No. 62

GOVERNMENT OF MALAYSIA
ECONOMIC PLANNING UNIT OF THE PRIME MINISTER'S DEPARTMENT

MALAYSIA

FEASIBILITY STUDY REPORT ON THE TEKAI HYDROELECTRIC POWER DEVELOPMENT PROJECT

Volume IV Geology

SEPTEMBER 1983

JAPAN INTERNATIONAL COOPERATION AGENCY

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PREFACE

In response to the request of the Government of Malaysia, the Government of Japan decided to conduct a feasibility study on the Tekai Hydro-electric Power Development Project and entrusted the study to the Japan International Cooperation Agency (JICA). The JICA sent to Malaysia a survey team headed by Mr. Keiichi Takahira from March 1, 1981 to December 15, 1982.

The team exchanged views with the officials concerned of the Government of Malaysia and conducted a field survey in the Tekai Project area, in Pahang State. After the team returned to Japan, further studies were made and the present report has been prepared.

I hope that this report will serve for the development of the Project contribute to the promotion of friendly relations between our two countries.

I wish to express my deep appreciation to the officials concerned of the Government of Malaysia for their close cooperation extended to the team.

Tokyo, August 1983

Keisuke Arita
President
Japan International Cooperation Agency

The feasibility study report is composed of the following volumes.

Executive Summary	
Volume I	Main Report
Volume II	Survey
Volume III	Hydrology
Volume IV	Geology
Volume IV	Geology Appendix
Volume V	Design and Construction Planning
Volume VI	Drawings
Supplementary Data	Estimated Construction Cost and Unit Price

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1. INTRODUCTION

1. INTRODUCTION

The Tekai Hydroelectric Power Development Project has been planned for the lower reaches of the Tekai River, a tributary of the Tembeling River of the Pahang River Basin in Pahang State of West Malaysia (Fig. 1.1).

The proposed site for the project is in the northern tip of Pahang State, situated in the mountains of the Trengganu Coastal Range. The site is adjacent to the southern border of the Taman Negara (National Park) and lies some 150 km to the northeast of the capital, Kuala Lumpur.

The Tekai Hydroelectric Power Development Project consists of two proposed sites (the upper and lower sites) within the project area in the lower reaches of the Tekai River (Fig. 1.2.).

As shown in Fig. 1.2, a geological investigation of the two selected dam sites (the upper and lower dam) and four quarry and borrow areas were conducted with the intent of clarifying the geological condition of the areas and obtaining basic data for the Development Project. The results of the geological investigation have been compiled in this report.

Fig.1.1 LOCATION MAP OF PROJECT SITE (S= 1/1,000,000)

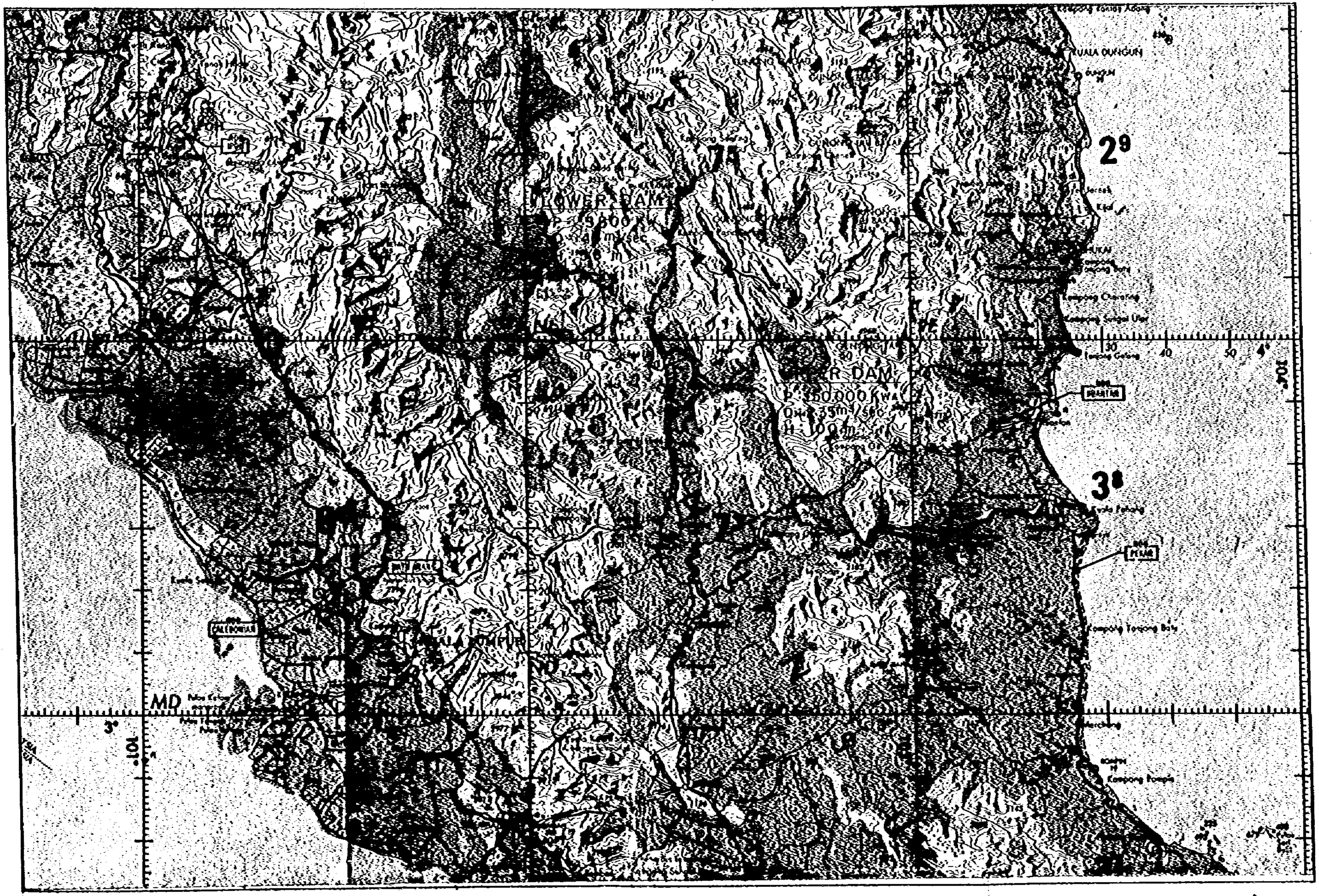
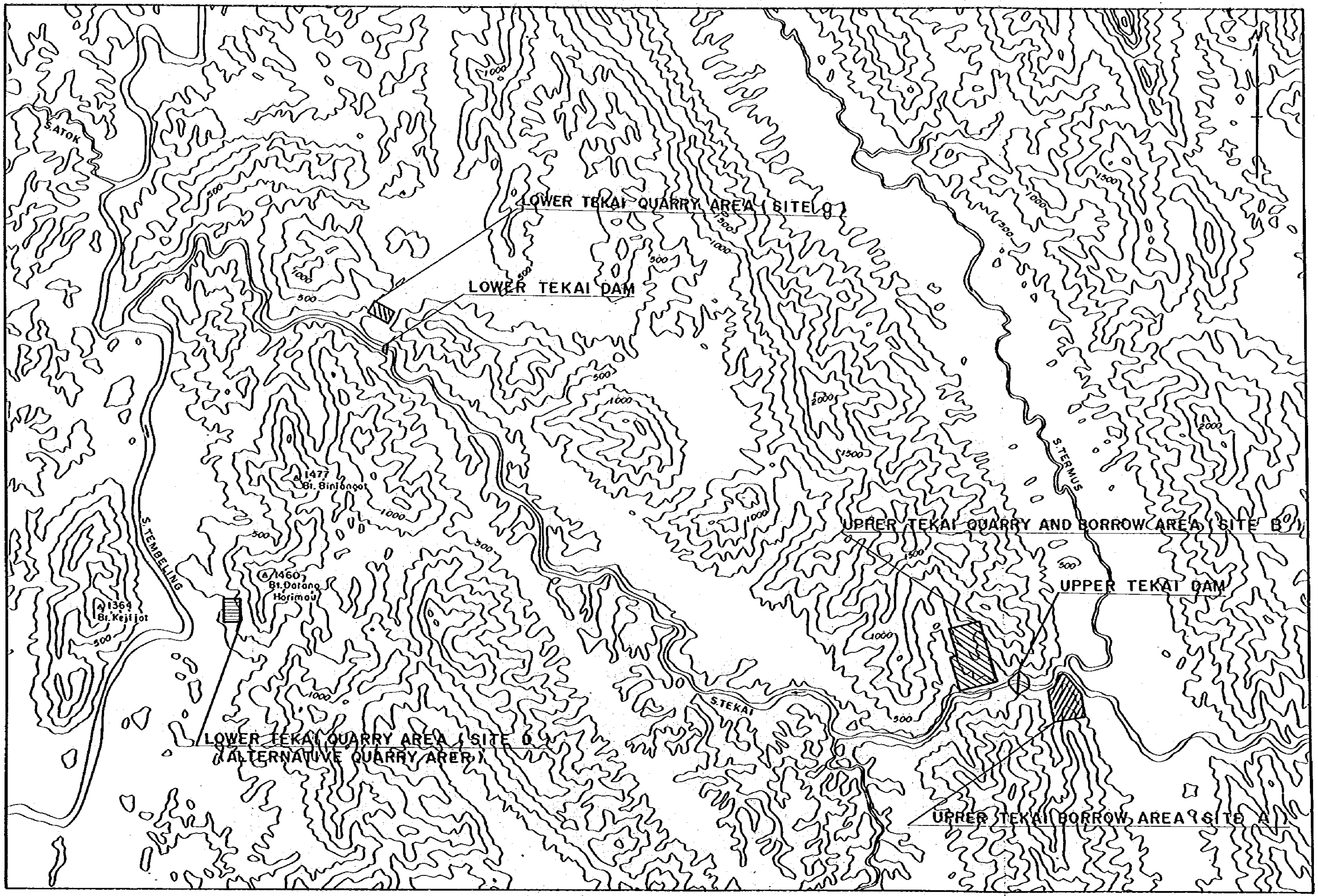


Fig. I.2 LOCATION MAP OF PROJECT SITE



2. OUTLINE OF GEOLOGICAL INVESTIGATION

2. OUTLINE OF THE GEOLOGICAL INVESTIGATION

2.1 INVESTIGATION ACTIVITIES

For the first stage, geological reconnaissances were conducted in March, 1981 around the project site to formulate a preliminary site investigation plan. In the meantime, basic geological data were collected in cooperation with the Geological Survey of Malaysia.

The preliminary site investigation was conducted for five months period from June to October, 1981. This investigation consisted mainly of geological reconnaissance drilling work and seismic prospecting. The geological survey reconnaissance the whole area of the project site (dam, spillway, power station, borrow, quarry, etc.). The drilling work including permeability testing was executed along the center lines of the upper and the lower dam sites. The measuring lines of seismic prospecting were set so as to cover the upper and the lower dam sites.

The detailed site investigation was conducted in order to obtain more detailed information, in addition to the results of the preliminary investigation. This investigation consists mainly of drilling work, seismic prospecting, pitting work and laboratory testing for rock and soil samples. These works were executed for eight months period from May to December, 1982. At the detailed investigation stage, the drilling points were set at the locations for main construction structures and construction materials, and the lines of seismic prospecting covered the borrow and the quarry areas of both sites.

The following Table 2.1. shows a summary of the activities of the geological investigations.

Table 2.1 Investigation Work Schedule

Item	1981								1982											
	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10	11	12
Data collection	1 25																			
Geological reconnaissance					3		10											30	31	
Drilling					10			11						22				21		
Seismic prospecting					21 26	12	7							15	9		8 29			
Test pit															2 17 29	21				
Rock testing																		1		5
Soil testing							26	3							22			15		
Check of drilling cores																			22	2

2.2 ITEM OF GEOLOGICAL INVESTIGATION

The following are the items covered by the field work and laboratory testing. Quantities are listed in Table 2.2.

(1) Geological Reconnaissance

Reconnaissance was carried out by engineering geologists who focused on riverside areas with good outcrop conditions, observing the areas' rock varieties and geological condition. In addition to clarifying the geological condition of the dam site and surrounding areas, the geological reconnaissance resulted in the selection of quarry and borrow areas also.

(2) Drilling and Permeability Testing

Drilling and permeability testing were carried out in order to gain a grasp of the geological properties of the basic rock of the dam and main structures and of the quarry and borrow areas, and also to obtain basic data for planning foundation treatment for the dam.

