*Chapter 3*

# POWERHOUSE

## Chapter 3 Powerhouse

This chapter is prepared to supplement planning of the powerhouse of the Jatibalang Multipurpose Dam in terms of civil engineering design.

### 3.1. Scope of Design

The powerhouse dealt within this chapter includes the structures from some part of the penstock to the end of the tailrace. The following structures, therefore, are designed and presented in this chapter.

(1) Penstock : The penstock from just 2 m upstream of the powerhouse to the inlet valve

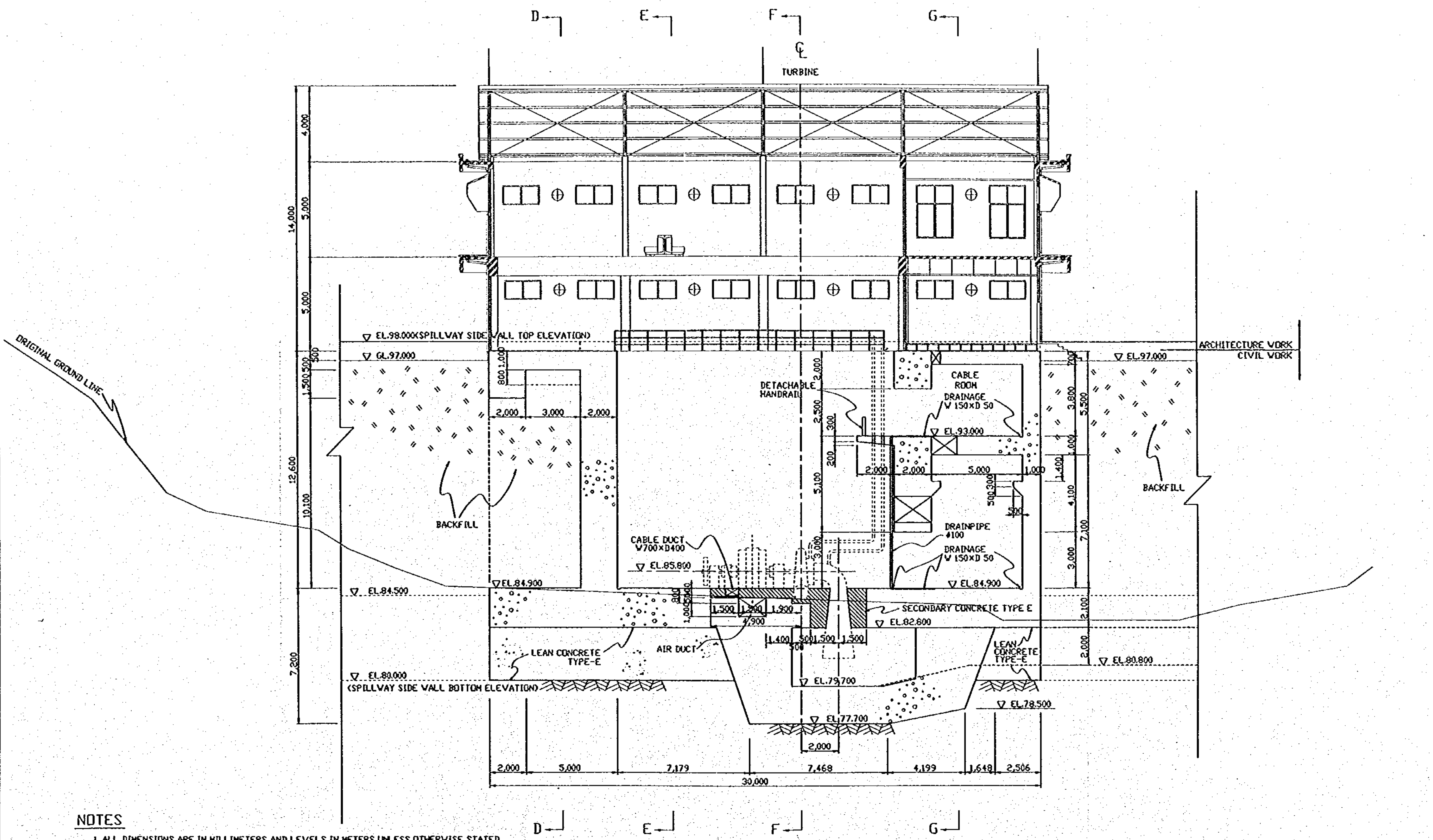
(2) Powerhouse : The structure below EL. 98.00 excluding architectural works above EL. 97.50

(3) Tailrace : The draft pit and the tailrace culvert under the powerhouse is designed and the reinforcement for the tailrace passing through the foot of spillway was studied.

(4) Tailrace Gate

For the design of the above structures, water hammer analysis was carried out. The head loss was also calculated to seek the installed capacity and energy to be produced by the powerhouse.

The concrete outline and reinforcement of the structures are shown in Figs.3.1.1 to 3.1.13.




## SECTION A-A

SCALE 0 5 10 m

Fig. 3.1.1 Powerhouse Concrete Outline - Profile

## NOTES

1. ALL DIMENSIONS ARE IN MILLIMETERS AND LEVELS IN METERS UNLESS OTHERWISE STATED.
2. CONCRETE SHALL BE OF TYPE-B AS PER SPECIFICATIONS UNLESS OTHERWISE DESIGNATED IN THE DRAVING.
3. THE TURBINE,GENERATOR AND ACCESSORIES SHOW IN THIS DRAVING ARE SUPPLIED BY OTHER CONTRACTOR AND INSTALLED BY THE CIVIL CONTRACTOR.
4. FLOOR ELEVATIONS INCLUDE THICKNESS OF FLOOR FINISHES. FOR DRAINAGE PURPOSES, FLOOR SHALL BE SLOPED AS REQUIRED AND DIRECTED BY THE ENGINEER.
5. ALL EXPOSED EDGES AND CORNERS SHALL BE CHAMFERED BY 2 CENTIMETERS UNLESS OTHERWISE NOTED.
6. SURFACES OF THE OUTRE VALLS BELOW EL.96.70 SHALL RECEIVE CLASS1 SURFACE FINISH AND OF THE INNER VALLS CLASS2 SURFACE FINISH.
7. THE FLOORS OF CIVIL VORK SHALL BE COLORED VITH IVORY BY DUST-TIGHT PAINT AND THE BATTERY ROOM'S FLOOR AND INNER VALLS SHALL BE COATED VITH ANTI-ACID PAINT FROM EL.93.00 TO EL.94.800

## REFERENCE DRAWINGS

JD-P1-HS-P1-1 GENERAL PLAN OF POVERHOUSE AREA
JD-P1-HS-St-3 POVERHOUSE-CONCRETE OUTLINE-SECTIONS(1/2)
JD-P1-HS-St-4 POVERHOUSE-CONCRETE OUTLINE-SECTIONS(2/2)
JD-P1-HS-St-5 POVERHOUSE-CONCRETE OUTLINE-PLAN

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JRATUNSELUNA FLOOD CONTROL PROJECT
COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE CONCRETE OUTLINE
PROFILE

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CTI ENGINEERING CO.,LTD. IN ASSOCIATION WITH
PACIFIC CONSULTANTS INTERNATIONAL AND
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PROJECT MANAGER

PROVINCE: CENTRAL JAVA
PROJECT NAME: FLOOD CONTROL, URBAN DRAINAGE AND WATER RESOURCES DEVELOPMENT IN SEMARANG IN THE REPUBLIC OF INDONESIA
DISTRICT: SEMARANG CITY
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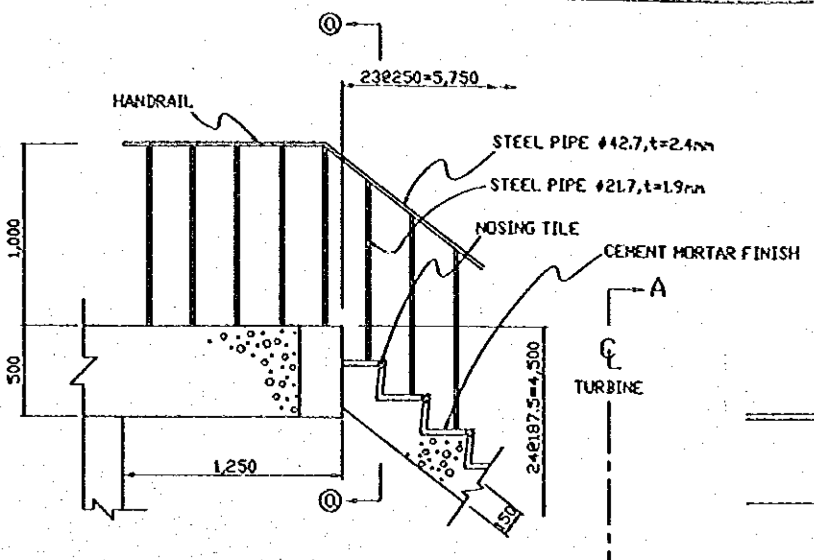
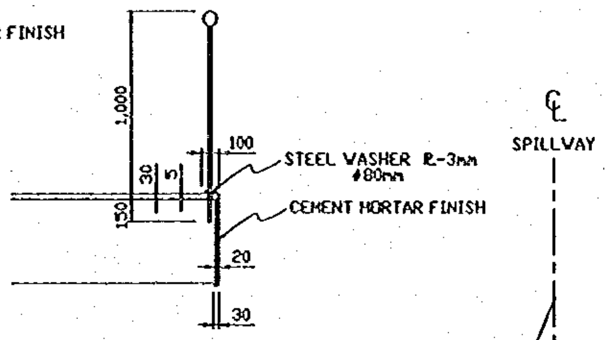
DATE
CONTRACT NO.



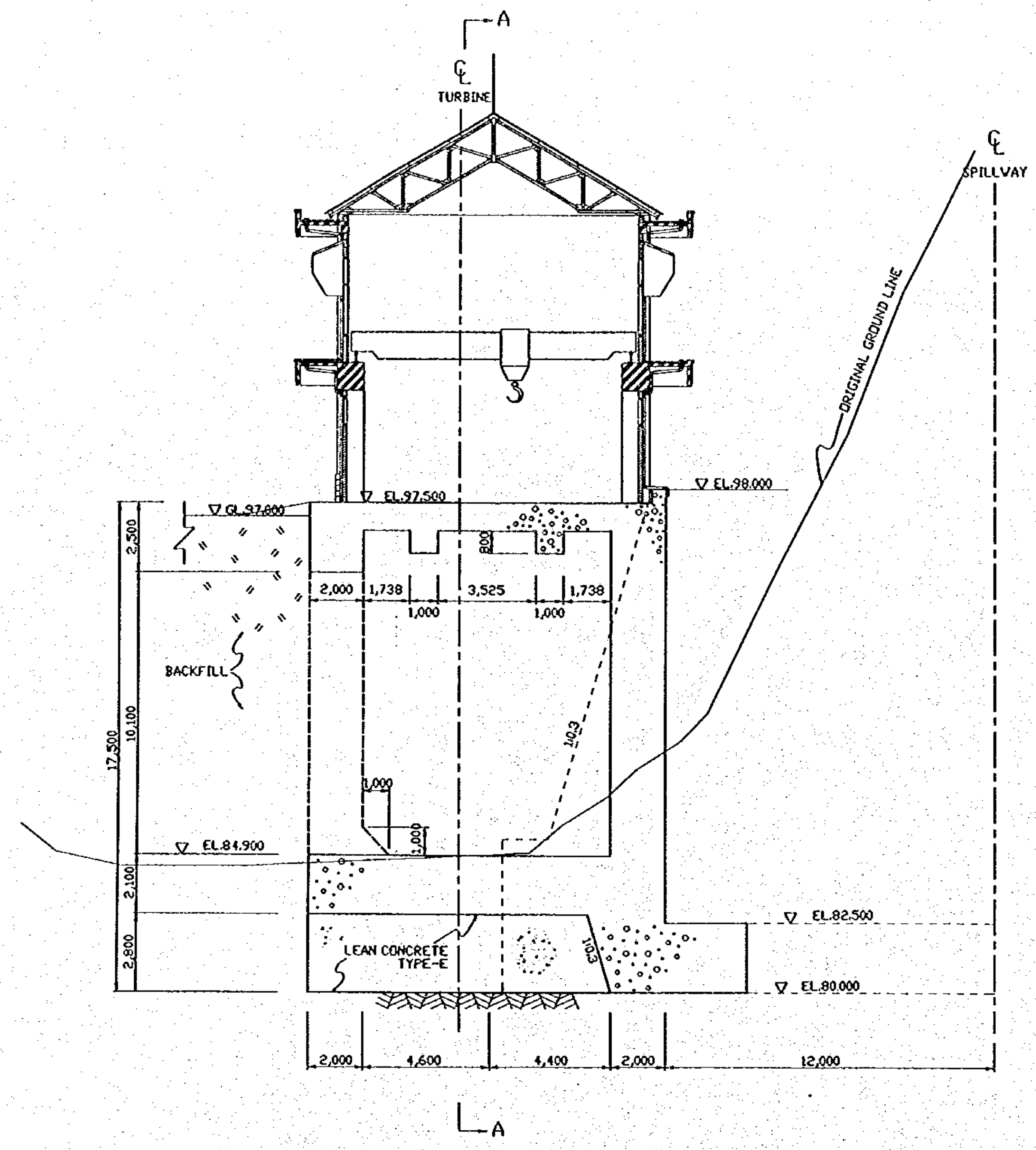

## DETAIL "a"

SCALE B



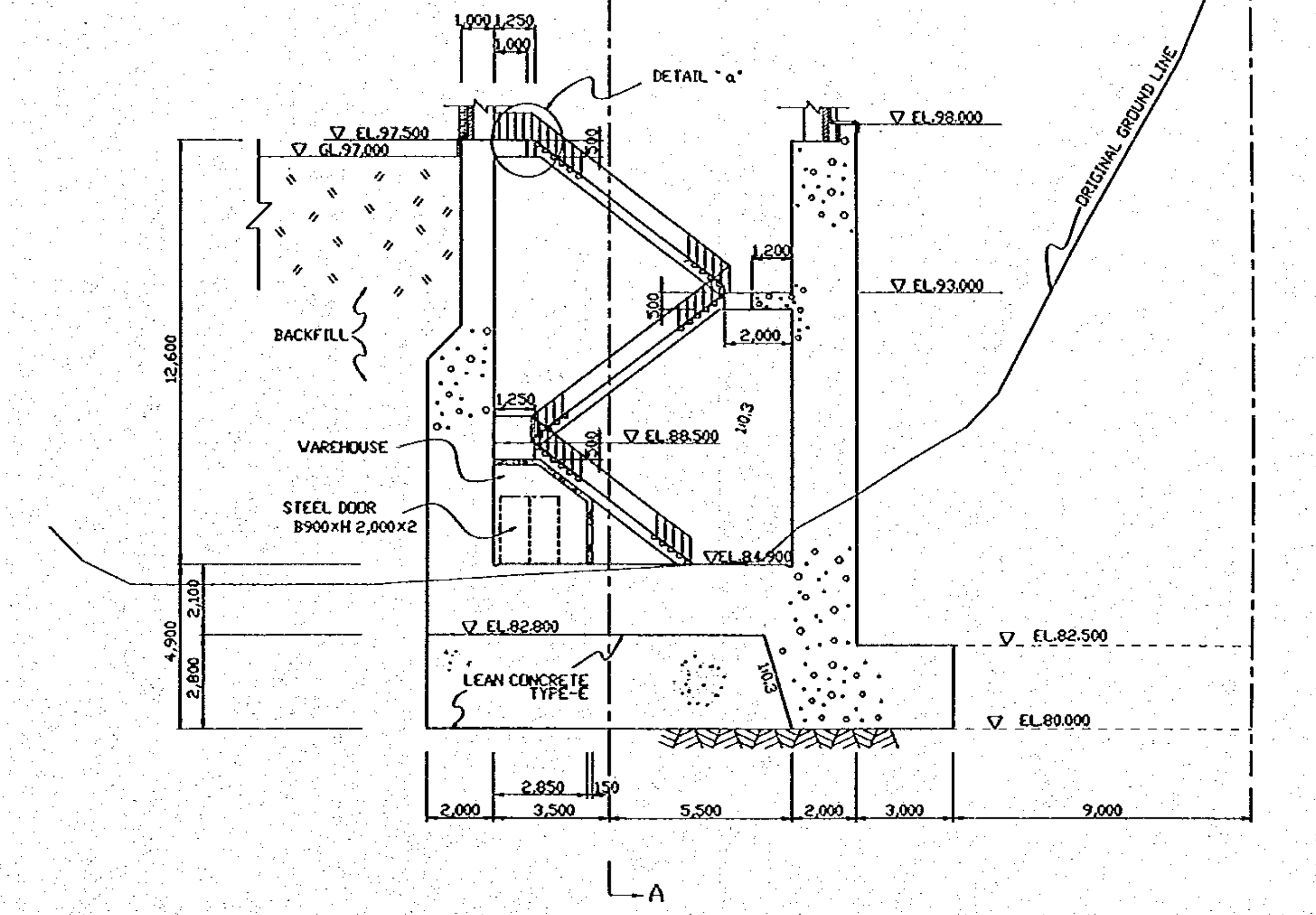

## SECTION @-@

SCALE B




## SECTION D-D

SCALE A




## SECTION E-E

SCALE A

SCALE A 0 5 10 m

SCALE B 0 0.5 1 1.5 2 m

## NOTES

1. HANDRAILS, STEEL DOORS FOR WAREHOUSE AND OTHER STEEL MEMBERS SHALL BE PAINTED BY THE PAINT MATERIAL SPECIFIED IN THE TECHNICAL SPECIFICATION.

