Appendix E

Geology and Seismicity

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1 GENERAL

This section presents a preliminary overview of geological conditions of the project area, and thereby gives a geotechnical evaluation of the proposed dam project, on the basis of the existing geological investigation reports as well as reconnaissance and interpretation of topographic features.

The reports and geological maps cited hereinafter are as follows:

- National Atlas, including geological map of Vietnam (1:2,500,000), Tectonic Map (1:2,500,000), Engineering Geology (1:4,000,000), and Geomorphology (1:2,500,000), the General Department of Land Administration, Hanoi, 1996.
- Geography of Vietnam, Nguyen Trong Dieu, the Gioi Publisher, 1995,
- Geological Investigation Reports (No. 123C-02-T1), Hydraulic Engineering Consultants Corporation, January 2000.
- Ta Trach Reservoir Thua Thien Hue Province Feasibility Study, Main Report (No.123C-6-T1), Hydraulic Engineering Consultants Corporation, May 2000.

2 GENERAL GEOLOGY OF THE HUONG RIVER BASIN

2.1 Geomorphological Setting

The Huong river basin can be geomorphologically divided into 3 types of landforms, that is, middle-low mountains, hills and plains from southwest to northeast. The middle-low mountains are characterized by the Northern Truong Son Range that stretches northwest with an altitude of 800 to 1200 meters. The hilly area consists of gentle slopes and plateaus and has an altitude of 10 to 50 meters. The plain area is between 0 and 5 meters in height and mostly below 1.5 meters.

The Huong River, the biggest one of Thua Thien Province, north central Vietnam, has a drainage area of about 3,000 square meters covering half of the provincial area. The river originates from the Northern Truong Son Mountains and flows into the East Sea northeastward. It has 3 tributaries, namely, Ta Trach, Huu and Bo rivers. These valleys are extremely broad and gentle both laterally and longitudinally in the hilly and plateau areas, and become steep and narrow in the mountain area.

The channels of the Huong river and its branches, showing a lattice pattern, are presumably controlled by geological structures.

2.2 Regional Geology

The stratigraphy of the Huong River Basin, as shown in the table below, begins with the Cambrian to early Ordovician. These rocks and those of the Ordovician to Silurian metamorphics of sedimentary origin, compose the bedrocks of the basin area. The early to middle Devonian, consisting mainly of conglomerate, sandstone and shale, is of limited occurrence. The Quaternary is represented by marine and alluvial sediments that unconformably overlie the older formations.

Geology and Stratigraphy of the Huong River Basin

Age	Formation	Symbol and Features	
Quanternary		Q	Alluvial and marine deposits of gravel, sand and silty clay, mostly 5.0 to 20.0 meters thick and up to about 40 meters in some places.
Devonian	Tam Lam	D_{1-2}	Upper sub-formation, about 500 meters thick, is composed mainly of conglomerate, sandstone and siltstone, and intercalated with thin quartzitic sandstone and shale bed.
		D_1	Lower sub-formation, 600 to 700 meters thick, consists of conglomerate, sandstone and siltstone.
Ordovician to Silurian	Long Dai	O-S	The formation consists of conglomerate and sandstone and contains an intercalated thin siltstone and shale bed
Cambrian to Ordovician		ε-O_1	The formation consists of quartz-sericitic schist, fine-grained sandstone, and quartz-feldspar shale.

Source: Modified from Geological Reports done by HEC-1, April 2000.

Furthermore, two groups of magmatic intrusions in these sedimentary rocks occurred - one, middle Paleozoic complex, consisting of granite and granodiorite, was scattered as dyke or vein; the other, early Mesozoic complex, composed of granite, biotite granite, gabrodiorite, granodiorite and diorite, was formed as rock sheet.

2.3 Geological Structure

The Huong river basin is situated in the northeastern part of the Truong Son tectonic belt and belongs to the Viet-Lao folded system in geological zonation. The basin area is folded and faulted. In the downstream of the Huong river, lies a fold zone developed in the formations of late Cambrian to middle Devonian age with an axis of northeast-southwest strike. Several large seismic faults, such as Truong Son Fault (I -1), Dakrong - Hue Fault (II -2), Nam O - Nam Dong Fault (II -3), are distributed around the basin, far from the proposed damsite. Of these faults, especially the northwest-southeast trending fault appears to contribute to the occurrence and distribution of these river valleys.

3 GEOLOGY OF TA TRACH RESERVOIR AREA

3.1 Topographical Feature

The Ta Trach damsite is located on the Ta Trach river, a branch of the Huong river, about 20 km from Hue city. It is to impound a 15-km stretch of the Ta Trach river. The reservoir is surrounded by low mountains and hills ranging in altitude from 80 to 500 meters. The river terraces and alluvial plains are developed in its upstream area. The Ta Trach river forms V-shaped and U-shaped valleys respectively in mountainous and hilly areas. The river channel at damsite is about 1000 meters wide and both slopes are 15 to 25 degrees.

3.2 Geology

The reservoir area is underlain mainly by metasedimentary rocks (sericitic schist, sandstone, shale, etc.) of Ordovician to early Silurian age. The formations strike nearly northsouth and dip 50 to 70 degrees west or northwest. At the river valley the bedrock is mainly shale and its strike crosses obliquely the dam axis.

