# Chapter 10 FEASIBILITY DESIGN

Chapter 10

# FEASIBILITY DESIGN

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# Chapter 10 FEASIBILITY DESIGN

## 10.1 General

The feasibility designs of the main civil structure, hydraulic equipment, electromechanical equipment, and the transmission line along with temporary structures are discussed in this chapter. Cofferdams and diversion tunnels are included in the category of temporary structures. Dam, spillway, intake, headrace tunnel, penstock, powerhouse, switchyard, tailrace tunnel, outlet, and their appurtenant gate and electromechanical equipment are included in main structures.

Regarding access roads to dam and powerhouse sites, they are to be discussed in Chapter 11.

## 10.2 Pre-Feasibility Design of Upper Kihansi Project

### 10.2.1 Dam and Appurtenant Structures

(1) Location and Outline

The projected dam site is located approximately 4.0 km upstream from Kihansi Waterfalls (height approximately 200 m) which is situated on the downstream part of the Kihansi River.

The topography in the vicinity of the dam site, as described in Chapter 7, is that of a V-shaped valley with continuations of steep slopes at parts. However, there is no place upstream of this dam site where it is possible to store the necessary volume of water, while downstream of the dam site, the river gradient becomes suddenly steep so that topographically there is no suitable site for a dam, and this is the only place available. The river bed is at an elevation of around 1,270 m with the water width of the river about 20 to 30 m, and from the results of drilling investigations it is estimated that the depth from the surface ground to bedrock is about 20 m at the left bank and 50 m at the right bank.

(2) Selection of Dam Type

Various types are conceivable for the dam, but in general, a fill dam or a concrete dam can be considered. The principal factors in design of the dam including the foundation are that the dam body is to be stable, the construction cost economical, and future maintenance and inspection easy.

The three kinds below are conceivable for the dam type considering the topography and geology of this site, and economical comparison studies are made.

i) Fill type dam (impervious center core type)
ii) Fill type dam (concrete facing type)
iii) Concrete dam (gravity type)

The results of the studies are as shown in Table 10-1 and Figs. 10-1 through 10-6.

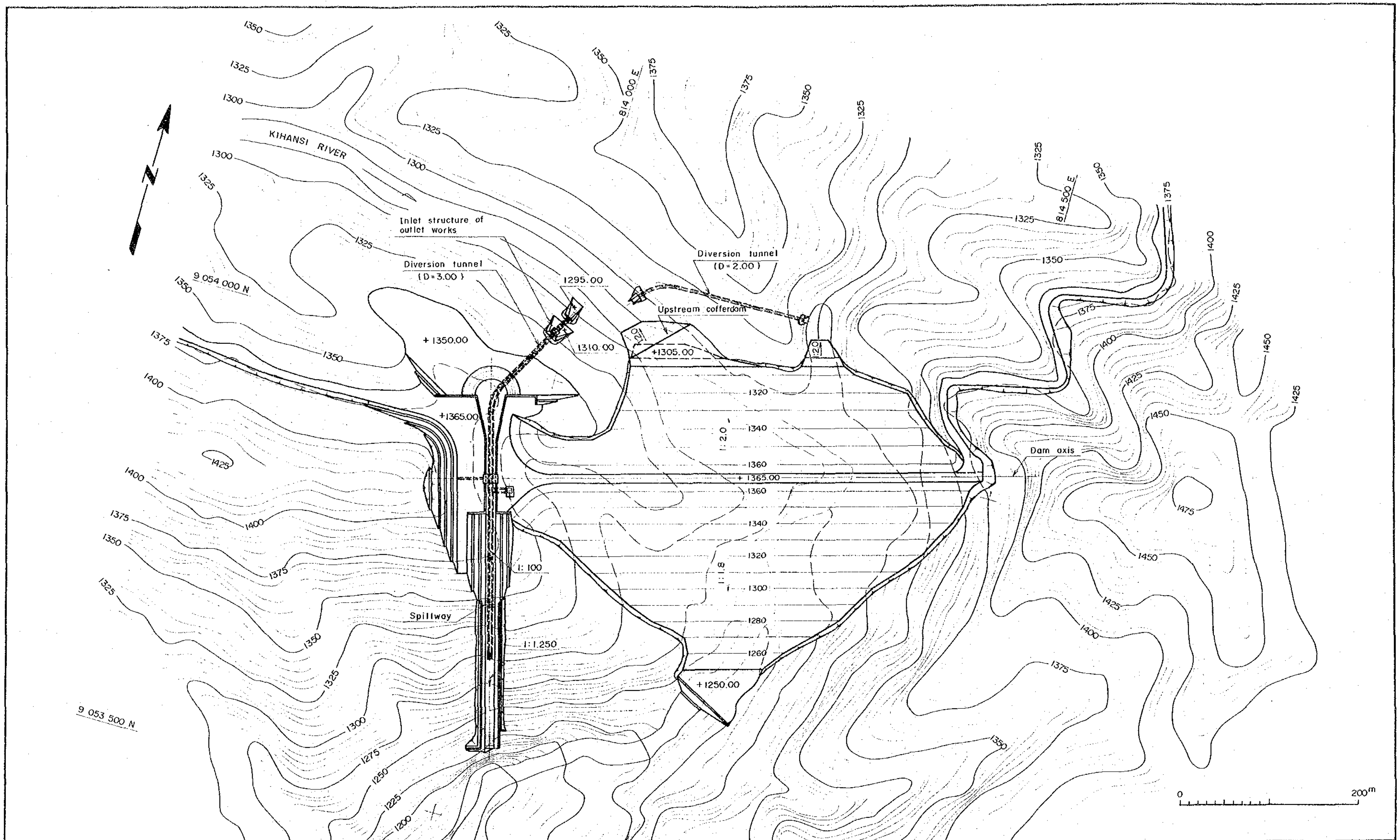
As Table 10-1 shows, the rockfill dam with impervious center core and the rockfill dam with concrete facing are superior economically at the present stage.

From the standpoint of constructability, there are no differences between any of the types as to superiority. Also, since differences among the three types are inconceivable with regard to maintenance and inspection, the rockfill dam with impervious center core is adopted.

However, the geological investigation works done at this dam site consist only of 3 drillholes, and from the facts that it cannot be considered the condition of the foundation has been adequately grasped, and that a thorough investigation has not been made of core materials in particular among fill materials, it will be necessary for comparison studies with a concrete facing rockfill dam to be made in more detail upon carrying out further investigations.

(3) Determination of Dam Crest Elevation

For the dam crest elevation the height adding freeboard to the flood water level is to be adopted. The flood water level is the EL. 1,361.88 m described under (4) 'Spillway', while the freeboard is an amount taking into account wind and earthquake wave heights, etc., calculations being performed using the equation below, provided that the minimum freeboard is to be 3.00 m.




KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

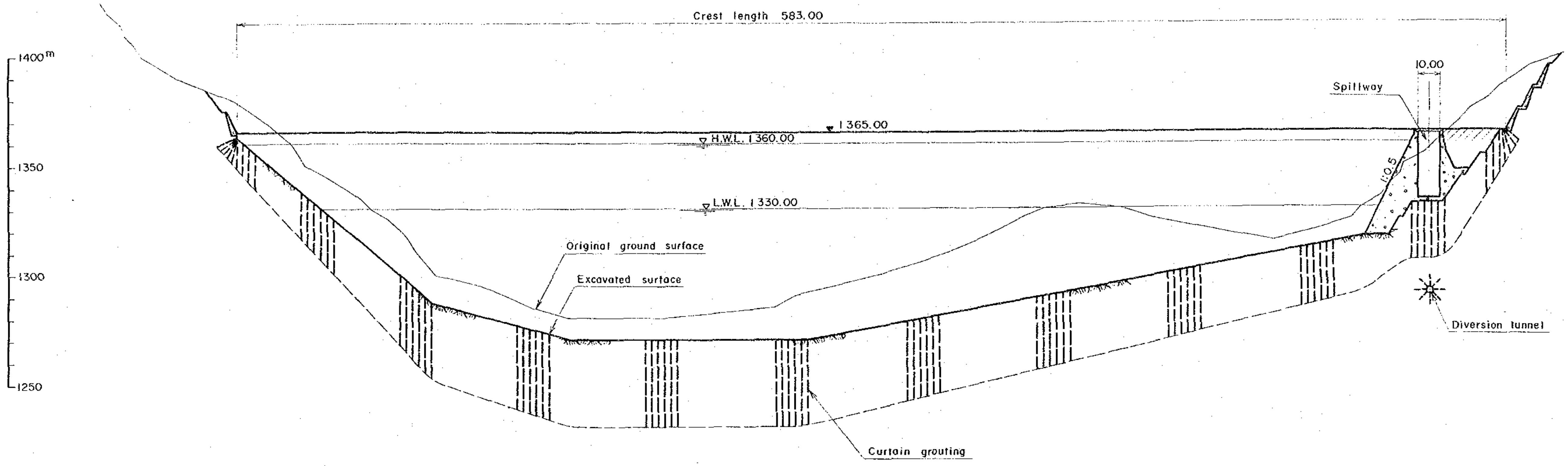
UPPER KIHANSI PROJECT

DAM

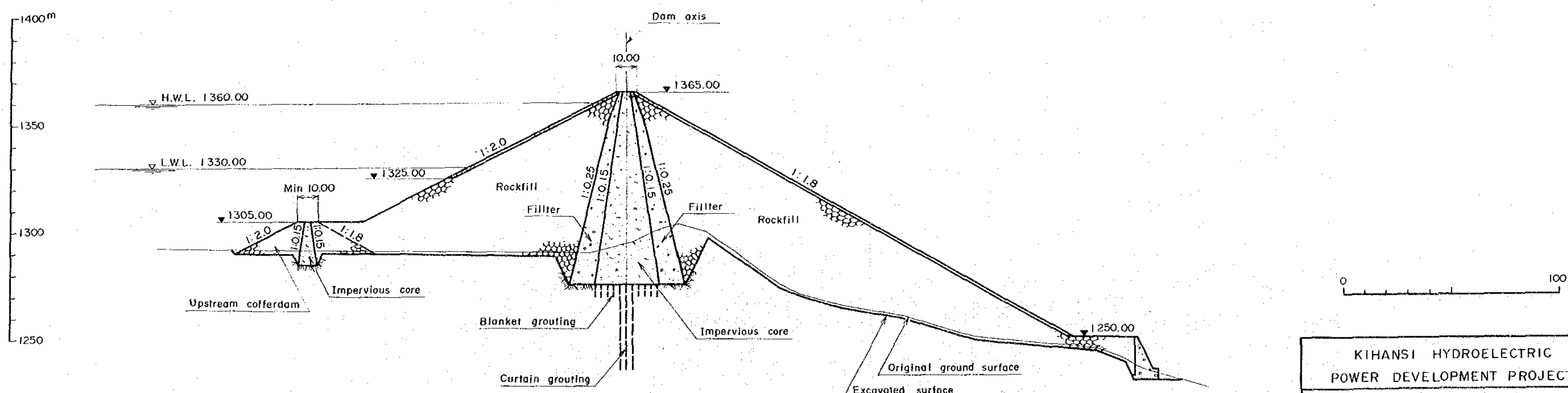
PLAN

| Fig. 10－1 | DATE; |
|---|---|

## PROFILE OF DAM




## TYPICAL SECTION OF DAM



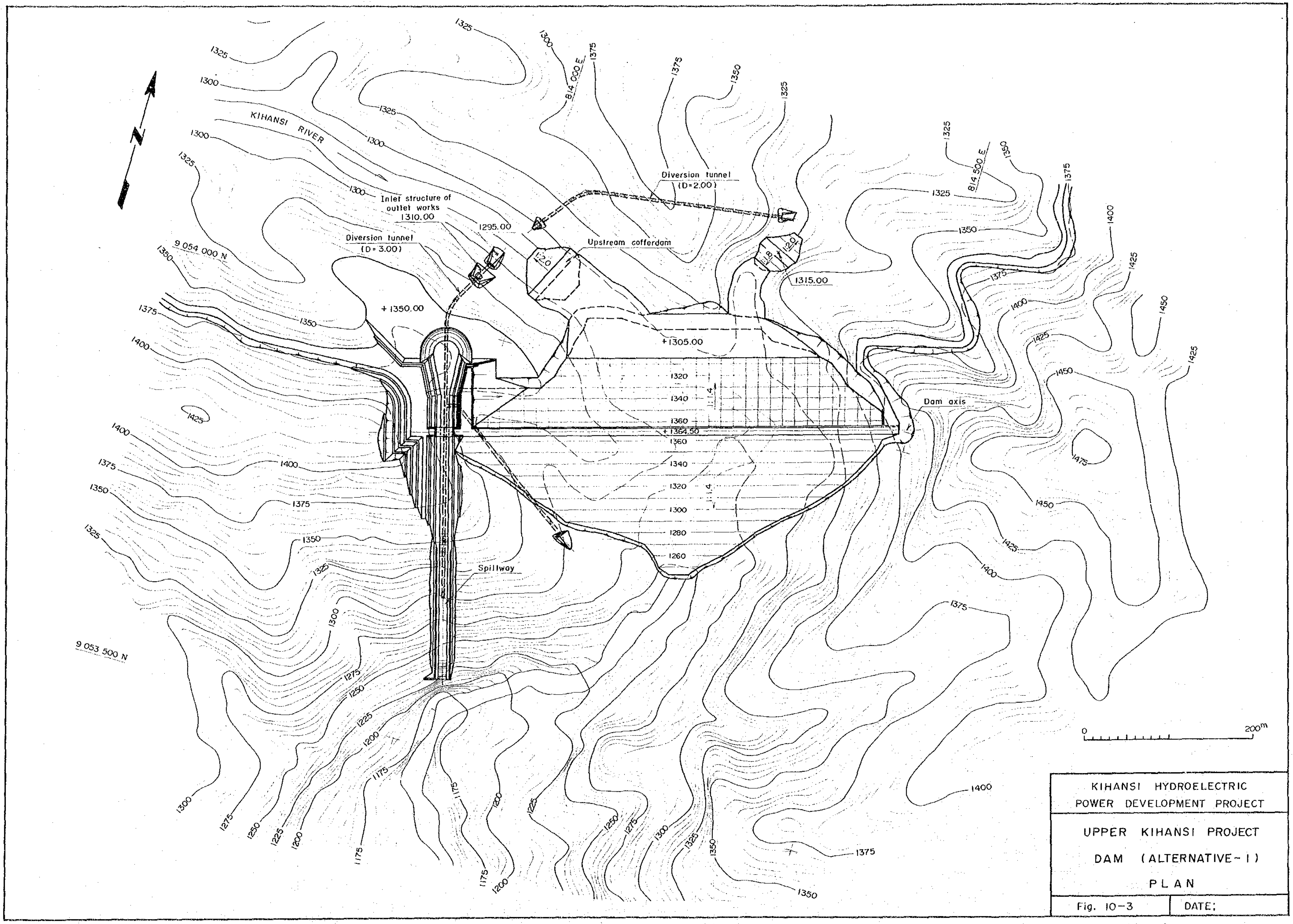

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI PROJECT

DAM

PROFILE AND TYPICAL SECTION

| Fig. 10 – 2 | DATE; |
|---|---|




KIHANSI HYDROELECTRIC
POWER DEVELOPMENT PROJECT

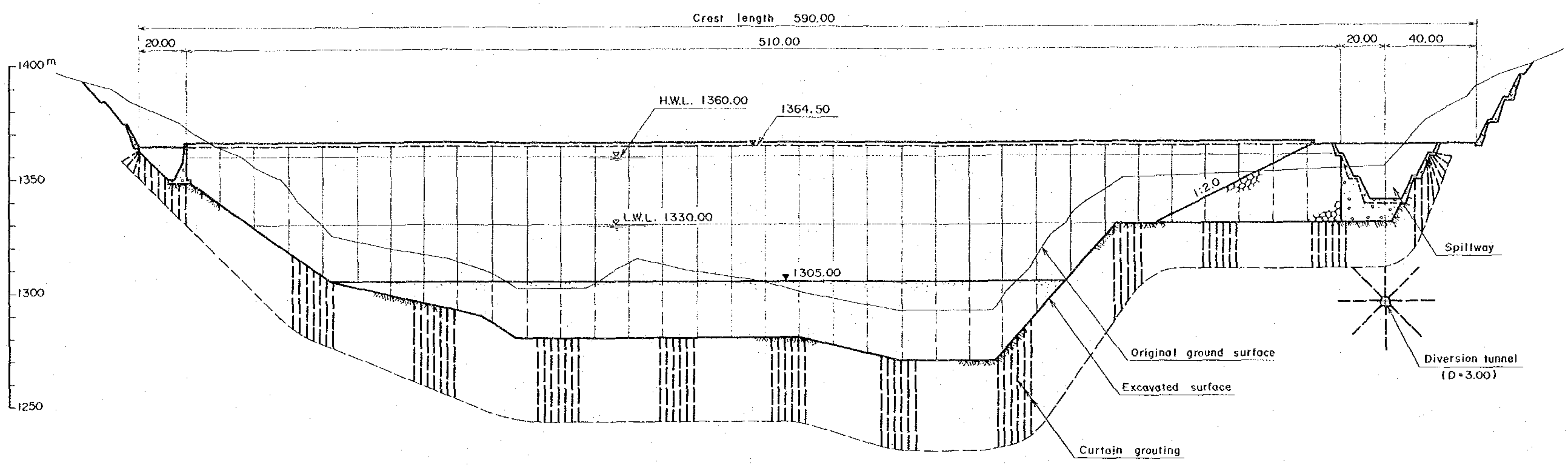
UPPER KIHANSI PROJECT

DAM (ALTERNATIVE-I)