Drilling was conducted at ϕ76(NX)m/m on an all-core basis. The following subjects were observed and measured.

a: Rock Name

b: Color

c: Grade of Weathering

Grades of weathering were based on the standards in Table 2.3.

Table 2.3 Grade of Weathering

Grade	Weathering	Description
I	Fresh	No visible deterioration.
II	Slightly weathered	Brown limonite staining along cracks, but pieces of NX core are fresh.
III	Moderately weathered	Considerably altered, but pieces of NX core cannot be broken off by hand.
IV	Highly weathered	Pieces of NX core are almost completely altered and can sometimes be broken off by hand.
V	Completely weathered	Sample disintegrates when placed in water.

d: Core Conditions (Visual Description)

Contains a description of crack conditions and frequency, core form, and so on.

e: R.Q.D.

R.Q.D. is defined as the total of all cores of at least 10 cm against the unit length of the drilling (reference No.6)[7]. This is obtained by means of the following formula.

$$R.Q.D. = \frac{\Sigma li}{L}$$

L : Length of drilling unit (100 cm)

li: Length above core length 10 cm

f: Core Recovery

g: Rock Classification

Rock classification was determined on the basis of the standards in Table 2.4. Items a - f were judged as a whole, however, and evaluated collectively for their suitability as foundation for a dam.

Table 2.4 Quality Classification of Foundation Rock

Classification	Characteristics
A	Rock-forming minerals are fresh and not weathered or altered. Joints and cracks are very closely adhered with no weathering along their planes. A clear sound is emitted when hammered.
B	Rock-forming minerals are weathered slightly or partially altered, the rock being hard. Joints and cracks are closely adhered. A clear sound is emitted when hammered.
C_H	Rock-forming minerals are weathered but the rock is fairly hard. The bond between rock blocks is slightly reduced and each block is apt to be exfoliated along joints and cracks by strong hammering. Joints and cracks sometimes contain clay and other material which may be coloured by limonite. A slightly dull sound is emitted when hammered.

Classification	Characteristics
C_M	Rock-forming minerals are weathered and the rock is slightly soft. Exfoliation of the rock occurs along joints and cracks by normal hammering. Joints and cracks sometimes contain clay and other material. A somewhat dull sound is emitted when hammered.
C_L	Rock-forming minerals are weathered and the rock is soft. Exfoliation of the rock occurs along joints and cracks by light hammering. Joints and cracks contain clay. A dull sound is emitted when hammered.
D	Rock-forming minerals are weathered, and rock is very soft. There is virtually no bond between rock blocks, and collapse occurs at the slightest hammering. Joints and cracks contain clay. A very dull sound is emitted when hammered.

(Source; Standards for Geological Investigation of Dam Foundations, J.N.C.I.C. on Large Dams)

h: Lugeon Value and Permeability Coefficient

The Lugeon value is the value obtained by injecting pressure water into a test hole at an injection pressure of 10 kg/cm^2 and converting the volume of injected water (l/min.) into the amount per 1 m of the length of the test hole. This is a widely used method of evaluating the permeability of rock foundation for a dam. Measurement was generally carried out on test segments of 5 m in length.

When confronted with cracky rock, weathered rock, or other cases in which the injection pressure did not reach 10 kg/cm^2, the Lugeon value was obtained by means of the follcwing formula.

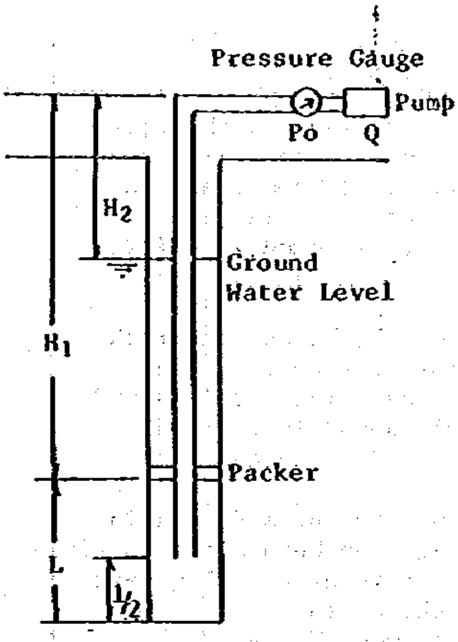
$$Lu' = 10\ (Q_1-Q_2)\ /\ (P_1-P_2)\cdot l$$

Lu': Converted Lugeon value

Q : Injected volume (l/min.)

P : Injection pressure (kg/cm^2)

l : Length of test segment (m)



The permeability coefficient K (cm/sec) was obtained by the following formula.

$$K = \frac{Q}{2\pi LP} \ln \frac{L}{r}$$

L : Length of test segment (cm)

r : Drilling diameter (cm)

Po: Water pressure at entrance (g/cm^2)

P : Test period water pressure (g/cm^2)

(i) P = Po + H1 + L/2 (no underground water level)

(ii) P = Po + H2 (underground water level exists)

k: Permeability Coefficient (cm/sec)

Q: Injected volume (cm^3/sec)

(3) Seismic Prospecting

Seismic prospecting was carried out using a 24-component refractive wave seismograph for civil engineering. Dynamite was used at the shot points. Measuring lines were implemented so as to cover the entire project area. The intention of the seismic prospecting was to determine the rock's seismic wave propagation velocity, estimate the properties of the rock,(according to the arrival time of seismic waves) and to obtain basic data for geological analysis.

(4) Test Pits

Test pits were dug at the selected borrow area in order to gain a grasp of the geological properties of the area as core material. Samples were also collected for laboratory testing.

(5) Laboratory Testing

i) Rock testing

Basic rock testing was carried out using a drilling core. This testing enabled the investigators to make a rough evaluation of the suitability of the rock as foundation for the dam and as constructio material (rock material, concrete aggregate). The following subjects were covered by the testing.

- Specific gravity, percentage of water absorption
- Ultrasonic wave velocity
- Unconfined compressive strength

ii) Soil testing

Soil testing was carried out with respect to the following items, in order to make a rough evaluation of the suitability of the soil as core material for the upper dam.

- Physical testing: Specific gravity
  Grading
  Moisture content
  Liquid limit, plastic limit
- Mechanical testing: Moisture - density relations
  Permeability

Table 2.2 Quantity of Geological Investigation

		Basic investigation (1981.6~1981.10)	Detailed investigation (1982.5~1982.10)	Total
Geological reconnaissance		15 km^2	-	15 km^2
Drilling	Upper dam site	230 m (5 holes)	700 m (18 holes)	2310 m (58 holes)
	Upper quarry and borrow site	-	470 m (11 holes)	
	Lower dam site	180 m (4 holes)	520 m (14 holes)	
	Lower quarry site	-	210 m (6 holes)	
Permeability testing	Upper dam site	34 times (5 holes)	68 times (7 holes)	190 times (22 holes)
	Lower dam site	27 times (4 holes)	61 times (6 holes)	
Seismic prospecting	Upper dam site	2750 m (11 lines)	-	12,570 m (35 lines)
	Upper quarry and borrow site	-	6100 m (10 lines)	
	Lower dam site	2520 m (11 lines)	-	
	Lower quarry site	-	1200 m (3 lines)	
Test pit	Upper quarry and borrow site	-	52.5 m (17 holes)	52.5 m (17 holes)
Laboratory testing	Soil testing	-	36 samples	36 samples
	Rock testing	-	72 samples	72 samples

3. REGIONAL TOPOGRAPHY AND GEOLOGY

3. REGIONAL TOPOGRAPHY AND GEOLOGY

3.1 TOPOGRAPHY

The Tekai River forms the upper waters of the largest river in Malaysia, the Pahang (refer to Fig. 1-1). The basin of the Tekai covers an area extending from 4°00' to 4°22' North Latitude and 102°24' to 102°42' East Longitude.

With its source in the mountainous area of the Pahang State, the Pahang River gathers numerous tributaries as it advances southward through the Jerantut region. The Tekai River which is the site for this project is the largest tributary of the Tembeling River, running principally west-northwest and merging with the Tembeling River at a point approximately 20 km upstream of Kuala Tembeling.

The Tekai River Basin is surrounded by the mountains of the Trengganu Coastal Range, which includes such lofty peaks as the G. Tapis (4,960 ft.), G. Dulang (3,488 ft.) and G. Ulu Bakar (4,561 ft.). These mountain ridges range NNW - SSE, nearly the same direction as the strike of stratum. Most of the rivers in the mountainous area also run in an identical direction; this drainage pattern is a topographical characteristic of the region.

The trend of the mountain ridges and the rivers has a close relationship with the geological structure of the area. Such characteristics that clearly show the close relationship between the geological structure and the topography.

In general, the mountainous area of the Tekai River Basin exhibits a gentle slopes caused by intensed weathering activity.

The gradient of the Tekai River is relatively steep in the mountainous area of its upper reaches, where it forms a steeply-graded river bed; in the lower reaches, however, the gradient becomes markedly gentle at about 1/1,000.

The site selected for the dam is some 25 km upstream of the confluence of the Tembeling and Tekai rivers for the upper dam, and some 8 km for the lower dam. This is a comparatively narrow point in the river, and the gradient is gentle, factors which would make possible the construction and operation of an efficient reservoir.

3.2 GEOLOGY

The geology of the Tekai River Basin has been mapped by the Geological Survey of Malaysia (Khoo 1977.) reference NO.2) as shown in Fig. 3.1. The region's stratigraphy is summarized in Table 3.1. The geology of the river basin area can be roughly grouped into sedimentary rocks, metasediments, and granitic rocks (adamellite).

The sedimentary rocks are known as the Tembeling Group, and consist of Mesozoic conglomerate, sandstone, shale, and other rocks. These are grouped into four formations according to their lithofacies. Listed in geochronological order, they comprise the following.

i) Kerum formation
ii) Lanis conglomerate
iii) Mangking sandstone
iv) Termus redbeds

These strata have a nearly NNW - SSE strike, and, because they have large and small fold systems, they are distributed zonally.

i) Kerum formation

This formation is distributed typically along the Kerum River, and is distributed within the reservoir of the upper dam. It is composed mainly of volcanic rocks, shale, and quartzose sandstone.

ii) Lanis conglomerate

This formation is distributed typically in the vicinity of the G. Lanis, and is distributed within the reservoir of the upper dam. It is composed of reddish conglomerate, sandstone, and shale. Because it is extremely hard, Lanis conglomerate forms steep cliffs along its strike direction.

iii) Mangking sandstone

This formation is distributed typically along the Mangking River, and is composed mainly of quartzose sandstone with interbedded gray or red shale. It is distributed widely in the middle and lower reaches of the Tekai River lying within the project area.

iv) Termus redbeds

These are distributed zonally along the Termus and Jemar rivers. They are distributed widely within the reservoirs of the upper and lower dams, and also in the quarry area of the upper dam. Reddish shale is the predominant structural rock, interposed with small amounts of quartzose sandstone. As the reddish shale is soft with rich cleavage, it forms a level topography along the riverbanks. The geological boundary between the Termus redbeds and Mangking sandstone is unclear due to the folding deformation both of which have undergone.

The metasediments are known as the Bangak metasediments. These are distributed in the area interposed between the sedimentary rocks and granitic rocks (adamellite) found in the upper reaches of the Tekai River. They are distributed typically along the Bangak River and are thought to be Paleozoic age. Although their metamorphic grade is low, these metasediments are generally foliated and have undergone contact metamorphism when in the vicinity of granite. They consist mainly of slate, phyllite, metaquartzite, metasandstone, semischist, and hornfels.

Granitic rocks are distributed in the Tekai River's upper reaches and are composed of adamellite. In the mountainous areas the granite has undergone deep weathering, the surface being formed of loose, coarse sand. The river bed deposits of the Tekai River are supplied largely from this granitic area.

As illustrated in Fig. 3.1, the sedimentary rocks have a NNW - SSE strike and have large and small fold systemes. The following are the representative fold axes within the Tekai River Basin; it is these that govern the Basin's geological structures.

i) Termus syncline

This is a large syncline extending along the Termus River Valley in a NNW - SSE direction as far as Kuala Tahan.

ii) Tekai syncline

Another large syncline runs parallel to the lower reaches of the Tekai River. It extends in a NNW - SSE direction as far as the Jemar River.

iii) Penut anticline

This is the principal anticline between the Tekai syncline and the Termus syncline. It plunges to the southeast.

