7.7 Electrical Facilities

7.7.1 Selection of Main Equipment

Chespi Power Station is planned as a dam-waterway type with normal effective head of 278 m and maximum available discharge of 70 m^3/s. As a result of study on the optimum turbine type and number of units at this development scale, the conclusion was reached that adoption of a plan for two vertical-shaft Francis turbines would be the most advantageous.

The value of σp was calculated based on the performance records of the many vertical Francis turbines in Japan. However, with regard to the value of TWL during minimum discharge, it will be advisable for the turbine center elevation to be reexamined at the time of the Definite Study.

Furthermore, because of the high content of sediment transported in the river water of the Rio Guayllabamba, an alternative based on Pelton turbines which are comparatively strong against abrasion by sediment was also studied. When the Pelton turbine is adopted for this project, 4-unit is considered to be recommendable, as described in Appendix-(6) Electrical Matters. And the Francis type is concluded to be preferable in the above appendix. For this Project of H_{nor} = 278 m and Q_{max} = 70 m^3/sec, adoption of the Pelton turbine would be extremely disadvantageous from the standpoint of construction cost.

Taking into consideration the performances at the Cumbaya and Nayon power stations it is thought there will be no problem since sediment of sizes 0.04 mm and over will be removed at the intake, but it is wished to adopt 13 Cr steel for the turbine and the guide vanes for the sake of safety. Siliceous sand which is the cause of turbine abrasion is not of very great quantity according to the results of sediment analyses.

The specifications of the main equipment are given below.

- Approximate Characteristic of Chespi Hydro Electrical Facilities -

Power station output: 167 MW

Turbine:

Type	Vertical-shaft Francis
Number	2 units
Normal effective head	275 m
Available discharge	35 m^3/s
Standard output	85.4 MW
Revolving speed	360 rpm

Generator:

Type	3-phase, A.C., synchronous generator
Number	2 units
Output	93 MVA (0.9 lagging of power factor)
Voltage	13.5 kV
Frequency	60 Hz

Main Transformer:

Type	Outdooe, 3-phase, pumped-oil, air-cooled type
Number	2 units
Capacity	93 MVA
Voltage	13.8/138 ± 10% kV

Outdooe Switchyard:

Type	Double-bus, GIS type
Voltage	138 kV
Transmission line	2 cct (3 cct in future)

7.7.2 Main Circuit and Outdoor Substation

The main circuit is to be of unit type, and the generator and the main transformer installed outdoors is to be connected by cross-linked polyethylene cable (XLPE cable) of 15 kV.

The 138-kV side of the main transformer is to be connected directly to the GIS type switchgear. The single-line diagram is shown in Fig. 7-23, and the outdoor switchyard equipment layout in Fig. 7-24.

7.7.3 Powerhouse Building

The power station building is to be a semi-underground type having windows at the river side only, and a building accomodating a delivery crane and elevator at the ground surface portion is to be provided. Further, in order to effectively utilize the space of the building, the distribution panel room, office, storeroom, etc. are to be located at the first basement floor, while GIS-type, 138-kV switchgear are to be installed on the roof.

7.7.4 Substation (Switchyard) - Facilities

A new 138-kV substation (switchyard) is to be provided at San Antonio for connection of the Chespi Transmission Line to the National Interconnected System. This substation is to have the transmission line from Ibarra led in by -connection, with the purpose of delivering the power generated at Chespi Power Station to the National Interconnected System and to supply power to the 138-kV capital city area outer loop transmission line of Empresa Electrica Quito S.A. (EEQ).

For the bus system of San Antonio Substation the transfer bus system (See Fig. 7-25, Single-Line Diagram.) which is the standard system of INECEL is to be adopted.

The equipment layout diagram is given in Fig. 7-26.

Further, when large-scale hydro development of the eastern part has progressed, it is imagined that this will be expanded as major substation of the National Interconnected System, and since this area is a broad and flat unused land it is thought possible for the necessary space to be acquired.

7.7.5 Telecommunications Facilities

The distance between Chespi Power Station and San Antonio Substation to be provided near the equator is to be connected by a transmission line of approximately 22 km. The protective device for the transmission line is to be a power line carrier relay apparatus. As for communication with the central dispatching office of INECEL to be provided in Quito and communication with the administrative sector, a power line carrier telephone system is to be installed.

The comunication between Chespi Dam and the powerhouse (10 km) is to be provided with VHF radio for telemetering of the dam water level, while a telephone channel will also be provided for business communication. This VHF radio will require one relay station because of the topography.

