GOVERNMENT OF THE REPUBLIC OF THE PHILIPPINES

REPORT ON STUDY

OF

CALIRAYA DAM REHABILITATION PROJECT

SEPTEMBER 1986

JAPAN INTERNATIONAL COOPERATION AGENCY

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Preface

It is with great pleasure that I present this Study Report on the Caliraya Dam Rehabilitation Project to the Government of the Republic of the Philippines.

This report embodies the result of a field survey which was carried out in the Caliraya Dam area, from October 8, 1985 to July 31, 1986 by a survey team sent to the Philippines by the Japan International Cooperation Agency following the request of the Government of the Philippines.

The survey team, headed by Mr. Yutaka Matsui, The New Japan Engineering Consultants, Inc. held a series of close discussions with the officials concerned of the Government of the Philippines and conducted a wide scope of field survey.

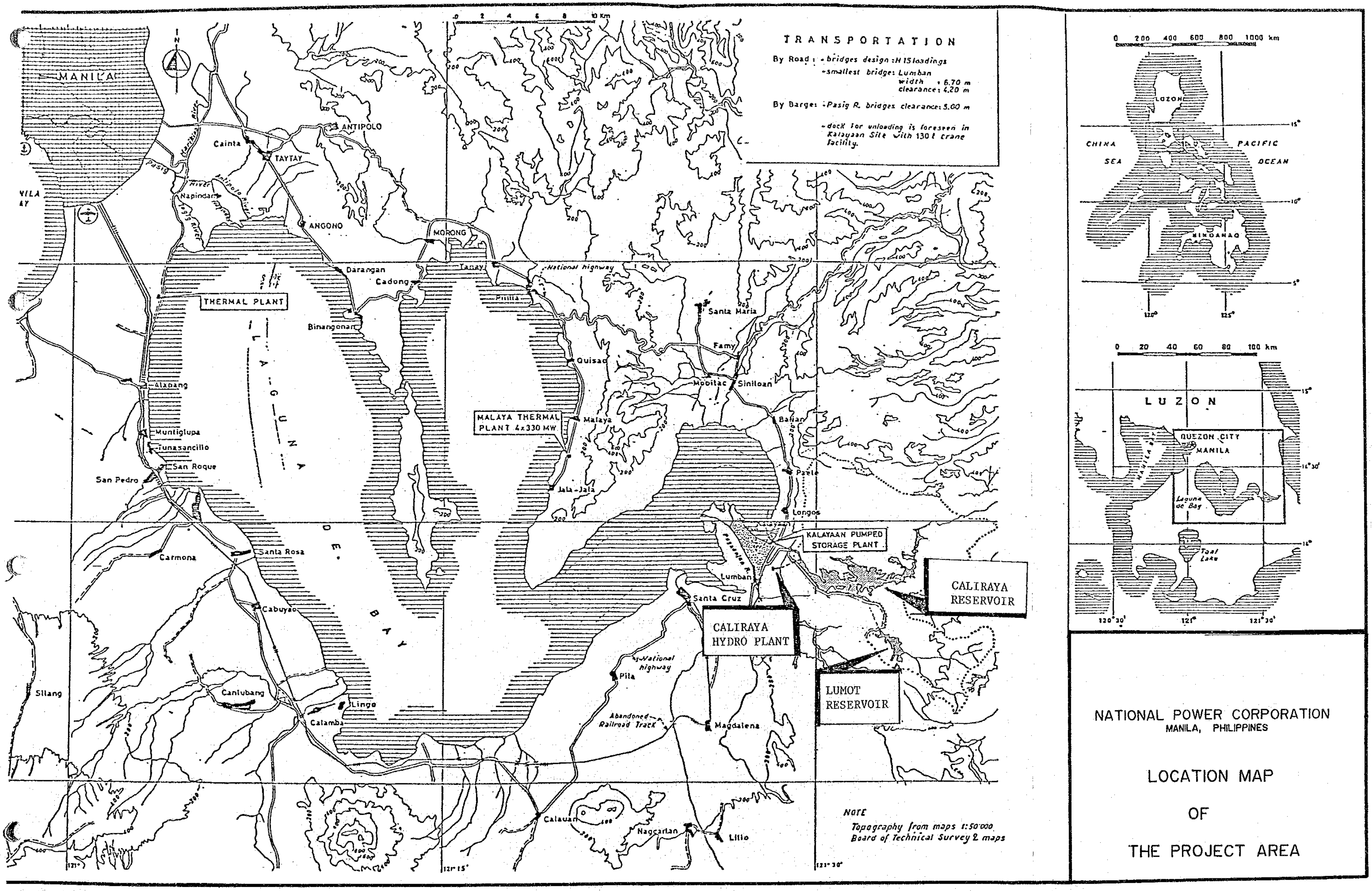
After the team returned to Japan, further studies were made and the present report has been completed.

I hope that this report will be useful as a basic reference for the project and contribute to the promotion of friendly relations between our two countries.

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

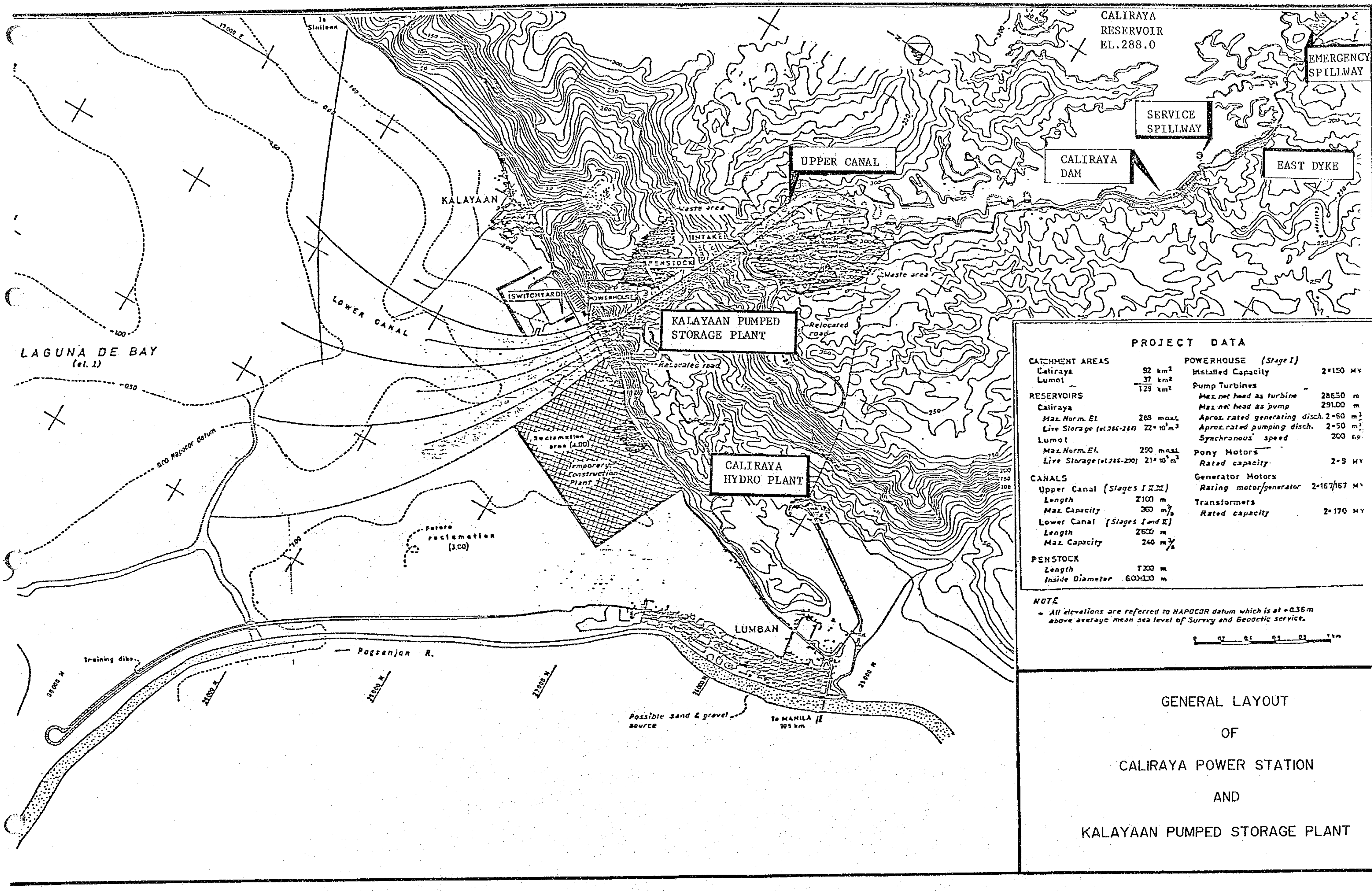
September, 1986

Keisuke Arita
President
Japan International Cooperation Agency



NATIONAL POWER CORPORATION
MANILA, PHILIPPINES

LOCATION MAP
OF
THE PROJECT AREA



PROJECT DATA

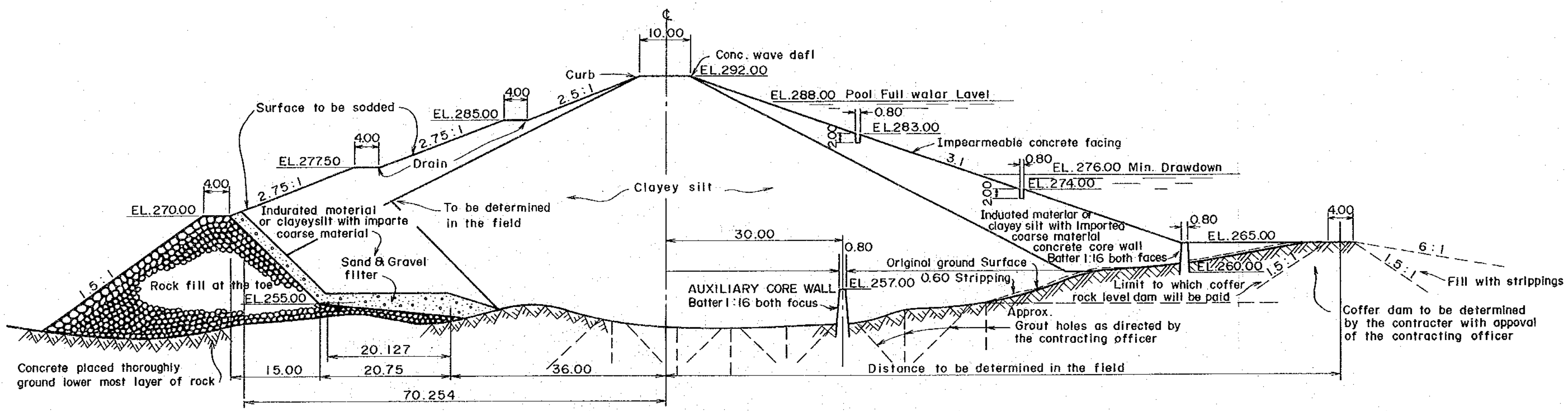
CATCHMENT AREAS	
Caliraya	92 km²
Lumot	37 km²
	129 km²
RESERVOIRS	
Caliraya	
Max. Norm. EL	288 m.a.s.l.
Live Storage (el. 286-288)	22 × 10⁶ m³
Lumot	
Max. Norm. EL	290 m.a.s.l.
Live Storage (el. 286-290)	21 × 10⁶ m³
CANALS	
Upper Canal *(Stages I II III)*	
Length	2100 m
Max. Capacity	360 m³/s
Lower Canal *(Stages I and II)*	
Length	2600 m
Max. Capacity	240 m³/s
PENSTOCK	
Length	1300 m
Inside Diameter	6.00-3.30 m
POWERHOUSE *(Stage I)*	
Installed Capacity	2×150 MW
Pump Turbines	
Max. net head as turbine	286.50 m
Max. net head as pump	291.00 m
Aprox. rated generating disch.	2×60 m³/s
Aprox. rated pumping disch.	2×50 m³/s
Synchronous speed	300 r.p.m.
Pony Motors	
Rated capacity	2×9 MW
Generator Motors	
Rating motor/generator	2×167/167 MW
Transformers	
Rated capacity	2×170 MW

NOTE

- *All elevations are referred to NAPOCOR datum which is at +0.36 m above average mean sea level of Survey and Geodetic service.*