## REFERENCE DRAWINGS

JD-PI-HS-PI-1 GENERAL PLAN OF POWERHOUSE AREA
JD-PI-HS-St-2 POWERHOUSE-CONCRETE OUTLINE-PROFILE
JD-PI-HS-St-4 POWERHOUSE-CONCRETE OUTLINE-SECTIONS(2/2)
JD-PI-HS-St-5 POWERHOUSE-CONCRETE OUTLINE-PLAN
JD-PI-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN

Fig. 3.1.2 (1/2) Powerhouse Concrete Outline - Sections

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POWERHOUSE CONCRETE OUTLINE
SECTIONS (SHEET 1 OF 2)

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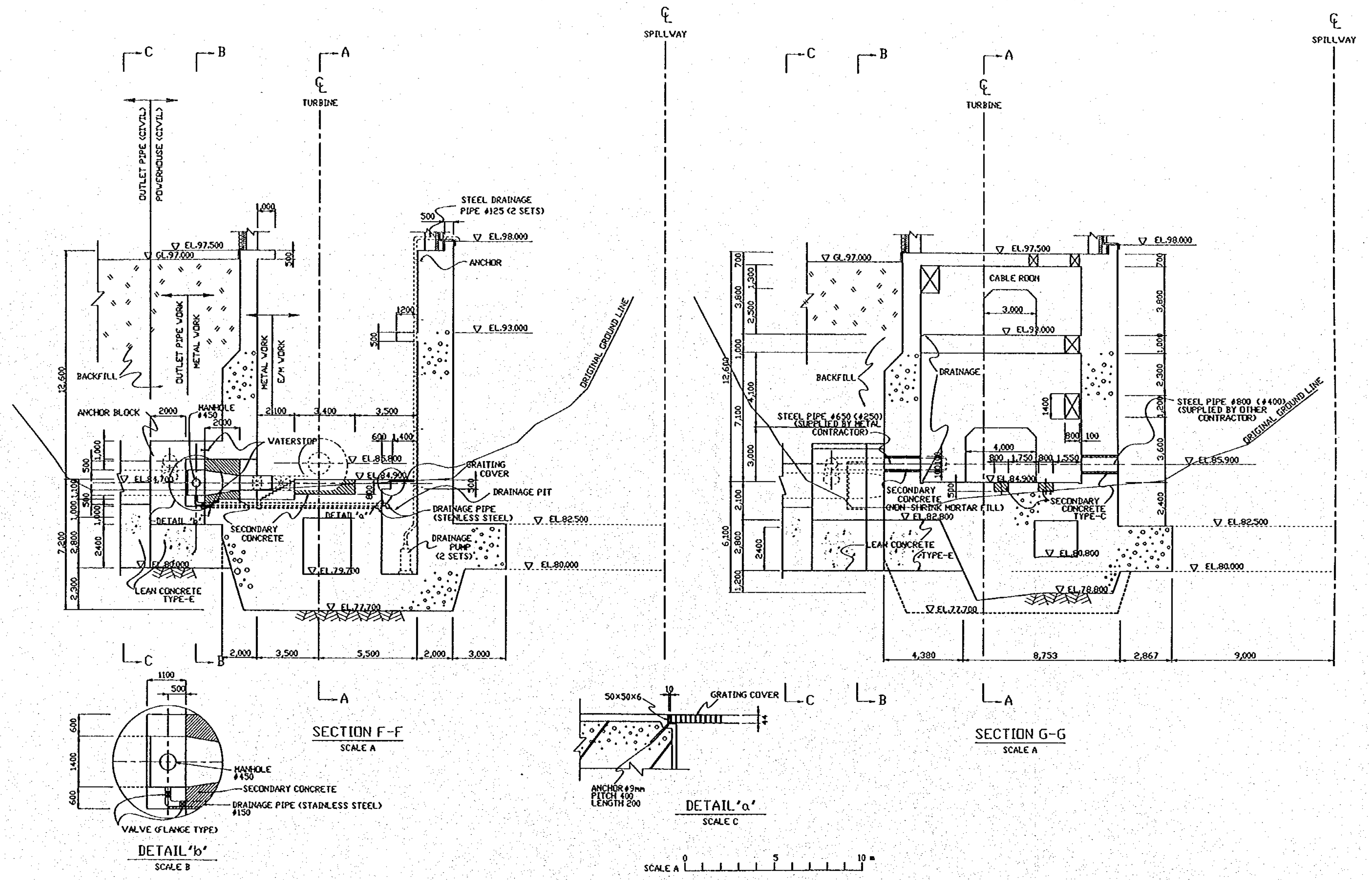
DATE
CONTRACT NO.




## NOTES

1. THE PENSTOCK, INLET VALVE, TURBINE, DRAINAGE PUMPS AND STAINLESS STEEL DRAINAGE PIPES SHOWN IN THIS DRAWING ARE SUPPLIED BY E/M AND METAL CONTRACTOR AND INSTALLED BY THE CIVIL CONTRACTOR.
2. GRATING COVER SHALL BE GALVANIZED.

## REFERENCE DRAWINGS

JD-P1-HS-St-2 POWERHOUSE-CONCRETE OUTLINE-PROFILE
JD-P1-HS-St-3 POWERHOUSE-CONCRETE OUTLINE-SECTIONS(1/2)
JD-P1-HS-St-5 POWERHOUSE-CONCRETE OUTLINE-PLAN
JD-P1-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN

Fig. 3.1.2 (2/2) Powerhouse Concrete Outline - Sections

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JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE CONCRETE OUTLINE
SECTIONS (SHEET 2 OF 2)

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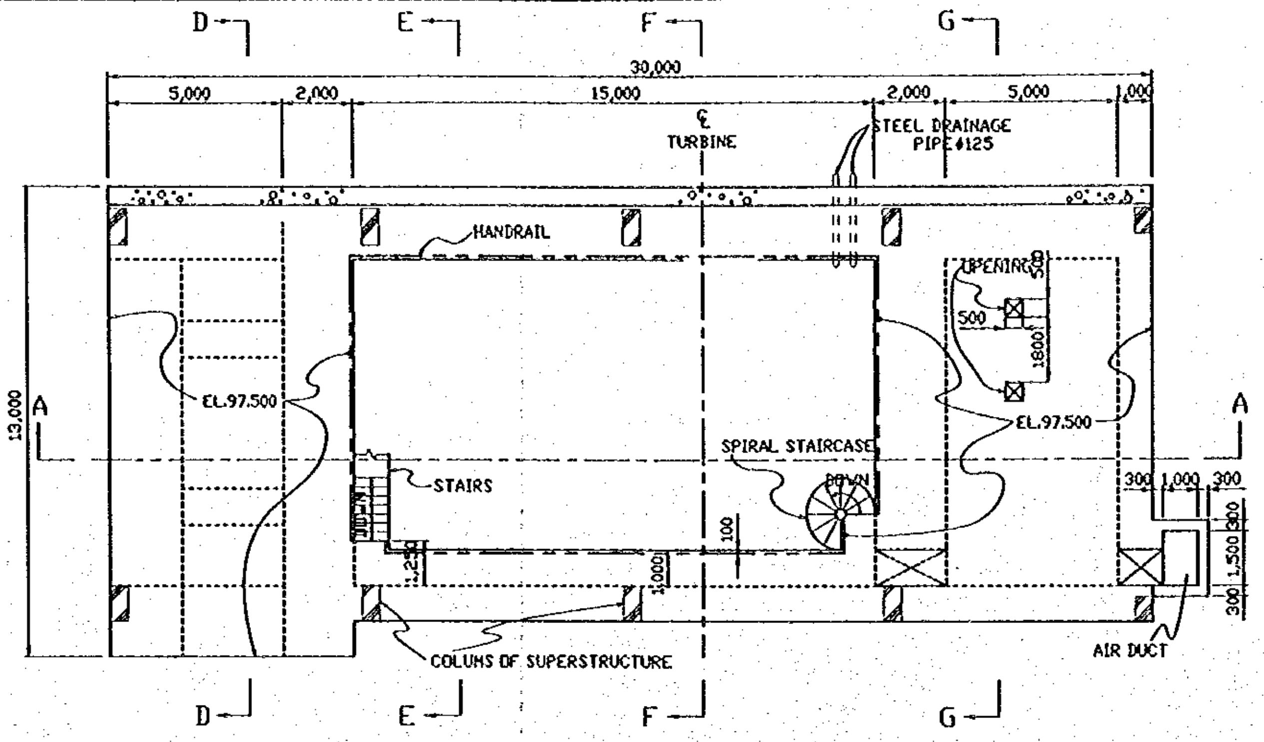
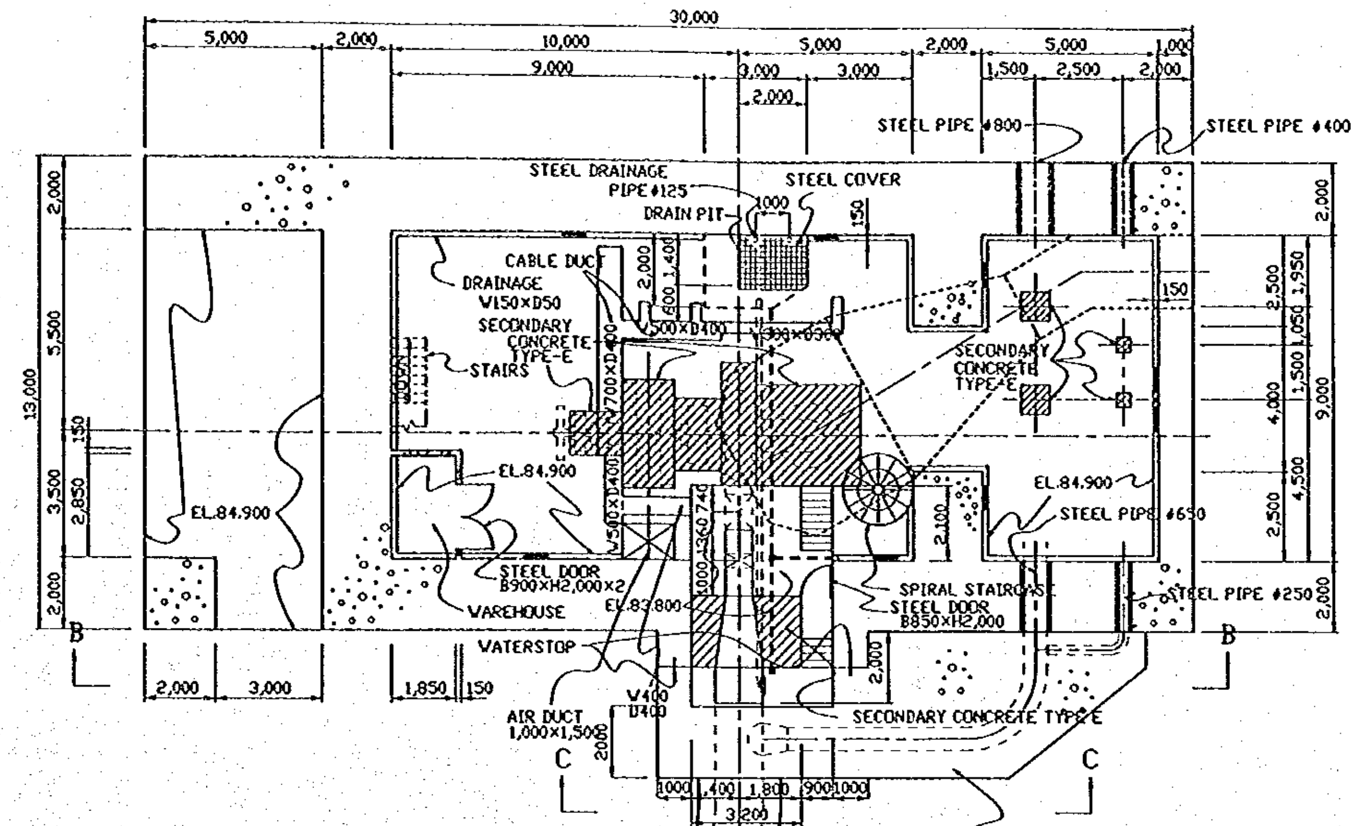
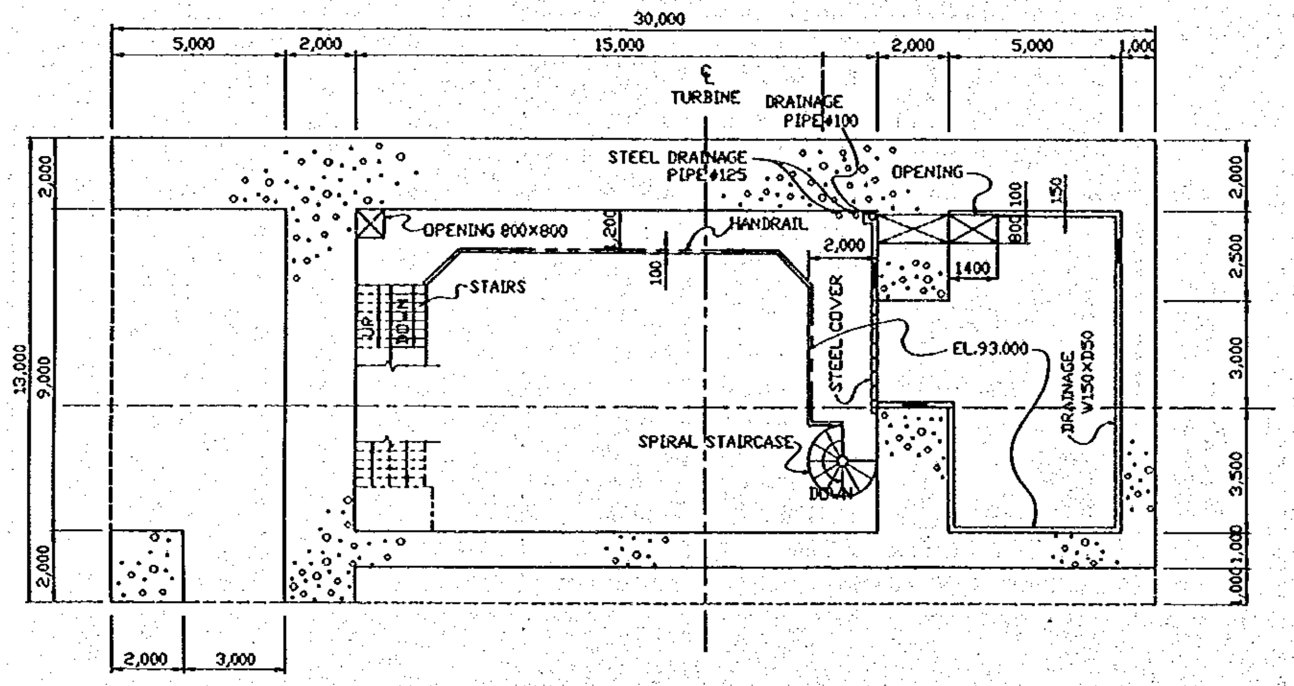
DATE
CONTRACT NO.



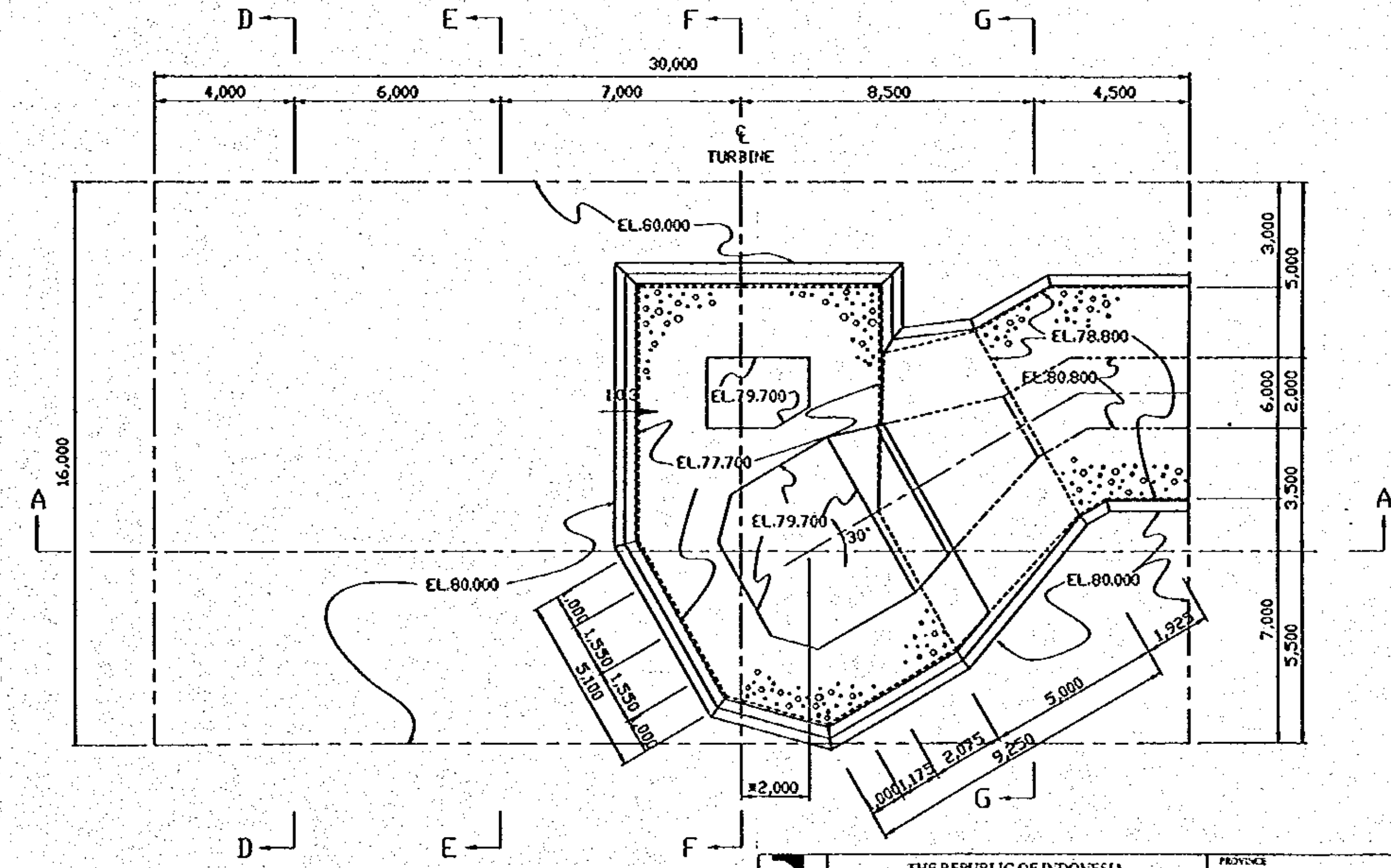

EL.97.500 FLOOR




EL.84.900 FLOOR




EL.93.000 FLOOR




EL.80.000 FLOOR

## NOTES

1. THE DIMENSION MARKED WITH * AND RELATED DIMENSIONS MAY BE CHANGED DEPENDING ON THE SIZE OF A TURBINE.
2. THE STEEL PIPES SHOWN IN EL.84.900 FLOOR SHALL BE EMBEDED AT THE EL.85.900 WHICH ARE SUPPLIED BY OTHER CONTRACTOR.