Fig. 7–23 One Line Diagram of Chespi Power Plant

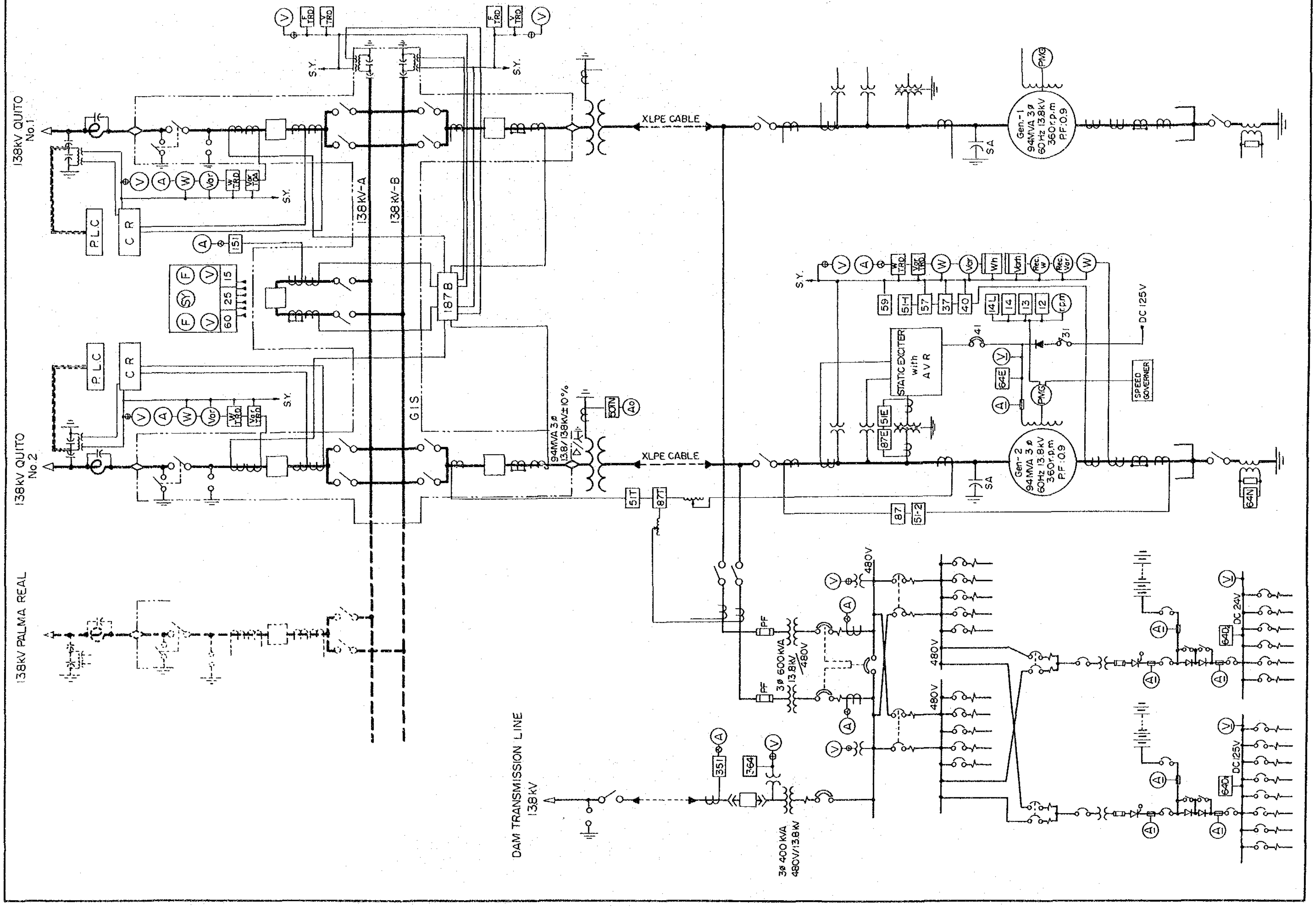