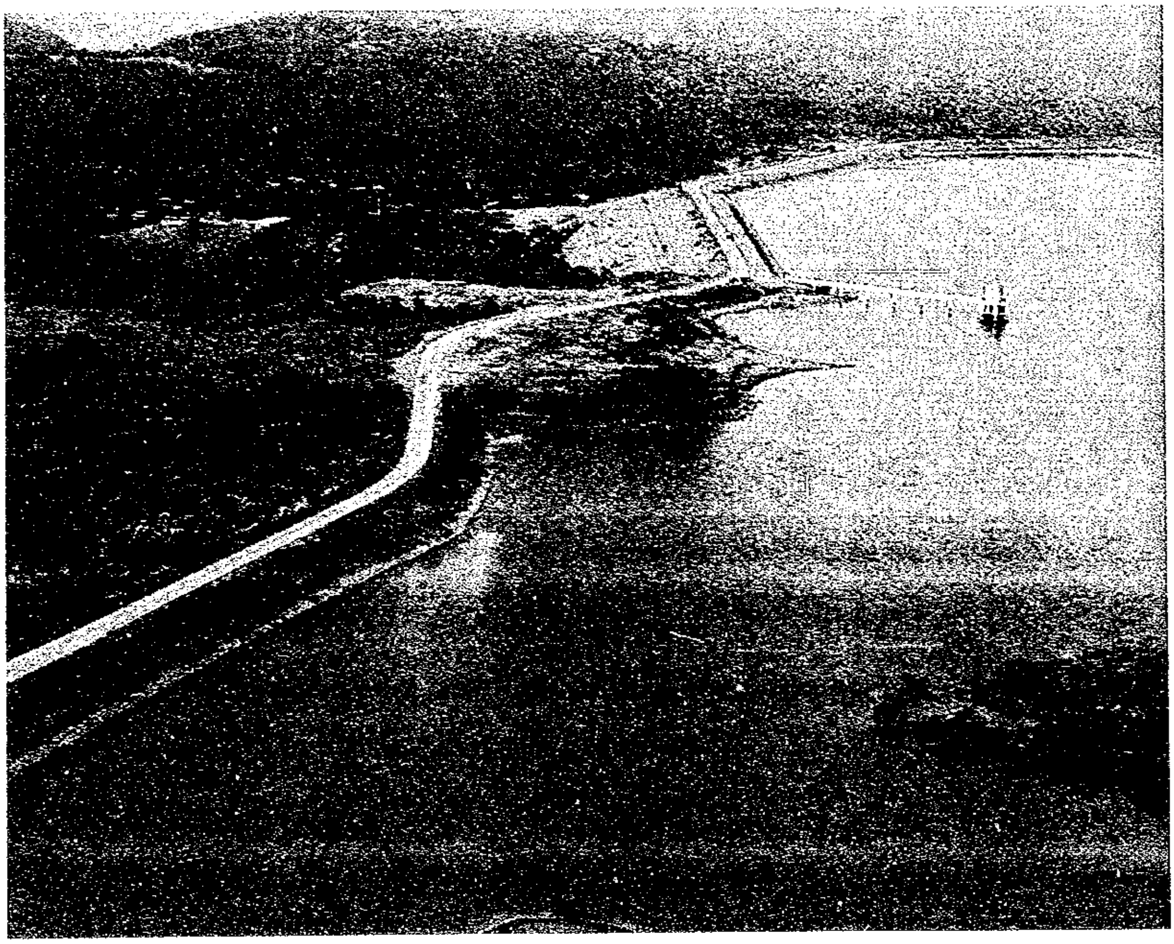
GENERAL LAYOUT OF CALIRAYA POWER STATION AND KALAYAAN PUMPED STORAGE PLANT

TYPICAL SECTION OF CALIRAYA DAM



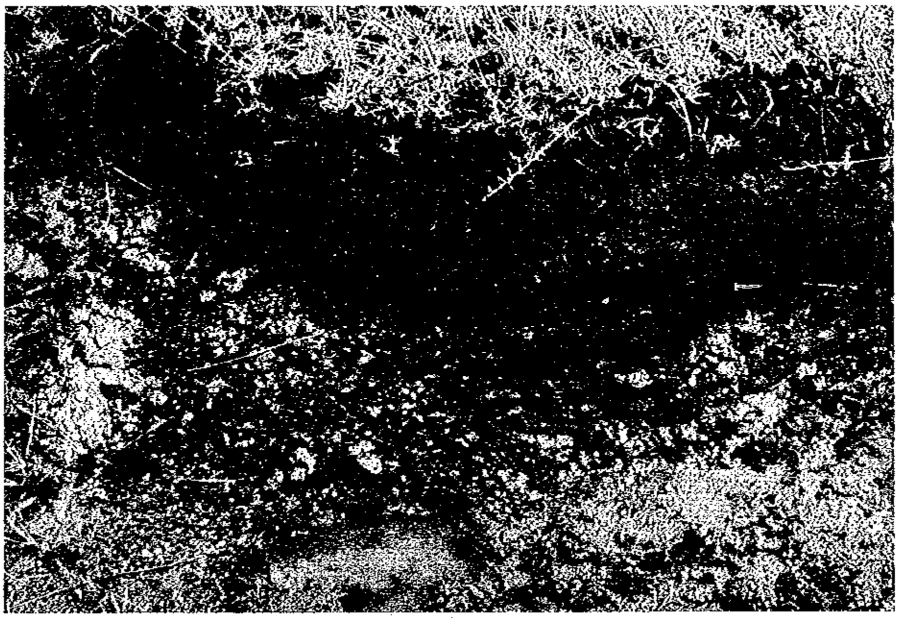
SECTION, STA 0+380

TYPICAL FROM STA 0+375 TO STA 0+390



Aerial photograph of Caliraya dam site

Surface erosion at downstream slope

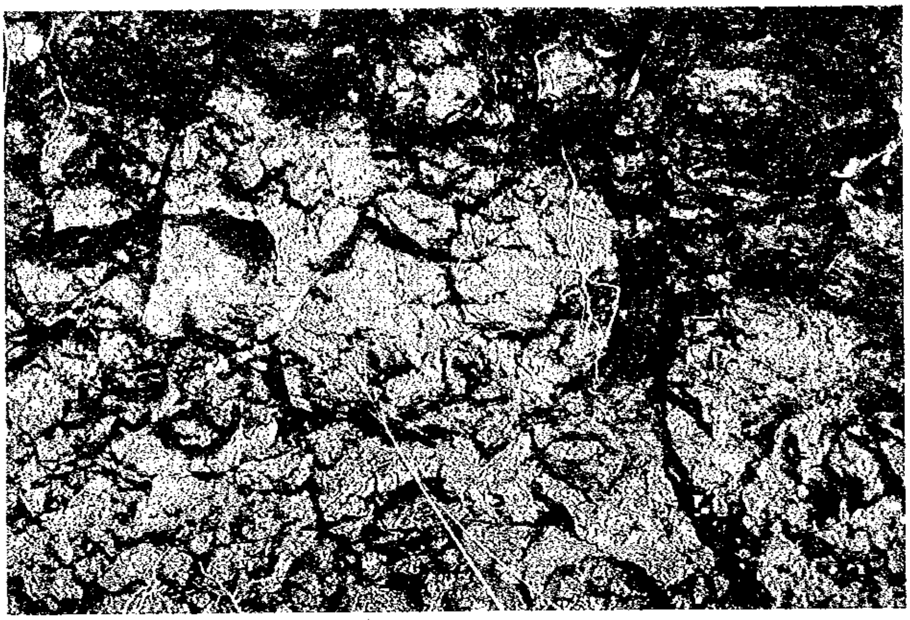


Top soil and dam embankment fill

Cracks developed at both materials show different looks.
Muddy portion (lower of photo) is water pools dug by carabaos.

Downstream slope and wandering animals

Surface damaged by carabaos



Exposed surface of embankment fill on the downstream slope
(changed into small pieces by shrinkage cracks)

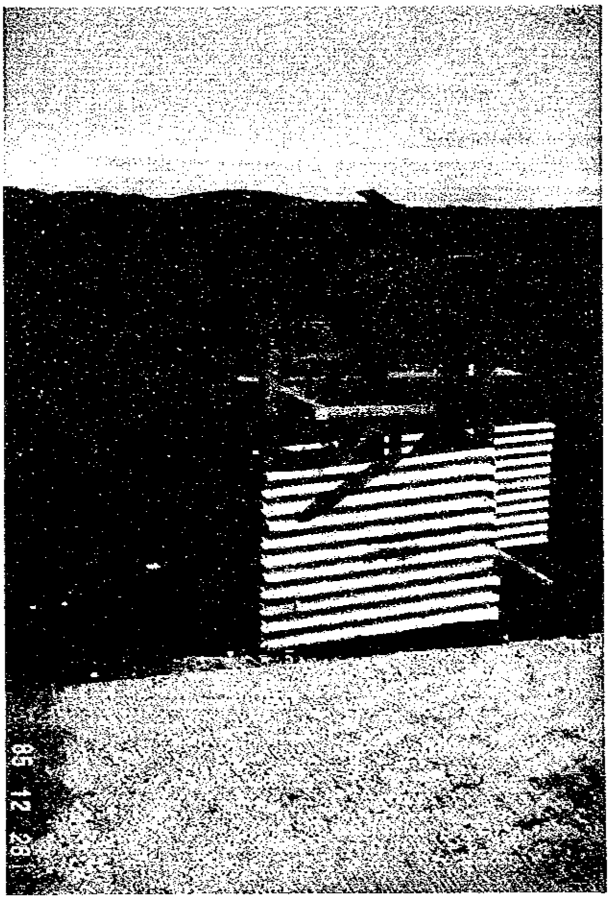
Completely weathered tuff breccia at the quarry for dam embankment fill.
No shrinkage cracks are observed.

Landslides at the right bank of the upper canal

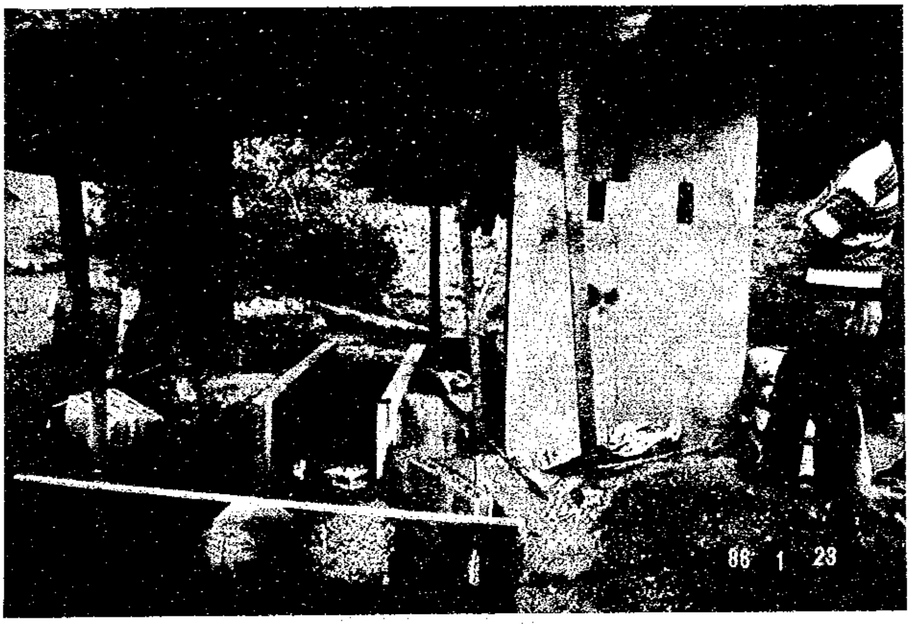
Restoration of landslides by rockfill at
the landslide right bank of the upper canal

Monitoring point for external deformation of the dam (under installation)

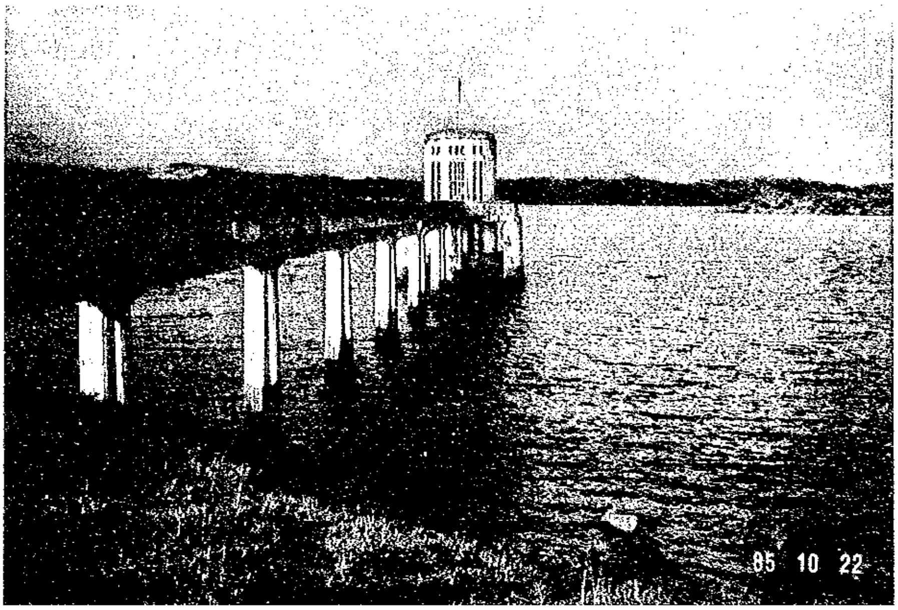
Landslide at the downstream side of the east dyke



