GOVERNMENT OF MALAYSIA
LEMBAGA LETRIK SABAH
(SABAH ELECTRICITY BOARD)

FEASIBILITY STUDY REPORT
ON
TENOM PANGI HYDROELECTRIC POWER DEVELOPMENT PROJECT, PHASE III
(SOOK RESERVOIR)

VOLUME III

APPENDIX-B : GEOLOGY
APPENDIX-C : TOPOGRAPHY
APPENDIX-D : CONSTRUCTION MATERIALS

SEPTEMBER 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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ABBREVIATIONS

(1) Domestic Organization

DID (JPT)	:	Drainage and Irrigation Department
DOA (JP)	:	Department of Agriculture
EPU	:	Economic Planning Unit
MMS	:	Malaysian Meteorological Service
SEB (LLS)	:	SABAH ELECTRICITY BOARD
SEDC	:	State Economic Development Corporation
SEPU	:	State Economic Planning Unit

(2) International or Foreign Organization

JICA	:	Japan International Cooperation Agency

(3) Measurement

<u>Length</u>

mm = millimeter
cm = centimeter
m = meter
km = kilometer

<u>Area</u>

ha = hectare
km^2 = square kilometer

<u>Volume</u>

l = liter
m^3 = cubic meter
cft = cubic feet

<u>Weight</u>

kg = kilogram
ton = metric ton

<u>Time</u>

sec, s = second
min = minute
hr = hour
yr = year
SST = Sabah Standard Time

<u>Electrical Measures</u>

V = Volt
kW = Kilowatt
MW = Megawatt
kWh = Kilowatt hour
MWh = Megawatt hour
GWh = Gigawatt hour

<u>Money</u>

M$ = Malaysian dollar
M¢ = Malaysian cent
US$ = US dollar
US¢ = US cent
¥ = Japanese Yen

<u>Other Measures</u>

% = per cent
o = degree
' = minute
" = second
m^3/sec, m^3/s = cubic meter per second
cusec = cubic feet per second

(4) Economy and Finance

EIRR	:	Economic Internal Rate of Return
FIRR	:	Financial Internal Rate of Return
FC	:	Foreign Currency
LC	:	Local Currency
GDP	:	Gross Domestic Product
GRDP	:	Gross Regional Domestic Product
OMR	:	Operation, Maintenance and Replacement
L.S.	:	Lump Sum

(5) Other Abbreviations

El.	:	Elevation above mean sea level
NHWL	:	Normal high water level
HWL	:	High water level
LWL	:	Low water level

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1. INTRODUCTION

This section states the following geological conditions based on result of geological survey carried out in this feasibility.

(1) Foundation of the proposed Sook dam and its two saddle dams,

(2) Bedrocks of the proposed quarry site,

(3) Foundation of the extension of the Tenom Pangi powerhouse, and

(4) Foundation of the conceived reregulation dam of the Sook dam.

The conditions of the first three were revealed by means of field investigations and laboratory test comprising all or some of the following ;

(1) Seismic exploration,

(2) Core drilling, and standard penetration test (SPT) and permeability test in the drillhole,

(3) Trench excavation and permeability test in the trench, and

(4) Laboratory test of unconsolidated strata obtained by SPT.

The field investigations and laboratory test were conducted by the Sabah Electricity Board and accomplished during 5 months since the end of July, 1985.

The above condition of the last is presumed based on result of field reconnaissance carried out by the Consultants.

2. GENERAL TOPOGRAPHY AND GEOLOGY

2.1 Topography and Geology of the Padas Basin

2.1.1 Topography of the Padas basin

The Padas basin, developed on the Padas river which is 265 km long, is situated in the southwestern part of Sabah Statex as shown in Fig. B1.

The geography of the Padas river basin is shown in Fig. B 2. The Padas river in the upper reaches of 155 km in length flows from its origin on the border of Sabah and Kalimantan toward the north-northeast and joins the Pegalan river, which is the largest tributary coming from a highland in north-northeast with nearly the same size as the upper Padas. In the lower reaches, the Padas takes its course northwestward through a 50 km long gorge across the Crocker range and a 60 km long meandering channel on a coastal plain, and pours itself into South China Sea. The Sook river is a major tributary of the Pegalan river, joining it about 50 km upstream of the Pegalan and Padas confluence.

A large part of the Padas river basin is divided into sub-basins of the upper Padas, the Pegalan and the Sook, all of which are located among the mountain ranges. The Crocker range, the Trusmadi range and the Witti range, from west to east in order, stretch in parallel rows with the north-northeasterly trend. Developed between the Crocker range and the Trusmadi range are wide open valley plains, such as the Tomani plain on the upper Padas river, the Tambunan and the Keningau plains on the Pegalan river and the Tenom plain at their confluence. The Sook plain lies between the Trusmadi range and the Witti range.

2.1.2 Geology of the Padas basin

As shown in Fig. B 3, the mountain ranges consist of sedimentary rocks of the Crocker Formation and the Temburong Formation of the Eocene to Miocene ages.

The Crocker Formation, widely exposed in the northern and eastern areas of the Padas basin, is strongly arenaceous and consists mainly of sandstone beds and sandstone/shale alternations. The sandstone is composed of poorly sorted angular sand particles and well cemented to a considerable hardness. The shale is also well consolidated, but fragile. The Crocker Formation is strongly folded, and shows a complicated stratigraphic sequence due to the isoclinal folding. The bedding has a general strike of northerly or north-northeasterly bearing, conformable with the orientation of the mountain ranges, and generally eastward dips.

The Temburong Formation is argillaceous, consisting mainly of shales and siltstones with subordinate intercalations of sandstones, and develops in the southwestern areas of the Padas river basin. These argillaceous rocks tend to be cracked and easily deteriorated on exposure to air, in spite that they are well consolidated in nature. The bedding shows the trend similar to the Crocker Formation, of which the upper horizons are deemed correlative in the age with the Trusmadi Formation.

The inter-mountain valley plains consist of four planes of varied levels, that is, the upper terrace more than 60 m high above the river bed, the middle terrance 30 m to 40 m high, the lower terrace with about 10 m of height and the flood plain within several metres of height from the river bed. The terrace deposits are composed of clay, sand and gravels of Pleistocene age, while the flood plain deposits are largely of sand and gravels of Holocene.

2.2 Topography and Geology of the Sook Reservoir

2.2.1 Topography of the Sook Reservoir

The Sook river rises in highlands between the Trusmadi range and the Witti range, and flows through 15 km course in the highlands to south, 30 km long meandering channel on the Sook plain to northwest, 40 km long gorge in the Trusmadi range to northwest or north and, the, 15 km long channel in the southern corner of the Keningau plain to northwest to drain finally into the Pegalan river from the left side. At the confluence with the Pegalan, the river bed is at elevation 240 m.

The proposed Sook reservoir will occupy an area from the southern margin of the Keningau plain to the western flank of the Trusmadi range. The locations of the Sook dam, the two saddle dams and the two quarry sites are shown in Fig. B 4. Outline of general geology in and around the reservoir is given in Fig. B 5 and undermentioned.

The reservoir area is surrounded from its northwest, west, south and east sides by hilly terrains of low relief, ranging from 350 m to 450 m in elevation of hilltops. The hills are composed of the Crocker Formation which trends in the direction of north to south and dips eastward. The bedrock is weathered thick. Landslides through the intensively weathered bedrock are located on the northwest rim of the reservoir area. The upper terrace planes are developed at elevation 300 m to 350 m on the hilly terrains.

Developed at elevation 300 m to 320 m in the north side of the reservoir area is the middle terrace, which forms a watershed between the reservoir area and the Keningau plain. The middle terrace is wide-spread also in the eastern to central part of the reservoir area, while the flood plain at about 255 m in elevation occupies a large part of the remaining western part. The lower terrace, 260 m to 270 m in elevation, occupies a minor area between the middle terrace and the flood plain.

The proposed Sook dam site is located in the hilly area northwest of the reservoir, where the Sook river flows northwestward through a narrow gorge. The slope shows approximately 30 degrees of inclination from the horizontal on the right bank and 15 to 20 degrees on the left bank.

A couple of saddle topography is located on the right bank of the reservoir; one at 317 m in elevation in the hilly area 2 km northeast of the dam site and the other on the middle terrace at elevation 300 m to 320 m at about 5 km northeast of the dam site.

2.2.2 Geology of the Sook Reservoir

Geological features of the bedrocks and the terrace deposits are as described below:

(1) Bedrock

The bedrock consists of sedimentary rocks of the Crocker Formation, which are for the most part irregularly alternating beds of sandstone, shale and mudstone. The sandstone occupies a large proportion of 70 to 90 percent in the bedrock, and the rest portion is shared by the shale and the mudstone, of which the latter proportion is only a few percent. The sandstone forms layers of thickness ranging from a few tens of centimetres to several metres, often intercalated with shales and mudstones with thickness of a few centimeters to a metre. Minor parts of the bedrock are formed with regular alternations of shale and sandstone, or mudstone and sandstone, of which unit layers are 5 cm to 10 cm thick. Thickness of each alternation ranges from 0.5 to 2 m.

The sandstone is composed of poorly sorted fine and angular particles, associated with calcite veinlets with slight pyritization, and well cemented. Fresh sandstones bears joints at intervals of 5 cm to 30 cm.

The shale is dominantly of clay origin and has strong fissility. The mudstone is varies mixtures of clay, silt and fine sand components with small quantity of carbonaceous matter and slightly fissile. The shales and mudstones are generally flaky and often clayey even in the fresh rock zone.

The close joints in the sandstone and the flaky or clayey shale and mudstone are deemed to reflect tectonic disturbances related with the folding that are characteristic with the mountain ranges in this area. Presumably, the tention along the beds which were folding caused plastic flow to relatively soft layers of shale and mudstone, and tention joints to hard sandstones.

(2) Upper terrace

The upper terrace deposits are composed mainly of brown sandy clay, approximately 5m thick, with intercalations of gravel layers at the middle part and the bottom. The gravels are of small pebble size, rounded, siliceous and possibly of metamorphic rock origin.

The terrace plain has been strongly dissected into the present terrain of rather sharp relief.

(3) Middle terrace

The middle terrace deposits have a thickness more than 60 m, consisting of silty clay in the 5 m thick upper layer, gravelly sand in the next 15 m thick layer and the underlying thick layer of pure sand and clay.

The silty clay and the pure sand contain much quantity of quartz grains. Gravels in the gravelly sand layer are siliceous, round, small to middle sized and of sandstone origin. The silty clay and the gravelly sand are tinged brown due to weathering, while the pure sand and clay in the lowest layer are fresh with grey to dark grey colour.

The pure sand and clay seem to be sediments of lake or bay, whereas the others are probably river or littoral sediments. The relation between the gravelly sand and the underlying pure sand and clay is deemed to be unconformable.

The middle terrace plane forms a vast flat land over major part of Keningau plain.

(4) *Lower terrace*

The lower terrace deposits consist normally of loose sandy silt and highly moistened clayey silt, partly associated with lenticular gravel layers. The thichness varies from 5 m to 10 m.

Gravels of the gravel layers are of siliceous sandstone, of round medium pebble size and brittle due to severe weathering in the reservoir area. Downstream of the reservoir area, they are round to sub-round and rather fresh with the size of large pebble to small cobble.

(5) Flood plain

The flood plain deposits are sandy silt and gravels, thicker than 5 m. The deposits in the reservoir area are for the most part silt including round gravels of small to medium pebble size, while those downstream of the reservoir consist of two layers, that is, a 2.5 m thick sandy silt layer in the upper part and a layer of gravels of small pebble to small cobble sizes in the lower part.