## REFERENCE DRAWINGS

- JD-Pl-HS-Pl-1 GENERAL PLAN OF POWERHOUSE AREA
- JD-Pl-HS-St-2 POWERHOUSE-CONCRETE OUTLINE-PROFILE
- JD-Pl-HS-St-3 POWERHOUSE-CONCRETE OUTLINE-SECTIONS(1/2)
- JD-Pl-HS-St-4 POWERHOUSE-CONCRETE OUTLINE-SECTIONS(2/2)
- JD-Pl-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN

SCALE 0 5 10 m

Fig. 3.1.3 Powerhouse Concrete Outline - Plan

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JRATUNSELUNA FLOOD CONTROL PROJECT
COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE CONCRETE OUTLINE
PLAN

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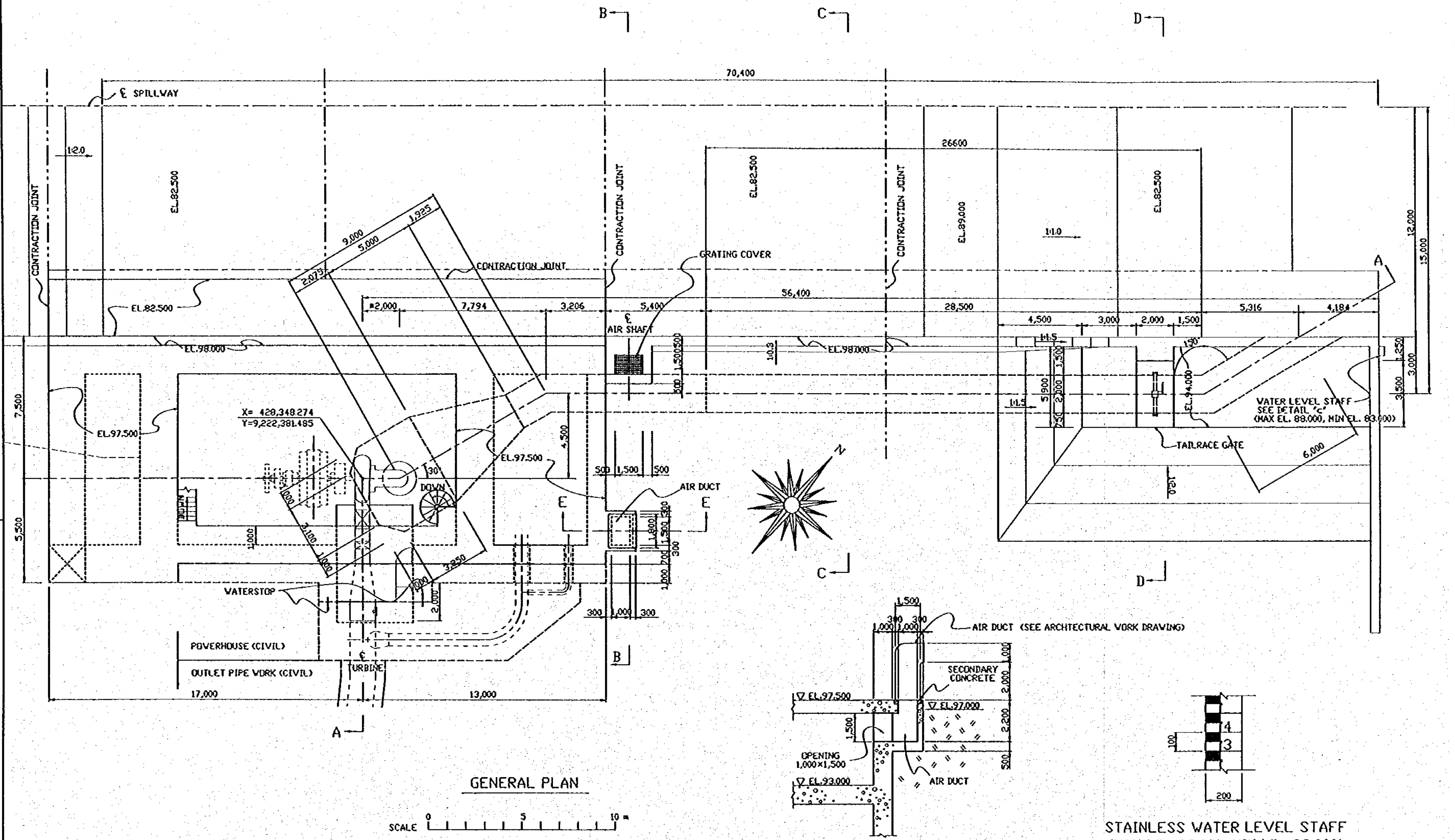
SHEET NO.
DATE | CONTRACT NO.




## GENERAL PLAN

SCALE 0 5 10 m



## SECTION E-E



STAINLESS WATER LEVEL STAFF
(MAX WL. 88.000, MIN WL. 83.000)

## DETAIL 'c'

## NOTES

1. THE ARCHITECTURAL WORK OF THE POWERHOUSE IS NOT SHOWN IN THIS DRAWING.
2. BACKFILL TO BE FILLED UP TO EL.97.000 IS NOT SHOWN IN THIS DRAWING.
3. THE DIMENSION MARKED WITH * AND RELATED DIMENSIONS MAY BE CHANGED DEPENDING ON THE SIZE OF A TURBINE.

## REFERENCE DRAWINGS

| | |
|---|---|
| JD-PI-HS-PI-1 | GENERAL PLAN OF POWERHOUSE AREA |
| JD-PI-HS-St-7 | POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-PROFILE |
| JD-PI-HS-St-8 | POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-SECTIONS |
| JD-PI-HS-St-9 | POWERHOUSE AND TAILRACE-TAILRACE GATE |

Fig. 3.1.4 Powerhouse and Tailrace - General Plan

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JRATUNSELUNA FLOOD CONTROL PROJECT
COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE AND TAILRACE
GENERAL PLAN

PROVINCE: CENTRAL JAVA
DISTRICT: SEMARANG CITY

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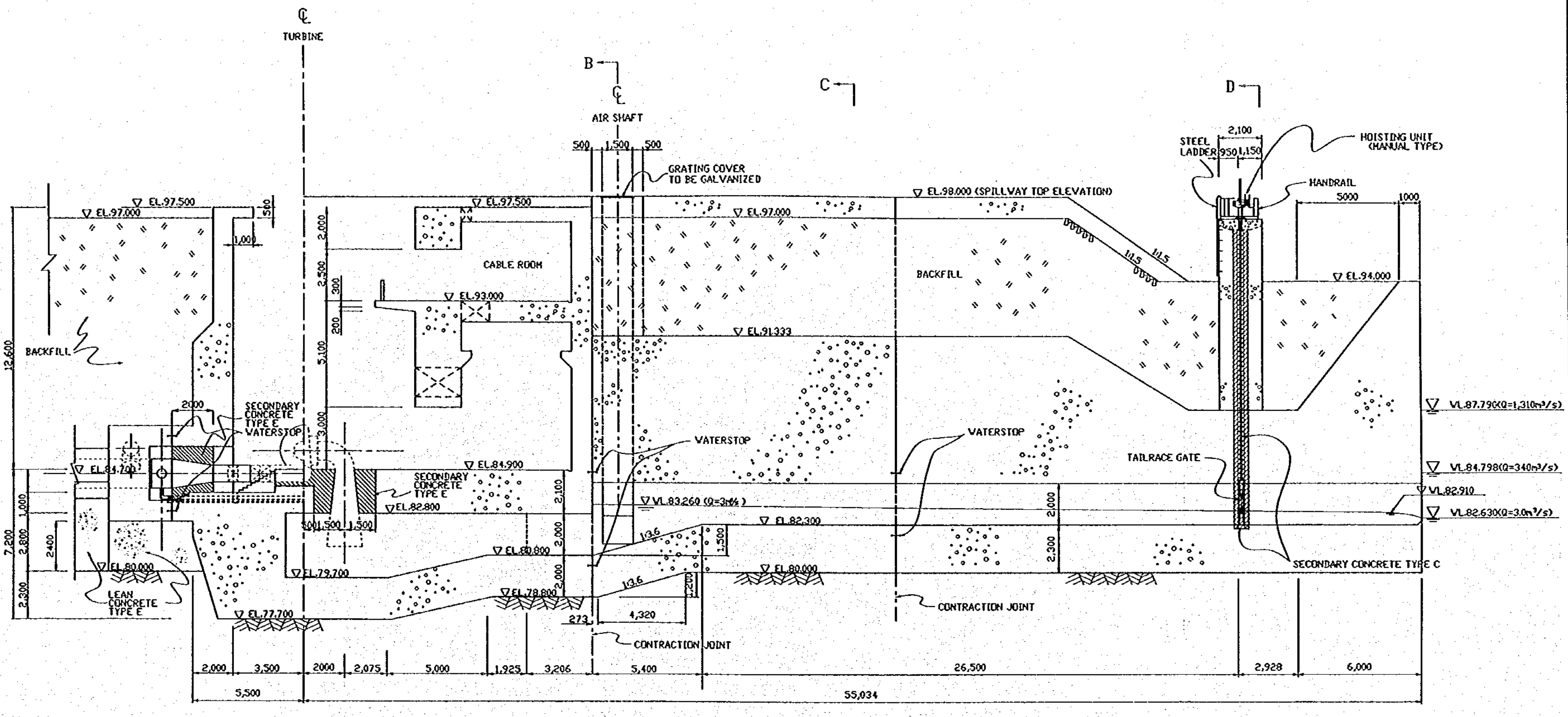


SECTION A-A

SCALE A

Fig. 3.1.5 Powerhouse and Tailrace Concrete Outline - Profile

SCALE A 0 5 10 m

## REFERENCE DRAWINGS

JD-P1-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN
JD-P1-HS-St-8 POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-SECTIONS
JD-P1-HS-St-9 POWERHOUSE AND TAILRACE-TAILRACE GATE

| NO | DATE | REVISIONS | ORIGINATED | DESIGNED | APPROVED |
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COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE AND TAILRACE
CONCRETE OUTLINE
PROFILE

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CTI ENGINEERING CO.,LTD. IN ASSOCIATION WITH
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PASCO INTERNATIONAL INC.

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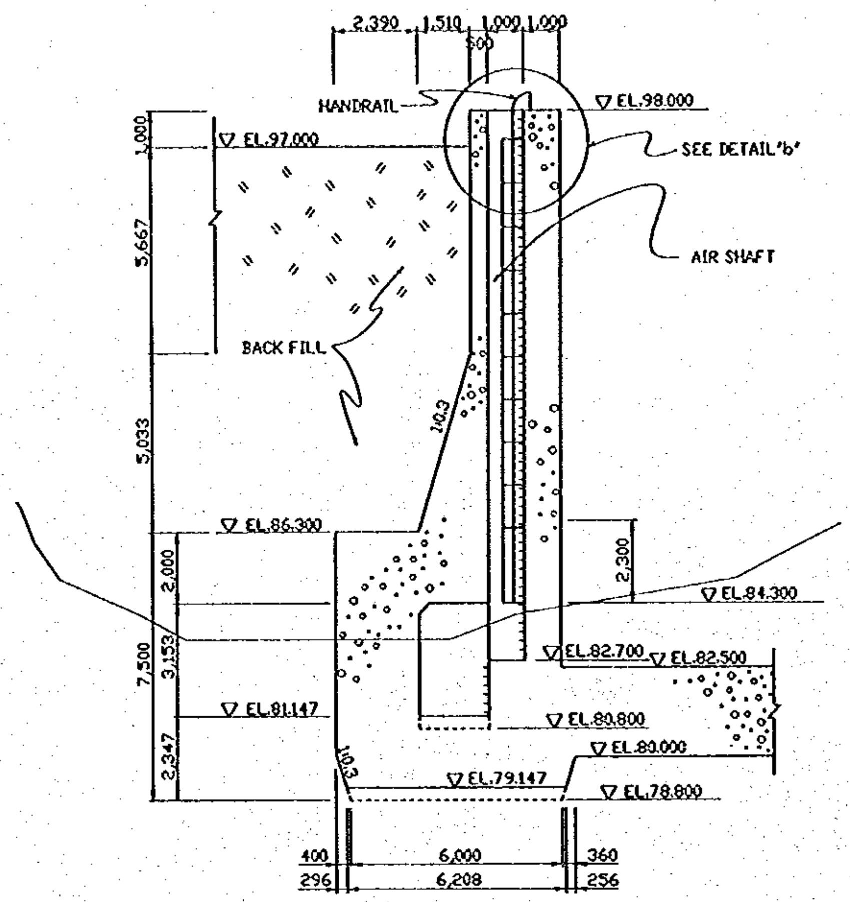
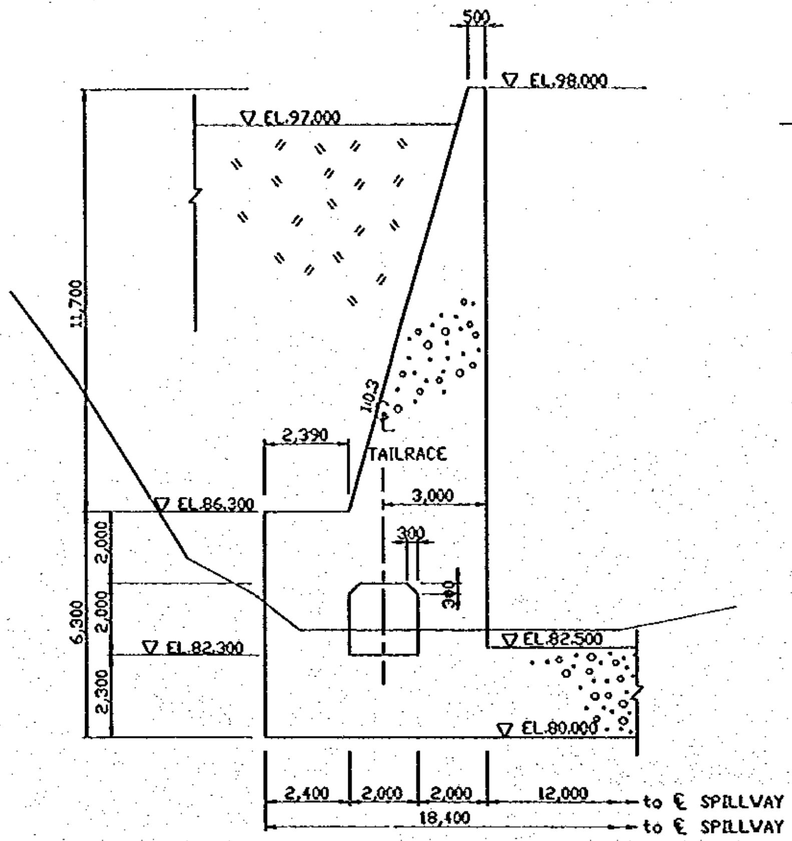
CHIEF OF PLANNING AND DESIGN
PROJECT MANAGER

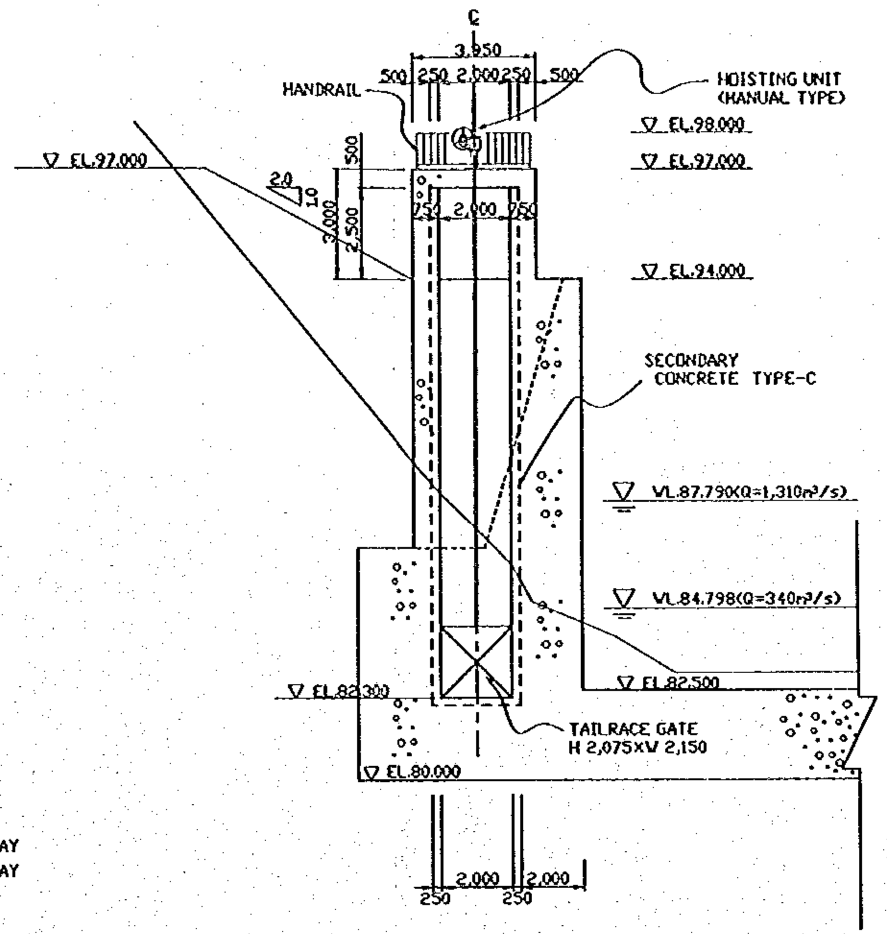
PROVINCE: CENTRAL JAVA
PROJECT NAME: FLOOD CONTROL, URBAN DRAINAGE AND WATER RESOURCES DEVELOPMENT IN SEMARANG IN THE REPUBLIC OF INDONESIA
DISTRICT: SEMARANG CITY
DRAWING NO. JD-P1-HS-St-7
SHEET NO.
DATE
CONTRACT NO.