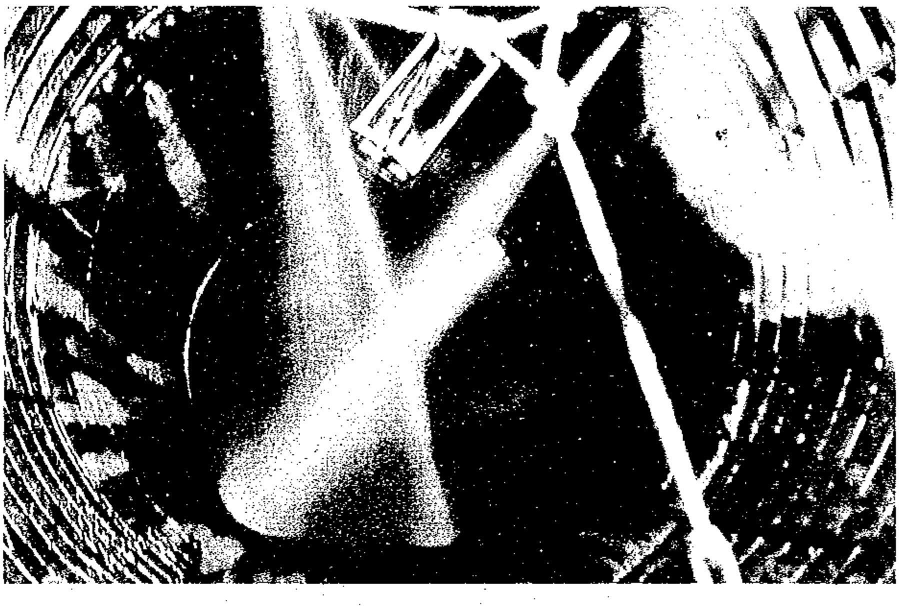
Groundwater level recorder
(under installation)



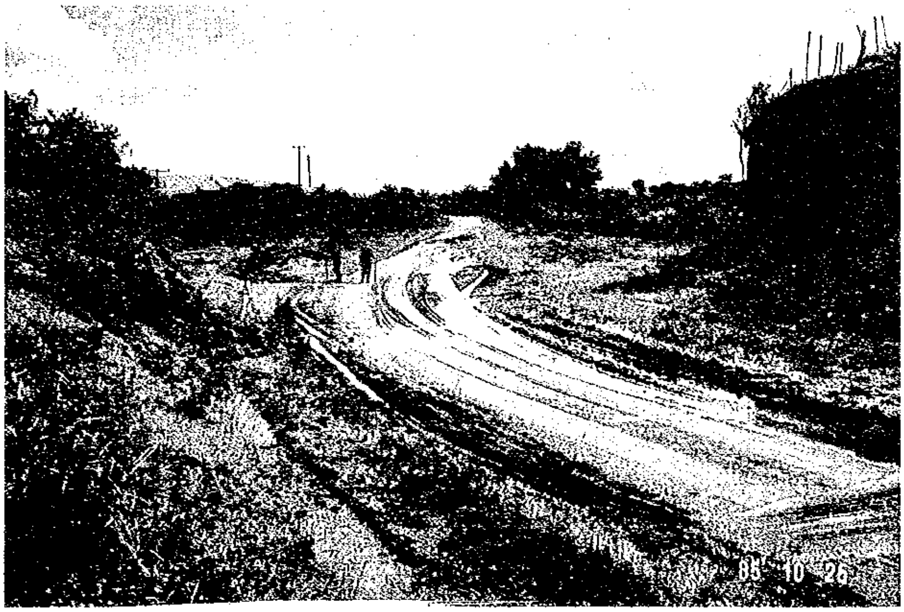
Measuring weir of dam leakage
(under construction)



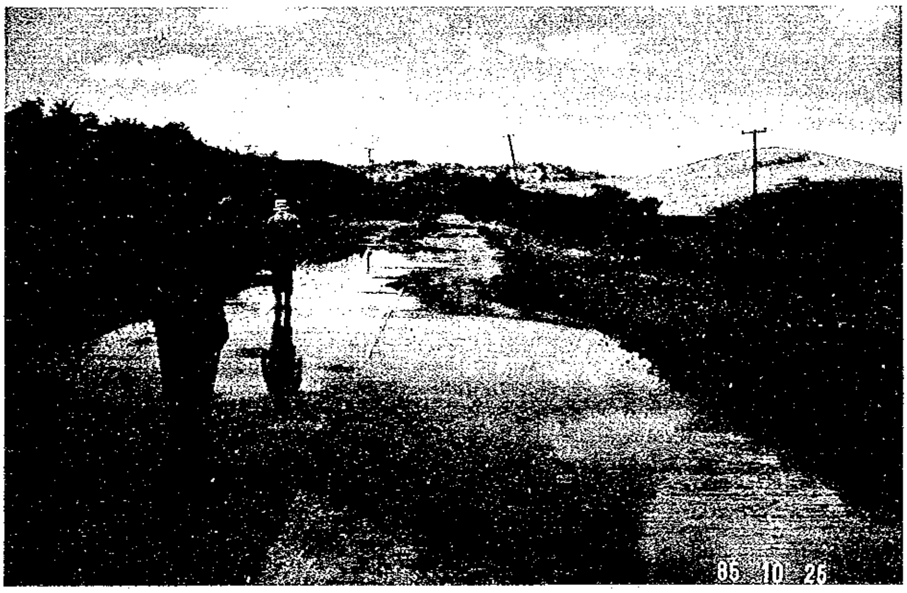
Service spillway intake tower



Leakage at vertical shaft of service spillway
(Rib structure is cylinder gate of service spillway intake.)



Saddle (emergency) spillway area



Overflow section of saddle spillway (used as road)

C O N T E N T S

CONCLUSION AND RECOMMENDATIONS

Conclusion and Recommendations

1. Damages to the Caliraya Dam

1.1. The damages to the downstream face of the Caliraya dam has developed by erosion due to rainwater. At present the sliding safety factor is judged to ensure more than 1.5 even in the event of earthquake. However, we estimate the erosion will progress at the rate of 30 centimeters per year and if left unattended, it is anticipated that after ten years the sliding safety factor will become less than 1.2 as provided for in the regulations of Japan in the event of earthquake. Hence, repair work should be undertaken at an early date.

1.2. The cracks on the upstream concrete slab are mainly caused by uneven settlement of the dam body. It is assumed that as the slab joints have opened due to corrosion of the joint iron plates, embankment material beneath the lower part of the slab has been partly washed away to create voids which have accelerated the spreading of the cracks.

Although there is little possibility that these cracks will develop rapidly in the future, it is necessary to repair them for protection against erosion due to wind wave at the upstream face of the dam. For this, it is recommended that the cracks be repaired at a time of replacement works of a cylinder gate of the service spillway with the reservoir water elevation below EL.282.0. However, if the water level could not be lowered for reasons of the reservoir operation, it is proposed that sand and gravel will be thrown and gabions laid on the upstream concrete slab under the water up to EL.285.0.

1.3. The landslide of the bedrock downstream of the east dyke looks like a circular arc slide. This relatively recent landslide is close to the filled parts of the dyke and is likely to extend to the foundation bedrock beneath the dyke. Therefore, it should immediately be stabilized by back-filling with rock materials.

1.4. A landslide occurred during excavation on the right bank of the upper canal leading to the Kalayaan intake. Further sliding here has been temporarily prevented by providing rock embankment and drainage.

However, around the starting point of the landslide, the bedrock surface is exposed and recurrence of landslide is feared. It is necessary, therefore, to continue monitoring the landslide behavior.

2. Probable Flood and Spillway Facilities

2.1. Two hundred years return flood volume into the Caliraya reservoir (drainage area 92 square kilometers) and the Lumot reservoir (drainage area 37 square kilometers) is computed to be 2,173 m^3/s and 874 m^3/s respectively. Both reservoirs are connected by a waterway tunnel of 2.0 meters in diameter and 1,850 meters in length. However, the watering capacity of this tunnel is so small, only 4.6 m^3/s, so the Lumot reservoir flood inflow is mostly discharged through the Lumot dam spillway and does not flow into the Caliraya reservoir. Therefore, 4.6 m^3/s only was considered as the inflow from the Lumot reservoir in studying the Caliraya dam spillway.

2.2. The Caliraya dam spillway presently comprises a service spillway (tunnel type) and an emergency spillway (open channel, free overflow type).

The service spillway is used to control discharge by means of a cylinder gate. The discharge capacity at the reservoir H.W.L. 288.0 meters is 252.7 m^3/s. The emergency spillway has a minimum overflow level of EL 289.3 meters across approximately 160 meters of potential overflow width, and it cannot discharge flood flow at the reservoir high water level 288.0.

Its discharge capacity can be given by $273 \times (W.L. - 289.3)^{3/2}$ when the reservoir water level exceeds EL.289.3.

2.3. The discharge capacities of the existing spillways (for both service and emergency) are small and the reservoir water level is approximately 290.55 meters for the flood of (two hundred years return flood) x 1.2 and the freeboard will be insufficient.

The land downstream of the emergency spillway overflow section is owned privately and there is no waterway allowing overflow water to disperse safely.

It is inevitable that an additional spillway be constructed for the Caliraya reservoir to give improved flood discharge capacity and lessen the chance of overflow via the emergency spillway as far as possible.

This new spillway should have a minimum overflow elevation of EL 284.0 meters and should be equipped with at least twin gates of 9.0 meters in width and 5.0 meters in height.

2.4. Problems with Service Spillway

The service spillway which is a tunnel spillway is over forty years old and has deteriorated badly. Leakage is occurring at numerous places over the watertight portion of the gate, lining concrete, steel liner, etc. The break-down of the service spillway may directly result in water overtopping over the dam at the time of floods which may lead to the collapse of the dam. Therefore, immediate repair should be taken.

3. Results of Investigation and Monitoring

3.1. The Caliraya dam embankment material is highly weathered tuff-breccia, a very fine grade material containing 55 per cent and 24 per cent less than 74 and 1 in grade diameter respectively. Clay minerals are mainly kaolinite and no montmorillonite with its characteristic swelling was found.

Other than at the foot of the downstream slope of the dam, where rock material is partly embanked, the Caliraya dam is a homogeneous earth dam.

3.2. According to the monitoring data on dam behavior since January, 1986, the amount of leakage of the dam body is large in the wet season and decreases in the dry season more or less within the range of 200 liters/min. to 100 liters/min., which seems quite normal for this type of dam.

3.3. The ground water level in the dam body is evenly distributed changing a little according to wet season and dry season with a difference of approximately two meters. Drainage effect of the drain layer extending to the upstream side along the basement surface from the rockfill zone of the dam body downstream portion is functioning well and near this drain layer the ground water level is sharply lowered, so that at present the face of slope of the dam body downstream is not unstabilized due to coming out of seepage water.

3.4. Continuous monitoring should be carried out in the dam, i.e. measurement of leakage, measurement of ground water level in the dam body and measurement of deformation of the dam body.

4. Proposed Repairs of Dam and Spillway

4.1. Priority and Costs of Proposed Repairs

The proposed items of repair work are classified into I, II and III Priority groups in the descending order of emergency measures, viz.

I Priority

- Prevention of landslides in the area downstream of the east dyke
- Prevention of water leakage from the service spillway structure
- Construction of a new spillway

II Priority

- Repair of erosion traces along the dam downstream slope

III Priority

- Replacement of a service spillway gate
- Repair of cracks in upstream concrete slab

The respective estimated direct costs (1986 price level) for the groups are shown as follows:

I Priority	US$5,483,900
II Priority	US$1,560,000
III Priority	US$ 467,000
Total	US$7,510,900

Adding the contingency, engineering cost and NAPOCOR administration cost, the estimated gross costs will arrive at US$9,542,990.-

The breakdown of the costs is shown on Tables VIII-1 and VIII-2.

The repair work should, in principle, be done in the descending order of the emergency priority. However, the work involves dozens of items, and many of them are closely interrelated. It is, therefore, advisable not to implement itemized measures in series, but to carry them out in parallel as part of an integrated project. The repair work to be done in such manner may be finished in some 32 months.

4.2. I.R.R. of Proposed Repairs

The internal rate of return of the immediate repair is about 26% as compared with an alternative case where the Caliraya Dam is left as it is and the dam will be reconstructed at a time (after about 10 years) when the sliding safety factor of the dam downstream slope (at the time of earthquake) is lowered to 1.2. This shows that the immediate repair is justified economically.

5. Maintenance Control of Dam

It is recommended that a Civil Engineering Monitoring Section (consisting of 2 civil engineers and 3 assistants) be established in NAPOCOR's Southern Luzon Regional Center. This section should be responsible for maintenance, inspection, repair and monitoring of civil structures for all hydro power plants including Caliraya Dam.

It is also recommended that similar organizational units be established in other regional centers. A Civil Engineering Maintenance Section should be established in the NAPOCOR head office to coordinate and supervise all activities undertaken by these Sections.

TEXT

I. BACKGROUND AND CONTENTS OF THE STUDY

I. Background and Contents of the Study

This report is the Final Report on the Feasibility Study of the Caliraya Dam Rehabilitation Project to be undertaken by National Power Corporation of the Philippines (hereinafter called "NAPOCOR"). The Report includes a review of the stability of the Caliraya Dam and the preparation of a rehabilitation program to repair the deformation and damage. Field investigation, field works and dam monitoring were carried out to obtain the necessary data and work results, which were used for this Feasibility Study.

The Caliraya Dam is of earth-fill type, 42 m in height and 480 m in crest length. It is located about 60 km southeast of Manila, Republic of the Philippines. Construction of the Dam commenced in 1939 and was completed in 1947 after the World War II. Almost the entire upstream face of the Dam is protected by a concrete slab with a thickness of 15 cm. The Dam creates the Caliraya reservoir (H.W.L. 288 m, effective reservoir volume 73 x $10^6 m^3$). There are two hydroelectric power plants which utilize heads between the Caliraya reservoir and Laguna de Bay; the first is the Caliraya Hydro Power Station, with a generating output of 36 MW (9 MW x 4 units) completed in 1950. The second is the Kalayaan Pumped Storage Hydro Power Station with a generating output of 300 MW (150 MW x 2 units) completed in 1982. Both power stations together operate as the main power sources to Metro Manila in Luzon Island.