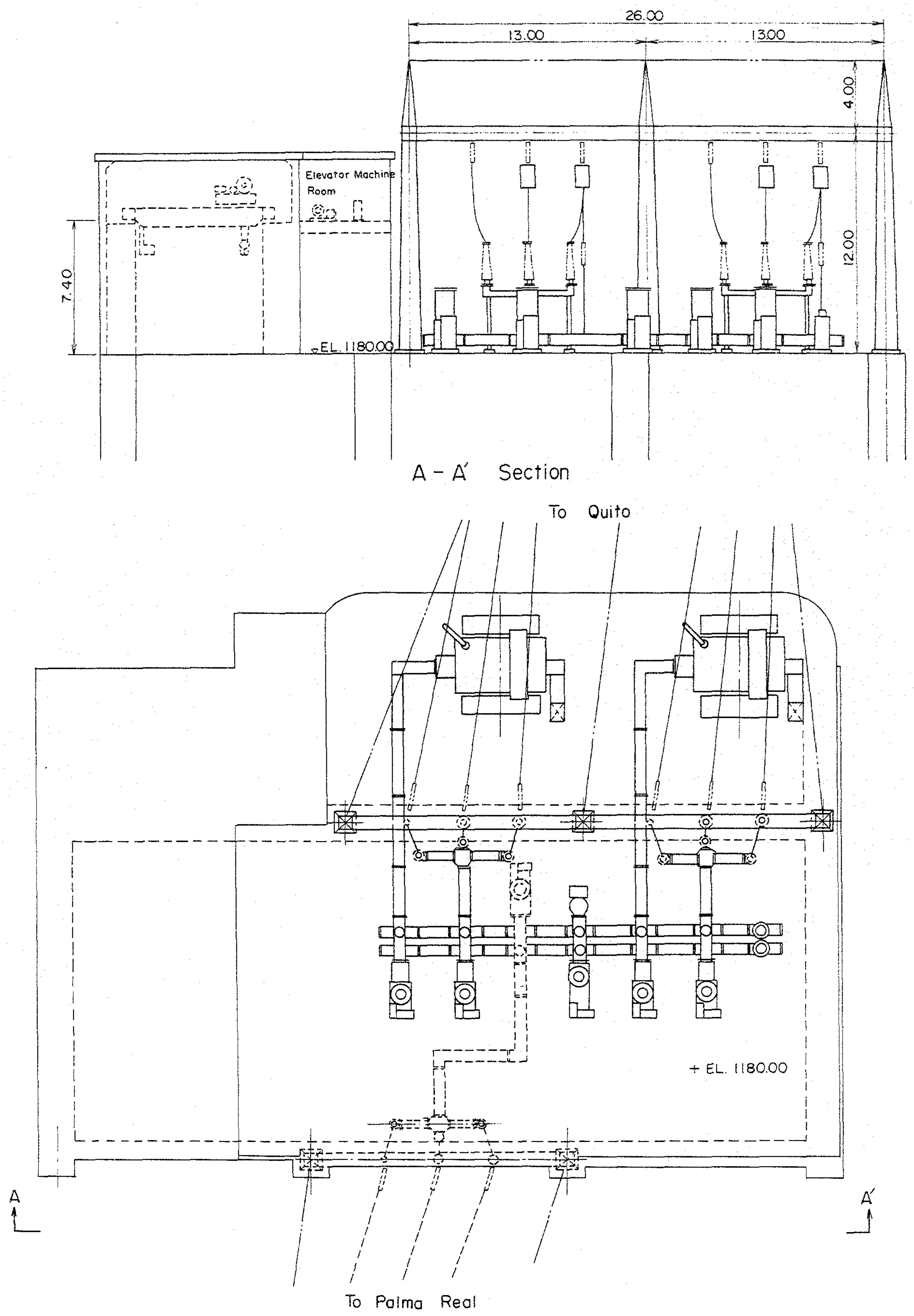
