CHAPTER 7 TOPOGRAPHY AND GEOLOGY

7.1 TOPOGRAPHY

Sites for the NN1 power station expansion are limited to the areas around the existing powerhouse and in the right bank vicinity of the dam. The existing dam was constructed utilizing a narrow neck section (river width of 100-150 m) of the Nam Ngum River. At 200 m downstream from the dam axis, the river width abruptly spreads to 300 m. The width of river is most narrow at 140 m downstream from the dam axis. This point is likely a part of an old rock ridge projecting from both banks before the dam construction. It is foreseen that the river bed at this point is formed by hard rock. The bottom level of the river at this point is assumed to be around EL. 164 m, and the hard rock bed seems to act as a control weir and govern the present tailrace water level. A map prepared in the 1960s shows a severely eroded river bed at the 200 m-section downstream of the narrow neck, and the deepest river bed was lower than EL. 145 m.

River bed rock humps crossing the river are seen 500 m downstream of the powerhouse. From this rock crop, it is supposed that the river bed of downstream vicinity is mostly covered with rock.

Both left and right abutments of the dam are on the line of a long ridge extending in the north-south direction. The ridge crest is mostly over EL. 250 m.

Approach road to the dam and powerhouse runs along the left bank of the Nam Ngum River. The road intersects national route No. 10 at a point 2 km downstream from the dam and, at 2 km further downstream, the road crosses a bridge over the Nam Ngum River, going towards national route No. 13. The bridge built in 1968 for the purpose of dam construction has a width of 5.2 m (carriage way 3.7 m) and length of 245 m, in total of eight spans. The bridge was designed for a 35-ton trailer truck load. The bridge is located 700 m downstream of the junction point of the Nam Ngum River and the Nam Lik River.

On the right abutment of the dam, a ski-jump type spillway is provided. The right bank area is accessible from the left bank through the dam crest road with an effective width of 5.5 m. However, the right bank area does not have a vehicle road and there is no bridge across Nam Ngum River that connects the left to the right bank. The spillway bridge along the dam crest road is a 6.0-m wide and 57.5-m long steel girder bridge. The bridge was designed for 40-ton trailer truck loads.

The topography of the dam area, including both banks, is presented in a 1:1000 contour map prepared in the 1960s. However, since the topography around the dam was changed after the construction work carried out in 1968-1971, the 1:1000 map is partly not usable for the study of the expansion plan. The altered topography is shown in a 1:500 map prepared during the F/S stage (1995) and it covers the right bank area between the spillway and the tail bay, and the left bank hill area of the powerhouse.

However, the 1:500 map does not cover the tail bay underwater.

In the present preparatory survey, topographic survey works were carried out as one of the sub-let works. The survey work items are as follows:

- Topographic survey of alternative expansion sites (1/500 map): 13.5 ha
- River cross section survey (along 23.5-km stretch): 25 sections

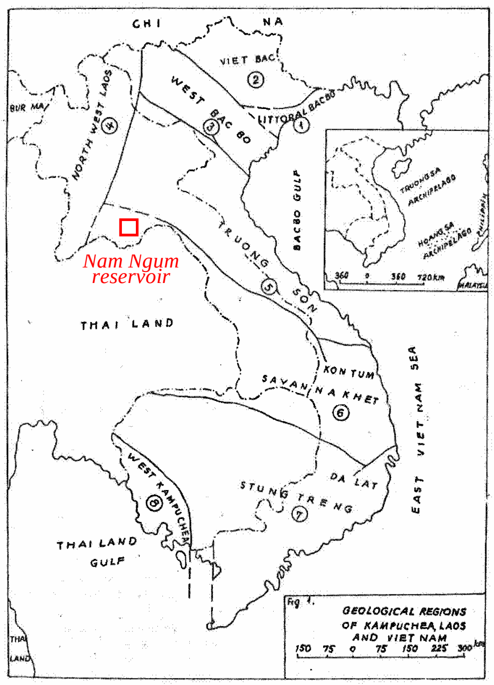
On the way of the work in the present study in Vientiane, the JICA Survey Team was requested by DOE/EdL to carry out additional study aiming at lowering the tail water level for increasing generation output by removing rock outcrops in the downstream river channel. The Survey Team consulted JICA about this request. JICA accepted to carry out additional preliminary study during the Survey. For the preliminary study, additional river cross section survey was performed. The additional survey work item is as follows.

- Additional river cross section survey (along 1 km stretch): 15 sections

7.2 GEOLOGY

(1) Regional Geology

Comprehensive researches on geology and mineral resources of the Indochina region were conducted by a study group cooperation of the geological branches of Vietnam, Lao PDR and Cambodia. The outcome of the researches is available in a publication (IIDMG, 1989). The concept of plate tectonics, which is considered as one of the fundamental principles of geology today, was deliberately avoided in the study group. Therefore, the geological history described in the publication is somewhat obscure (MMAJ, 1990). However, the distribution of rock formations is basically unchangeable and the tectonic boundaries would be the same if the concept had been accepted. Hence, the publication was selected as reference for the following description of regional geology. The tectonic provinces of Indochina region are shown in Figure 7.2.1.



Source: Explanatory Note to the Geological Map of Kampuchea, Laos and Vietnam at 1:1.000,000 scale (IIDMG, 1989)

Figure 7.2.1 Geological Regions of Kampucha, Laos and Vietnam

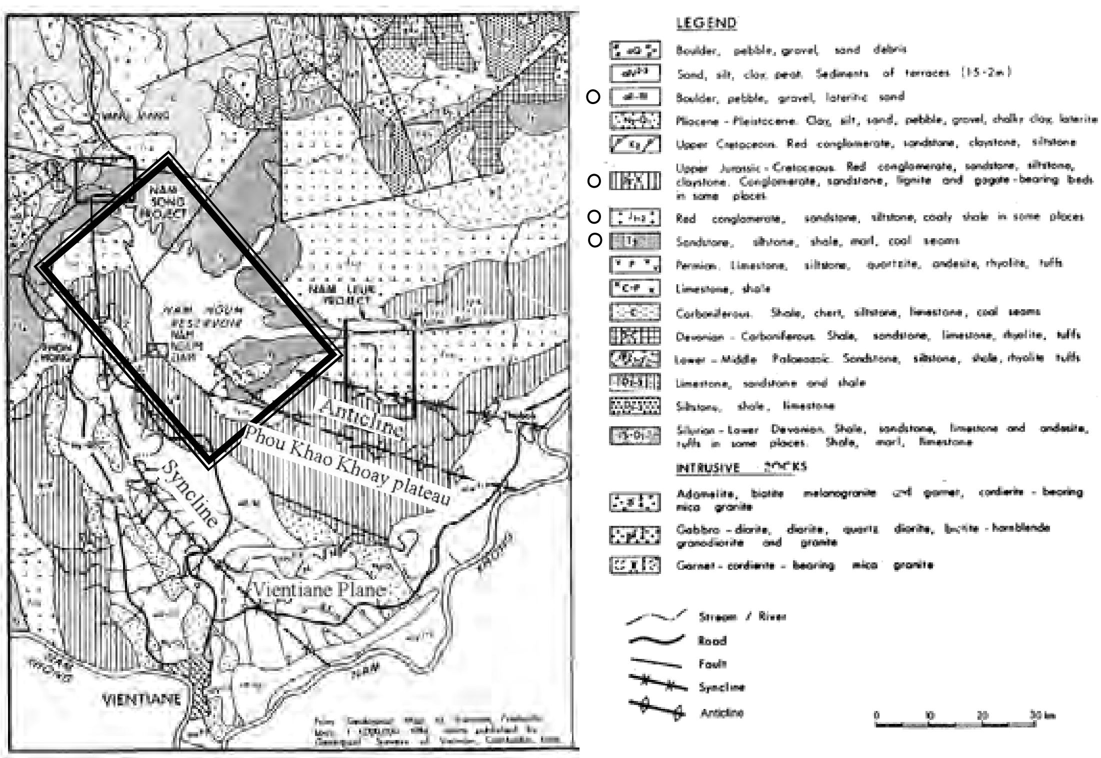
The project area is situated in Kontum Savannakhet province, which had been regarded as a "Hercynian folded belt" prior to the cooperation study. After the study, it is now regarded as

"Baicalian folded belt" or "Caledonian folded belt". Half of the Kontum Savannakhet province is covered with Mesozoic platform sediments, which is the basement rock of the project area. Compression strains associated with crustal plate movements gently folded the thick sequences of sediments, producing large wavelength folds generally oriented about the northwest-southeast axes in the Mesozoic era. The resulting synclines and anticlines, and associated faults dominate the present landforms.

The regional geology is shown in Figure 7.2.2. Four formations of geology are mapped in the project area.

a. Quaternary (all-III).
   boulder, pebble, sand, silt and clay
b. Upper Jurassic to Cretaceous (J3-K).
   conglomerate, sandstone, siltstone, claystone
c. Jurassic (J1-2)
   conglomerate, sandstone, siltstone, coaly shale
d. Triassic (J1-2)
   siltstone, shale, rhyolite, tuff

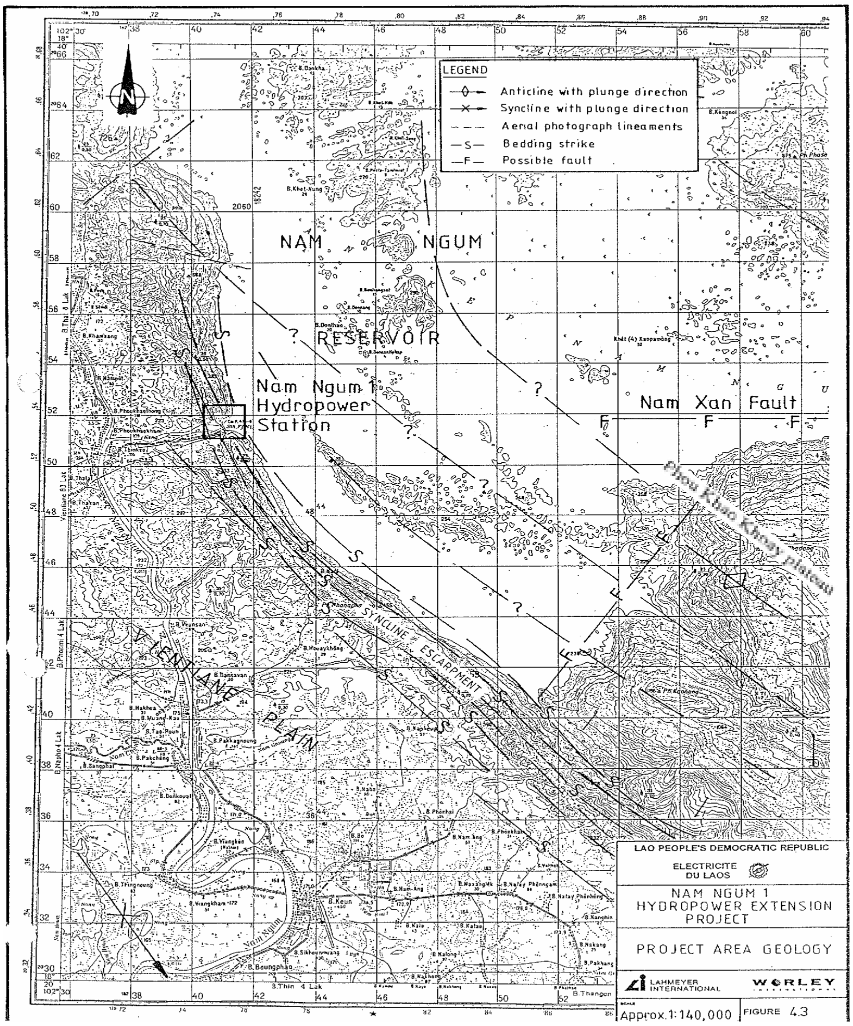
The upper Jurassic to Cretaceous formations (J3-K) are the basement rock in the project site, which is covered with quaternary sediments (all-III) around the river bed.



Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995); partly corrected (original geological map is from IIDMG, 1989)

Figure 7.2.2 Regional Geology

The topography and geological structure are shown in Figure 7.2.3. The Nam Ngum Dam site is located in the Nam Ngum River approximately 4 kilometers upstream of the Nam Lik confluence. The eastern and northern sides of the reservoir are on the flank of high mountainous regions over 1,500 meters in altitude, and the western and the southern sides of the reservoir are on the flank of a narrow ridge, which is 300-400 meters in altitude. The river flows out to the west through a break in the above ridge, which is the location of NN1 dam site. Downstream of the ridge, the river flows through low hilly areas until the Vientiane Plain, approximately 10 kilometers downstream of the Nam Lik confluence. Thereafter, Nam Ngum River flows southward in the hilly area, and meanders in the Vientiane Plain, changing the direction from south to east, and finally discharges into the Mekong River. The basement rock is gently folded into the major structural features of the Vientiane Plain syncline and Nam Gnong anticline of the Phou Khao Khoay plateau. Landforms in the region reflect the geological structure and lithology. Steep and sharp slopes are common with ridges defined by strong sandstone and conglomerate strata. Low rounded hills and plains are typically associated with weathering and erosion of weak units such as mudstone and some sandstones.

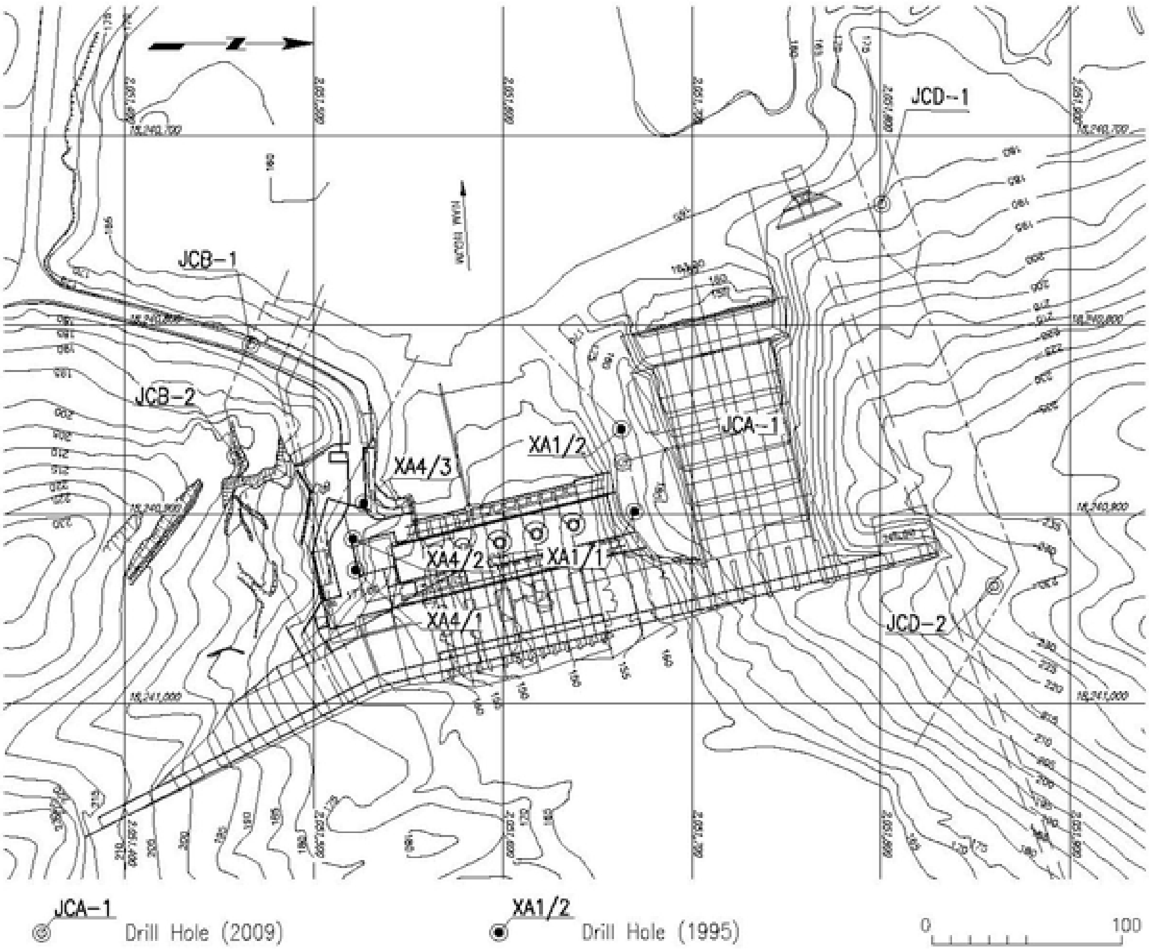


Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995)

Figure 7.2.3 Topography and Geological Structure

(2) Geological Investigation Works

Geological investigation works were carried out in three stages. The first one is the investigations in 1962 to 1971 for studies and construction of the existing NN1 power station; the next one is the expansion feasibility study in 1995; and the last is this preparatory survey for expansion in 2009. Although most of the works were carried out in the investigation stage, documents from the investigation works have already been lost and basic data such as drilling logs or test records are not available at present. However, the feasibility study report for the expansion (Lahmeyer, 1995) and its basic data are on hand. The locations of drilling works on the feasibility study and this preparatory survey are shown in Figure 7.2.4



Prepared by the JICA Survey Team

Figure 7.2.4 Location of Drill Holes

1) Previous Investigation Works

The previous investigation works are listed in Table 7.2.1 to Table 7.2.3. The details for the investigation works of the existing power station are not available, but the numbers and summary of test results can be seen in the completion report, the Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei, 1972-1). Moreover, in the as-built drawings (Nippon Koei, 1972-2), the geological sketches and geological section drawings are presented. A few inconsistencies about the geologic boundary are found between the sketches and the section drawings, however, in which case, the sketches are presumed to have precedence over the section drawings in this preparatory survey. In the 1995 feasibility study stage, the drilling works were executed around A1, A2 and A4 options. Additionally, concrete aggregate tests were carried out in each stage.

Table 7.2.1 List of Geological Drawings

Area	type	reference	remarks
Dam Site area	Geological Plan	As Built Drawings (Nippon Koei,1972-2)	
ditto	Geological Plan	FS report (Lahmeyer,1995)	
ditto	Geological Sections	As Built Drawings (Nippon Koei,1972-2)	37 sections
ditto	Foundation Sketch	As Built Drawings (Nippon Koei,1972-2)	obscure
ditto	Log of Inspection Adits	(Logs are not left.)	2 in each abutment
Spillway	Geological Section	As Built Drawings (Nippon Koei,1972-2)	included in dam sections
ditto	Foundation Sketch	As Built Drawings (Nippon Koei,1972-2)	
Power House	Geological Sections	As Built Drawings (Nippon Koei,1972-2)	24 sections, sound rock line
Diversion Tunnel	Geological Profile	Completion Report (Nippon Koei,1972-1)	

Prepared by the JICA Survey Team

Table 7.2.2 List of Existing Investigation Drillings

drill hole No.	length (m)	elevation (m)	inclination (degree)	direction (degree)	location	coordinates E	coordinates N	stage	remarks
D-,DX-,B-, P-,Q-,S- total 94 holes	total 1,714	(respective)	90	(N/A)	dam site, powerhouse	(respective)	(respective)	construction	Logs are not left. Test results are written in completion report.
XA1/1	30	178.192	90	(N/A)	A1 option	18,240,899	2,051,670	FS,1995	
XA1/2	25	177.498	90	(N/A)	A1 option	18,240,855	2,051,663	FS,1995	
XA4/1	30	177.108	90	(N/A)	A4 option	18,240,930	2,051,522	FS,1995	
XA4/2	25	177.169	90	(N/A)	A4 option	18,240,913	2,051,521	FS,1995	
XA4/3	25	177.102	90	(N/A)	A4 option	18,240,894	2,051,527	FS,1995	20m very weak rock

Coordinates are revised by the topographic survey carried out in this study.

Prepared by the JICA Survey Team

Table 7.2.3 List of Investigations for Construction Materials

type	number	geology	place	reference	material
Drilling	30 holes	Nam Lik alluvium	a few kirometers upstream of the confluence	Completion Report (Nippon Koei,1972-1)	sand and gravel
Test Pit	13 pits	ditto	ditto	Completion Report (Nippon Koei,1972-1)	ditto
Test Pit	2 pits	ditto	ditto	FS report (Lahmeyer,1995)	ditto

Prepared by the JICA Survey Team

2) Geological Investigation Works Carried Out in the Preparatory Survey

In this preparatory survey stage, the drilling locations were selected in options B2 and D2 where available drilling data have not existed and on option A1 which had been assumed as the most optimum. The purpose of these drillings are 1) to confirm the geological condition at B2 and D2 powerhouse sites, 2) to confirm the depth of weathered zone at each bank, and 3) to execute the permeability test in the basement rock at the intake of D2 option and at the new powerhouse of A1 option.

Routine down hole testing comprises standard penetration test (SPT) and water table measurement at all holes. In addition, the outcrop observation was carried out to confirm the geological conditions of basement rock. The geologic investigation works carried out in the preliminary survey are listed as follows:

Table 7.2.4 List of Geological Mapping and Drawings Prepared in this Study

area	type	output	remarks
Dam Site Area	Outcrop Mapping	Appendix "Outcrop Map"	
ditto	Geological Plan	Drawing "Geological Plan"	revision (integration of all investigation results)
Water Way	Geological Profile	Figure 7.2.16-18	all alternatavive options
New Power House	Geological Section	Drawing "Geological Section"	optimum option(A1) only

Prepared by the JICA Survey Team

Table 7.2.5 List of Investigation Drillings Carried Out in This Study

drill hole No.	length (m)	elevation (m)	inclination (degree)	direction (degree)	location	coordinates E	coordinates N	stage	in-situ test
JCA-1	20	177.296	90	(N/A)	A1 option	18,240,872.7	2,051,663.3	preparatory survey,2009	Standard Penetration Test water pressure test
JCB-1	25	177.689	90	(N/A)	B2 option	18,240,810.6	2,051,466.8	preparatory survey,2009	Standard Penetration Test
JCB-2	25	204.893	90	(N/A)	B2 option	18,240,869.3	2,051,458.8	preparatory survey,2009	Standard Penetration Test
JCD-1	25	176.887	90	(N/A)	D2 option	18,240,736.2	2,051,800.3	preparatory survey,2009	Standard Penetration Test
JCD-2	55	224.777	90	(N/A)	D2 option	18,240,938.0	2,051,859.8	preparatory survey,2009	Standard Penetration Test water pressure test

Prepared by the JICA Survey Team

Table 7.2.6 List of Laboratory Tests Carried Out in This Study

test name	JCA-1 nos.	JCB-1 nos.	JCB-2 nos.	JCD-1 nos.	JCD-2 nos.
Specific Gravity and Absorption test	2	2	2	2	4
Unconfined Compression Strength test	6	0	0	0	0
Splitting Tensil Strength test	6	0	0	0	0

Prepared by the JICA Survey Team

(3) Estimated Features of the Foundation Rock

1) Rock Type

The basement rock of the project site consists of alternating coarse and fine sedimentary rocks. Most of the coarse sedimentary rocks are categorized as sandstone and sometimes associated with thin layers of conglomerates. The two types of rocks are distributed conformably and show the same characteristics when they are weathered or jointed. Therefore, both rocks were categorized as same sandstone in this preparatory survey. The fine sedimentary rocks such as mudstone, siltstone, claystone and shale are commonly described in the existing documents as weak rock in comparison with sandstone. Furthermore, the lines on the use of rock names are obscure, so these are not discriminated in this preparatory survey and categorized as same mudstone. Additionally, weathering plays an important part in rock properties, so the weathering is classified into three categories, considering the quality and quantity of existing data. The rock types used for this survey are shown in Table 7.2.7.