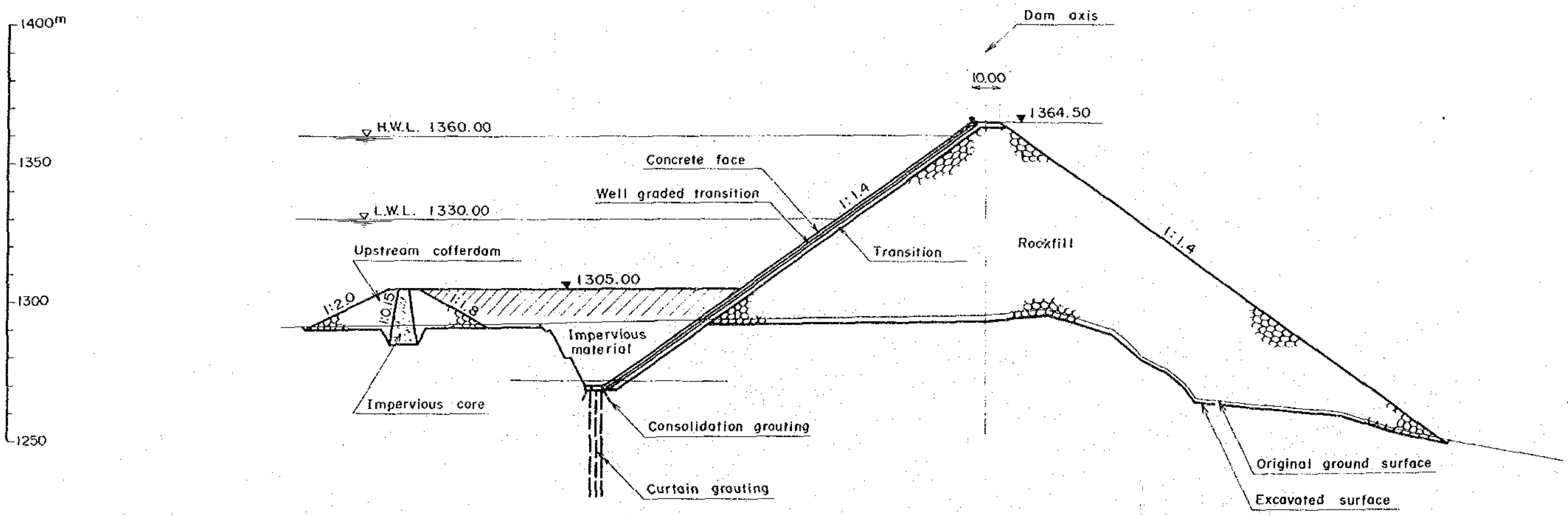
PLAN

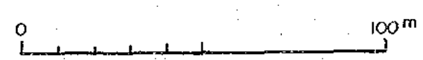
Fig. 10-3 | DATE;

## PROFILE OF DAM

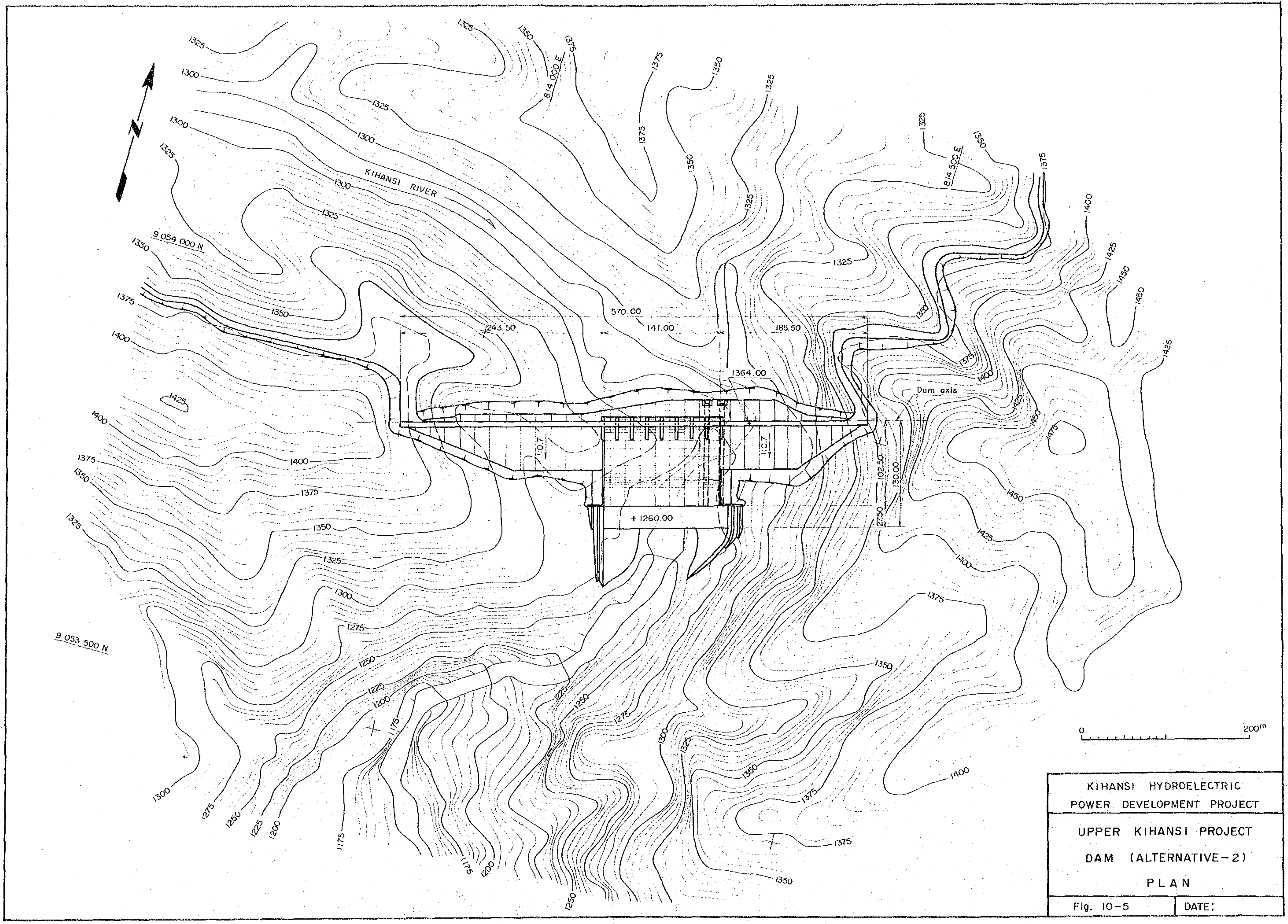



## TYPICAL SECTION OF DAM




| KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT | |
|---|---|
| UPPER KIHANSI PROJECT<br>DAM (ALTERNATIVE - 1)<br>PROFILE AND TYPICAL SECTION | |
| Fig. 10-4 | DATE; |




KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

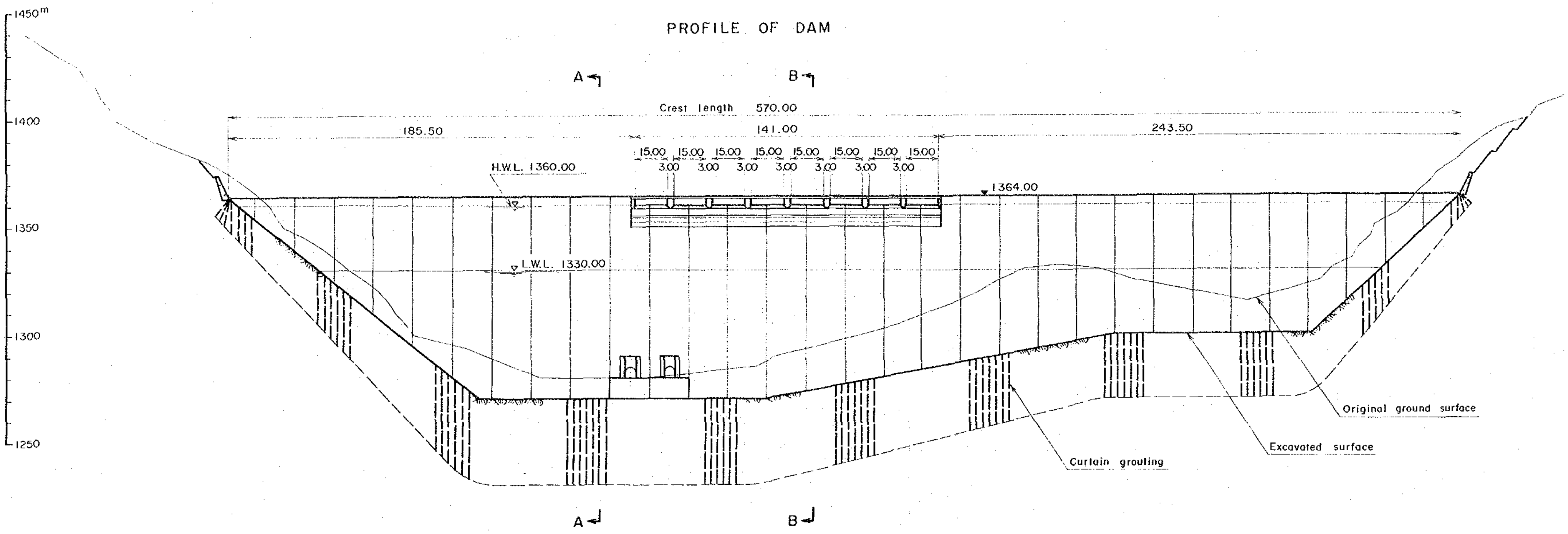
UPPER KIHANSI PROJECT

DAM (ALTERNATIVE-2)

PLAN

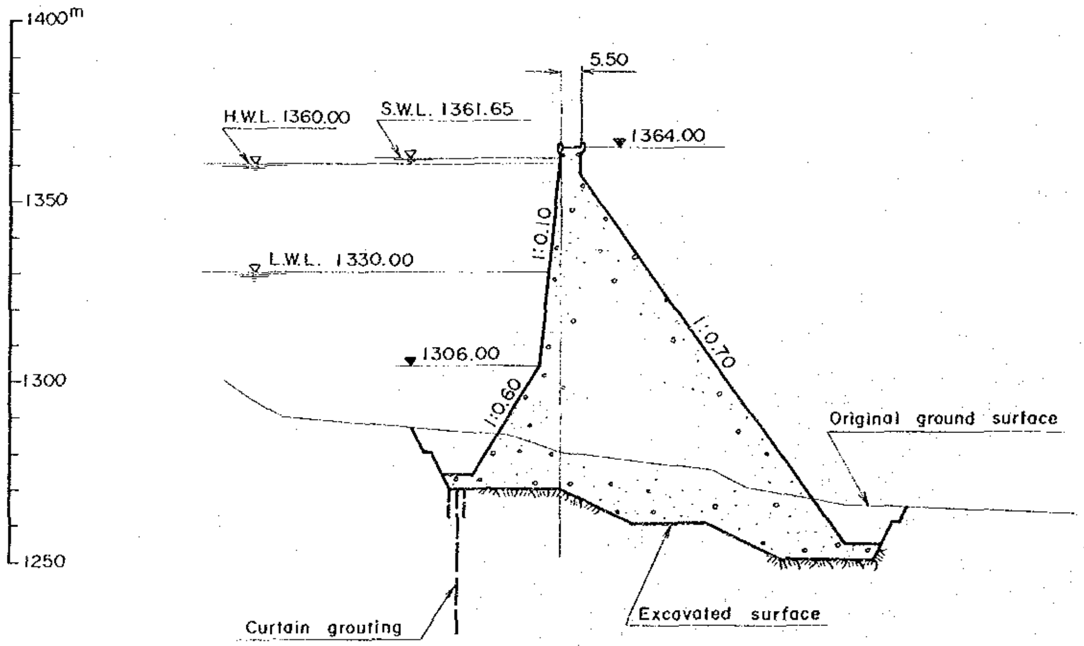
| | |
|---|---|
| Fig. 10-5 | DATE; |

## PROFILE OF DAM

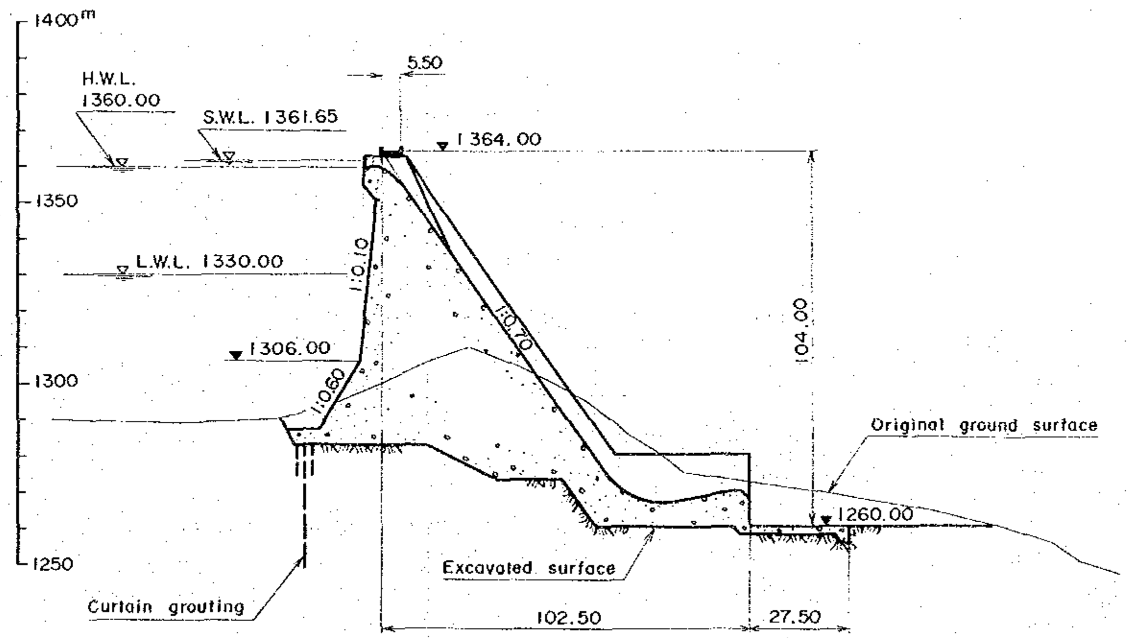



## TYPICAL SECTION OF DAM

### SECTION A – A




### SECTION B – B





KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

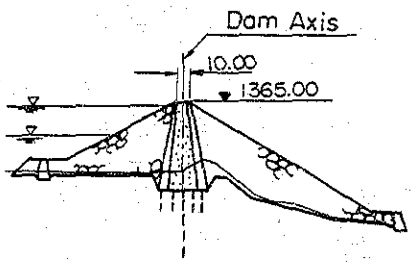
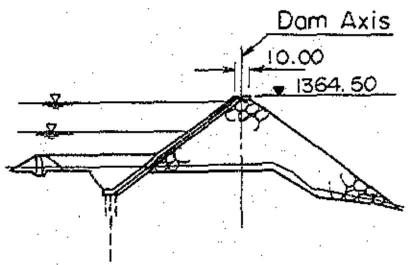
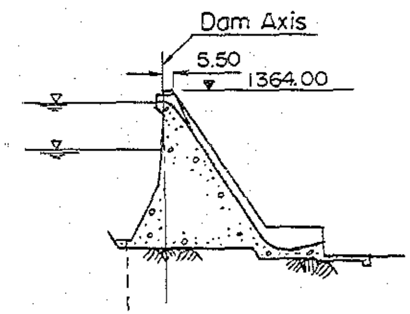
UPPER KIHANSI PROJECT

DAM (ALTERNATIVE-2)

PROFILE AND TYPICAL SECTION

| Fig. 10 – 6 | DATE; |
|---|---|

Table 10-1 Comparison of Dam Type

| Item | | Rockfill Type (Impervious Core) | Rockfill Type (Concrete Facing) | Concrete Gravity Type |
|---|---|---|---|---|
| Typical Section | |  |  |  |
| Slope | Upstream | 1 : 2.0 | 1 : 1.4 | 1 : 0.1 (1:0.6) |
| | Downstream | 1 : 1.8 | 1 : 1.4 | 1 : 0.7 |
| Dam Volume | | 5,350,000 $m^3$ | Rockfill 4,490,000 $m^3$<br>Concrete 52,000 $m^3$ | 1,510,000 $m^3$ |
| Construction Cost | | $144.4 \times 10^6$ US$ | $170.0 \times 10^6$ US$ | $243.1 \times 10^6$ US$ |
| Ratio of Construction Cost | | 1.00 | 1.18 | 1.68 |

$$H_f \geq h_w + h_e + h_a + h_i$$

where, $H_f$ = freeboard (m)

$h_w$ = wave height due to wind (m)

$h_e$ = wave height due to earthquake (m)

$h_a$ = water level rise due to unforeseen accident in spillway operation (m)

$h_i$ = additional amount according to type and importance of dam

i) Wave Height due to Wind

Although there are various formulae available regarding the relations of wind speed and fetch with wave height, the uprush height obtained by the combination of the S.M.B. method and Saville's method is used here.

| | |
|---|---|
| Fetch | 700 m |
| Average wind speed for 10 minutes | 30 m/sec |
| Wave height | 0.45 m |

ii) Wave Height due to Earthquake

With regard to earthquake wave height the formula of Seiichi Sato which gives a comparatively large wave height is used.

$$h_e = \frac{k\tau}{2\pi} \sqrt{gHo}$$

where, $h_e$: Wave height due to earthquake at the front face of the dam

k : Horizontal seismic coefficient (= 0.1)

$\tau$ : Earthquake period (= 1 sec)

$H_o$: Reservoir water depth from normal water level (= 90 m) g : Acceleration of gravity (= 9.8 m/sec$^2$)

$$h_e = \frac{0.1 \times 1}{2\pi} \times \sqrt{9.8 \times 90} \fallingdotseq 0.50 \text{ m}$$

iii) Water Level Rise due to Unforseen Accident in Spillway Operation

This is not added since there is no spillway gate operation.

iv) Extra Height According to Dam Type and Importance

Being a fill dam, 1.00 m is additionally considered for the sake of safety.

v) Calculation of Total Freeboard

$H_f$ = 0.45 + 0.50 + 1.00
= 1.95 m

vi) Determination of Freeboard

Since the minimum freeboard is greater than the calculated value, 3.00 m is to be taken for this dam site.

vii) Elevation of Non-overflow Section

The elevation of the non-overflow section is to be 1,365.00 m, adding water level rise of 1.88 m during flood and freeboard of 3.00 m to the high water level of 1,360.00 m.