Although the above large fold axes are not continuous in the neighbourhood of the dam site, some small fold structures are distributed here and there. Of particular note is the irregular dip of the strata at the site of the upper dam site.

A number of small faults are distributed sporadically through out the Tekai River Basin, but no large faults which could significantly govern the geological structure have been detected.

Fig.3.1 OUTLINE OF GEOLOGY IN THE SUNGAI TEKAI AREA

(after KHOO HAN PENG, 1977, page 93, Annual report of the geological surveyof Malaysia)

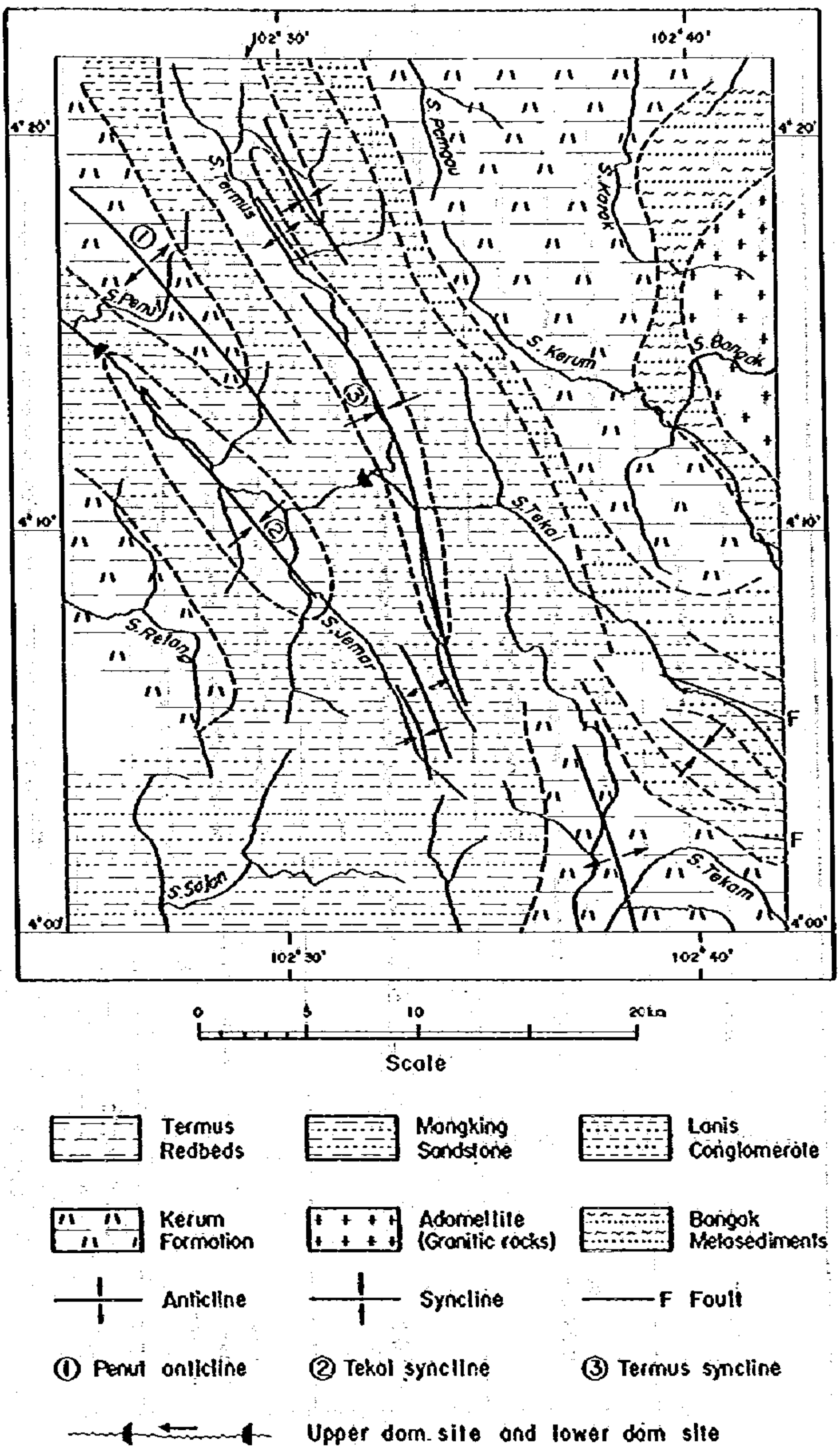


Table. 3.1 Stratigraphy of The Tekai River Basin

THICKNESS	AGE	FORMATION	LITHOLOGY
+ 1500m	U. CRETACEOUS	Termus Redbeds	Predominantly reddish/purplish-red ferruginous ARGILLACEOUS ROCKS consisting of claystone mudstone siltstone and shale interbedded with minor amount of reddish and non ferruginoug lithic sandstone (greywacke subgreywacke) and some quartzose sandstone
≈ 2200m	U. JURASSIC	Mangking Sandstone	Predominantly greyish to whitish QUARTZOSE SANDSTONE (orthoquartzite protoquartzite) inter-bedded with grey to brown argillaceous rocks and some ferruginous rocks Sandstone slightly conglomeratic with pebbles and granules mostly of quartz
≈ 900m		Lanis Conglomerate	Interbedded reddish/purplish red pebble to granule lithic conglomerate, conglomeratic lithic sandstone lithic sandstone and some reddish ferruginous siltstone mudstone and shale. These rocks are all of the same clastic composition. Volcanic clasts are abundant in the southeasterly extension of this unit.
Actual thickness not known		Karum Formation	Interbedded tuff/lava, tuffaceous sediments, lithic sandstone and reddish ferruginous (rarely tuff-aceous) argillaceous rocks. Same quartzose sandstone also present. Locally any of the lithologic type may predominante.
	U. TRIASSIC	Adamellite	
	UPPER PALEOZOIC	Bangak Metasediments	Slates, phyllites metaquartzite, metasandstone, semischists, hornfels. Hornfeleses are found near the granite margin (epidote-actinolite a hornblende-quartz-chlorite hornfels) Slates and phyllites are commonly graphitic. Slates are spotted with andalusite or graphitic dust.

(From "The Geology of The Sungai Tekai Area" Annual Report, the Geological Survey of Malaysia, 1977)

4. GEOLOGY OF THE UPPER SITE

4. GEOLOGY OF THE UPPER SITE

4.1 TOPOGRAPHY

The upper site is located in the lower reaches of the Tekai River, at a point some 25 km upstream of the confluence of the Tekai and Tembeling rivers. A tributary of the Tekai River, the Termus, converges with the Tekai about 1 km above the dam site.

The dam site was set in a comparatively narrow 2 km range of the valley within the project area. Determination was made following a comparison study of dam axes (refer to Main Report). The river surface at the dam axis is 72 m above sea level.

The river gradient in the vicinity of the dam site is about 1/1,000, and the river width is a narrow 60 m.

On both banks, the river has formed terrace surfaces and other level surfaces, and these can be seen distributed in the areas upstream and downstream of the dam site

Because the slope gradient at the dam axis exhibits a relatively steep valleylike form of about 42° at the left bank and about 36° at the right bank, it does not contain any large distribution of talus deposits.

Because of the relatively steep, valleylike form, presuming the construction of a dam of height 100m, the ratio (L/H) of the valley width (L) and the dam height (H) would be approximately 3.8.

A gentle slope, having an average gradient of some 20°, widens at the right bank of the Tekai River about 1 km downstream of the dam site; this area was thus selected as the upper borrow site (Site B).

4.2 GEOLOGY

The geological reconnaissance of the upper site employed a 1/2,500 topographical map and focused mainly on the dam site.

The geology of the upper site is composed of Termus redbeds and Mangking sandstone. Lithologic maps of the Upper Tekai Site are given in Figs.* 4.1 ∿ 4.4, and the stratigraphy of the Upper Tekai Site is summarized in Table 4.1.

The Termus redbeds are distributed along the Termus River in the area upstream of the dam site and are thought to belong to the Cretaceous period of Mesozoic in age.

Around the upper site, the Termus redbeds are composed mainly of shale (Tsh) and sandstone.

The shale (Tsh) consists of red to red-violet rock with well developed cleavage, intercalating massive mudstone in places. There is also much pronounced weathering, with weathered rock extending to great depths. The mountains following the Termus River, having distributions of this shale (Tsh), therefore take the form of gradual slopes.

The sandstone is composed mainly of fine quartzose sandstone, and is distributed only rarely around the upper site.

Mangking sandstone is distributed widely at the upper site. Thought to belong to Jurassic period of Mesozoic in age, it is composed mainly of sandstone and shale. Sandstone predominates at the upper site's western end, while shale is distributed widely in the eastern sector upstream.

The sandstone is a hard, compact rock forming steep mountains along the Tekai River. The shale, on the other hand, shows developing cleavages and surface weathering advanced to greater depth.

The Mangking sandstone is distributed below the Termus redbeds, and is inferred to come into contact with the latter, having a NNW - SSE trending conformable geological boundary, in the vicinity of the confluence of the Termus and Tekai rivers.

The rocks at the upper site were classified according to their lithofacies into the 14 groups described in Table 4.1. A further classification was then performed from the engineering geological standpoint, resulting in the four groups listed below. Geological maps were then prepared as shown in Figs. 4.5~4.7.

1) Stratum of predominantly sandstone (referred to hereinafter as "sandstone")

2) Stratum of predominantly shale (referred to hereinafter as "shale")

3) Alternation of sandstone and shale

4) Conglomerate

Overlying these strata are terrace deposite (Qtr) and river bed deposits (r) distributed along the river, and small scale talus deposits distributed on the mountainside slopes.

Terrace deposits (Qtr) are distributed widely around the confluence of the Tekai and Termus rivers and on a small scale along the Tekai River at the upper site. Terrace deposits, consisting of, comparatively firm clay, sand, and small gravel, is distributed along the left bank of the Tekai River some 250 m upstream of the dam site and also some 200 m downstream of the dam site.

River bed deposits are distributed along the Tekai River. These are composed of sand, silt and other material carried down by the river. This is a relatively shallow stratum, measuring 5 m or less at the river bed.

Strata at the upper site generally strike in a NNW - SSE direction. Large and small fold axes, following the Termus syncline (Fig. 3.1) are distributed here. As indicated in Figs. 4.1 ∿ 4.3, fold axes (synclines, anticlines) are distributed at the upper site, and for this reason the strata here do not have a uniform dip.

Small-scale faults, and fractured zones, are also distributed at the upper site. Fig. 4.6 shows two large fractured zones, having a NNE - SSW strike, distributed at the upper and lower reaches of the upper dam site. One of these intersects the dam axis at a low angle and may continue to the right bank abutment.

On the basis of the geological conditions described above, a narrow point in the valley was selected as the site for the dam axis, and geological investigation was carried out: a shale distribution area along the left bank of the Tekai River some 800 m upstream of the dam site was selected as the upper borrow site (Site A); a shale distribution area along the right bank of the Tekai River about 1 km downstream of the dam site was selected as the upper borrow site (Site B); and a sandstone distribution area at the latter location, as the upper quarry site (Site A).

Table 4.1 Stratigraphy of Upper Tekai Site

Geological age		Symbol	Formation	Lithology
Cenozoic	Quaternary	r	River bed deposits	Mainly quartz sand containing silt and gravel
		Qtr	Terrace deposits	Mainly clay containing gravel and organic material
Mesozoic	Lower Cretaceous	TSh	Termus redbeds	Reddish, purplish - red shale interbedded with massive mudstone and sandstone
		TSs		Quartzose sandstone and sandstone
	Upper Jurassic	MSh_3	Hangking Sandstone	Purplish shale interbedded with greyish shale and yellow ocher mudstone
		MSs_3		Mainly quartzose sandstone and sandstone interbedded with shale
		MMs		Yellow ocher mudstone interbedded with light grey mudstone or siltstone
		MSh_2		Mainly greyish shale and greenish shale interbedded with silty shale and mudstone
		MsS_2		Shaly sandstone and fine sandstone
		MfS		Mainly fine sandstone interbedded with shaly sandstone and shale
		MSs_2		Predominantly quartzose sandstone and sandstone interbedded with shaly sandstone and shale
		MsS_1		Shaly sandstone interbedded with shale
		Mal_1		Alternation of sandstone and shale
		MSh_1		Dark grey shale interbedded with sandstone
		Mcg		Conglomerate and coarse quartzose sandstone
		MSs_1		Predominantly quartzose sandstone and sandstone interbedded with conglomerate and shale

4.3 DRILLING AND PERMEABILITY TESTING

4.3.1 Location of Boreholes

Drilling was conducted at: 1) the dam site, including projected locations for the cofferdam, spillway, diversion tunnel, penstock, and power station; 2) the upper borrow site (Site A) situated upstream of the dam site; and 3) a quarry site in the upper quarry and borrow site (Site B) situated downstream of the dam site.