3. METHOD OF INVESTIGATION AND ANALYSIS

3.1 Location and Quantity

Location of the seismic exploration, core drilling and trench excavation is shown in Fig. B 6, B 7 and B 8 and their quantity is given in Tables B 1 to B 3.

3.2 Seismic Exploration

The seismic exploration was carried out to outline the geological conditions, especially thickness of overburden and weathered zone in the proposed Sook damsite, two saddle damsites and quarry site.

The exploration was executed by means of the refraction method with spacing of geophones at intervals of 5m.

Analysis on results of the exploration was performed by using the Hagiwara's method mainly. Multilayer refraction equations were applied to estimate depth from ground surface to basement layer in the No.2 saddle damsite where remarkably thick terrace deposits overlie.

Result of the analysis is shown in Fig. B 26 to B 33.

3.3 Core Drilling

The core drilling aimed at clarifying facies of strata, weathering condition and frequency of joints in the bedrock, and thicknesses of overburden, strata and weathered zone. It was carried out at the proposed Sook damsite, two saddle damsites, quarry site and extension yard of the Tenom Pangi powerhouse.

The core drilling was executed by using drilling machines of hydraulic driven rotary type. Double tube type core barrels with diamond bits were employed to recover core samples from every strata.

Bedrock and unconsolidated strata are classified from the stratigraphic point of view. Result of the classification is given in Drill Logs at the end of this report. Geological profiles, Fig. B 17 and B 23 for the No.2 saddle dam and extension yard of the Tenom Pangi powerhouse are illustrated based on the classification.

Besides, the bedrock in the Sook damsite, the No.1 saddle damsite and the quarry site is classified from the viewpoint of engineering geology based on condition of core samples. Three criteria as mentioned below are used for the engineering geological classification :

(1) Classification criterion based on weathering condition of core samples is shown in Table B 4. Interpretation on condition of bedrock in the project sites is given mostly by using this criterion.

(2) Classification criterion by K. Kikuchi et.al. (Geotechnically Integrated Evaluation on the Stability of Dam Foundation Rocks, proc. of the 14th Congress on Large Dams, ICOLD Vol.II, 1982) is shown in Table B 5, which shows also physical values of bedrock. This criterion is used in this section, so as to interpret outline of mechanical characteristics of bedrock.

(3) Classification criterion based on three elements such as hardness of rock blocks, spacing of joints and condition of joint planes, is

shown in Table B 6. This criterion is used in drill logs to interpret detailed conditions of core samples.

Result of three kinds of classiffication is given in Drill Logs. Geological profiles, Figs. B 9, B 11, B 13, B 16 and B 21, are illustrated based on the said criterion (1).

3.4 Standard Penetration Test

The standard penetration test (SPT) was carried out to determine penetration resistivity in order to estimate strength of clayey detritus and decomposed material in the Sook damsite and No.1 saddle damsite, and unconsolidated strata in the No.2 saddle damsite and extension yard of the Tenom Pangi powerhouse.

While SPT was performed following the method of ASTM D1586-67, split-barrel sampler was driven by 30 cm in depth without preliminary seating drive and number of blows required to effect each 10 cm of penetration was recorded.

To estimate penetration resistance (N-value) of strata except gravelly ones, the first 10 cm of penetration is neglected because it shall be considered as the seating drive. N-value is estimated by converting the number of blows for the last 20 cm of peneration into that for 30 cm of peneration.

To estimate practical strength of matrix in the gravelly strata, the smallest number of blows among for the first, second and third penetrations is converted into that for 30 cm of penetration.

Results of SPT and the estimated N-value are given in Drill Logs, and geological profiles are shown in Figs. B 16 and B 17.

Strength of both clayey foundation and sandy foundation is estimated based on the following equations;

(1) Strength of clayey foundation

- Unconfined compressive strength(qu) = N/8 (kg/cm^2),

- Cohesion (c) under the condition of zero degree of internal friction angle = 0.6N to 0.65N (t/m^2), and

- Allowable bearing capacity (qa) = 1.2N (t/m^2).

(2) Strength of sandy foundation

Internal friction angle (Ø) under the condition of zero cohesion

$$\phi = \sqrt{12\ N} + 20$$

3.5 Permeability Test in Drillhole

The permeability test was performed to evaluate water tightness of foundation strata and their improvability.

The test in drillhole was carried out by means of water pressure test at the Sook damsite and open-end pipe test at two saddle damsites.

3.5.1 Water Pressure Test

The water pressure test was performed by measuring flow rate of water under various water pressure. The water was injected through rods into a test section which was 2.5 or 5m long and plugged by installing a packer of pneumatically expanded sleeve type at the top of the test section. A water pump to inject the water had the maximum capacity of 60 l/min. Pumping pressure measured at the top of the rods was raised by step of every 0.5 or 1 kg/cm^2 up to the maximum of 6 kg/cm^2 and then reduced by the same step. Pressure to expand the packer was more than twice of that of total head in a test section.

A test to make clear energy loss of injected water due to friction with the side of the rods was carried out at the damsite, which result is shown in Fig. B 14.

Results of the water pressure test are given in P-Q graphs which show correlation between the flow rate and the total head. The total head includes pumping pressure, static head above the test section and friction loss in rods.

Breaking point (BP) and Lugeon unit (Lu) are determined from the P-Q graph. BP in the P-Q graph reflects sudden increase in the flow rate as against the increase in pressure due to rapid fracturing of rock and/or opening of fissures.

Permeability of the bedrock in Lugeon unit was determined from the water intake under the pressure of 10 kg/cm^2, that is read from P-Q graph extended up to the point for that pressure. In case that BP exists in the P-Q graph, the graph below BP was extended so as to evaluate Lu of original bedrock. In case that only one point was on the P-Q graph due to remarkable permeability and insufficient pumping capacity, Lu was evaluated by using straight line through the origin of the coordinate axes and the point.

Results of the determination of BP and Lu are shown in Lugeon maps, Figs. B 10, B 12 and B 13.

3.5.2 Open-end Pipe Test

The open-end pipe test was performed at the two saddle damsites by measuring flow rate of water under a certain head. The water permeated into the ground at the bottom of the open-end pipe, which was casing pipes sunk to the bottom of the drillhole. The test depth was at every 2m interval in the 10m thick subsurface zone and at every 10m interval below the 10-m zone. Duration of each test was more than 60 minutes.

Results of the test are given in graphs attached in this report, Correlation between Flow Rate and Duration, which show that the flow rate becomes constant around 40 minutes after the commencement of the test.

The permeability coefficient is obtained from the following equation quoted from Earth Manual by USBR;

$$k = Q/(5.5 \times r \times H)$$

where, k : Permeability coefficient (cm/sec)
Q : Constant flow rate (cm3/sec)
r : Internal radius of casing (cm)
H : Constant head above test depth (cm)

Results of the calculation are given in geological profiles, Figs.B 16 and B 17.

3.6 Trench Excavation

Trenches were excavated to confirm conditions of the foundation strata, especially for distribution of loose sand and gravel layers, at 5m thick subsurface zone in the No.2 saddle damsite. A backhoe was employed for the excavation.

Results of the trench excavation are given in Geological Sketch of Trench.

3.7 In-situ Permeability Test in Trench

The in-situ permeability test was performed in the trench excavated in the No.2 saddle damsite.

The in-situ test was carried out by means of the constant load method. Test hole was the dimension of 60 cm in diameter and 1m in depth, and filled with river gravel up to its top. Water was allowed to permeate into the side wall of the hole and its bottom. Duration of each test was more than 60 minutes.

Results of the test are given in graphs entitled Correlation between Flow Rate and Duration attached in this appendix, which show that the flow rate becomes constant about 40 minutes after the commencement of the test.

Permeability coefficient is obtained from the following equation ;

$$k = [Q/2\pi H^2]\ [\ln\ [(H/r) + \sqrt{1 + (H/r)^2}] - 1]$$

where, k : Permeability coefficient (cm/sec)
Q : Constant flow rate (cm3/sec)
r : Radius of test hole (cm)
H : Constant Road in test Role (cm)
In : Natural logarithm

Results of the calculation on k are given in geological profile, Fig. B 17.

3.8 Laboratory Test

The laboratory test was performed to clarify physical characteristics of foundation strata of the No.2 saddle dam, so as to study piping and liquefaction problems of the dam foundation.

Samples were obtained by the split-barrel sampler for SPT and tested on three items such as grain size distribution, specific gravity and moisture content.

The sampling depth and the results of the test are given in Figs.B 18 and B 19.

4. SOOK DAM

4.1 Topography of the Sook Damsite

The proposed Sook damsite is located at the northwestern hilly area of the reservoir area. The Sook river forms a narrow and somewhat steep gorge with the length of 2.5 km in the hilly area. Direction of the gorge is north-northwest for the 1 km long upstream part, northwest for the 0.7 km long middle part and west for the 0.8 km long downstream part of the gorge.

The damsite is in the middle part of the gorge. The riverbed there has the elevation of 245m and the width of 30m approximately. Two alternative dam axes are conceived. The two axes are apart by 260m from each other and almost in parallel with each other. The conceived dam crest is at the elevation of 313.5m and 68.5m high from the riverbed.

Bedrock, consisting mainly of sandstone and partly of shale and mudstone, crops out at the riverbed. The bedrock strikes NS to N30° W and dips 30°E, and is open-jointed in the direction of the bedding at intervals of 0.2 to 0.5m.

On the left bank, there is a hilltop with the height of 120m above the riverbed. A ridge is stretched out downstream from the hilltop. A small mound, 95m high from the riverbed, is on the ridge, 260m downstream of the hilltop. The alternative dam axes are located at the centres of the hilltop and the small mound. A saddle, 85m high from the riverbed and 130m wide at the dam crest elevation, is situated 60m upstream of the downstream alternative dam axis.

The left bank slope is 15° to 20° and sub-parallel with the bedding of the bedrocks. There are several horseshoe depressions on the slope. The depressions seem to be caused by creep along the bedding plane with slips at the upper part. Colluvial deposits with rock debris of cobble to boulder size cover the foot of the slope. Thickness of the deposits is a few meters to more than 5m.

On the right bank is a straight ridge with northwesterly trend, developing parallel with the river. Slope of the ridge is almost smooth and about 30°. There is a small zone of gentle slope or the higher terrace, at the elevation of 320 to 340m. Narrow and deep gulleys cut both the upstream and downstream sides of the gentle slope.

The upstream dam axis is located at the smooth slope and the downstream one is in the gulley downstream of the gentle slope. Height of the ridge above the riverbed is 110m for the upstream dam axis and 130m for the downstream one.

Weathered and loose bedrocks crop out at minor portions of lower part of the slope. Rock debris, 1 to 3m thick, is accumulated at the foot of the slope.

4.2 General Engineering Characteristics of the Bedrock

The bedrock is alternating beds of sandstone, shale and mudstone. The sandstone forms about 70% of the bedrock while shale occupy 30% and the mudstone a few percent of the bedrock.

The sandstone under fresh condition has an unconfined compressive strength(qu) of 600 to 1000 kg/cm^2 approximately. The shale and the mudstone are deemed to have qu of 100 to 200 kg/cm^2 under fresh and well preserved condition, and show remarkable slakings when they are exposed to the sunshine and rain.

Even under fresh condition, the sandstone is closely jointed and major beds of the shale and the mudstone are flaky to clayey because of disturbance from folding, as described in Chapter 2.2.2.