Table 7.2.7 Rock Mass Classification in This Study

		Weathering		
		slightly weathered, unweathered	moderately weathered	completely weathered,
Lithology	sandstone, conglomerate	**FRESH SANDSTONE**	**MODERATELY WEATHERED SANDSTONE**	**HIGHLY WEATHERED SANDSTONE**
	mudstone, siltstone, claystone, shale,	**FRESH MUDSTONE**	**MODERATELY WEATHERED MUDSTONE**	**HIGHLY WEATHERED MUDSTONE**

Prepared by the JICA Survey Team

Rock conditions of each rock type are summarized below:

i) Sandstone

Sandstone is very hard and resistant to weathering if compared with mudstone, and is often exposed at the ground. Component particle size varies from fine to coarse and sometimes intercalates into conglomerate layers. Cross-bedding patterns are sometimes identified, which suggests that it is originally marine sediments. Color varies from grayish white to bluish grey in fresh rock, and shows purple at the face of weathered joints. Sandstone strata are not uniform, but rather a group of sequential sandstone layers with thin mudstone layers, occasionally intercalated with rectangular mudstone layers. Sandstone is strongly jointed in the eminent bedding planes with spacing of 1 meter or less, and frequently jointed in gradual and steep planes, which cross the bedding planes at 45 to 90 degrees.

a Fresh Sandstone

The rock is quite fresh and more than 30 centimeters is the spacing of joints. The existing geological sections suggest the fresh rock zone may appear after 5 to 10 meters excavation below the ground.

b Moderately Weathered Sandstone

The rock is weathered but still sufficiently hard, with the minimum spacing of joints at ten centimeters.

c Highly Weathered Sandstone

The rock is almost weathered and brittle. The maximum spacing of joints is ten centimeters.

Generally, the rock zone is distributed at the top of the basement rock or shared zones. Comparatively, coarse-grained sandstone layers tend to maintain moderately weathered condition while the fine-grained sandstone is highly weathered. Hence, it is often observed that highly weathered sandstone is alternated with the moderately weathered sandstone.

ii) Mudstone

In fresh condition, mudstone is generally massive with fewer fissures, but the unconfined compressive strength is approximately 50% that of sandstone. Component particle size varies from clay to silt, and some layers can be differentiated by particle size. Color varies from black to dark grey in fresh rock, and from brown to reddish brown in weathered rock. Mudstone is far more apt to be weathered and to be decomposed than sandstone. When mudstone is exposed to air, it easily cracks and is deteriorated by stress relief or by repetition of swelling and shrinking due to the changes in moisture content. Mudstone sections of the diversion tunnel actually showed the muddy foundation condition wetted by spring water (Nippon Koei, 1972-1). By contrast, sandstone is resistant to weathering, so some weathered mudstone layers are found within the fresh sandstone strata. On the other hand, there are a few mudstone strata being sheared, not by the effect of weathering, but possibly as the result of tectonic strain during folding.

a Fresh Mudstone

The rock is quite fresh and massive with less fissures when it is in the ground, but when it is exposed in the air, it decomposes gradually. The existing geological sections suggest that the fresh rock zone may appear after 10 to 20 meters excavation below the ground.

b Moderately Weathered Mudstone

More than ten centimeters is the spacing of joints and the rock is a little bit brittle when it is in the ground, and will decompose just after it is exposed to air. The moderately weathered mudstone seems alternated with highly weathered mudstone

c Highly Weathered Mudstone

The maximum spacing of joints is ten centimeters and the rock is completely brittle or softened. Generally, the rock zone is distributed at the top of the basement rock or sheared zones, and sometimes lies between fresh sandstone strata. In addition, this rock type includes the mudstone strata being sheared not by the effect of weathering but possibly as a result of tectonic strain during folding.

2) Structural Geology

The westward extension of the Nam Xan fault indicated in Figure 7.2.3 may disrupt the anticline assumed to extend into that area (Lahmeyer, 1995), and not any other major fault has been identified in the powerhouse site. Based on the site reconnaissance executed by the JICA Survey Team, there are no identified unstable large sediments or talus deposits which cling on the slopes either.

The strata show a conformable dip angle to the large folding structure from upstream anticline to downstream syncline. Their westward dip shows 45 to 65 degrees of inclination around the dam site and most measurements range between 55 degrees and 60 degrees. Dip direction is also consistent at 255 degrees to 270 degrees, which points to the downstream direction exactly.

3) Weak Rock

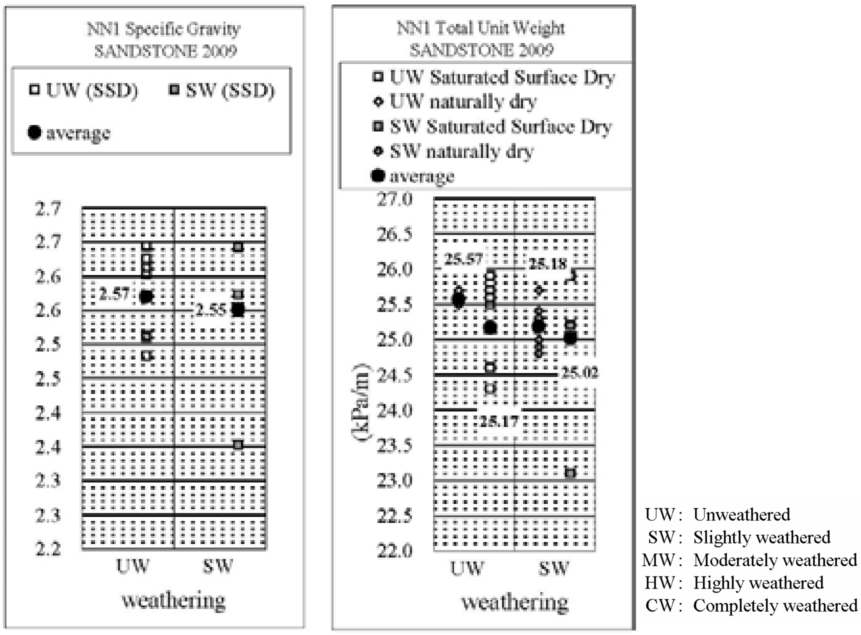
Some attention is required for all mudstone strata, which are relatively infirm and quick to decompose at the excavated faces even in the fresh rock zone. At drill hole XA4/3 at the southern end of A4 powerhouse site, a 20-m very weak mudstone layer had been encountered, which was interpreted as sheared (Lahmeyer, 1995). The exposure of this weak mudstone layer and the core log of another drill hole indicate the texture of lithified shear rock. This suggests the possibility to be the result of tectonic strain during folding. In sandstone strata, many minor bedding faults exist, but these are, in most cases, not anything more than slicken-sides or thin clay. Moreover, several weathered mudstone layers or weathered fine grained sandstone layers with maximum thickness of 1.5 meters have been found between the fresh coarse grained sandstone strata.

(4) Properties of the Foundation Rock

The test results and the estimated conditions of the foundation rock are described below.

1) Physical Properties

The specific gravity and absorption test on the new drilled cores were carried out, and the total unit weight of mechanical test samples were measured in this preparatory survey. The test results are shown in Table 7.2.8 and Figure 7.2.5. The samples are all fresh sandstone. These are in the range of typical sandstone variation and show a tendency of decrease based on the weathering.



Prepared by the JICA Survey Team

Figure 7.2.5 Point Diagram of Specific Gravity and Total Unit Weight

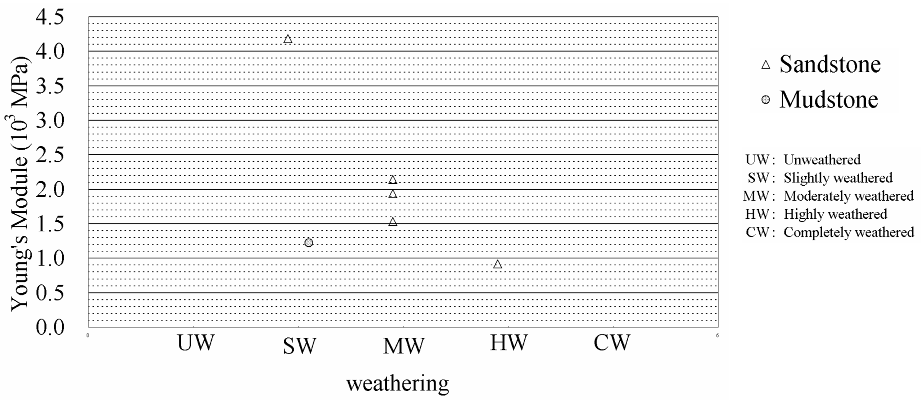
Table 7.2.8 List of Specific Gravity and Total Unit Weight

Drillhole	Sample	Depth		Material Type			Specific Gravity		total unit weight	executed year	remarks
(no.)	(no.)	(m)	~(m)	(geology)	(feature)	(weathering)	% Water Absorption	Saturated Surface Dry	(kPa/m)		
JCA-1	sample 1	10.72	10.93	Sand stone	mudstone spot	SW	1.98	2.641	25.9	2009	
JCA-1	sample 2	17.72	17.87	Sand stone		UW	1.02	2.644	25.9	2009	
JCB-1	sample 3	17.73	18.00	Sand stone	grey,brown spot	SW	1.13	2.643	25.9	2009	
JCB-1	sample 4	18.12	18.29	Sand stone	dark grey	UW	4.32	2.602	25.5	2009	
JCB-2	sample 5	10.40	10.60	Sand stone	dark grey	UW	3.95	2.483	24.3	2009	
JCB-2	sample 6	22.00	22.19	Sand stone	grey,brown spot	SW	5.05	2.573	25.2	2009	
JCD-1	sample 7	9.85	10.00	Sand stone	grey,brown spot	SW	4.86	2.353	23.1	2009	
JCD-1	sample 8	22.77	23.00	Sand stone	grey,brown spot	SW	2.87	2.547	25.0	2009	
JCD-2	sample 9	5.50	5.66	Sand stone	dark grey	UW	3.86	2.513	24.6	2009	
JCD-2	sample 10	17.00	17.20	Sand stone	dark grey	UW	1.75	2.612	25.6	2009	
JCD-2	sample 11	41.64	41.89	Sand stone	dark grey	UW	2.28	2.510	24.6	2009	
JCD-2	sample 12	54.00	54.31	Sand stone	dark grey	UW	1.28	2.625	25.7	2009	
JCA-1	TT-1	10.10	10.14	Sand stone	grey,brown spot	SW	-	-	24.8	2009	naturally dry condition
JCA-1	TT-2	10.14	10.18	Sand stone	grey,brown spot	SW	-	-	24.9	2009	naturally dry condition
JCA-1	TT-3	10.18	10.22	Sand stone	grey,brown spot	SW	-	-	25.0	2009	naturally dry condition
JCA-1	TT-4	16.49	16.53	Sand stone	dark grey	UW	-	-	25.5	2009	naturally dry condition
JCA-1	TT-5	16.53	16.58	Sand stone	dark grey	UW	-	-	25.5	2009	naturally dry condition
JCA-1	TT-6	16.58	16.62	Sand stone	dark grey	UW	-	-	25.6	2009	naturally dry condition
JCA-1	UC-1	11.20	11.33	Sand stone		SW	-	-	25.4	2009	naturally dry condition
JCA-1	UC-2	11.33	11.43	Sand stone		SW	-	-	25.3	2009	naturally dry condition
JCA-1	UC-3	11.43	11.53	Sand stone		SW	-	-	25.7	2009	naturally dry condition
JCA-1	UC-4	17.10	17.20	Sand stone		UW	-	-	25.5	2009	naturally dry condition
JCA-1	UC-5	17.20	17.31	Sand stone		UW	-	-	25.6	2009	naturally dry condition
JCA-1	UC-6	17.31	17.42	Sand stone		UW	-	-	25.7	2009	naturally dry condition

Prepared by the JICA Survey Team

2) Deformation Property

Loading tests in dam site adits were carried out during the construction stage (Nippon Koei, 1972-1). The test results are shown in Figure 7.2.6 and Table 7.2.9.