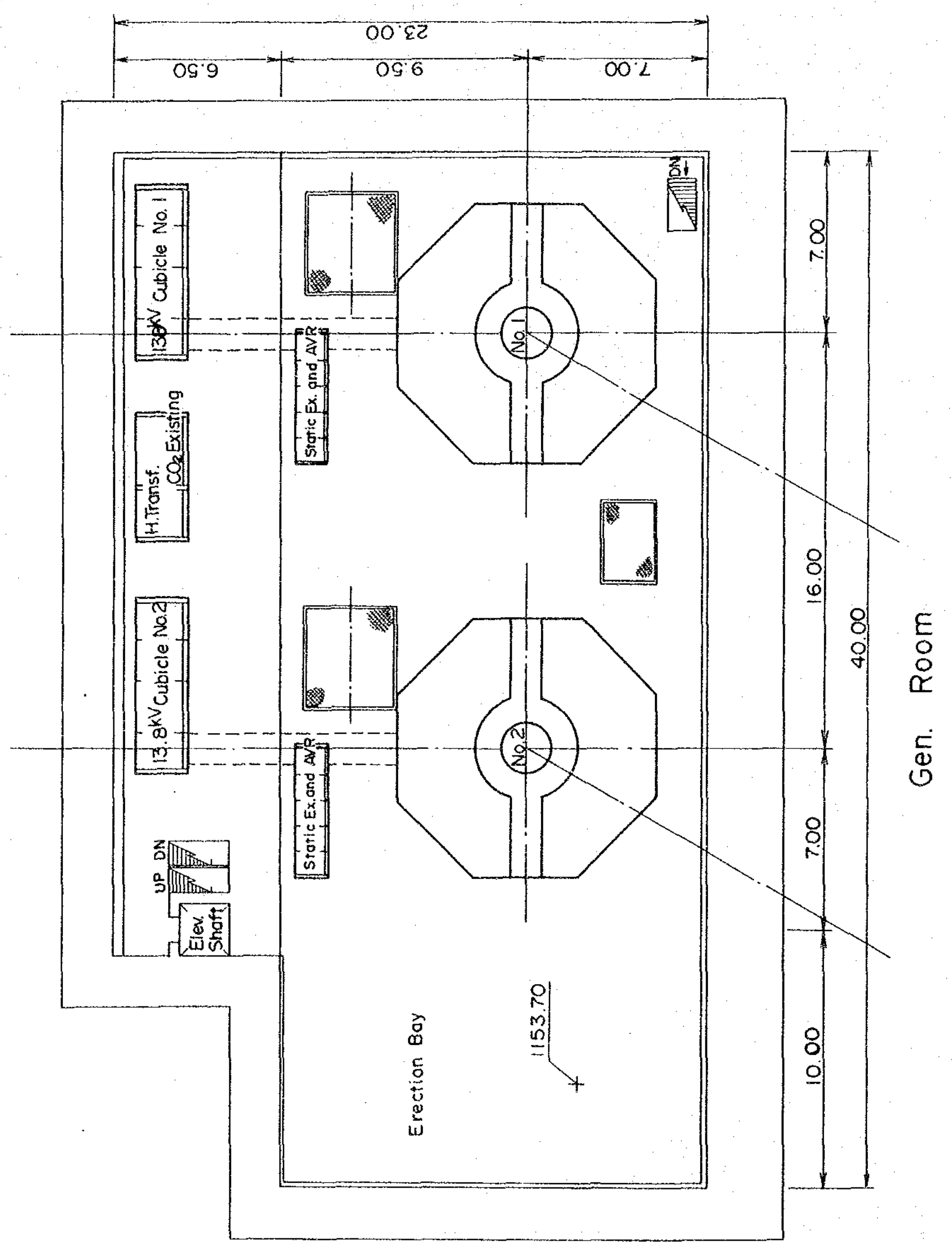
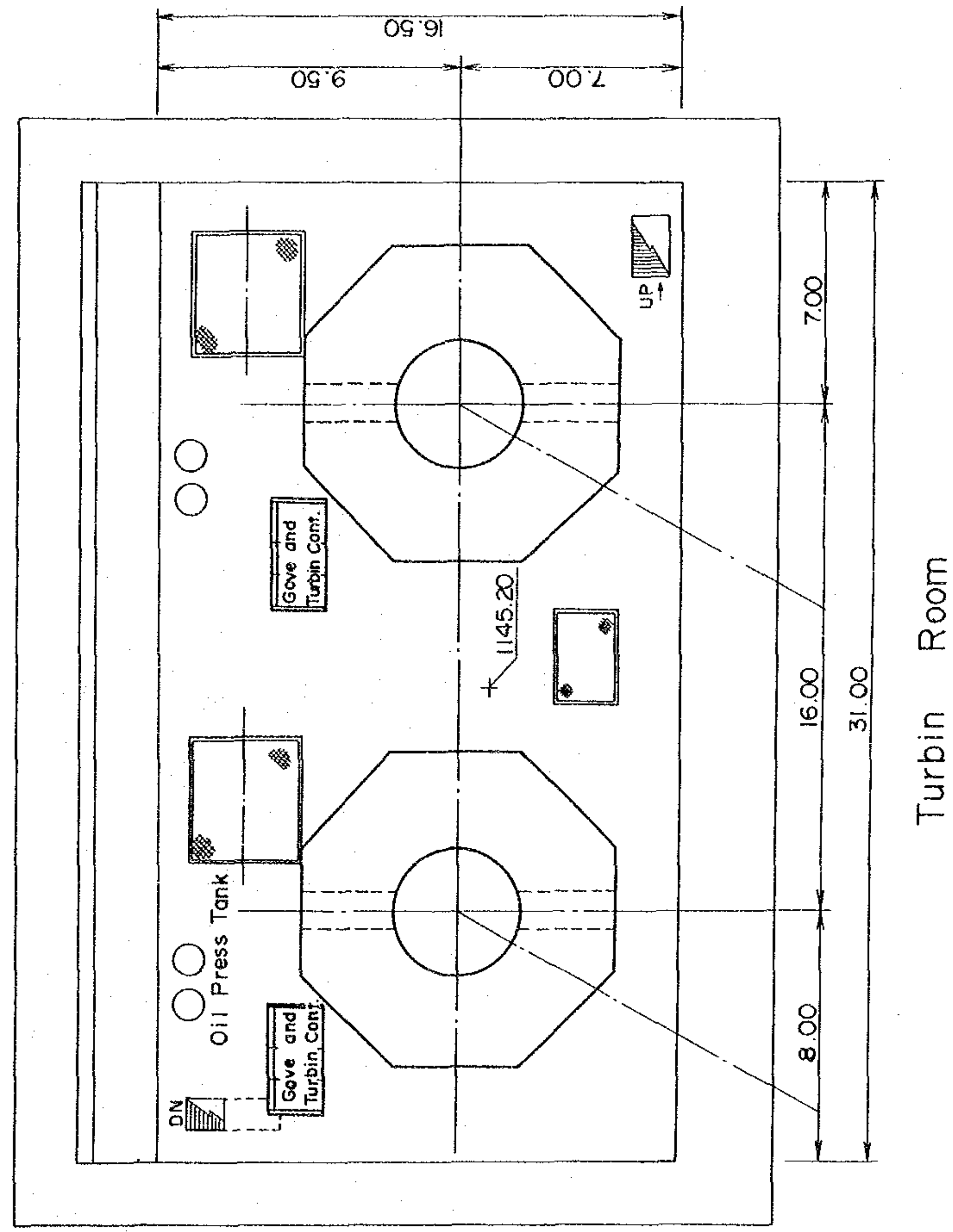