Accordingly, the dam foundation rock is alternating beds of the moderately hard and closely jointed sandstone and the flaky to clayey shale and mudstone. On a profile perpendicular to the dam axis, the alternating beds are almost horizontal. It is, therefore, deemed that shear strength of the foundation rock as a mass is considerably small, as 10 kg/cm^2 or less though that of sandstone may be 15 kg/cm^2 or more.

Rock grade classification in this report is made based on the criterion by Kikuchi et.al. as shown in Table B 5. The sandstone under fresh condition is classified in C and D grades while the shale and the mudstone are in E and F grades, if they are in fresh condition. Since foundation rock is alternating beds of C, D, E snd F grades, and they are horizontal on the longitudinal profile, the fresh rock foundation at large is evaluated as E grade.

4.3 Condition of the Dam Foundation Rock

4.3.1 Elastic Wave Velocity

The dam foundation rock is classified into 4 layers based on elastic wave velocity (Vp). The 4 layers are in order from ground surface to underground as follows;

- Surface layer with Vp of 0.3 to 0.4 km/sec,

- Second layer with Vp of 1.0 to 1.2 km/sec,

- Third layer with Vp of 1.8 to 2.0, 2.0 and 2.2 km/sec, and

- Basement with Vp of 3.4 km/sec for the most part and 2.8 km/sec for a portion below the hill and ridge on the left bank.

Thickness of each layer and its continuity are illustrated in Figs.B 26 to B 29 and summarized as follows ;

(1) For both of the alternative dam sites, the abutments are divided into four velocity layers, while the river bed portions consist of only two layers.

(2) Each layer is developed sub-parallel with the slopes of the abutments and increases the thickness of the layer gradually toward upper portion of the abutments on both dam axes.

(3) The surface layer is 1 to 2m thick in general and 3m thick at upper portions of the left abutments of two dam axes.

(4) The second layer is about 5m thick at lower portions of both abutments of the two dam axes and about 10m thick at the upper portions.

(5) The third layer is generally 7m thick at the lower portions of the abutments and 15m thick at the upper portions.

(6) The basement layer lies 10 to 20m below the ground surface in the lower part of the abutments and in the upper part, 20 to 30m below the ground surface for both the alternative dam sites.

(7) At the left abutment of the downstream dam axis, boundaries of the socond and third layers and the third and basement layers undulate because the foundation rock above the basement is disturbed more or less probably due to sliding or creeping.

In the upstream damsite, the impervious core zone of a fill dam with the height of over 60m shall be found within the third layer which is deemed to be barely competent if adequate treatment by grouting is done, while in the downstream site, an competent foundation for the core zone will be reached only at the top of the basement layer.

4.3.2 Weathering Condition and Hardness

Based on the weathering condition, the dam foundation rock is classified into 6 zones in order from ground surface to underground, i.e., (1) Top soil and detritus, (2) Completely weathered zone, (3) Highly weathered zone, (4) Moderately weathered zone, (5) Slightly weathered zone and (6) Fresh zone.

General condition of completely weathered to fresh zones is given in Table B 4. Figs. B 9 and B 11 show thickness of 6 zones, and those continuity and Vp.

Top soil and detritus, representing the surface layer of 0.3 to 0.4 km/sec, are 1 to 2m thick in general and 2 to 4m thick at the upper portions of the left abutments of the two dam axes. Top soil is less than 0.5m thick typically. Detritus comprises much component of clay and fragile rock debris. While penetration resistance (N-value) of the whole detritus is 15 to 30, that of the clay component is evaluated at about 10. Strength of the clay component is estimated based on N-value as mentioned in Chapter 3.4, i.e., qu is 1.3 kg/cm^2, C is 6.3 t/m^2 and qa is 12 t/m^2.

Completely weathered zone, corresponding representatively to upper zone of the second layer with Vp of 1.0 to 1.2 km/sec, is 1 to 2m thick in general and about 4m thick at lower portion of the left abutment of the downstream dam axis. The foundation rock is mixture of decomposed sandy to clayey material and fragile rock blocks. The rock grade is F. N-value of this zone is nearly the same with that on debris, i.e.,that of the whole zone is 15 to 30 and that of the decomposed material is around 10. Total thickness of the top soil and detritus zone and the completely weathered zone is about 5m at the left abutments of the two dam axes and 3m at both the right abutments.

Highly weathered zone, lying at middle to lower zone of the second layer, is 3 to 10m thick. The foundation is parted into blocks of pebble size from numerous cracks with small quantity of clayey to sandy material. The blocks are weathered into the inner part and somewhat softened. Consequently, the foundation rock in this zone is extremely cracky and loose. The rock grade is E. N-value for upper part of this zone is 100 to 150.

Moderately weathered zone is 3 to 5m thick in general. This zone at the right abutment of the downstream dam axis, Vp of the third layer here is 1.8 to 2.0 km/sec, lies at upper zone of the third layer. It at the remaining portions, where Vp of the third layer is 2.0 and 2.2 km/sec, lies around the second-third layer boundary. It is, therefore, presumed that Vp of this zone is around 1.8 km/sec. The blocks in this zone are almost fresh. While hair cracks are closed, joints are loosely opened and stained. Major joints are at intervals of 5 to 30 cm. Most calcite veinlets are dissolved and slits are formed along the veinlets. Sandstone in this zone is the rock grade of D.

Slightly weathered zone and fresh zone lie at middle to lower zone of the third layer. The slightly weathered zone is the majority of the third layer at upper portions of both the abutments of the two dam axes and decreases in thickness gradually toward the riverbed. The fresh zone, therefore, is the majority at the lower portions. The blocks in the slightly weathered and fresh zones are fresh. Major joints in the slightly weathered zone are partly weathered and stained, and those in the fresh zone are fresh. Sandstone in these zones is C and D grades. Thickness of layer above these zones is about 15m throughout both abutments of the two dam axes.

The basement of 3.4 km/sec is also fresh zone. Sandstone in this zone is C and D grades.

In consequence, about 15 m thick zone from ground surface to the lowest of the moderately weathered zone is cracky and loose foundation with Vp of less than 2.0 km/sec. Deeper zone than the moderately weathered zone is somewhat tight foundation with Vp of 2.0 km/sec or more. It is judged based on the general consideration mentioned in Chapter 4.3.1 that the conceived dam shall be based on the foundation of more than 15m below the ground surface.

4.3.3 Permeability

The foundation rock is zoned into 5 based on range of Lugeon unit (Lu) in order from ground surface to underground, i.e., remarkably permeable zone of over 100 Lu, considerably permeable zone of 50 to 99 Lu, slightly to moderately permeable zone of 10 to 49 Lu, slightly water-tight zone of 5.0 to 9.9Lu and water-tight zone of less than 5.0 Lu. Figs.B 10 and B 12 show result of the zoning.

The foundation rock at the upstream dam axis decreases its Lu and increases its breaking point (BP) in proportion to increase the depth as follows.

(1) The remarkably and considerably permeable zones below ground surface is about 10m thick for the left abutment, 5m thick for the riverbed and 15 to 20m thick for the right abutment. BP of both the zones is less than 1 kg/cm^2. Two permeable zones at the left abutment correspond to the weathered zones above middle part of the moderately weathered zone, whereas those at the riverbed and the right abutment cover major part of the slightly weathered zone.

(2) The slightly to moderately permeable zone, about 20m thick, underlies the remarkably and considerably permeable zones through the dam axis. While major part of this zone is 10 to 49 Lu and BP of 2 to4 kg/cm^2, the minor part is over 100 Lu and BP of less thanl kg/cm^2. This zone at the riverbed and the right abutment is the slightly weathered to fresh zones, whereas that at the left abutment overlap middle to lower part of the moderately weathered zone.

(3) The slightly water-tight zone lies below the slightly to moderately permeable zone except at lower portion of the left abutment where the water-tight zone underlies the slightly to moderately permeable zone. BP of the slightly water-tight zone is 4 to 5 kg/cm^2 and that of the water-tight zone is 9 kg/cm^2. Both the zones lie in the fresh zone.

At the downstream dam axis, the foundation rock except at upper portion of the left abutment is more permeable compared with that on the upstream dam axis, i.e.;

(1) At the right abutment, the remarkably permeable zone is distributed down to the depth of 45m from the ground surface.

(2) The slightly to moderately permeable zone, more than 40m thick, underlies the remarkably permeable zone at lower portion of the left abutment to the right abutment.

(3) At upper portion of the left abutment, permeability of the foundation condition is in simillar condition to that on the left abutment of the upstream dam axis.

Depth of groundwater table below ground surface is around 15 to 30m for lower half portions of both the abutments of two dam axes and 40m for the upper half portions except for middle and upper portions of the left abutment of the upstream dam axis. At the middle and upper portions, groundwater table is 45m deep and 20m deep respectively.

4.4 Condition of the Saddle on the Left Bank

The saddle is situated 60m upstream of the downstream dam axis and on the left bank.

Vp and weathering condition of the bedrock here are in similar condition to those on upper portion of the left abutment of the downstream, dam axis as illustrated in Fig. B 8. However, the bedrock is extremely permeable and loose, i.e. Lu and BP are more than 100 and less than 1 kg/cm^2 respectively down to the depth of more than 30 m from the ground surface. Groundwater table is forecasted 40m below the ground surface and around 290m in elevation, though that measured during the drilling is the elevation of 305m.

4.5 Engineering Consideration

4.5.1 Selection of Dam Axis

It is judged based on the following consideration that the upstream dam axis is superior to the downstream one ;

(1) At the downstream dam axis, permeability of the right abutment to the lower portion of the left abutment is considerably high compared with that on the downstream one.

(2) The saddle on the left bank of the downstream dam axis is weathered thickly and permeability here is remarkably high.

(3) From the said conditions, foundation improvement by means of curtain grouting and rim grouting for the downstream dam axis will be technically difficult and costly compared with that for the upstream dam axis.

4.5.2 Dam Type

Shear strength of the fresh foundation rock is presumed at 10 kg/cm^2 or less as mentioned in Chapter 4.2.

The conceived dam is about 70m high above the riverbed. Sufficient shear strength for concrete gravity dam, more than 70m high and normal triangular section, must be more than 15 kg/cm^2. To construct concrete gravity dam, the dam base must be widened to make up the insufficient shear strength.

It is, therefore, forecasted that construction of concrete gravity dam is difficult technically and economically. Construction of fill dam is recommendable.

Besides, it is recommendable to construct concrete gallery below the dam core zone to execute main curtain grouting and supplemental grouting from the gallery during and after the dam embankment. The main curtain grouting under the condition loaded with the dam core will make the grouting more effective compared with that from exposed surface, because higher pressure can be applied under the loaded condition. The supplemenal grouting may be required to an unexpected groundwater leakage which may appear below the core zone after impounding the reservoir.

4.5.3 Dam Base Line

It is judged considering as follows that the dam core shall be based on a deeper one of either top of the slightly weathered to fresh zone with Vp of over 2.0 km/sec or top of the slightly to moderately permeable zone of less than 50 Lu.

(1) In case that the dam core zone and the proposed concrete gallery are based on the foundation above the slightly weathered to fresh zones, the foundation will incur significant deformation in itself and differential settlement between itself and the gallery because of its loose condition with Vp of less than 2.0 km/sec. The foundation of the slightly weathered to fresh zones are deemed to have sufficient bearing capacity to load from the dam core.

(2) It will be technically difficult and costly to improve the remarkably to considerably permeable zones, having Lu of over 50 and wide areal extent. The considerably permeable zone of 10 to 49 Lu will be improvable by means of ordinary cement grouting method, even though minor part of the zone is over 50 Lu.