(4) Spillway

The spillway is to be set at the right bank of the dam taking into consideration to the topography, geology, and the downstream direction of river flow. The inlet is to be located approximately 100 m upstream of the dam axis, and the configuration is to be a semi-circular shape for a free overflow type. This is to make it possible for flood to be easily discharged with safety making it unnecessary for gate operation. The design flood discharge is taken to be the 400 $m^3$/sec decided on in Chapter 6. The free overflow quantity is calculated according to the following:

i) Design Conditions

| | |
|---|---|
| Design flood discharge | :400 $m^3$/sec |
| Overflow crest elevation | :1,360.00 m |
| Overflow crest length | :100 m |
| Overflow crest configuration | :Standard overflow crest |

ii) Calculation Equation

$$Q = CBH^{3/2}$$

$$C_d = 2.200 - 0.0416\ (H_d/W)^{0.99}$$

$$C = 1.60\ \frac{1 + 2a\ (H/H_d)}{1 + 1\ \ (H/H_d)}$$

where, Q : Overflow discharge ($m^3$/sec)
C : Overflow coefficient
B : Overflow crest length (= 100 m)
H : Overflow depth (m)
$C_d$: Overflow coefficient at $H = H_d$
W : Dam height
a : Constant

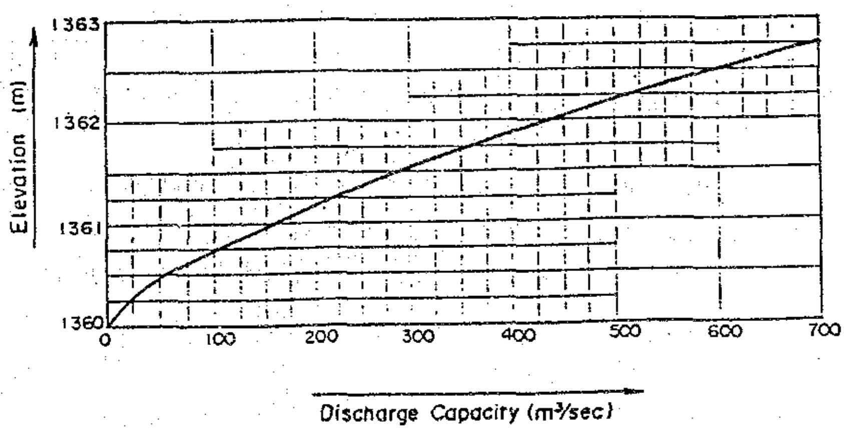
iii) Calculation Results

The result of calculation is shown in Fig. 10-7 and the water elevation at the time when design flood discharge flows is 1,361.88 m.

As for the energy dissipation system of the spillway, because of the topographic condition that the river-bed gradient around the end of the spillway is approximately 1/3, there is a series of rapids and both banks are steep cliffs, water is to be conducted by chute as far as the tops of the cliffs from where it is to be dropped to the river bed by ski jump.

The configuration of the spillway is shown in Fig. 10-1.

**Fig. 10-7 Discharge Capacity of Spillway**




(5) Cofferdams

A cofferdam is for prevention of inflow of river water to the work area while constructing the dam and for diverting river water into a diversion tunnel.

Cofferdamming during construction is to be at the upstream side only and a cofferdam at the downstream side is to be omitted since the river gradient on that side is steep at 1/3 and there is no reverse flow into the work area from below.

The cofferdam crest elevation is made 1,305.00 m at which there is no overtopping even if there occurs 20-

year return period flood discharge of 90 $m^3$/sec, the diversion tunnel discharge capacity. The structural form is made the same impervious center core rockfill as the main dam with the upstream face slope 1:2.0 and the downstream face slope 1:1.8. Locations are arranged so that the cofferdams are used as parts of the main dam, and are at two places: the mainstream and a tributary.

(6) Diversion Tunnels

i) Diversion Tunnel for Tributary

The sub-diversion tunnel for the tributary is of a route for connection by the shortest distance giving consideration to the locations of the cofferdams on the mainstream and the tributary. Since the 20-year return period flood discharge is small at 10 $m^3$/sec, the cross section is made the minimum possible to construct, a height of 2.0 m and a width of 2.0 m with the excavated tunnel surface protected with shotcrete.

ii) Diversion Tunnel for Mainstream

With regard to the main diversion tunnel on the mainstream, as shown in Fig. 10-1, a route from upstream of the cofferdam to the outlet constructed at the part way of the spillway chute by way of the inlet of the spillway is selected. This is because the diversion tunnel would need to be a diagonal shaft and the length of the tunnel approximately 100 m longer because of the steepness of the downstream river gradient, if the outlet were to be provided at the river bed.

This diversion tunnel is to be lined with concrete throughout its length in order that it can be transformed into a bottom outlet for lowering the reservoir water level at a time of emergency at the dam. The shape is of semi-circular top and rectangular bottom cross section of inside diameter 3.0 m and width 3.0 m, the design discharge capacity of 90 $m^3$/sec, the same 20-year return period flood as for the tributary diversion tunnel. This diversion tunnel and the spillway chute section are to be constructed simultaneously, and the river water is to be diverted to it after they are completed.

(7) Bottom Outlet

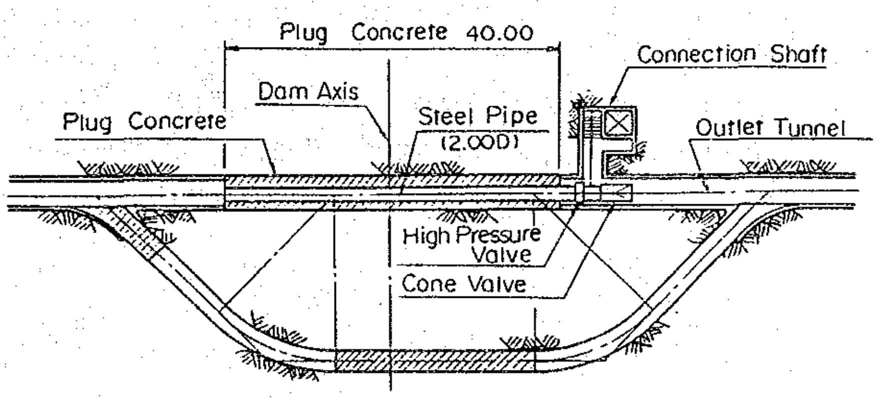
In the event an abnormal situation arises at the dam or spillway and it becomes necessary to lower the reservoir water level, the reservoir is to be emptied by discharging water using a bottom outlet.

The amount of discharge is adjusted by manipulating a valve provided on the dam axis in the mainstream diversion tunnel.

The inlet orifice structure of reinforced concrete is to be in the vicinity of the diversion tunnel inlet, the elevation coinciding with the reservoir sedimentation level of 1,300.00 m.

The valve chamber is to be located at the downstream side of the dam axis as shown in Fig. 10-8 and connection to the ground surface is to be by a vertical shaft having an elevator and a stairway.

**Fig. 10-8 Detail of Outlet Valve Chamber**



### 10.2.2 Waterway and Powerhouse

(1) Study of Waterway Route

Waterway routes can be broadly divided into right-bank proposals and left-bank proposals.

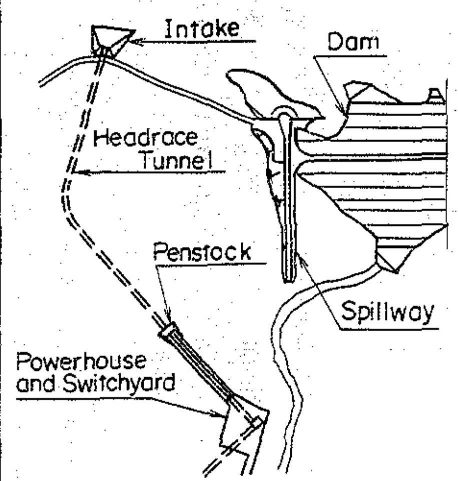
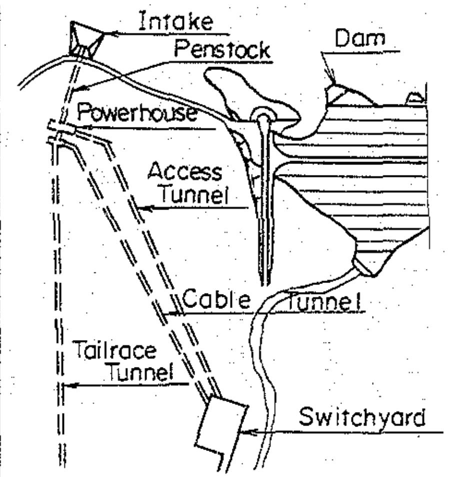
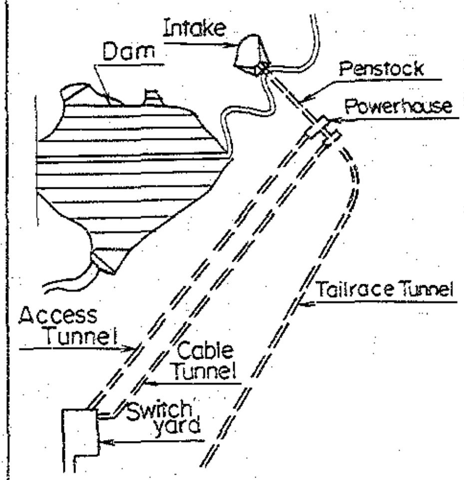
Topographically, there are no problems about a right-bank proposal, but geologically, the top soil depth to the foundation rock is assumed to be great. Locations for the powerhouse and switchyard are favorable from the standpoints of both topography and geology, and it is possible for a semi-underground powerhouse and switchyard to be provided.

With a left-bank proposal, the top soil depth to foundation rock is comparatively small, but the topography is rugged and of complex relief and the tunnel length becomes to be great. The powerhouse is to be arranged as an underground type while the switchyard is as an outdoor type requiring a large volume of soil excavation so that the construction cost is estimated to be too high.

Table 10-2 gives a comparison of right- and left-bank proposals, and as is clear from this table a right-bank proposal is superior, and so it is decided that the waterway and powerhouse are to be provided at the right-bank side.

For the right-bank chosen according to the above study, a comparison is made whether to make the powerhouse a semi-underground type or an underground type, the results of which are given in Table 10-2, and a semi-underground type is adopted for the reasons given below.

## Table 10-2 Comparison of Waterway

| Item | Right Bank (Semi Underground Type) | Right Bank (Underground Type) | Left Bank (Underground Type) |
|---|---|---|---|
| Plan |  |  |  |
| Total Length of Waterway | 1,804 m | 1,471 m | 2,300 m |
| Construction | Good | Good | Good |
| Construction Cost | 20.4 × $10^6$ US$ | 22.4 × $10^6$ US$ | 28.0 × $10^6$ US$ |
| Ratio of Construction Cost | 1.00 | 1.10 | 1.37 |

i) The construction cost is 10 percent cheaper for a semi-underground type and, therefore, it is more economical.

ii) With an underground type the transformer room has to be provided adjacent to the powerhouse and a high-voltage cable is to be needed to the outdoor switchyard.

iii) Since geological investigation work has not been adequately carried out, there is a possibility a problem will arise concerning the stability of the cavern for the underground powerhouse.

iv) Compared with an underground type, it is easier to execute works for a semi-underground type.

The semi-underground and underground powerhouse proposals for the right bank are shown in Figs. 10-9 through 10-12.

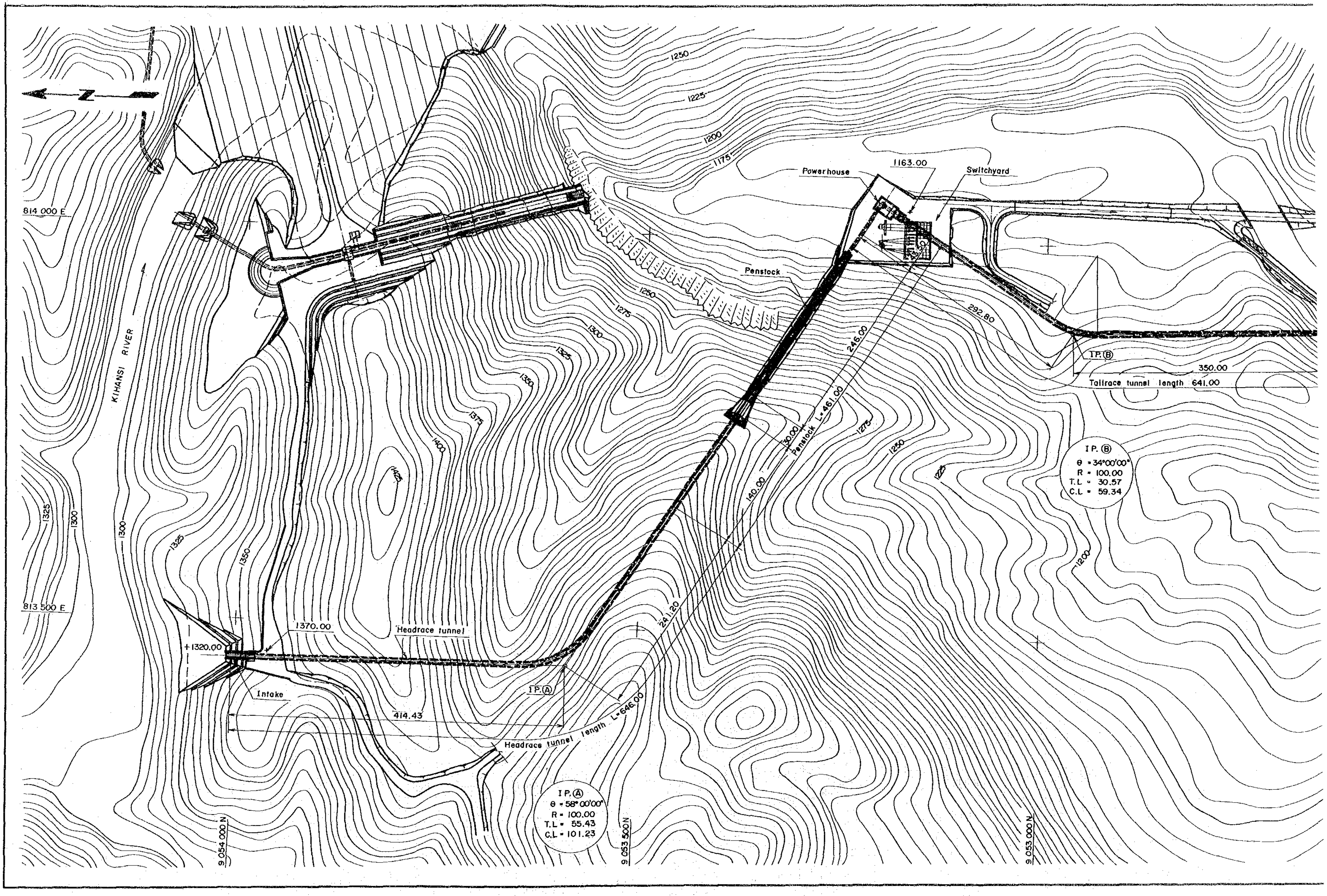
(2) Intake

The intake is to be provided at a point where the mainstream bends from south to east, approximately 500 m west from the spillway. This site is selected for the reasons below.

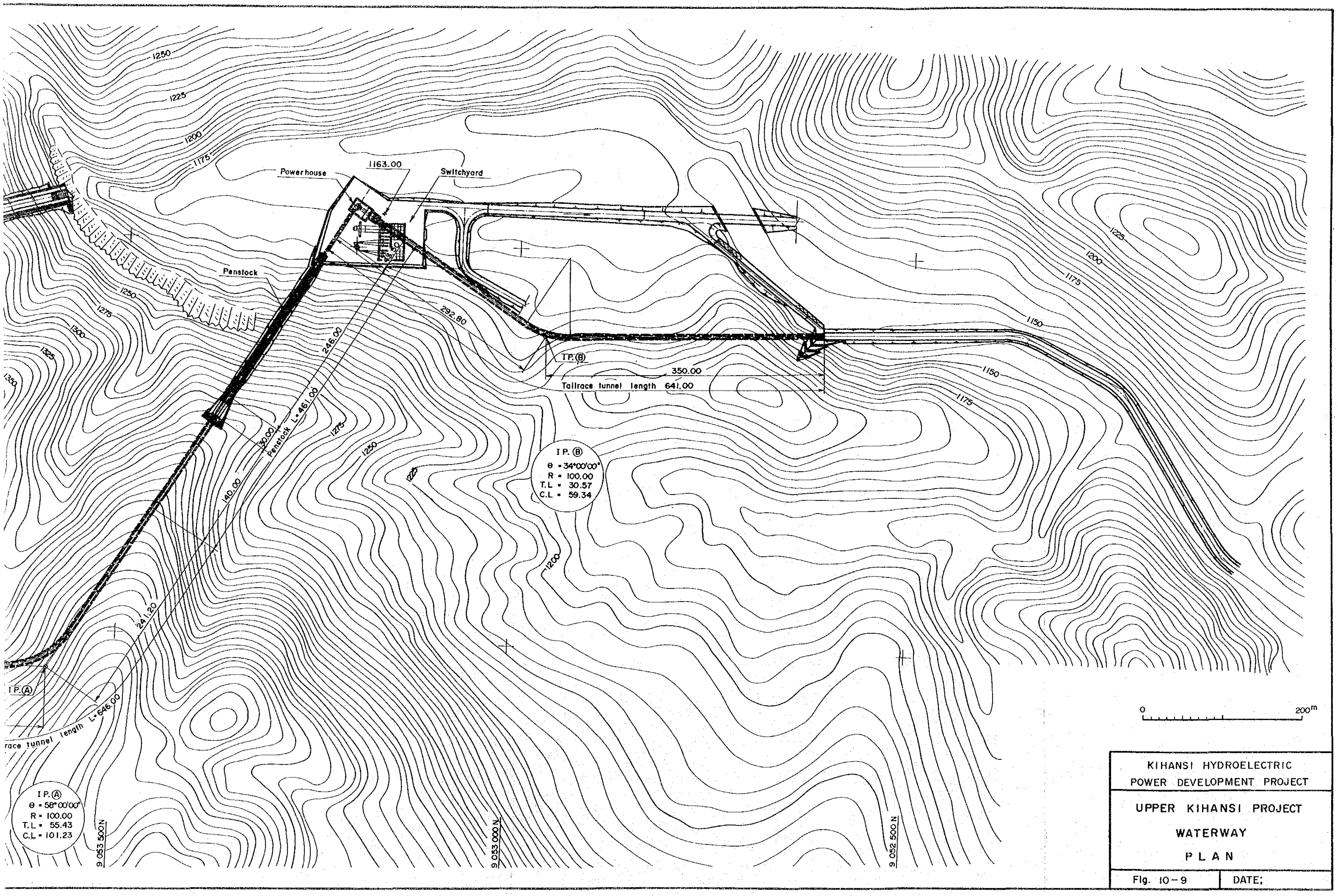
i) The conditions concerning topography and geology with regard to providing the intake are the same within approximately 1 km upstream from the dam and spillway.