The Quaternary deposits, 0.5 to 5.0 meters thick, consisting of gravel, sand and silty clay of alluvial and residual origins, are developed on the mountainous and hilly slopes of the metamorphosed sedimentary rocks. The riverbed deposit at the damsite, 15 to 20 meters thick, is subdivided, in terms of sedimentary processes and their composition, into the following 7 layers:

- 1b) Medium to fine-grained sandy clay, greenish to brownish gray, soft, originated from the flood plain alluvial and distributed locally in the river terrace with thickness of 0.5 to 1.0 meters.
- 1a) Rounded cobble, gravel and sand mixtures, yellowish to brownish gray. The layer contains 40 to 60% gravels ranging in size from 5 to 30 mm and about 30 to 40% medium to coarse sand and, is distributed mainly in the river terrace.
- 2c) Sandy clay with little light clay, light gray to brown, soft, 0.5 to 0.7 m thick, scattered on the top of the Ⅰ- grade river terrace in the river bank.
- 2b) Mean to heavy loam, yellowish brown to yellowish gray, soft to firm, 6 to 10 meters thick, originated from river alluvial.
- 2a) Rounded cobble, gravel and sand with light loam, yellowish gray with a little light loam, 0.5 to 2 m thick. Cobble and gravel of sandstone and granite, ranging in size from 5 to 10 mm, accounts for 60 to 80%.

Coarse sand and light loam amounts to 20 to 40 %

- 3b) Gravelly clay of deluvial origin, gray to reddish brown, soft, 1 to 3 m thick, distributed mostly at the slope of the reservoir area.
- 3a) Deluvial deposits consisting of light loam and breccia, reddish brown, soft to firm. Distributed mostly at the slope and slope toe.

Moreover, geological investigation showed that shallow intrusive bodies of granite cut the metasedimentary rocks at river valley. The emplacement of granite enhanced the jointing and weathering of the rocks, hence leading probably to relatively high water leakage from the dam foundation.

3.3 Geological Structure

Three faults in the project area were shown in the geological map (1:2,500,000) and hereinafter designated by F1 through F3. The fault F1 (Huong river fault), nearly parallel to the Ta Trach river, starts from the Nam Dong and stretches to the sea northwestwards on the left side of the Ta Trach river. The fault F2 (Rao Trang - Phu Loc fault) crosses the Ta Trach river at about 4 km upstream of the damsite. The fault F3 (Khe Tre - Khe La Ma fault), with an approximately eastwest trend, about 15 km from the damsite, runs across the Nam Dong area in the upstream of the damsite.

Lineaments representing possible faults have been identified through aerial photographic and topographical interpretation. However, micro-topography related to active fault, such as gap and differentiate settlement of terrace and fan surfaces, fresh steep cliff and terminal facet, is obscure or invisible both on aerial photographs and in field reconnaissance. Also, no evidence has been found from fault and earthquake records to indicate that the three faults are active. The three faults are thus considered ancient and inactive, causing no particular difficulty for dam construction.

However, especially the fault F1 is nearest to the proposed damsite, further investigation such as test trench is necessary to observe if the fault F1 cut into the Quaternary deposits.

4 ENGINEERING GEOLOGY

4.1 Rock Mass Classification

The foundation rock, consisting mainly of shale and sandstone, is classified, in terms of the degree of weathering, hardness and joint distribution, into three weathering zones at drilled depth, namely, strongly weathered, moderately weathered and slightly weathered zones. In strongly weathered zone (V), specially the shale is softened by weathering and cracking, and partly weathered into sandy soil. The moderately weathered rock (VI), partially discolored to dark gray, is hard and cannot be broken by hand. In the slightly weathered zone (Ⅲ), however, only joints and cracks are slightly oxidated, the rock remains the original dark color.

The following table gives the rock classification of the Ta Trach dam foundation. The Standard of Rock Classification in Japan is presented in Table E.1.

Ta Trach Dam	Japanese Standard	Thickness (m)
I – II	A – B	–
Ⅲ	C_H	–
VI	C_M	2 - 10
V	D – C_L	5 - 20

4.2 Engineering Properties

ⅰ) Strength properties

Because of no laboratory test and insitu test data available, the strength properties of the foundation rock was estimated from the experienced relation of rock classification and its engineering properties as shown in the table below.

On the basis of the experienced estimation, the rock of the moderately weathered zone, corresponding to the C_M grade rock, has compressive strength of 40,000 to 20,000 kN/m^2 and therefore, is sufficient for the foundation of 50 –60 m high concrete gravity type dam.

Rock classification and rock parameters

Rock Grade	qu (kN/m^2)	Es (kN/m^2)	Ed (kN/m^2)	C (kN/m^2)
A - B	Over 80,000	Over 8,000,000	Over 5,000,000	Over 4,000
C_H	80,000-40,000	8,000,000-4,000,000	5,000,000-2,000,000	4,000-2,000
C_M	40,000-20,000	4,000,000-1,500,000	2,000,000-500,000	2,000-1,000
D - C_L	Below 20,000	Below 1,500,000	Below 500,000	Below 1,000

Source: Rock classification and its application, K. Yoshinaka, et al., Japanese Society of Civil Engineering, 1989.
qu = Uniaxial compressive strength, Es = Modulus of elasticity, Ed = Modulus of deformation, c = Cohesion, 1 kgf/cm^2 = 100 kN/m^2.

ⅱ) Permeability

Permeability tests were carried out in the foundation rock by constant head method (CHP) and by single pneumatic packer method (SPP). CHP tests were undertaken mainly in the strongly weathered zone (V) and SPP tests in the moderately and slightly weathered zone (III and IV). The test results are summarized in the following tables.