In consequence, the base line of core zone is about 15m deep below ground surface at the left abutment, 5m deep at the riverbed and 10 to 20m deep at the right abutment.

The top soil and detritus zone and the completely weathered zone shall be removed for the dam shell zone, because those zones comprise much clayey component with N-value of 10 approximately and those cohesion deemes to be two small for the shell zone. However, critical decision on this matter shall be given after confirmation of cohesion of the foundation and embankment material, and stability analysis.

4.5.4 Foundation Improvement

It is recommendable, as shown in Fig. B 15, to provide grout curtain around the dam axis and grout blanket in the core zone outside of the grout curtain zone in order to reduce quantity of groundwater leakage through the foundation rock and velocity of groundwater just below the core zone. The grout curtain includes the rim grout curtain at both the crest portion.

(1) Grout curtain

The conceived grout curtain comprises main grout holes and supporting grout holes. The main grout holes are at 2m interval on 2 lines, 1.5m apart from each other, and at staggered positions. The supporting grout holes are at 3m interval on and/or 4 lines, the first 2 lines and the second 2 lines laid respectively 2m and 4m outside of the main grout holes, and at staggered positions. Depth of grout holes and numbers of grout lines are decided by considering the dam height and path length ;

Range of dam height (m)	Depth of grout holes (m)		
	Main grout holes of 2 lines	Supporting grout holes	
		The first 2 lines	The second 2 lines
(1) 75-60	50	35	15
(2) 60-45	45	30	10
(3) 45-30	40	25	5
(4) 30-15	35	20	-
(5) 15-0	30	15	-

The said depth of the grout curtain is decided by employing equation authorized empirically in Japan;

$$D = (H/3) + C$$

where, D: Depth of grout hole (m),

H: Dam height above the grout hole (m), and

C: Constant ranging from 8 to 25, the figure of 25 is applied so that the rim grout curtain covers a zone from the dam crest elevation to groundwater table.

Width of the grout curtain is decided to secure the same path length through the curtain zone with that below the curtain by referring the method of seepage pattern and by presuming Lu of the curtain zone at 10% of that the foundation rock, i.e., path length through the curtain zone is 10 times of that of the foundation rock ;

$$L1 + L2 + 2D1 = L1 + (L2 - L3) + 10L3 + 2D2 \; ; \; 2D1 = 9L3 + 2D2$$

where, L1: Width of core zone at its base except grout curtain (m),

L2: Width of grout curtain at base of core zone (m),

L3: Width of grout curtain at various depth corresponding to D2 (m),

D1: Depth of grout curtain (m), and

D2: Depth from base of core zone to an elevation where width of grout curtain is calculated (m).

To cover an extent of the grout curtain, the number of grout lines are decided by forecasting that effectively improvable extent by the grouting is 1 to 1.5m from one grout hole. It is, however, recommendable to provide the main grout curtain of 2 lines and with the hole interval of 1.8m in minimum in order to produce a reliable curtain zone.

(2) Grout blanket

The conceived grout blanket is 5m deep below the base of the dam core zone outside the grout curtain. The grout holes are at 3m interval on various numbers of lines, 2m apart from each other, and at staggered positions. The number of the lines depends on width of the core zone at its base and that of the grout curtain at its top.

5. SADDLE DAMS

5.1 No. 1 Saddle Dam

5.1.1 Topography of the No. 1 Saddle

The No.1 saddle is proposed at a watershed in a small valley 2.5 km northeast of the Sook main damsite. The valley is 3.5 km long and drains gently from its midway toward both the Sook reservoir and its downstream side. A 2.2 km long reach, 1.5 km long toward the reservoir and 0.7 km long its downstreamward respectively from the watershed, of the valley is U-shape, 200 to 300m wide at its floor and the elevation of 300 to 315m.

The saddle is about 250m wide and undulates at the elevation of 317 to 326m. The left bank is a somewhat slender ridge which trends northeast and ranges in elevation from 365 to 390m. Width of the ridge around the valley floor elevation is more than 300m. The right bank is a large hill culminating at 460m in elevation.

A wide flood plain, 248m in elevation, is situated at the northwestern foot of the ridge. Hydraulic gradient between the valley and the flood plain is around 0.1.

5.1.2 Geology of the No.1 Saddle

Bedrock at the No.1 saddle is of the same Crocker Formation with that on the Sook damsite.

The middle terrace deposits overlie the bedrock at the U-shape valley floor. The deposits are 15m thick approximately, and consist of silty clay at 10m thick upper zone and gravelly sand at 5m thick lower zone. The silty clay, which is light gray and tinged with brown due to weathering, comprises much component of quartz grains and intercalates thin layers of micaceous fine sand. The gravelly sand, brownish gray, comprises fine to medium sand at its matrix and includes gravels of small pebble size. The sand grains and gravels are sub-angular to sub-rounded and metamorphic-rock-origin possibly.

5.1.3 Foundation condition of the No.1 Saddle Dam

The bedrock and deposits are classified into four layers including basement, as shown in Fig. B 16. The layers have values of Vp of 0.3 to 0.4, 0.8 to 1.0, 1.7 to 2.0 and 3.4 to 3.6 km/sec respectively from top to basement. Those layers lie in order from the ground surface to the underground and are almost in parallel with the ground surface. Thickness of the respectrive layers are 1 to 4m for the surface layer, 5 to 8m for the second layer and 6 to 12m for the third layer. The basement lies 15 to 20m below the ground surface.

At the valley floor, the said velocity layers correspond representatively to the following engineering geological condition;

(1) The surface and second layers are silty clay of the terrace deposits. Silty clay at about 4m thick upper zone has penetration resistance (N-value) of 10 to 15 and allowable bearing capacity (qa) of 12 to 18 t/m^2. At about 6m thick lower zone, N-value is of 20 to 30 and qa of 24 to 36 t/m^2. Permeability coefficient (k) is under $1x10^{-6}$ cm/sec throught the silty clay layer.

(2) Upper to middle zones of the third layer are gravelly sand, about 5m thick, of the terrace deposits. Sand component of gravelly sand has N-value of 10 to 20, internal friction angle (ø) of 30^{o} to 35^{o} and k of $4x10^{-6}$ cm/sec.

(3) About 3m thick lower zone of the third layer and the basement are the bedrock. The upmost zone, 1 to 2m thick, of the bedrock is the highly to moderately weathered zone whose condition is given in Table 4. The fresh zone underlies the weathered zones. Lugeon unit (Lu) and breaking point (BP) of the weathered zone are evaluated at over 50 Lu and less than 1 kg/cm^2 respectively by referring test result for the Sook dam. Lu and BP measured in the fresh zone are 5 to 10 and more than 10 kg/cm^2.

Groundwater table in the saddle is situated around 311m in elevation.

At both the left and right banks, weathering conditions of the bedrock are forecasted as next based on the results of seismic exploration shown in Fig. B 30.

- The surface zone is top soil and clayey detritus.
- Upper 1 to 3m thick zone of the second layer is the completely weathered zone.
- Middle to lower zone of the second layer is the highly weathered zone.
- Upper half zone of the third layer is the moderately weathered zone.
- Lower half zone of the third layer is the slightly weathered to fresh zone.
- Basement is the fresh zone.
- Thickness from ground surface to top of the slightly weathered to fresh zone is 15m approximately.

5.1.4 Engineering Consideration

It is forecasted based on the foillowing considerations that no significant groundwater leakage will take place through the foundation in the saddle and the bedrock in the left bank ridge after impounding the reservoir ;

- The conceived high water level (HWL) is 7m below the saddle and the reservoir is apart 600m from the saddle.

- Groundwater table is not below HWL.

- Impermeable silty clay, about 10m thick, is deemed to overlie whole the valley floor.

- HWL does not rise up to the elevation of side slope of the left bank ridge.

- Hydraulic gradient between the dam high water and the downstream side foot of the left bank ridge is less than 0.06.

However, in case that HWL is the elevation of 115m or more, areal extent of the impermeable silty clay shall be made clear in order to clarify groundwater leakage problem.

5.2 No.2 Saddle Dam

5.2.1 Topography of the No.2 Saddle

No. 2 saddle damsite is located 5 to 6.5 km northeast of the Sook main damsite and at the northern rim of the Sook reservoir. This saddle consists of the middle terrace lying between the Sook reservoir and its northern Keningau valley plain. The middle terrace is about 4 km long and 0.5 to 1.5 km wide. Western part of the terrace (referred to as western terrace hereinafter) is 1.5 km long and trends north-northeast. The remaining part (eastern terrace hereinafter) is 2.5 km long and trends east and west. South-western side of the western terrace and eastern side of the eastern terrace are hilly area.

Majority of the western terrace is flat and at the elevation of 317m approximately. There are two gulleys at the westmost. The gulleys are V-shape and at the elevation of 303 to 305m, and have the width of 35m at the top of terrace plain.

The eastern terrace inclines gently from east to west, that is, elevation of the eastmost is about 325 m and that of the westmost is about 305m.

There is terrace cliff between the western terrace and the eastern terrace. The terrace cliff is about 10m high, and inclines from west to east by 7^{o} with trends of north-northeast.

The conceived saddle dam is east of the gentle terrace cliff and at western to middle part of the eastern terrace.

5.2.2 Geology of the No.2 Saddle

The middle terrace consists of thick terrace deposits, and bedrock of the Crocker Formation underlies the deposits. Thickness of the deposits is 25m and 40 to 60m respectively at western half and eastern half of the western terrace, and more than 60m and 50m respectively at western to middle part and eastern part of the eastern terrace.

The deposits are silty clay, gravelly layer and layers of clay and sand in order from ground surface to underground.

Silty clay is about 4m thick at the western terrace and 6.5m thick at the eastern terrace. Its major component, quartz grains, at the western terrace is weathered more severely as compared with that at the eastern terrace. It is, therefore, forecasted that the western terrace plain appeared above water level earlier than the eastern terrace. Surface zone, 0.2 to 1.5m thick, of the silty clay layer has been humificated more or less throughout both the terraces.

Gravelly layer, 14m thick, at the western terrace comprises gravels of more than its half volume. The gravels are pebble size and sub-angular to sub-round. Its matrix at both the 2m thick upmost and the 3m thick lowest zones is clay, and at 9m thick middle zone is sand. It decreases in gravel content and increases in sand content toward the eastern terrace. The layer, 20m thick, at middle part of the eastern terrace consists of fine sand at the respective 3.5m thick upmost and lowest zones, and gravelly coarse sand at 13m thick middle zone.

Layers of clay and sand at the western terrace are 20 to 40m thick. Clay layer, 17m thick upper layer, is stiff and has a few joints. Sand layer there is silty. They increase in thickness of sand layer and decrease in clay content of the sand. The layers at middle part of the eastern terrace are irreqularly alternating beds of pure sand, clay and silt with the respective thickness of 5 to 15m, 2 to 3m and 0.5 to 1m. Areal extent of each layer and layers in farther deeper zone than 60m below ground surface have not been confirmed yet.

Bedrock confirmed below the terrace deposits at the western terrace is fresh. At the eastern terrace, top of the bedrock is presumed based on results of field reconnaissance and seismic exploration. At both the westmost and eastern parts of the terrace, top of the bedrock is about 50m deep from ground surface, and subsides down to the depth of 180m at the middle part.