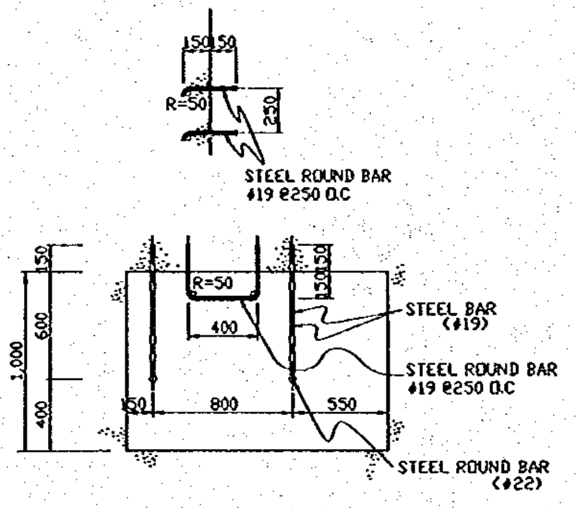

SECTION B-B
SCALE A



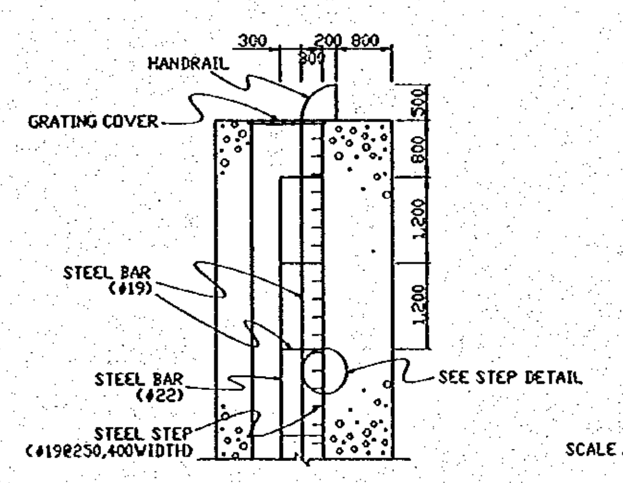

SECTION C-C
SCALE A



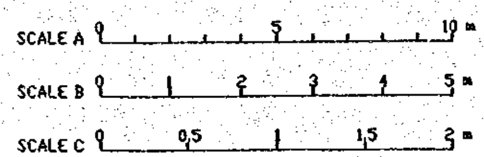

SECTION D-D
SCALE A




STEP DETAIL
SCALE C




DETAIL'b'
SCALE B




## REFERENCE DRAWINGS

JD-P1-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN
JD-P1-HS-St-7 POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-PROFILE
JD-P1-HS-St-9 POWERHOUSE AND TAILRACE-TAILRACE GATE

Fig. 3.1.6 Powerhouse and Tailrace Concrete Outline - Sections

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JRATUNSELUNA FLOOD CONTROL PROJECT
COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE AND TAILRACE
CONCRETE OUTLINE
SECTIONS

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DISTRICT: SEMARANG CITY
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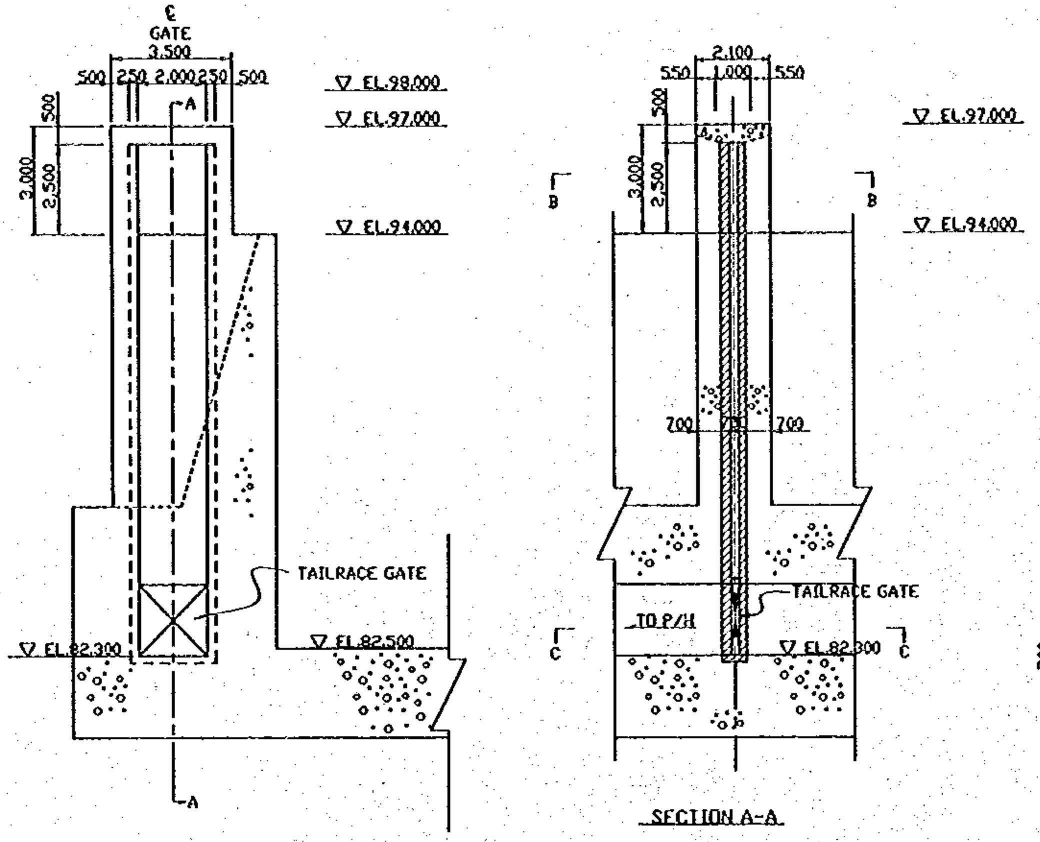
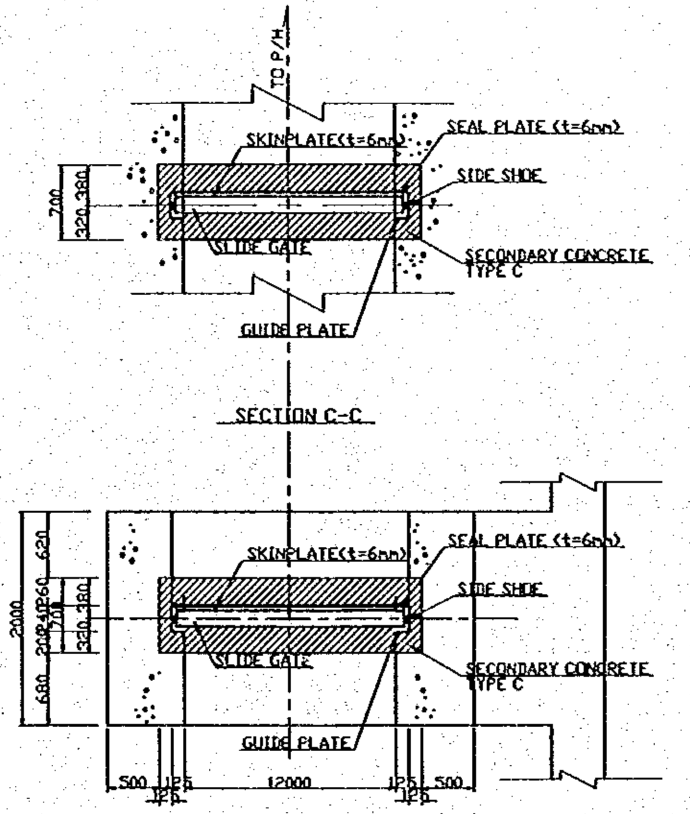
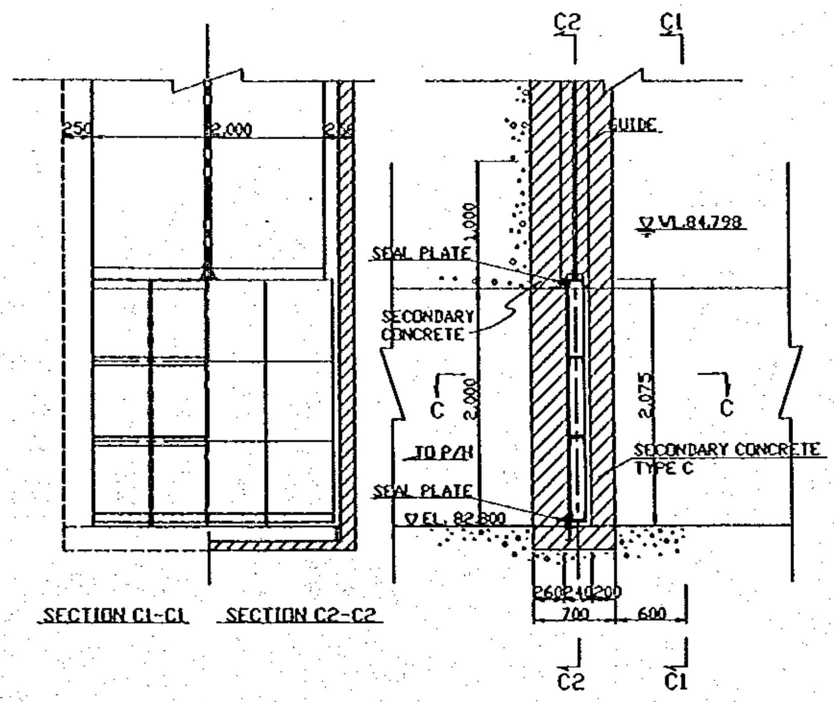



## PROFILE AND SECTION OF TAILRACE GATE TOWER

SCALE A

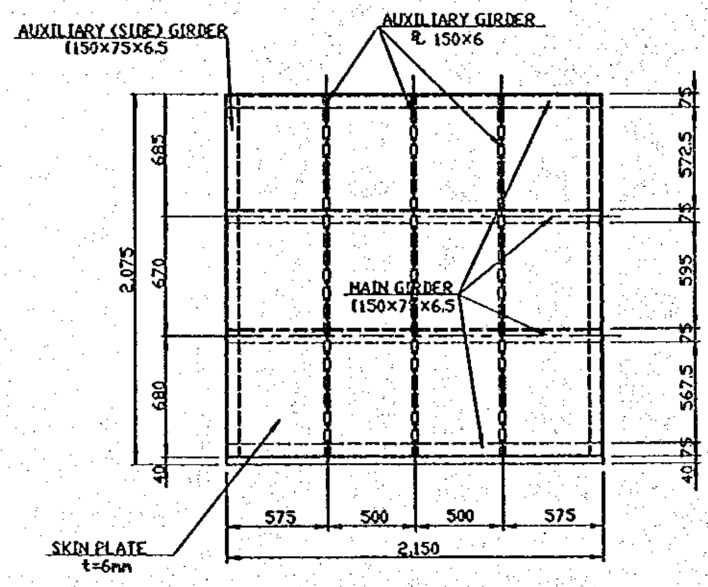
| DESIGN CONDITION | |
|---|---|
| TYPE | STEEL SLIDE GATE |
| QUANTITY | 1 GATE |
| CLEAR SPAN | 2.000m |
| CLEAR HIGHT | 2.000m |
| GATE VIDTH | 2.150m |
| GATE HIGHT | 2.075m |
| DESIGN HEAD | 2.438m (100 YEAR RETURN PERIOD FLOOD) 5.490m (PMF) |
| HOYSTING SYSTEM | MANUAL OPERATION |



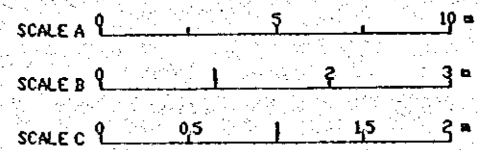

## TAILRACE GATE

SCALE B




## DIMENSION OF TAILRACE GATE

SCALE C




## NOTES

1. ANCHOR BARS TO FIX THE SEAL PLATES ARE NOT SHOWN IN THIS DRAWING. THESE ANCHOR BARS WILL BE SUPPLIED BY OTHER CONTRACTOR AND SHALL BE INSTALLED BY THE CIVIL CONTRACTOR.

## REFERENCE DRAWINGS

JD-P1-HS-St-6 POWERHOUSE AND TAILRACE-GENERAL PLAN
JD-P1-HS-St-7 POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-PROFILE
JD-P1-HS-St-8 POWERHOUSE AND TAILRACE-CONCRETE OUTLINE-SECTIONS

Fig. 3.1.7 Powerhouse and Tailrace – Tailrace Gate

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JRATUNSELUNA FLOOD CONTROL PROJECT
COMPONENT : JATIBARANG DAM CONSTRUCTION
JATIBARANG DAM MANAGEMENT COMPLEX
POWERHOUSE AND TAILRACE
TAILRACE GATE

PROVINCE: CENTRAL JAVA
PROJECT NAME: FLOOD CONTROL, URBAN DRAINAGE AND WATER RESOURCES DEVELOPMENT IN SEMARANG IN THE REPUBLIC OF INDONESIA
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DATE | CONTRACT NO.

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Fig. 3.1.8 Powerhouse Reinforcement Section (1/4)

Fig. 3.1.9 Powerhouse Reinforcement Section (2/4)

Fig. 3.1.10 Powerhouse Reinforcement Section (3/4)

Fig. 3.1.11 Powerhouse Reinforcement Section (4/4)

Fig. 3.1.12 Powerhouse Reinforcement Plan (1/2)

Fig. 3.1.13 Powerhouse Reinforcement Plan (2/2)

## 3.2. Main Features

Main features of the powerhouse are tabulated in the following table.

| | Description | Unit | Main Feature |
|---|---|---|---|
| (1) | Hydropower Generation | | |
| | - Maximum plant discharge | $m^3/s$ | 3.00 |
| | - Maximum gross head | m | 69.10 |
| | - Design head | m | 64.38 |
| | - Installed capacity | kW | 1,550 |
| (2) | Dam and Water Level | | |
| | - Reservoir NWL | EL. m | 148.90 |
| | - Reservoir LWL | EL. m | 136.00 |
| | - Tail water level TWL | EL. m | 82.91 |

## 3.3. Geological Condition in the Powerhouse Area

The powerhouse will be founded on the same rock formation as that of the spillway stilling basin. Judging from the geological profile made along the centerline of the spillway and outlet facilities, rock foundation for the powerhouse would be expected at EL. 80.80.

## 3.4 Effective Head

### 3.4.1. Reservoir Water Level and Tailrace Water Level

#### 1) Reservoir Water Level

The normal water level (NWL) of EL.148.9m was used for calculating the effective head and annual generation.

#### 2) Tailrace Water Level

The water level at the tailrace exit is defined as the tailrace water level (TWL) for generation. Generally, TWL is equal to the water level of the downstream river channel when it is higher than the water level at the tailrace exit. The water level of the downstream river channel can be obtained by the H-Q curve of the river reach downstream of the spillway shown in Table 3.4.1 and Fig.3.4.1. The water level of the downstream river channel and depth at the outlet section of the tailrace corresponding to the maximum plant discharge of Q= 3 $m^3/s$ are as follows:

| Discharge | Water Level (m) | Water Depth (m) |
|---|---|---|
| Maximum plant discharge (Q=3 $m^3/s$) | 82.631 | 0.331 |

Notes: The bottom elevation of the tailrace at exit is 82.3m.