(1) Upper Dam Site

At the preliminary investigation stage (1981), a drilling programe was conducted based on proposed dam axis which had been selected in accordance with pertinent topographical and geological conditions.

A more detailed investigation was carried out in 1982, based on the outcome of the previous year's investigation. For this investigation, a new dam axis was decided upon and drilling was conducted according to the layout of the spillway, power station, and other facilities.

The location of the boreholes are shown in Fig*. 4.8, while operational quantities are given in Table 4.2.

Table 4.2 Quantity of Drilling Work at Upper Dam Site

Location		Borehole	Depth (m)	Permeability Testing (times)
Main Dam Site	Preliminary Inv. Stage	U-1	46.0	5
		U-2	44.0	8
		U-3	40.0	7
		U-4	50.0	8
		U-5	50.0	6
	Detailed Inv. Stage	UD-2	20.0	3
		UD-3	20.0	4
		UD-4	50.0	7
		UD-5	50.0	9
		UD-6	100.0	17
		UD-7	100.0	19
		UD-8	50.0	9
Coffer Dam Site	Detailed Inv. Stage	UD-1	20.0	-
		UD-9	20.0	-
Diversion Tunnel	ditto	UD-10	20.0	-
		UD-11	50.0	-
		UD-12	30.0	-
		UD-13	20.0	-
Spillway	ditto	UD-14	20.0	-
		UD-15	20.0	-
Penstock	ditto	UD-16	50.0	-
		UD-17	40.0	-
Power Station	ditto	UD-18	20.0	-
Total			930.0	102

(2) Upper Borrow Site (Site A) and Upper Quarry and Borrow Site (Site B)

As a result of the geological reconnaissance conducted during the preliminary investigation stage (1981), a shale distribution area situated along the left bank of the Tekai River upstream of the dam site was selected as the upper borrow site (Site A) and a sandstone distribution area situated along the right bank of the Tekai River was selected as the upper quarry site (Site B). Drillings were carried out at these sites during the detailed investigation stage in 1982.

The location of the boreholes are shown in Figs. 4.9 ∿ 4.10, while operational quantities are given in Table 4.3.

Table 4.3 Quantity of Drilling Work at Upper Quarry and Borrow Areas

Location	Borehole	Depth (m)
Upper borrow site (Site A, upper reach of the dam site)	UB-1 UB-2 UB-3 UB-4 UB-5 UB-6	20.0 30.0 20.0 50.0 50.0 50.0
Upper quarry and borrow site (Site B, lower reach of the dam site)	UQ-1 UQ-2 UQ-3 UQ-4 UQ-5	50.0 49.0 50.0 51.0 50.0
Total		470.0

4.3.2 Findings of Drilling

The geological log of the drilling is given in Fig. 4.11. The following is a summary of the findings obtained.

(1) Upper Dam Site

At the upper dam site are distributed strata of sandstone, shale, and shallow conglomerate (Fig. 4.6).

i) River bed deposits, relatively shallow at 5 m or less, are composed of sand and small gravel.

Table 4.4 Thickness of River Bed Deposits at Upper Dam Site

Borehole	Thickness of River Bed Deposits
U-3	0.90 m
UD-1	2.95 m
UD-2	3.00 m
UD-9	4.80 m
UD-18	1.00 m

ii) Top soil and completely weathered rock (D class rock) are relatively shallow (thickness given in Table 4.5).

Table 4.5 Thickness of Top Soil and Weathered Rock

Left Bank		Right Bank	
Borehole	Depth (m)	Borehole	Depth (m)
U-1	15.20	U-3	0.90
U-2	0.70	U-4	5.10
UD-2	0.35	U-5	9.80
UD-4	7.50	UD-1	2.95
UD-5	3.75	UD-3	0
UD-6	2.00	UD-7	5.00
UD-10	3.10	UD-8	3.20
UD-11	13.35	UD-9	4.80
UD-12	1.35	UD-16	5.00
UD-13	2.00	UD-17	1.40
UD-14	1.00	UD-18	1.00
UD-15	5.60		

iii) Remarkable cracky or clayey zones (fractured zone) observed at the boreholes are given in Table 4.6.

Table 4.6 Remarkable Cracky or Clayey Zones at Upper Dam Site

Borehole	Remarkable Cracky or Clayey Zone
U-2	10.00 - 11.50 m
U-4	7.40 - 9.70 m
U-5	17.60 - 18.70 m
U-5	19.50 - 23.00 m
UD-1	15.00 - 19.00 m
UD-4	15.00 - 19.00 m
UD-8	12.20 - 14.00 m
UD-9	10.00 - 12.00 m
UD-9	15.00 - 16.40 m
UD-14	12.00 - 15.75 m
UD-16	9.45 - 37.70 m
UD-16	39.50 - 43.00 m
UD-16	46.00 - 50.00 m

(over some 50 cm width except weathered rock)

Borehole UD-16 shows a particularly large fractured zone, from a depth of 50 m down to bottom of the hole. This may possibly be continuous with the fractured zone comfirmed by geological reconnaissance at the upper portion of the dam site, and is inferred to continue to the right bank of the dam site and penstock area.

(2) Upper Borrow Site (Site A)

The upper borrow site (Site A) is composed mainly of shale (Fig. 4.5)*. The plan provides for the weathered portions of the shale (which has thicker weathered strata than sandstone) to be gathered for use as core material.

i) Table 4.7 gives the thickness of top soil, including organic soil, and of weathered rock suitable for use as core material (D class, C_L class rock).

Table 4.7 Thickness of weathered Rock for Core Material

Borehole	Top Soil (m) (Unsuitable)	Weathered Zone (m) (Suitable)
UB-1	3.00	12.00
UB-2	1.00	0
UB-3	0.20	0.60
UB-4	0.90	2.10
UB-5	4.05	3.05

ii) Shale, having developed cleavage, is inferior to sandstone as rock material (cf. 7. "Rock Testing"). As shown in Fig. 4.5* and Table 4.8, Site A has a large proportion of shale and is therefore unsuitable as a quarry site for rock material.

Table 4.8 Ratio of Shale and Sandstone

Borehole	Shale	Sandstone
UB-1	90%	10%
UB-2	15%	85%
UB-3	95%	5%
UB-4	15%	85%
UB-5	60%	40%

(3) Quarry Site (Site B)

A sandstone distribution area within the upper quarry and borrow area (Site B) was selected as a quarry site, and a drilling investigation was conducted.

i) Table 4.9 shows the depth from ground surface to comparatively hard rock (C_M class rock or above) which can be considered suitable as rock material.

Table 4.9 Depth to Hard Rock from Ground Surface

Borehole	Depth to Hard Rock (m)
UQ-1	5.25
UQ-2	14.20
UQ-3	5.10
UQ-4	4.40
UQ-5	21.35

ii) The ratio of shale and sandstone at the quarry site at Site B is given in Table 4.10. The high proportion of sandstone makes this a favorable quarry site.

Table 4.10 Ratio of Shale and Sandstone

Borehole	Shale	Sandstone
UQ-1	0%	100%
UQ-2	10%	90%
UQ-3	5%	95%
UQ-4	5%	95%
UQ-5	20%	80%

4.3.3 Finding of Permeability Testing and Ground Water Level

* Water pressure test results of boreholes are summarized in Table 4.11. The leakage rates are given in Lugeon value and permeability coefficient. If simplifying assumptions are made that the rock around the tested borehole section is homogeneous and isotropic with respect to its permeability, then 1 Lugeon is approximately equivalent to a leakage rate of 1×10^{-5} cm/sec.

The permeability of solid rock is mainly due to water percolation along bedding planes and joints. The surface layers of the rocks possess high permeability (Lu>20), since the bedding planes and joints are widened by weathering.

An outline of the Lugeon values under designed high water level at the upper dam axis is given in Table 4.12.

Table 4.12 Outline of Lugeon Value at Upper Dam Axis

	Left Bank	River Bed	Right Bank
MAX.	27.6	28.1	4.2
MIN.	1.0	0	0.9
AVE.	11.0	2.0	2.1

At the both flanks of the upper dam site, groundwater levels are approximately the same with Tekai river water. At the abutments, they are encountered about 30 m below ground surface as shown in Fig 4.4.

Table 4.13 shows the underground water level at each borehole.

Table 4.13 Depth of Ground Water Level from Ground Surface

Left Bank		Right Bank	
Borehole	Depth (m)	Borehole	Depth (m)
U-1	37.2	U-3	0
U-2	23.8	U-4	19.1
UD-2	1.0	U-5	19.7
UD-4	29.0	UD-1	1.0
UD-5	43.0	UD-3	7.0
UD-6	2.2	UD-7	12.0
UD-10	3.0	UD-8	32.5
UD-11	4.2	*UD-9	+0.2
UD-12	0.1	UD-16	6.0
UD-13	14.1	UD-17	6.7
UD-14	-	UD-18	1.0
UD-15	5.2		

* Center of River Bed

4.4 SEISMIC PROSPECTING

Siesmic prospecting was carried out along pre-determined lines of seismic prospecting which covered the project area including the dam site, the upper borrow site (Site A), and the upper quarry and borrow sites (Site B).

4.4.1 Line of Seismic Prospecting

At the preliminary investigation stage, seismic prospecting focused on the dam site, affording a grasp of the general geology of the site. At the detailed investigation stage it was extended to include the upper quarry and borrow areas (Site A, Site B).

The location of the line of seismic prospecting is shown in Figs. 4.8 ∿ 4.10, while operational quantities are given in Tables 4.14 ∿ 4.15.

Table 4.14 Quantity of Seismic Prospecting Work at Upper Dam Site

Name of Line	Length (m)	Spread
U-A	670	7
U-B	290	3
U-C_1	110	1
U-C_2	110	1
U-D	310	3
U-E	280	3
U-F	290	3
U-G	200	2
U-H	200	2
U-J_1	110	1
U-J_2	180	2
Total	2,750	28

Table 4.15 Quantity of Seismic Prospecting Work at Upper Quarry and Borrow Areas

Name of Line	Length (m)	Spreads	Remarks
A B C D_1	600 300 400 800	6 3 4 8	Upper Borrow Site (Site A, upper reach of the dam site)
D E F G H I	1,100 600 600 600 500 600	11 6 6 6 5 6	Upper Quarry and Borrow Site (Site B, upper reach of the dam site)
Total	6,100	61	-

The rocks of the project site consist of interbedded areneous and argillaceous sediments which are mainly composed of sandstone and shale respectively. The seismic waves are mostly refracted along zones of abrupt change in degree of weathering which cut across lithological boundaries, although there is some lithological control on the development of these weathering zones.

According to the statistical study on seismic velocities of various rocks in Japan [reference No.8], velocities of fresh rocks of Mesozoic sandstone and shale are shown in Table 4.16.

Table 4.16 Velocity of Fresh Sandstone and Shale in Japan

Rock	Velocity (m/sec)		
	Mean	Maximum	Minimum
Fresh Sandstone	4,180 ± 240	5,310	2,700
Fresh Shale	4,020 ± 170	5,280	2,830

Table 4.17 shows the relationship between the seismic velocity, the weathering grade, and the rock classification in the project site.

Table 4.17 Relationship between Seismic Velocity, Weathering and Rock Classification

	Weathering	Rock Classification	Velocity (m/sec)
1	Slightly - fresh	C_H ~ B	3,000 ~
2	Moderately - slightly	CH	1,500 ~ 3,000
3	Completely - highly	C_L ~ D	600 ~ 1,500
4	Top soil - completely	D	300 ~ 600

(1) The Upper Dam Site

The seismic profile of the upper dam site is shown in Fig.* 4.12. Three refractors were detected below the 300 to 400 m/sec., uppermost of layer. The velocity of the upper layer ranges 700 to 1,000 m/sec., and it may be interpreted as completely to highly weathered zones. The velocity of the intermediate layer is about 1,500 m/sec., and it may be considered as highly to moderately weathered zones. The third layer range 2,800 and 5,000 m/sec.m which corresponds to the moderately, slightly weathered zones and fresh formation.

(2) Upper Borrow Site (Site A)

A seismic profile of the upper borrow site (Site A) is given in Fig.* 4.13.