5.2.3 Foundation Condition of the No.2 Saddle Dam

(1) Elastic wave velocity

Velocity layers in the eastern terrace are (1) surface layer, 0.4 to 0.5 km/sec and 2 to 4m thick throughout the terrace, (2) second layer, 1.0 km/sec and 10 to 15m thick throughout it, (3) third layer, 1.8 km/sec and 45m thick at its westmost, 165m thick at its middle part and 30m thick at its eastern part, and (4) basement of 3.8 km/sec, in order from grand surface to underground, as shown in Fig. B 32.

In the western terrace, the second layer is Vp of 0.7 to 0.8 km/sec and the thickness of about 5m. The third layer is 20 to 50m thick and divided into two sub-layers of 1.5 to 1.6 km/sec and 2.2 to 2.3 km/sec respectively at its upper half and lower half zones. The result of the seismic exploration is shown in Fig. B 31.

(2) Hardness and permeability

Silty clay, corresponding to the first layer and 2 to 5m thick upper zone of the second layer, ranges in Vp from 0.4 to 0.8 km/sec. Its N-value is 9 mostly though the measured value ranges from 6 to 25. Its k is less than $5x10^{-5}$ cm/sec mostly and $1x10^{-4}$ to $1x10^{-3}$ cm/sec partly. Estimated qu, c and qa based on N-value are approximately 1 kg/cm^2, 5.5 t/m^2 and 10 t/m^2.

Gravelly layer, occupying middle to lower zone of the second layer and 5 to 7m thick upper zone of the third layer, is Vp of 1 km/sec in unsaturated condition and 1.6 to 1.8 km/sec in saturated condition. The second-third layer boundary represents approximately groundwater table. N-value of clayey and sandy matrix is 10 to 15 for its upper half zone at the eastern terrace and whole the layer at the western terrace, and that for the lower half zone at the eastern terrace is 30 to 60. The k for clayey matrix is $1x10^{-5}$ to $3x10^{-5}$ cm/sec and that for sandy matrix is a lower range in the order of 10^{-4} cm/sec.

Layers of clay and sand, occupying major part of the third layer, are Vp of 1.6 to 2.8 km/sec in saturated condition and increase the value in proportion to the depth due to the mirage phenomonon. N-value of the layers is 20 to 30 mostly and about 50 partly. The K-value is less than $5x10^{-5}$ cm/sec.

5.2.4 Engineering Consideration

(1) Dam height

It is recommendable by considering strength of silty clay and top layer, that height of the saddle dam shall be less than 10m. More detail investigation by means of sounding test and laboratory test by using undisturbed sample will be required in the future stage, in order to confirm strength of silty clay.

(2) Liquefaction problem

Possibility of liquefaction is studied preliminarily for gravelly layer with sandy matrix and sand layer by considering grain size distrbution and correlation between N-value and the maximum horizontal acceleration.

The grain size distribution curves of those layers are given in Fig. B 19. The maximum horizontal acceleration of earthquake motion at the project area is about 100 gal as mentioned afterward in Chapter 9. Liquefaction appearing ranges of both the grain size distributioln and N-value are given in Fig.B 20, which is design criteria by Ministry of Construction, Japan. It shows that grain size distribution of those layers is in that range and those N-values is out of that range.

Consequently, liquefaction may not take place in those layers due to the high N-value. It is, however, recommendable to confirm the possibility by means of accurate Standard Penetration Test and grain size analysis for numerous samples in the future stage.

(3) Piping problem

Possibility of piping is studied about the two cases, that is, piping below the dam and piping through the saddle. Method of critical velocity of groundwater by Justin, and methods of average hydraulic gradient by Bligh and Lane are employed for the study.

(A) Method of critical velocity by Justin

This method is applied hereinafter for general study on possibility of piping in silty clay, gravelly layer and sand. Equation is as follows;

$$Vc = \sqrt{(W g) / (A rw)}$$

where, Vc : Critical velocity (cm/sec)

W : Effective weight of particle in water (g), particle of 10% grain size (D10) is used for the calculation.

g : Acceleration of gravity (980 cm/sec^2)

A : Sectional area of particle of D10 (cm^2)

rw : Unit weight of water (g/cm^3)

$$V = k / [1-(1-e)^{2/3}]$$

where, V : Actual velocity through void in soil (cm/sec)

k : Permeability coefficient of soil (cm/sec)

e : Void ratio of soil

The following figures are employed for the calculation based on result of laboratory test and permeability test, and by considering soil characteristics ;

Category of soil	D10(cm)	G	e	k(cm/sec)
Silty clay	0.00001	2.7	0.8	$5x10^{-5}$
Gravelly layer	0.004	2.8	0.4	$3x10^{-5}$
Sand	0.004	2.8	0.5	$5x10^{-5}$

Result of the calculation on Vc and V is as follows ;

	Silty clay	Gravelly layer	Sand
Vc(cm/sec)	$1.1x10^{-1}$	2.2	2.2
V(cm/sec)	$7.6x10^{-5}$	$1.0x10^{-4}$	$1.3x10^{-4}$

Consequently Vc has 10^4 times of safety factor to V. It is, therefore, forecasted that the said three layers are safety from the piping process.

(B) Method of average hydraulic gradient by Bligh

This method is applied hereinafter to study the piping possibility in silty clay below the saddle dam and that through both gravelly layer and sand in the saddle. Equation is as follows;

$$Cr = L/H \; ; \; L = H\,Cr$$

Where, Cr : Critical creep ratio by Bligh shown below

L : Path length (m)

H : Water head (m)

Material	Creep ratio by	
	Bligh	Lane
(1) Very find sand or silt	18	8.5
(2) Fine sand	15	7
(3) Medium sand	-	6
(4) Coarse sand	12	5
(5) Fine gravel	9	4
(6) Medium gravel	-	3.5
(7) Coarse gravel including cobbles	4-6	3
(8) Boulders with some cobbles and gravel	-	2.5
(9) Soft clay	-	3
(10) Medium clay	-	3
(11) Hard clay	-	1.8
(12) Very hard clay or hardpan	-	1.6

Note :

Materials of (1) to (8) are non-cohesive.

Cr of silty clay is 4 or less from the above table.

In case that the saddle dam has the inclination of 1:2 or more gentle for both the slopes, the dam has the width of 4Hm or more at its base, and thus piping process will not take place in silty clay at the dam toe.

Cr of matrix of gravelly layer and that of sand are evaluated at 10 because they have about 10% of fine component. The maximum water head for both the layers is 40m, i.e., difference between the conceived HWL and valley floor at the reservoir side of the saddle and may be at its other side. The minimum path length required not to incur the piping process against the maximum water head is 400m. Width of the saddle is more than 500m. It is, therefore, forecasted that the piping process does not take place at the downstream side of saddle.

(C) Method of average hydraulic gradient by Lane

This method is applied hereinafter to study the piping possibility in gravelly layer below the saddle dam. Equation is as follows ;

$$Cw = (Lh/3 + Lv)/H; Lh/3 + Lv = H\ Cw$$

where, Cw : Weighted creep ratio by Lane shown in the foregoing section (B)

Lh : Horizontal component of path length, this component is path length in gravelly layer

Lv : Vertical component of path length, this component is path length in silty clay

Cw of matrix of gravelly layer is evaluated at 5 from the said table. Silty clay is 5m thick and has Lv of 10. In case that the saddle dam is 10m heigh, more than 14m wide of dam is enough not to incur piping process in gravelly layer.

6. QUARRY SITES

6.1 Topography of the Quarry Sites

Two quarry sites are conceived in the reservoir area within 1 km from the Sook damsite.

One, which is called No.1 quarry site hereinafter, is located 0.5 km upstream of the upstream dam axis and at the right bank of the Sook River. There are two small hills at the No.1 quarry site. The hills are gentle and 60 to 70m high from the riverbed.

Another, which is called No.2 quarry site hereinafter, is located 0.5 to 0.9 km northeast of the upstream dam axis. The No.2 quarry site is southeastern slope of a large hill. The hilltop is at the elevation of 430m and is 160m high from foot of the hill. The southeastern slope is 20 and 300 to 400m wide.

6.2 Rock Facies and General Characteristics of the Bedrock

The bedrock at the No.1 and No.2 quarry sites is of the Crocker Formation, as that at the Sook damsite. While rock facies of the bedrocks and those general characteristic are similar to those on the Sook damsite, sandstone is more predominant at the quarry sites compared with the damsite, that is, the sandstone at the quarry site forms 70 to 90% of the bedrocks.

6.3 Condition of Bedrock

6.3.1 Condition of Bedrock at the No.1 Quarry Site

Condition of bedrocks was investigated by means of seismic exploration and core drilling. Result is shown in Fig. B 33 and summarized as follows.

The bedrocks are divided into 4 layers based on velocity of elastic wave, that is, surface layer, second layer, third layer and basement.

The surface layer has Vp of 0.3 to 0.4 km/sec and the approximate thickness of 5m, and is distributed throughout the quarry site. This layer is top soil and the completely weathered zone of the bedrock and corresponds to the rock grade of F.

The second layer has Vp of 1.0 to 1.2 km/sec, the thickness of 10m approximately and is in sub-parallel with the ground surface. This layer corresponds representatively to the highly weathered zone and grade E to F. This zone comprises 20% of rock blocks of which size is about 10 cm, 60% of rock fragments and 20% of sandy material.

The third layer has Vp of 1.8 to 2.0 km/sec. Majority of the layer has the thickness of 20 to 25m. While top of the layer is in sub-parallel with the ground surface and undulates, bottom of the layer is almost horizontal and ranges in elevation from 265 to 275m. Upper zone, 2 to 3m thick, of the third layer is the moderately weathered zone. The remaining major part is the slightly weathered zone. While the rock grade of sandstone in the moderately to slightly weathered zones at major part of the quarry site may be grade D, that at the northeastern part is deteriorated due to fracturing, and grade E.

The basement at the major part of the quarry site is 3.4 km/sec in Vp and corresponds to the fresh zone. Sandstone is grade D. The basement at the northeastern part is 3.0 km/sec in Vp. While the bedrock in the basement is fresh, it is deteriorated into mixture of rock blocks of pebble size, fragile fragments and clayey material. Sandstone here is grade E.

6.3.2 Condition of Bedrock at the No.2 Quarry Site

Condition of bedrocks was investigated by means of core drilling. Result is given in Drill Logs and summarized as follows.

Top soil and the completely weathered zone below the top soil have a thickness of 2 to 3m in total.

The highly weathered zone below the completely weathered zone is distributed down to the approximate depth of 15m from the ground surface. Sandstone in this zone is grade E, tinged with light brown and softened slightly due to weathering. The bedrock is very closely jointed and mixture of sandstone blocks, of which size is 10 to 30 cm, sandstone fragments, of which size is a few to 10 cm, and fragile fragments of shale and mudstone. The sandstone blocks are around 30 per cent of the bedrocks. The sandstone fragments and fragile fragments are 50 per cent and 20 per cent of the bed rocks respectively.

Lower zone of the highly weathered zone is moderately weathered zone with the thickness of 15m. Sandstone in this zone is mostly fresh and partly tinged with brown due to weathering along joints. Rock grade of the sandstone is D. The sandstone blocks with the size of 30 to 50 cm and those with the size of 10 to 30 cm are 30 per cent respectively of the bedrocks. The sanstone fragments with the size of less than 10 cm and the fragile fragments of shale and mudstone are 10 to 30 per cent respectively of the bedrocks.

Mixture of the slightly weathered zone and the fresh zone underlies the moderately weathered zone. Sandstone in the mixture is grade C. Respective percentage of the sandstone blocks, the sandstone fragments and the fragile fragments is the same with that on the moderately weathered zone.