Permeability test results in zone V (Total 29 Nos)

K (cm/sec)	Numbers	Percentage (%)
1.06×10^{-3} - 1.40×10^{-3}	2	6.9
1.08×10^{-4} - 8.02×10^{-4}	10	34.5
1.03×10^{-5} - 8.30×10^{-5}	17	58.6

Single Pneumatic Packer Test in zones IV and III (Total 29 Nos)

Lugeon Value	Numbers	Percentage (%)
0 - 5	19	65.6
5 - 10	3	10.3
10 - 20	3	10.3
20 - 30	1	3.5
>30	3	10.3

The above results show that the permeability in the strongly weathered zone (V) is in the range of 1.08×10^{-4}cm/sec to 8.30×10^{-5} cm/sec (>90%). The strongly weathered zone is thus considered moderately permeable rock.

On the other hand, the permeability of the zones III and IV is generally less than 10 Lugeon (75%), of which 65% of the test results gives values less than 5 Lugeon. The zones have low permeability.

4.3 Distribution of Landslide Around Reservoir Area

As stated before, the reservoir area is underlain by hard shale and sandstone, which are considerably resistant to the process of weathering, erosion and slide. Therefore, on the reservoir slope no landslides have occurred except some shallow collapses with volume of less than 500 m^3. These small collapses are distributed mainly in residual soils of shale and sandstone, especially in the upper slope with less vegetation.

These shallow collapses are small both in size and in number, and therefore, have less impact on the reservoir project. Moreover, these collapses are mainly associated with heavy rainfall events due presumably to the occurrence of porewater pressure between the residual soil and the underlying bedrocks. Forestation work is thus considered more suitable for stabilization of these potential and unstable slopes both by preventing filtration from rainfall and by fastening subsurface soil with a root system.

5 GEOLOGICAL EVALUATION AT THE PLANNED PROJECT

The proposed Ta Trach dam, a multi-purposes dam, is designed to mitigate flood disaster, to supply water for irrigation, domestic and industrial use, and to generate electric power. The outline of the dam proposed in the feasibility study is summarized as follows:

- Dam type: Mixed earth and rockfill dam
- Dam height: 55 m
- Dam crest elevation: 55 m
- Dam crest length: 1,112 m
- Full supply level: 45.0 m
- Spillway type: Overflow spillway with gate
- Spillway crest elevation: 35 m
- Spillway width: 60 m
- Length of Spillway slope: 123 m

5.1 Selection of Dam Type

Earthfill dam has been proposed by Hydraulic Engineering Consultants Corporation (HEC-1) during the pre-feasibility study and feasibility study stages of the project. The proposal is possible and appropriate technically and economically. In construction, however, the earthfill dam seems to be less reliable and less safe in handling floods during construction. Therefore, concrete facing rockfill dam (CFRD) and concrete gravity type dam, such as roller compacted concrete (RCC) dam are considered as alternative plan.

As described above, the bedrock of the damsite is classified into four weathering zones. Zones I to IV will be appropriate for the foundation of 50 to 60 meters high RCC dam. The rock layer of Zone V is considered unsuitable for the RCC dam foundation because:

- The zone V, which is formed by strongly weathered rocks, has insufficient shear strength.

Accordingly, in case of RCC dam, the excavation depth of the foundation will be about 35 meters or more in depth up to zone IV for the RCC dam foundation.

In case of rockfill dam, the strongly weathered rock (zone V) can be used as a dam foundation. Excavation of the overlying river alluvium only will be thus necessary in general. Moreover, the river valley, U shape of about 1000 meters wide, sustains good efficiency for embankment work. A careful study on dam type in consideration of the merits and demerits of each dam type is considered necessary, although the Study has difficulty to examine and determine the dam type at this stage.

5.2 Selection of Damsite

The damsite is selected mainly in consideration of the following conditions and factors.

- Two ranges of flat mountains and hills at an elevation of 80 to 500 meters nearly parallel with the course of the Ta Trach river. At the proposed damsite these ranges lessen the river width to about 1,000 meters, while the valley floor upstream widens as much as 3000 meters. Accordingly, the proposed damsite will result in the effective storage capacity of reservoir.
- Geology of the reservoir area is very similar, and therefore, the geological condition has little or no effect on the selection of damsite.
- The proposed damsite provides a great convenience of layout of appurtenant structures and an easy access for construction.

5.3 Excavation Depth and Line

The alluvium in the riverbed generally ranges in thickness from 10.0 to 15.0 meters with the maximum of 20.0 meters, while in both banks, it is 0.5 to 5.0 meters thick.

The strongly weathered rock (zone V), estimated to have compressive strength of about 20,000 kN/m^2, will be appropriate as the foundation of the earthfill dam. Accordingly, the excavation depth of the dam foundation will be 0.5 to 5.0 meters in depth from the ground surface at both abutments and 15.0 to 20.0 meters from the riverbed at the river valley up to the top surface of zone V. In the upper part of the zone V, these rocks, which are completely weathered into gravelly or sandy soils, should be removed in the impervious core zone.

5.4 Foundation Treatment

The rocks of the dam foundation are Paleozoic sandstone and shale, with granitic intrusions. Granitic rocks provide a better foundation than the shale, and the major portion of the dam is on the jointed shale, which has permeability of 1.08×10^{-4}cm/sec to 8.30×10^{-5} cm/sec. Therefore, curtain grouting below the impervious core of the earthfill dam is proposed to improve the permeability of the dam foundation. The depth of curtain grouting shall be determined according to dam height or passing time of waterhead.