Fig. 7–24 138 kV Switchyard Layout




23.00
6.50
9.50
7.00
DN
138kV Cubicle No. 1
H.Transf.
CO2 Existing
13.8kV Cubicle No.2
Static Ex. and AVR
Static Ex. and AVR
No.1
No.2
UP DN
Elev. Shaft
Erection Bay
1153.70
7.00
16.00
7.00
10.00
40.00
Gen. Room


16.50
9.50
7.00
UP
Gove and Turbin Cont.
Gove and Turbin Cont.
1145.20
Oil Press Tank
DN
7.00
16.00
8.00
31.00
Turbin Room

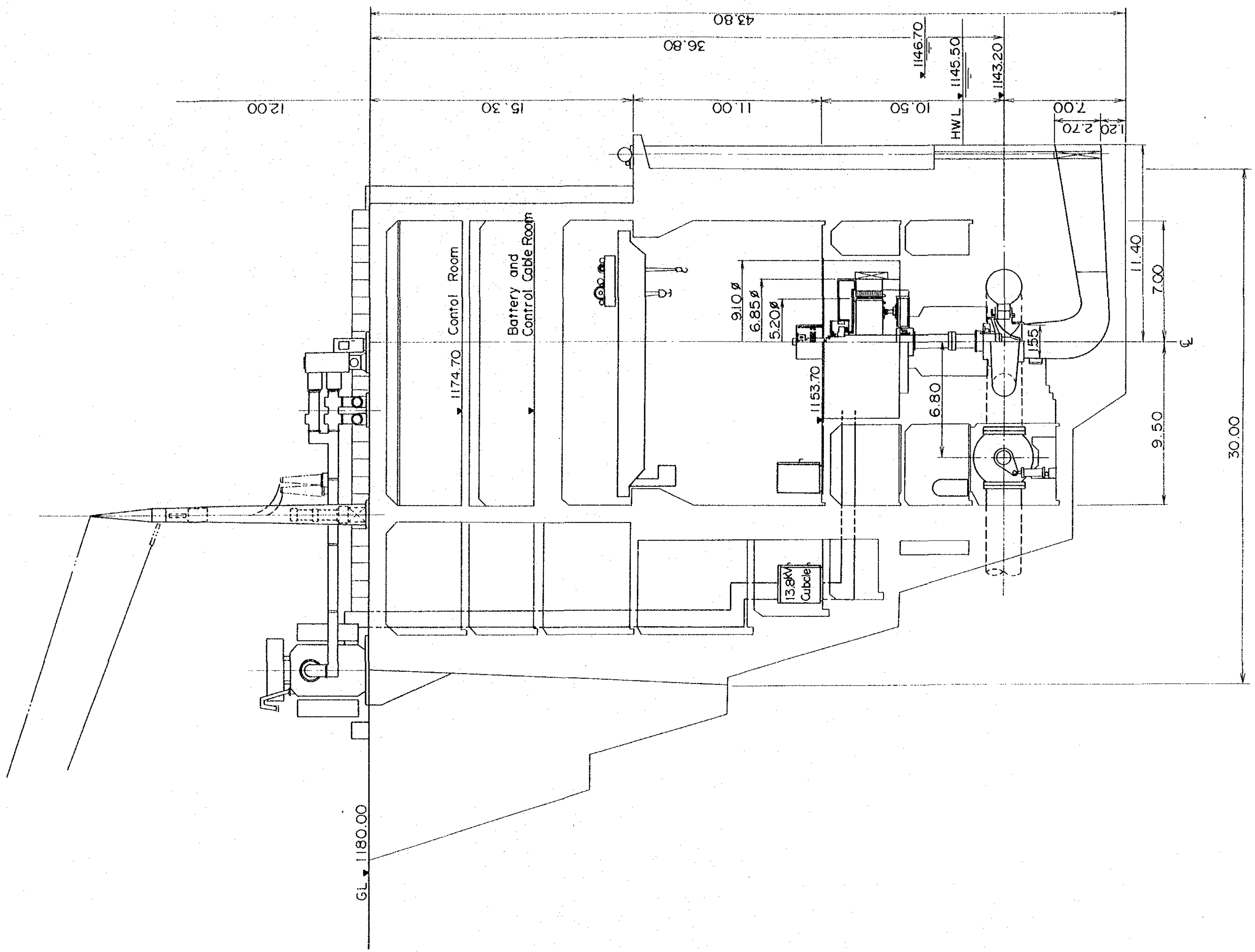

43.80
36.80
12.00
15.30
11.00
10.50
7.00
2.70
1.20
1146.70
HWL 1145.50
1143.20
Contol Room
Battery and Control Cable Room
1174.70
1153.70
9.10ø
6.85ø
5.20ø
6.80
1.55
11.40
7.00
9.50
30.00
13.8kV Cubcle
GL 1180.00