On the other hand, the critical depth at the outlet section is calculated by

$$h_c = [\alpha Q^2/(gB)]^{1/3}$$

Where

$h_c$: critical depth (m)

Q: discharge ($m^3/s$)

B: width of section (m)

$\alpha$: kinetic energy correction factor

g: gravity acceleration

The calculated parameters are given

$\alpha = 1.0$

$Q = 3.0\ m^3/s$

$B = 2.0\ m$

Therefore, the critical depth is equal to

$$h_c = [\alpha Q^2/(gB)]^{1/3} = (1.0\times3^2/9.8/2)^{1/3} = 0.612\ (m)$$

It can be found that the critical depth is larger than the water depth of the downstream river channel of 0.331m. Thus, the water level of the downstream river channel has no effect on the water depth in the tailrace, consequently, the water level at the tailrace exit is determined by the bottom elevation and critical depth. Hence, the water level at the tailrace exit is obtained by

$$H = 82.3 + h_c = 82.3 + 0.612 = 82.912\ m$$

Therefore, the TWL for calculating effective head and generation is taken as EL.82.91m.

### 3.4.2. Computation of Head Loss

#### 1) Design Condition

The Jatibarang Power Station is designed as a part of the multipurpose reservoir. The maximum power discharge of 3 $m^3/s$ is conveyed by a branched pipe which is a part of the outlet facilities that consist of an inclined intake structure with bulkhead and emergency gate, outlet tunnel, steel outlet pipe, control gate, penstock, tailrace gallery and tailrace gate. The bifurcation valve is set just before the power station so as to enable to directly release the water for domestic use without passing the power station. The maximum design discharge of the outlet pipe is 6 $m^3/s$, which is used for determining the size of the outlet facilities before the bifurcation. The maximum power discharge of 3 $m^3/s$ is used for computing the head losses of the whole outlet facilities for hydropower generation. The head loss computation is carried out by dividing the outlet facilities into three portions, that is,

a) Intake structure including trash racks
b) Outlet steel pipe
c) Tailrace

The schematic of the outlet facilities is shown in Fig. 3.4.2.

### 2) Head Loss Calculation Formulae

The calculation of the head losses was principally carried out in accordance with the formulas and hydraulic coefficients as stipulated in the Design Criteria Report, Vol.2, CTI Engineering Co., Ltd., Pacific Consultants International and PASCO International Inc., March 1999.

The roughness coefficients for different waterways are selected as follows

| | |
|---|---|
| Concrete | $n = 0.0125$ |
| Steel | $n = 0.0115$ |

The value of the gravity acceleration is taken as $9.8 m/s^2$. Other coefficients used for the loss calculation are explained in respective section.

### 3) Head Loss of Intake Portion

The head losses of the intake portion is consisted of the head loss through trash racks, friction loss and entrance loss.

(1) Head Loss through Trash Racks

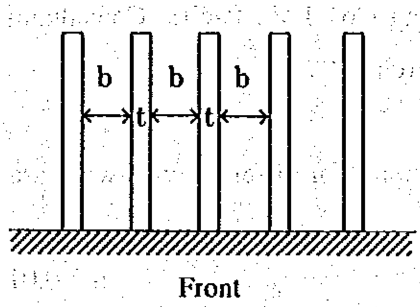
The head loss through the trash racks is computed by

$$H_t = \alpha \cdot K_t \cdot \frac{V_1^2}{2g} = \alpha \cdot K_t \cdot \frac{1}{A_1^2} \cdot \frac{Q^2}{2g}$$

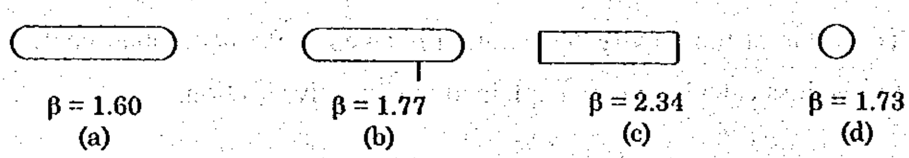
$$K_t = \beta \cdot \sin\theta \cdot \left(\frac{t}{b}\right)^{4/3}$$

Where

| | |
|---|---|
| $H_t$: | head loss through trash racks (m) |
| $K_t$: | loss coefficient through trash racks |
| $V_1$: | mean velocity before trash racks (m/s) |
| $\alpha$ : | safety factor for clogging due to trash |
| $\beta$ : | bar shape coefficient |
| $\theta$ : | trash rack inclination (°) |
| t : | width of bar (m) |
| b : | clear span between bars (m) |
| Q : | discharge ($m^3/s$) |
| $A_1$: | flow sectional area before trash racks ($m^2$) |
| g : | gravity acceleration |




**Trash Rack**




**Bar Shape Coefficient**

Since

$\beta = 2.34$

$\theta = \tan^{-1}(1:1.4) = 35.538°$

$t/b = 0.25$

$\alpha = 3.0$

$Q = 3\ m^3/s$

$A_1 = 2.0 \times 18.9 = 37.8\ m^2$

Therefore, the head loss through trash rack is equal to

$K_t = 2.34 \times \sin(35.538) \times 0.25^{4/3} = 0.214$
$H_t = 3.0 \times 0.214 \times (3/37.8)^2/19.6 = 0.0002 = 0.000$ (m)

(2) Friction Head Loss of Intake Structure

The following formula is used for the calculation of the friction loss of the intake structure.

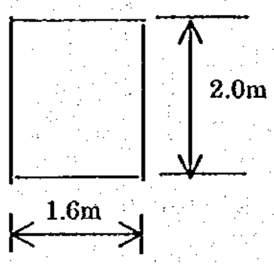
$H_f = K_f \cdot L/R \cdot V^2/(2g) = K_f \cdot L/R \cdot (Q/A)^2/(2g)$
$K_f = 2g \cdot n^2/R^{1/3}$

Where

| | |
|---|---|
| $H_f$: | friction head loss (m) |
| $K_f$: | friction coefficient |
| n : | roughness coefficient |
| L : | length of pipe (m) |
| V : | flow velocity (m/s) |
| Q : | discharge ($m^3$/s) |
| R : | hydraulic radius = A/S |
| A : | flow area ($m^2$) |
| S : | wetted perimeter (m) |
| g : | gravity acceleration |

The following calculation conditions are used.

n = 0.0125 (concrete)
L = 24.939 m
Q = 3 $m^3$/s
A = 2.0×1.6 = 3.2 ($m^2$)
S = 2×2.0+2×1.6 = 7.2 (m)
R = A/S = 3.2/7.2 = 0.444 (m)



Therefore, the friction head loss of the intake structure is

$$K_f = 19.6 \times 0.0125^2 / 0.444^{1/3} = 0.004$$
$$H_f = 0.004 \times 24.939 / 0.444 \times (3/3.2)^2 / 19.6 = 0.010 \text{ m}$$

(3) Entrance Loss

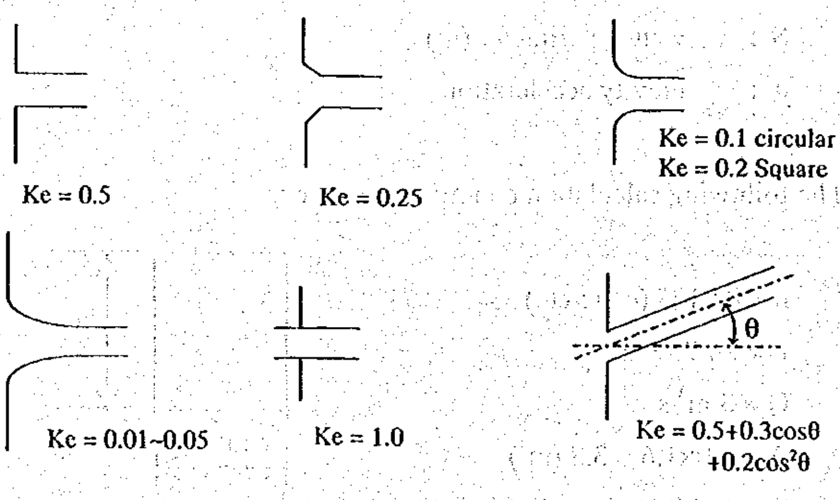
The entrance loss from the intake structure into the outlet pipe is calculated by

$$H_e = K_e \cdot V^2/(2g) = K_e \cdot (Q/A)^2/(2g)$$

Where

- $H_e$: entrance loss (m)
- $K_e$: entrance loss coefficient
- $V$ : flow velocity (m/s)
- $Q$ : discharge ($m^3/s$)
- $A$ : flow area at entrance ($m^2$)
- $g$ : gravity acceleration

The values of $K_e$ are as follows:




**Entrance Loss Coefficient**

The discharge and flow area are

$$Q = 3\ m^3/s$$
$$A = 1.4 \times 1.4 = 1.96\ m^2$$

From the above figure, the entrance loss coefficient is selected as $K_e = 0.05$. Therefore, the entrance loss is computed to be

$$H_e = 0.05 \times (3/1.96)^2/19.6 = 0.006\ m$$

(4) Summary of Head Loss of Intake Portion

Assuming the allowance of 1% for the above-mentioned calculated loss, the head loss of the intake structure is summarized as follows

| | |
|---|---|
| Through trash rack: | 0.000 m |
| Friction: | 0.010 m |
| Entrance: | 0.006 m |
| Allowance (1%): | 0.000 m |
| Total: | 0.016 m |

4) **Head Loss of Steel Pipe**

The head losses of the steel pipe include the friction loss, gradual contraction loss, bending loss and the loss due to bifurcation.

(1) Friction Head Losses of Steel Pipe

The friction losses are composed of the loss through the portions with the same diameter and the one through the gradual contraction portion. The different formulae are employed for calculating the losses through the different portions.

A. Losses through the portions with the same diameter

The friction losses of the portions with the same diameter are computed by

$$H_f = 124.5n^2/D^{4/3}LV^2/(2g) = 124.5n^2/D^{4/3}L\,(Q/A)^2/(2g)$$

Where

- $H_f$ : friction head loss (m)
- n : roughness coefficient
- D : internal diameter of pipe (m)
- L : length of pipe (m)
- V : flow velocity (m/s)
- Q : discharge ($m^3/s$)
- A : flow area ($m^2$)
- g : gravity acceleration

The calculated parameters and friction losses of the portions with the same diameter are summarized in the following table.

Friction Losses of portions with same diameter

| Part | D (m) | n | L (m) | A ($m^2$) | $H_f$ (m) |
|---|---|---|---|---|---|
| 1(before branching) | 1.4 | 0.0115 | 403.161 | 1.539 | 0.822 |
| 2(just after branching) | 1.4 | 0.0115 | 2.000 | 1.539 | 0.004 |
| 3(after gradual portion) | 0.8 | 0.0115 | 1.500 | 0.503 | 0.060 |

B. Losses through Gradual Contraction Portion

The friction loss through the gradual contraction portion is calculated by

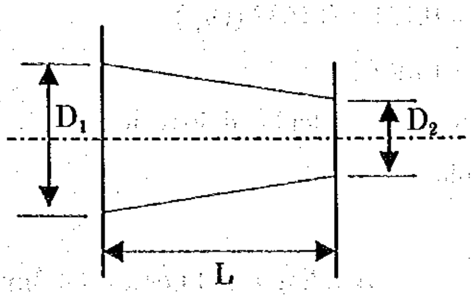
$$H_f = 2.37n^2LQ^2(1/D_2^{13/3} - 1/D_1^{13/3})\,/(D_1 - D_2)$$

Where

- $H_f$ : friction head loss (m)
- n : roughness coefficient
- $D_1$ : internal diameter before contraction (m)
- $D_2$ : internal diameter after contraction (m)

L : length of pipe (m)

Q : discharge ($m^3/s$)




The parameters and calculated friction loss through the gradual contraction portion are summarized in the following table.

Friction Losses through Gradual Contraction Portion

| Part | $D_1$ (m) | $D_2$ (m) | n | L (m) | $H_f$ (m) |
|---|---|---|---|---|---|
| 1 (D1400 to D800) | 1.400 | 0.800 | 0.0115 | 2.860 | 0.032 |

(2) Bending Head Losses

The horizontal and vertical friction losses between the intake structure and the branching valve are computed in this study. The location of the bends is shown in Fig.3.4.4. The following formula is employed for calculating the bending losses.

$$H_b = K_{b1} \cdot K_{b2} \cdot V^2/(2g) = K_{b1} \cdot K_{b2} \cdot (Q/A)^2/(2g)$$

Where

$H_b$ : bending head loss (m)

$K_{b1}$ : loss coefficient determined by the ratio (=ρ/D) of the bending radius ρ to the pipe diameter D, in case that a center angle of bending is 90°{Anderson-Straub adjustment value is given in Figure (a)}

$K_{b2}$ : ratio of the loss for a center angle θ to the loss for a center angle of 90°

V : flow velocity (m/s)

Q : discharge ($m^3/s$)

A : flow area ($m^2$)

g : gravity acceleration

The Anderson-Straub adjustment values of $K_{b1}$·and $K_{b2}$ are defined empirically as follows

$$K_{b1} = 0.131 + 0.1632 \cdot (D/\rho)^{7/2}$$

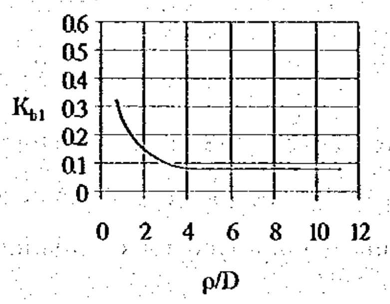
$$K_{b2} = (\theta/90°)^{1/2}$$

The parameters and calculated loss at each bend are summarized in the following table.

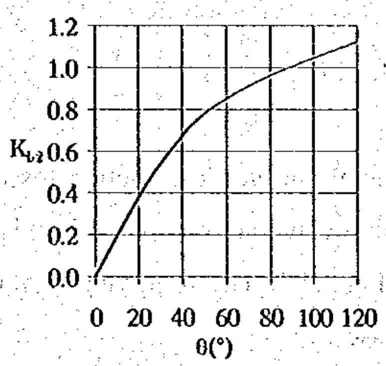
Bending Head Losses ($Q=3m^3/s$)

| No. of Bend | D (m) | ρ (m) | θ (°) | $K_{b1}$ | $K_{b2}$ | A ($m^2$) | $K_{b1} K_{b2} / A^2$ | $H_b$ (m) |
|---|---|---|---|---|---|---|---|---|
| VIP1 | 1.400 | 2.800 | 50°33'27" | 0.145 | 0.749 | 1.539 | 0.046 | 0.021 |
| HIP1 | 1.400 | 45.000 | 90° | 0.131 | 1.000 | 1.539 | 0.055 | 0.025 |
| HIP2 | 1.400 | 45.000 | 45° | 0.131 | 0.707 | 1.539 | 0.039 | 0.018 |
| VIP2 | 1.400 | 4.200 | 3°54'18" | 0.134 | 0.208 | 1.539 | 0.012 | 0.006 |
| HIP3 | 1.400 | 4.200 | 19°21'04" | 0.134 | 0.464 | 1.539 | 0.026 | 0.012 |
| Total | | | | | | | | 0.082 |

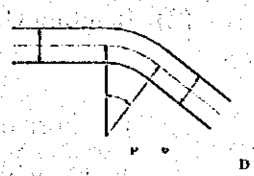
Notes: The values of $K_{b1}$·and $K_{b2}$ are obtained by the empirical formulae.