Careful attention shall be paid to the distribution of the discontinuities between the metamorphic rocks and granitic rocks during construction; these discontinuities should be tightly backfilled with stone blocks and concrete.

Consequently, the following foundation treatment will be required for the purpose of reducing leakage through the foundation rocks and hardening the foundation rocks for the Ta Trach dam.

- Curtain grouting
    - Two rows at 1 m interval, hole spacing of 2 m on each row
    - Hole arrangement to be made at zigzag
    - 30 meters in depth for the section of dam height more than 30 meters, and 20 meters for the section of dam height of 10 to 30 meters.
- Consolidation grouting

  The whole area of the foundation rock for the impervious core zone and the filter zone at about 5 m in depth.
- Concrete replacement, if necessary

  Discontinuities or weak zones between metamorphic rocks and granitic rocks.

5.5 Spillway

The proposed spillway is located at the saddle of the right bank ridge with crest elevation of EL.35.0 m, and will cater to the design flood of 11,400 m^3/sec flown into a reservoir.

According to the draft design, the moderately weathered rocks (zone IV) will be used for the spillway foundation. The rocks of zone IV, having compressive strength of 20,000 to 30,000 kN/m^2, are sufficient for the spillway foundation. However, the consolidation grouting should be carried out for the spillway foundation.

5.6 Inlet Sluice and Diversion Structures

In the feasibility study, two inlet sluice structures (6×8 m in diameter) were proposed to discharge flood during construction and to supply water into hydropower plant after completion of the project. The proposal seems unsafe in view of the unusual flood and the construction plan.

Therefore, diversion tunnels in the left bank are proposed as an alternative diversion structure. Although further geological investigation is necessary, the preliminary investigation shows that the thin ridge of the left bank formed along monoclinal structure has benefit to the layout of the tunnels because:

- The proposed tunnel axis intersects the rock strata with large angle, this provides a favourable situation for the stability of the tunnel;
- The rock strata at upstream portals dip into the mountain and the overlying loose deposits are very thin. The outlet portal slopes of the tunnels are thus stable during excavation.

However, because of the monoclinic structure to catch water, during the tunnel excavation seepage from jointed shale layers may be encountered especially at their contact with underlying sandstone layers. Dewatering measures are needed.

5.7 Others

ⅰ) Water leakage due to fracture zones

Three faults (F1, F2, and F3) run across the reservoir area with fracture zone, of 20 to 50 thick. Field reconnaissance shows that these fracture zones are tightly filled with impervious materials. The possibility of water leakage to the adjacent catchment through these fracture zones is considered very low or less even if the reservoir is impounded. However, geological investigation or insitu tests related to the permeability and continuity of these fracture zones should be carried out at the detailed design stage.

ⅱ) Dam foundation (Left abutment)

The left abutment will be placed on the steep opposite-dip slope covered by alluvial deposit of 2 to 5 meters thick. Although no rock outcrop is found to observe the stability and joint condition of rock slope, small unstable rock mass due to creep may be usually confronted. Unstable rocks shall all be removed from the dam foundation.

6 CONSTRUCTION MATERIAL

The Ta Trach dam is planned as an earthfill dam in the feasibility study, and the construction materials required for the project are given in the table below.

Required quantity of main construction materials (m^3)

Item	Earthfill dam	Spillway	Auxiliary dam	others	Total
1. Earth material	9,417,820	349,000	1,037,030	571,380	11,375,230
2. Sand and gravel filter	242,440	1,250	17,910	1,050	262,650
3. Riprap	219,500		38,210	420	258,130

According to this, several quarry sites and borrow areas have been initially investigated within the range of 5 km upstream the damsite. The quantities and engineering properties of various kinds of natural construction materials investigated will be outlined as follows:

6.1 Earth Material

Boring investigation and laboratory tests show that two types of earth materials can be used as earth material for the dam embankment, namely, river terraces alluvial (2b) and (3b). The two layers are both distributed mostly within 0.5 km to 3 km from the damsite. The reserves of the layers 2b and 3b are estimated to be $7,247 \times 10^6$ m^3 and $9,347 \times 10^6$ m^3 , respectively. Table E.2 summarizes the laboratory test results of the materials from the two layers.

As shown in Table E.2, the materials of layer 2b can be classified as Silty CLAY (CM) by the Unified Soil Classification System of ASTM. The permeability coefficient of the layer 2b is in range of 10^{-5} to 10^{-6} cm/s, indicating that the layer 2b is suitable for impervious core materials for the earthfill dam. Moreover, on the basis of one dimensional consolidation test results, total settlement of the dam embankment is roughly estimated to be a maximum of 5 % of the dam height (50 to 60 m high), and more than 80% of the total settlement will occur during the construction period.

The layer 3b has the same index properties as those of the layer 2b. Similarly, the layer is considered suitable for the fill material of the earthfill dam.

6.2 Sand and Gravel filter

A sand and gravel filter needs to be provided between the impervious core zone and the shell zone. In the river valley near the damsite, underlies the river gravel layer that mainly consists of course sand, gravel, pebble and cobble of granite and sandstone. The gravel layer, having an exploitable volume of about 400,000 m^3, is considered suitable for the filter materials. The index properties of the layer are given in the table below.