Source: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei,1972-1)

Figure 7.2.6 Point Diagram of Young's Module of Dam Foundation Rock

Table 7.2.9 List of Loading Test of Dam Foundation Rock

Rock condition			Diameter	Max load	Creep under Max load		Total testing time	Total settlement	Load of failure	Young's moduls		executed year
(geology)	(feature)	(weathering)	(cm)	(kgf/cm2)	(mm)	(hr)	(hr)	(mm)	(kgf/cm2)	(kgf/cm2)	(Mpa)	
Sandstone	fresh	SW	350	104.1	0.214	22:58	26:35	1,320	no failure	41,000	4,184	1960's
Sandstone	weathered	MW	350	72.9	0.210	22:31	25:42	1,450	no failure	21,000	2,143	1960's
Sandstone	weathered	MW	350	83.3	0.343	23:10	26:35	2,912	no failure	19,000	1,939	1960's
Sandstone	weathered	MW	350	83.3	0.307	46:00	49:25	3,185	no failure	15,000	1,531	1960's
Sandstone	seriously weathered	HW	350	83.3	0.641	22:10	25:35	7,610	no failure	9,000	918	1960's
Mudstone	fresh, shale	SW	350	78.1	0.349	20:20	117:05	3,381	no failure	12,000	1,225	1960's
Mudstone	decomposed, stiff clay	CW	350	23.9	-	-	141:10	50.8	16.7	-	-	

Source: Based on the Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei,1972-1)

3) Strength Properties

Direct tests for the strength properties have not been executed on this site. In the safety design during the construction stage, assumed values shown in Table 7.2.10 were utilized (Nippon Koei, 1972-1). For the confirmation of the assumption, estimates were undertaken based on the indirect test results of the drilled cores, which are shown in Table 7.2.11.

As far as evaluating the estimated values, mudstone does not have much margin against the required strength of the dam foundation. Moreover, the strength of the actual rock mass may be less than this core strength because of the influences of joints or bedding planes.

Table 7.2.10 Mechanical Strength Used for Dam Safety Design of Nam Ngum 1

Bearing capacity of foundation rock	400 tons/m^2	3.92 MPa
coefficient of internal friction	0.65	33 degree
shear resistance	200 tons/m^2	1.96 MPa

Source: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei, 1972-1)

Table 7.2.11 Mechanical Strength Estimated Based on the Unconfined Compressive and Tensile Strengths

Rock Type		Weathering	Test Result		Estimation A		Estimation B	
			UCS (Mpa)	TS (Mpa)	SS (Mpa)	IFA (°)	SS (Mpa)	IFA (°)
Sandstone	Fresh	UW	82.2	20.1	20.3	37.4	12.1	39
		SW	50.0	5.8	8.5	52.4	7.8	37
	Moderately weathered	MW	33.1	-	-	-	5.4	35
Mudstone	Fresh	SW	22.4	-	-	-	3.8	34
	Moderately weathered	MW	13.0	-	-	-	2.4	32

UCS: Unconfined Compression Strength
TS: Tensile Strength
SS: Shear Strength
IFA: Internal Friction Angle (degree)

UW: Unweathered
SW: Slightly weathered
MW: Moderately weathered
HW: Highly weathered
CW: Completely weathered

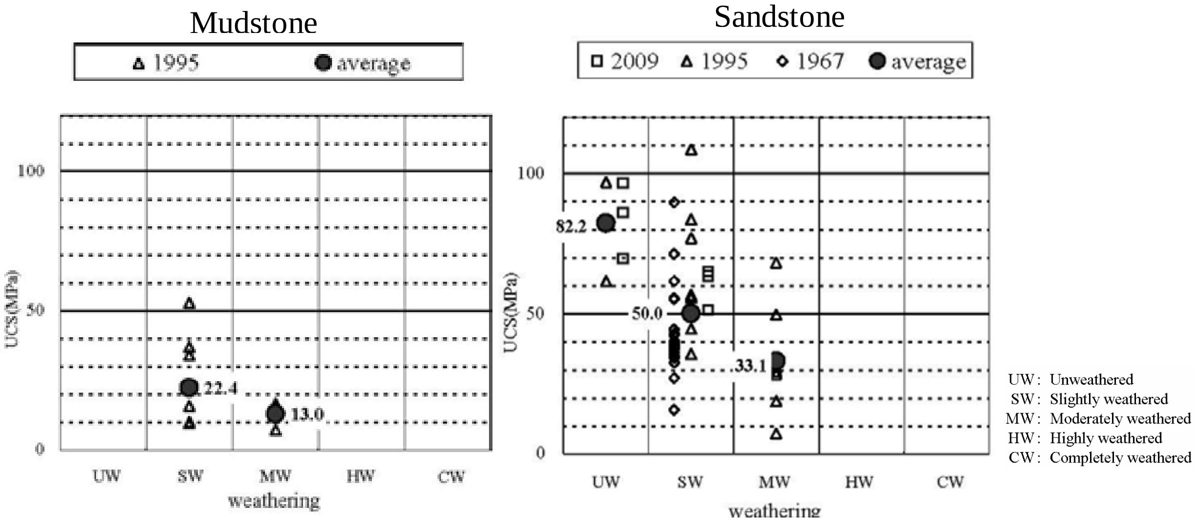
Estimation A : Mohr's stress circle
SS= 1/2*√(UCS*TS)
sin(IFA)= (UCS-TS)/(UCS+TS)

Estimation B : empirical formula (JAEA,2000)
SS= 0.24 * UCS^(0.89)
IFA= 22.7+8.30log(UCS)

Prepared by the JICA Survey Team

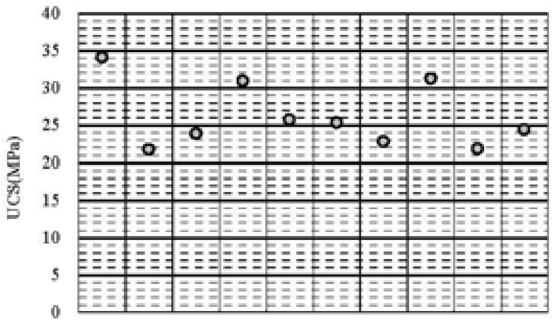
i) Unconfined Compressive Strength

Unconfined compressive strength is not used directly in the civil design, but the value can be used as strength reference. The test results are shown in Figure 7.2.7 and Table 7.2.12. Mudstone shows comparatively small values, but sandstone shows high values in fresh condition. As some slightly weathered sandstone show very small values, which are hardly seen in the fresh sandstone, the latent weak beddings might come out when it is weathered. The dam concrete of block no.20 was also tested as shown in Figure 7.2.8 and Table 7.2.13.



Sources: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei, 1972-1)
and Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995)

Figure 7.2.7 Point Diagram of Unconfined Compressive Strength



Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995)

Figure 7.2.8 Point Diagram of Unconfined Compressive Strength of Dam Concrete

Table 7.2.12 List of Unconfined Compression Test

Drillhole	Sample	Depth		Material Type			Diameter	Length	UCS		Elasticity	Poisson ratio	total unit weight	executed year
(no.)	(no.)	(m)	~(m)	(geology)	(feature)	(weathering)	(cm)	(cm)	(kgf/cm2)	(MPa)	(MPa)		(kPa/m)	
(dam foundation)	A-1	-	-	Sand stone	medium coarse	SW	49.00	98.00	265.00	27.0				1967
(dam foundation)	A-2	-	-	Sand stone	medium coarse	SW	49.00	106.00	366.00	37.3				1967
(dam foundation)	A-3	-	-	Sand stone	medium coarse	SW	49.00	100.00	414.00	42.2				1967
(dam foundation)	A-4	-	-	Sand stone	medium coarse	SW	49.00	98.00	541.00	55.2				1967
(dam foundation)	A-5	-	-	Sand stone	medium coarse	SW	49.00	100.00	371.00	37.9				1967
(dam foundation)	B-1	-	-	Sand stone	coarse	SW	39.00	80.00	879.00	89.7				1967
(dam foundation)	B-2	-	-	Sand stone	coarse	SW	39.00	81.00	435.00	44.4				1967
(dam foundation)	B-3	-	-	Sand stone	coarse	SW	39.00	63.00	544.00	55.5				1967
(dam foundation)	B-4	-	-	Sand stone	coarse	SW	39.00	78.00	368.00	37.6				1967
(dam foundation)	B-5	-	-	Sand stone	coarse	SW	39.00	84.00	335.00	34.2				1967
(dam foundation)	C-1	-	-	Sand stone	fine medium	SW	49.00	93.00	604.00	61.6				1967
(dam foundation)	C-2	-	-	Sand stone	fine medium	SW	49.00	100.00	419.00	42.8				1967
(dam foundation)	C-3	-	-	Sand stone	fine medium	SW	49.00	97.00	700.00	71.4				1967
(dam foundation)	C-4	-	-	Sand stone	fine medium	SW	49.00	104.00	387.00	39.5				1967
(dam foundation)	D-1	-	-	Sand stone	medium	SW	49.00	100.00	153.00	15.6				1967
(dam foundation)	D-2	-	-	Sand stone	medium	SW	49.00	98.00	381.00	38.9				1967
(dam foundation)	D-3	-	-	Sand stone	medium	SW	49.00	86.00	435.00	44.4				1967
(dam foundation)	D-4	-	-	Sand stone	medium	SW	49.00	80.00	318.00	32.4				1967
(dam foundation)	E-1	-	-	Sand stone	very coarse	SW	49.00	90.00	355.00	36.2				1967
(dam foundation)	E-2	-	-	Sand stone	very coarse	SW	49.00	100.00	392.00	40.0				1967
(dam foundation)	F-1	-	-	Sand stone	medium	SW	39.00	80.00	335.00	34.2				1967
(dam foundation)	F-2	-	-	Sand stone	medium	SW	39.00	80.00	544.00	55.5				1967
(dam foundation)	F-3	-	-	Sand stone	medium	SW	39.00	90.00	343.00	35.0				1967
(dam foundation)	A'-1	-	-	Sand stone	coarse	SW	58.00	116.00	190.00	19.4				1967
(dam foundation)	B'-1	-	-	Sand stone	coarse	SW	58.00	95.00	152.00	15.5				1967
(dam foundation)	B'-2	-	-	Sand stone	coarse	SW	58.00	116.00	284.00	29.0				1967
(dam foundation)	B'-3	-	-	Sand stone	coarse	SW	58.00	85.00	190.00	19.4				1967
(dam foundation)	C'-1	-	-	Sand stone	medium coarse	SW	39.00	80.00	167.00	17.0				1967
(dam foundation)	D'-1	-	-	Sand stone	medium	SW	39.00	75.00	335.00	34.2				1967
XA1/1	1	2.82	2.95	Sand stone		MW	5.20	10.40	301.38	30.8				1995
XA1/1	2	6.70	6.90	Sand stone		MW	5.50	11,00	320.00	32.7				1995
XA1/1	3	12.00	12.15	Sand stone		SW	5.20	10.40	819.20	83.6				1995
XA1/1	4	15.00	15.15	Sand stone		SW	5.20	10.40	546.14	55.7				1995
XA1/1	5	18.75	19.00	Silt stone		MW	5.20	10.40	162.53	16.6				1995
XA1/1	6	20.00	20.20	Silt stone		MW	5.10	10.20	146.93	15.0				1995
XA1/1	7	22.05	22.30	Silt stone		SW	5.20	10.40	518.22	52.9				1995
XA1/1	8	26.15	26.30	Silt stone		SW	5.20	10.40	94.22	9.6				1995
XA1/1	9	28.50	28.65	Silt stone		SW	5.20	10.40	94.22	9.6				1995
XA1/2	2	4.40	4.60	Sand stone	fine grained	MW	5.20	10.40	487.35	49.7				1995
XA1/2	3	5.75	5.90	Sand stone		MW	5.20	10.40	70.63	7.2				1995
XA1/2	5	10.75	11.00	Silt stone	dark purple	SW	5.10	10.20	100.35	10.2				1995
XA1/2	7	17.50	17.70	Silt stone	dark purple	SW	5.20	10.40	94.17	9.6				1995
XA1/2	8	21.75	22.80	Silt stone	sandy	SW	5.20	10.40	334.27	34.1				1995
XA1/2	9	24.45	24.65	Sand stone		SW	5.20	10.40	555.62	56.7				1995
XA4/1	1	3.50	3.70	Sand stone		MW	5.40	10.80	183.38	18.7				1995
XA4/1	2	6.30	6.50	Sand stone		SW	5.20	10.40	348.39	35.6				1995
XA4/1	3	10.75	10.90	Sand stone		UW	5.20	10.40	951.03	97.0				1995
XA4/1	4	16.85	17.00	Sand stone		UW	5.20	10.40	602.64	61.5				1995
XA4/1	5	19.70	19.90	Mud stone		MW	5.00	10.00	71.30	7.3				1995
XA4/1	6	24.00	24.15	Mud stone		SW	5.20	10.40	362.57	37.0				1995
XA4/1	7	27.65	27.80	Mud stone		SW	5.00	10.00	155.33	15.9				1995
XA4/2	1	7.00	7.18	Sand stone	fine medium	MW	5.20	10.40	668.64	68.2				1995
XA4/2	2	9.35	9.55	Sand stone	conglomeratic	MW	5.20	10.40	287.23	29.3				1995
XA4/2	3	13.10	13.30	Sand stone	fine coarse	MW	5.20	10.40	277.81	28.3				1995
XA4/2	4	18.55	18.70	Sand stone	fine coarse	SW	5.40	10.80	436.64	44.6				1995
XA4/2	5	22.25	22.50	Sand stone	fine coarse	SW	5.40	10.80	755.38	77.1				1995
XA4/2	6	24.40	24.60	Sand stone	fine medium	SW	5.40	10.80	1065.40	108.7				1995
XA4/3	3	9.80	10.00	Mud stone		CW	5.00	10.00	56.01	5.7				1995
JCA-1	UC-1	11.20	11.33	Sand stone		SW	5.38	10.18	636.6	64.961	12,847	0.33	25.4	2009
JCA-1	UC-2	11.33	11.43	Sand stone		SW	5.40	10.10	501.8	51.201	12,002	0.27	25.3	2009
JCA-1	UC-3	11.43	11.53	Sand stone		SW	5.38	10.23	621.4	63.410	19,664	0.23	25.7	2009
JCA-1	UC-4	17.10	17.20	Sand stone		UW	5.40	10.48	946.9	96.627	17,532	0.30	25.5	2009
JCA-1	UC-5	17.20	17.31	Sand stone		UW	5.40	10.51	682.1	69.599	14,362	0.21	25.6	2009
JCA-1	UC-6	17.31	17.42	Sand stone		UW	5.40	10.55	843.4	86.057	16,251	0.24	25.7	2009