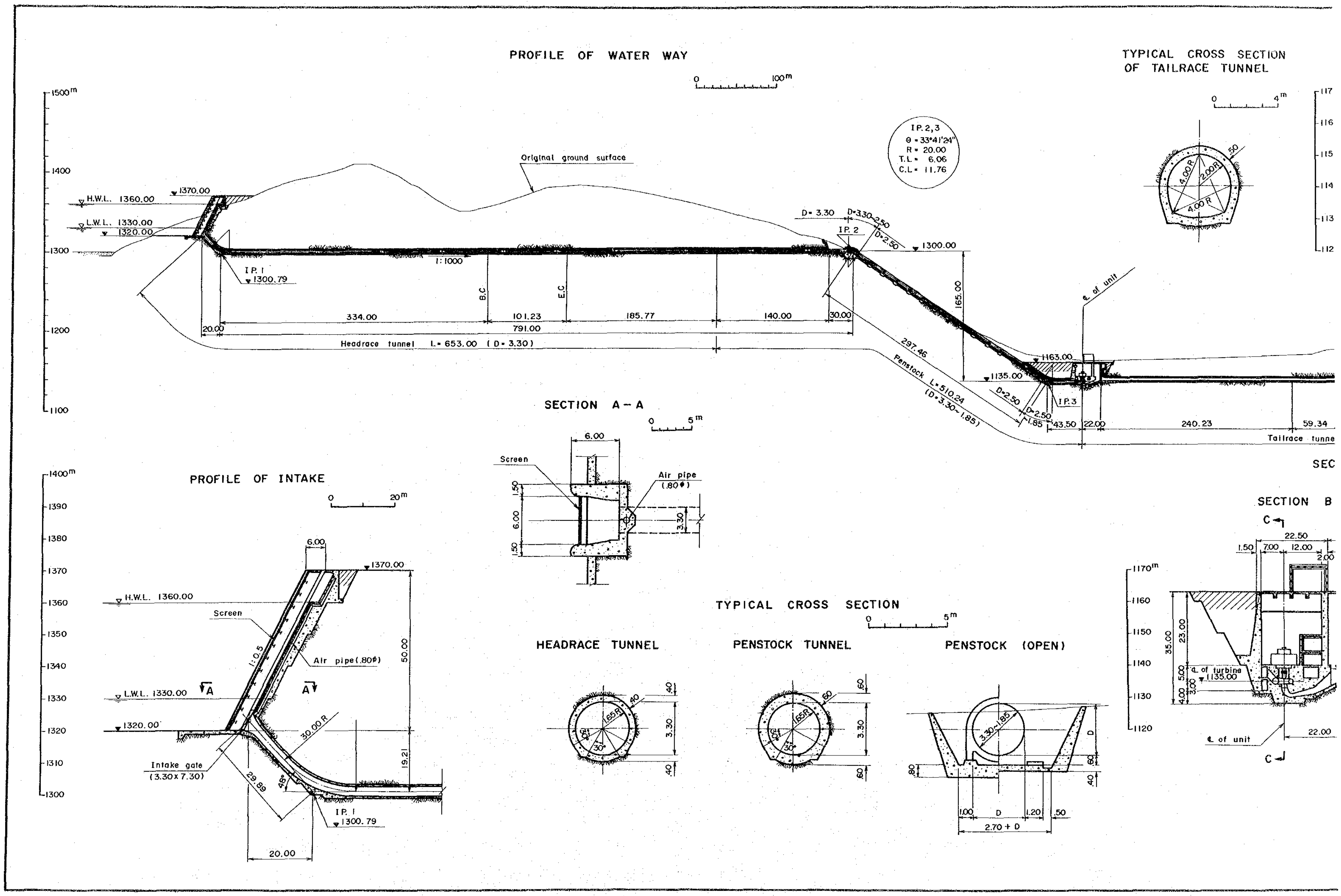
ii) The right bank downstream of the dam has a gully cutting deeply into its side and it is necessary for the headrace tunnel to detour around this gully.

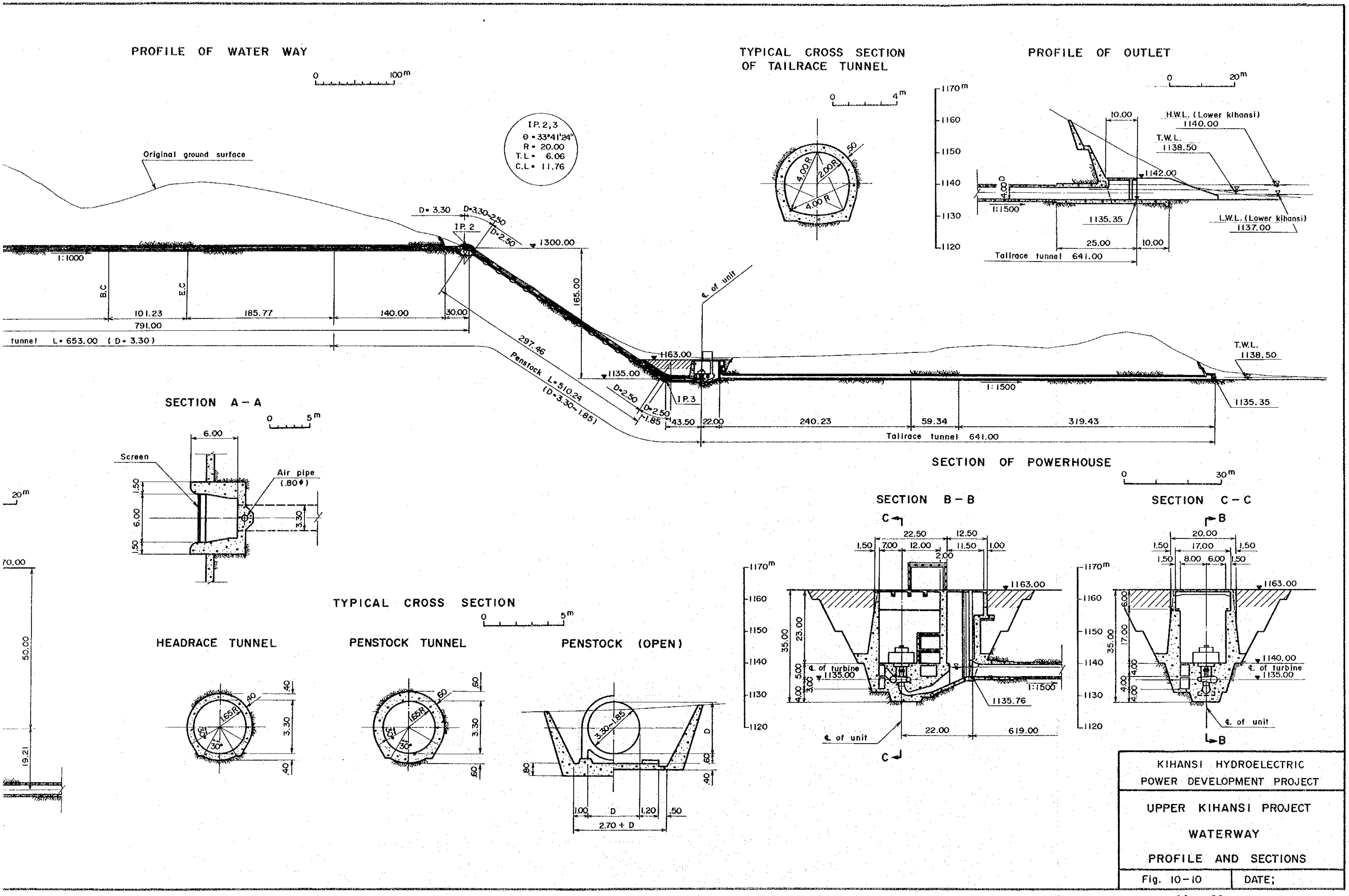
iii) The intake site is to be selected so that the distance from the intake to the powerhouse becomes



Z
814 000 E
813 500 E
KIHANSI RIVER
Powerhouse
1163.00
Switchyard
Penstock
292.80
IP. Ⓑ
350.00
Tailrace tunnel length 641.00
246.00
Penstock L=461.00
30.00
140.00
241.20
1370.00
Headrace tunnel
+1320.00
Intake
IP. Ⓐ
414.43
Headrace tunnel length L=646.00
IP. Ⓑ
θ = 34°00'00"
R = 100.00
T.L = 30.57
C.L = 59.34
IP. Ⓐ
θ = 58°00'00"
R = 100.00
T.L = 55.43
C.L = 101.23
9 054 000 N
9 053 500 N
9 053 000 N


Powerhouse
1163.00
Switchyard
Penstock
292.80
246.00
I.P.Ⓑ
350.00
Tailrace tunnel length 641.00
Penstock L=461.00
30.00
140.00
241.20
I.P.Ⓐ
race tunnel length L=646.00
I.P.Ⓑ
θ = 34°00'00"
R = 100.00
T.L = 30.57
C.L = 59.34
I.P.Ⓐ
θ = 58°00'00"
R = 100.00
T.L = 55.43
C.L = 101.23
9 053 500 N
9 053 000 N
9 052 500 N
1250
1225
1200
1175
1150
1275
1300
1325
1350
0
200m
KIHANSI HYDROELECTRIC
POWER DEVELOPMENT PROJECT
UPPER KIHANSI PROJECT
WATERWAY
PLAN
Fig. 10-9
DATE;


PROFILE OF WATER WAY
0 100m
Original ground surface
I.P. 2,3
θ = 33°41'24"
R = 20.00
T.L = 6.06
C.L = 11.76
H.W.L. 1360.00
L.W.L. 1330.00
1370.00
1320.00
I.P. 1
1300.79
1:1000
B.C
E.C
334.00
101.23
185.77
140.00
30.00
20.00
791.00
Headrace tunnel L = 653.00 (D = 3.30)
D = 3.30
D = 3.30~2.50
I.P. 2
D = 2.50
1300.00
165.00
297.46
Penstock L = 510.24
(D = 3.30~1.85)
1163.00
1135.00
D = 2.50
I.P. 3
D = 2.50
1.85
43.50
22.00
240.23
59.34
Tailrace tunne
℄ of unit
TYPICAL CROSS SECTION
OF TAILRACE TUNNEL
0 4m
4.00R
2.00R
4.00R
4.00R
.50
SECTION A – A
0 5m
6.00
Screen
Air pipe
(.80ϕ)
1.50
6.00
1.50
3.30
PROFILE OF INTAKE
0 20m
6.00
1370.00
H.W.L. 1360.00
Screen
1:0.5
Air pipe (.80ϕ)
50.00
L.W.L. 1330.00
A
A
1320.00
30.00 R
19.21
Intake gate
(3.30 x 7.30)
29.89
48°
I.P. 1
1300.79
20.00
TYPICAL CROSS SECTION
0 5m
HEADRACE TUNNEL
PENSTOCK TUNNEL
PENSTOCK (OPEN)
1.65R
.40
3.30
.40
.60
3.30
.60
30°
3.30~1.85
D
.60
.40
.80
1.00
D
1.20
.50
2.70 + D
SEC
SECTION B
C
22.50
1.50
7.00
12.00
2.00
35.00
23.00
5.00
4.00
3.00
℄ of turbine
1135.00
℄ of unit
22.00
C
1500m
1400
1300
1200
1100
1400m
1390
1380
1370
1360
1350
1340
1330
1320
1310
1300
1170m
1160
1150
1140
1130
1120



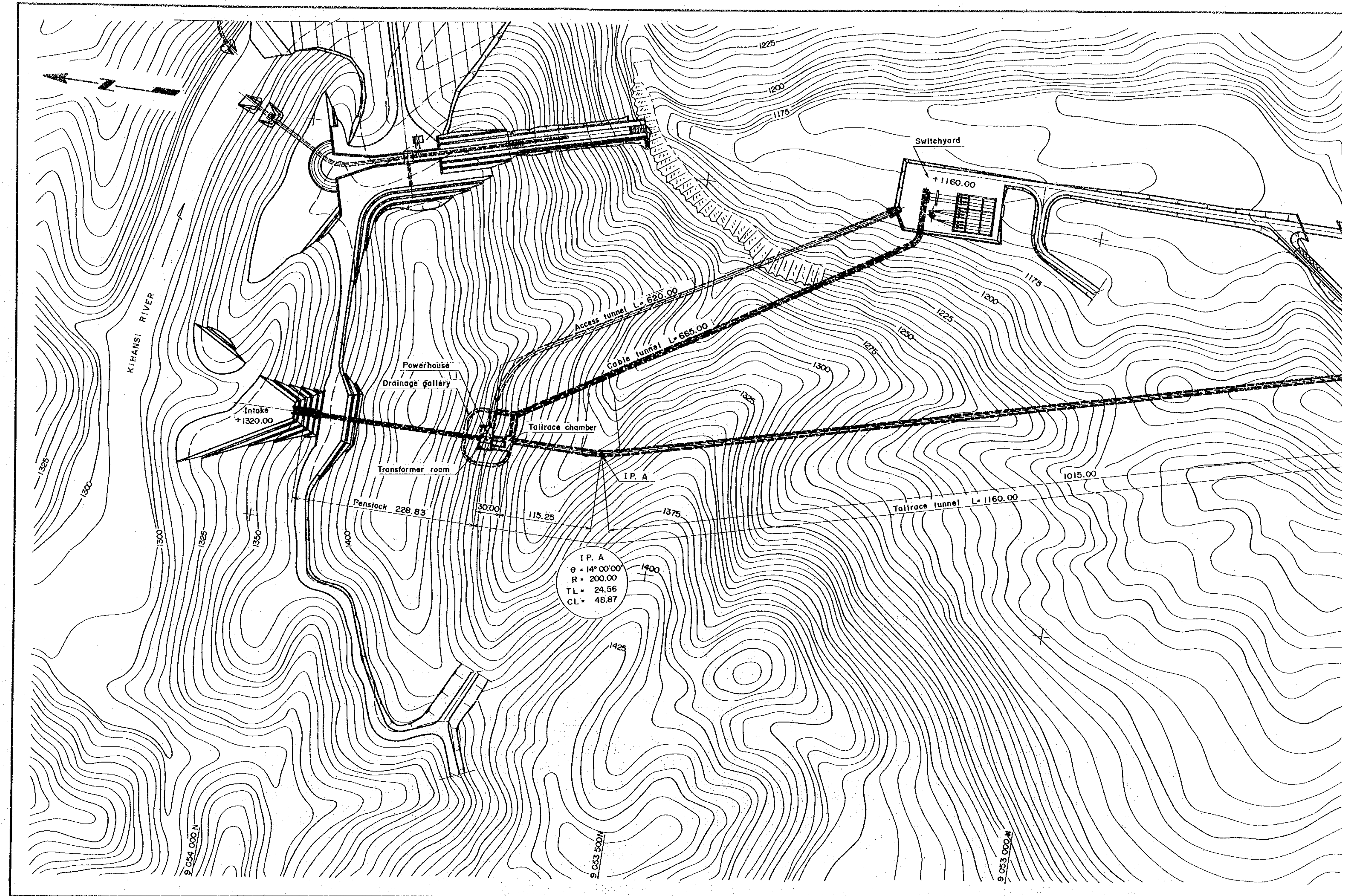

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI PROJECT

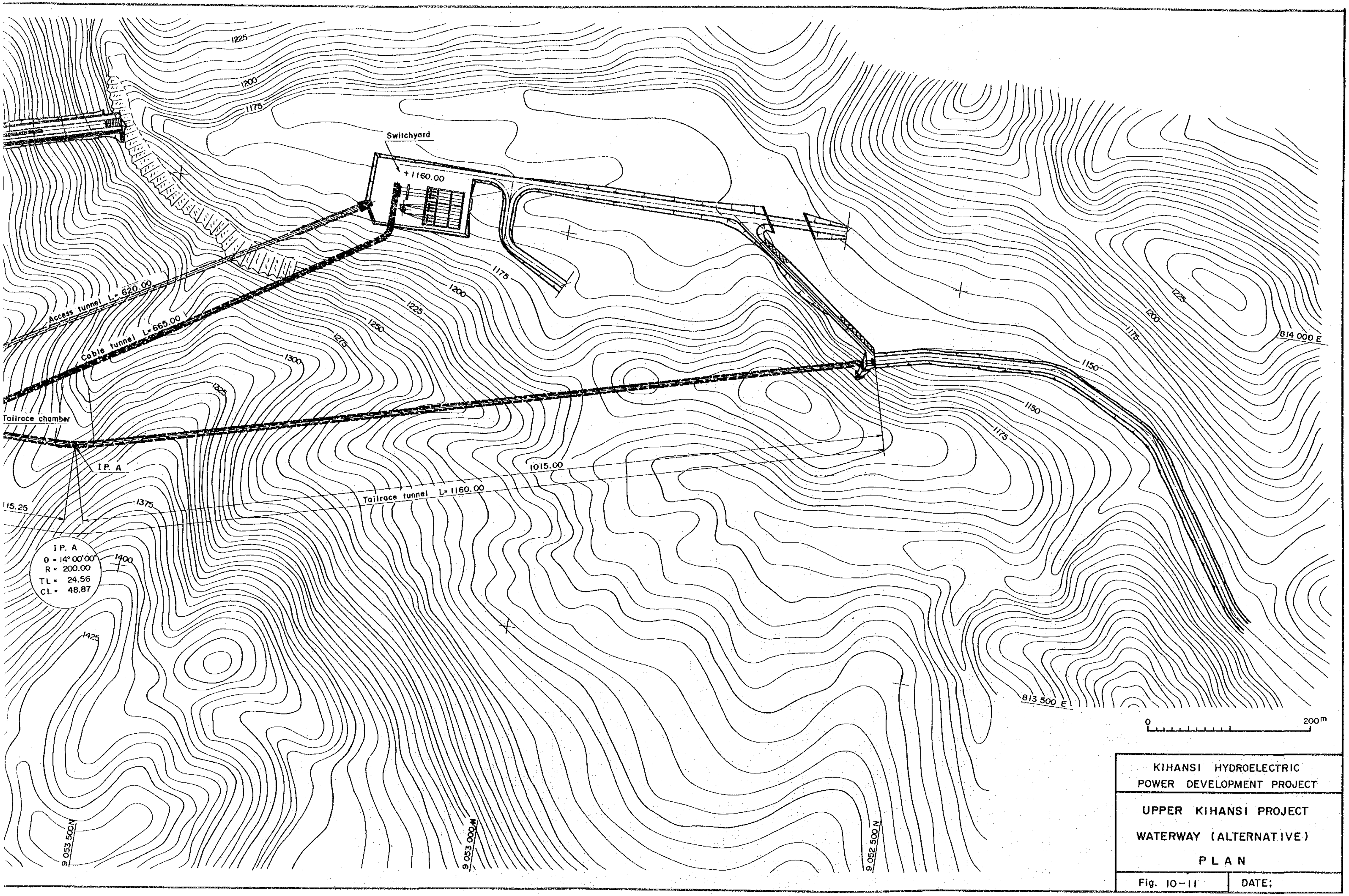
WATERWAY

PROFILE AND SECTIONS

Fig. 10-10 | DATE;