Fig. 7–25 One Line Diagram of San Antonio Substation

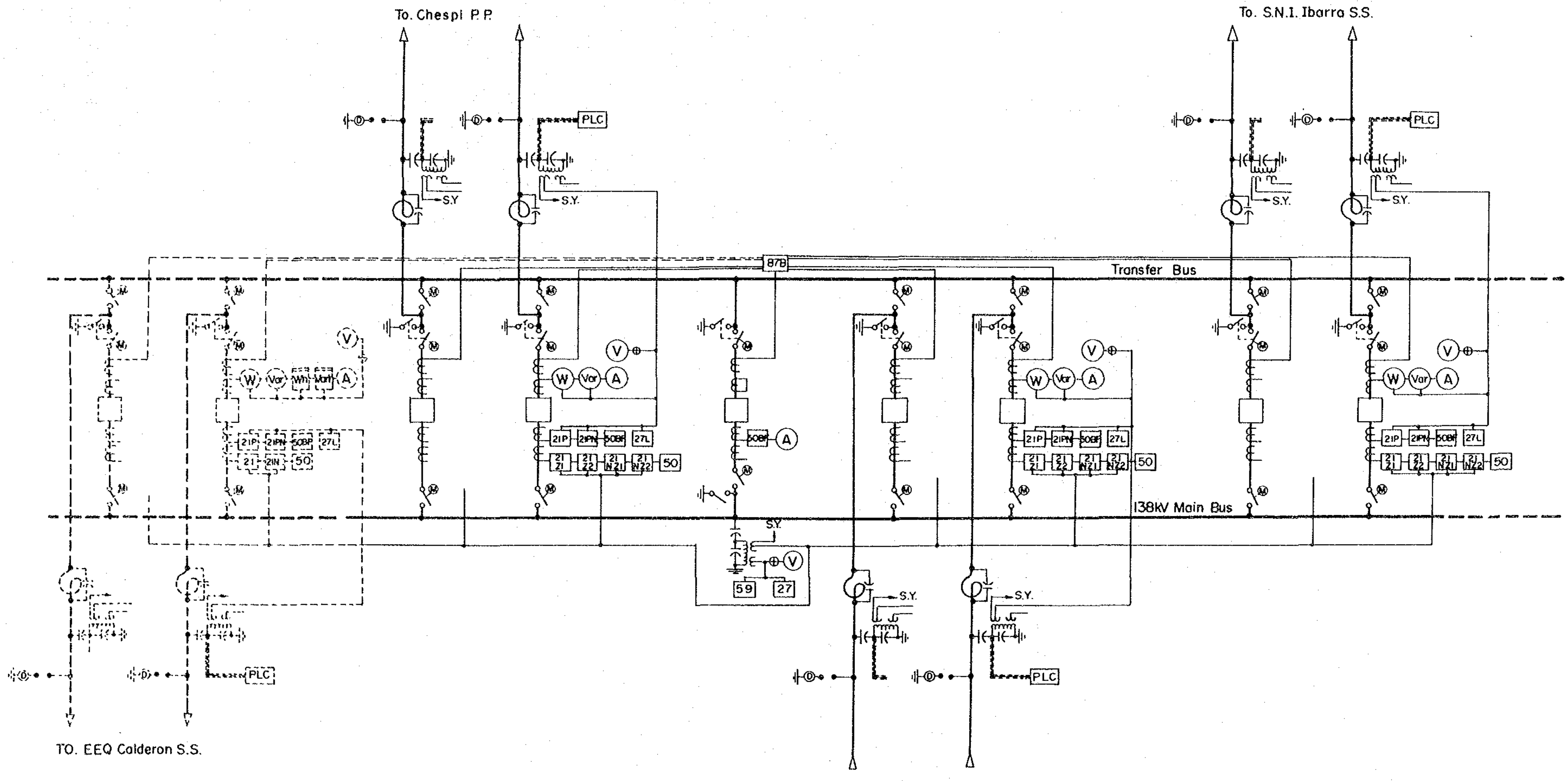
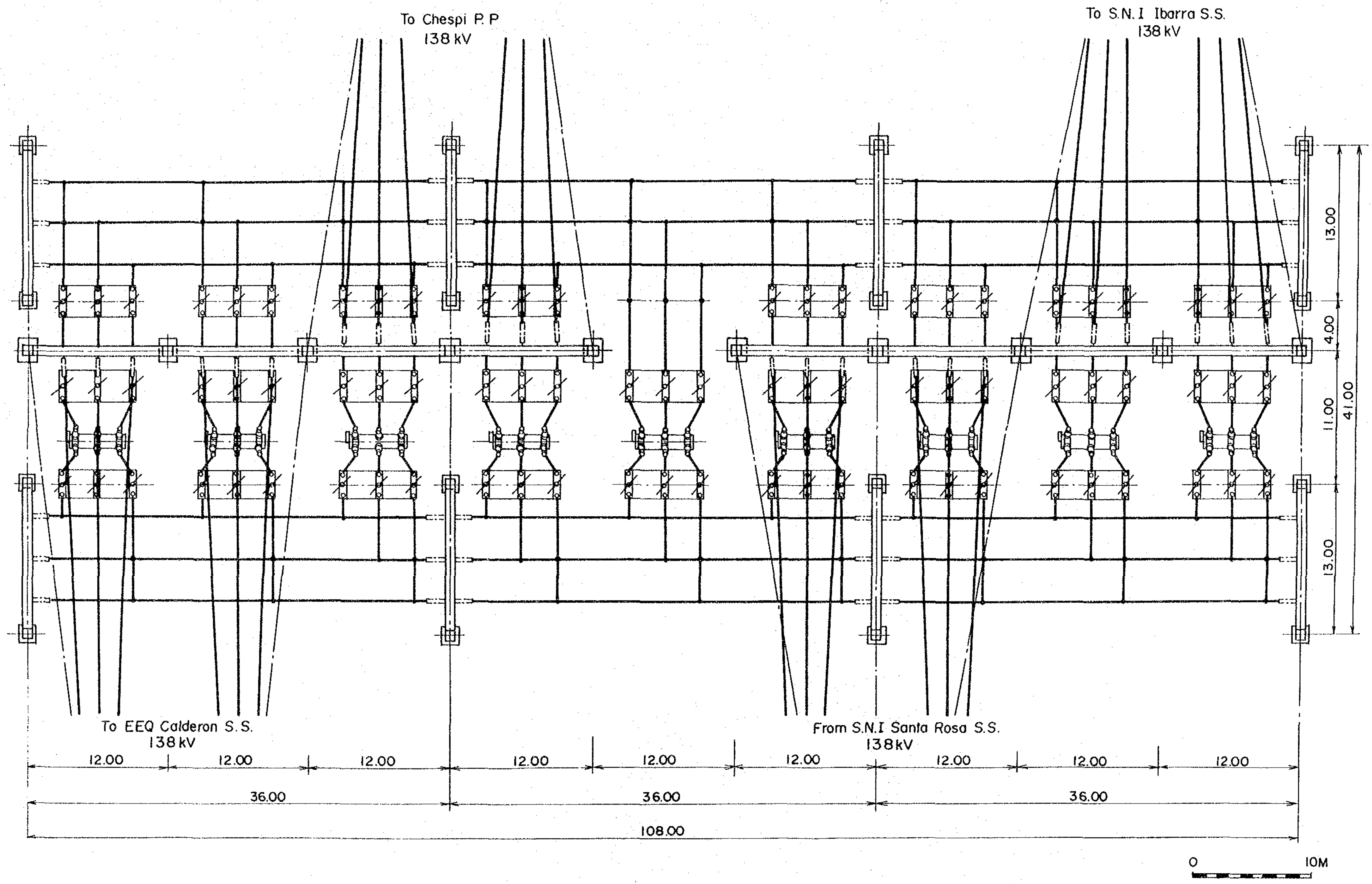


Fig. 7-26 Plan of 138 kV Switchyard of the San Antonio Substation



7.7.6 Transmission Line Facilities

a) Principal Specifications

The principal specifications of the power transmission facilities are as given below.