Towards the end of 1983 when the reservoir water level was lowered due to generation by the Kalayaan Pumped Storage Power Station, many horizontal cracks were evident on the upstream concrete slab of the dam. In addition, in August 1984 many small landslide traces and water leakage were revealed along the downstream face of the dam. These phenomena gave rise to misgivings regarding the stability of the dam body among NAPOCOR staff. It was considered necessary to take appropriate countermeasures and rehabilitation of the Caliraya Dam as soon as possible.

NAPOCOR made their own study of this matter, while the Government of the Republic of the Philippines officially made a request for technical cooperation for the rehabilitation study to the Government of Japan. Taking into account the seriousness and urgency of this problem, a pre-study mission was dispatched to the dam site in June, 1985 by the Japan International Cooperation Agency, Japan (hereinafter called "JICA"), and the scope of the study for the Feasibility Study were settled between NAPOCOR and the pre-study JICA mission. Based on these terms of reference, the Feasibility Study of the Caliraya Dam Rehabilitation Project commenced in October 1985.

The agreed terms of reference were as follows:

1. Review of available data and information

2. Review of the present monitoring system which is under operation by NAPOCOR, and programming of field works.

3. Field works will include: (to be undertaken by NAPOCOR)

   a) Topographic surveys
   b) Establishment of a system for monitoring of dam behaviour
   c) Drilling and pitting
   d) Laboratory soil tests and site permeability tests
   e) Measurement of water leakage.

4. Monitoring of dam behavior (to be undertaken by NAPOCOR);

   a) Water leakage from the Caliraya Dam
   b) Deformation of the Caliraya Dam
   c) Ground water level

5. Study and analysis of dam and spillway stability

6. Formulation of a safety control system for the dam and reservoir

7. Formulation of a rehabilitation plan

II. SITE INVESTIGATION

II. Site Investigation

Four (4) experts of the JICA Study Team were dispatched to the project site during the following periods (October 8 - November 6, 1985):

a) Mr. Yutaka MATSUI, Team leader
Period: October 8, 1985 - November 6, 1985

b) Mr. Yuuichiro TSURUMAKI, Hydrologist
Period: October 8, 1985 - November 6, 1985

c) Dr. Haruo TANAKA, Geologist
Period: October 17, 1985 - October 30, 1985

d) Mr. Noboru DAIGUSHI, Civil Engineer
Period: October 17, 1985 - November 6, 1985

Following completion of the above schedule, Mr. N. Daigushi remained at the site until December 30, 1985 in order to give technical instruction for field work and to supervise installation and operation of monitoring equipment to be undertaken by NAPOCOR.

Mr. Daigushi was dispatched again to the Philippines twice from January 19 to January 25, 1986 and March 9 to March 15, 1986 to give technical guidance on the monitoring to NAPOCOR's operation staff and to check the monitoring results at the site.

The main activities of the JICA Study Team during their stay in the Philippines were as follows:

1. Inspection of damage to the dam, dykes, service spillway and related structures.

2. Inspection of shore-line along the Caliraya Reservoir.

3. Collection of additional data and information regarding the Caliraya Dam, including dam structures, hydrology, earthquake data and geology.

4. Finalization of the program and sites for field work to be undertaken by NAPOCOR.

5. Inspection of prospective quarry sites for future remedial works for the dam, and sampling of potential quarry materials.

6. Inspection of former borrow pit area and sampling of earth materials for analysis of mineral composition of the dam embankment.

In the home office, Mr. Yoshiro Shirai and Mr. Masatoki Ikeda supported the dispatched experts, in charge of civil engineering (stability analysis) and civil engineering (maintenance control) respectively.

III. FIELD WORK AND MONITORING INSTRUMENTATION

III. Field Work and Monitoring Instrumentation

The field work sites and the locations for installation of the monitoring instrument determined from the site inspection, are shown in Fig.III-1.

The main items and the progress of the field work completed by NAPOCOR were as follows:

1. Core Boring

   a) upstream slope (3 holes, UB-1, UB-2 & UB-3, 1.2 m depth and 75 mm diameter)

      Cracks were found in the concrete slabs protecting the upstream slope. In this respect, boring work was carried out to investigate whether cracks and voids would appear in the lower portion of the concrete slab due to the out-flow of slab supports, etc. No cracks and voids were revealed by this boring work.

   b) downstream slope (3 holes, CDB-1, CDB-2, CDB-3, 75 mm diameter)

      Boring work was carried out at the downstream slope to investigate the distribution condition of embankment materials, to confirm the location of dam foundation, and to collect the necessary data for the judgement of compaction by N-value distribution measurement.

      These three (3) drilled holes were also utilized for the measurement of underground water level in the dam body. The holes are situated at the downstream slope along the largest cross-section of the dam.

CDB-1 - Completed, with results of 38.9 m depth to rock foundation, 7.8 m of ground water level. N-value distribution measurement was:

0 to 7 m	:	10 to 15
7 m or deeper	:	15 to 40

CDB-2 - Completed, with results of 33.35 m depth to rock foundation, 6.0 m of ground water level. N-value distribution measurement was:

0 to 2 m	:	10 to 15
2 m or deeper	:	15 to 40

CDB-3 - Completed, with results of 24.5 m depth to rock foundation, no record of ground water level.
N-value distribution measurement was:

0 to 2 m	:	8 to 15
2m or deeper	:	15 to 40

Note: Underground water levels in the above are those measured at the time of completion of the boring works.

Core samples obtained by these boring works show that there is little difference in the embankment materials among the locations of three (3) drilled holes. All samples are composed of clay to silt materials with fine grain diameter, and classified to MH to CH. On the other hand, tuff-breccia was found in the old borrow pit near the dam site. It is judged from this core observation that the main part of the Caliraya Dam is an earth dam of uniform fill composed of heavily weathered tuff-breccia.

2. Test Pit (2.5m in depth, 1 point)

The purpose of this pit was to collect undisturbed samples for the measurement and test of physical properties of the dam embankment materials. The test pit was excavated at the middle elevation of the downstream slope along the largest cross-section of the dam.

3. Survey

This survey consisted of following three (3) items:

a) topographic survey at the downstream area of the main dam:

b) longitudinal and sectional surveys at saddle spillway

c) longitudinal and sectional surveys at land-slide area downstream of east dyke

The survey also included levelling and measurement of location of each drilled hole and monitoring instrument.

4. Soil Test

A soil test was performed by NAPOCOR on the undisturbed samples collected from the test pit. Tables III-1 and III-2 show the results.

5. Monitoring Instrumentation

The following three (3) types of dam behavior monitoring were undertaken in this Study.

- Measurement of underground water level in the dam body

- Measurement of dam external deformation
- Measurement of water leakage in the dam body

a) Measurement of Underground Water Level of the Dam Body

Three (3) drilled holes along the largest cross-section of the dam were used for the measurement of underground water level (seepage line from the reservoir) in the dam body. These holes are CDB-1, -2 and -3, drilled as part of the field work. Casing pipes (strainers) were inserted to each hole for the measurement of underground water level. Recording was made by three (3) float type auto recording devices which were installed at the ground surface of the drilled holes.

Fig. III-2 is the illustration of the installed recording device. Monitoring by use of this auto recording device was commenced at the end of December 1985 and is now going on.

b) Measurement of Dam External Deformation

Dam external deformation was measured by the deviation length and settlement depth from the base lines. In this measurement, two (2) base lines along the dam crest, and two (2) base lines along berms at middle elevation (EL.285.0) were considered. Based on this consideration, totally six (6) fixed points and ten (10) measuring points were set for this study, and the measurement of dam deformation was started by NAPOCOR at the end of January 1986 with these base lines and measuring points.

c) Measurement of Water Leakage in the Dam Body

NAPOCOR had already carried out the measurement of water leakage in the dam body, by means of a wooden measuring weir. In this Study, water leakage was found at the weir foundation of the wooden weir, which was rotten already. Since high accuracy of measurement could not be expected with this existing wooden weir, a weir assembled with concrete and steel plate was newly installed for this Study. (See Figs. III-3, III-4 and III-5).

The water level was recorded by an auto recording device. However, due to the delay in the installation of the new weir, recording did not start until mid February 1986.

d) Provided Measuring Instruments

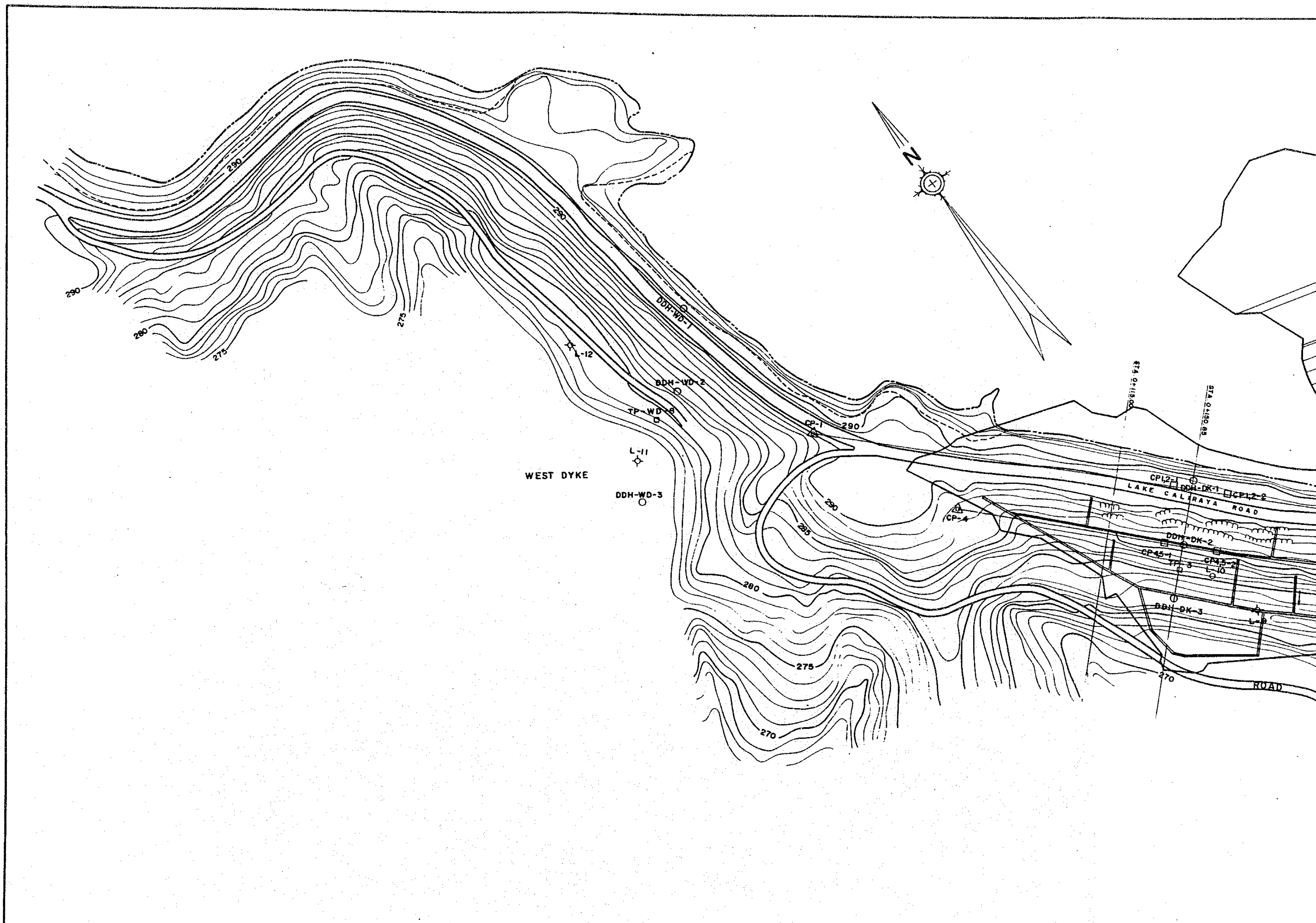
For the execution of the monitoring in this Study, following measuring instruments were provided by JICA Study Team to NAPOCOR.

i) Portable ground water table meter: 2 sets
   - Model SKT-2B

ii) Point gauge for water level measurement: 2 sets

iii) Float type auto recording ground water table meter: 3 sets
   - Model W-722

iv) Water leakage measuring device: 1 set
   - Water Level Gauge W-435
   - Data Logger W-551-02
   - Auto Voltage Regulator ARS-500
   - Transformer F3-B5