Z
KIHANSI RIVER
Switchyard
+1160.00
Access tunnel L= 620.00
Cable tunnel L= 665.00
Powerhouse
Drainage gallery
Intake
+1320.00
Tailrace chamber
Transformer room
I.P. A
Penstock 228.83
30.00
115.25
Tailrace tunnel L= 1160.00
1015.00
I.P. A
θ = 14° 00' 00"
R = 200.00
TL = 24.56
CL = 48.87
9 054 000 N
9 053 500 N
9 053 000 N



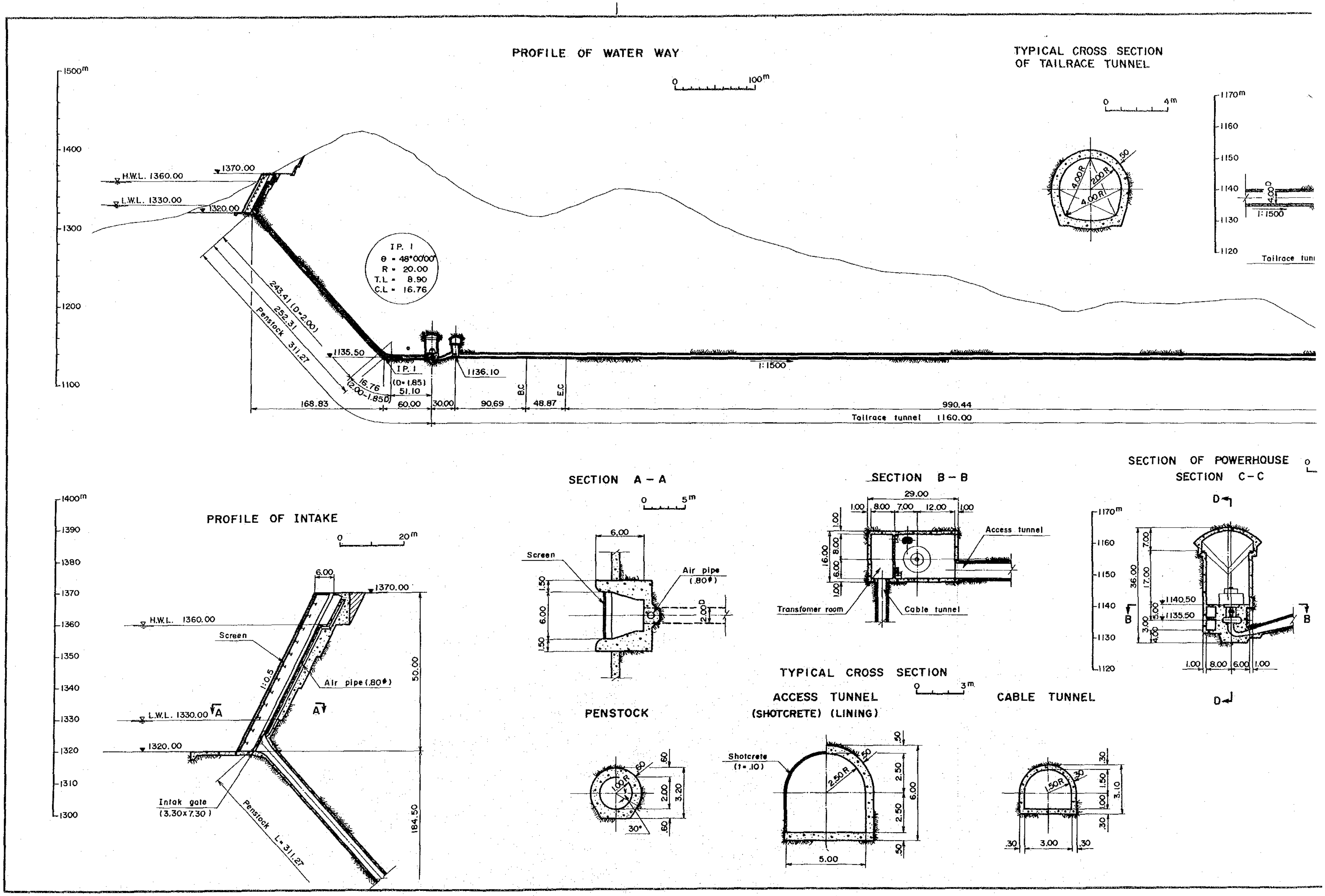

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI PROJECT

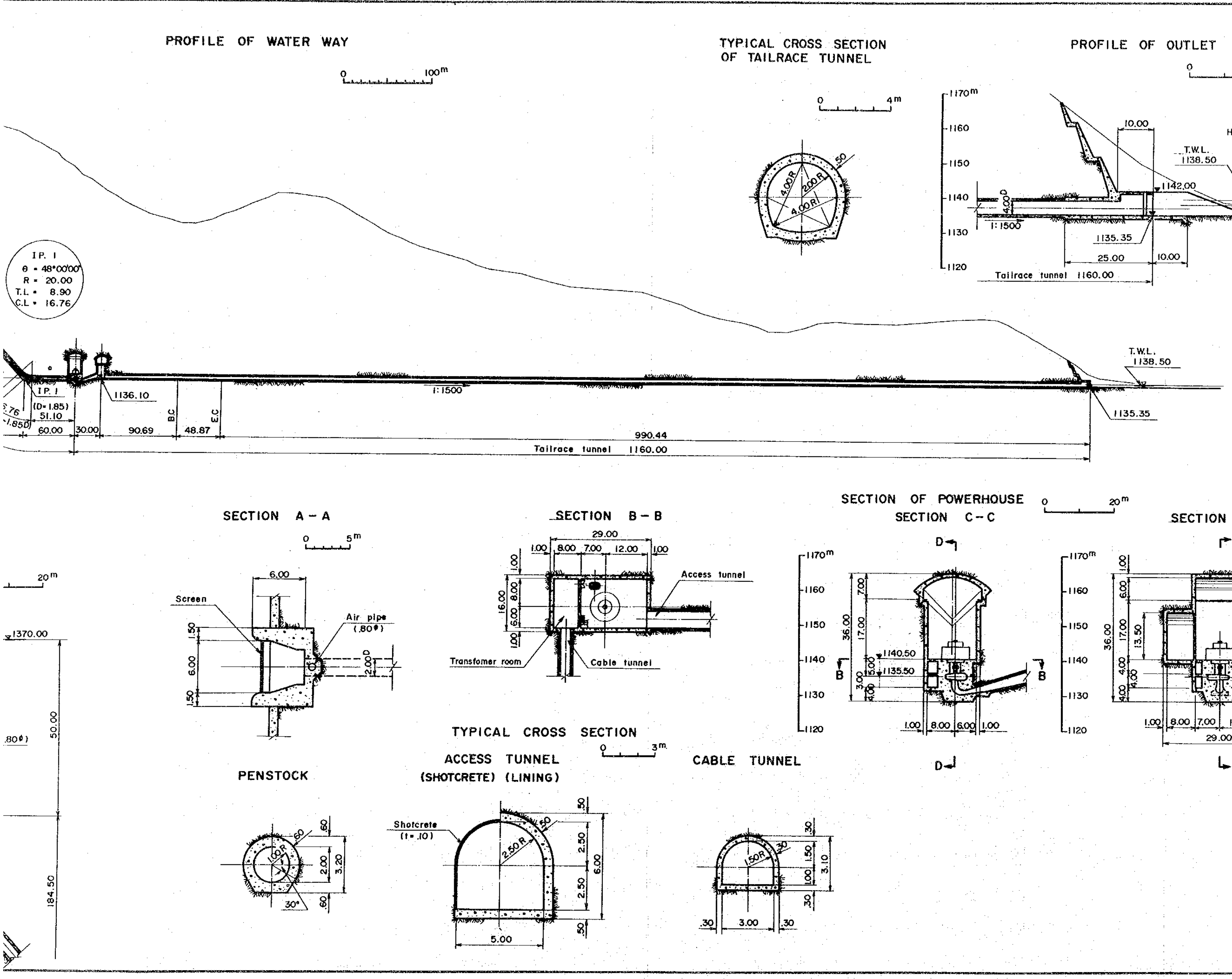
WATERWAY (ALTERNATIVE)

PLAN

| Fig. 10-11 | DATE; |
|---|---|



PROFILE OF WATER WAY
0 100m
H.W.L. 1360.00
L.W.L. 1330.00
1370.00
1320.00
1135.50
1136.10
I.P. 1
θ = 48°00'00"
R = 20.00
T.L = 8.90
C.L = 16.76
243.41 (D=2.00)
252.31
Penstock 311.27
16.76
(2.00~1.850)
(D=1.85)
51.10
168.83
60.00
30.00
90.69
48.87
990.44
B.C
E.C
1:1500
Tailrace tunnel 1160.00
TYPICAL CROSS SECTION OF TAILRACE TUNNEL
0 4m
4.00R
2.00R
4.00R
.50
4.00D
1:1500
Tailrace tunnel
PROFILE OF INTAKE
0 20m
6.00
1370.00
H.W.L. 1360.00
Screen
1:0.5
Air pipe (.80φ)
L.W.L. 1330.00
A
1320.00
50.00
184.50
Intak gate
(3.30x7.30)
Penstock L=311.27
SECTION A – A
0 5m
6.00
Screen
Air pipe
(.80φ)
1.50
6.00
1.50
2.00D
PENSTOCK
1.00R
.60
.60
2.00
3.20
.60
30°
SECTION B – B
29.00
1.00
8.00
7.00
12.00
1.00
16.00
Access tunnel
Transfomer room
Cable tunnel
TYPICAL CROSS SECTION
0 3m
ACCESS TUNNEL
(SHOTCRETE) (LINING)
Shotcrete
(t=.10)
2.50R
.50
2.50
6.00
2.50
5.00
CABLE TUNNEL
1.50R
.30
1.50
1.00
3.10
3.00
SECTION OF POWERHOUSE
SECTION C – C
D
B
36.00
7.00
17.00
1140.50
1135.50
3.00
4.00
1.00
8.00
6.00
1.00




KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI PROJECT

WATERWAY (ALTERNATIVE)

PROFILE AND SECTIONS

Fig. 10-12 | DATE:

a minimum while taking into consideration safety and economy of structures.

The topography and geology of the intake site are as described in Chapter 7. The intake structure is made an inclined type supported by the whole ground avoiding a special type of structure such as a tower type for the reasons that the top soil depth to foundation rock is great, that ground surface gradient is gentle at 22 to 25 deg, and that the geological conditions for supporting the structure are not clearly known in this stage.

The intake orifice elevation is decided at EL. 1,320.00 m giving consideration to the facts that the sedimentation level of the reservoir is about EL. 1,300.00 m, and that ample intake capacity is taken even at low water level of the reservoir of EL. 1,330.00 m. The top of the intake is made EL. 1,370.00 m since an inclined type intake is designed and in order to secure the intake gate resting chamber above high water level.

(3) Headrace Tunnel

The headrace tunnel is to be of total length 653.00 m for safely and economically conducting water from the intake to the powerhouse as mentioned in (2) 'Intake', and the internal and external pressure is designed to be born by the concrete lining. The surface section from a part of the tunnel to the powerhouse is to be a penstock whose steel can bear the entire pressure.

The median elevation of the headrace tunnel of EL. 1,300.00 m is selected as a height at which negative pressure is not to be produced in pressure variation inside the tunnel at low water level of the reservoir and it is possible for the maximum internal pressure to be borne by reinforced concrete.

The diameter of the tunnel is designed an inside diameter of 3.30 m for average flow velocity to be 3.00 m/sec so that supply of water is facilitated under pressure variations in view of the fact that a surge tank is omitted.

(4) Omission of Surge Tank

A surge tank is normally provided at the junction between headrace tunnel and penstock for the reasons given below.

i) The headrace tunnel from the reservoir is a pressure tunnel, and the length of the tunnel is fairly long.

ii) An extraordinary rise in pressure occurs in the pressure tunnel due to water hammer action in case the turbine is suddenly stopped. The surge tank reduces this pressure rise.

iii) Water flow in accordance with increases and decreases of load on the power station is supplied or absorbed.

However, for the Upper Kihansi Project, a surge tank is not included in the water way as a result of various studies. The cases with and without a surge tank are compared in Table 10-3.

In order to omit a surge tank it is necessary to have an alternative appurtenant facility. The pressure control valve and relief valve are provided as the appurtenant facilities shown in Fig. 10-13.

## Table 10-3 Comparison of Surge Tank

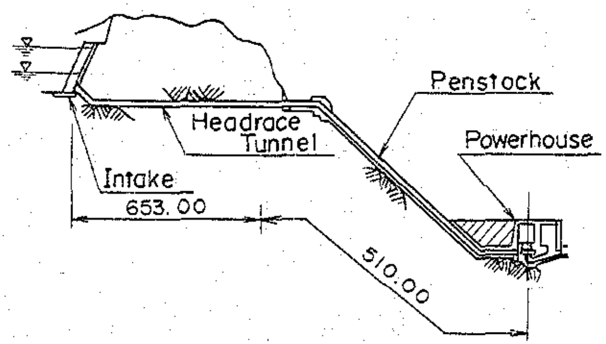
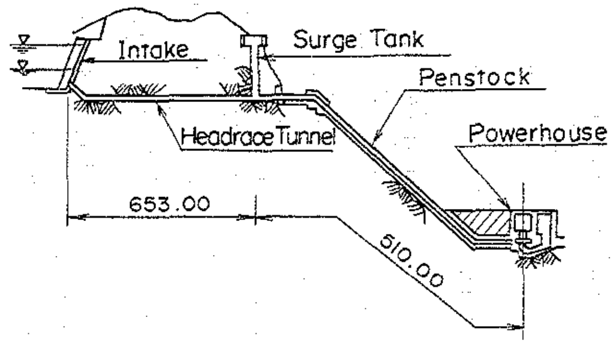
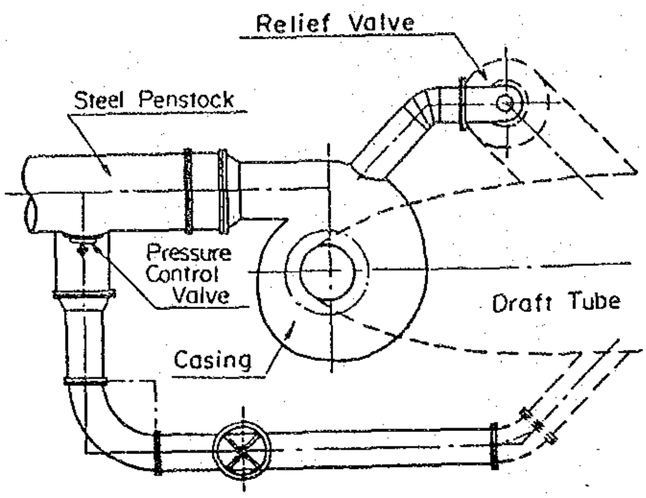
| Item | Without Surge Tank | With Surge Tank |
|---|---|---|
| Profile |  |  |
| Maximum Water Hammer | 15 m (7%) | 49 m (36%) |
| Penstock | 480 ton | 540 ton |
| Construction Cost | $11.7 \times 10^6$ US$ | $17.5 \times 10^6$ US$ |
| Ratio of Construction Cost | 1.00 | 1.50 |
| Stability | Good | Good |

Fig. 10-13 Detail of Pressure Control Relief Valve




The reasons for omitting the surge tank are as follows:

i) The length of the headrace tunnel is to be 653.00 m, which is not exceedingly long.

ii) Even in case a surge tank were to be provided it would suffice for the cross-sectional area of the vertical shaft necessary for stability of the water surface to be a minimum. At this site it would be permissible for the inside diameter to be 3.30 m, the same as for the headrace tunnel.

iii) There are double safety devices in the vicinity of the turbine and it is amply possible to deal with an emergency.

iv) The economics is improved by omitting the surge tank.

The method of controlling the turbine is as follows:

i) In normal operation, the pressure control valve operates interacting with the guide vanes of the turbine, so that extraordinary pressure and water level fluctuation in the headrace tunnel and penstock do not occur.

ii) The pressure control valve is to start to close 0.05 sec later than the 0.25 sec which is the lag time for sudden closing of guide vanes to start, while the closing time is taken to be 6.0 sec for both.

iii) In the event the pressure control valve does not act interacting with the guide vanes, it is possible for guide vanes to change the closing from 6.0 sec to 200 sec.

iv) In the event it becomes impossible for controlling to be done electrically and mechanically and pressure rises abnormally in the penstock, the pressure relief valve is to open and relieve pressure.

(5) Penstock

As shown in Figs. 10-9 and 10-10, a section of 140 m of the penstock is to be a horizontal tunnel and the remainder is to be supported on the surface by anchor blocks and saddles, with connection to the powerhouse made at a gradient of approximately 34 deg.

The topographical and geological conditions of this site are as described in Chapter 7, and there are no noticeable problematic points which pose serious obstacles to structures.

The entire water pressure at the penstock is to be borne by the penstock pipe, the pressure and the thickness of the steel pipe being as shown in Fig. 10-14. The design conditions for the penstock are as given below.

i) the static pressure is to be the whole head corresponding to the difference in elevation between the reservoir high water level and the median elevation of the penstock.

ii) Water-hammer pressure is considered as 15 m on the turbine center, which is approximately 7 percent adding an allowance to the pressure calculated using the 0.05 sec, the time differential in activation of guide vanes and pressure control valve. It is assumed to be linear variation proportional to the penstock length with the pressure to be zero at the reservoir.

iii) The entire length of the tunnel portion and part of the surface portion is to be made the minimum shell thickness.

