency of 0.7.

$$C = C_1 + C_2$$

= Construction cost(Baht) x 13.7(%)

+ Annual Pumping Energy (kWh) x 0.4084(Baht/kWh)

(Note) Construction cost includes transmission line cost.

500 MW: Lam Ta Khong PS - Existing 230 kV; 4 circuits

600 MW ~ 1000 MW: Lam Ta Khong PS - Existing 230 kV: 2 circuits

Lam Ta Khong PS - Thalan 3 substation: 2 circuits

1200 MW: Lam Ta Khong PS - Thalan 3 substation: 4 circuits

(Note) Discount Rate 12%,

Capital Recovery Factor; 12.16% for Average Service Life of 38 yrs (civil structures 50 yrs, electrical equipment 25 yrs, average service life 38yrs)

Operation & Maintenance cost; 1.48%

Annual Conversion Factor; 13.7%

(Note) Pumping Energy Cost 0.4084 Baht/kWh: See Chapter 14

(Note) Annual Pumping Energy = Annual Generating Energy/0.7 = Max. Output of Pumped Storage x 800 hours/0.7

(b) Annual Benefit

The annual benefit (B) is the annual cost of the alternative thermal power plant. It consists of the fixed cost (B_1: including O&M cost of facility) and the variable cost (B_2).

The fixed cost (B_1) is estimated by using construction cost of the alternative thermal and annual conversion factor of 16.4%. Installed capacity of the alternative thermal plant is determined from effective output of the pumped storage and difference in reliability (kW adjustment ratio 13%) between hydro power plant and thermal power plant. Supposing the Khanom No.1 and No.2 classes' combined cycle as the alternative thermal power plant, the unit economic cost of 13,800 Baht/kW is used.

The variable cost (B_2) is the fuel cost of the alternative thermal power plant, and it is estimated by using annual generating energy and unit energy cost (0.4334 Baht/kWh). The annual generating energy for "B_2" is the same value as the pumped storage. Difference in reliability (kWh adjustment ratio) between hydro and thermal for the generating energy is neglected because the difference is very small.

$B = B_1 + B_2$

= Construction cost of alternative thermal (Baht) x 16.4 (%) + Annual generating energy of alternative thermal (kWh) x 0.4334 (Baht/kWh)

= Effective output of pumped storage (MW) x 1.13 x 13,800 (฿/kW) X 0.164 + annual generating energy (kWh) x 0.4334 (฿/kWh)

(Note) Capital Recovery Factor; 13.39% for service life of 20 years

O&M cost; 3.0%

Annual Conversion Factor; 16.4%

(Note) kW Adjustment Ratio

$$\frac{{}^{*1}(1-0.003) \times {}^{*2}(1-0.01) \times {}^{*3}(1-0.005) \times {}^{*4}(1-0.03)}{(1-0.013) \times (1-0.08) \times (1-0.05) \times (1-0.025)} \quad \begin{matrix} \text{<Hydro>} \\ \text{<Thermal>} \end{matrix}$$

$= 1.13$

- *1 Station Service Rate
- *2 Scheduled Outage Rate
- *3 Forced Outage Rate
- *4 Transmission Loss Rate

(Note) kWh Adjustment Ratio

$$\frac{{}^{*1}(1-0.003) \times {}^{*4}(1-0.015)}{(1-0.05) \times (1-0.015)} = 1.01 \fallingdotseq 1.0$$

(Note) energy cost 0.4334 ฿ kWh : combined cycle

(c) Effective Output

The effective output of the pumped storage plant is used to estimate the annual fixed cost "B_1" of the alternative thermal plant.

In case the possible daily generating hours "T_d" described in section 10.4.2 is smaller than peak duration hours required from power system, the power plant should be operated by lowering the output level during the required peak duration hours as shown in Fig. 10-7. The lowered output is defined as effective output (P_1).

$$P_1 = P_0 \times T_d/I$$

Where, P_1: Effective output (MW)

P_0: Maximum output (MW)

I : Peak duration hours required from power system (hr); I = 6 hours, See Appendix B-3

T_d: Possible daily generating hours (hr); See Section 10.4.2

(2) Alternatives Concerning Development Scale and Reservoir Capacity

Development scale and reservoir capacity are studied as follows:

Maximum Output (MW)	500	600	800	1,000	1,200
Reservoir Capacity (hr)	4~14	4~14	4~14	4~14	4~14

(Note) Reservoir Capacity = Continuous generating capability

(3) Results of Comparison Study

The alternatives mentioned above were compared from an economic viewpoint (B-C, B/C). The result is shown in Table 10-3 and the followings were obtained. Detail of the construction cost of each alternative is shown in Appendix B-5.

(a) The development scales of 1,000 MW and 1,200 MW are much superior to the cases of other installed capacity from a viewpoint of effective utilization of pumped storage's resource at Lam Ta Khong site.

Max. Output (MW)	B-C (M฿)	B/C
500	345	1.31
600	360	1.26
800	592	1.34
1,000	824	1.40
1,200	951	1.38

(Note): Reservoir Capacity 8 hours

(b) There is no significant difference in economics between 1,000 MW and 1,200 MW from B/C and B-C. However, 1,000 MW was selected from the efficiency of investment cost (B/C) and engineering judgment of pumping possibility in the future.

(c) Reservoir capacity of 8 hours was selcted from an economic view point.

Reservoir Capacity (hr)	B-C (M฿)	B/C
6	735	1.36
8	824	1.40
10	755	1.35

(Note) Maximum output 1,000 MW

(4) Selected Development Plan

From a viewpoint of the most effective utilization of the Lam Ta Khong pumped storage's resource, the installed capacity of 1,000 MW and reservoir capacity of 8 hours are selected in the "Investigation Stage".