6.4 Engineering Consideration

Result of the geological investigations shows that both the quarry sites are weathered thickly. Besides, at the No.2 quarry site, thickness of the completely weathered zone is thin and the highly weathered zone comprises much amount of rock debris respectively compared with those at the No.1 quarry site.

It is, therefore, considered that the No.2 quarry site is superior to the No.1 quarry site. However, the following problems shall be made clear in the future stage to develop this quarry site ;

(1) The highly weathered zone comprises fragile fragments of weathered sandstone, shale and mudstone. In case that the fragments are used for the embankment material, they will be changed into mudy condition due to saturation by the reserved water. Proportion of weathered sandstone, shale and mudstone shall be made more clear by means of additional core drilling and test adit in order to decide design volume of embankment material employed from the highly weathered zone. Mechanical characteristics and permeability of those material in saturated condition shall be revealed by means of laboratory test by using sample obtained from the test adit.

(2) Bedding plane of bedrock will be in sub-parallel with the hillside. The quarry site shall be developed along the bedding plane so as not to incur landslide after impounding the reservoir. For the development plan, geological structure in the quarry site shall be revealed by means of test adit.

7. REREGULATING DAM

7.1 Topography of Reregulating Damsite and Its Reservoir

The reregulating damsite is proposed around the confluence of the Pegalan river. The confluence is about 4 km downstream of the Sook main damsite. The Sook river mouths into the Pegalan river from its left bank. Two dam axes are conceived there. One is located 150m upstream of the confluence and on the Sook river. Another is 150m downstream of the confluence.

Hilly area spreads downstream of the confluence and at both the right bank of the Pegalan river and the left bank of the Sook river upstream of the confluence. One mound, which is 50m high from the riverbed, is situated just upstream of the confluence and between the Pegalan river and the Sook river. Flood plain, about 5m high from the riverbed, spreads upstream of the mound and between both the rivers.

In the reregulating dam site, the Pegalan and Sook rivers are 50m in width approximately, and the Sook river is the elevation of about 240m and meanders on the flood plain.

7.2 Geology of Reregulating Damsite and Its Reservoir

The hilly area and mound are composed of bedrock of the Crocker Formation and covered by the middle terrace deposits at higher elevation than 260m approximately. Besides both banks downstream of the confluence are deemed to be covered by the lower terrace deposits.

Bedrock around the two dam axes is considered to be more weathered as compared with that at the Sook main damsite, because outcrops of the bedrock at both riversides are less and the bedrock is open-jointed more loosely respectively as compared with those on the Sook damsite.

The middle terrace deposits comprise glavelly layer at the 5m thick lowest parts. Facies of the remaining upper part is not revealed by the reconnaissance.

The lower terrace deposits and flood plain deposits comprise gravelly layers and sandy to clayey silt layers. Silt is less cohesive and tends into muddy condition due to saturation. The silt layers form rills and notch at its surface due to rain wash and flood water respectively. It is, therefore, forecasted that the silt layers have little resistibility against wave erosion and slope failure takes place by daily repetition of ups and downs of the reservoir.

8. TENOM PANGI EXTENSION POWERHOUSE

8.1 Topography at Tenom Pangi Powerstation

The Tenom Pangi powerstation is located about 10 km downstream of the confluence of The Padas and Pegalan rivers, and in a steep gorge.

Width of the Padas river there is 100m approximately. Numerous big boulders are scattered on the riverbed. Narrow flood plains, about 5m high above the riverbed, are situated at some portions of both the riversides. The powerstation is located on the flood plain.

Slopes of both the banks have the inclination of 45° approximately. Although major part of the slopes is covered with thin top soil and plant life, some parts are rocky and incur slope failures at those surface. A few and small scale of middle terrace plains occupy the elevation of 50m high from the riverbed.

8.2 Geology at Tenom Pangi Powerstation

Bedrock at the Tenom Pangi Powerstation is the Temburong Formation, which is mostly rhythmically alternating beds of sand and shale, and intercalates partly a few meters thick layers of sandstone. The bedrock has been undergone intraformational folding.

River deposits including the flood plain deposits are sandy gravel with the thickness of 25m approximately.

8.3 Foundation Condition of Extension Powerhouse

Thickness of the river deposits is revealed by core boring conducted both in this stage and in 1974. Bedrock contour and geological profile are shown in Figs. B 22 and B 23 respectively.

The river deposits increase their thickness from the existing powerhouse to the extension one, and at the later, the deposits are about 25m thick. They comprise more than 50% of gravel component ranging in size from granule to boulder. The maximum diameter is around 50 cm. Those matrix is mudy sand. N-value of the matrix ranges from 12 to 30 and is evaluated at 20. Internal friction angle based on the evaluated N-value is 35^{o}.

Bedrock below the river deposits is sandstone and mudstone, which intercalate thin layers of shale. The bedrock is fresh to slightly weathered and closely jointed. The rock grade is D to E.

9. SEISMICITY OF PROJECT SITE

9.1 General

This Chapter states earthquake environment of the project site and seismic coefficient to be applied for design of the conceived permanent structures.

The project site is located around 5.23°N 116.13°E. Earthquake record within 0°N to 10°N and 111°E to 121°E, that is within 500 to 700 km from the project site, was collected through International Seismological Center,U.K. (ISC) and Geological Survey, Sabah (GSS). The record includes 121 events showing both identified epicenter and estimated magnitude, and covering 88 years since 1897.

Catalog of the 121 events and location of those epicenters are shown in Table B 7 and Fig. B 24 respectively.

9.2 Earthquake Environment of the Project Site

The project site is located at inland of northern part of Borneo Island. The northern part (the north Borneo hereinafter) is surrounded by the Celebes Sea, the Sulu Sea and the South China Sea respectively at the east side, northeast side and northwest side.

Both the Celebes Sea and the Sulu Sea are farther than 200 km from the project site. Two earthquake active zones are situated in the two seas. One active zone is southern part of the Celebes Sea and the Makassar Strait where active subduction zone, North Sulawesi Trench, of E-W direction and transcurrent fault of NNW-SSE direction are situated respectively. The other active zone is Sulu Archipelago lying in NE-SW direction between the Celebes Sea and the Sulu Sea, and consisting of Tertiary to Quaternary volcanic belt. The volcanic belt extends to eastern coast of the north Borneo.

Most earthquakes among the 121 events have occurred in and around the two active zones. Two events, which occurred around 650 km east of the project site in 1897, are the magnitude of 8.6 and 8.7. Intensity felt at the project site from the two events is 4.7 and 4.8 on Modified Mercalli scale (MM scale). Other numerous events, being relevant to the active zones, are the magnitude of 4.0 to 7.1 and the intensity of less than 3.9 on MM scale at the project site.

The South China Sea is farther than 70 km from the project site and stable area except around the Balabac Strait interconnecting the South China Sea and the Sulu Sea. 5 earthquakes, the magnitude of 4.4 to 6.0, have occurred around the Balabac Strait. Epicenters of the 5 earthquakes are around 200 km north of the project site. Their intensities are less than 3.7 on MM scale at the project site.

Epicenters of 3 earthquakes, the magnitude of 4.5 to 5.75, are distributed at inland of the north Borneo and within 100 to 200 km from the project site. Focal depth of the earthquakes is 20 to 58 km. Their intensities are less than 5.1 on MM scale at the project site.

9.3 Seismic Coefficient

Intensity (I) of each earthquake event is given on Modified Mercalli scale (MM scale) based on the following formula quoted by Cornell (1968) Bulletin of the Seismological Society of America (BSSA), Vol.58, page 1586, and shown in Table B 7.

$$I = 8.0 + 1.5M - 2.5\ln r$$

where, M : Magnitude

r : Focal distance in km

ln : Natural logarithm

Frequency of earthquake events in each grade of intensity on MM scale, within 88 years from 1897 to 1985, is converted into frequency in 100 years and hence culmulative number of frequency (Nc) for 100 years is obtained, that is, as follows ;

Intensity on modified Mercalli scale	Frequency in 88 years	Frequency in 100 years	Culmulative number of frequency for 100 years
0 (0-0.5)	75	85.2	145.5
1 (0.6-1.5)	21	23.9	60.3
2 (1.6-2.5)	14	23.9	36.4
3 (2.6-3.5)	5	5.7	12.5
4 (3.6-4.5)	3	3.4	6.8
5 (4.6-5.5)	3	3.4	3.4
T o t a l	121	145.5	-

Relation betwen I and Nc for 100 years is shown in Fig. B 25. For the case of Nc=1 in the figure, the expected maximum intensity in a probable return period of 100 years is obtained as I=6.6.

The maximum horizontal acceleration (ah) of earthquake motion in the probable return period of 100 years is calculated at 99 gal based on the following formula given by Trifunac and Brandy (1975), BSSA, Vol.65, P.147.

$$\log ah = 0.014 + 0.30I$$

Seismic coefficient to the calculated ah, 99 gal, is 0.10 which is the same with the design seismic coefficient for the existing Tenom Pangi power station and its relevant structures.

Result of the foregoing calculation is confirmed supplementally by using Kawasumi's formulae to estimate intensity in Japan Meteorological Agency scale and to calculate the maximum horizontal acceleration, and nearly the same seismic coefficient with the above result is obtained as shown in Table B 8.

It is recommendable by considering as follows that the design seismic coefficient for the conceived major structures of this project is 0.12.

- The major structures such as main dam and saddle dam are great important ones.
- A few shallow earthquakes have occured around 100 km far from the project site. Generally speaking, the shallow earthquake has hazard to incur damage to structures.

Table B1 QUANTITY OF SEISMIC EXPLORATION

Line number		Location	Length of line (m)	Geophone interval(m)
1.	Sook dam			
	S-I	Downstream damsite, dam axis	650	5
	S-II	-do-, left bank ridge	100	5
	S-III	-do-, middle of left abut.	400	5
	S-IV	-do-, middle of right abut.	200	5
	S-V	Upstream damsite, dam axis	650	5
	S-VI	-do-, crest of left abut.	200	5
	S-VII	-do-, middle of left abut.	200	5
	S-VIII	-do-, middle of right abut,	200	5
	Sub total	8 lines	2,600	
2.	Saddle dam			
	S-IX	No. 1 saddle, dam axis	500	5
	S-X	No. 2 saddle, -do-	1,400	5
	S-XI	-do-, -do-	2,600	5
	Sub total	2 lines	4,500	
3.	Quarry site			
	S-XII	No. 1 quarry site	600	5
	Total	12 lines	7,700	

Table B2 QUANTITY OF CORE DRILLING AND DRILLHOLE TEST (SOOK DAMSITE)

Hole No.	Location	Depth(m)	Drillhole test (nos.) SPT	Drillhole test (nos.) Permeability test
1.	Downstream damsite			
D85-1	Upper part of left abut., S-I, STN 14, EL.328.54m	50	3	9
D85-2	Middle part of left abut., S-I, STN 36, EL.292.60m	50	3	10
D85-3	Lower part of left abut., S-I, STN 52, EL.265.61m	50	3	10
D85-4	Middle part of right abut., S-I, STN 80, EL.287.56m	50	-	9
D85-5	Upper part of right abut., S-I, STN 98, EL.328.78m	50	-	9
D85-6	Saddle on left bank ridge S-II, STN 12, EL.330.75m	30	-	5
D85-7	500 m downstream of downstream dam axis, left bank, EL.280.00m approximately	30	-	-
2.	Upstream damsite			
U85-1	Upper part of left abut., S-V, STN 35, EL.329.23m	50	3	9
U85-2	Middle part of left abut., S-V, STN 63, EL.289.31m	50	3	10
U85-3	Lower part of left abut., S-V, STN 74, EL269.45m	50	-	10
U85-4	Middle part of right abut., S-V, STN 100, EL.276.16m	50	-	10
U85-5	Upper part of right abut., S-V, STN 116, EL.329.61m	50	-	9
TOTAL	12 holes	560	15	100