WEST DYKE
DDH-WD-1
DDH-WD-2
DDH-WD-3
TP-WD-8
L-11
L-12
CP-1
CP-4
DDH-DK-1
DDH-DK-2
DDH-DK-3
LAKE CALIRAYA ROAD
ROAD
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290
285
280
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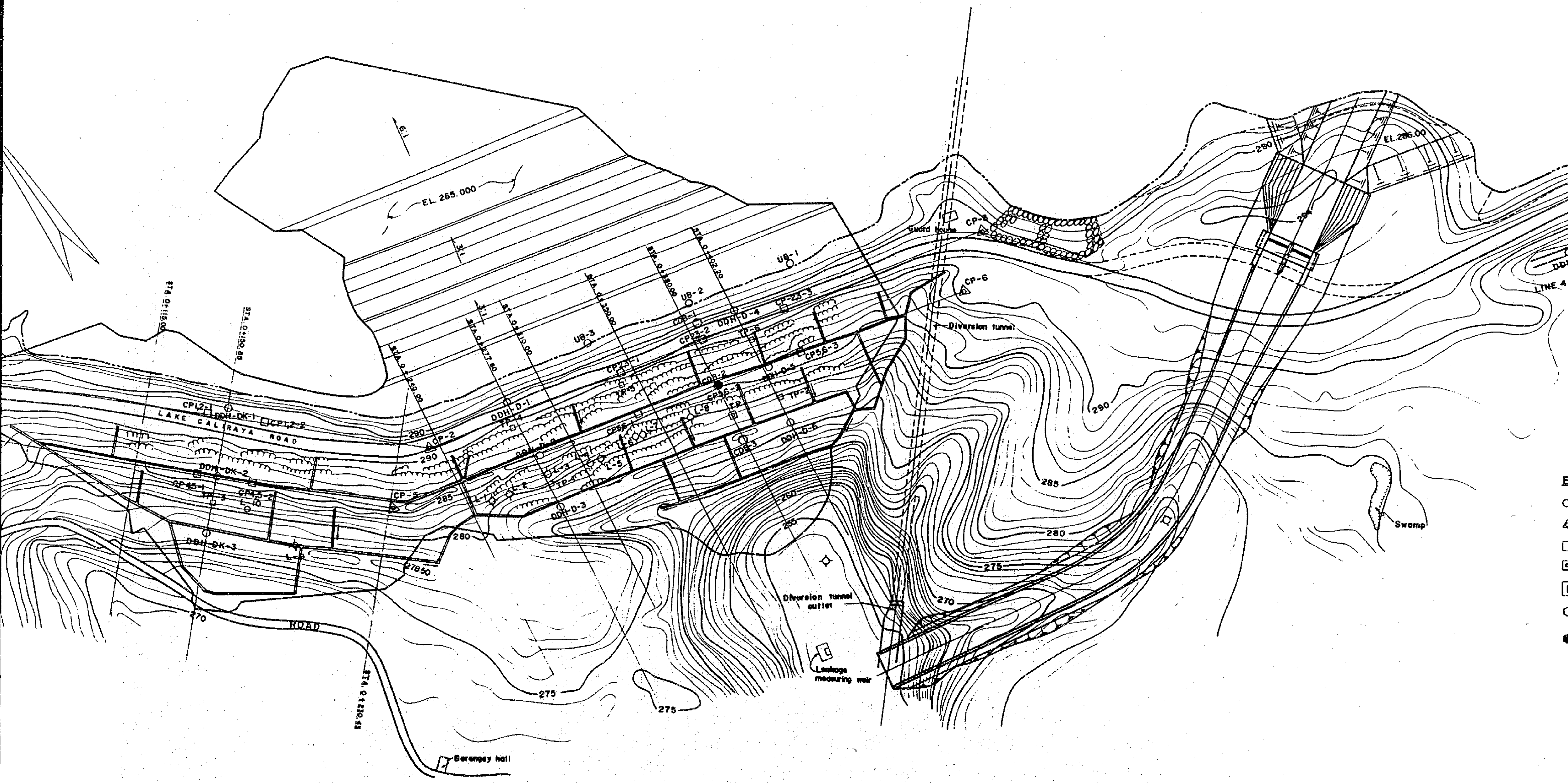
270



EL. 265.000
EL.286.00
LAKE CALIRAYA ROAD
ROAD
Guard House
CP-5
CP-6
Diversion tunnel
Diversion tunnel outlet
Leakage measuring weir
Swamp
Barangay hall
UB-1
UB-2
UB-3
DDH-DK-1
DDH-DK-2
DDH-DK-3
DDH-D-1
DDH-D-3
DDH-D-4
CP-2
CP-5
TP-3
L-10
STA. 0+115.00
STA. 0+150.85
290
285
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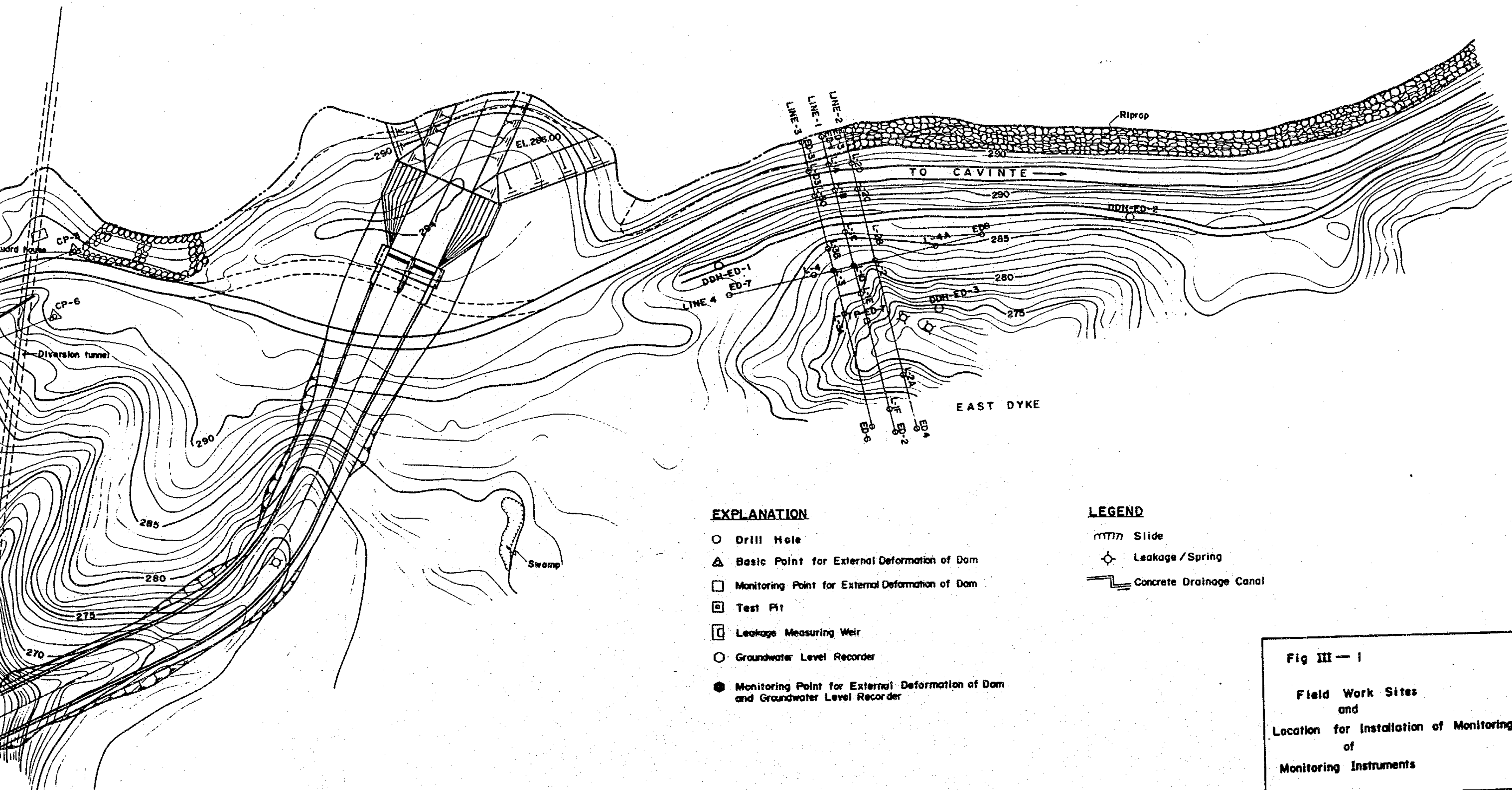

Fig III — 1

Field Work Sites and Location for Installation of Monitoring of Monitoring Instruments

Fig. Ⅲ - 2 Water Level Recorder

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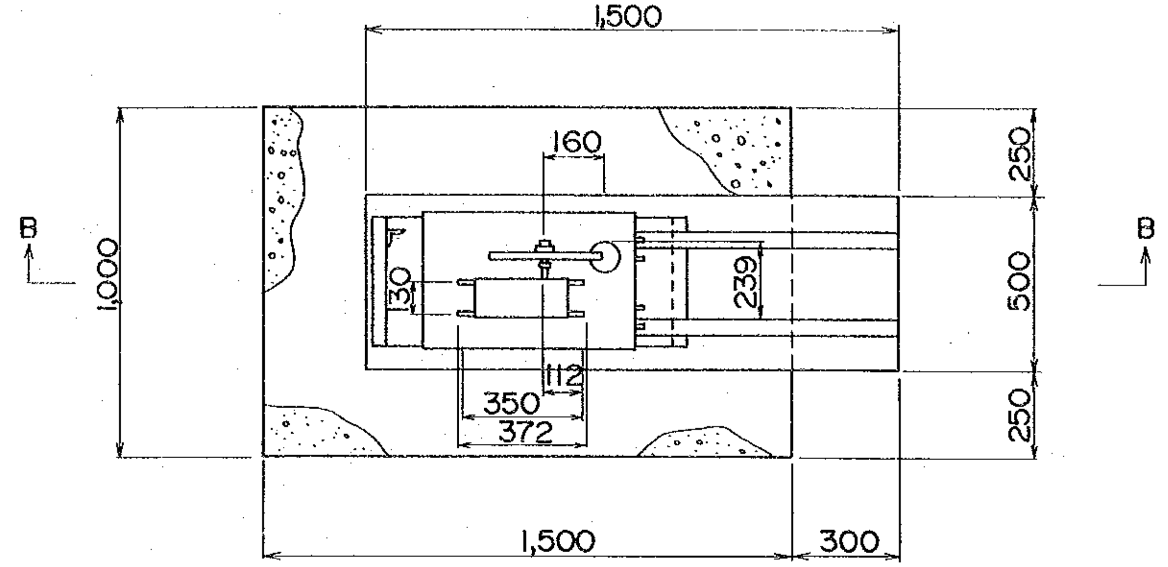
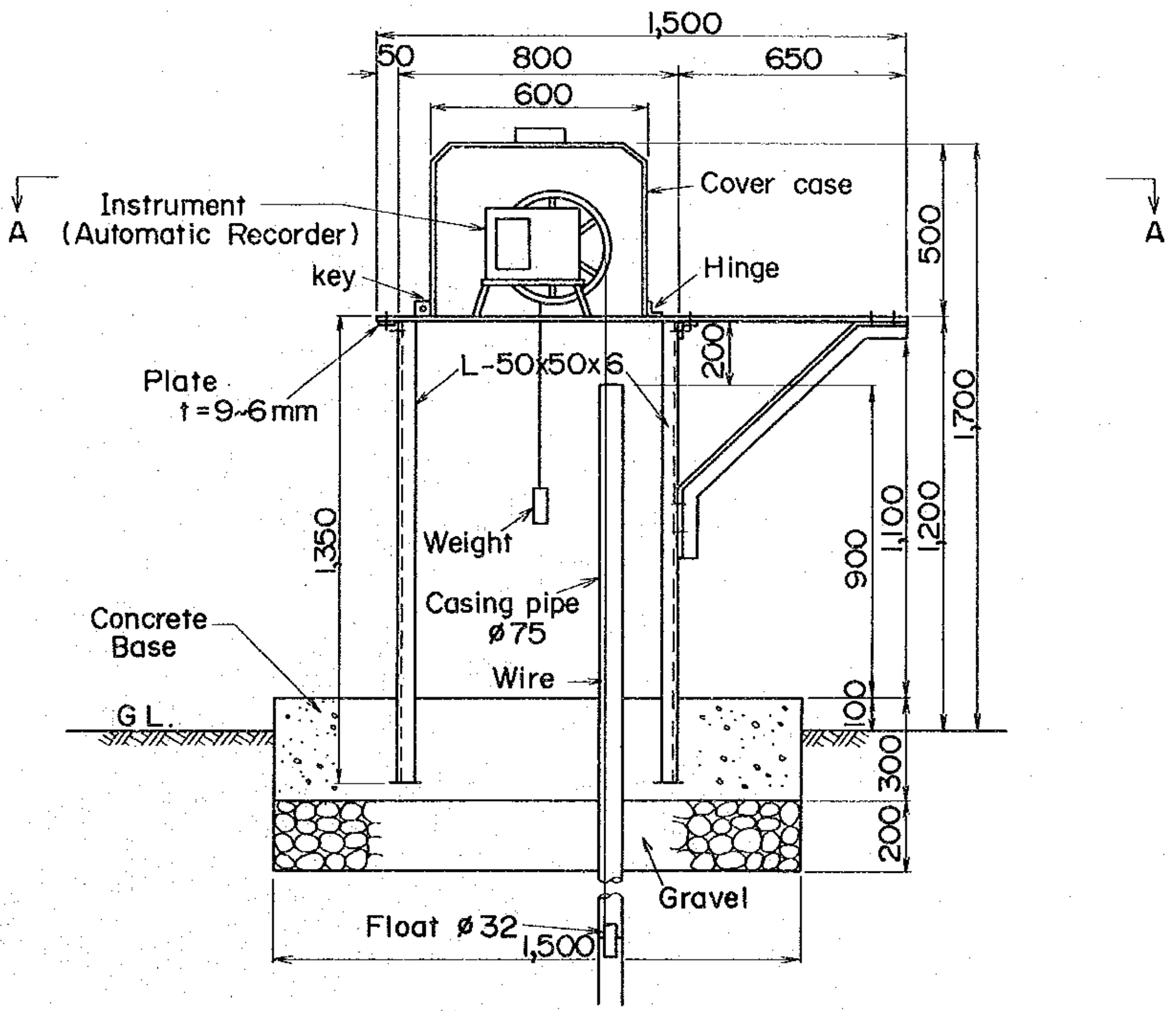