UW: Unweathered
SW: Slightly weathered
MW: Moderately weathered
HW: Highly weathered
CW: Completely weathered

Sources: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei, 1972-1),
Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995), and Appendix

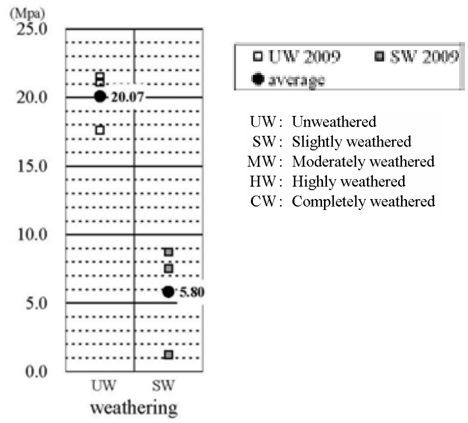
Table 7.2.13 List of Unconfined Compression Test on Dam Concrete

Drillhole	Sample	Material Type	Diameter	Length	UCS		executed year
(no.)	(no.)	(geology)	(cm)	(cm)	(kgf/cm2)	(MPa)	
Dam	1	concrete	11.20	12.60	334.21	34.1	1995
Dam	2	concrete	11.10	22.40	213.10	21.7	1995
Dam	3	concrete	11.10	22.40	233.54	23.8	1995
Dam	4	concrete	11.20	12.30	302.47	30.9	1995
Dam	5	concrete	11.20	13.70	251.72	25.7	1995
Dam	7	concrete	11.20	14.30	247.66	25.3	1995
Dam	7	concrete	11.20	16.20	223.39	22.8	1995
Dam	9	concrete	11.10	17.90	305.88	31.2	1995
Dam	9	concrete	11.20	12.60	213.42	21.8	1995
Dam	10	concrete	11.40	14.30	239.05	24.4	1995

Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995)

ii) Splitting Tensile Strength

Splitting tensile strength can also be used as a strength reference. The test results are shown in Figure 7.2.9 and Table 7.2.14. Sandstone was tested in this preparatory survey. There is much difference between unweathered and slightly weathered, which often comes from the influence of latent weak beddings.



Prepared by the JICA Survey Team

Figure 7.2.9 Point Diagram of Splitting Tensile Strength

Table 7.2.14 List of Splitting Tensile Strength Tests

Drillhole	Sample	Depth		Material Type			Diameter	Length	Max Applied Strength	Tensile Strength		total unit weight	executed year
(no.)	(no.)	(m)	~(m)	(geology)	(feature)	(weathering)	(cm)	(cm)	(kN)	(kgf/cm2)	(MPa)	(kPa/m)	
JCA-1	TT-1	10.10	10.14	Sand stone	grey,brown spot	SW	5.23	4.02	3.8	11.8	1.2	24.8	2009
JCA-1	TT-2	10.14	10.18	Sand stone	grey,brown spot	SW	5.15	3.93	27.7	85.3	8.7	24.9	2009
JCA-1	TT-3	10.18	10.22	Sand stone	grey,brown spot	SW	5.19	4.03	24.8	73.5	7.5	25.0	2009
JCA-1	TT-4	16.49	16.53	Sand stone	dark grey	UW	5.39	4.49	66.8	172.5	17.6	25.5	2009
JCA-1	TT-5	16.53	16.58	Sand stone	dark grey	UW	5.40	4.28	76.7	206.8	21.1	25.5	2009
JCA-1	TT-6	16.58	16.62	Sand stone	dark grey	UW	5.39	4.41	80.4	210.7	21.5	25.6	2009

Prepared by the JICA Survey Team

iii) N value

Standard penetration tests (SPTs) were carried out at the surface sediment zone and highly weathered zone. The target zones are so thin and the numbers of the tests are so little that the strength can not be estimated exactly for each zone. However, it does not seem necessary to carry out additional tests anymore since there is no deep soil distribution to be considered, or any structure which will be found on the soil. The list of SPTs and test results are shown in Table 7.2.15.

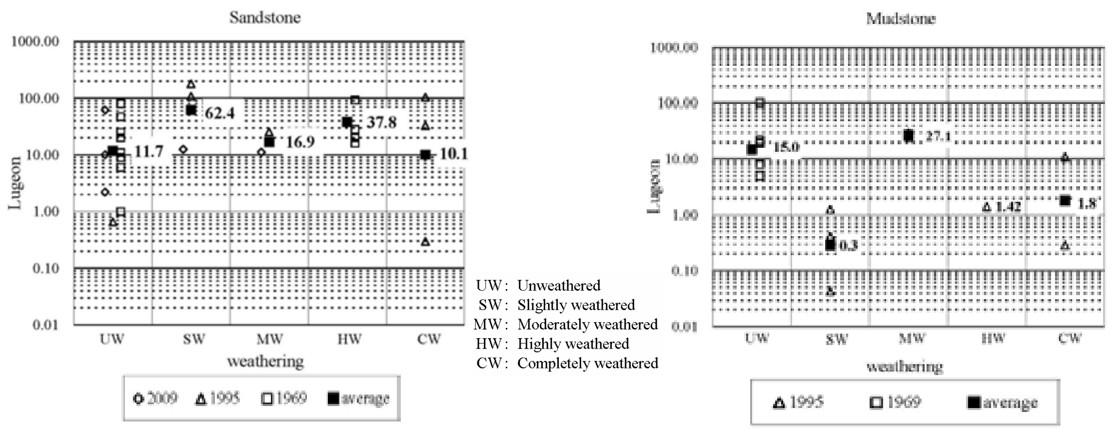
Table 7.2.15 List of Standard Penetration Tests

Drillhole	Stage	Depth		Material Type		Diameter	N	penetrate	Number of Blows						total penetrate	total blows	executed
(no.)	(no.)	(m)	~(m)	(geology)	(weathering)	(cm)	(15-45)	(cm)	(0-10)	(10-20)	(20-30)	(30-40)	(40-50)	-	(cm)		year
XA4/2	1	1.50	2.00	fill materiai A	-	9.90	36	30	14	17	10	11	13	-	50	65	1995
	2	3.00	3.26	fill materiai A	-	9.90	>50	6	19	30	50	-	-	-	26	99	1995
	3	5.20	5.27	Mudstone	CW	9.90	>50	7	50	-	-	-	-	-	27	50	1995
XA4/3	1	1.00	1.50	Sandstone	CW	9.90	5	30	1	1	2	2	1	-	50	7	1995
	2	3.45	3.95	Mudstone	CW	9.90	14	30	2	3	4	5	8	-	50	22	1995
	3	5.00	5.50	Mudstone	CW	9.90	46	30	6	11	12	18	22	-	50	69	1995
	4	7.05	7.19	Mudstone	CW	9.90	>50	14	37	50	-	-	-	-	34	87	1995
									(0-7.5)	(7.5-15)	(15-22.5)	(22.5-30)	(30-37.5)	(37.5-45)			
JCA-1	SS1	1.00	1.45	Sandstone	CW	10.0	15	30	4		5		10		45	19	2009
	SS2	2.00	2.45	Sandstone	CW	10.0	20	30	17		13		7		45	37	2009
	SS3	3.00	3.45	Sandstone	CW	10.0	56	30	15		26		30		45	71	2009
	SS4	4.00	4.45	Sandstone	CW	10.0	43	30	15		20		23		45	58	2009
	SS5	5.00	5.45	Sandstone	CW	10.0	61	30	12		29		32		45	73	2009
	SS6	6.00	6.05	Sandstone	CW	10.0	>50	5	unknown	unknown	50	-	-	-	20	>50	2009
	SS7	7.00	7.05	Sandstone	HW	10.0	>50	5	unknown	unknown	50	-	-	-	20	>50	2009
	SS8	8.00	8.08	Sandstone	HW	10.0	>50	7.5	unknown	unknown	50	-	-	-	23	>50	2009
JCB-1	SS1	1.00	1.45	fill materiai	-	10.0	13	30	3	3	3	4	3	3	45	19	2009
	SS2	2.00	2.45	fill materiai	-	10.0	11	30	3	3	3	3	2	3	45	17	2009
JCB-2	SS1	1.00	1.45	fill materiai	-	10.0	16	30	16	6	3	6	3	4	45	38	2009
	SS2	2.00	2.45	fill materiai	-	10.0	>50	3	24	45	50	-	-	-	18	119	2009
JCD-1	SS1	1.00	1.45	Mudstone	CW	10.0	26	30	4	6	5	8	6	7	45	36	2009
	SS2	2.00	2.45	Mudstone	CW	10.0	30	30	5	7	6	8	7	9	45	42	2009
	SS3	3.00	3.45	Mudstone	CW	10.0	36	30	8	6	7	9	9	11	45	50	2009
	SS4	4.00	4.30	Mudstone	CW	10.0	>50	30	15	15	20	32	-	-	45	82	2009
JCD-2	SS1	1.00	1.45	Sandstone	CW	10.0	>50	30	6	8	9	10	18	21	45	72	2009

Prepared by the JICA Survey Team

4) Permeability

Results of water pressure test (Lugeon type) are shown in Figure 7.2.10 and Table 7.2.16. These show that mudstone has lower permeability than sandstone. Based on the results of site reconnaissance and the drilled core observations, the reason is presumed as follows: Sandstone is strongly jointed in the eminent bedding planes and there are little filling between the joints, therefore, the permeability becomes high in the bedding direction. On the other hand, mudstone is basically massive and there are enough fill materials between the joints, hence, mudstone has low permeability. The reason why unweathered mudstone and moderately weathered mudstone show high permeability is presumed as follows: Since the data are the results from construction stage, these are assumed to be values from thin mudstone layers in the sandstone foundation at the dam site. Such mudstone can be jointed and highly permeable.



Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995))

Figure 7.2.10 Point Diagram of Lugeon Value

Table 7.2.16 List of Water Pressure Test (Lugeon type)

Drillhole	stage	Depth		section	Material Type			Lugeon		(break	(max	executed
(no.)	(no.)	(m)	~(m)	(m)	(geology)	(feature)	(weathering)	(original)	(JICA '09)	pressure)	pressure)	(year)
D-1	-	6.90	9.30	2.40	mud stone	weak		5.0		(kgf/cm2)	(kgf/cm2)	1966
D-16	-	4.30	9.30	5.00	mud stone	decomposed		5.0				1966
D-16	-	9.30	14.30	5.00	sand stone, mud stone	jointed		10.0				1966
D-16	-	14.30	19.30	5.00	sand stone, mud stone	jointed		5.0				1966
D-16	-	19.30	24.30	5.00	mud stone	jointed		19.0				1966
D-16	-	24.30	27.30	3.00	sand stone	jointed		6.0				1966
D-28	-	7.50	12.50	5.00	sand stone, mud stone		weathered	20.0				1966
D-28	-	12.50	17.50	5.00	sand stone, mud stone	jointed		12.0				1966
D-28	-	17.50	20.50	3.00	sand stone, mud stone			6.0				1966
D-29-1	-	5.00	10.00	5.00	sand stone		weathered	28.0				1966
D-29-1	-	15.00	21.00	6.00	sand stone		weathered	16.0				1966
D-29-3	-	6.80	11.80	5.00	sand stone		weathered	93.0				1966
D-29-3	-	11.80	16.80	5.00	sand stone		weathered	93.0				1966
D-29-3	-	16.80	20.00	3.20	sand stone	hard		1.0				1966
D-33	-	4.50	9.50	5.00	sand stone		weathered	20.0				1966
D-33	-	15.00	20.50	5.50	sand stone	hard		80.0				1966
D-34	-	10.00	15.00	5.00	sand stone	hard		80.0				1966
D-18	-	9.60	15.00	5.40	sand stone	cracks		9.0				1966
D-25	-	11.60	15.40	3.80	sand stone	jointed		11.0				1966
D-25	-	15.50	20.50	5.00	mud stone	jointed		8.0				1966
D-24	-	6.10	11.00	4.90	mud stone	decomposed		102.0				1966
D-24	-	16.00	20.00	4.00	sand stone	hard		25.0				1966
D-30	-	6.00	11.00	5.00	mud stone	jointed		22.0				1966
D-30	-	11.00	16.00	5.00	mud stone	jointed		20.0				1966
D-30	-	16.00	20.00	4.00	sand stone	jointed		11.0				1966
DX-2	-	11.00	17.00	6.00	sand stone	jointed		47.0				1966
DX-2	-	5.00	10.00	5.00	sand stone	decomposed		20.0				1966
XA1/1	1	8.65	14.20	5.55	sand stone	conglomrate	MW	62.0	25.4	-	2.20	1995
XA1/1	2	14.00	18.50	4.50	sand stone, mud stone	breaken	SW-MW	20.0	33.3	-	2.11	1995
XA1/1	3	19.00	23.60	4.60	mud stone	crack	SW-MW	101.0	24.4	1.81	1.81	1995
XA1/1	4	24.00	29.00	5.00	mud stone		UW-SW	30.0	1.3	2.15	2.65	1995
XA1/2	1	5.00	9.75	4.75	mud stone	core loss	MW	42.0	30.1	-	1.92	1995
XA1/2	2	9.75	15.15	5.40	mud stone		SW	0.4	0.4	-	2.15	1995
XA1/2	3	16.00	20.80	4.80	mud stone	crushed	CW	0.4	0.3	1.67	2.17	1995
XA1/2	4	19.00	25.00	6.00	mud stone		SW	0.1	0.043	-	2.19	1995
XA4/1	1	6.00	11.00	5.00	sand stone	core loss	SW, CW	133.0	104.2	-	2.45	1995
XA4/1	2	10.00	15.00	5.00	sand stone		UW	1.0	0.7	-	2.66	1995
XA4/1	3	15.00	20.00	5.00	sand stone, mud stone	core loss	MW, CW	17.0	5.4	1.48	2.44	1995
XA4/1	4	20.00	25.05	5.05	mud stone	core loss	SW, CW	19.0	10.9	-	2.44	1995
XA4/1	5	25.00	30.00	5.00	mud stone		SW, HW	1.0	1.4	-	2.32	1995
XA4/2	1	6.90	12.15	5.25	sand stone	core loss	MW, CW	47.0	32.7	1.26	1.65	1995
XA4/2	2	12.80	17.30	4.50	sand stone	core loss	MW, CW	3.0	0.3	-	2.34	1995
XA4/2	3	17.00	22.30	5.30	sand stone		SW	62.0	107.4	-	1.33	1995
XA4/2	4	20.00	25.00	5.00	sand stone		SW	28.0	180.0	-	1.00	1995
JCA-1	1	14.50	20.00	5.50	sand stone		UW		61.6	-	3.55	2009
JCD-2	1	10.00	15.00	5.00	sand stone		SW		12.6	-	5.33	2009
JCD-2	2	15.00	20.00	5.00	sand stone		UW		2.2	-	5.48	2009
JCD-2	3	41.00	46.00	5.00	sand stone	core loss	MW		11.2	-	5.09	2009
JCD-2	4	50.00	55.00	5.00	sand stone		UW		10.1	-	5.33	2009

Source: Nam Ngum 1 Hydropower Station Extension Feasibility and Engineering Study (Lahmeyer, 1995)

5) Grouting

At the temporary enclosure, the sandstone layers and the weathered zone of the foundation rock may need to be grouted in order to prevent seepage through the foundation. Therefore, grouting tests should be carried out in the detailed design stage. For reference, the actual results of curtain grouting executed during the construction stage are summarized as follows: The grouting criteria were divided in four zones which were separated by its depth from the cutting line as indicated in Table 7.2.17. Total cement weight injected at each zone in each block is shown in Table 7.2.18, and the typical overall arrangement of grout holes pattern is shown in Figure 7.2.11. The average distance of the holes was about 80 centimeters; the injection pressure was limited within the load pressure of the ground, then the average weight of cement injected was 1 to 2 kg per 1 meter distance of each hole. These are the results for fresh sandstone rock type, therefore the cement weight will be more injected in the weathered zone, and the cement weight will be lighter in the low permeable mudstone strata.

Table 7.2.17 Criterion on Curtain Grouting

Zone	depth		width	max.	limit for determining intermediate hole	
				pressure	total cement	cement / 1m
no.	(m)		(m)	(kgf/cm2)	(kg)	(kg/m)
zone I	0	4	4	1	50	12.5
zone II	4	10	6	2	80	13.3
zone III	10	20	10	4	100	10.0
zone IV	20	30	10	8	150	15.0

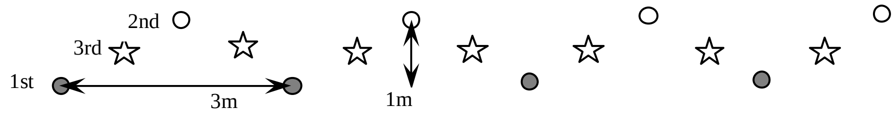
Source: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei,1972-1)

Table 7.2.18 Total Cement Injection on Curtain Grouting

	Blocks															
	Average	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
no. of holes (nos.)	21.8	27	18	21	20	20	23	19	24	29	22	28	13	23	24	19
length of each hole (m)	25.7	-	20	20	20	20	20	30	30	30	30	30	30	30	30	30
block width (m)	15.9	-	15	15	15	15	15	15	15	15	15	15	15	18	15	18
average width between holes(m)	0.78	-	0.83	0.71	0.75	0.75	0.65	0.79	0.63	0.52	0.68	0.54	1.15	0.78	0.63	0.95
average no. of hole in 1m width	1.37	-	1.20	1.40	1.33	1.33	1.53	1.27	1.60	1.93	1.47	1.87	0.87	1.28	1.60	1.06
Cement Weight per	29.2	15.9	17.0	16.2	25.1	20.8	28.3	13.3	2.3	14.1	25.0	4.3	0.7	62.8	54.5	136.6
1 square meter of	19.4	6.8	14.4	10.6	25.8	13.8	21.9	14.5	27.9	25.8	1.8	16.2	3.2	7.1	23.6	35.7
curtain face (kg/m2)	21.1	20.1	44.8	21.8	11.3	17.0	17.0	9.9	12.1	21.3	19.0	26.0	4.6	26.0	25.0	10.7
	46.2	-	-	-	-	-	-	19.2	11.4	18.5	48.5	127.7	9.2	52.0	69.0	10.5
Cement Weight per	1.30	0.59	0.94	0.77	1.26	1.04	1.23	0.70	0.10	0.49	1.14	0.15	0.05	2.73	2.27	7.19
1 meter of hole	0.90	0.25	0.80	0.50	1.29	0.69	0.95	0.76	1.16	0.89	0.08	0.58	0.25	0.31	0.98	1.88
(kg/m)	0.96	0.74	2.49	1.04	0.58	0.85	0.74	0.52	0.30	0.73	0.86	0.93	0.35	1.13	1.04	0.56
	1.90	-	-	-	-	-	-	1.01	0.48	0.64	2.20	4.56	0.71	2.26	2.88	0.55

	Blocks															
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	
no. of holes (nos.)	33	28	27	17	22	20	35	27	18	20	12	19	14	13	18	
length of each hole (m)	30	30	30	30	30	30	30	20	20	20	20	20	20	20	-	
block width (m)	18	18	21	18	18	15	15	15	15	15	15	15	15	15	-	
average width between holes(m)	0.55	0.64	0.78	1.06	0.82	0.75	0.43	0.56	0.83	0.75	1.25	0.79	1.07	1.15	-	Zone
average no. of hole in 1m width	1.83	1.56	1.29	0.94	1.22	1.33	2.33	1.80	1.20	1.33	0.80	1.27	0.93	0.87	-	no.
Cement Weight per	115.8	34.1	108.3	9.0	13.4	5.6	24.6	40.3	2.1	24.6	14.0	15.1	11.3	6.3	13.9	zone I
1 square meter of	13.2	21.9	42.4	87.2	8.3	25.0	7.8	37.3	10.3	9.9	2.1	10.2	11.0	6.2	40.0	zone II
curtain face (kg/m2)	34.0	19.6	28.6	17.8	55.4	13.6	45.3	27.4	19.3	19.8	17.1	6.0	10.2	5.3	7.7	zone III
	29.9	43.0	83.7	82.4	24.6	20.9	88.9	-	-	-	-	-	-	-	-	zone IV
Cement Weight per	3.51	1.22	4.01	0.53	0.61	0.28	0.70	1.49	0.12	1.23	1.17	0.79	0.81	0.48	0.77	zone I
1 meter of hole	0.40	0.78	1.57	5.13	0.38	1.25	0.22	1.38	0.57	0.50	0.18	0.54	0.79	0.48	2.22	zone II
(kg/m)	1.03	0.70	1.06	1.05	2.32	0.68	1.87	1.01	1.07	0.99	1.43	0.32	0.73	0.42	0.43	zone III
	0.91	1.54	3.10	4.85	1.12	1.05	2.54	-	-	-	-	-	-	-	-	zone IV