Item	Outline of Design
Section	Chespi P/S ~ San Antonio S/S
Distance	22km
Nominal Voltage	138 kv
Conductor	ACSR 636 MCM
Number of Circuit	2 cct
Ground Wire	2 × 3/8 GSW
Insulator Size	254 × 146
Number of Insulator	13

b) Transmission Line Route

The transmission line route from Chespi Power Station to San Antonio Substation will have a length of approximately 22 km.

The transmission line, after being taken out from the powerhouse site at El. 1,160 m, will cross the Rio Guayllabamba, pass by San Jose Niebli at El. 1,800 m and Loma Las Monjas at El. 2,800 m, and be taken in at San Antonio Substation. Since all of this transmission line route will be located in the central mountain region, it will be necessary for more detailed topographical and geological investigations to be carried out for concrete implementation of the plan. (Figs. 7-27, 7-28)

c) Transmission Line Design Conditions

INECEL has established design standards considering topographical and meteorological conditions.

A separation is made according to elevation into Zone 1 (up to 1,000 m) and Zone 2 (1,000 to 3,500 m), and the Chespi Transmission Line is in Zone 2.

The design criteria for Zone 2 are the following:

Max. air temperature	32°C
Max. conductor temperature	45°C
Max. conductor temperature (emergency)	60°C
Min. air temperature	-5°C
Max. wind speed	90 km/hr at 5°C
EDS temperature	12°C

d) Conductor

The transmission voltage from Chespi to San Antonio will be 138 kV for technical and economic reasons as previous described. The conductor size will be Rook-636 MCM (322.3 mm^2) which has adequate thermal capacity for transmitting the 167 MW of power generated at Chespi, and which is also economically advantageous. The specifications according to ASTM Standards on Rook-636 MCM and aerial ground wire GSW-3/8" are given in Table 7-18.

Table 7–18 Properties of ACSR and GSW

Description	"Rook" 636 MCM	GSW 3/8"
Stranded Al	24/4.14	—
st	7/2.76	7/3.05
Overall diameter (mm)	24.81	9.15
Weight (kg / m)	1.129	0.406
Approx Thermal Capacity	160 MVA	—