(a) Value of $K_{b1}$ (90°)



(b) Value of $K_{b2}$



Bending Loss Coefficient

(3) Branching Loss

The following Gardel formula is used for calculating the head loss due to branching.

$$H_b = H_\alpha - H_\beta = K_b \cdot V_\alpha^2 / (2g) = K_b \cdot (Q_\alpha / A_\alpha)^2 / (2g)$$

$$K_b = 0.58 q_\beta^2 - 0.26 q_\beta + 0.03$$

Where

$H_b$ : head loss due to branching

$K_b$ : branching head loss coefficient

$H_\alpha$ : working pressure head before branching (m)

$H_\gamma$ : working pressure head after branching (m)

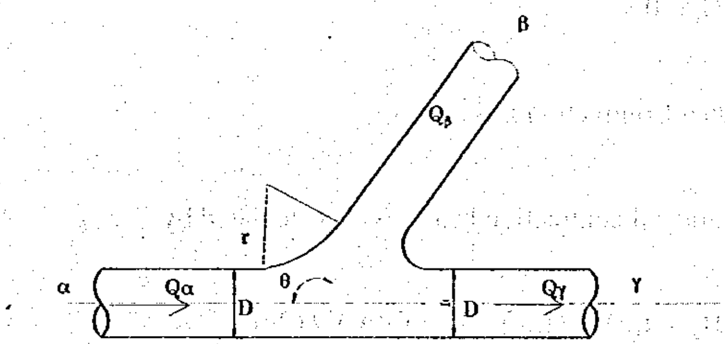
$V_\alpha$ : flow velocity before branching (m/s)

$Q_\alpha$ : original discharge ($m^3/s$)

$A_\alpha$ : flow area before branching ($m^2$)

D : internal diameter of pipe (m)

$q_\beta$ : ratio of branched discharge $Q_\beta$ to original discharge $Q_\alpha$




The calculated parameters are

$Q_\alpha = 3.0\ m^3/s$

$Q_\beta = 0\ m^3/s$

$q_\beta = Q_\beta/Q_\alpha = 0$

$D = 1.4$ m

$A_\alpha = \pi D^2/4 = 3.1415926 \times 1.4^2/4 = 1.539\ (m^2)$

Therefore, the branching head loss becomes as follows:

$K_b = 0.58q_\beta^2 - 0.26q_\beta + 0.03 = 0.03$

$H_b = K_b(Q_\alpha/A_\alpha)^2 / (2g) = 0.03 \times (3/1.539)^2/19.6 = 0.006$ m

(4) Valve Loss

The head loss due to valve is calculated by

$H_v = f_v \cdot V^2 / (2g) = f_v \cdot (Q/A)^2 / (2g)$

Where

$H_v$: head loss due to valve

$f_v$ : valve head loss coefficient, $f_v$=0, when the valve is full open

V : flow velocity (m/s)

Q : discharge ($m^3/s$)

A : flow area of pipe ($m^2$)

D : internal diameter of pipe (m)

Since $f_v$= 0 is applicable to calculating the effective head, then

$H_v = 0$

(5) Gradual Contraction Loss

The gradual contraction head loss is calculated by

$$H_{gc} = f_{gc} \cdot V_2^2 / (2g) = K_{gc} \cdot (Q/A_2)^2 / (2g)$$

Where

$H_{gc}$ : gradual contraction loss (m)

$f_{gc}$ : gradual contraction loss coefficient, it is a function of the contraction angle $\theta$ and the ratio of the cross sectional areas of the flow before and after contraction, $A_2/A_1$(see the following figure)

$V_2$ : velocity after contraction (m/s)

Q : discharge ($m^3/s$)

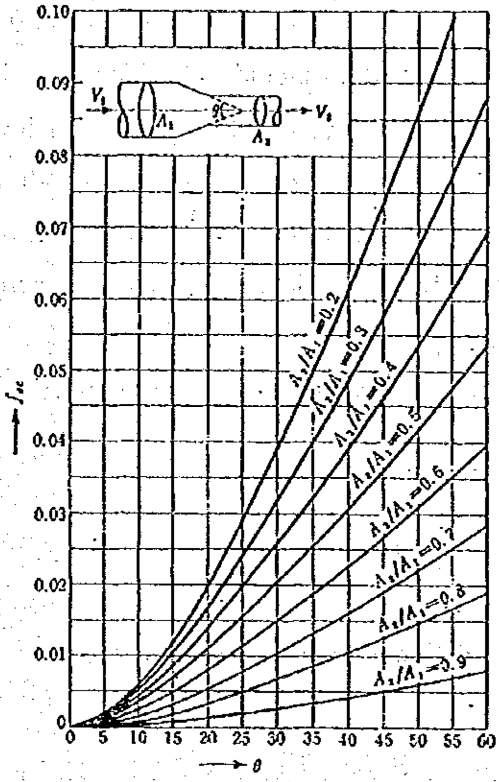
$A_1$ : sectional flow area before contraction ($m^2$)

$A_2$ : sectional flow area after contraction ($m^2$)

The parameters of the gradual contraction portion and calculated gradual contraction loss are given in the following table.

Gradual Contraction Loss

| D (mm) | $A_1$ ($m^2$) | $A_2$ ($m^2$) | $A_2/A_1$ | θ (°) | $f_{gc}$ | $f_{gc}/A_2^2$ (m) | $h_{gc}$ (m) |
|---|---|---|---|---|---|---|---|
| 1400 to 800 | 1.539 | 0.503 | 0.327 | 11°58'34" | 0.006 | 0.0237 | 0.011 |




*Contraction Loss Coefficient*

(6) Summary of Head Loss through Steel Pipe

Assuming the allowance of 1% for the above-mentioned calculated loss, the head loss through the steel pipe is summarized as follows

| | |
|---|---|
| Friction: | 0.918 m |
| Gradual contraction: | 0.011 m |
| Bending: | 0.082 m |
| Bifurcation: | 0.006 m |
| Valve: | 0.000 m |
| Allowance: | 0.010 m |
| Total: | 1.027 m |

## 5) Head Loss of Tailrace

The head losses of the tailrace consist of the head loss of the pressure portion (upper part of the tailrace) and non-pressure portion (lower part of the tailrace).

The head loss of the pressure portion consists of the draft-tube outlet loss, bending loss, sudden contraction and expansion losses and friction loss. The head loss along the non-pressure portion includes the friction loss and exit loss due to velocity decrease. The exit loss by abrupt drop of water level is not considered because the critical depth is selected as the exit depth for determining the effective head. The bending loss along non-pressure portion is also negligible. The typical sections for calculating the tailrace loss are shown in Fig.3.4.3.

(1) Head Loss along Non-pressure Portion (between Section A-A and Section C-C)

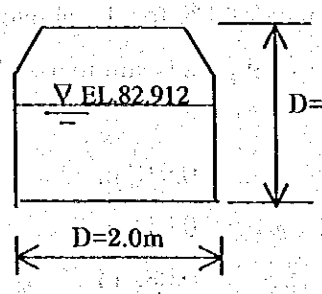
A. Velocity Head Loss at Exit

From the calculation in the above section, the flow area at the exit of the tailrace is

$$A = Bh_c = 2.0 \times 0.612 = 1.224\ m^2$$

Therefore, the loss at the exit due to velocity decrease is

$$H_{exit} = V^2/(2g) = (Q/A)^2/(2g) = 1.0 \times (3/1.224)^2/19.6 = 0.307\ (m)$$



Section A-A

B. Friction Loss along Non-pressure Portion

The friction loss along the non-pressure portion is calculated by

$$H_{Lf} = \Delta L \cdot \overline{S_f}$$
$$\Delta L = \Delta E/(i - \overline{S_f}) = (E_2 - E_1)/(i - \overline{S_f})$$

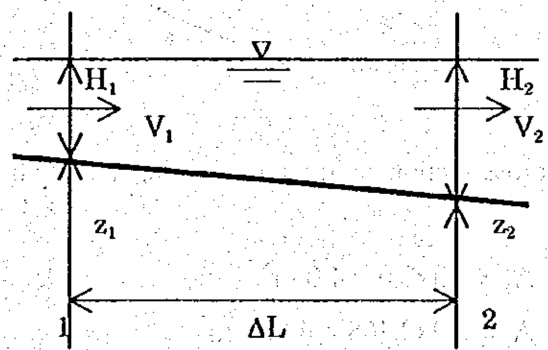
$$\overline{S_f} = 0.5\left(\frac{1}{R_1^{4/3}} \cdot \frac{n^2 V_1^2}{2g} + \frac{1}{R_2^{4/3}} \cdot \frac{n^2 V_2^2}{2g}\right)$$

$$E = h + \alpha \cdot \frac{V^2}{2g}, \qquad i = (z_1 - z_2)/\Delta L$$

Where

| | | |
|---|---|---|
| $h_{Lf}$ | : | friction loss (m) |
| E | : | specific energy (m) |
| $\Delta E$ | : | change in specific energy (= $E_2 - E_1$) |
| h | : | water depth (m) |
| $\overline{S_f}$ | : | average friction slope |
| $V$ | : | velocity of flow (=Q/A) |
| Q | : | discharge |
| $A$ | : | flow area |
| $R$ | : | hydraulic radius |
| $i$ | : | bottom slope |
| $z$ | : | bottom elevation |
| $\Delta L$ | : | interval distance |
| $n$ | : | roughness coefficient |
| g | : | gravity acceleration |
| $\alpha$ | : | kinetic energy correction factor (=1.0) |

Suffixes 1 and 2 indicate the upstream and downstream sides of the reach of length, $\Delta L$.




The upstream depth $h_1$ is calculated by direct step method. The calculated conditions and results are shown in Table 3.4.2. From Table 3.4.2, the friction loss between Section A-A and Section C-C is 0.068m.

(2) Head Loss along Pressure Portion

The computation is carried out from downstream section to upstream section.

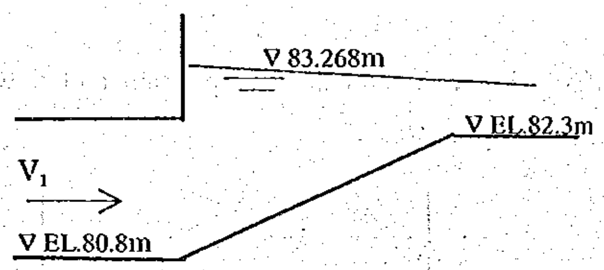
A. Sudden Expansion Loss at Section C-C

The sudden expansion head loss is calculated by

$$H_{se} = K_{se} \cdot V_1^2 / (2g) = K_{se} \cdot (Q/A_1)^2 / (2g)$$
$$K_{se} = (1 - A_1/A_2)^2$$

Where

| | | |
|---|---|---|
| $H_{se}$ | : | sudden expansion loss (m) |
| $K_{se}$ | : | sudden expansion loss coefficient |
| $V_1$ | : | velocity before sudden expansion (m/s) |
| $Q$ | : | discharge ($m^3/s$) |
| $A_1$ | : | sectional flow area before sudden expansion ($m^2$) |
| $A_2$ | : | sectional flow area after sudden expansion ($m^2$) |
| $g$ | : | gravity acceleration |




The cross section parameters and the velocity before expansion are

$$A_1 = 2.0 \times 2.0 = 4.0 \text{ m}^2$$
$$A_2 = 2.0 \times 2.468 = 4.936 \text{ m}^2$$

Therefore, the sudden expansion head loss at Section C-C becomes as follows.

$K_{se} = (1 - 4.0/4.936)^2 = 0.036$

$H_{se} = 0.036 \times (3/4)^2/19.6 = 0.001(m)$

B. Friction Head Loss between Section C-C and Section F-F

The friction loss along the pressure portion is the sum of the loss between Section C-C and Section D-D, the one between Section D-D and Section E-E and the one between Section E-E and Section F-F.

The following formula is used for the calculation of the friction loss:

$$H_f = K_f \cdot L/R \cdot V^2/(2g) = K_f \cdot L/R \cdot (Q/A)^2/(2g)$$

$$K_f = 2g \cdot n^2/R^{1/3}$$

Where

| | |
|---|---|
| $H_f$ | : friction head loss (m) |
| $K_f$ | : friction coefficient |
| n | : roughness coefficient |
| L | : length of reach(m) |
| V | : flow velocity (m/s) |
| Q | : discharge ($m^3$/s) |
| A | : flow area ($m^2$) |
| S | : wetted perimeter (m) |
| R | : hydraulic radius (m) |
| g | : gravity acceleration |

The parameters concerned are given as follows:

Section D-D for the portion between Section C-C and Section D-D:

$L = 1.925 + 3.206 = 5.131$ m

$A = 2.0 \times 2.0 = 4.0$ ($m^2$)

$S = 2 \times 2.0 + 2 \times 2 = 8.0$ (m)

$R = A/S = 4.0/8.0 = 0.5$ (m)

$V = Q/A = 3.0/4.0 = 0.75$ (m/s)

Therefore, the friction head loss between Section C-C and Section D-D is

$K_{f1}$ =19.6×0.0125²/0.5^{1/3} =0.004

$H_{f1}$ = 0.004×5.131/0.5×0.75²/19.6=0.001 m

Section E-E for the portion between Section E-E and Section F-F:

L = 2.075 m

A = 3.1×5.1 = 15.81 ($m^2$)

S = 2×3.1+2×5.1 = 16.4 (m)

R = A/S = 15.81/16.4= 0.964 (m)

V = Q/A = 3.0/15.81= 0.190 (m/s)

Therefore, the friction head loss between Section E-E and Section F-F is

$K_{f2} = 19.6 \times 0.0125^2 / 0.964^{1/3} = 0.003$

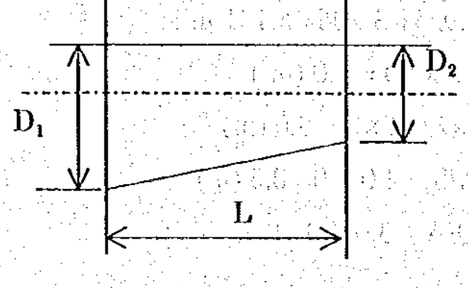
$H_{f2} = 0.003 \times 2.075/0.964 \times 0.19^2/19.6 = 0.00001 = 0.000$ m

The formula for gradual contraction is used for calculating the friction loss of the portion between Section D-D and Section E-E, that is

$H_{f3} = 2.37 n^2 L Q^2 (1/D_2^{13/3} - 1/D_1^{13/3}) / (D_1 - D_2)$

Where

| | | |
|---|---|---|
| $H_{f3}$ | : | friction head loss (m) |
| n | : | roughness coefficient |
| $D_1$ | : | equivalent diameter before contraction (m) |
| $D_2$ | : | equivalent diameter after contraction (m) |
| L | : | length (m) |
| Q | : | discharge ($m^3$/s) |



The length of the portion between Section D-D and Section E-E, L = 1.55 m, and equivalent diameters are

$D_1=(4A/\pi)^{1/2}=(4\times15.81/3.1416)^{1/2}=4.487$ m

$D_2=(4A/\pi)^{1/2}=(4\times4.0/3.1416)^{1/2}=2.257$ m

Therefore, the friction head loss between Section D-D and Section E-E becomes as follows.

$H_{f3}=2.37\times0.0125^2\times1.55\times3.0^2\times(1/4.487^{13/3}-1/2.257^{13/3})/(4.487-2.257)$

$=0.00004$ m

Hence, the friction head loss along the whole pressure portion is

$H_{fpp}=0.001+0.00001+0.00004=0.001$m

C. Bending Loss between Section C-C and Section D-D

The miter bending loss between Section C-C and Section D-D is computed by converting the rectangular cross section into a circular section. The following formula is employed for the bending loss.

$H_b=K_bV^2/(2g)$

$K_b=0.946\sin^2(\alpha/2)+2.05\sin^4(\alpha/2)$

Where

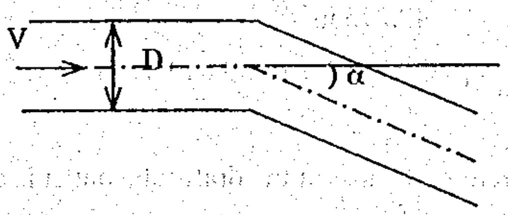
$H_b$ : bending head loss (m)

$K_b$ : bending loss coefficient

$V$ : flow velocity (m/s)

$\alpha$ : bending angle (°)

$g$ : gravity acceleration




Since the section area is $A=4.0m^2$, then the equivalent diameter of a circular section is determined as follows:

$$D=(4A/\pi)^{1/2}=(4\times4.0/3.1416)^{1/2}=2.257\ m$$

When the bending angle $\alpha=30°$ and the coefficient is applied

$$K_b = 0.946\times\sin^2(30/2)+2.05\times\sin^4(30/2)=0.073$$

Therefore, the bending loss between Section C-C and Section D-D is

$$H_b = 0.073\times(3/4)^2/19.6=0.002\ m$$

D. Loss at Draft-tube Outlet

The loss at the draft-tube outlet is calculated by the following formula for sudden expansion loss:

$$H_{se}= K_{se}V_1^2/(2g)$$

$$K_{se}= \{1-A_1/ A_2\}^2$$

Where

- $H_{se}$ : loss due to sudden expansion (m)
- $K_{se}$ : sudden expansion loss coefficient
- $A_1$ : flow area at draft-tube outlet ($m^2$)
- $A_2$ : flow area after sudden expansion ($m^2$)
- $V_1$ : velocity at draft-tube outlet (m/s)
- $g$ : gravity acceleration

The area and velocity at the draft-tube outlet and the area after sudden expansion are as follows

$$A_1 = \pi D^2/4=3.1416\times1.4^2=1.539\ m^2$$

$$A_2 = 5.1\times4.25+0.5\times(2.0+15.1)\times5.0-2.0\times0.5\times1.0\times1.925+1.0\times2.0$$
$$=42.275\ m^2$$

$$V_1 =Q/ A_1 =3.0/1.539 =1.949\ m/s$$

Therefore, the loss at the draft-tube outlet is equal to

$$K_{se}=(1-1.539/42.275)^2= 0.964\ (m)$$

$$H_{lv}= 0.964\times(3/1.539)^2/19.6 = 0.187\ (m)$$

E. Gradual Contraction Loss between Section D-D and Section E-E

$$H_{gc} = f_{gc} \cdot V_2^2 / (2g) = K_{gc} \cdot (Q/A_2)^2 / (2g)$$

Where

- $H_{gc}$ : gradual contraction loss (m)
- $f_{gc}$ : gradual contraction loss coefficient, it is a function of the contraction angle $\theta$ and the ratio of the cross sectional areas of the flow before and after contraction, $A_2/A_1$
- $V_2$ : velocity after contraction (m/s)
- $Q$ : discharge ($m^3/s$)
- $A_1$ : sectional flow area before contraction ($m^2$)
- $A_2$ : sectional flow area after contraction ($m^2$)

The contraction angle, $\theta$, is

$$\theta = 2\arctan[(5.1-2)/2/5]=34.447°$$

The areas of Section E-E and Section D-D are $A_1$=15.81 $m^2$ and $A_2$=4.0 $m^2$, thus

$$A_2/A_1 = 4.0/15.81 = 0.253m$$

From the above-mentioned figure,

$f_{gc}$ = 0.05, when $A_2/A_1$=0.2; and

$f_{gc}$ = 0.04, when $A_2/A_1$=0.3

Thus the factor for $A_2/A_1$=0.253 can be obtained by

$$f_{gc} = (0.04-0.05)\times(0.253-0.2)/(0.3-0.2) + 0.05 = 0.045$$

Therefore, the gradual contraction loss between Section E-E and Section D-D is calculated as follows

$$H_{gc} = 0.045\times(3/4)^2/19.6=0.001 \text{ m}$$

(3) Summary of Head Loss of Tailrace Portion

Assuming allowance of 4.0% for the sum of the loss of the non-pressure portion and loss of the pressure portion, the head loss of the whole tailrace is summarized as follows

| | |
|---|---|
| Pressure Portion: | |
| Draft-tube outlet: | 0.187 m |
| Friction: | 0.001 m |
| Bending: | 0.002 m |
| Gradual contraction: | 0.001 m |
| Sudden expansion: | 0.001 m |
| Non-pressure Portion: | |
| Friction: | 0.068 m |
| Exit : | 0.307 m |
| Allowance (4%): | 0.020 m |
| Total: | 0.587 m |

6) **Summary of Head Loss**

The whole head losses from the intake to the tailrace in case of $Q=3m^3/s$ are summarized in Table 3.4.3. It can be found that the total head loss along the outlet facilities is 1.608m.