Table B3 QUANTITY OF CORE DRILLING, TRENCH EXCAVATION AND IN-SITU TEST (SADDLE DAMS, QUARRY SITES AND TENOM PANGI POWERHOUSE)

Drillhole or trench number	Location	Dimension of drilled or trench(m)	In-situ test (nos.) SPT	Permeability test
I. Core drilling				
1.1 Saddle dams				
S85-1	No.1 saddle S-IX, STN 50, LE.317.00m	20	10	6
S-85-2	No. 2 saddle S-XI, STN 6, EL.317.91m	40	15	7
S-85-3	No. 2 saddle S-XI, STN 106, EL.308.34m	40	15	7
S-85-4	No. 2 saddle S-XI, STN 206, EL.305.56m	60	15	8
1.2 Quarry sites				
Q85-1	No.1 quarry site, 0.55Km NE of u.s.d.a., EL346.91m	40	-	-
Q85-2	No.2 quarry site, S-XII STN 89 + 4m, EL.315.22m	40	-	-
Q85-3	No. 1 quarry site, 0.85Km NE of u.s.d.a., EL.323.45m	40	-	-
1.3 Tenom Pangi Powerhouse				
T85-1	Powerhouse, EL.106.30m	30	10	-
T-82-2	Tailrace, EL.103.00m	30	10	-
1.4 Total	9 holes	300	75	28
II. Trench excavation at No. 2 saddle				
T-1	S-X, STN 228, EL.316.90m	2x5.5x4	-	2
T-2	S-XI, STN 145, EL.304.49m	1.5x5x5.5	-	-
T-3	S-XI, STN 53+ 2.5m to STN 58 + 2m, EL. 314.05m	1x25x5	-	-
Total	3 trenches	-	-	4

Remarks: (1) u.s.d.a.: upstream dam axis of the Sook dam

(2) Dimension of trench is width x length x depth respectively in maximum profile.

Table B4 CLASSIFICATION CRITERION ON WEATHERING CONDITION

(1) Fresh rocks (zone);

Sandstone is gray and hard to rather hard. Shale and mudstone are black to dark gray and soft. Every joint is fresh and closed a lit.

(2) Slightly weathered rocks (zone);

Most joint planes are fresh, although some ones are stained due to weathering along them. Calcite veinlets in the joints remain. Every rock block is fresh.

(3) Moderately weathered rocks (zone);

Most joint planes are stained. Calcite veinlets are dissolved and continuous slits are formed in the joints. Rock blocks except those inner parts are weathered and tinged with light brown. Inner part of sandstone is rather hard and its surface is somewhat soft. Shale has remarkable fissility and is fragile more or less.

(4) Highly weathered rocks (zone);

Rock blocks are parted from numerous joints, which are stained and intercalate thin film of clay, and tinged with brown due to weathering. Major sandstone is rather hard to soft, and its minority is decomposed into sandy material. Shale is brown, excessively fragile and decomposed partly into clayey material.

(5) Completely weathered rocks (zone);

This rocks are mixture of decomposed sandy to clayey material and fragile rock blocks, although proportion of both decomposed material and rock blocks varies from place to place.

Table B5 CLASSIFICATION CRITERION BY K. KIKUCHI ET. AL. (1/2)

(1) Criterion to be used for rock grade classification

	Hard rocks	Medium hard rocks	Soft rocks
Rock grade	As an approximate criterion, rocks of more than "800 to 1,000 kg/cm^2" in the unconfined compression strength of test pieces of fresh rocks are hard rocks. When hit by a rock hammer, they produce a metallic sound.	As an approximate criterion, rocks of "200 to 300kg/cm^2" to "800 to 1,000kg/cm^2" in the dry unconfined compression test of test pieces of rocks are medium hard rocks. When hit by a rock nammer, they produce a very tight sound, but generally do not produce a metallic sound. Of the rocks in this range, those rather soft may be depressed slightly on the surface, when hit by the spire of rock hammer.	As an approximate criterion, rocks of less than "200 to 300kg/cm^2" in the dry unconfined compression test of test pieces of fresh rocks are soft rocks. When hit by a rock hammer, they produce a thick and loose sound, and may collapse. They are easily depressed on the surface, when hit by the spire of rock hammer.
A	Very fresh in lighologic character. The rock-forming minerals of igneous rocks and the constituent grains of sedimentary rocks are not weathered and altered at all. Few joints are distributed. The rocks as a whole are very solid and densely hard.		
B	Fresh in lighologic character. The rock-forming minerals of igneous rocks and the constituent grains of sedimentary rocks are little wheathered and altered. Joints are sparesely distributed, assuring close adhesion. The rocks as a whole are solid and densely hard.	Fresh in lighologic character. The constituent grains are quite free from secondary weathering and alteration. Fissures of joints, etc. are little distributed. The rocks as a whole are solid and hard. In this case, those close to soft rocks which have the above properties may not belong to this class, but to C(u).	
C	Almost fresh, solid and hard in lighologic character. Among the rock-forming minerals of igneous rocks, feldspars and colored minerals such as mica and amphibole may be slightly weathered and altered, and in sedimentary rocks feldspars and colored minerals existing secondarily as constituent grains may be slightly weathered and altered. Joints are distributed considerably and joint walls are mostly weathered and altered, being discolored. Sometimes, weathered materials adhere thinly to joint walls. However, in general, the joints assure close adhesion. The rocks as a whole are solid and hard.	Fresh in lighologic character. The constituent grains are free from secondary weathering and alteration. Joints are sparsely distributed, assuring close adhesion. The rocks as a whole are almost solid and hard. In this case, those close to hard rocks may belong to Class B.	Rocks of this class are close to medium hard rocks (about 150kg/cm^2 in the dry unconfined compression strength of fresh rocks). Fresh in lighologic character. Constituent grains are quite free from weathering and alteration, and joints are little distributed.
D	Generally a little weathered and altered in lithologic character. In igneous rocks, feldspars and colored minerals excluding quartz are weathered, often being brown or reddish brown. In sedimentary rocks, feldspars and colored minerals existing secondarily as constituent grains are weathered and altered, aften being brown or reddish brown as in case of igneous rocks. Joints are open and often hold clay or weathered materials. Rocks of this class often have many fine hair-like fissures. Therefore, when hit strongly by a rock hammer, they often collapse, being separated at the hair-like fissures. In addition, rocks which are fresh in lighologic character but have open joints distributed considerably to indicate cracky state are also included in this class.	Feldspars and colored minerals existing secondarily as constituent grains are mostly a little weathered and altered. The weathering is not so intensive, but since the rocks are medium hard, they give a little soft impression in absolute hardness. Joints are distributed considrably, and most of them are a little open. The joints are weathered and altered, being discolored and often hold thin layers and weathered materials. Rocks of this class have hair-like fissures to some extent. Therefore, when hit by a rock hammer, they often collapse, being separated at the hair-like fissures.	Fresh in lighologic character. Constituent grains are free from secondary weathering and alteration. Joints are little or sparsely distributed, assuring close adhesion. The rocks as a whole are little weathered, but since they are soft, they give soft impression in absolute hardness. In this case, those less than about about "60 to 70kg/cm^2" in the dry unconfined compression strength do not belong to this class, but to C(1).
E	Since the rock-forming minerals of igneous rocks or the constituent grains of sedimentary rocks are considerably weathered, the rocks as a whole are generally brown or reddish brown. Joints are open, and hold clay and weathered materials considerably. In rocks of this class, fine hair-like fissures are distributed remarkably, and weathering occurs along the fissures. Therefore, even if hit lightly by a rock hammer, they easily collapse or are depressed. In addition, rocks which are fresh in lighologic character but have open joints considerably distributed to indicate mansonry state are also included in this class.	Constituent grains are weathered and altered, and the degree of consolidation is very low. Since the rocks are medium hard, they give considerably soft impression in absolute hardness. Joints are considerably distributed. They are open, and hold weathered materials and clay layer considerably. Rocks of this class are considerably weathered along hair-like fissures, and when hit lightly by a rock hammer, they collapse easily.	Constituent grains are a little wheathered and altered, and the degree of consolidation is very low. The rocks as a whole give very soft impression in absolute hardness. When the rocks are hit by the spire of rock hammer, the spire often sticks in them.

Table B5 CLASSIFICATION CRITERION BY K. KIKUCHI ET. AL. (2/2)

F	The rock-forming minerals of igneous rocks or the constituent grains of sedimentary rocks are considerably weathered, and sandy and clayey portions are often seen. With rocks of this class, the distribution of joints is rather unclear.	Constituent grains are considerably weathered and altered, and the degree of consolidation is considerably low. They are often sandy and clayey. With rocks of this class, the distribution of fissures is rather unclear.	The degree of consolidation of constituent grains is very low, and most are sandy or clayey.

(2) Physical values corresponding to each rock grade

Rock Grade	Static modulus of elasticity of rocks (kg/cm^2)	Modulus of deformation of rocks (kg/cm^2)	Cohesion of rocks (kg/cm^2)	Internal frictional angle of rocks (°)	Velocity of elastic wave of rocks (km/sec)	Rebound of rock test hammer
B	80,000 or more	50,000 or more	40 or more	55 - 65	3.7 or more	36 or more
C	80,000 - 40,000	50,000 - 20,000	40 - 20	40 - 55	3.7 - 3	36 - 27
D	40,000 - 15,000	20,000 - 5,000	20 - 10	30 - 45	3 - 1.5	27 - 15
E - F	15,000 or less	5,000 or less	10 or less	15 - 38	1.5 or less	15 or less

Table B6 CLASSIFICATION CRITERION FOR DETAIL INTERPRETATION OF FOUNDATION CONDITION

(1) Hardness of rock blocks

A : hard, unconfined compressive strength (qu) $\geqq$ 800 kg/cm^2. Rock blocks sound clearly and metallically by hammering.

B : rather hard, 200 $kg/cm^2 \leqq$ qu $<$ 800 kg/cm^2. Rock blocks sound light and tightly by hammering, and can be depressed slightly by a hit of spire.

C : soft, qu $<$ 200 kg/cm^2. Rock blocks sound dully and thickly by hammering, and can be crushed by the hit.

D : excessively soft, fragile at some parts and sandy to clayey at the others. Rock blocks of this category are crushed by fingers.