Index properties of the river gravel layer

Component	Gs	BD	D60	D10	Cu	Proportion
Sand	2.67-2.68	13.1-13.7	0.4-0.6	0.2-0.3	2	20-30 %
Gravel	2.60-2.65	15.6-16.0				70-80 %
Mixture	2.65	18.0-19.0	30-48	0.6-1.0	48-50	

Note: Gs = Specific gravity, BD = Bulk density (kN/m3), Cu = Coefficient of uniformity, D60 = Grain diameter (in mm) corresponding to 60% passing by mass and, D10 = Grain diameter (in mm) corresponding to 100% passing by mass.

6.3 Rock Material

Geological investigation shows that the riverbed gravel (Layer 1) and river terrace gravel (Layer 2a, refer to Section B Geology of Ta Trach reservoir area) can be used as riprap, toe rock and concrete aggregate materials. These layers are, however, of limited quantity and among these layers, gravel and boulder (grain size bigger than 4,75 mm) make up only 30 to 60%.

An alternative quarry site of granitic rocks is being considered in this study, which is located at the Tuan intersection, about 18 km far from the proposed damsite. The granitic rocks, having an exploitable volume of about 1,000,000 m^3, are slightly weathered and jointed with a compressive strength of 50 to 80 Mpa. The rock quarry site is thus considered, in terms of exploitable quantity and strength, to basically satisfy the design requirements. However, the crusher test of the rock should be carried out at the detailed design stage.

7 SEISMICITY

7.1 Characteristics of Earthquake Activity

The Ta Trach reservoir is located at the central Vietnam that is seismically stable and characterized by occurrence of less and smaller earthquakes. Moreover, no major faults attributed presumably to earthquake are reported in the Ta Trach reservoir and its surrounding areas.

The following table gives the list of earthquakes occurred in the Ta Trach reservoir and its surrounding areas, within the latitude of 15°00' - 17°20' and the longitude of 106°-109°, from 1666 through 1992. The earthquake records were obtained mainly from the International Seismological Center (ISC), Berkshire UK and Vietnamese Seismological Stations.

List of earthquakes at the Ta Trach reservoir and its surrounding areas

No.	Year	Lat.	Long.	Depth (km)	M	I	Location
1	1666	17.05	107.05	15	4.1	5	Ho xa
2	1685	16.50	106.60	15	4.1	5	Ta xing
3	1715	15.53	108.15	15	4.7	5	Tan an
4	1821	17.63	106.35	17	6.0	8	Dong hoi
5	1829	16.48	107.41	15	4.8	6	Hue
6	1919	15.00	109.00	33	4	-	North Lyson island
7	1947	16.55	107.43	10	4	-	Hue
8	1947	16.09	108.09	15	4.8	6	Da Nang
9	1954	16.09	108.09	15	3.0	-	Da Nang
10	1966	16.94	107.07	15	3.8	5	Gio linh
11	1966	16.22	108.27	15	2.7	-	Son tra
12	1968	17.30	105.50	15	5.0	6	Trung lao
13	1992	15.68	108.87	15	3.8	-	Dung quat

Note: Lat. = Latitude, Long. = Longitude, M = Magnitude in Richter scale, I = Intensity.

Around the Ta Trach reservoir area, the earthquake recorded first occurred in 1666 at Gio Linh, 115 km away from Ho Xa. The earthquake had a seismic intensity of 5 and magnitude of 4.1 in Richter scale. In 1829, a destructive earthquake with seismic intensity of 6 and magnitude of 4.8 in Richter scale occurred in Hue City and caused considerable damage to the old Hue Castle. During more than 100 years since that, only 2 small earthquakes occurred at Hue and Da Nang areas. These recorded earthquake events showed that the project area has low susceptibility to earthquake but probably suffers seismic influence.

7.2 Estimation of Probable Maximum Acceleration

The probable maximum acceleration in the return period of 100 and 200 years was evaluated in this study on the basis of the earthquake record (13 records / 326 years) of the years from 1666 to 1992 for the area within a distance of about 200 km from the Ta Trach damsite.

The formulas used in this study are as follows.

$MMI = 8.0 + 1.5\ M - 2.5\ Ln(d^2 + h^2 + 400)^{0.5}$	Cornell
$a = 2000\ e^{0.8M} / (d^2 + h^2 + 400)$	Cornell
$Log\ a = MMI / 3 - 0.5$	Richter
$a = 5000\ e^{0.8M} / (r + 40)^2$	Estava

Where,

MMI: Modified Mercalli Intensity

M: Magnitude of earthquake in Richter Scale

d: Distance from epicenter to the damsite in km

h: Depth of focus in km

r: Distance from focus to the damsite in km

a: Maximum acceleration in gal or cm/sec^2

e: The exponential constant

The maximum acceleration (a) and the maximum intensity (MMI) at the damsite for each earthquake are estimated by the formulas of Cornell and Estava for comparison. The estimated results are summarized in the table below.