In the upper borrow site (Site A), the top layer of velocity 350 to 600 m/sec., which is suitable for core materials, is very thin (less than 5 m in depth). Therefore, it may be inadvisable to adopt Site A for a borrow area. On the other hand, this condition is good for a quarry site as the top layer to be stripped is very thin. However, the rock consists mainly of cleaved shale.

(3) Upper Quarry and Borrow Site (Site B)

A seismic profile of the upper quarry and borrow site (Site B) is given in Fig.* 4.14.

Along the main alignment D for the quarry, the top layer of velocity 350 to 800 m/sec. is comparative thick (less than 10 m) The bedrock consists mainly of hard sandstone. Therefore, the area around alignment D is suitable for a quarry site, and enough volume of rock materials would be picked up.

A borrow site is proposed around the intersection of lines I and E. The top soil and completely weathered zones (350 to 1,000 m/sec. in velocity) around this intersection is considerably thick (about 7 m in depth). Therefore, enough volume of core materials would be available at this locality.

4.5 TEST PITS

A test pitting was conducted at the borrow sites within the upper borrow site (Site A) and the upper quarry and borrow site (Site B), as indicated in Figs.* 4.9 and 4.10. Samples were collected for laboratory testing.

A geological log of the test pits is given in Fig.* 4.15.

Organic soil containing tree roots and top soil, etc. was distributed in each test pit to a depth of about 1 m. Below this depth was distributed weathered rock considered suitable for use as core material. Tables 4.18 ∿ 4.19 give the thickness of top soil and organic soil at each test pit.

Table 4.18 Thickness of Top Soil and Organic Soil (Site A)

Pit Number	Sample Number for Soil Testing	Depth (m)	Depth of Top Soil & Organic Soil(m)	Geology
P-1	2	2.40	1.10	Shale
P-2	1	1.50	0.80	Shale
P-3	3	4.65	1.10	Fine Sandstone
P-4	2	2.70	1.20	Fine Sandstone
P-5	3	5.10	1.40	Talus
P-6	2	2.10	1.00	Silty Shale
P-7	3	3.15	1.00	Alternation of Sandstone and Shale
P-8	2	2.10	1.10	Shale
P-9	2	2.40	2.00	Mudstone, Shale

Table 4.19 Thickness of Top Soil and Organic Soil (Site B)

Pit Number	Sample Number for Soil Testing	Depth (m)	Depth of Top Soil and Organic Soil(m)	Geology
P-10	2	2.30	1.25	Talus
P-11	2	3.80	1.60	Terrace Deposits
P-12	2	1.50	1.10	Mudstone
P-13	2	3.00	1.10	Shale, Mudstone
P-14	2	1.75	0.50	Mudstone
P-15	2	2.80	0.90	Talus
P-16	2	3.50	1.30	Talus
P-17	2	3.30	1.00	Quartzose Sandstone and Shale

5. GEOLOGY OF THE LOWER SITE

5. GEOLOGY OF THE LOWER SITE

5.1 TOPOGRAPHY

The lower site is located at the lowest reach of the Tekai River, some 8 km upstream of the confluence of the Tembeling and Tekai rivers.

The valley of the Tekai River broadens below the upper dam site, and, once again, a relatively narrow point in the valley was selected. A comparison study for the dam axis (refer to Main Report Fig. 3.1, 3.2) resulted in the water level of the river at the dam axis being set at elevation 55 m.

The river gradient around the dam site is about 1/1,000, while the river's approximate width is a relatively narrow 30 m.

While districtions of terrace deposits and other level surfaces are few in comparison with the upper dam, some small-scale terrace deposits can be seen on the right bank directly downstream of the dam site. River bed deposits can also be found distributed on the left bank upstream of the dam site.

The slope gradient of the dam axis is about 40° at the left bank and about 24° at the right bank, forming an asymmetrical valley with the left bank steep and the right bank comparatively gentle.

The ratio (L/H) of the valley width (L) and the dam height (H) of an approximately 40 m height dam constructed at a site such as this would be about 3.5.

5.2 GEOLOGY

The geological reconnaissance of the lower site employed a 1/2,000 geological map and focused on the dam site.

The geology of the lower site resembles that of the upper site in that it is composed of the Mangking sandstone thought to date from Jurassic period of Mesozoic in age. Lithologic maps of this site are given in Figs. 5.1 ~ 5.3, while the stratigraphy is shown in Table 5.1.

The Mangking sandstone consists mainly of sandstone and shale, with sandstone having the wider distribution.

The sandstone is a hard, compact rock that forms the right bank of the dam axis. The shale is distributed at the left bank of the dam axis; it shows developed cleavage and deeper weathering than the sandstone.

The Mangking sandstone found at this site is classified into seven groups, as shown in the stratigraphy of the lower site(Table 5,1).

Downstream of the dam site on the right bank is an area in which sandstone is widely distributed. This site was selected and investigated as the lower quarry site (Site C) for the lower dam (Fig. 5.2). The lower quarry site is composed of the same Mangking sandstone as the dam site, also with sandstone predominating. Four strata of shale are interposed.

The rocks at the lower site were classified according to their lithofacies into the seven groups described above. A further classification was then performed from the engineering geological standpoint, resulting in the three groups listed below. Geological maps were prepared as shown in Figs. 5.4 ∿ 5.5.

(1) Stratum of predominantly sandstone

(2) Stratum of predominantly shale

(3) Alternation of sandstone and shale

Overlying these strata are terrace deposits (Qtr) and river bed deposits (r) distributed along the river, and small talus deposits distributed on the mountainside slopes.

Terrace deposits (Qtr) are distributed on a small scale downstream of the dam site and at bends in the river. These are composed of clay, sand, and small gravel.

River bed deposits (r) are distributed along the left bank of the dam axis; no other large distributions had been observed. The river bed deposits are composed mainly of quartzose sand and also contain silt and small gravel. They are also distributed along the river bed, having an irregular thickness ranging from 3 ∿ 10 m.

While almost no talus deposits are distributed at the dam site, they are distributed to a comparatively wide extent on the mountainside slopes at the lower quarry site (Site C).

The strata at the lower site generally strike in a NE $\sim$ SW direction. At the dam site, the strata dip $20^\circ \sim 40^\circ$ to the southeast; at the lower quarry site they dip $30^\circ \sim 60^\circ$ to the southwest, exhibiting a monocline structure.

While the lower site contains small-scale faults and fractured zones, there have been no confirmations of any faults which could affect the geological structure or of any fractured zones which could exert an effect upon structures.

In addition, as shown in Fig. 1.2, a limestone distribution area situated near Kg. Lubuk Payong, on the left bank of the Tembeling River some 15 km downstream of the lower dam site, was selected as an alternative quarry site (Site D).

In 1974, this area was the subject of a geological survey conducted by the Geological Survey of Malaysia.

An outline of its geology has been discussed in the report (reference No.9) "Geological Investigation for Proposed Quarry Site, near KG. LUBUK PAYONG, Jerantut, Pahang." At the time of this survey subsurface investigation was carried out by diamond drilling in the limestone and favorable results were obtained concerning its suitability as a construction material.

Table 5.1 Stratigraphy of Lower Tekai Site

Geological Age		Symbol	Formation	Lithology
Cenozoic	Quarternary	r	River bed deposits	Mainly quartz sand containing silt and gravel
		Qtr	Terrace deposits	Mainly clay and sand containing gravel and organic material
Mesozoic	Upper Jurassic	Msh_3	Hangking sandstone	Purplish, purplish-red shale interbedded with purplish fine sandstone
		MSs_3		Predominantly quartzose sandstone and sandstone
		Mal_2		Alternation of sandstone and shale
		MSh_2		Mainly greyish shale and purplish shale interbedded with sandy shale and silty shale
		MSs_2		Predominantly quartzose sandstone and sandstone interbedded with shale and shaly sandstone
		MSh_1		Dark grey, greyish shale
		MSs_1		Mainly quartzose sandstone and sandstone, interbedded with shale and shaly sandstone

5.3 DRILLING AND PERMEABILITY TESTING

5.3.1 Location of Boreholes

Drillings were conducted at the following two sites: 1) the dam site including projected locations for the dam and power station and 2) the lower quarry site (Site C) located downstream of the dam site.

(1) Lower Dam Site

At the preliminary investigation (1981) stage, drilling was carried out at the dam axis selected in accordance with pertinent geological and topographical conditions. At the detailed investigation stage (1982), a survey was conducted on the basis of the proposed dam shape and power plant, which had been studied in light of the previous year's results. The location of the boreholes are shown in Fig. 5.6, while operational quantities are given in Table 5.2.

Table 5.2 Quantity of Drilling Work at Lower Dam Site

Location		Borehole	Depth (m)	Permeability Testing
Main Dam Site	Preliminary Inv. Stage	L-1 L-2 L-3 L-4	50.0 40.0 39.0 51.0	7 6 7 7
	Detailed Inv. Stage	LD-2 LD-3 LD-4 LD-5 LD-6	50.0 49.0 80.0 50.0 50.0	8 9 16 9 9
Coffer Dam	ditto	LD-1 LD-10	19.0 20.0	-
Spillway, & Power Station	ditto	LD-7 LD-8 LD-9	20.0 22.0 20.0	-
Diversion Tunnel	ditto	LD-11 LD-12 LD-13	20.0 50.0 20.0	-
Saddle	ditto	LD-14	50.0	10
Total			700.0	88

(2) Lower Quarry Site (Site C)

As a result of the geological reconnaissance conducted at the preliminary investigation stage (1981), a sandstone distribution area situated along the right bank of the Tekai River downstream of the dam site was selected as the lower quarry site for the lower dam. Drillings were carried out at the detailed investigation stage (1982). The location of the boreholes are shown in Fig.5.7*, while operational quantities are given in Table 5.3.

Table 5.3 Quantity of Drilling Work at Lower Quarry Site

Location	Borehole	Depth (m)
Quarry Site (Site C)	LQ-1 LQ-2 LQ-3 LQ-4 LQ-5 LQ-6	50.0 50.0 25.0 25.0 35.0 25.0
Total		210.0

5.3.2 Findings of Drilling

Observation records of the geological log are illustrated in Fig. 5.8*. The findings of the drilling can be summarized as follows:

(1) Lower Dam Site

The lower dam site is composed of sandstone, shale, and partial alternation of sandstone and shale.

1) The river bed deposites have irregular thickness layers, ranging from 2 to 10 m and composed primarily of sand and small gravel.

Table 5.4 Thickness of River Bed Deposits at Lower Dam Site

Borehole	Thickness of River Bed Deposits
L-2 LD-9 LD-1 LD-8 LD-10	3.30 m 10.85 m 2.45 m 5.50 m 3.15 m

ii) The top soil and the completely weathered rock (D Class rock) is relatively thin, but is thicker in the right bank than in the left bank.

Table 5.5 Thickness of Top Soil and Completely Weathered Rock

Left Bank		Right Bank	
Borehole	Depth (m)	Borehole	Depth (m)
L-3	1.00	L-1	7.00
L-4	5.10	L-2	3.30
LD-4	0	LD-1	2.45
LD-5	5.00	LD-2	9.00
LD-6	5.00	LD-3	3.45
LD-7	3.55	LD-14	2.50
LD-8	8.20		
LD-10	4.30	LD-9	10.85
LD-11	6.10		
LD-12	4.00		
LD-13	2.75		

*Center of river bed

iii) Details of remarkable cracky or clayey zones, seen in the geological log, are as shown in the Table 5.6.

Table 5.6 Remarkable Cracky or Clayey Zones at Lower Dam Site

Borehole	Remarkable Cracky or Clayey Zone
LD-2	19.50 - 20.40 m, 29.00 - 30.00 m
L-1	35.90 - 36.90 m
LD-3	20.00 - 24.00 m, 42.00 - 42.90 m
L-2	--
LD-4	51.05 - 55.00 m, 59.00 - 68.00 m, 72.00 - 80.00 m
L-3	--
LD-5	27.00 - 29.80 m
L-4	12.00 - 13.30 m
LD-6	15.00 - 16.00 m

(over 50 cm width except some weathered rock)

The LD-4 log, in particular, features fragments of rock with clay at a depth between 72 to 80 meters, indicating that it is a cracky zone. The continuity of this cracky zone has not been confirmed so far.

(2) Lower Quarry Site (Site C)

As regards the construction material (concrete aggregate) for the lower dam, the following results have been obtained from the drilling work performed in an area downstream of the dam site where sandstone is widely distributed.

i) Shale, having developed cleavage is inferior in quality to sandstone as concrete aggregate (cf. 7. "Rock Testing"). As shown in Table 5.7 below, Site C features a high ratio of sandstone, suggesting that it is a promising area for a quarry site.