PLAN (A-A)



SEC. B - B

Fig. Ⅲ - 3 General Plan of Dam Water Leakage Measuring Device

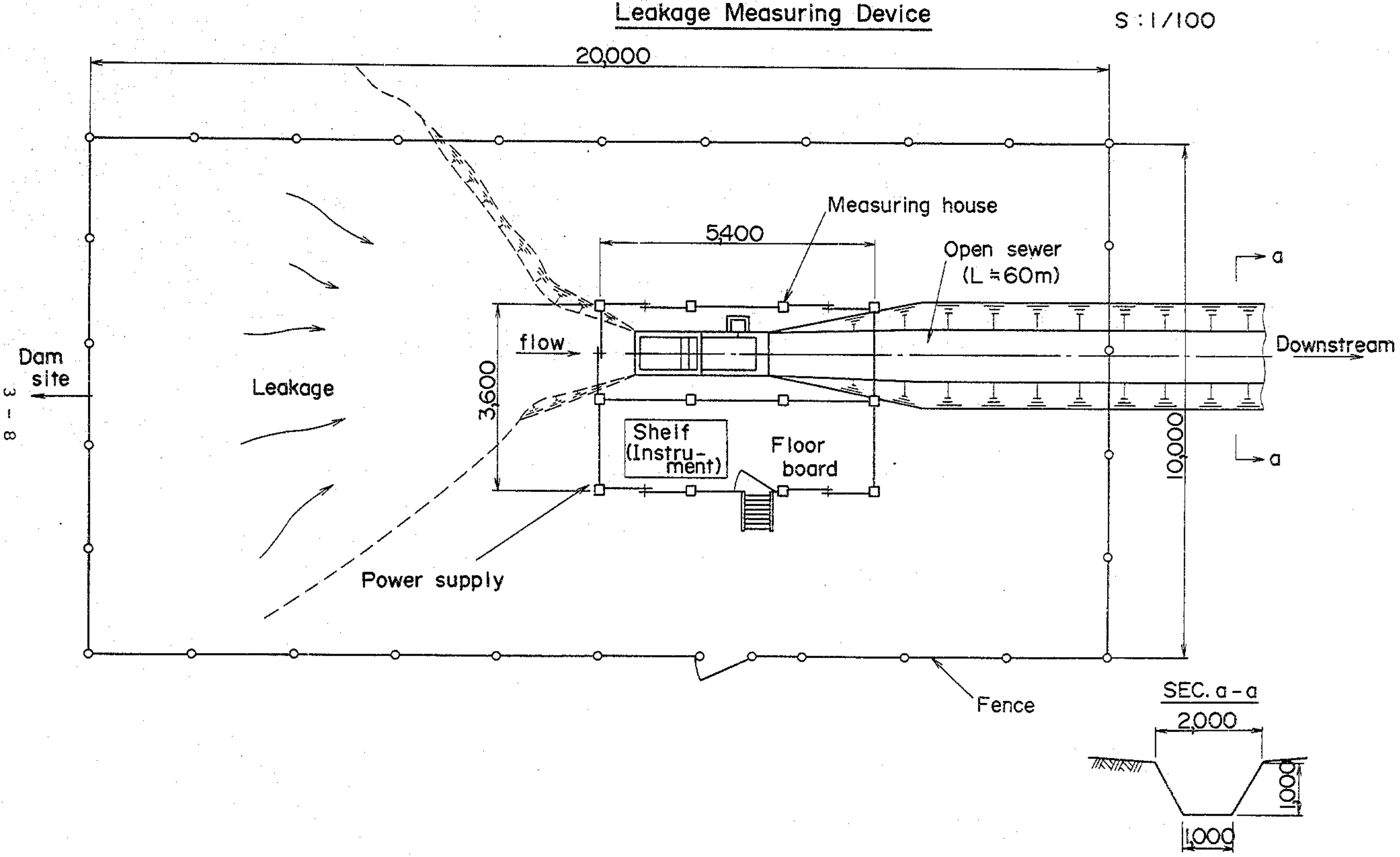
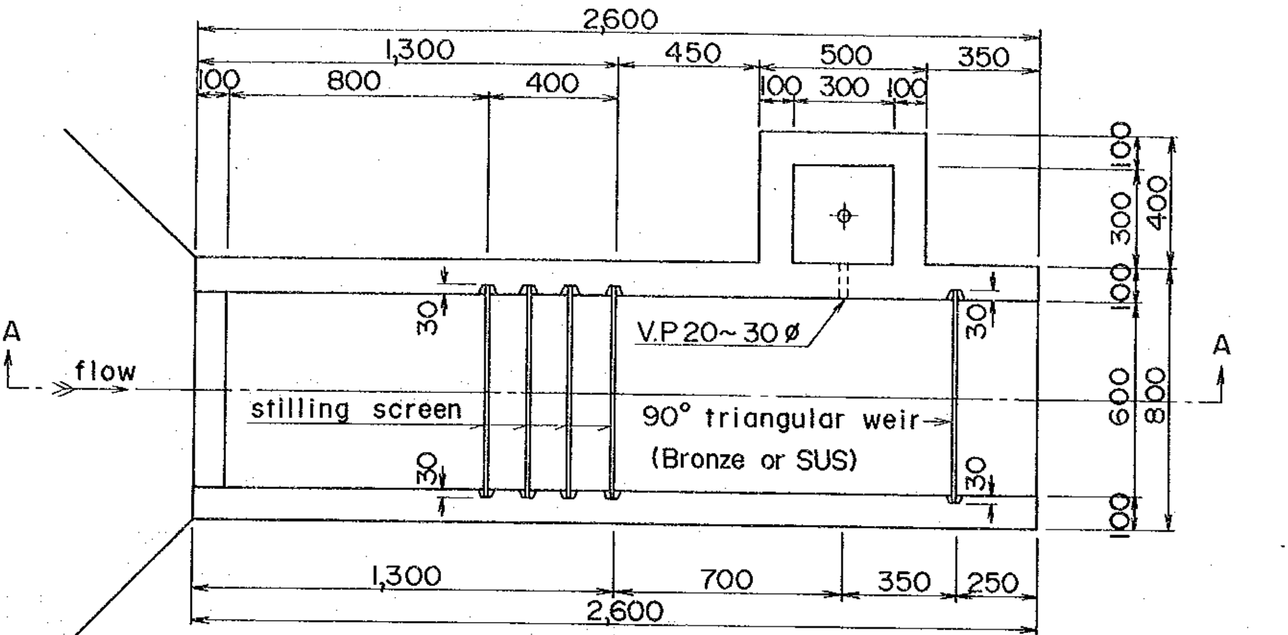
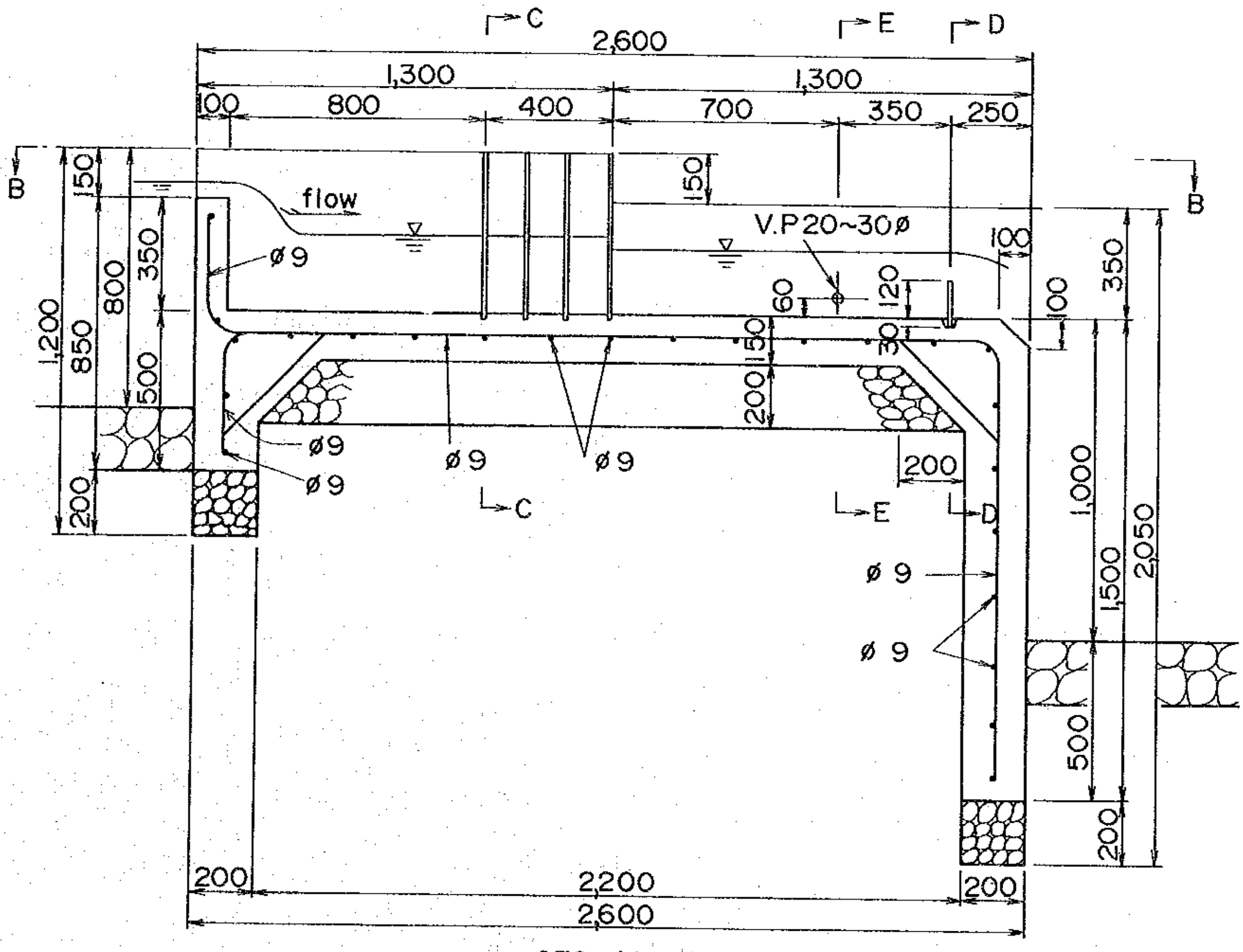


Fig. Ⅲ-4 Dam Water Leakage Measuring Weir

NOT TO SCALE

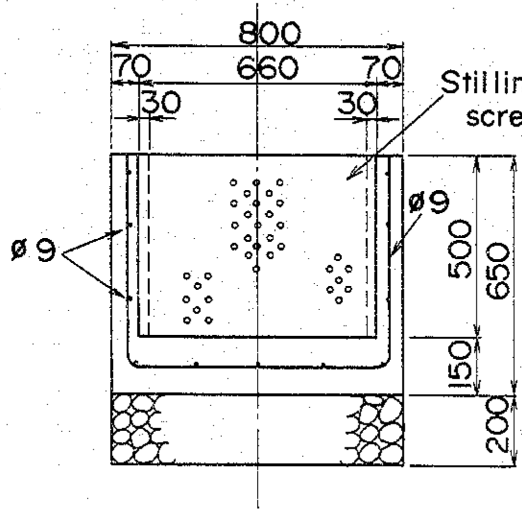


PLAN (B-B)

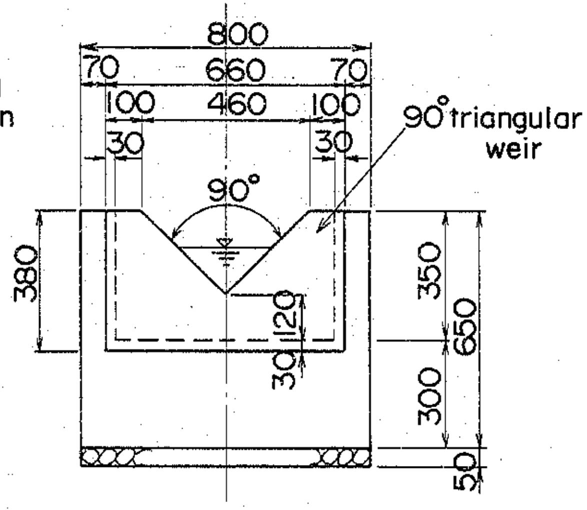


SEC. (A-A)