Estimated maximum acceleration (a) and maximum intensity (MMI) at the damsite for each earthquake

No.	Year	Lat.	Long.	Depth (km)	M	Dist. (km)	Cornell		Richter	Estava
							MMI	a (gal)	a (gal)	a (gal)
1	1666	17.05	107.05	15	4.1	105	2.4	4.56	2.07	6.23
2	1685	16.50	106.60	15	4.1	118	2.2	3.65	1.67	5.26
3	1715	15.53	108.15	15	4.7	104	3.4	7.51	4.20	10.20
4	1821	17.63	106.35	17	6.0	205	3.7	5.69	5.30	10.06
5	1829	16.48	107.41	15	4.8	32	5.9	56.43	30.02	40.98
6	1919	15.00	109.00	33	4.0	210	0.6	1.08	0.50	1.92
7	1947	16.55	107.43	10	4.0	35	4.7	28.44	11.51	2.01
8	1947	16.09	108.09	15	4.8	35	4.9	25.49	14.09	24.72
9	1954	16.09	108.09	15	3.0	55	2.2	6.04	1.77	5.86
10	1966	16.94	107.07	15	3.8	94	2.3	4.42	1.79	5.72
11	1966	16.22	108.27	15	2.7	70	1.3	3.14	0.84	3.48
12	1968	17.30	105.50	15	5.0	262	1.6	1.58	1.05	2.98
13	1992	15.68	108.87	15	3.8	153	1.1	1.74	0.73	2.78

Note: 1 gal = 10^{-2} m/s^2 = 0.001 g

The study was made for two cases as follows.

Case 1: the return period of 100 years by Cornell formula

Case 2: the return period of 200 years by Cornell formula

The estimation of the maximum intensity and the maximum acceleration at the damsite for each earthquake is made according to Cornell formula as mentioned above.

The probable maximum intensity at the damsite is estimated from recorded numbers of earthquakes exceeding given intensities, according to Gutemberg linear relation between the intensity and the logarithm of the frequency of earthquakes exceeding it. The probable maximum acceleration at the damsite is then estimated from the probable maximum intensity at the damsite by Richter formula presented above.

The annual frequencies for earthquakes exceeding intensities of each grade are plotted on logarithm - normal graphs as shown in Figure E.1 for Case 1 and Figure E.2 for Case 2, to obtain the linear relations between the intensity exceeded and the logarithm of the frequency. The probable maximum intensity and acceleration at the damsite for the return period of 100 and 200 years are also given in Figure E.1 (Case 1) and Figure E.2 (Case 2), respectively.

The estimated probable maximum acceleration at the damsite for the return period of 100 and 200 years are summarized as follows:

100 years	200 years
0.01 g	0.04 g

Accordingly, the estimated probable maximum acceleration at the damsite is in a range of 0.01g to 0.04g for the return period of 100 and 200 years.

7.3 Determination of Design Seismic Coefficient

i) Estimation

The following table presents a determination of seismic coefficient in connection with dam type and seismic intensity in Japan.

A determination of seismic coefficient in Japan

Seismic Zoning	Dam Foundation	Type of Dam			
		Concrete gravity	Concrete arch	Zone fill	Homogeneous fill
Strong	Rock	0.12 – 0.15	0.24 – 0.30	0.15	0.15 – 0.18
	Soil			0.18	0.20
Moderate	Rock	0.12	0.24	0.12 – 0.15	0.15
	Soil			0.15 – 0.18	0.18 – 0.20
Weak	Rock	0.10 – 0.12	0.20 – 0.24	**0.10 – 0.12**	0.12
	Soil			0.15	0.18

Source: Rock or soil: Type of foundation, Ministry of Construction, Japan, 1997

The Ta Trach reservoir area, which is seismologically stable, is considered to correspond to the weak zone of Japan. From the table above, the design seismic coefficient of the Ta Trach dam is estimated to be 0.10 to 0.12.

According to the seismic hazard analysis of the Global Seismic Hazard Assessment Program (GSHAP) made by ISC, the center Vietnam belongs to Low zone. The peak ground acceleration for the return period of 475 years on the zone of GSHAP is estimated to be as follows:

Low zone: Less than 0.8 m/s^2 (0.08g)

The Ta Trach dam is located in the Low zone. Therefore, the design seismic coefficient of the damsite will be 0.08g.

ii) Determination of design seismic coefficient at the Ta Trach reservoir project

The estimated design seismic coefficient for the Ta Trach damsite in this study is summarized as follows:

Cornell's formula (Cases 2)	0.01 - 0.04g
A standard in Japan	0.10 - 0.12g
GSHAP (ISC)	0.08g

Accordingly, the design seismic coefficient will be probably in the range of 0.04 - 0.12 for the Ta Trach dam. The estimated values are mostly less than 0.10.

The general region of the Ta Trach dam is a low seismic area and in the 100-year record available no great earthquakes have been experienced within 50 km of the damsite. For the preliminary designs of the dam, it is, therefore, recommended to use the seismic coefficients in the range of 0.08 to 0.10. The values correspond to a seismic intensity of 5 to 7.5 on the Richter scale, and are regarded as sufficiently conservative in view of the historic record of earthquake and geological conditions in the area as well as the planned design specification.

Table E.1 Rock Mass Classification

Term	Grade	Description
Fresh rock.	A-B	Fresh rock.
Slightly weathered rock.	CH	The rock mass is relatively solid. The rock forming minerals and grains undergo weathering except for quartz. The cohesion of joints and cracks is slightly decreased and rock blocks are separated by strong hammer blow along joints. Clay minerals adhere to the separation surface. Sound by hammer blow is a little dim.
Moderately weathered rock	CM	The rock mass is somewhat softened by weathering, except for quartz. The cohesion of joints and cracks is somewhat decreased and rock blocks are separated by ordinary hammer blow along the joints. Clay materials remain on the separation surface. Sound by hammer blow is somewhat dim.
Highly weathered rock	CL	The rock mass is soft. The rock forming minerals and grains are softened by weathering. The cohesion of Joints and cracks is decreased and rock blocks are separated by soft hammer blow along the joints. Clay materials remain on the separation surface. Sound by hammer blow is dim.
Completely weathered rock	DH	Can be broken by hand. It is easy to break by hammer. Biotite turning to golden colour, and brown in the periphery. Particles are hard, forming small, sand-like pieces. Apparent spacing of cracks becomes wider.
Decomposed rock (Residual soil)	DM	Breaking by hand, it becomes sand-like remaining crystal of quartz and potassium feldspar. Mica loses its crystal form and plagioclase is mostly deteriorated. Apparent spacing of cracks becomes even wider.
	DL	Breaking my hand, mostly becomes powder, except for party sand form. Most feldspar is deteriorated and becomes clayey soil. Original joint planes become indistinguishable.