(2) Spacing of joints

I : more than 30 cm

II : 10 to 30 cm

III : 5 to 10 cm and columnar shape

IV : less than 5 cm and rock blocks of pebble size

V : particles such as decomposed material and flaky fragments such as fractured material

(3) Condition of joint planes

a : fresh

b : stained partly due to weathering along joint planes

c : stained almost

d : intercalating clayey to silty material produced by weathering, fracturing and alteration

Table B7 CATALOG OF EARTHQUAKE EVENT (1/5)

Event	Date of event			Location of focus			Mag-nitude	Distance (km)	Intensity
	Year	Month	Day	Latitude (N)	Longitude (E)	Depth (km)			
1	1897	9.	20	6.0	122.0	0	8.6	657	4.7
2	1997	9.	21	6.0	122.0	0	8.7	657	4.8
3	1913	1.	11	1.5	122.0	0	7.1	771	2.0
4	1923	4.	19	2.5	117.5	0	7.0	338	3.9
5	1923	8.	11	4.5	119.5	0	6.5	382	2.9
6	1924	4.	13	1.0	118.0	128	6.25	511	1.7
7	1926	12.	25	1.0	116.0	610	6.75	467	1.5
8	1927	8.	8	1.4	117.9	680	6.25	467	0.6
9	1930	7.	21	7.5	116.0	0	6.0	251	3.2
10	1932	9.	15	5.9	120.7	0	6.25	511	1.8
11	1932	12.	4	2.5	121.0	0	7.1	619	2.6
12	1932	12.	4	2.4	121.0	0	6.25	624	1.3
13	1933	10.	27	0.0	119.5	420	6.0	688	0.3
14	1934	6.	14	2.4	121.0	0	5.6	624	0.3
15	1940	7.	21	2.5	121.0	100	6.25	619	1.3
16	1940	12.	19	9.0	118.0	0	5.6	465	1.0
17	1941	2.	8	2.0	120.3	0	6.5	584	1.8
18	1950	3.	7	10.0	120.0	60	6.75	678	1.8
19	1951	6.	2	6.75	116.5	0	5.75	173	3.7
20	1951	11.	29	0.6	120.5	96	6.5	705	1.4
21	1955	9.	3	1.0	120.0	287	6.53	635	1.7
22	1958	9.	15	2.5	120.5	600	6.13	571	0.4
23	1958	10.	26	5.5	117.0	58	5.75	101	5.1
24	1959	7.	14	0.5	120.0	142	5.63	676	0.2
25	1959	10.	15	1.0	121.0	0	6.9	715	1.9

(to be continued)

Remarks: (1) Distance is from project site to epicenter.
(2) Intensity is of project site and measured in Modified Mercalli Scale.

Table B7 CATALOG OF EARTHQUAKE EVENT (2/5)

Event No.	Date of event			Location of focus			Mag-nitude	Distance (km)	Intensity
	Year	Month	Day	Latitude (N)	Longitude (E)	Depth (km)			
26	1961	9.	29	2.0	121.0	100	6.2	648	1.1
27	1963	7.	4	0.5	121.0	0	4.9	752	0
28	1964	10.	17	0.62	119.19	58	5.5	612	0.2
29	1964	11.	16	0.93	118.89	26	5.6	565	0.6
30	1965	10.	25	0.73	119.37	52	5.4	614	0
31	1966	1.	11	0.50	120.18	88	5.3	689	0
32	1966	1.	25	1.92	118.06	74	5.1	424	0.5
33	1966	5.	18	5.96	116.64	52	5.3	98	4.2
34	1967	5.	10	1.21	120.30	111	5.0	641	0
35	1968	6.	27	6.06	120.86	65	5.0	531	0
36	1968	8.	14	0.06	119.73	22	6.1	697	0.8
37	1968	8.	15	0.48	119.94	73	5.0	674	0
38	1968	8.	15	0.04	120.01	33	5.2	717	0
39	1968	8.	23	0.79	119.94	64	5.2	648	0
40	1968	8.	27	0.98	120.08	33	4.9	642	0
41	1968	10.	15	0.86	119.89	40	5.2	638	0
42	1968	10.	15	0.87	120.03	23	5.0	648	0
43	1969	4.	25	1.23	120.30	26	5.1	640	0
44	1969	4.	27	0.75	120.00	45	5.4	655	0
45	1969	5.	1	1.19	120.43	62	5.1	653	0
46	1970	2.	16	1.18	120.19	21	5.2	635	0
47	1970	2.	17	1.03	120.12	9	5.1	641	0
48	1970	3.	27	0.28	119.37	11	6.0	654	0.8
49	1971	2.	10	0.618	118.171	33	5.2	558	0
50	1971	2.	22	0.996	120.102	58	5.4	643	0.3

(to be continued)

Table B7 CATALOG OF EARTHQUAKE EVENT (3/5)

Event No.	Date of event			Location of focus			Magnitude	Distance (km)	Intensity
	Year	Month	Day	Latitude (N)	Longitude (E)	Depth (km)			
51	1971	9.	10	1.022	120.160	15	5.4	645	0.3
52	1972	2.	16	0.510	120.836	99	5.5	738	0.2
53	1972	5.	22	1.400	120.836	44	5.2	634	0
54	1973	4.	28	6.438	117.842	71	5.1	232	1.7
55	1974	4.	8	1.173	117.655	33	4.9	479	0
56	1974	8.	23	1.020	116.877	33	4.9	472	0
57	1974	8.	30	0.466	119.973	50	5.0	677	0
58	1975	3.	26	3.58	121.91	33	5.3	667	0
59	1976	1.	8	0.411	120.739	161	4.8	738	0
60	1976	6.	18	5.873	119.488	100	4.5	378	0
61	1976	7.	25	5.032	118.442	33	5.2	257	1.9
62	1976	7.	26	4.934	118.337	29	5.6	247	3.3
63	1976	7.	26	5.078	118.596	33	5.1	274	1.4
64	1976	7.	26	5.132	118.453	33	4.7	257	0.3
65	1976	7.	26	5.041	118.615	36	4.9	276	0.8
66	1976	7.	26	4.971	118.329	99	4.9	245	0.9
67	1976	7.	26	4.890	118.363	57	5.2	250	1.9
68	1976	7.	26	4.907	118.456	71	4.9	260	0.8
69	1976	7.	26	4.592	118.173	36	4.5	237	0
70	1976	8.	14	4.804	118.567	52	5.0	274	1.1
71	1976	8.	27	4.89	118.59	0	4.5	221	0.7
72	1976	9.	18	4.656	118.101	33	5.0	227	1.6
73	1976	9.	20	5.00	119.00	0	4.6	205	1.6
74	1977	5.	9	1.375	119.382	92	5.2	558	0
75	1978	4.	20	0.159	119.819	88	4.9	694	0

(to be continued)

Table B7 CATALOG OF EARTHQUAKE EVENT (4/5)

Event No.	Data of event			Location of focus			Mag-nitude	Distance (km)	Intensity
	Year	Month	Day	Latitude (N)	Longitude (E)	Depth (km)			
76	1978	9.	26	1.185	120.300	29	5.7	643	1.2
77	1978	10.	8	0.903	120.123	112	5.0	652	0
78	1979	3.	8	1.021	120.397	4	5.9	664	1.8
79	1979	3.	16	0.985	120.286	33	4.0	658	0
80	1979	3.	30	6.924	117.006	26	4.4	211	0
81	1979	7.	27	0.409	120.615	116	5.2	729	0
82	1979	9.	13	0.730	119.965	43	4.9	654	0
83	1979	12.	18	0.316	119.894	57	4.6	685	0
84	1980	5.	1	3.365	116.096	20	4.5	206	0.2
85	1980	9.	3	3,197	119.722	33	4.0	457	0
86	1980	10.	23	6.508	117.910	62	5.0	242	1.3
87	1980	12.	11	2.001	117.779	78	4.3	401	0
88	1981	1.	2	0.801	120.573	112	4.6	695	0
89	1981	1.	12	4.776	120.429	120	4.0	479	0
90	1981	1.	29	1,377	120.914	150	4.4	680	0
91	1981	2.	24	2.318	117,743	122	4.0	368	0
92	1981	10.	11	0.415	120.803	102	5.5	743	0.2
93	1981	11.	12	0.412	120.119	80	4.7	692	0
94	1981	12.	9	3.898	117,369	68	4.8	201	1.1
95	1981	12.	25	4.740	118,454	47	5.4	263	2.5
96	1982	2.	24	0.594	119.526	112	4.6	636	0
97	1982	2.	24	1.046	120.010	82	4.8	632	0
98	1982	2.	28	5.682	118.877	0	4.0	308	0
99	1982	6.	4	1.485	117.915	33	5.1	459	0.1
100	1982	9.	24	0.196	120.679	82	5.6	751	0.5

(to be continued)

Table B7 CATALOG OF EARTHQUAKE EVENT (5/5)

Event No.	Data of event			Location of focus			Magnitude	Distance (km)	Intensity
	Year	Month	Day	Latitude (N)	Longitude (E)	Depth (km)			
101	1982	9.	30	0.659	120.777	100	4.6	722	0
102	1982	11.	26	4.999	118.462	43	4.4	260	0
103	1982	12.	8	0.659	119.931	84	5.0	658	0
104	1982	12.	11	0.655	119.889	130	4.6	655	0
105	1983	3.	22	3.835	118.862	58	5.0	340	0.5
106	1983	5.	20	0.980	120.011	34	4.7	637	0
107	1983	6.	30	0.645	119.921	25	5.0	658	0
108	1983	7.	26	0.648	120.074	45	4.6	666	0
109	1983	7.	28	0.609	120.008	67	5.0	668	0
110	1983	7.	31	1,306	117.798	33	5.1	471	0.1
111	1983	7.	31	0.664	120.123	33	4.4	671	0
112	1983	10.	25	1.131	120.858	33	6.1	693	0.8
113	1983	10.	27	1.093	120.833	28	6.2	694	0.9
114	1983	11.	13	0.435	120.491	591	5.1	718	0
115	1983	11.	14	1.113	120.399	33	5.2	657	0
116	1983	11.	23	1.253	120.866	17	5.2	685	0
117	1983	12.	11	0.504	120.594	232	4.8	720	0
118	1983	12.	26	1.411	120.914	17	5.0	678	0
119	1984	3.	14	5.203	118.387	50	5.6	250	3.2
120	1984	5.	15	0.820	119.929	46	4.9	644	0
121	1984	5.	24	4.108	118.600	33	4.5	301	0

Remarks: (1) Distance is from project site to epicenter.
(2) Intensity is of the project site and measured by Modified Mercalli Scale.

Table B8 RESULT OF SUPPLEMENTAL STUDY OF SEISMIC COEFFICIENT BY KAWASUMI'S METHOD

LIST OF EARTHQUAKES (DATA B)

No.	DATE			EPICENTER		Depth	Magnitude	Distance (km) from Site to Epicenter	Intensity Felt at The Site
	Year	Month	Day	Latitude	Longitude				
1	1897	9	20	6.00°N	122.00°E	0.00	8.60	655	2.7
2	1897	9	21	6.00°N	122.00°E	0.00	8.70	655	2.9
3	1923	4	19	2.50°N	117.50°E	0.00	7.00	344	1.4
4	1923	8	11	4.50°N	119.50°E	0.00	6.50	383	0.1
5	1930	7	21	7.50°N	116.00°E	0.00	6.00	249	0.2
6	1951	6	2	6.75°N	116.50°E	0.00	5.75	170	0.6
7	1958	10	26	5.50°N	117.00°E	58.00	5.75	100	1.8
8	1966	5	18	5.96°N	116.64°E	52.00	5.30	95	0.9

Note: These data were complied from the Table of Gorshkov and the data of U.S.C.& G.S.

CORDINATE OF THE SITE

LATITUDE : 5.27°N
LONGITUDE : 116.13°E

Intensity	Frequency	Frequency in 100 Years	Cumulative Frequency in 100 Years
0 - 0.5	2	2.27	9.09
0.6 - 1.5	3	3.41	6.82
1.6 - 2.5	1	1.14	3.41
2.6 - 3.5	2	2.27	2.27
3.6 - 4.5	0	0.00	0.00
4.6 - 5.5	0	0.00	0.00
5.6 - 6.5	0	0.00	0.00
6.6 or larger	0	0.00	0.00

Intensity (100) : 4.68
Acceleration (gal) : 98
Acceleration (g) : 0.1 (Seismic coefficient)