Source: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei,1972-1)

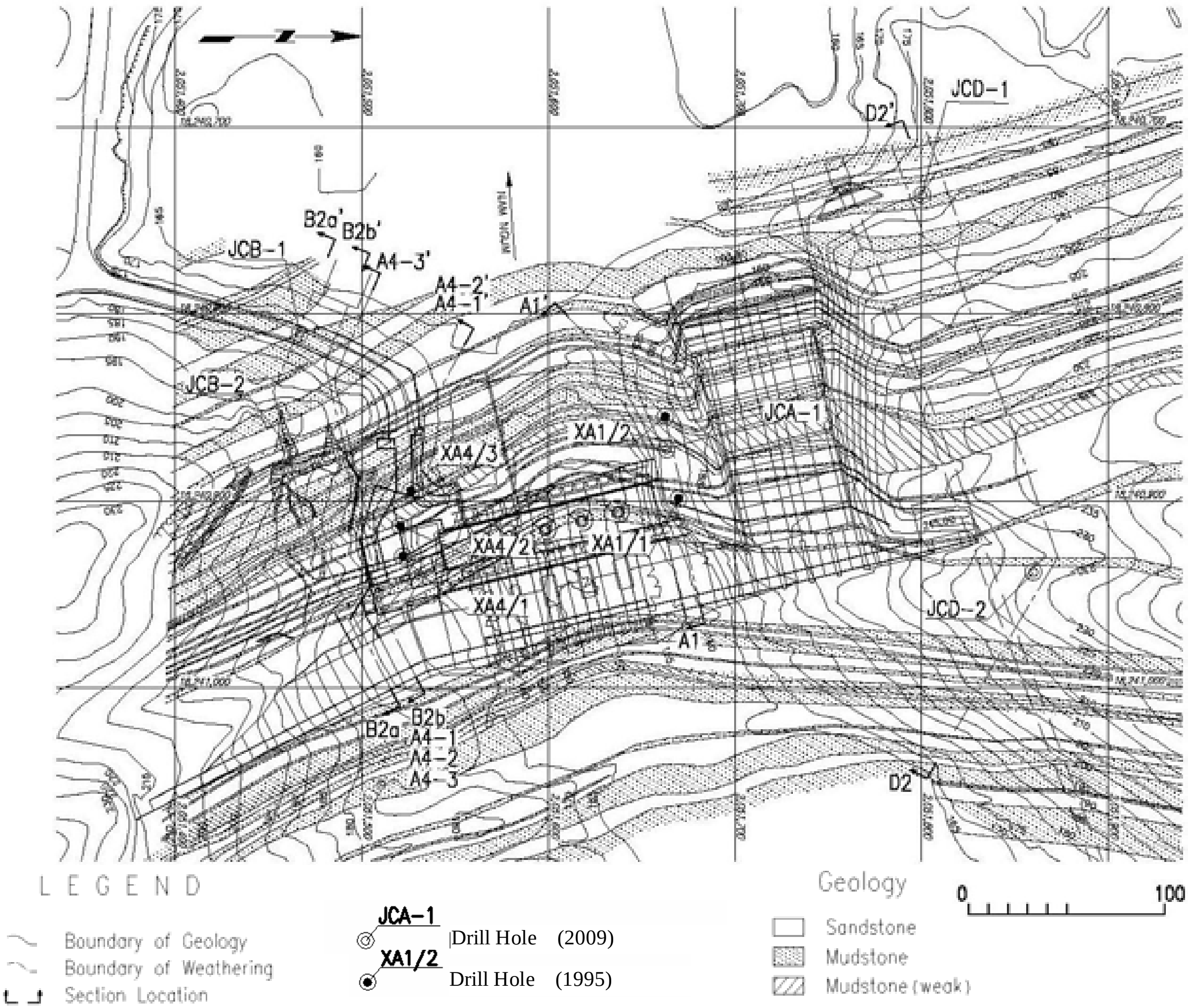


Source: Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei,1972-1)

Figure 7.2.11 Pattern of Grout Hole Arrangements

(5) Engineering Geology of the Alternative Options

The geological plan revised by the JICA Survey Team is shown in Figure 7.2.12. As shown in the plan, there has not been any serious geological characteristic, such as a major fault or large landslide, identified in the project site. Therefore, every alternative option can be regarded as feasible from the geological viewpoint. The rock strata are distributed parallel to the dam axis, so the foundation rock of each alternative option is basically the same. However, the superiority and inferiority for each stratum occurs by the difference of the structure formation and position,. The geological issues which should be paid attention to are summarized in three points, as follows: 1) mudstone is not strong, and it is prone to deteriorate after excavation, 2) sandstone is jointed in the eminent bedding planes, and blocks can slip on the joints easily, and 3) permeability is high in the sandstone strata. Additionally, the concerns caused by the layout of each structure are summarized in five points, as follows: 1) stability of long cutting slope, 2) stability of the tunnel, 3) firmness of the powerhouse foundation rock, 4) water-tightness of the temporary enclosure foundation rock, and 5) stability of existing structures. The geological issues for each option are summarized as indicated in Figure 7.2.13.



Prepared by the JICA Survey Team

Figure 7.2.12 Geological Plan

	Fatal Geology	Long Cut Slope			Mudstone Sections in Basement Rock		Seepage along Sandstone strata	
		existing structure		new structure	new structure		temporal closure	
	fault, landslide	toe of dam	side of spillway	behind power house	tunnel	generator / power house	inlet portal	outlet portal
A1,A2	-	O	O	-	-	O	-	O
A4	-	O	-	-	O	O	-	O
B2	-	-	-	O	O	O	-	O
D2	-	-	-	O	O	O	O	O

"O" indicates the need for countermeasures.

Prepared by the JICA Survey Team

Figure 7.2.13 Geological Issues for Each Alternative Option

1) Optimum Option (A1 Option)

The new powerhouse is situated between the existing powerhouse and the spillway. The existing tail bay is shared by the new unit. The space for the new powerhouse is so narrow that steep cut slopes are required to reach the foundation rock. Further, the temporary enclosure in the tail bay is required to prevent the restriction of generation during the construction. The longitudinal profile of the waterway alignment is shown in Figure 7.2.14.

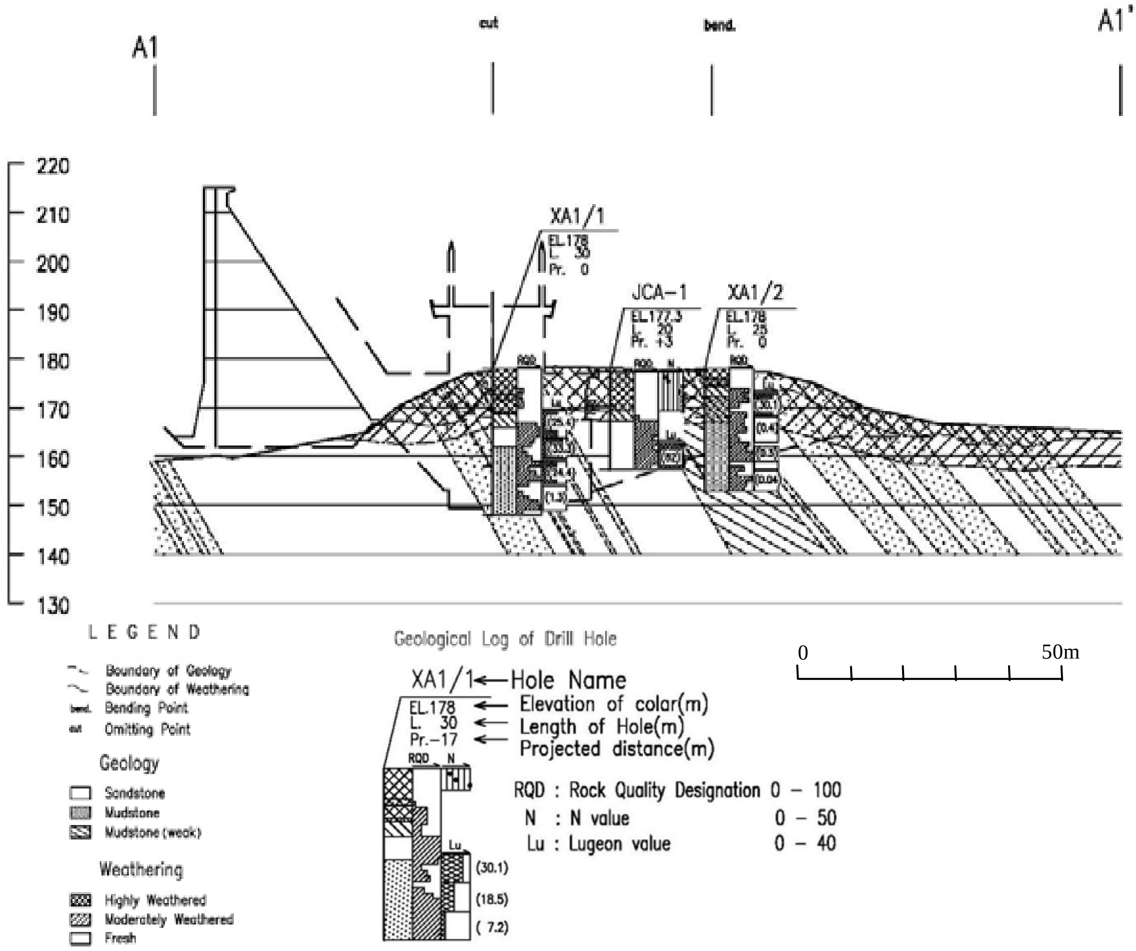


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Figure 7.2.14 Geological Profile (A1)

It is necessary to consider the influence of cutting out the basement rock very near to the spillway and the dam. As the cut slope at the spillway faces perpendicularly to the strike of the bedding plane, the slope will be basically stable, but the slope will be so long that surface protection is necessary and the reinforcement for the foundation rock should be considered if necessary. On the other hand, the cut slope at the dam faces almost parallel to the bedding planes of dam foundation sandstone. Therefore, some bedding joints may cause the slope failure as indicated in Figure 7.2.15. The estimated dip of the bedding plane is about 55 degrees, but additional drilling investigation is necessary to confirm the failure type and plan suitable countermeasures. Some mudstone layers are distributed at the foundation of the new powerhouse, the immediate facing protection to the mudstone part is necessary to prevent deterioration of the mudstone. As the basement rock of the tail bay consists mainly of mudstone, its permeability will relatively be low. However, there are some permeable sandstone layers in mudstone, hence, the grouting at the sandstone parts may be necessary to prevent the seepage under the temporal closure.