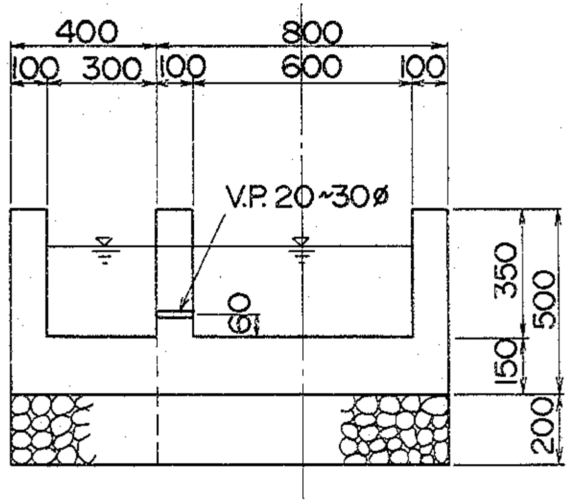
Fig. III - 5 Weir Details



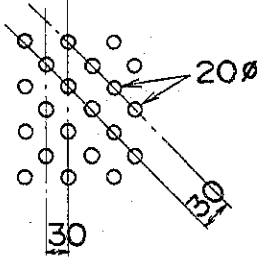
SEC. C-C
S:1/20



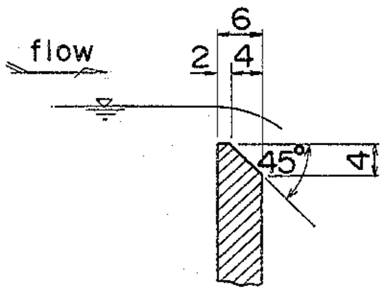
SEC. D-D
S:1/20



SEC. E-E
S:1/20



Hole arrangement



Edge S: 1/1
(90° Triangular weir)

JIS A 1204 TABLE III-1 RESULT OF SOIL GRAIN TEST

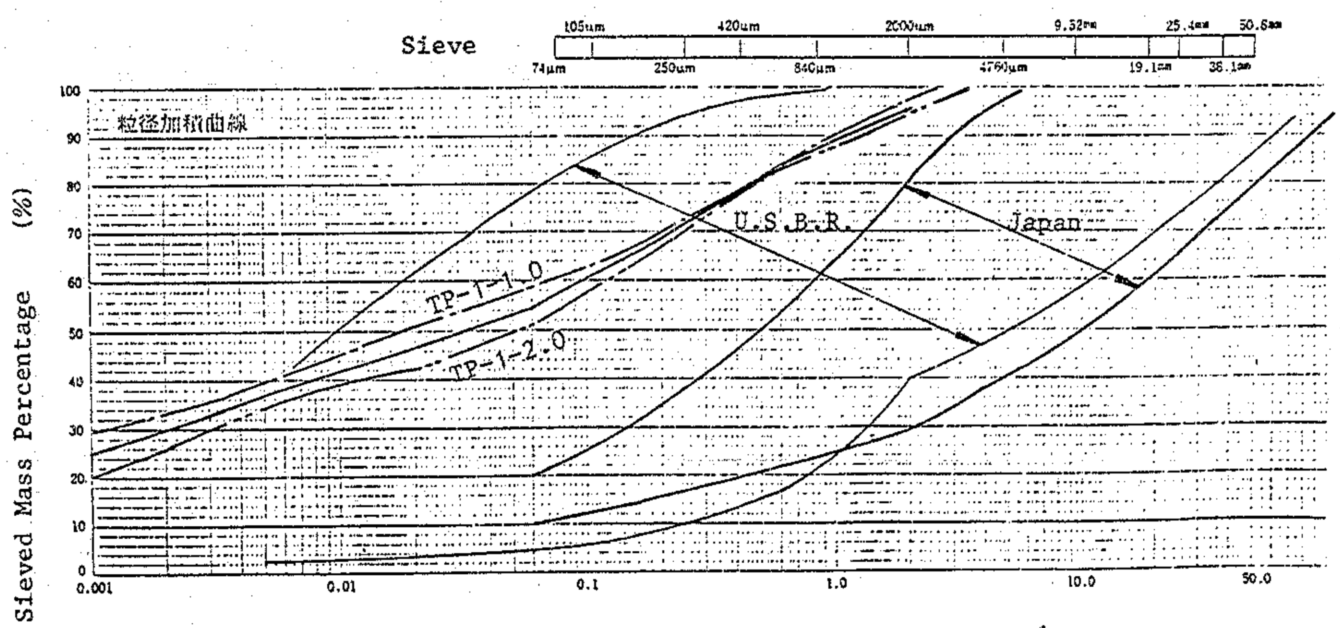
Site of Soil Collection: Caliraya Main Dam

Date of Test: December 1985
Tested by : NAPOCOR

Sample No. Depth	No. TP-1-1.0 (1.0 m)		No. TP-1-2.0 (2.0 m)	
	Grain Diameter	Mass Percentage	Grain Diameter	Mass Percentage
Sieve Analysis	50.8	(sieved %)	50.8	(sieved %)
	38.1		38.1	
	25.4		25.4	
	19.1		19.1	
	9.52		9.52	
	4.76	100	4.76	100
	2.38	98.82	2.38	96.89
	0.84	92.10	0.84	89.40
	0.42		0.42	
	0.25		0.25	
	0.105		0.105	
	0.074	60.3	0.074	52.9
Measurement of Specific Gravity by Floating Gauge	0.061	58.9		51.0
	0.021	51.6		42.4
	0.005	38.7		34.4
	0.002	33.1		25.3

Sample No. Depth	No. TP-1-1 (1.0 m)	No. TP-1-2 (2.0 m)
Grain (4.76mm or more %	0	0
Granule (4.76 - 2mm) %	2.5	5
Coarse sand (2 - 0.42mm) %	17.5	16
Fine sand (0.42-0.074mm) %	27	18
Silt (0.074 - 0.005mm) %	14	26
Clay (0.005mm or less) %	39	35
Colloid(0.001mm or less) %	24	20
2000μm sieved Percentage %	97.5	95
420 μm sieved percentage %	80	79
74 μm sieved percentage %	61	53
Max. Grain Size		
60 % Grain diameter mm	0.065	0.13
30 % Grain diameter mm	0.0012	0.003
10 % Grain diameter mm	(0.00005)	(0.00035)
Coefficient of uniformity Uc	1300	370
Coefficient of curvature Uc'	0.44	0.2
Specific gravity of soil particles Gs	2.8	2.57
Diapersing agent		
Class	MH	MH

Grain Size Distribution Curve



Grain Diameter (mm): 0.001 | 0.005 | 0.074 | 0.42 | 2.0 | 4.76 | 75

Clay w/o colloid | Silt | Fine Sand | Coarse Sand | Granule | Gravel | Rock Materials

Table III-2 Soil Test Results

Test Items \ Sample	Sample No.1	Sample No.2	Average
Natural water content (%)	52.3	45.7	49.0
Wet density (g/cm^3)	1.78	1.71	1.75
Dry density (g/cm^3)	1.17	1.17	1.17
Grading (%)			
Sand	39.70	47.10	43.70
Silt, Clay	60.30	52.90	56.60
Atterberg's limit (%)			
Liquid limit L.L.	99.00	80.00	89.50
Plastic limit P.L.	45.90	41.50	43.70
Plasticity index P.I.	53.10	38.50	45.80
Specific gravity	2.83	2.57	2.70
Permeability Coefficient (10^{-6} cm/sec.)	-	2.68	2.68
Cohesion (C) (kg/cm^2)	0.31	0.27	0.29
Angle of internal friction (ϕ)	33.66°	32.12°	32.89°
Classification symbols of soil	MH	MH	MH

IV. GEOLOGY OF THE PROJECT AREA

1. General Geology of the Caliraya Dam and Its Neighboring Area

2. Geology of the Caliraya Dam

3. Geotechnical Consideration on Dam Body

4. Mineralogy of Borrow Materials

IV. Geology of the Project Area

1. General Geology of the Caliraya Dam and Its Neighboring Area

The geology of the Kalayaan Pumped Storage Plant site is reported by Mr. Luigi Belloni, a geologist of Electro-consult Geotechnical Division, in the paper presented during the PSEG Lecture-Seminar in Engineering Geology, Nov. 10, 1983 titled "SLOPE FAILURES IN SURFICIAL WEATHERED TUFF AT THE KALAYAAN PUMPED STORAGE POWER PLANT, LAGUNA, PHILIPPINES" and "Kalayaan Pumped Storage Plant - Geology Comprehensive Report" presented by NAPOCOR, Manila, Philippines. In the JICA REPORT of "Preliminary Study Report of the Caliraya Dam Rehabilitation" July, 1985, the outline of geology of the Caliraya dam and reservoirs area was reported.

The general geology of this area is well studied in these reports and, therefore, the general geology of this area will be described below briefly in this report.

This area is composed of tuffacious rocks and basaltic lava in descending order, and these layers incline toward west with very gentle dip. These rocks belong to the Neogene Tertiary to Quaternary volcanic debris derived from Mt. Banahaw south of the area.

The tuffacious rocks distribute on the higher parts of the Caliraya Plateau, but in some localities they are found in the basaltic rocks in a shape of lens or sheet. The tuffacious rocks sometimes contain subangular boulders or cobbles of basaltic rock near the top of the layer.

Almost all of the tuffacious rocks are deeply weathered and changed into red soil near the surface.

This mode of occurrence of tuffacious rocks is well observed at the cutting of the road from the Caliraya Reservoir to the Lumot Reservoir.

The basaltic rocks expose on the left bank of outlet portal of spillway tunnel of the Caliraya Dam and at the downstream area of the Caliraya River. At the downstream area of the Caliraya River, they have very beautiful columnar joints and the river stream runs as beautiful fall. The basaltic rocks expose along the cutting of road from Pagsanjan to Paete.

In accordance with data of drilling in the area, the basalt rock bodies have a thickness of 150-300 m intercalated with a lot of layers of agglomerate, and it seems that the basalt rocks composed of many lava flow layers which are intercalated with pyroclastic rocks.

2. Geology of the Caliraya Dam

The drilling cores of the dam, east and west dykes were checked at the site. The results of check are as follows:

The location of the drilling is shown on Fig.III-1.

(1) Dam

- DDH-D-1 : All are of fill materials, but core recovery is not good
- DDH-D-2 : It seems the drilling reach to the base andesite (Basalt) at 13.5 m in depth
- DDH-D-3 : Reach to base andesite (Basalt) at 2.15 m in depth
- DDH-D-4 : Reach to base rock at 41.0m in depth

DDH-D-5	:	From top to 25.0 m in depth is fill material (Geological log show 21.5m in depth, but cores show 25.0m)
DDH-D-6	:	Reached to the filter material at the base of drilling, and so recognizes this drilling reached to the base rock

(2) East Dyke

ED-1	:	0 - 4.15m	Red soil
		- 10.60	Weathered Agglomerate (pale brownish)
		- 12.15	Andesite or Basalt (pale brownish yellow)
		- 19.50m	Andesite (Basalt) Agglomerate (moderately weathered and weak)
		- 27.90	Alternation of Lapilli tuff, Tuff breccia and Welded tuff
		- 30.80	Basalt or Andesite
ED-2	:	0 - 3.20m	Red soil
		- 13.00	Weathered Agglomerate Agglomerate
		- 31.50	Fresh Porphyritic Basalt
		- 35.0	Fresh Basalt
ED-3	:	0 - 2.15m	Top soil
		- 6.15	Weathered Agglomerate
		- 8.35	Moderately weathered Agglomerate
		- 24.90	Fresh Basalt (Core recovery is not good)
		- 32.70m	Slime, but perhaps Sandy tuff
		- 38.0	Vesicular pink Basalt (Andesite)

	- 41.0	Vesicular pale bluish Basalt
	- 44.0	Sandy tuff
	- 45.5	Vesicular Basalt

(3) West Dyke

WD-1 :	0 - 21.0m	Fill material (0-4.0 contains many boulders)
	- 32.85	Weathered Agglomerate (Recognized as base rock)
	- 56.45	Fresh Basalt (R.Q.D. is not good)
WD-2 :	0 - 5.15m	Fill material
	- 17.0	Completely weathered Agglomerate
	- 25.0	Weathered Agglomerate
	- 26.50	Agglomerate
	- 52.0	Fresh Basalt
WD-3 :	0 - 3.0m	Red soil
	- 11.6	Weathered tuff breccia
	- 18.3	Agglomerate (R.Q.D. is not good)
	- 36.0	Basalt

(4) West Wing of Dam

DDH-DK-1 :	0 - 9.0m	Fill material
	9.0 - Bottom	Highly weathered Agglomerate (moderately reddish brown)
DDH-DK-2 :	0 - 6.7m	Fill material
	6.7 - Bottom	Weathered Agglomerate (pink colour) Around 6.7m, there are remains of plant roots, and shows that this portion corresponds to older ground surface

DDH-DK-3 :	0 - 3.3m	Fill material
	- 3.6m	Filter material (Dark gray sand and pebble)
	- Bottom	Base rock

As to the drilling cores of the Caliraya Dam, it is very difficult to distinguish fill materials from highly weathered agglomerate which composes the dam foundation. Because fill materials borrowed from the hill on the way from the Caliraya Reservoir to the Lumot Reservoir are quite resemble to the in-situ agglomerate which is completely decomposed into pink coloured clayey materials with strip pattern of white clayey materials.

The actual mode of occurrence, the strip pattern of white clayey materials and the pink colour of the fill materials which are observed at the small pits of dam have a strong resemblance to the weathered agglomerate at the assumed borrow site although there are thin layers of silty sand materials which seem to be derived from weathered lapilli tuff, in the pits of dam body.

3. Geotechnical Consideration on Dam Body

At the downstream face of the Caliraya Dam, a lot of step faults like slidings are found parallel to the dam axis in the horizontal arrangement and also a small number of spring water were detected in some places of these slidings. These springs reportedly disappeared in the dry season.

The scale of these slidings is rather small and their maximum throws are less than 1.0m and direction of slides is toward the downstream toe.

By the precise observation at the test pits and exposure of small scraps of slidings, it was found that slidings were not structural and took place on the surface area of fill materials and did not proceed in a deeper portion of dam body at the time of this study.

The slides are caused by the separation of each small solid blocks of embankment materials surrounded by three joints.