Table 5.7 Ratio of Shale and Sandstone

Borehole	Rock	
	Shale	Sandstone
LQ-1	10%	90%
LQ-2	20%	80%
LQ-3	10%	90%
LQ-4	70%	30%
LQ-5	80%	20%
LQ-6	60%	40%

ii) Concrete aggregate requires a hard and compact rock and so does construction material for a rock fill dam. According to the principle of rock classification, all rocks below C_L Class are unsuitable and those above C_H Class are suitable, in terms of quality as concrete aggregate. Also, adequate testing and study are necessary when C_M Class rock is to be used as concrete aggregate. The ratio of sandstone for the lower quarry site, according to rock classification, is as shown in Table 5.8.

Table 5.8 Ratio of Rock Classification (Sandstone)

Borehole	Below C_L Class	C_M Class	Above C_H Class
LQ-1	31.3 %	68.7 %	0 %
LQ-2	51.9 %	48.1 %	0 %
LQ-3	74.0 %	26.0 %	0 %
LQ-4	66.0 %	34.0 %	0 %
LQ-5	0 %	0 %	0 %
LQ-6	85.0 %	15.0 %	0 %

As shown in Table 5.8 above, the quarry site (Site C) features a high ratio of C_L and C_M Class rock, indicating that a large volume of superior concrete aggregate (above C_H Class) is not readily and effectively obtainable from this site.

5.3.3 Finding of Permeability Testing and Ground Water Level

Water pressure test results of drill holes are summarized in Table 5.9.*

The lower dam site is composed of high permeability zones. With regards to the surface layers of the rocks, the Lugeon values are more than 20 Lugeons. Even fresh rocks possess 10 - 20 Lugeons.

A high permeability zone (24 Lu) within a fractured zone, is found at the bottom of borehole LD-4, which has no zone belowe 10 Lu.

An outline of the Lugeon values, which is under designed high water level at the dam axis, is given in Table 5.10.

Table 5.10 Outline of Lugeon Value at Lower Dam Axis

	Left Bank	River Bed	Right Bank
MAX.	39.7	54.3	53.0
MIN.	1.4	6.0	2.4
AVE.	17.7	20.5	20.0

At the both flanks of the lower dam site, ground water levels is located about 30 m below the ground surface as shown in Fig. 5.3.

Table 5.11 shows the depth of the ground water levels at each borehole.

Table 5.11 Depth of Ground Water Level from Ground Surface

Borehole	Depth (m)	Borehole	Depth (m)
L-3	10.5	L-1	39.6
L-4	26.8	L-2	1.4
LD-4	4.5	LD-1	0.2
LD-5	32.5	LD-2	24.0
LD-6	32.0	LD-3	7.5
LD-7	3.3	LD-14	31.0
LD-8	1.7		
LD-10	0.7	*LD-9	+0.6
LD-11	12.0		
LD-12	27.0		
LD-13	11.0		

* Center of river bed

5.4 SEISMIC PROSPECTING

Seismic prospecting was conducted by means of seismic lines covering the areas proposed for the dam site and lower quarry site (Site C).

5.4.1 Line of Seismic Prospecting

At the preliminary investigation stage (1981), seismic prospecting was conducted mainly at the dam site in order to obtain general geological date. At the detailed investigation stage (1982), it was extended to include the lower quarry site (Site C).

The seismic prospecting lines and the quantity of this work are shown in Fig.* 5.6 ∿ 5.7, and Table 5.12 respectively.

Table 5.12 Quantity of Seismic Prospecting Work at Lower Dam Site

Name of Line	Length (m)	Spread
L-A	570	5
L-B	310	3
L-C_1	110	1
L-C_2	220	2
L-D_1	210	2
L-D_2	210	2
L-E	250	3
L-F_1	110	1
L-F_2	100	1
L-G_1	200	2
L-G_2	230	2
Total	2,520	24

Table 5.13 Quantity of Seismic Prospecting Work at Lower Quarry Area (Site C)

Name of Line	Length (m)	Spread
A	550	6
B	400	4
C	250	3
Total	1,200	13

(1) Lower Dam Site

The seismic profile of the lower site is shown in Fig. 5.9.* Three refractors were detected below the 300 to 400 m/sec. uppermost layer. The velocity of the upper layer is about 800 to 1,000 m/sec. The velocities of the intermediate and third layer respectively 1,400 to 1,500 m/sec. and 2,500 to 3,000 m/sec. These conditions are very similar to those of the upper dam site, however, the thickness of the uppermost and the top layers of the lower dam site are much thinner than those of the upper site.

(2) Lower Quarry Site (Site C)

The seismic profile of lower quarry area (Site C) is shown in Fig. 5.10.* Two refractors were detected under 350 m/sec. in the lower quarry site. The velocity of the shallower ranges 800 and 1,500 m/sec., and the deeper ranges 2,500 m/sec. The deeper layer is interpreted as moderately or slightly weathered zone.

The velocity of the bedrock is up to 2,800 m/sec., a speed lower than all other areas including the upper site. This figure coincides with the results of the drilling, indicating that there is a C_H Class layer of rock distributed in the foundation (cf. Table 5.8). Thus the findings of the seismic prospecting also suggest that concrete aggregate of good quality is not readily and effectively available at this site.

6. SOIL TESTING

6. SOIL TESTING

6.1 GENERAL

The soil test was carried out to judge the suitability of core material, i.e. impermeable construction material, samples of which are collected from the borrow site of the upper dam. The upper dam is a center core type rock fill dam located in the Tekai area.

As the results of the soil test, the materials from the both sites (Sites A and B) have been proven to be suitable as core material. However, it is desirable that Site A is the reserve for Site B because the effective collection of material is difficult at Site A.

6.2 TEST ITEMS

The following tests were conducted in order to judge the suitability of core material (for use in the upper dam site) collected from the two borrow sites (Sites A and B).

6.2.1 Physical Tests

The following physical tests were conducted in order to study the basic properties of soil, suitability for core material, and soil classification.

(1) Specific gravity
(2) Grading
(3) Moisture content (natural)
(4) Liquid limit
(5) Plastic limit

6.2.2 Mechanical Tests

The optimum moisture content and maximum dry density shall be found based on the relations between moisture content and dry density as well as on the permeability which is the fundamental property of core material. The following mechanical tests were conducted in order to obtain the basic data for designing.

(1) Moisture-density relationship (Compaction test)
(2) Permeability (natural compaction condition)

6.3 SPECIMEN AND QUANTITY

The list in Table 6.1 shows the test quantities as well as the locations where test samples were collected. Figs. 1.2, 4.9, and 4.10 show a ground plan of the Tekai area, rough sketch of the project site, and pit location map of Sites A and B respectively.

Table.6.1. LIST OF TEST

Borrow Site	No	Pit	Depth (m)	Physical Test: Specific Gravity GS	Physical Test: Grading 74µm Over	Physical Test: Grading 74µm Under	Physical Test: Moisture Content Wn	Physical Test: Liquid Limit WL	Physical Test: Plastic Limit Wp	Mechanical Test: Moisture Density Relation	Mechanical Test: Permeability	Remarks
	1	P-1	1.0	O	O		O			O	O	
	2		1.8	O	O	O	O	O	O	O	O	
	3	P-2	1.0	O	O		O	O	O	O	O	
	4	P-3	1.0	O	O		O			O	O	
	5		2.0	O	O		O			O	O	
	6		4.0	O	O	O	O	O	O	O	O	
	7	P-4	1.0	O	O		O			O	O	
	8		1.8	O	O		O	O	O	O	O	
Site A	9	P-5	1.2	O	O		O			O	O	
	10		2.4	O	O		O			O	O	
	11		4.5	O	O	O	O	O	O	O	O	
	12	P-6	1.0	O	O		O			O	O	
	13		1.7	O	O		O	O	O	O	O	
	14	P-7	1.0	O	O		O			O	O	
	15		2.0	O	O	O	O	O	O	O	O	
	16		3.1	O	O		O			O	O	
	17	P-8	1.3	O	O		O			O	O	
	18		1.8	O	O		O	O	O	O	O	
	19	P-9	1.4	O	O		O			O	O	
	20		1.9	O	O		O	O	O	O	O	
	21	P-10	1.1	O			O			O	O	
	22		2.1	O	O	O	O	O	O	O	O	
	23	P-11	2.1	O	O		O			O	O	
	24		4.0	O	O	O	O	O	O	O	O	
	25	P-12	1.0	O	O		O			O	O	
	26		2.0	O	O	O	O	O	O	O	O	
	27	P-13	2.4	O	O		O			O	O	
Site B	28		3.4	O	O	O	O	O	O	O	O	
	29	P-14	1.0	O	O		O			O	O	
	30		2.0	O	O	O	O	O	O	O	O	
	31	P-15	2.3	O	O		O			O	O	
	32		3.3	O	O	O	O	O	O	O	O	
	33	P-16	2.5	O	O		O			O	O	
	34		3.3	O	O	O	O	O	O	O	O	
	35	P-17	2.5	O	O		O			O	O	
	36		3.2	O	O	O	O	O	O	O	O	

6.4 TEST METHOD

The ASTM Method was employed in the following tests.

6.4.1 Physical Test on Soil

1)	Specific Gravity:	ASTM D854-58 (1972) 'Test for Specific Gravity of Soils'
2)	Grading:	ASTM D422-63 (1972) 'Particle Size Analysis of Soils'
3)	Moisture Content:	ASTM D2216-71 'Laboratory Determination of Moisture Content of Soil'
4)	Liquid Limit:	ASTM D423-66 (1972) 'Test for Liquid Limit of Soils'
5)	Plastic Limit	ASTM D424-59 (1971) 'Test for Plastic Limit and Plasticity Index of Soils'

6.4.2 Mechanical Test on Soil

1)	Moisture Density Relations:	ASTM D1557-70 'Moisture Density Relations of Soils using 10 lb (4.5 kg) Rammer and 18 in. (457 mm) Drop
2)	Permeability (Natural Moisture Content):	ASTM D2434-68 (1974) 'Test for Permeability of Granuale Soils (Constant Head) - (Falling Head)

(For full particulars of the test, see "Annual Book of ASTM Standards" Part 19.)

6.5 TEST RESULTS

6.5.1 Results of Physical Tests

1) Specific gravity:

2.50 to 2.75, averaging 2.62, in both Sites A and B (see Fig. 6.1).

2) Moisture content:

18 to 19% on the average in both Sites A and B, ranging wider (10 to 30%) in Site A but nearing the average (16 to 24%) in Site B (see Fig. 6.2).

3) Consistency:

This was plotted in the Plasticity Chart for the purpose of soil classification based on liquid and plastic limits (see Fig. 6.3). As a result, it proved that CL (silt and clay) predominates in Site A, whereas CH (highly plastic silt and clay) is mixed in Site B.

4) Grading:

Fig. 6.4 shows the grain size cumulative curves of Site A and B. Fine grading averages 65% in both sites (see Fig. 6.5). Clay accounts for 25% in Site A and 40% in Site B; the latter features greater clay content.

6.5.2 Results of Mechanical Tests

1) Moisture-density relationship

Fig. 6.6 shows the relationship between moisture content and dry density in Sites A and B. Maximum dry density ranges from 1.6 to 1.9 g/cm^3 in both sites but averages 1.79 g/cm3 in Site A and 1.74 g/cm^3 in Site B (see Fig. 6.7).

The relation between maximum dry density and optimum moisture content features a proportional relation, focusing on the zero air void curve (based on the average specific gravity of 2.62), as shown in Figs. 6.8.1 and 6.8.2.

There is little difference in optimum and natural moisture contents between Sites A and B, i.e. $W_{opt} = W_n \pm 4(\%)$ in Site A and $W_{opt} = W_n \pm 3(\%)$ in Site B (see Fig. 6.9).