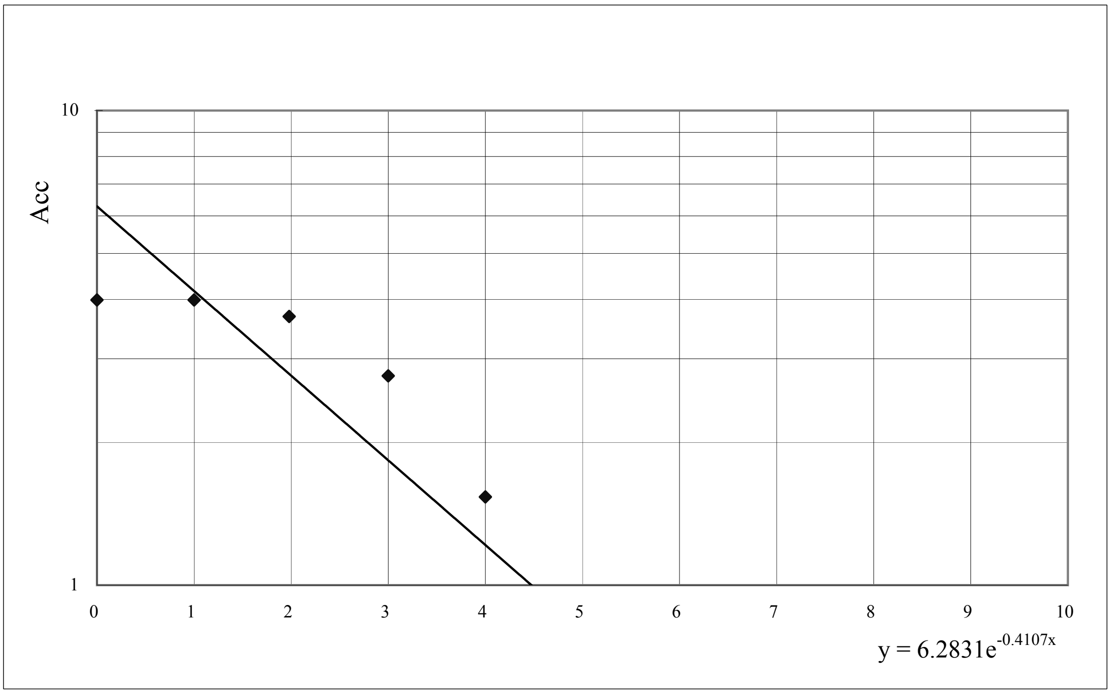
Source: Japanese Standard by Central Research Institute of Electric Power Industry.

Table E.2 Summary of laboratory test results on earth materials of the proposed borrow areas

Borehole No.	Layer	Gs	BD	DD	MC	Gradation				Atterberg Limit			Remolding condition				Parameters after remolding				Remarks
						Clay	Silt	Sand	Gravel	LL	PL	LI	BDR	MBDR	Wr	Wop	c	ϕ	Mv	K	
			kN/m^3	kN/m^3	%	%	%	%	%	%	%	%	kN/m^3	kN/m^3	%	%	kN/m^2	degree	$10^{-4}m^2/kN$	$10^{-5}cm/s$	
VD-Ⅰ	2b	2.67	18.30	15.50	18.45	21	27	49	3	34.5	17.5	17.0	17.0	17.8	16.0	15.5	24.0	16.0	0.9	0.1	
	3b	2.74	17.40	14.10	23.10					38.3	20.0	18.3	18.5	16.8	15.0	19.2	20.0	18.0	1.5	5.0	
VD-Ⅱ	2b	2.71	18.70	15.20	23.86					40.6	23.5	17.1	16.5	16.3	19.0	21.6	25.0	15.0	1.6	1.0	
	3b	2.77	18.90	15.70	21.05					40.2	25.3	14.9	18.5	17.1	15.0	19.3	20.0	18.0	1.7	5.0	
VD-Ⅲ	2b	2.70								41.0	24.7	16.3	16.0		21.0		25.0	15.0	2.0	0.1	
VD-Ⅳ	2b	2.69	16.60	13.70	20.70					31.8	19.6	12.2	16.5		17.0		20.0	18.0	1.6	1.0	
VD-Ⅴ	2b	2.69								27.5	16.3	11.2	17.0		17.0		20.0	16.0	2.2	1.0	
VD-Ⅵ	2b	2.79	17.50	14.60	20.00					37.7	20.0	17.7	16.3	16.7	18.0	19.0	30.0	15.0	1.2	0.1	
	3b	2.69	18.50	15.50	19.00					30.0	16.0	14.0	17.4	19.0	17.0	11.0	30.0	20.0	0.8	0.1	
VD-Ⅶ	3b	2.79	18.90	15.30	24.08					42.2	27.2	15.0	18.5	16.3	15.0	22.3	20.0	20.0	1.6	5.0	
VDP-Ⅱ	3b	2.69								28.5	14.5	14.0	17.4		15.0		20.0	18.0	1.5	1.0	

Note: GS=Specific gravity, BD=Bulk density, DD=Dry density, MC=Moisture Content, LL=Liquid Limit, PL=Plastic Limit, PI=Plasticity Index, BDR=Bulk density afer remolded, MBDR=Maximum bulk density after remolded, Wr=Water content after remoulded, Wop=Optipum water content, c=Cohesive soil, ϕ=internal friction angle, Mv=Coefficient of volume compressibility, K=Permeability coefficient.