That is to say, the first joint is perpendicular to the axis of dam with about vertical dip, and the second joint is parallel to the axis of dam with about 90° inclination, and the third joint almost corresponds to the boundaries of fill layers (sometimes incline about 20° from horizontal). The spacing of these joints range 1 to 15 cm. These joints should be developed genetically in construction stage. The small cubic or platy fill material blocks separated by these joints move a little in the wet season owing to an increase of vertical load and loss of frictional resistance which are brought by an intrusion of rain water into these joints.

In the dry season, these joints open a little by the shrinkage of each small fill material blocks and the openings develop a little toward inner side and also extend to the lateral direction. These phenomena are taking place cyclic in each of the wet and dry seasons resulting in an extension of sliding depth and area. These are specific phenomena in the tropical zone, and are found not only in the Caliraya Dam body but also in any other places where a disintegrated tuff breccia exposes on the surface. In order to prevent these phenomena, the downstream surface of the dam must be covered by filter and rockfill materials to keep moisture of embankment materials in a appropriate range.

4. Mineralogy of Borrow Materials

It is said that the fill materials were borrowed around the area of road cutting between the Caliraya Dam and the Lumot Dam. These materials consist of yellowish brown to reddish brown soils mainly derived from heavy weathered tuff breccia. The stratigraphy of this cutting is as follows:

On the uppermost of the cutting, there are 1.5 - 2.0m thick yellowish tuff which has rather small contents of breccia, and below this layer, 1.0m - 2.0m thick reddish brown tuff lies with basalt subangular blocks. These two layers seem to be conformable in each stratigraphical situation.

Below this reddish brown tuff there are heavily weathered tuff breccia with medium size breccia of white tuff as the lowest strata.

The lowest tuff breccia has a widest distribution and this has been used widely for fill materials of the Caliraya Dam. This tuff breccia disintegrated into fine grained clayey materials and has a sticky character.

In this exposure the lapilli tuff layer is not to be detected, however, judging from the existence of lapilli tuffacious materials in the pit samples of fill materials, the layers of lapilli tuff will be intercalated in the tuff breccia formation.

The tuff breccia sometimes called agglomerate but it seems reasonable to nominate these materials as tuff breccia judging from its lithological characters.

The component minerals of the samples collected from the old borrow area and the main dam body are checked by X-ray diffraction analysis about the existence of Montmorillonite which is liable to expand in wet conditions. The result is shown in TABLE IV-1.

This Table shows no containment of Montmorillonite.

TABLE IV-1 List of Samples and Minerals

Sample No.	Sample Name	Locality	Sampling Date	Component minerals (by X-ray, microscope)
No.1	Yellow-brown lateritic soils (Upper)	Caliraya Borrow Pit	1985 10.28	Halloysite Meta-halloysite, quartz
No.2	Reddish-brown lateritic soils (Middle)	ditto	ditto	Halloysite, kaolinite Meta-halloysite, quartz
No.3	Reddish-brown lateritic soild (Lower)	ditto	ditto	Kaolinite, halloysite Meta-halloysite, quartz
No.4	Basalt	Valley at the up-stream of powerhouse	1985 10.29	Section A: plagioclase olivine Section B: plagioclase olivine, clinopyroxene
No.5	Lapilli Tuff	Embankment of Caliraya Dam	1985 10.30	Kaolinite, illite quartz
No.6	Lapilli Tuff	ditto	ditto	Kaolinite, quartz
No.7	River sand	Fine aggregate plant area	ditto	Pyhoxene, horn-plagioclase opaque mineral

V. RESULTS OF FIELD WORK

1. Sliding around the Reservoir

2. Results of Monitoring

3. Conditions and Causes of Damage at the Downstream Face of the Dam

4. Cracks in the Concrete Slab (Upstream Face of the Dam)

5. Spillway Facilities

V. Results of Field Work

1. Sliding around the Reservoir

1.1. Landslide at the Intake

On the right bank of the upper canal, about 500 m up-stream of intake of the Kalayaan Power Station, there is an old slided area.

The sliding had taken place during the excavation of the canal. The geology of this area seem to be tuff breccia and lapilli tuff but all rocks deeply weathered and changed into reddish brown to brown soil.

The slided area is composed of combination of two or three horse shoe shape slidings. The highest top of sliding scape is estimated about 60m from the canal water level. It seems that the sliding had taken place along small creek which branches into two smaller creeks at about 30m above canal. That is to say, the sliding should have taken place at the uppermost area of these two small creeks at first and then the slide materials run into a main creek. At present, some amount of spring water can be observed in the bottom of these two branch canals. It seems that after the sliding occurred at two branch creeks, the hill slope located between these two creeks slided.

At present, these slides are prevented by the rock fill in the downstream area of the two creeks and a few row of horizontal drain diches on the hill side. These prevention works are well contributing to the stability of hill slope, but some new small slidings are likely now taking place near the right bank shore of the canal and the disturbance of ground surface of the hill slope between two small creeks seems not to be stabilized. Therefore, future monitoring and surveillance of this slide area are very much important.

There are no other conspicuous slidings in the reservoir rim according to the observation from the boat.

1.2. Landslide on the Downstream Face of the East Dyke

A localized landslide was noticed at the downstream face of west end of east dyke which lies alongside the east side of the Dam. (See Figs. V-1 and V-2). This slide approx. 20 m wide, approx. 5 m high and approx. 15 m long as of end of December, 1985 has the characteristics of circle sliding. It lies above a gully in the original ground, into which slide material is deposited. Ground water is present at the foot of the slide, the front edge of the slide material being muddy.

To date, no measures have been taken to counter this slide, which has already extended 10 to 15 m from the downstream edge of the east dyke and endangers the stability of the dyke. The earliest possible rehabilitation measures are considered necessary.

2. Results of Monitoring

2.1. Underground Water Level in the Dam Body

Fig.V-3 shows the underground water levels observed during this study. Three (3) drilled holes were used for measurement. Since commencement of water level measurement, no underground water has been observed in hole CDB-No.3 having the most downstream location. This fact leads us to conclude that highly efficient drainage from drain layer occurs at the lowest part of the dam body.

In the other two (2) holes, some temporary raise of ground water table were observed, which is assumed to be caused by the rainfall. But overall observation shows a tendency towards gradual decrease of underground water level. Two (2) reasons are presumed for this. The first is that the measurement was commenced on the midst of rainy season and the rain water continuously penetrated in the dam embankment. The second is that the water level in the dam body which had temporarily raised due to the water supply at the drilling works, thereafter gradually decreased during observation.

In mid May 1986, a sudden raise of water level was observed in hole CDB-No.1. This may have been due to surface water soaking into the holes at times of heavy rain.

It is clear from this measurement that at present the seepage line in the dam body is not accross the downstream slope.

2.2. External Deformation of the Dam

Figs. V-4, V-5 and V-6 represent the displacement of the measurement points installed at the dam crest and the downstream slope at the middle elevation. Considerable variation was found both in the horizontal displacement and vertical displacement, especially during April to May 1986. These Figs. also indicate that the vertical displacement is remarkable throughout the entire measurement period from January to June 1986.

The reason for this large displacement may be that the ground dried and shrunk due to the change in season from rainy to dry. However, measurement itself may be the probable reason for this large displacement. Accordingly, it is necessary to continue the observation of the dam deformation by the proposed NAPOCOR Civil Engineering Monitoring Section.

2.3. Water Leakage from the Dam

Fig.V-6 represents the discharge variation measured at the new weir. This new weir was installed in the Study at the old river-bed at the downstream of the dam to measure water leakage from the dam body and its foundation and the water inflow from the ground surface including rainfall water, etc.

As seen in the variation, the discharge generally decreases from rainy season to dry season. This is a normal variation. However a very high discharge was observed in mid May (May 18, 1986), on the same day as the underground water level in CDB-No.1 hole extraordinarily increased. It indicates that on that date there was a mass of very concentric heavy rainfall in a very short time. Fig.V-7 is a detailed figure of this extraordinary leakage measurement.

3. Conditions and Causes of Damage at the Downstream Face of the Dam

There are many traces of small slides spread over at the downstream face of the Dam. These are generally 20 to 70 cm deep, 2 to 3 m wide and 2 to 20 m long. Most are aligned horizontally (the direction of dam axis) rather than vertically.

The downstream face of the dam is turfed and covered with top soil of 30 to 50 cm in thickness and the underlying materials of the compacted dam body are exposed.

Innumerable shrinkage cracks appear in this exposed material, which is therefore fragmented in small pieces. These blocks are easy to detach, but the exposed surface itself remains firm. A man's footmarks make no imprint even on the wet exposed surface after rain.

Grain size analysis on the embankment materials collected at the test pit (2.0 m depth) on the downstream middle berm (EL.277.5 m) of the dam shows that the materials consist of very fine grains, and that 20 to 30 per cent of the materials have a grain diameter of 0.001 mm or less.

Mineral analysis by X-ray diffraction shows that the embankment materials are mainly composed of kaolinite including a small quantity of illite and quartz grain but no montmorillonite.

These materials are judged to have a 90% of liquid-limit and approx. 45% of plasticity index and 49% of natural water content, classified as MH according to the unified classification.

On the other hand, the triaxial compression test indicates that the mechanical characteristic values of these materials are 2.9 to 3.1 t/m^2 of cohesion and 33.6 to 32.1 degrees of internal friction angle, larger than expected. The reason for such a large internal friction angle appears to be that the clay minerals in the embankment are mainly composed of kaolinite, and the embankment materials have a good grading distribution.

The underground water level was measured by a ground water level recording device installed along the maximum dam cross-section. Judging from the results, the seepage line from the reservoir will not cross the downstream face of the dam. The above-mentioned sliding traces also occur above the high reservoir water level, with the same scale and distribution density. This fact tends away from the conclusion that leakage from the reservoir is the cause of these small slides.

No sliding plane was found and the exposed face remains comparatively hard, therefore so-called "slip circle sliding" is not considered to be a problem.

The most likely cause of sliding is erosion by rainwater over the surface. As described above, the downstream face is turfed. This turfed area is used as a grazing ground for domestic animals such as carabaos and goats belonging to local farmers. In fact, during the field investigation the JICA Survey Team saw carabaos around the downstream face. The Team also noticed some water wallow holes dug by carabaos on the downstream face of the dam. This indicates that carabaos have been grazing this area for some time.

These animals have walked around the face of slope after rain, made footmarks on the surface and caused much damage. This damage gradually extends and develops through erosion from rainwater. Only a few shrinkage cracks from the effects of drying were noticed in the turf soil, but the generation of such cracking was more noticeable in the dam embankment material beneath the turf soil. As mentioned above, this dam embankment material is easily detachable and borken into small pieces. This occurs naturally from gravity and rain-water, and the erosion of the exposed surface is more serious in the vertical direction than in the horizontal direction. It is estimated therefore that the top edge of the damaged portion will erode away in an upward direction. The process of erosion on the downstream face of the Caliraya Dam is shown in Fig.V-8.

Many errosion points were detected on the downstream face of dam in August 1983. During the reconnaissance survey in October, JICA Team found some errosion points about 60 cm in depth. This damage evidently first occurred in the wet season 1983 - 1984. It was not apparent in 1983. Therefore it seems that erosion on the downstream face will proceed at about 30 cm per year unless treatment is carried out.

Errosion this type generally proceeds slowly at first, accelerating later. The distance from the downstream face of dam to the permeation line of dam body is about 5.5 m at present and will become zero after 18 years with an intersection of the permeation line and the erosion face in case of continuous erosion rate of 30cm/year.

When the underground water level of dam body reaches the face of downstream slope, the sliding safety factor of dam slope will be 0.964 (refer to FIG.VII-4) at earthquake (K=0.15) while the safety factor of dam slope without erosion is 1.558 (refer to FIG.VII-3).

Therefore, the sliding safety factor of downstream slope of dam will decrease year by year and is provably below 1.2 at earthquake after 10 years on the assumption that the safety factor decreases 0.033* per year. This advocates the necessity of immediate repair work.

* (1.558 - 0.964) ÷ 18

4. Cracks in the Concrete Slab (Upstream Face of the Dam)

In October 1985 when the JICA Survey Team made its field investigation, the reservoir was at almost high water level, so it was not possible to examine the large cracks. According to NAPOCOR's data, the cracks are in a limited area. (See Fig.V-9).

Fig.V-9 represents the cross-section of the dam body, where numerous cracks were observed. As seen in this Figure, cracks occur mainly at the point directly above the shoulder of the original ground line, which descends towards the upstream direction.

Generally, settlement due to consolidation continues after completion of embankment. As shown on the section in Fig. V-9 the height of the embankment above the foundation surface is greater at the upstream side (lower portion) of the dam. Therefore, settlement value of the dam embankment was greater at the lower elevation, and the concrete slab on the face was pulled by this uneven settlement in a downward (upstream) direction. This has resulted in opening of construction joints and shearing of the concrete slab. In the Caliraya Dam, the plates used for the slab joints are iron plates, which are easily corrosive. In time, the slab joints have developed to open and embankment material beneath the damaged concrete slab has been washed away by wave action. It is assumed that the present damage at the concrete slab was produced as a result of the above described process. This indicates that the protection work of the dam upstream face is partly damaged. It is recommended therefore that the cracks should be repaired at a time when the reservoir water level can be lowered to less than EL.282.0. However, if the water level could not be lowered for reasons of the reservoir operation, it is proposed that sand and