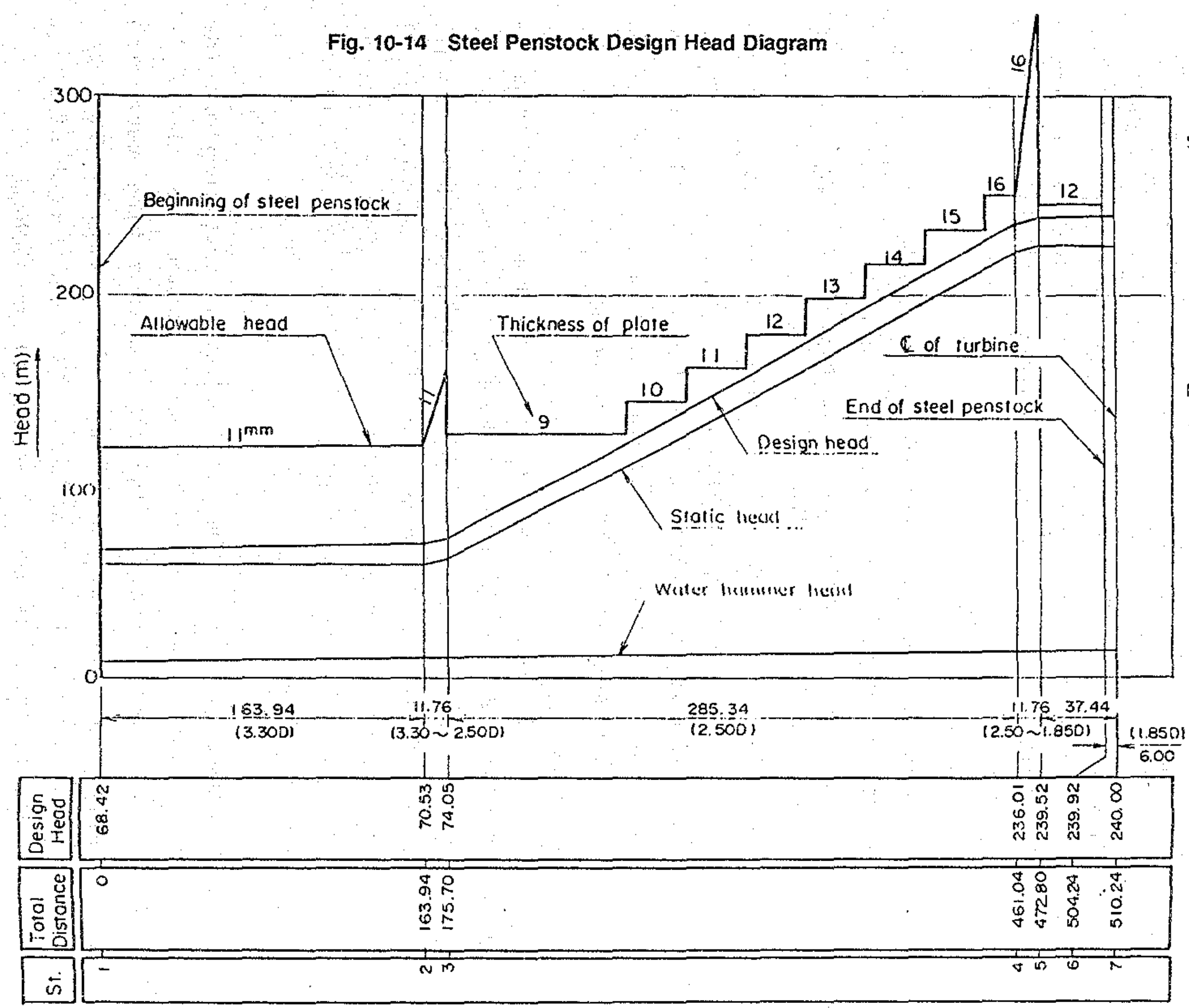
(6) Powerhouse and Switchyard

The powerhouse and the switchyard are to be located at a table on the right-bank side approximately 0.6 km downstream from the dam site as shown in Figs. 10-9 and 10-10.

The topography and geology of this site are as described in Chapter 7. Topographically, it is a flat area from EL. 1,160.00 m to EL. 1,170.00 m, and this area presently consists of cultivated fields or waste land. Geologically, the area is covered with deposits from the ground surface to a depth of about 10 m, while deeper than this is foundation rock, which is thought to pose no problem.

The powerhouse is to be a semi-underground type as decided under the subsection (1) 'Study of Waterway

**Fig. 10-14 Steel Penstock Design Head Diagram**




Specification

| | |
|---|---|
| Maximum discharge | 25.7 $m^3$/sec |
| Maximum static head | 225 m |
| Water hammer (at turbine) | 15 m |
| Closing time | 6.25 sec |

Material

| | |
|---|---|
| Allowable tensile stress | 2400 kgf/$cm^2$ |
| Welding efficiency | 90% |
| Corrosion allowance | 1.5 mm |

Route', with one unit of turbine and generator, the dimensions required at the generator hall being a width of 14.00 m and a length of 19.00 m.

The turbine center is to be at EL. 1,135.00 m considering the necessary suction head from the outlet water level. The generator hall and the erection bay are determined based on the turbine center and are respectively to be at EL. 1,140.00 m and EL. 1,149.50 m. The finished ground elevation around the powerhouse is made EL. 1,163.00 m in view of the topography. This is decided on as the height of the river bed is at around EL. 1,155.00 m, and based on safety and economy at time of flood.

Because of height differences between the ground elevation around the powerhouse and the generator hall or erection bay being approximately 15 to 20 m making it necessary to go deeper than the surrounding river bed to directly haul in materials and equipment so that the access road becomes longer, and making it necessary for precautionary measures to be taken against floods, the structure is designed for an unloading crane to be installed separately at the ground surface.

The total depth of excavation for the powerhouse is 35.00 m and mix-ups occur between this work and work on the penstock, tailrace tunnel and draft gate chamber during construction, but considering the geological conditions and work execution conditions it is thought there is not any possibility of collapse of the natural ground occurring.

The switchyard is to be provided at a location alongside the powerhouse to make the distance to the main transformer a minimum and at the same time rendering future maintenance and inspection easy. The area required is to have a width of 80 m and length of 130 m including the powerhouse and draft gate chamber.

(7) Tailrace Tunnel

The tailrace tunnel is a facility provided to effectively utilize the height difference of approximately 15 m from the river-bed elevation of approximately 1,155.00 m at the powerhouse site to the Lower Kihansi regulating reservoir water level, the route and configuration of which are as shown in Figs. 10-9 and 10-10.

Methods of utilizing this height difference of approximately 15 m to the Lower Kihansi regulating reservoir water level are i) a proposal for the entire length made to be a tunnel, ii) a proposal for a part to be a tunnel and a part the present river bed excavated in the open, and iii) a proposal for the entire length to be the present river bed excavated in the open. Comparisons of these three proposals are made in Table 10-4.

As the table shows, the proposal of ii) is adopted. This proposal is for approximately 650 m from the powerhouse to be excavated as a tunnel and the remaining 500 m the present river bed excavated in the open. The feature of this proposal is that it is the most economical, maintenance and inspection at time of flood after completion will be easy, and that there are few problems from the standpoint of work execution.

Calculation of the discharge capacity of the tailrace tunnel is done by Manning's formula. The discharge capacity and flow velocity are as shown in Fig. 10-15, and it is amply possible for maximum discharge of $Q = 25.7\ m^3/sec$ to be passed through.

## Table 10-4 Comparison of Tailrace

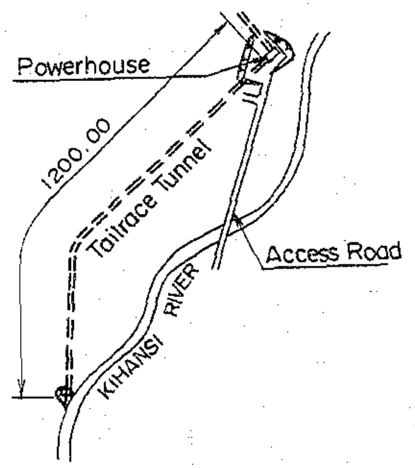
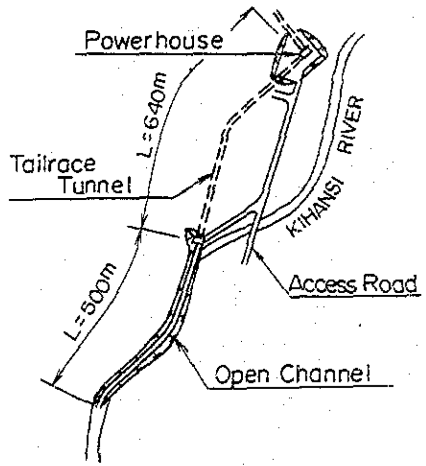
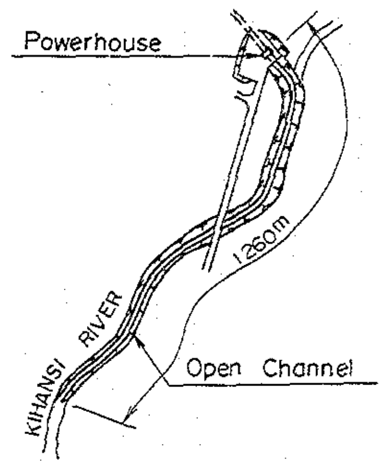
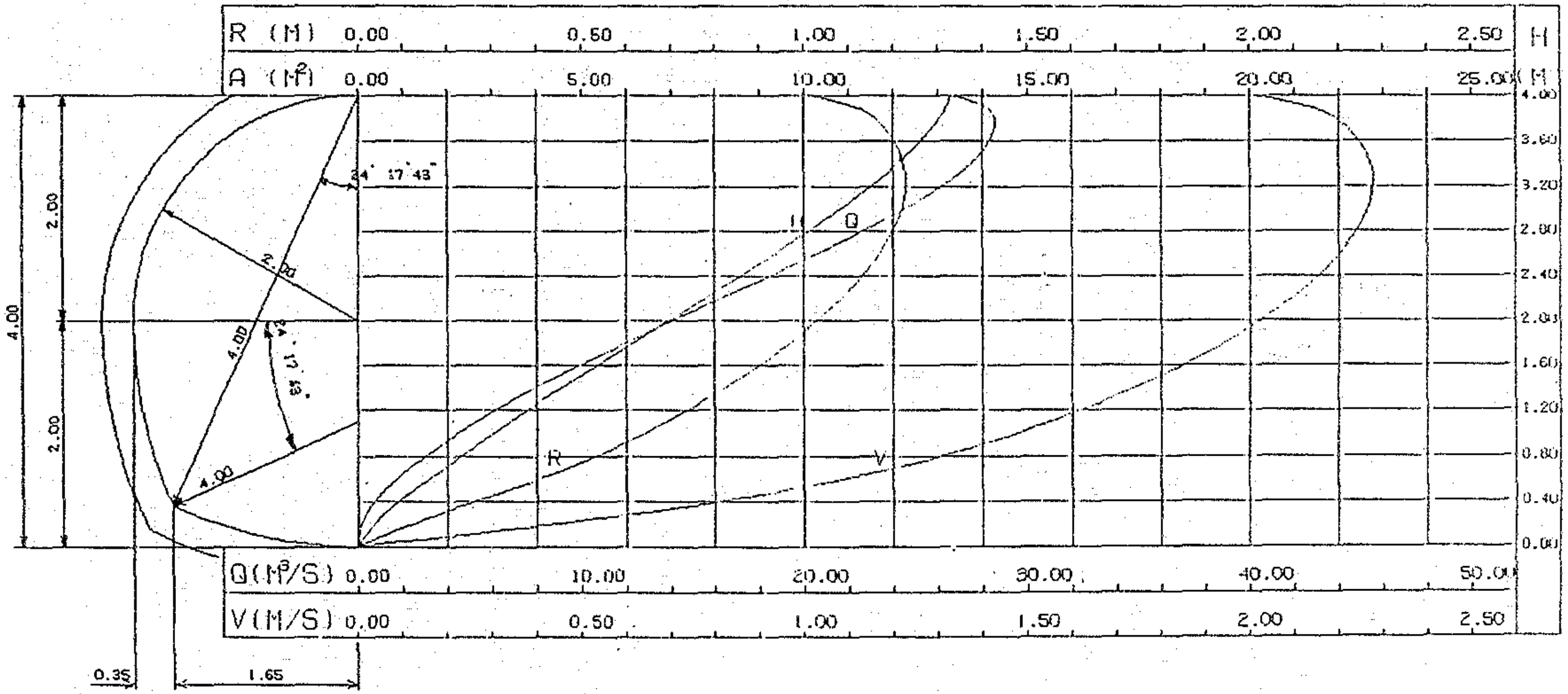
| Item | Tunnel Type | (Tunnel + Open) Type | Open Type |
|---|---|---|---|
| Plan |  |  |  |
| Excavation Volume | 28,000 $m^3$ | 63,000 $m^3$ | 288,000 $m^3$ |
| Construction Cost | 4,700,000 US$ | 3,300,000 US$ | 3,400,000 US$ |
| Construction | Good | Good | Good |
| Maintenance | Good | Good | Fine |

Fig. 10-15 Rating Curve in Tailrace Tunnel




FORMULA

$Q = A \cdot V$

$= A \cdot R^{\frac{2}{3}} \cdot I^{\frac{1}{2}} / N$

V ;VELOCITY (M/S)
Q ;DISCHARGE (M³/S)
A ;CROSS-SECTIONAL AREA OF FLOW (M²)
R ;HYDRAULIC RADIUS (M)
N ;COEFFCIENT OF ROUGHNESS (NC=0.0130)
I ;CHANNEL GRADE (1:1500)
H ;WATER LEVEL (M)

### 10.2.3 Electrical Equipment

(1) Selection of Major Equipment

Upper Kihansi power station has an effective head of 214.5 m, a maximum water discharge of 25.7 m3/sec, with the output of 47,000 kW. With these design features, the Vertical Francis turbine is most suitable, and this type of turbine has been selected.

The main transformers are selected as outdoors type by which cable circuits on the high voltage of 220 kV side can be eliminated. The single phase transformers are selected based on considerations on transportation and ease of recovery from failure.

A single bus system is selected for the 220 kV switchyard in view of economy and maintainability, and the switchyard bus conductors are to be aluminum cable supported by outdoor steel structures.

The interconnection between the main transformers and the switchyard is to be provided by overhead lines.

The pertinent performance and data of the waterturbine, generator, main transformers and 220 kV switchyard equipment are presented below:

- Turbine

| | |
|---|---|
| Type | Vertical shaft Francis turbine |
| Number of unit | 1 |
| Rated effective head | 214.50 m |
| Water discharge | 25.7 $m^3$/sec |
| Rated output | 48 MW |
| Revolving speed | 429 rpm |

- Generator

| | |
|---|---|
| Type | 3-phase, AC, synchronous generator |
| Number of unit | 1 |
| Capacity | 53 MVA (with 0.9 lagging power factor) |
| Revolving speed | 429 rpm |
| Frequency | 50 Hz |
| Voltage | 11 kV |

- Main Transformer

| | |
|---|---|
| Type | Outdoor, single-phase transformer |
| Number of units | 4 (including 1 spare transformer) |
| Capacity | 53 MVA (17.7MVA × 3 + 1) |
| Voltage | 11 kV |

- Switchyard

| | |
|---|---|
| Bus type | Single bus |
| Bus | Aluminum cable |
| Number of lines | 2 circuits |
| Voltage | 220 kV |
| Conductor type | ACSR, 400 $mm^2$ |
| Section | Upper Kihansi Power Station to Lower Kihansi Power Station<br>Upper Kihansi Power Station to Iringa Substation |

- Interconnection Line

| | |
|---|---|
| Number of circuit | 1 circuit |
| Number of Bay | 1 |
| Voltage | 220 kV |
| Conductor type | ACSR 380 $mm^2$ |
| Section | Main transformer to switchyard |

(2) Main Generator Circuit

The main generator circuit is to be low-voltage-side synchronized, unit type circuits to enhance reliability and maintainability, and to assure station service power supply.

The main generator and main transformers are connected by power cables, and the main transformers and switchyard are connected by overhead lines.

The single line diagram of the power station is presented in Fig. 10-16.

(3) Interconnection Overhead Line

The interconnection overhead line is a single-circuit, 220 kV overhead line that connects the 53,000 kVA main transformers to the outdoor switchyard.

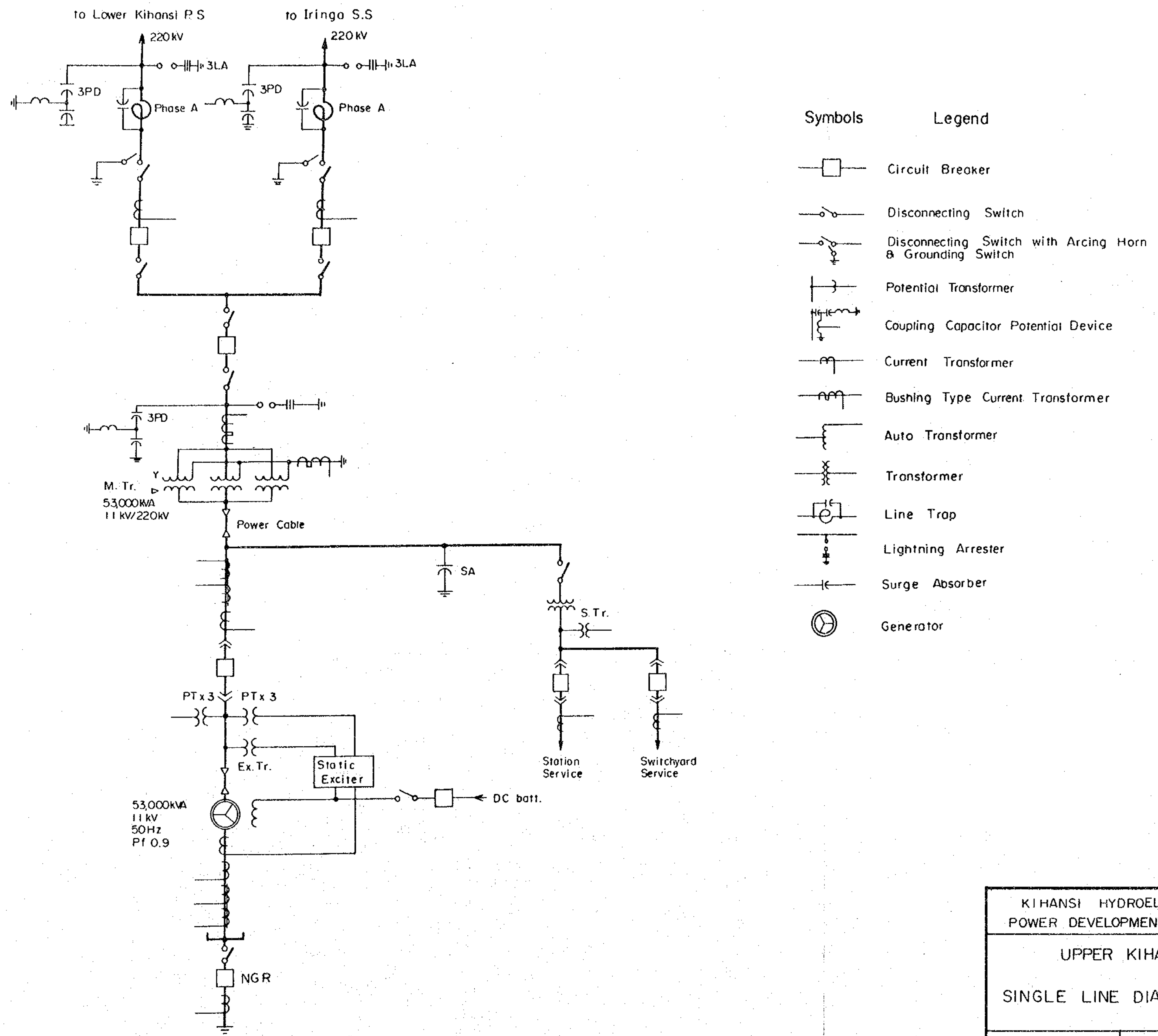
The conductor of this overhead line is 380 $mm^2$ ACSR and the lines connect the transformer to the switchyard bay at the shortest possible route. The circuit is shielded by G.S 70 $mm^2$ overhead ground wires, which is connected to the grounding system of the switchyard.