(a) Sliding Failure (b) Buckling Failure, Toppling Failure

Figure 7.2.15 Slope Failure Types

2) Other Options

Other geological matters shown in the Figure 7.2.13 include the following: In the B2 and D2 options, the powerhouse is located downstream of the tail bay and the long cut slope will appear behind the new powerhouse. The slope is almost parallel to the bedding planes, although there is no existing construction or any load acting on the slope. Therefore, the probable slope failure will be type (a) in Figure 7.2.15. In the A4, B2 and D2 options, there is a water tunnel. As described in the Final Report on Nam Ngum Hydroelectric Project, 1st Stage (Nippon Koei, 1972-1), the mudstone sections will need countermeasures to stabilize the walls and prevent the deterioration. Particularly for the tunnel of the A4 option in the weathered zone therefore, much supports will be required for all sections. In the D2 option, the temporary enclosure is also located in the inlet portal. The basement rock consists dominantly of permeable sandstone, thus grouting at the sandstone parts may be necessary. The longitudinal profile of the waterway alignment is shown in Figure 7.2.16 to Figure 7.2.18.

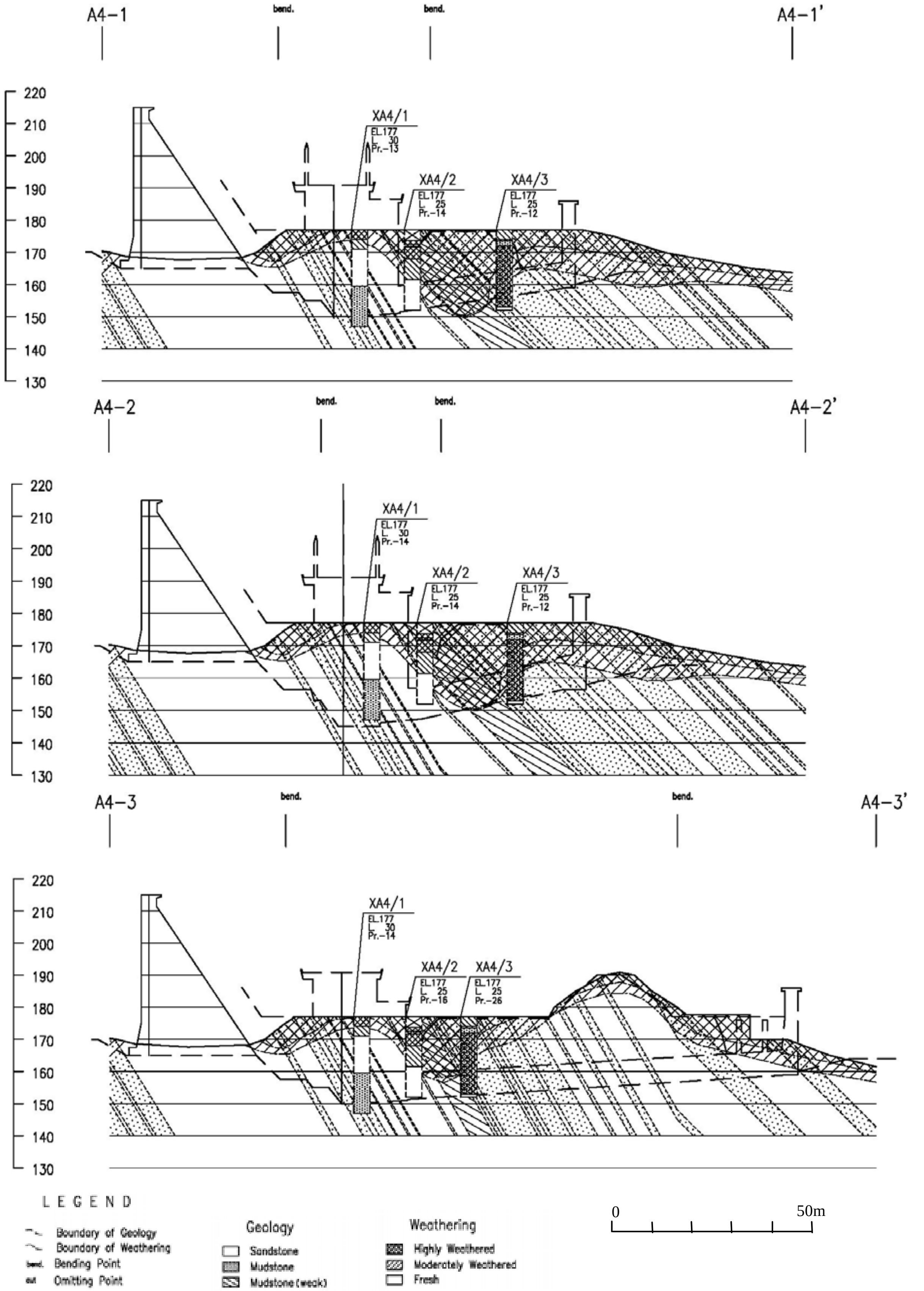

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Figure 7.2.16 Geological Profile (A4)

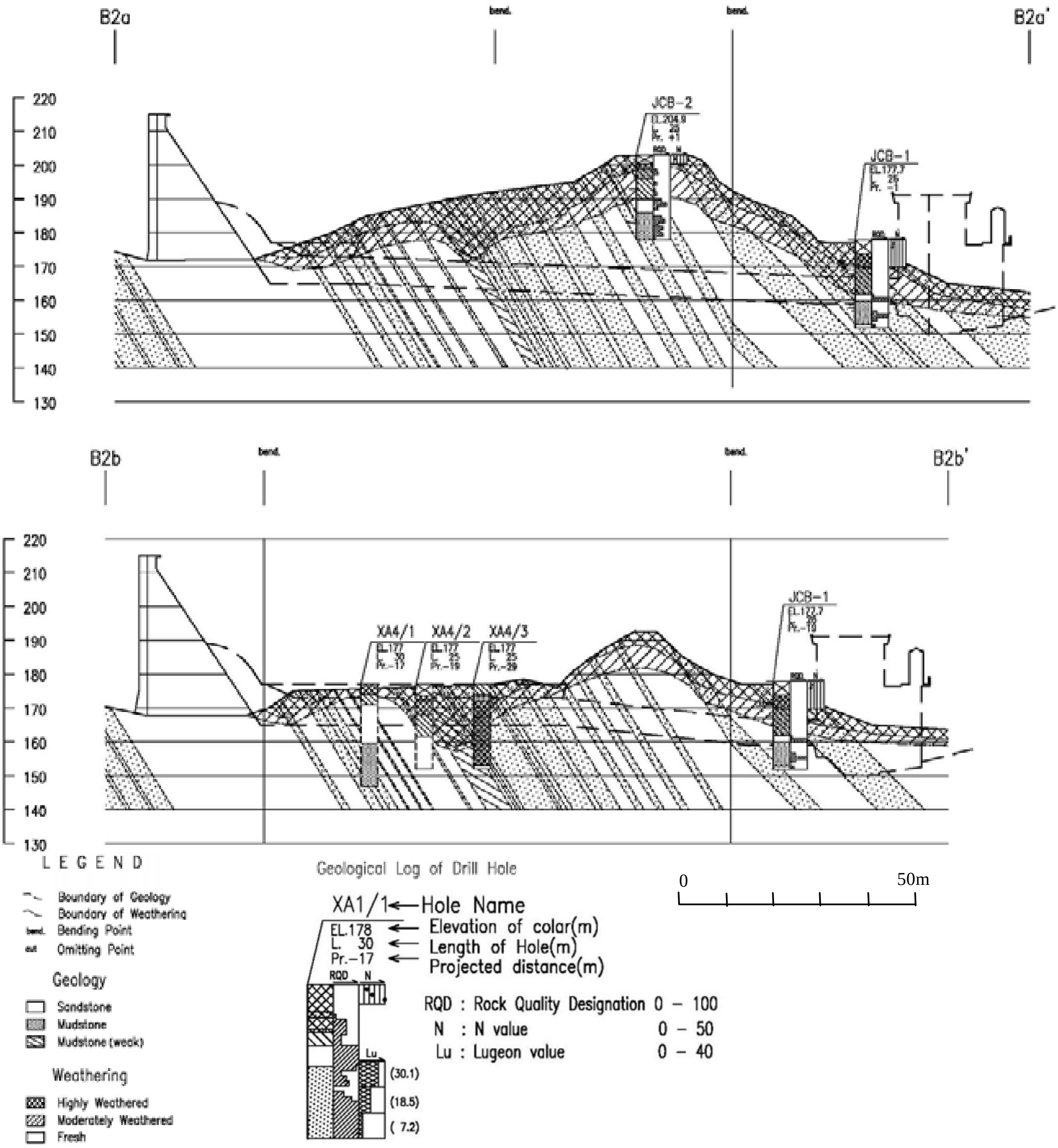

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Figure 7.2.17 Geological Profile (B2)

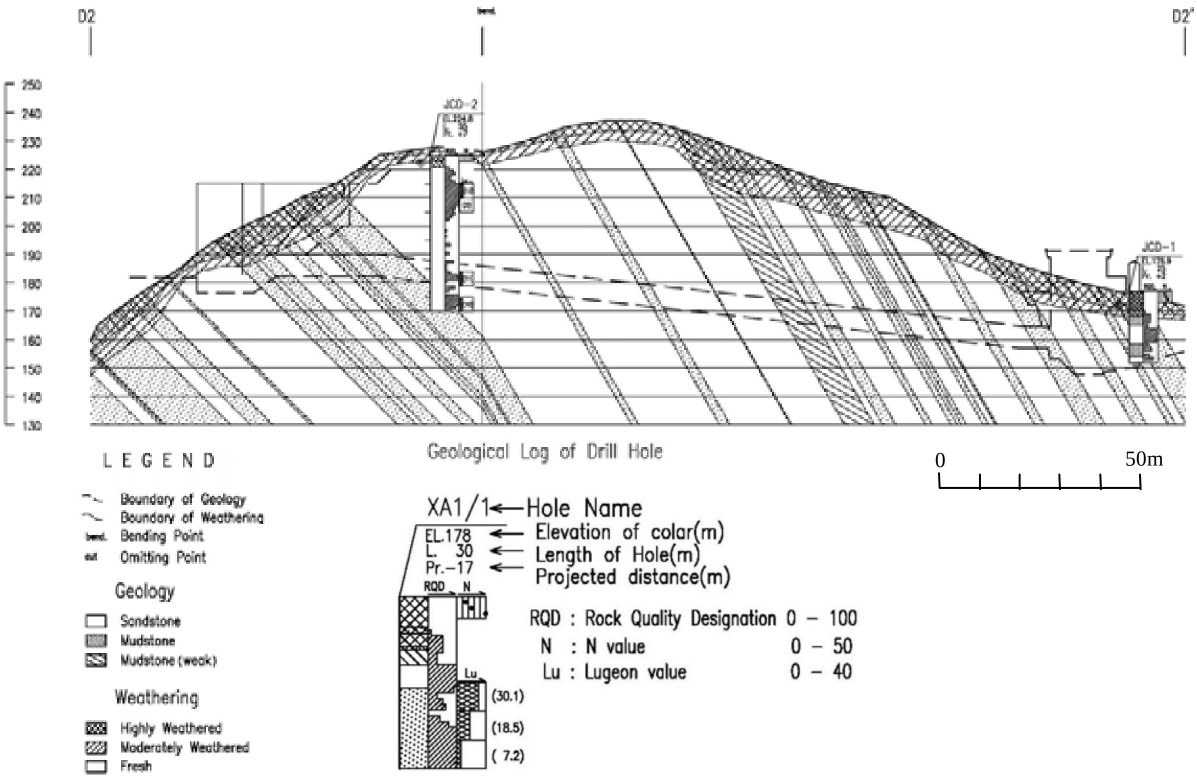

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Figure 7.2.18 Geological Profile (D2)

(6) Construction Materials

As for the concrete aggregates, the most promising prospect is alluvium from the Nam Lik River, as this was likewise used for the existing powerhouse (Nippon Koei, 1972-1). The results of alkali reactivity tests indicate that the materials would be suitable as concrete aggregates (Lahmeyer, 1995). The location of the alluvium is three to four kilometers upstream of the Nam Ngum confluence. A company named "VATSANA PONGPANYA ABORBROCK BEACH COMPANY" runs the quarrying there.

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