2) Permeability:

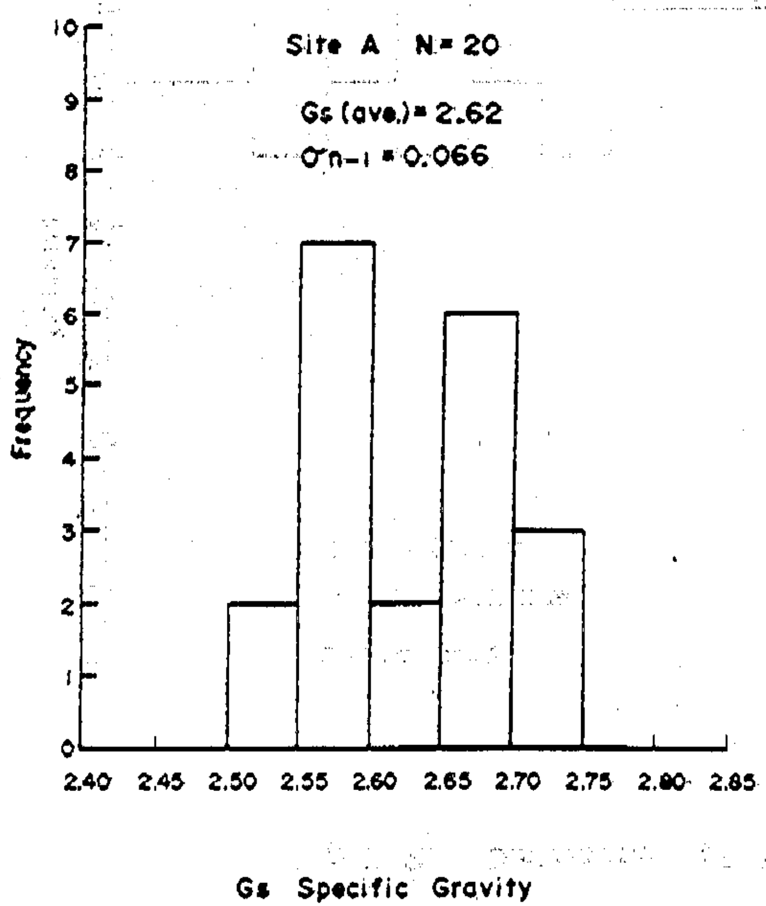
The coefficient of permeability ranges from 3.0×10^{-7} to

6.0×10^{-7} cm/s in Site A and from 1.0×10^{-7} to 2.0×10^{-7} cm/s in Site B (see Fig. 6.6).

6.5.3 Summary of Test Results

A summary of test results is given in Tables 6.3.1 and 6.3.2. Also, the test results for each test pit are shown in Table 6.4.1. to 6.4.17.

Fig.6.1 Distribution of Specific Gravity



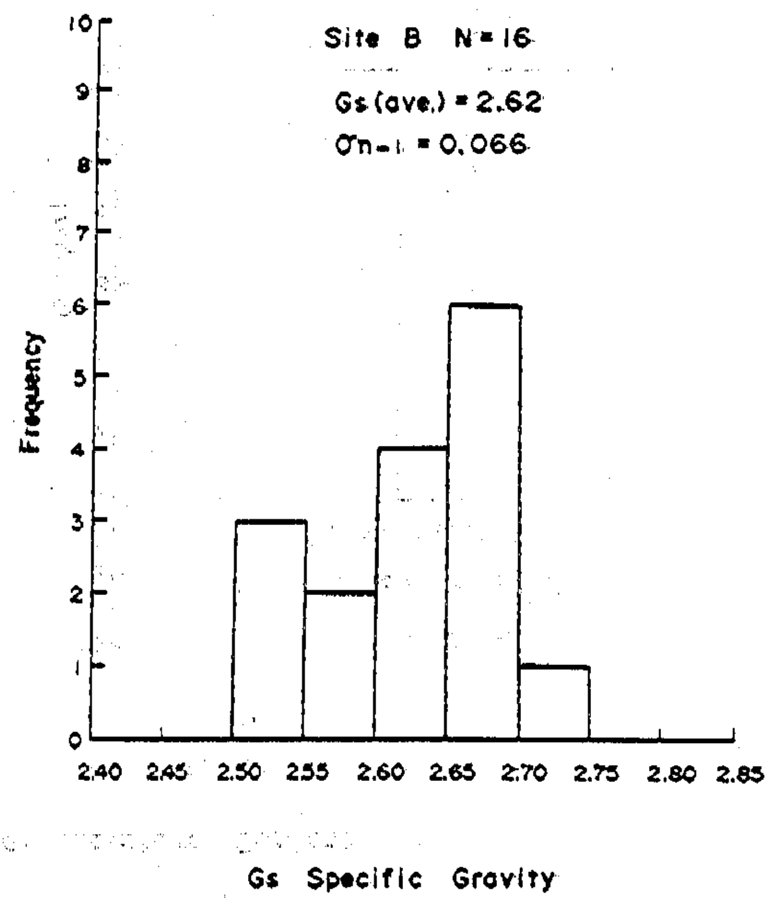


Fig. 6.2 Distribution of Natural Moisture Content

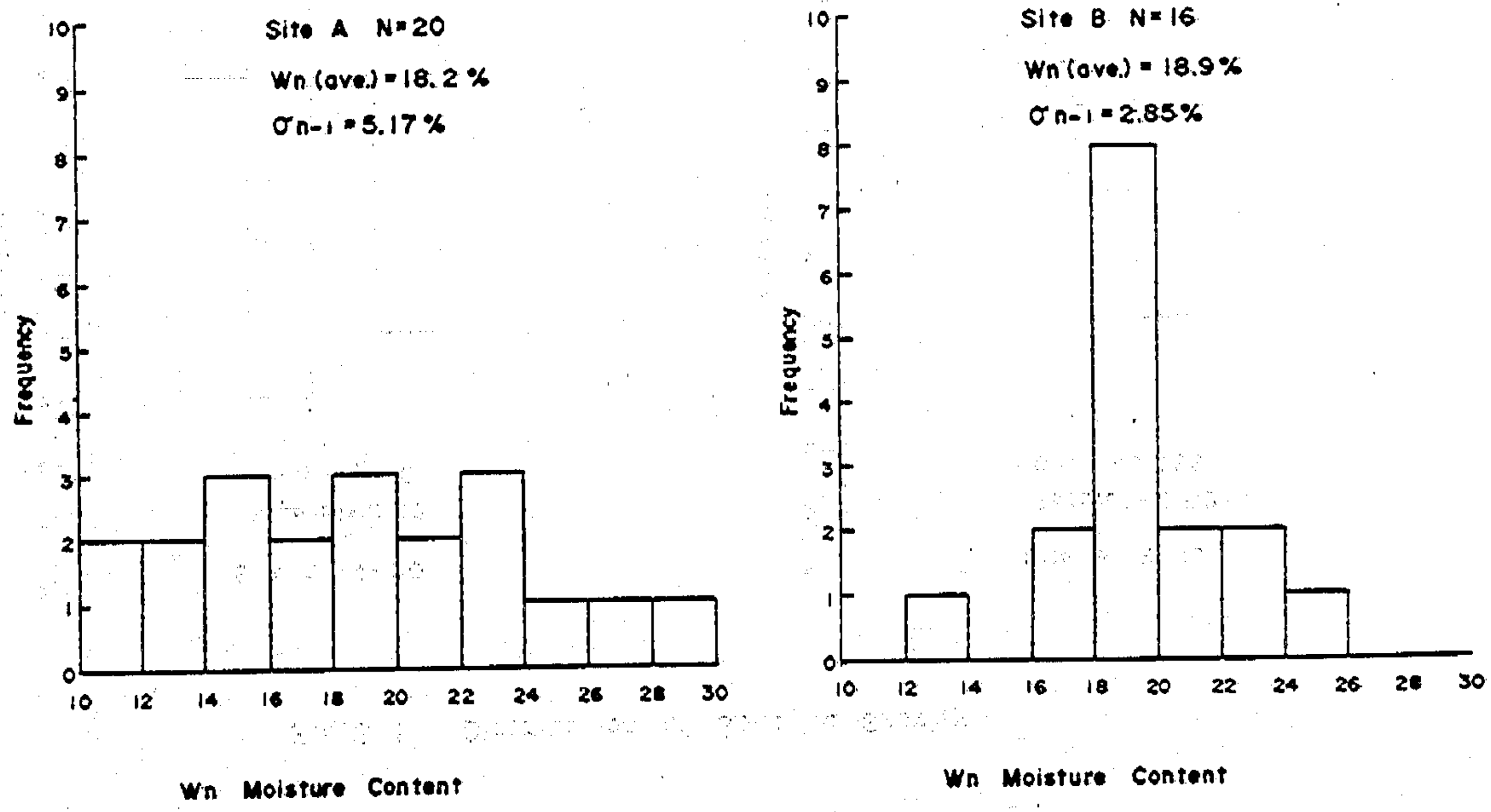
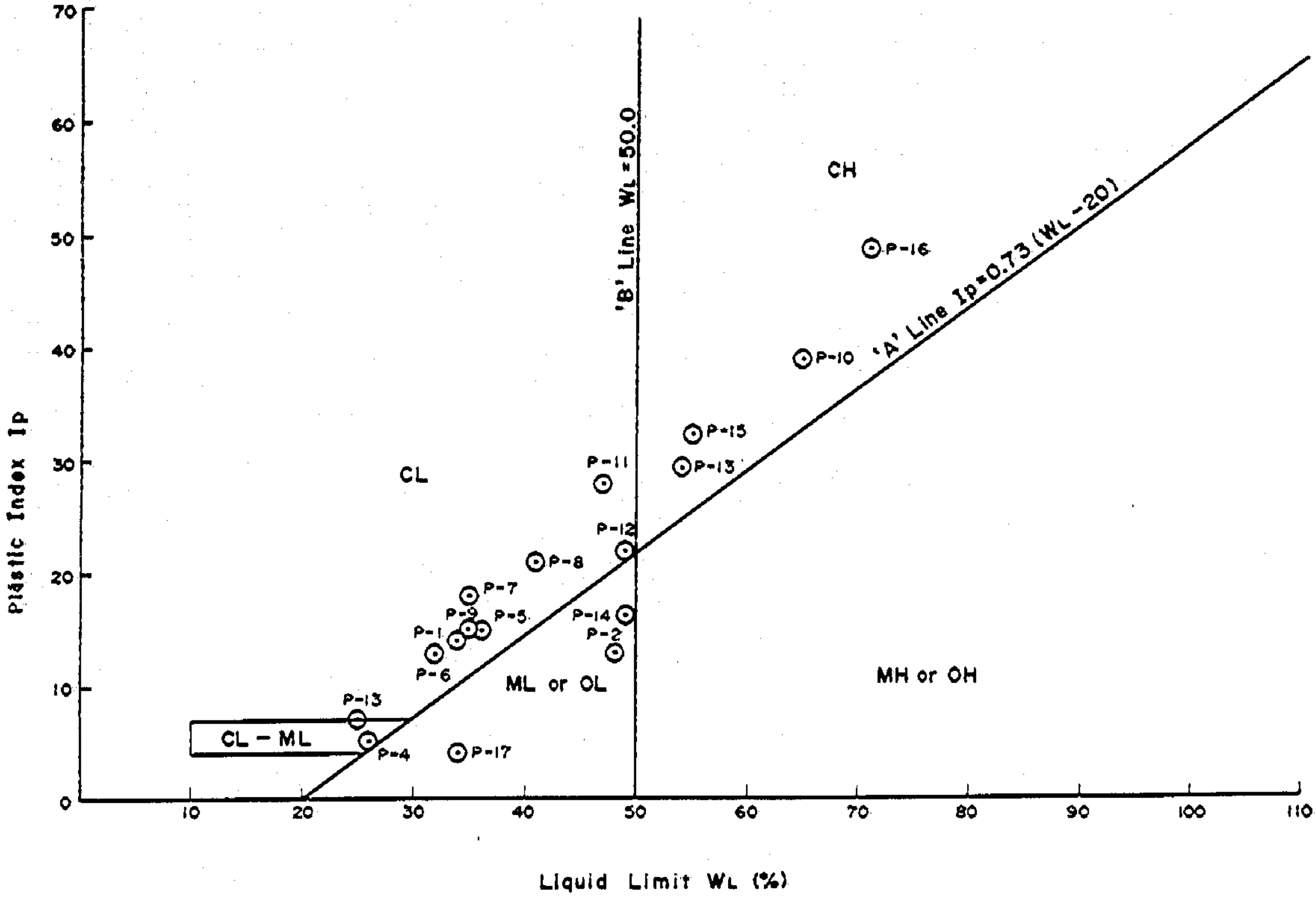