(4) Electrical Equipment of Power Station

The power station is a semi-underground design, with the erection bay located at the tailrace side of the powerhouse.

The single water-turbine-generator unit and the related auxiliary equipment are installed at an underground level.

An overhead traveling crane is installed in the generator hall of the building, and a gantry crane for transportation of parts into the erection bay is




KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI

SINGLE LINE DIAGRAM

| Fig. 10 – 16 | DATE ; |
|---|---|

installed outside the building. The main transformers are installed outside of the building.

The equipment layout in the powerhouse is illustrated in Figs. 10-17 through 10-20.

(5) Electrical Equipment in Switchyard

The switchyard is constructed on the side of the powerhouse facing the tailrace, to make best use of the geographical conditions of the site, and the double circuit, 220 kV transmission line extend to the right bank of the river. The 11 kV distribution line for operation of dam is constructed in parallel with the 220 kV transmission line.

The equipment layout in the switchyard is presented in Fig. 10-21.

(6) Communication Equipment

i) Design Conditions

a) The communication equipment of the Upper Kihansi power station is designed with the assumption that Upper Kihansi power station is operated with operators stationed.

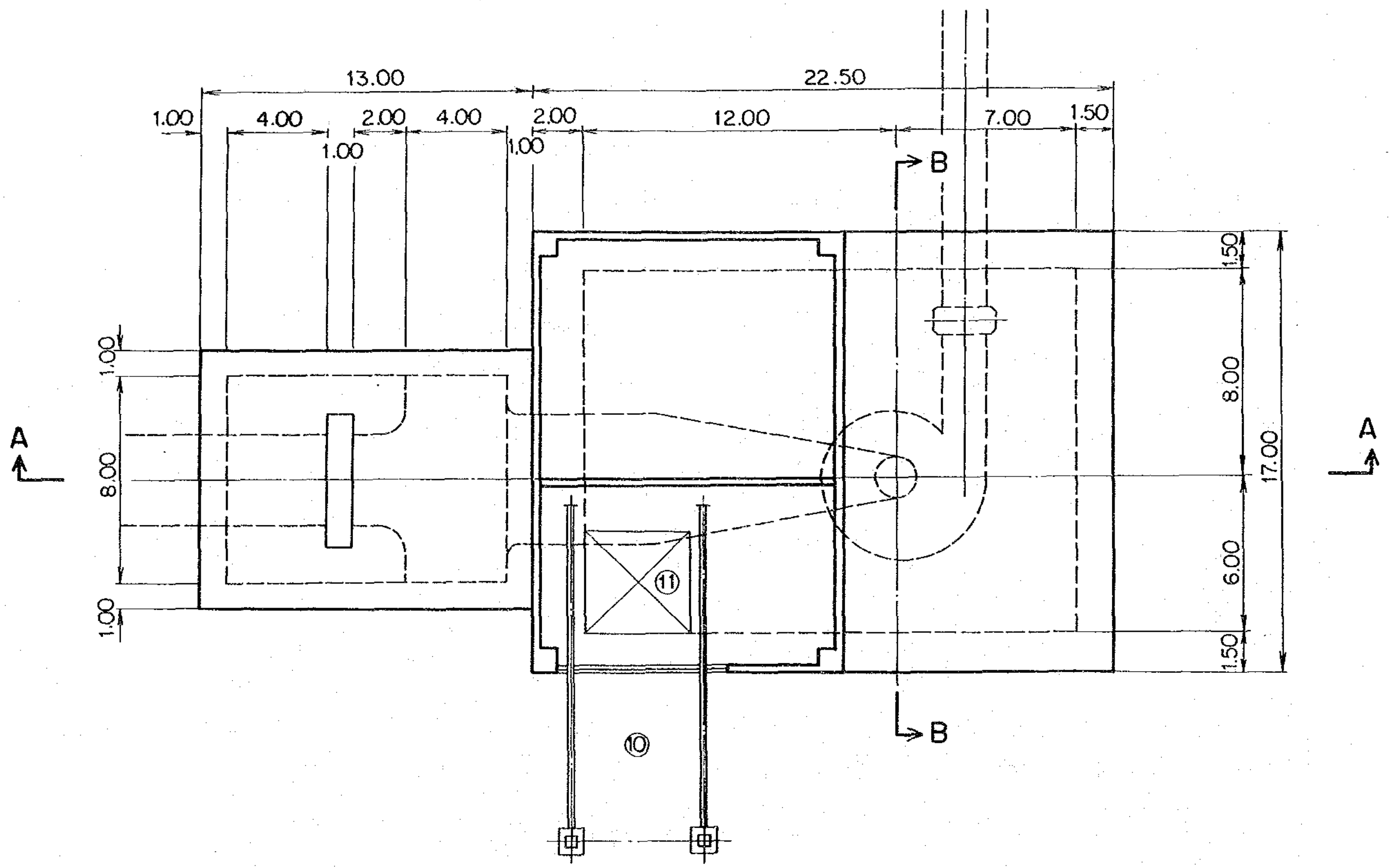
b) The information and data of this power station is to be transmitted to the neighboring Iringa Substation, so that the power station is monitored and supervised by SCADA System which is installed at Ubungo Central Load Dispatching Office.

ii) Development of Communication Channels

The communication channels required in relation to the "pi" branching of the aforementioned

PLAN

EL. 1163.00




LEGEND

(10) Gantry Crane

(11) Crane Hatch

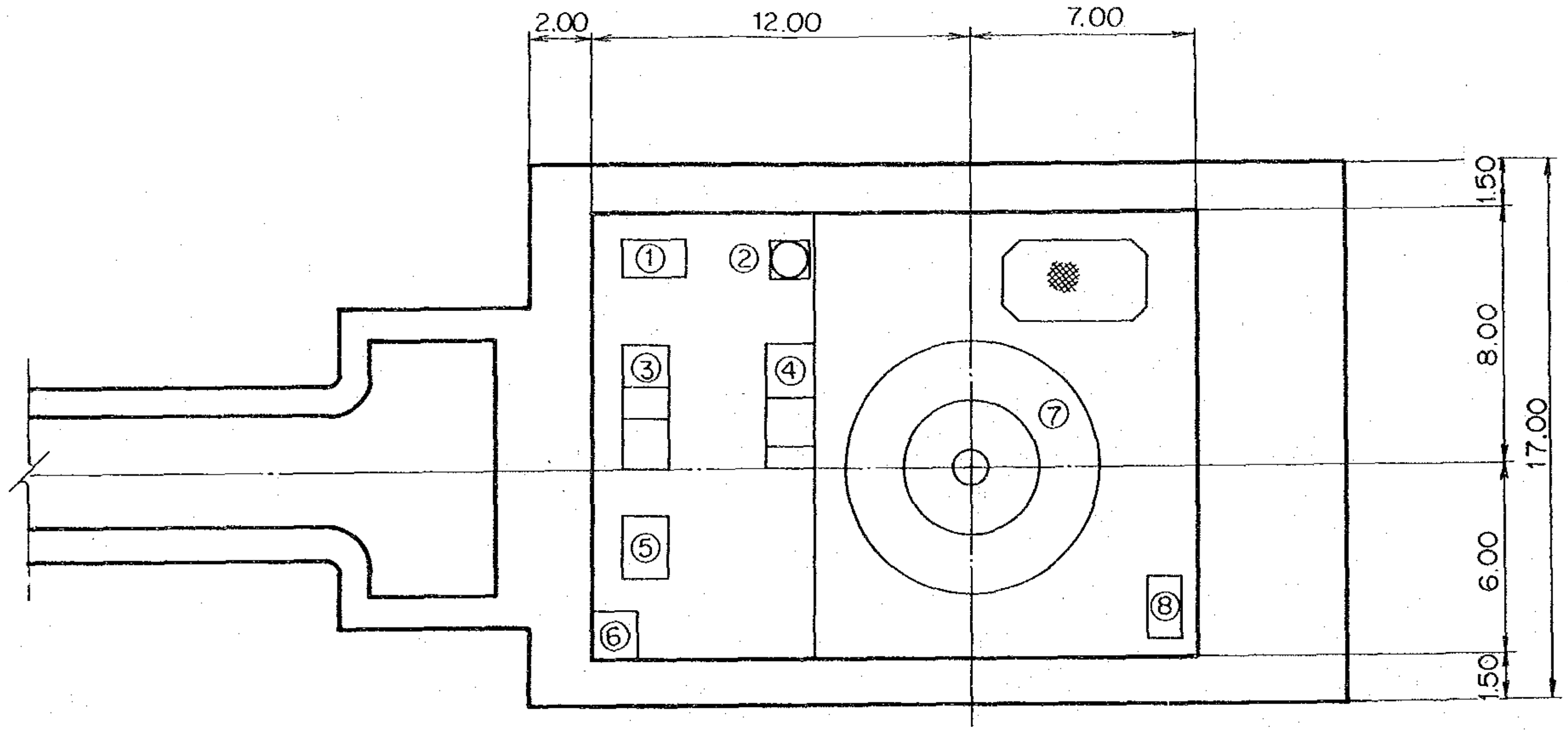
KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI POWERHOUSE GROUND LEVEL PLAN

Fig. 10 - 17 | DATE:

# PLAN

EL. 1140.00




## LEGEND

(1) Oil Pressure Pump

(2) Oil Pressure Tank

(3) Speed Governor Cabinet

(4) Station Service Cabinet

(5) Oil Drainage Tank with Pump

(6) Fire Extinguisher of Generator

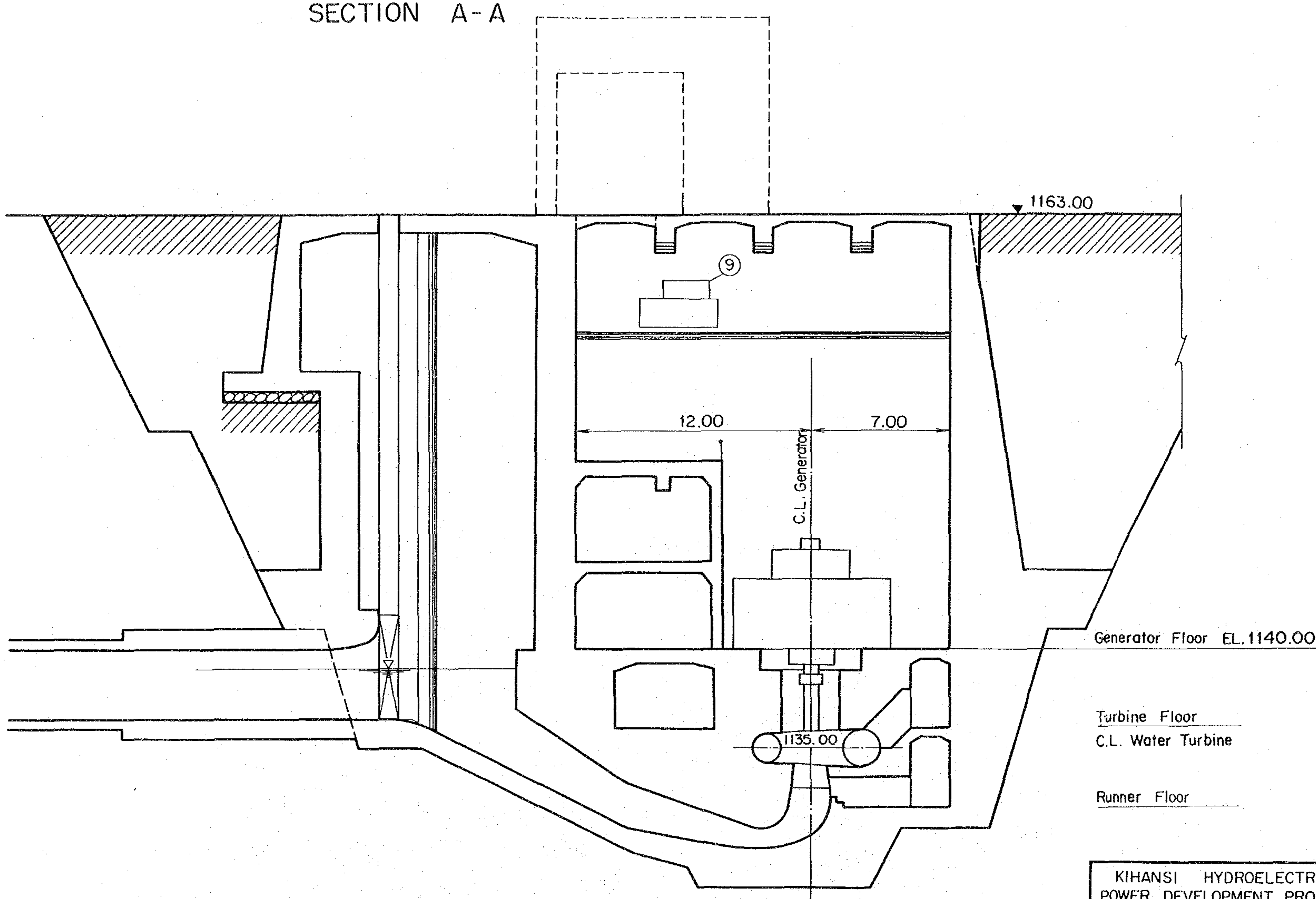
(7) Generator

(8) N.G.R Cubicle

(9) Overhead Travelling Crane

| KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT | |
|---|---|
| UPPER KIHANSI POWERHOUSE GENERATOR FLOOR PLAN | |
| Fig. 10 - 18 | DATE ; |

## SECTION A-A

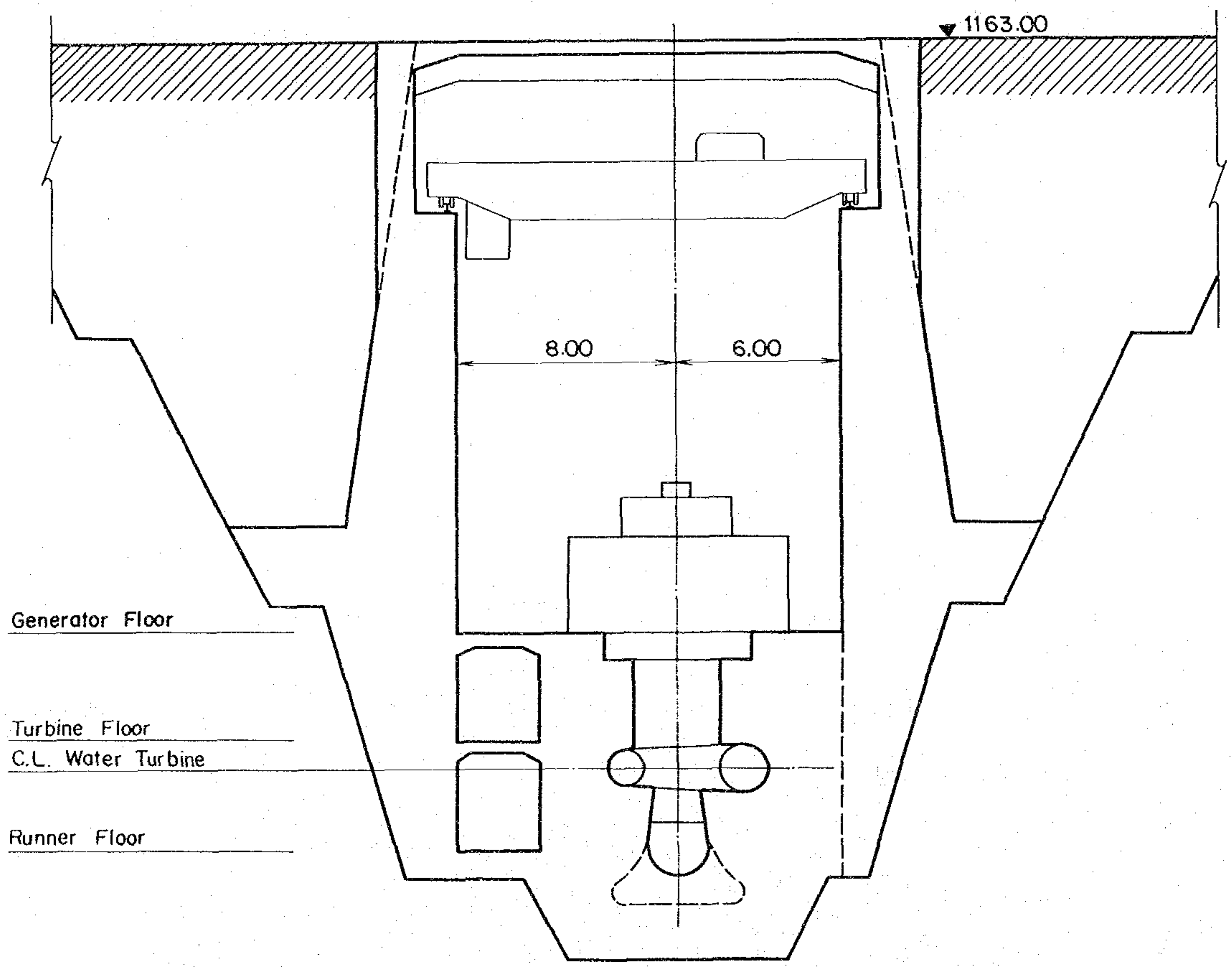



KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI POWERHOUSE LONGITUDINAL SECTION

Fig. 10 - 19 | DATE:

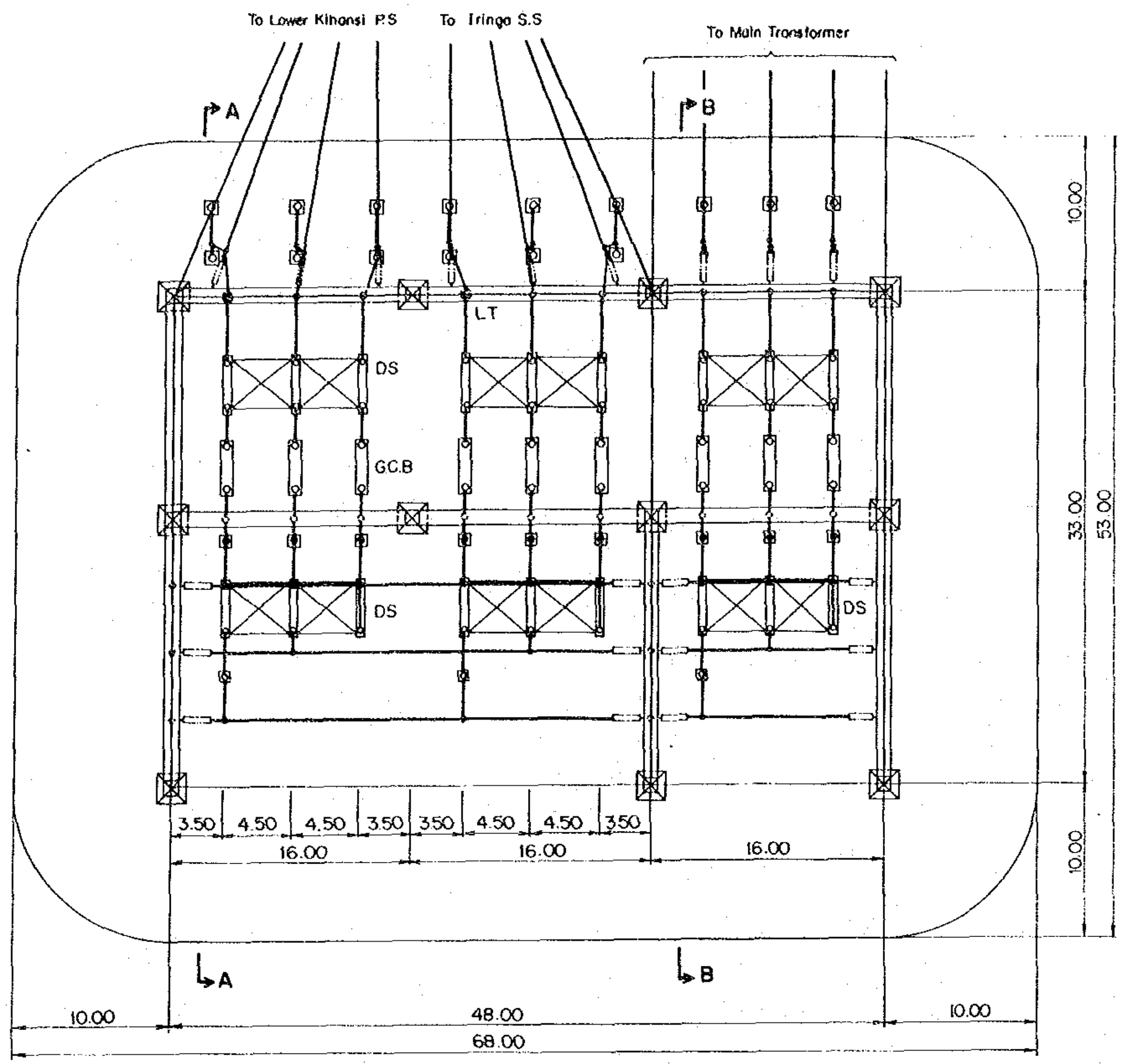
## SECTION B-B



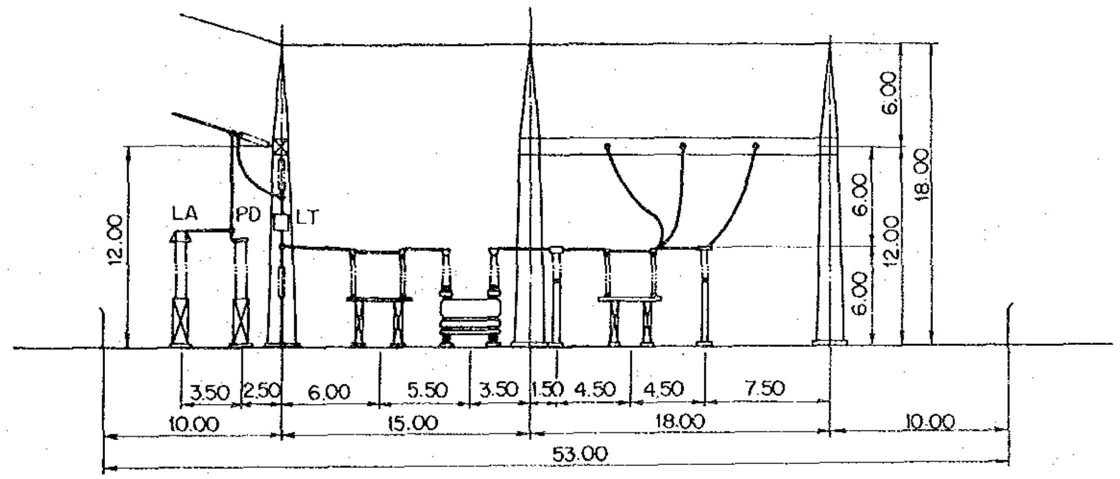

KIHANSI HYDROELECTRIC POWER DEVELOPMENT PROJECT

UPPER KIHANSI POWERHOUSE TRANSVERSE SECTION

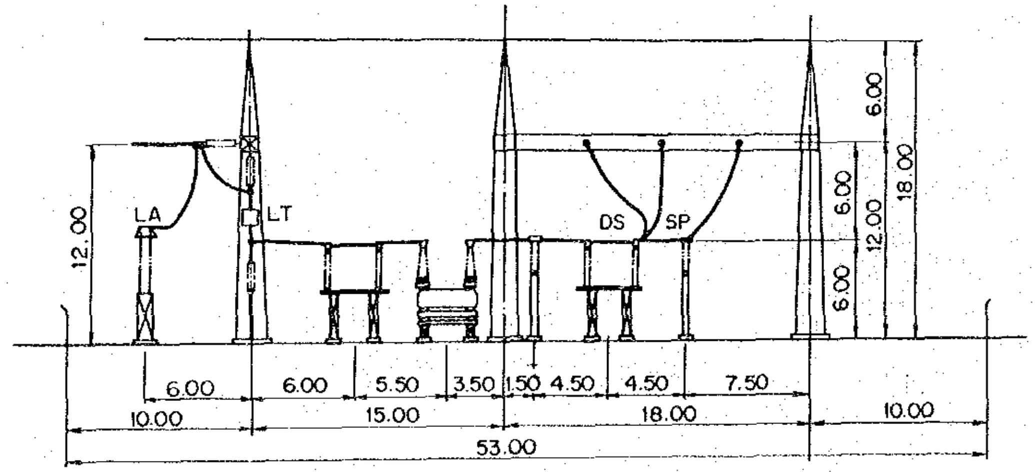
Fig. 10 - 20 | DATE:




## Section A - A




## Section B - B




KIHANSI HYDROELECTRIC
POWER DEVELOPMENT PROJECT

UPPER KIHANSI
SWITCHYARD PLAN

Fig. 10 - 21 | DATE :

transmission line is structured. The sections and numbers of circuits of these communication channels are as described below.

- Between Upper Kihansi Power Station and Lower Kihansi Power Station

| | |
|---|---|
| Load Dispatching Telephone Channel | 1 channel |
| Maintenance Work Telephone Channels | 3 channels |
| PLC Protection Signal Transmission Channels | 2 channels |

- Between Upper Kihansi Power Station and Iringa Substation

| | |
|---|---|
| Load Dispatching Telephone Channel | 1 channel |
| Maintenance Work Telephone Channels | 3 channels |
| PLC Protection Signal Transmission Channels | 2 channels |
| Load Dispatching Signal Transmission Channel | 1 channel |

- Between Lower Kihansi Power Station and Iringa Substation

| | |
|---|---|
| Load Dispatching Signal Transmission Channel | 1 channel |

The load dispatching signal transmission system is operated as a three-terminal system by installing the tone ringer function. A VHF base station is established at Upper Kihansi Power Station, to expand the transmission line maintenance channels provided by the VHF base station at Iringa Substation which is to be constructed in Lower Kihansi Power Station construction work. An automatic telephone exchange system is installed at Upper Kihansi Power Station to provide telephone service for maintenance and to create paging circuits for maintenance works in the power station.

iii) Outline of Communication Equipment

The outline of communication equipment which are required for the construction of the above communication channels is described below.

a) Power Line Carrier Units

A total of six, 2-channel power line carrier equipment is installed at Upper Kihansi Power Station, with three units facing Lower Kihansi Power Station and three units facing Iringa Substation. In addition, the inter-circuit coupling type coupling devices are installed facing Lower Kihansi Power Station and Iringa Substation.

b) Power Line Carrier Protective Relay Terminal Equipment

A total of four power line carrier protective relay terminal equipment is installed, a total of two equipment shall be installed at Upper Kihansi Power Station, for the double circuit transmission lines connecting Lower Kihansi Power Station and Iringa Substation.

c) Load Dispatching Signal Terminal Equipment

One load dispatching signal terminal equipment is installed at Upper Kihansi Power Station to provide communication channels reaching Iringa Substation so that the signals are exchanged with the SCADA system at Ubungo Central Load Dispatching Office.

d) Automatic Telephone Exchange System

One, 100-channel automatic exchange system is installed at Upper Kihansi Power Station.

e) Line Maintenance VHF System

Two portable radio units are procured. A base station equipment is installed at Upper Kihansi Power Station, and one car-borne radio unit and one portable radio unit are procured.

f) Paging System

One paging system is installed at Upper Kihansi Power Station.

g) DC Power Supply System

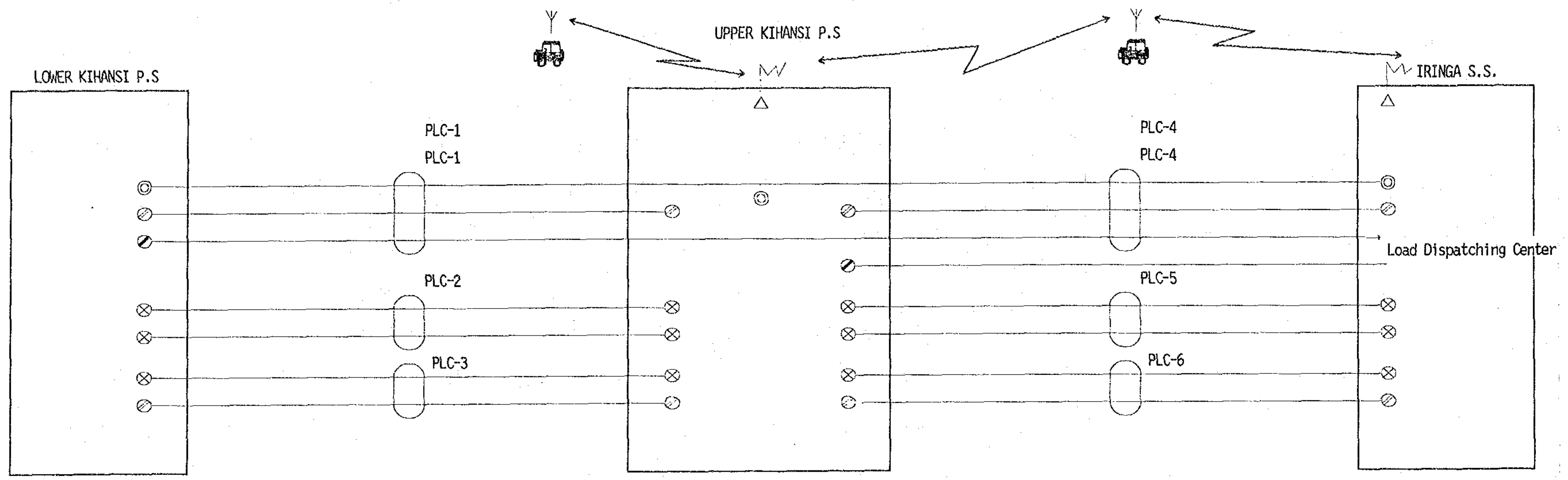
One DC power supply system each, consisting of batteries and battery charging unit, is installed at Upper Kihansi Power Station.

The equipment to be installed and their features are given in Table 10-5 below.

Table 10-5 A List of the Communication Facilities on Upper Kihansi Project

| Equipment | Features | Upper Kihansi Power Station |
|---|---|---|
| Power Line Carrier Terminal Equipment | 10 W, 2-channel type | 6 |
| Coupling Devices for the Above | Inter-circuit coupling | 2 |
| PLC Protective Relay Terminal Equipment | | 4 |
| Load Dispatching Signal Terminal Equipment | SCADA slave station | 1 |
| Automatic Telephone Exchange | 100 channels | 1 |
| Line Maintenance VHF Base Station | 150 MHz, 100 W | 1 |
| VHF Car-Borne Unit | 150 MHz, 10 W | 1 |
| VHF Portable Unit | 150 MHz, 5 W | 1 |
| Paging System | 2 kW, 100 sets | 1 |
| Tone Ringer | 10 channels | 1 |
| Battery Charger Unit | 48 V, 100 A | 1 |
| Batteries | 48 V, 500 AH | 1 |

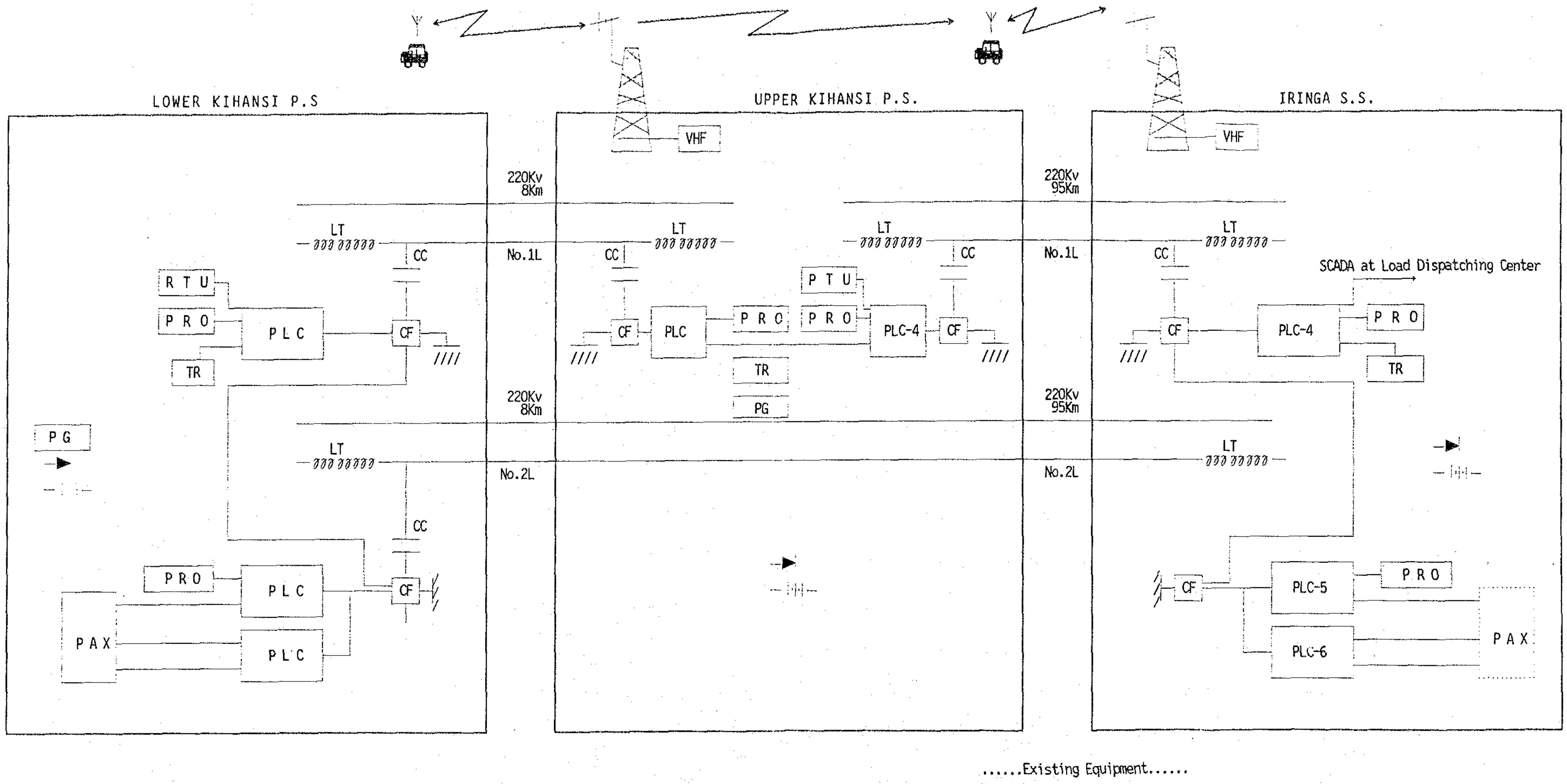
Fig. 10-22 Upper Kihansi Project Telecommunication System (1)




Legend

- ◎—: Load Dispatching Telephone Circuit
- ⊗—: Administration Use Telephone Circuit
- ⊘—: Data Transmission Circuit for Teleprotection
- ⊘—: Data Transmission Circuit for SCADA

Fig. 10-23 Upper Kihansi Project Telecommunication System (2)




Legend

- :Line Trap
- CF :Coupling Capacitor and Coupling Filter
- PLC :Power Line Carrier Terminal Equipment
- PRO :Protection Signal Equipment
- PAX : Private Automatic Telephone Exchange Equipment
- PG : Paging Equipment
- VHF : VHF Radio Equipment
- : Charging Rectifier for Telecommunication Equipment

### 10.2.4 Transmission Line

The transmission line for Lower Kihansi Project is constructed preceding to the construction of Upper Kihansi Project. It passes just before the Upper Kihansi Power Station.

So, the transmission line for Upper Kihansi Project is a short distance double circuit incoming line which connects between this line and the switchyard of Upper Kihansi Power Station.

Description of the feasibility design of the transmission line for Lower Kihansi Project is given in 10.3.4 section.