### 3.4.3 Effective Head

The effective head can be obtained by

$$H_e = H_g - \sum H_L$$

Where

$H_e$ : effective head (m)

$H_g$ : gross head (m), $H_g$ =NWL-TWL

$\sum H_L$ : total head loss

From the aforementioned sections, NWL, TWL and total head loss of the generation system for $Q=3\ m^3/s$ are

NWL: 148.9 m

TWL: 82.91 m

$\sum H_L$: 1.69m

Therefore, the effective head corresponding to Q=3.0 $m^3/s$ is

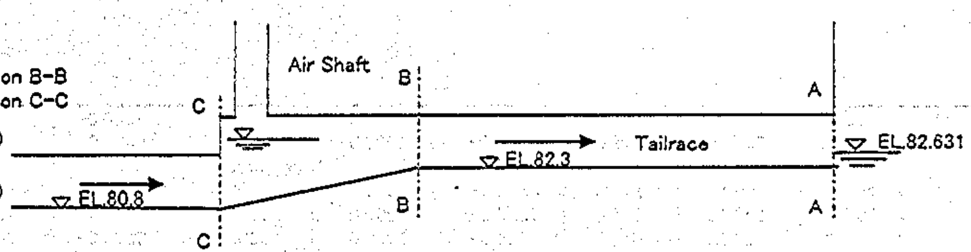
$$H_e = NWL-TWL - \sum H_L = 148.9-82.91- 1.69 = 64.30 \text{ m}$$

## Table 3.4.1 Stage Discharge Table of River Reach Downstream of Spillway

| Elevation (m) | Depth h (m) | Bottom width B1 (m) | Surface width B2 (m) | Area A (m2) | Wetted perimeter S (m) | Hydraulic radius R (m) | $R^{2/3}$ | Slope I | $I^{1/2}$ | Manning coef. n | Discharge Q (m3/s) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.000 | 0.000 | 24.0 | 24.0 | 0.0 | 24.0 | 0.00 | 0.00 | 0.0125 | 0.112 | 0.03 | 0.0 | |
| 0.100 | 0.100 | 24.0 | 24.1 | 2.4 | 24.2 | 0.10 | 0.21 | 0.0125 | 0.112 | 0.03 | 1.9 | |
| 0.131 | 0.131 | 24.0 | 24.1 | 3.1 | 24.3 | 0.13 | 0.26 | 0.0125 | 0.112 | 0.03 | 3.0 | 3 $m^3/s$ |
| 0.198 | 0.198 | 24.0 | 24.2 | 4.8 | 24.4 | 0.20 | 0.34 | 0.0125 | 0.112 | 0.03 | 6.0 | 6 $m^3/s$ |
| 0.200 | 0.200 | 24.0 | 24.2 | 4.8 | 24.4 | 0.20 | 0.34 | 0.0125 | 0.112 | 0.03 | 6.1 | |
| 0.300 | 0.300 | 24.0 | 24.3 | 7.2 | 24.7 | 0.29 | 0.44 | 0.0125 | 0.112 | 0.03 | 11.9 | |
| 0.400 | 0.400 | 24.0 | 24.4 | 9.7 | 24.9 | 0.39 | 0.53 | 0.0125 | 0.112 | 0.03 | 19.2 | |
| 0.500 | 0.500 | 24.0 | 24.5 | 12.1 | 25.1 | 0.48 | 0.62 | 0.0125 | 0.112 | 0.03 | 27.8 | |
| 0.534 | 0.534 | 24.0 | 24.5 | 13.0 | 25.2 | 0.51 | 0.64 | 0.0125 | 0.112 | 0.03 | 31.0 | 31 $m^3/s$ |
| 0.600 | 0.600 | 24.0 | 24.6 | 14.6 | 25.3 | 0.58 | 0.69 | 0.0125 | 0.112 | 0.03 | 37.6 | |
| 0.700 | 0.700 | 24.0 | 24.7 | 17.0 | 25.6 | 0.67 | 0.76 | 0.0125 | 0.112 | 0.03 | 48.5 | |
| 0.800 | 0.800 | 24.0 | 24.8 | 19.5 | 25.8 | 0.76 | 0.83 | 0.0125 | 0.112 | 0.03 | 60.4 | |
| 0.900 | 0.900 | 24.0 | 24.9 | 22.0 | 26.0 | 0.85 | 0.89 | 0.0125 | 0.112 | 0.03 | 73.4 | |
| 0.984 | 0.984 | 24.0 | 25.0 | 24.1 | 26.2 | 0.92 | 0.95 | 0.0125 | 0.112 | 0.03 | 85.0 | 85 $m^3/s$ |
| 1.000 | 1.000 | 24.0 | 25.0 | 24.5 | 26.2 | 0.93 | 0.96 | 0.0125 | 0.112 | 0.03 | 87.2 | |
| 1.500 | 1.500 | 24.0 | 25.5 | 37.1 | 27.4 | 1.36 | 1.23 | 0.0125 | 0.112 | 0.03 | 169.6 | |
| 2.000 | 2.000 | 24.0 | 26.0 | 50.0 | 28.5 | 1.76 | 1.46 | 0.0125 | 0.112 | 0.03 | 271.2 | |
| 2.298 | 2.298 | 24.0 | 26.3 | 57.8 | 29.1 | 1.98 | 1.58 | 0.0125 | 0.112 | 0.03 | 340.0 | 100 yr Flood |
| 2.500 | 2.500 | 24.0 | 26.5 | 63.1 | 29.6 | 2.13 | 1.66 | 0.0125 | 0.112 | 0.03 | 389.9 | |
| 3.000 | 3.000 | 24.0 | 27.0 | 76.5 | 30.7 | 2.49 | 1.84 | 0.0125 | 0.112 | 0.03 | 523.9 | |
| 4.000 | 4.000 | 24.0 | 28.0 | 104.0 | 32.9 | 3.16 | 2.15 | 0.0125 | 0.112 | 0.03 | 834.1 | |
| 5.000 | 5.000 | 24.0 | 29.0 | 132.5 | 35.2 | 3.77 | 2.42 | 0.0125 | 0.112 | 0.03 | 1195.3 | |
| 5.292 | 5.292 | 24.0 | 29.3 | 141.0 | 35.8 | 3.94 | 2.49 | 0.0125 | 0.112 | 0.03 | 1310.0 | PMF outflow |
| 5.991 | 5.991 | 24.0 | 30.0 | 161.7 | 37.4 | 4.32 | 2.65 | 0.0125 | 0.112 | 0.03 | 1600.0 | PMF inflow |
| 6.000 | 6.000 | 24.0 | 30.0 | 162.0 | 37.4 | 4.33 | 2.66 | 0.0125 | 0.112 | 0.03 | 1603.8 | |

# Table 3.4.2(1/2) Non-uniform Computation of Tailrace by Direct Step Method

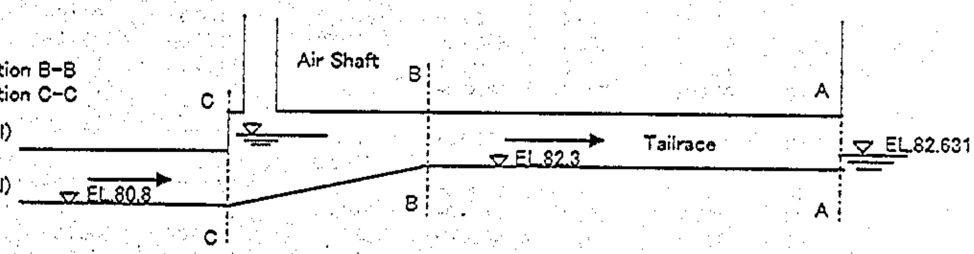
| | | | | | | |
|---|---|---|---|---|---|---|
| Discharge | Q= | 3.0 | ($m^3/s$) | | | |
| Width of rectangular cross section | B= | 2.0 | (m) | | | |
| Kinetic energy correction factor | $\alpha$= | 1.0 | | | | |
| Roughness coefficier | n= | 0.0125 | | | | |
| Bottom slope | I= | 0.0 | Between Section A-A and Section B-B | | | |
| Bottom slope | I= | -0.2778 | Between Section B-B and Section C-C | | | |
| Increment in depth direction for I=0 (m) | Δh= | 0.01 | (Initial) | 0.007 | (Final) | |
| Increment in depth direction for I<0 (m) | Δh= | 0.09 | (Initial) | 0.038 | (Final) | |
| Initial depth | H= | 0.612 | (m) | | | |
| Critical depth | hc= | 0.612 | (m) | | | |




| No. | Bottom elevation (m) | Depth h(m) | Area A($m^2$) | Wetted perimeter P(m) | Hydraulic radius R(m) | Velocity V(m/s) | Velocity head $\alpha$ $V^2/2g$(m) | Specific energy E(m) | ΔE | Slope of energy grade line $S_f=n^2V^2/R^{4/3}$ | Average slope of energy grade line $\bar{S}_f$ | $I-\bar{S}_f$ | ΔL (M) | ΣΔL (m) | Surface elevation (m) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 82.3 | 0.612 | 1.225 | 3.225 | 0.380 | 2.450 | 0.306 | 0.918 | | 0.0034 | | | | 0.000 | 82.912 | Sec. A-A |
| 1 | 82.3 | 0.622 | 1.245 | 3.245 | 0.384 | 2.410 | 0.296 | 0.919 | -0.0002 | 0.0033 | 0.0033 | -0.0033 | 0.072 | 0.072 | 82.922 | |
| 2 | 82.3 | 0.632 | 1.265 | 3.265 | 0.387 | 2.372 | 0.287 | 0.919 | -0.0007 | 0.0031 | 0.0032 | -0.0032 | 0.219 | 0.291 | 82.932 | |
| 3 | 82.3 | 0.642 | 1.285 | 3.285 | 0.391 | 2.335 | 0.278 | 0.921 | -0.0011 | 0.0030 | 0.0030 | -0.0030 | 0.371 | 0.662 | 82.942 | |
| 4 | 82.3 | 0.652 | 1.305 | 3.305 | 0.395 | 2.299 | 0.270 | 0.922 | -0.0015 | 0.0029 | 0.0029 | -0.0029 | 0.526 | 1.189 | 82.952 | |
| 5 | 82.3 | 0.662 | 1.325 | 3.325 | 0.398 | 2.265 | 0.262 | 0.924 | -0.0019 | 0.0027 | 0.0028 | -0.0028 | 0.686 | 1.875 | 82.962 | |
| 6 | 82.3 | 0.672 | 1.345 | 3.345 | 0.402 | 2.231 | 0.254 | 0.926 | -0.0023 | 0.0026 | 0.0027 | -0.0027 | 0.849 | 2.724 | 82.972 | |
| 7 | 82.3 | 0.682 | 1.365 | 3.365 | 0.406 | 2.198 | 0.247 | 0.929 | -0.0026 | 0.0025 | 0.0026 | -0.0026 | 1.017 | 3.740 | 82.982 | |
| 8 | 82.3 | 0.692 | 1.385 | 3.385 | 0.409 | 2.167 | 0.239 | 0.932 | -0.0029 | 0.0024 | 0.0025 | -0.0025 | 1.188 | 4.928 | 82.992 | |
| 9 | 82.3 | 0.702 | 1.405 | 3.405 | 0.413 | 2.136 | 0.233 | 0.935 | -0.0032 | 0.0023 | 0.0024 | -0.0024 | 1.363 | 6.292 | 83.002 | |
| 10 | 82.3 | 0.712 | 1.425 | 3.425 | 0.416 | 2.106 | 0.226 | 0.939 | -0.0035 | 0.0022 | 0.0023 | -0.0023 | 1.543 | 7.835 | 83.012 | |
| 11 | 82.3 | 0.722 | 1.445 | 3.445 | 0.419 | 2.077 | 0.220 | 0.942 | -0.0038 | 0.0021 | 0.0022 | -0.0022 | 1.727 | 9.562 | 83.022 | |
| 12 | 82.3 | 0.732 | 1.465 | 3.465 | 0.423 | 2.048 | 0.214 | 0.946 | -0.0040 | 0.0021 | 0.0021 | -0.0021 | 1.914 | 11.476 | 83.032 | |
| 13 | 82.3 | 0.742 | 1.485 | 3.485 | 0.426 | 2.021 | 0.208 | 0.951 | -0.0043 | 0.0020 | 0.0020 | -0.0020 | 2.106 | 13.582 | 83.042 | |
| 14 | 82.3 | 0.752 | 1.505 | 3.505 | 0.429 | 1.994 | 0.203 | 0.955 | -0.0045 | 0.0019 | 0.0020 | -0.0020 | 2.302 | 15.885 | 83.052 | |
| 15 | 82.3 | 0.762 | 1.525 | 3.525 | 0.433 | 1.968 | 0.198 | 0.960 | -0.0047 | 0.0018 | 0.0019 | -0.0019 | 2.503 | 18.388 | 83.062 | |
| 16 | 82.3 | 0.772 | 1.545 | 3.545 | 0.436 | 1.942 | 0.192 | 0.965 | -0.0049 | 0.0018 | 0.0018 | -0.0018 | 2.707 | 21.095 | 83.072 | |
| 17 | 82.3 | 0.782 | 1.565 | 3.565 | 0.439 | 1.917 | 0.188 | 0.970 | -0.0051 | 0.0017 | 0.0018 | -0.0018 | 2.916 | 24.011 | 83.082 | |
| 18 | 82.3 | 0.792 | 1.585 | 3.585 | 0.442 | 1.893 | 0.183 | 0.975 | -0.0053 | 0.0017 | 0.0017 | -0.0017 | 3.129 | 27.140 | 83.092 | |
| 19 | 82.3 | 0.802 | 1.605 | 3.605 | 0.445 | 1.870 | 0.178 | 0.981 | -0.0055 | 0.0016 | 0.0016 | -0.0016 | 3.346 | 30.486 | 83.102 | |
| 20 | 82.3 | 0.810 | 1.619 | 3.619 | 0.447 | 1.853 | 0.175 | 0.985 | -0.0040 | 0.0016 | 0.0016 | -0.0016 | 2.550 | 33.036 | 83.110 | Sec. B-B |
| 21 | 82.24 | 0.900 | 1.799 | 3.799 | 0.474 | 1.668 | 0.142 | 1.041 | -0.0567 | 0.0012 | 0.0014 | -0.2792 | 0.203 | 33.239 | 83.143 | |
| 22 | 82.18 | 0.990 | 1.979 | 3.979 | 0.497 | 1.516 | 0.117 | 1.107 | -0.0654 | 0.0009 | 0.0010 | -0.2788 | 0.234 | 33.473 | 83.168 | |
| 23 | 82.11 | 1.080 | 2.159 | 4.159 | 0.519 | 1.389 | 0.099 | 1.178 | -0.0713 | 0.0007 | 0.0008 | -0.2786 | 0.256 | 33.729 | 83.187 | |
| 24 | 82.03 | 1.170 | 2.339 | 4.339 | 0.539 | 1.283 | 0.084 | 1.253 | -0.0754 | 0.0006 | 0.0007 | -0.2784 | 0.271 | 34.000 | 83.202 | |
| 25 | 81.95 | 1.260 | 2.519 | 4.519 | 0.557 | 1.191 | 0.072 | 1.332 | -0.0784 | 0.0005 | 0.0005 | -0.2783 | 0.282 | 34.282 | 83.213 | |