Fig. 6.3 PLASTICITY CHART



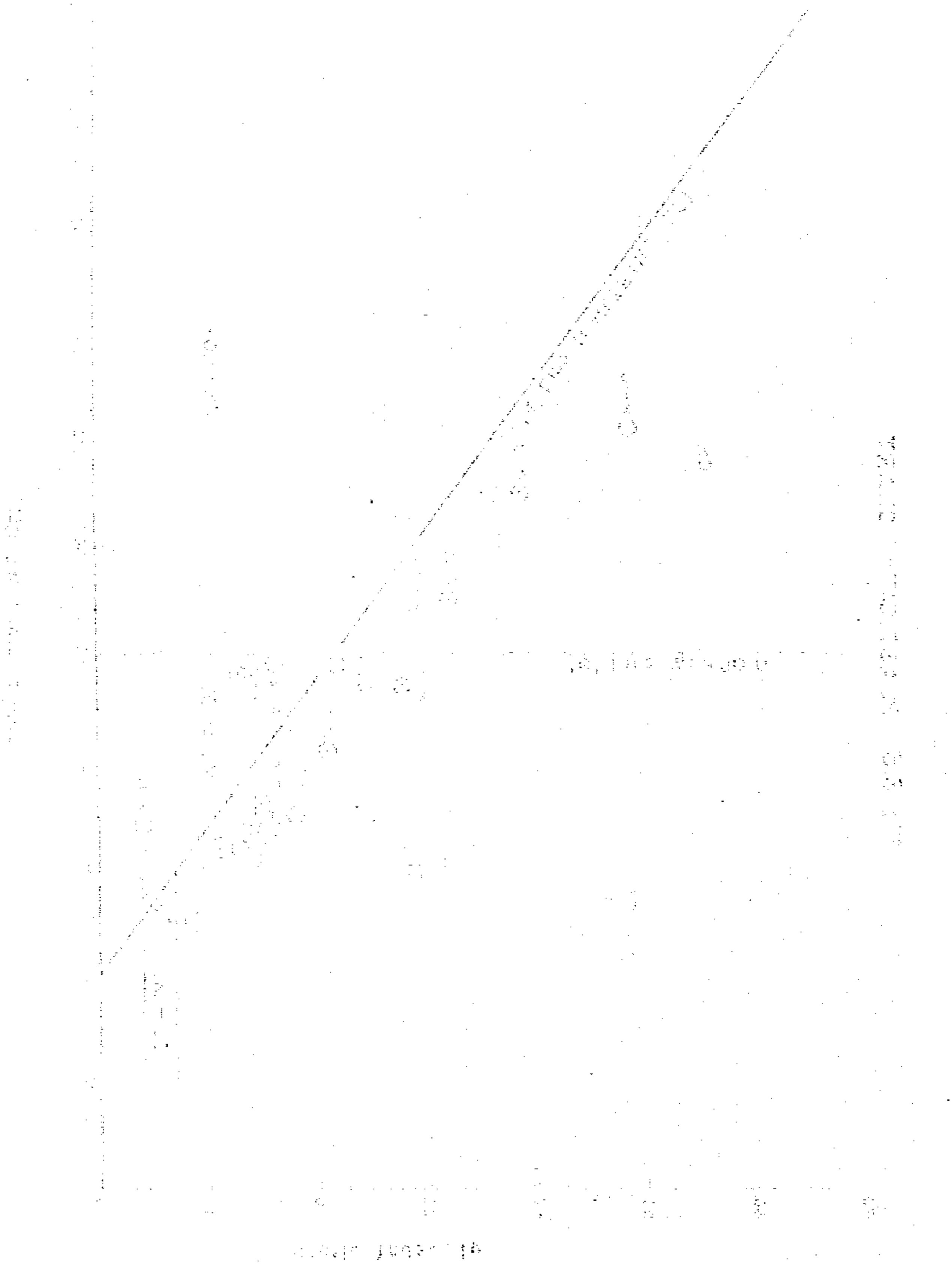


Table. 6.2 Unified Soil Classification Chart

UNIFIED SOIL CLASSIFICATION INCLUDING IDENTIFICATION AND DESCRIPTION

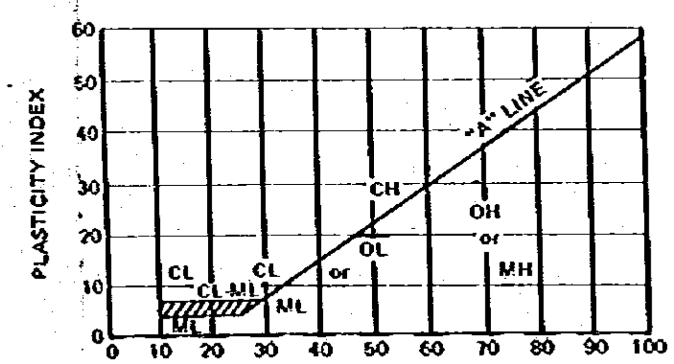
Major divisions			FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)	GROUP SYMBOLS	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA	
COARSE GRAINED SOILS More than half of material is larger than No. 200 sieve size. (The No. 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS More than half of coarse fraction is larger than No. 4 sieve size. (For visual classifications, the 1/4" size may be used as equivalent to the No. 4 sieve size.)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures little or no fines.	Give typical name, indicate approximate percentages of sand and gravel, max size, angularity, surface condition, and hardness of the coarse grains, local or geologic name and other pertinent descriptive information, and symbol in parentheses.	$C_U = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.		Not meeting all gradation requirements for Gw	
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.	Atterberg limits below "A" line. or PI less than 4	Above "a" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.		Atterberg limits above "A" line with PI grater than 7	
	SANDS More than half of coarse fraction is smaller than No. 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.	SW	Well graded sands, gravelly sands, little or no fines.	EXAMPLE:– Silty sand, gravelly; about 20 % hard, angular gravel particles 1/2" in maximum size, rounded and subangular sand grains coarse to fine, about 15 % non plastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM)	$C_U = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3	
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines.		Not meeting all gradation requirements for SW	
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixtures.		Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols
			Plastic fines (for identification procedures see CL below)	SC	ClayeY sands, poorly graded sand-clay mixtures.		Atterberg limits above "A" line with PI greater than 7	

Laboratory classification criteria (coarse grained soils): Use grain-size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse grained soils are classified as follows:–

- Less than 5 % — GW, GP, SW, SP.
- More than 12 % — GM, GC, SM, SC.
- 5 % to 12 % — Borderline cases requiring use of dual symbols.

IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No. 40 SIEVE SIZE

Major divisions		DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GROUP SYMBOLS	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS
FINE GRAINED SOILS More than half of material is smaller than No. 200 sieve size.	SILTS AND CLAYS Liquid limit less than 50	Non to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses.
		Medium to high	None of very slow	Medium	CL	Inorganic clays of low to meidum plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity.	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
	SILTS AND CLAYS Liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	
		High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays.	EXAMPLE:– Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loses; (ML)
		Meidum to high	None of very slow	Slight to medium	OH	Organic clays of medium to high plasticity.	
HIGHLY ORGANIC SOILS		Readily identified by color, odor, spongy feel and frequently by fibrous texture.			Pt	Peat and other highly organic soils.	



PLASTICITY CHART

* Boundary classifications: – Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.

** All sieve sizes on this chart are US standard.

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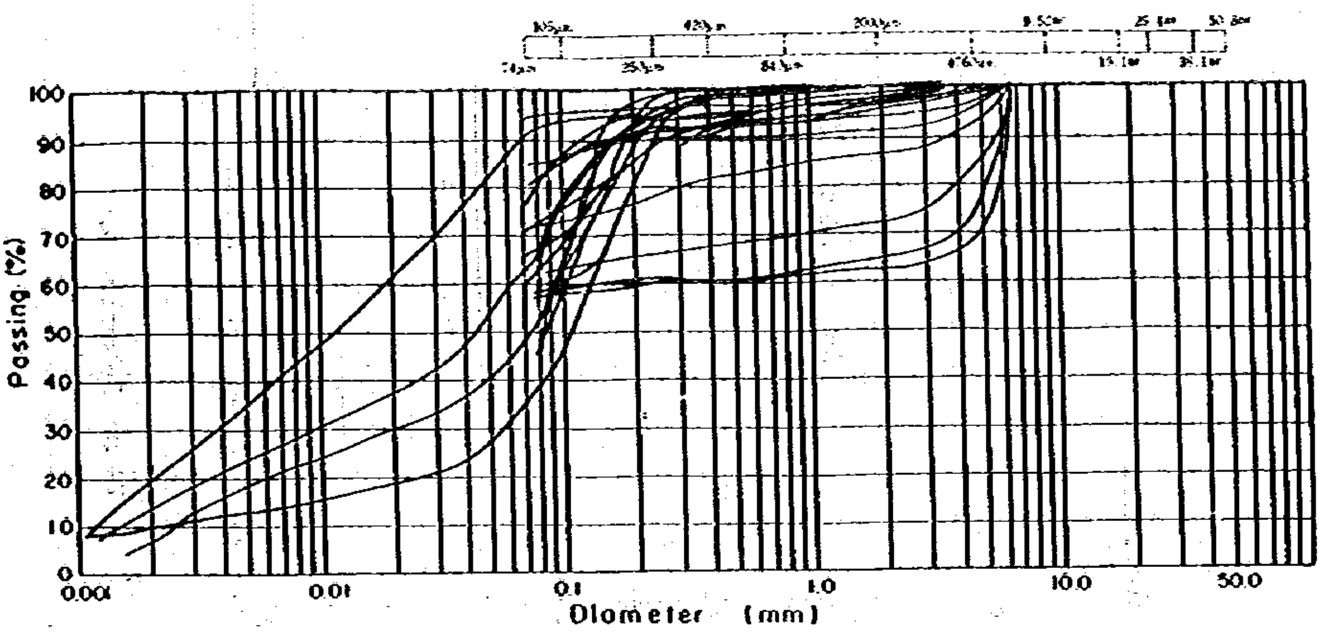
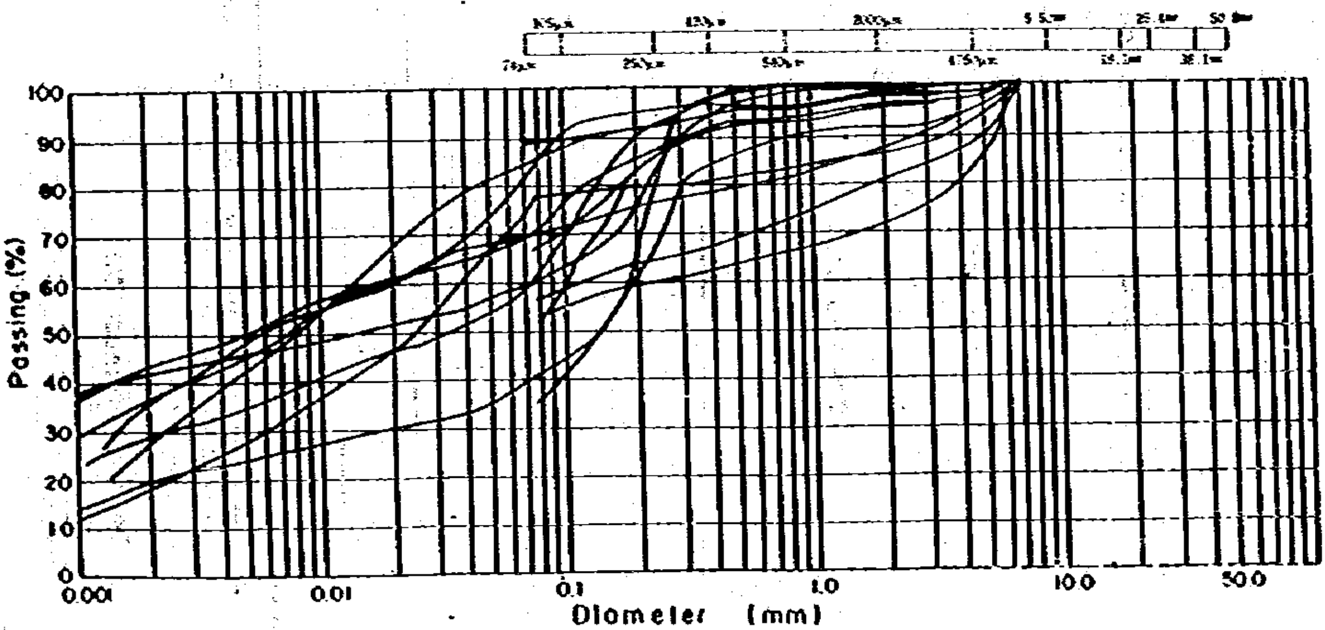
Fig.6.4 Grading



Site A



Site B