$1kgf/m^3=10N/m^3$, $1kgf/cm^2=100kN/m^2$, $1cm^2/kg=0.01m^2/kN$.



Estimation of Maximum Acceleration by Cornell (Case 1)

Intensity MMI	Frequency in 326 years	Frequency in 100 years	Cumulative number for 100yrs N
0	0	0.00	3.99
1	1	0.31	3.99
2	3	0.92	3.68
3	4	1.23	2.76
4	2	0.61	1.53
5	2	0.61	0.92
6	1	0.31	0.31
7			
8			
9			
	13.00	3.99	17.18

For 100 years

Log(N) = -0.1784 (MMI) + 0.7982

Expected Maximum Intensity for 100 years (Log(N)=1)

MMI = 4.47

Maximum Acceleration in a Return Period of 100 years

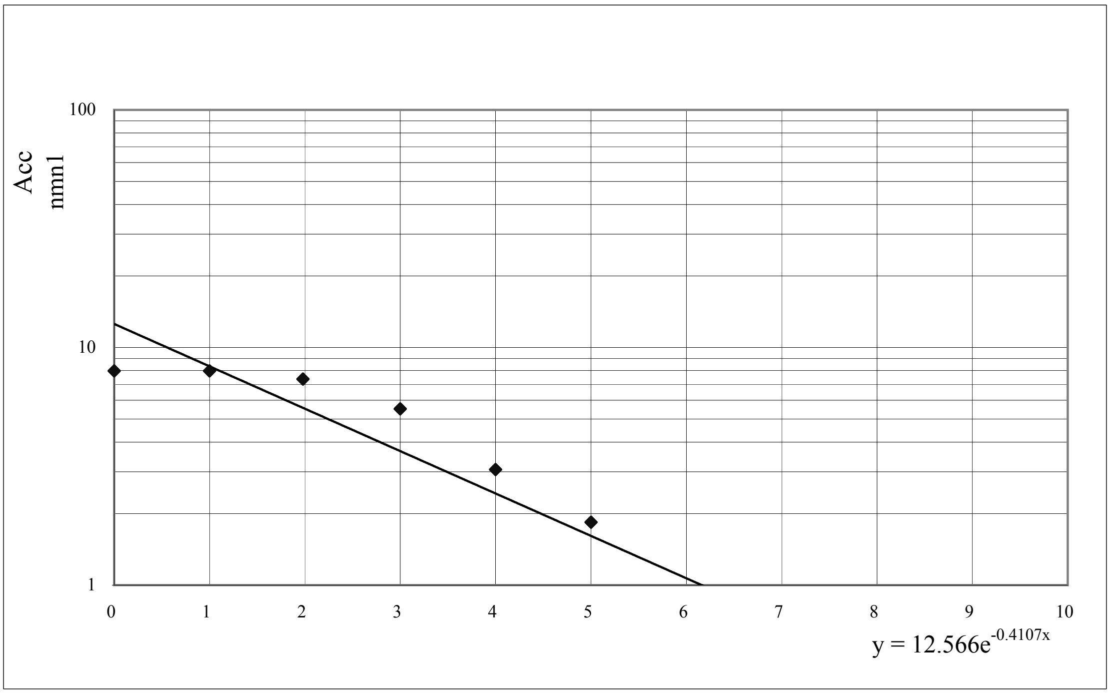
Log(a) = MMI/3 - 0.5 (Richter)

a = 10 gal

= **0.01** g

MMI : Modified Mercalli Intensity, estimated according to Cornell.
a: Estimated Maximum Acceleration at the Site.

Figure E.1 **Relation between Accumulated Frequency and Intensity of Earthquakes, Cornell: for 100 years (Case 1), Ta Trach Dam**



Estimation of Maximum Acceleration by Cornell (Case 2)

Intensity MMI	Frequency in 326 years	Frequency in 200 years	Cumulative number for 200yrs N
0	0	0.00	7.98
1	1	0.61	7.98
2	3	1.84	7.36
3	4	2.45	5.52
4	2	1.23	3.07
5	2	1.23	1.84
6	1	0.61	0.61
7			
8			
9			
	13.00	7.98	34.36

For 100 years

Log(N) = -0.1784 (MMI) + 1.0992

Expected Maximum Intensity for 100 years (Log(N)=1)

MMI = 6.16

Maximum Acceleration in a Return Period of 100 years

Log(a) = MMI/3 - 0.5 (Richter)

a = 36 gal

= **0.04** g

MMI : Modified Mercalli Intensity, estimated according to Cornell.

a: Estimated Maximum Acceleration at the Site.

Figure E.2 Relation between Accumulated Frequency and Intensity of Earthquakes, Cornell: for 200 years (Case 2), Ta Trach Dam