## Table 3.4.2(2/2) Non-uniform Computation of Tailrace by Direct Step Method

| | | | | | | |
|---|---|---|---|---|---|---|
| Discharge | Q= | 3.0 | ($m^3/s$) | | | |
| Width of rectangular cross section | B= | 2.0 | (m) | | | |
| Kinetic energy correction factor | $\alpha$= | 1.0 | | | | |
| Roughness coefficier | n= | 0.0125 | | | | |
| Bottom slope | I= | 0.0 | Between Section A-A and Section B-B | | | |
| Bottom slope | I= | -0.2778 | Between Section B-B and Section C-C | | | |
| Increment in depth direction for I=0 (m) | Δh= | 0.01 | (Initial) | 0.007 | (Final) | |
| Increment in depth direction for I<0 (m) | Δh= | 0.09 | (Initial) | 0.038 | (Final) | |
| Initial depth | H= | 0.612 | (m) | | | |
| Critical depth | hc= | 0.612 | (m) | | | |




| No. | Bottom elevation (m) | Depth h(m) | Area A($m^2$) | Wetted perimetter P(m) | Hydraulic radius R(m) | Velocity V(m/s) | Velocity head $\alpha V^2/2g$(m) | Specific energy E(m) | ΔE | Slope of energy grade line $S_f=n^2V^2/R^{4/3}$ | Average slope of energy grade line $\overline{S_f}$ | I-$\overline{S_f}$ | ΔL (M) | ΣΔL (m) | Surface elevation (m) | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 26 | 81.87 | 1.350 | 2.699 | 4.699 | 0.574 | 1.111 | 0.063 | 1.413 | -0.0807 | 0.0004 | 0.0004 | -0.2782 | 0.290 | 34.572 | 83.223 | |
| 27 | 81.79 | 1.440 | 2.879 | 4.879 | 0.590 | 1.042 | 0.055 | 1.495 | -0.0824 | 0.0003 | 0.0004 | -0.2782 | 0.296 | 34.868 | 83.231 | |
| 28 | 81.71 | 1.530 | 3.059 | 5.059 | 0.605 | 0.981 | 0.049 | 1.579 | -0.0837 | 0.0003 | 0.0003 | -0.2781 | 0.301 | 35.169 | 83.237 | |
| 29 | 81.62 | 1.620 | 3.239 | 5.239 | 0.618 | 0.926 | 0.044 | 1.663 | -0.0847 | 0.0003 | 0.0003 | -0.2781 | 0.305 | 35.473 | 83.242 | |
| 30 | 81.54 | 1.710 | 3.419 | 5.419 | 0.631 | 0.877 | 0.039 | 1.749 | -0.0855 | 0.0002 | 0.0002 | -0.2780 | 0.308 | 35.781 | 83.247 | |
| 31 | 81.45 | 1.800 | 3.599 | 5.599 | 0.643 | 0.834 | 0.035 | 1.835 | -0.0862 | 0.0002 | 0.0002 | -0.2780 | 0.310 | 36.091 | 83.251 | |
| 32 | 81.36 | 1.890 | 3.779 | 5.779 | 0.654 | 0.794 | 0.032 | 1.922 | -0.0867 | 0.0002 | 0.0002 | -0.2780 | 0.312 | 36.403 | 83.254 | |
| 33 | 81.28 | 1.980 | 3.959 | 5.959 | 0.664 | 0.758 | 0.029 | 2.009 | -0.0871 | 0.0002 | 0.0002 | -0.2779 | 0.314 | 36.716 | 83.257 | |
| 34 | 81.19 | 2.070 | 4.139 | 6.139 | 0.674 | 0.725 | 0.027 | 2.096 | -0.0875 | 0.0001 | 0.0001 | -0.2779 | 0.315 | 37.031 | 83.260 | |
| 35 | 81.10 | 2.160 | 4.319 | 6.319 | 0.683 | 0.695 | 0.025 | 2.184 | -0.0878 | 0.0001 | 0.0001 | -0.2779 | 0.316 | 37.347 | 83.262 | |
| 36 | 81.01 | 2.250 | 4.499 | 6.499 | 0.692 | 0.667 | 0.023 | 2.272 | -0.0881 | 0.0001 | 0.0001 | -0.2779 | 0.317 | 37.664 | 83.264 | |
| 37 | 80.93 | 2.340 | 4.679 | 6.679 | 0.701 | 0.641 | 0.021 | 2.361 | -0.0883 | 0.0001 | 0.0001 | -0.2779 | 0.318 | 37.982 | 83.266 | |
| 38 | 80.84 | 2.430 | 4.859 | 6.859 | 0.708 | 0.617 | 0.019 | 2.449 | -0.0885 | 0.0001 | 0.0001 | -0.2779 | 0.318 | 38.300 | 83.267 | |
| 39 | 80.80 | 2.468 | 4.935 | 6.935 | 0.712 | 0.608 | 0.019 | 2.487 | -0.0376 | 0.0001 | 0.0001 | -0.2779 | 0.135 | 38.436 | 83.268 | Sec. C-C |

Notes: $E=h+\alpha V^2/2g$(m)

Average slope of energy grade line $\overline{S_f}=0.5(n^2V_1^2/R_1^{4/3}+n^2V_2^2/R_2^{4/3})$

Flow depth at starting section is set to equal the critical depth, $hc=(\alpha Q^2/gB^2)^{1/3}$

Tailwater level = 82.631m

Minimum specific energy Ec=1.5hc= 0.918 m $<E_B<E_C$ Subcritical flow

Head loss $H_{Lf}=E_1-E_2+z_1-z_2$
0.068 Between Section A-A and Section C-C
0.066 Between Section A-A and Section B-B
0.002 Between Section B-B and Section C-C

*Table 3.4.3 Summary of Head Loss*

*($Q=3\ m^3/s$ and NWL=EL.148.9m)*

| Portion | Structure | Item | Head Loss (m) |
|---|---|---|---|
| Intake | Trash racks | | 0.000 |
| | Intake | Friction | 0.010 |
| | | Entrance | 0.006 |
| | | Allowance | 0.002 |
| | | Sub total | 0.019 |
| Steel pipeline | | Friction | 0.918 |
| | | Gradual contraction | 0.011 |
| | | Bend | 0.082 |
| | | Bifurcation | 0.006 |
| | | Valve | 0.000 |
| | | Allowance | 0.067 |
| | | Sub total | 1.084 |
| Tailrace | Pressure portion | Draft-tube | 0.187 |
| | | Friction | 0.001 |
| | | Bend | 0.002 |
| | | Gradual contraction | 0.001 |
| | | Sudden expansion | 0.001 |
| | Non-pressure portion | Friction | 0.068 |
| | | Exit | 0.307 |
| | | Allowance | 0.020 |
| | | Sub total | 0.587 |
| Total | | | 1.690 |

Note: Effective head = NWL - TWL - Loss = 64.300 m

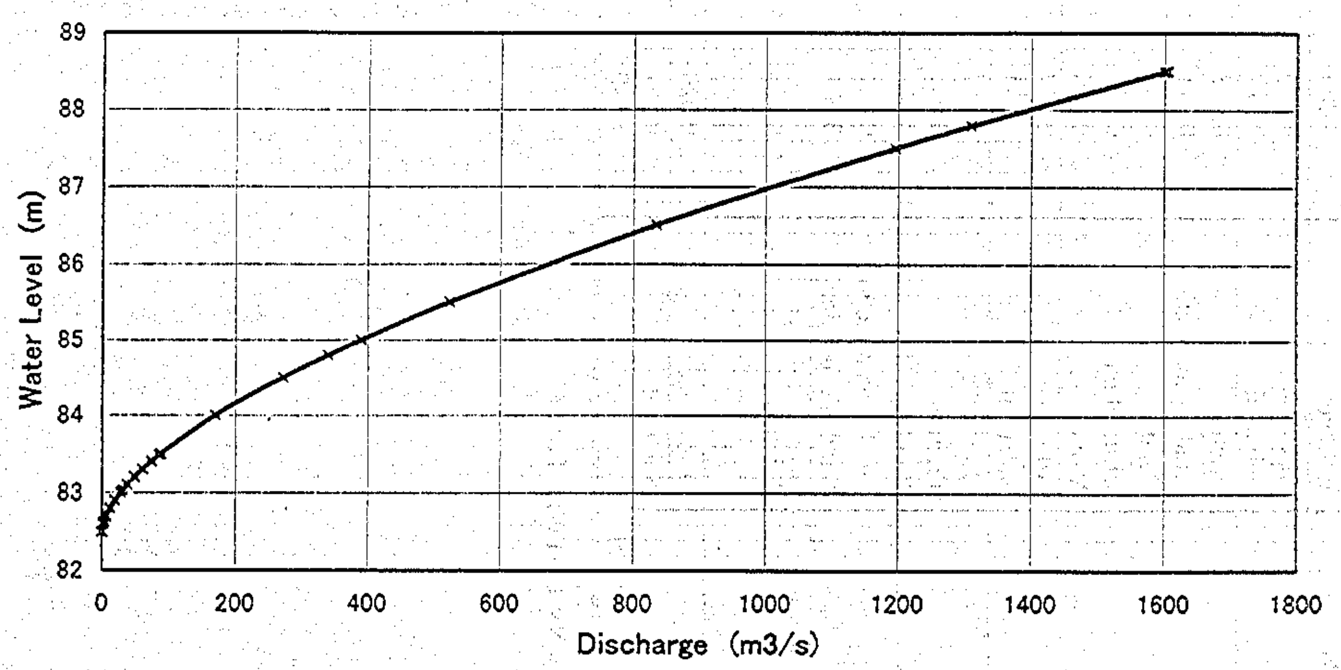



Fig. 3.4.1 H–Q Curve of River Reach Downstream of Spillway

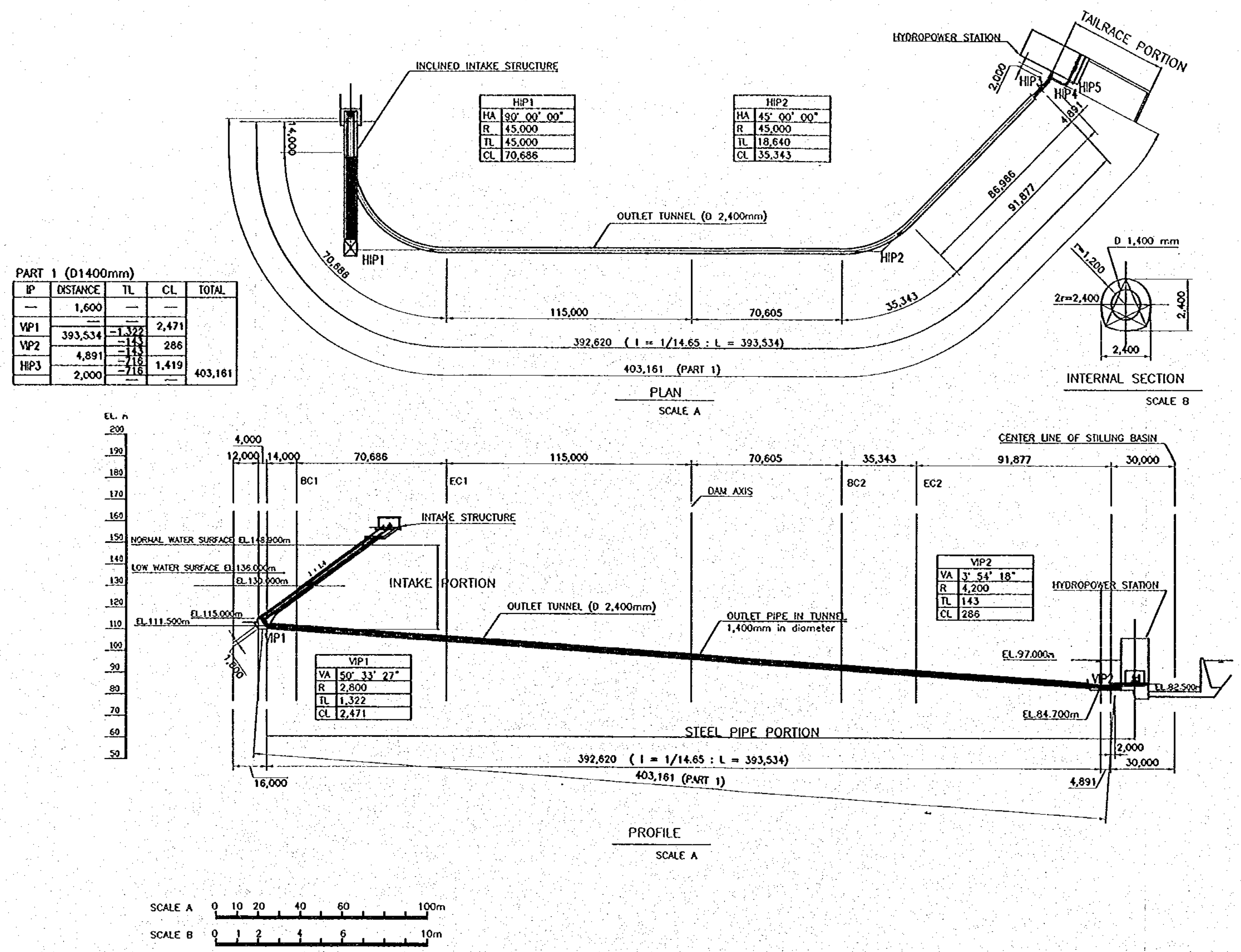
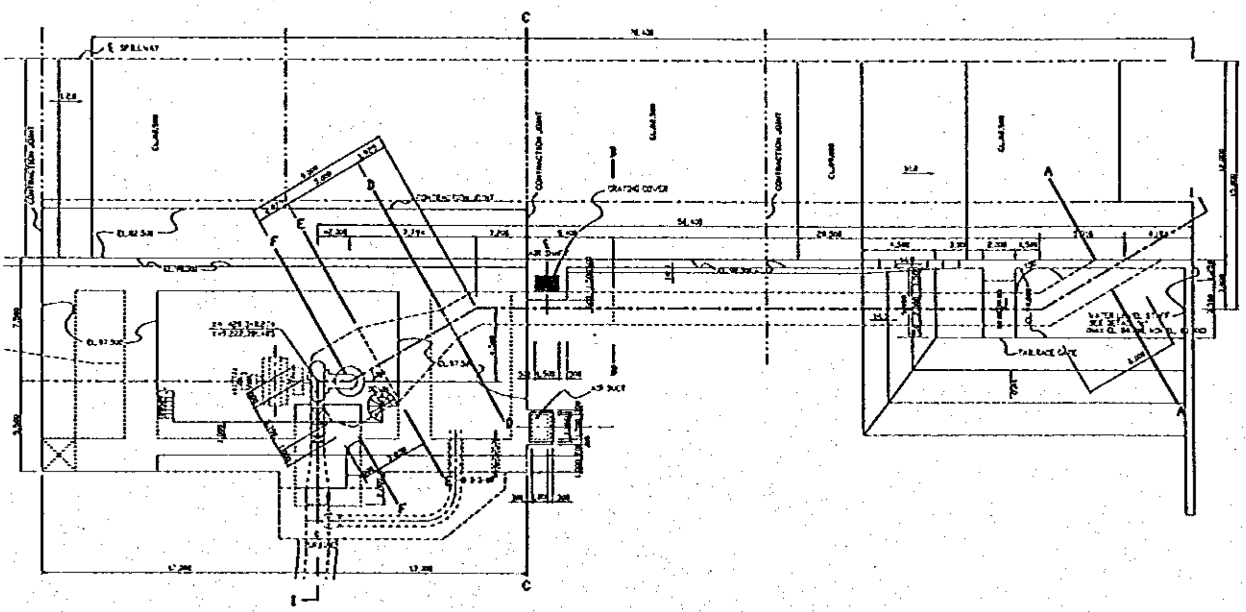
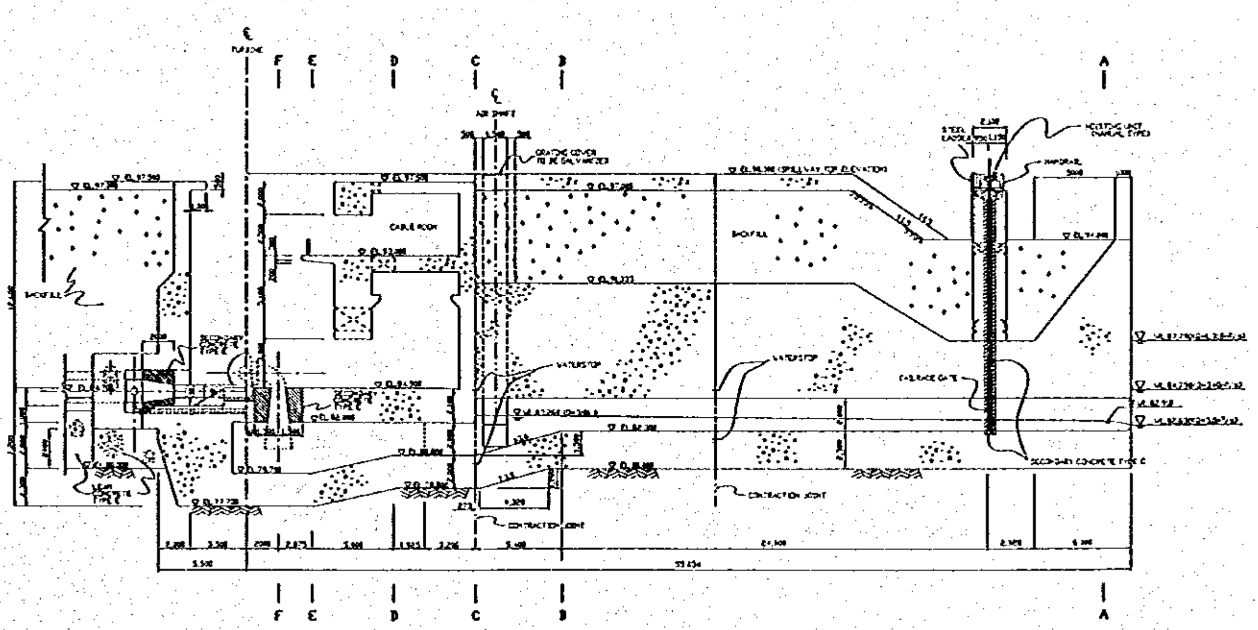



Fig. 3.4.2 CALCULATION PORTIONS FOR HEAD LOSS



GENERAL PLAN



SECTION I-I

Fig. 3.4.3 Typical Sections For Loss Calculation