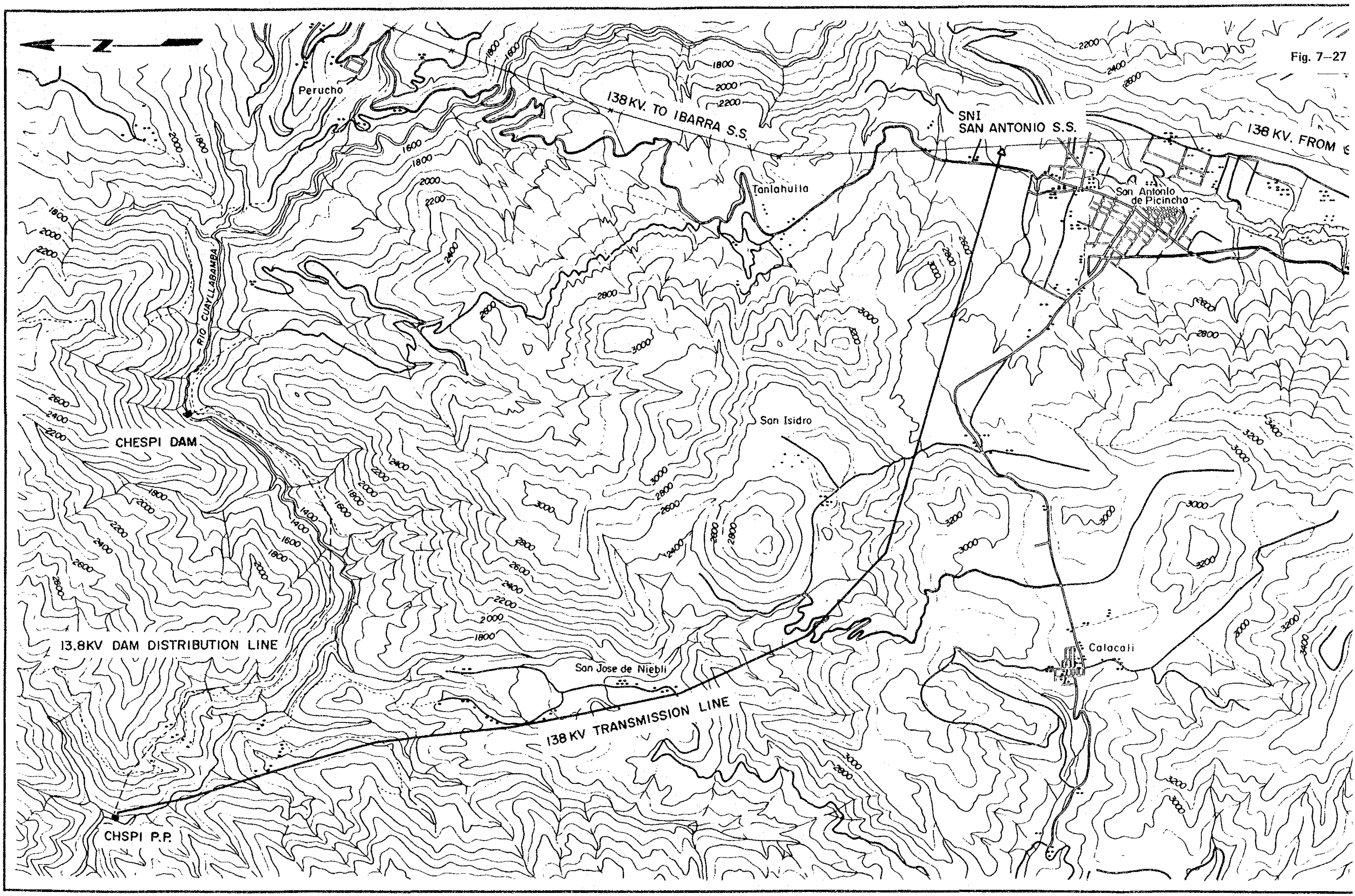

Z
Perucho
138 KV. TO IBARRA S.S.
SNI
SAN ANTONIO S.S.
138 KV. FROM
Tanlahuila
San Antonio de Picincha
RIO GUAYLLABAMBA
CHESPI DAM
San Isidro
13.8KV DAM DISTRIBUTION LINE
San Jose de Niebli
Calacali
138 KV TRANSMISSION LINE
CHSPI P.P.

Fig. 7–27

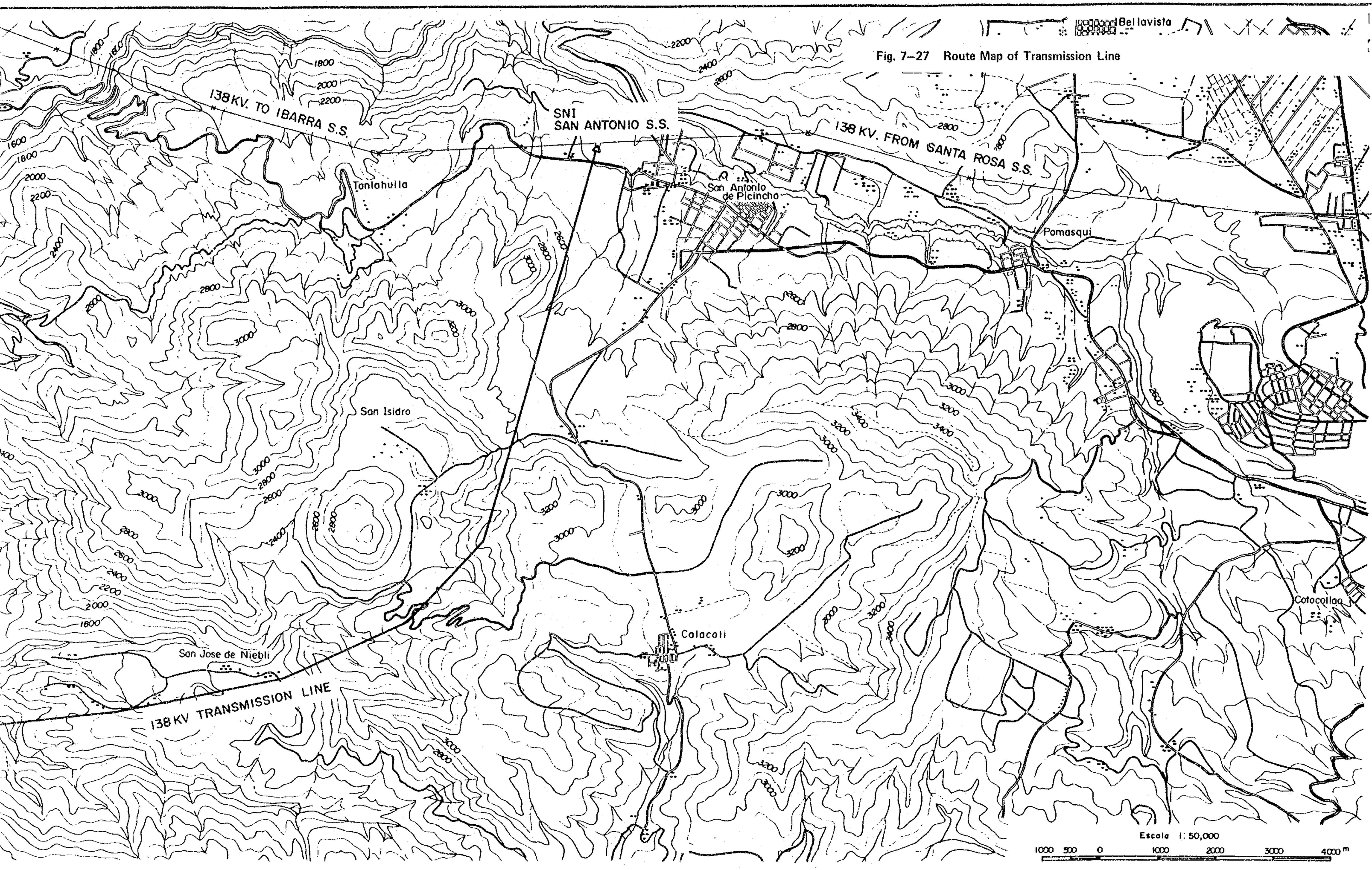


Fig. 7–27 Route Map of Transmission Line

Fig. 7–28 Steel Tower Configuration

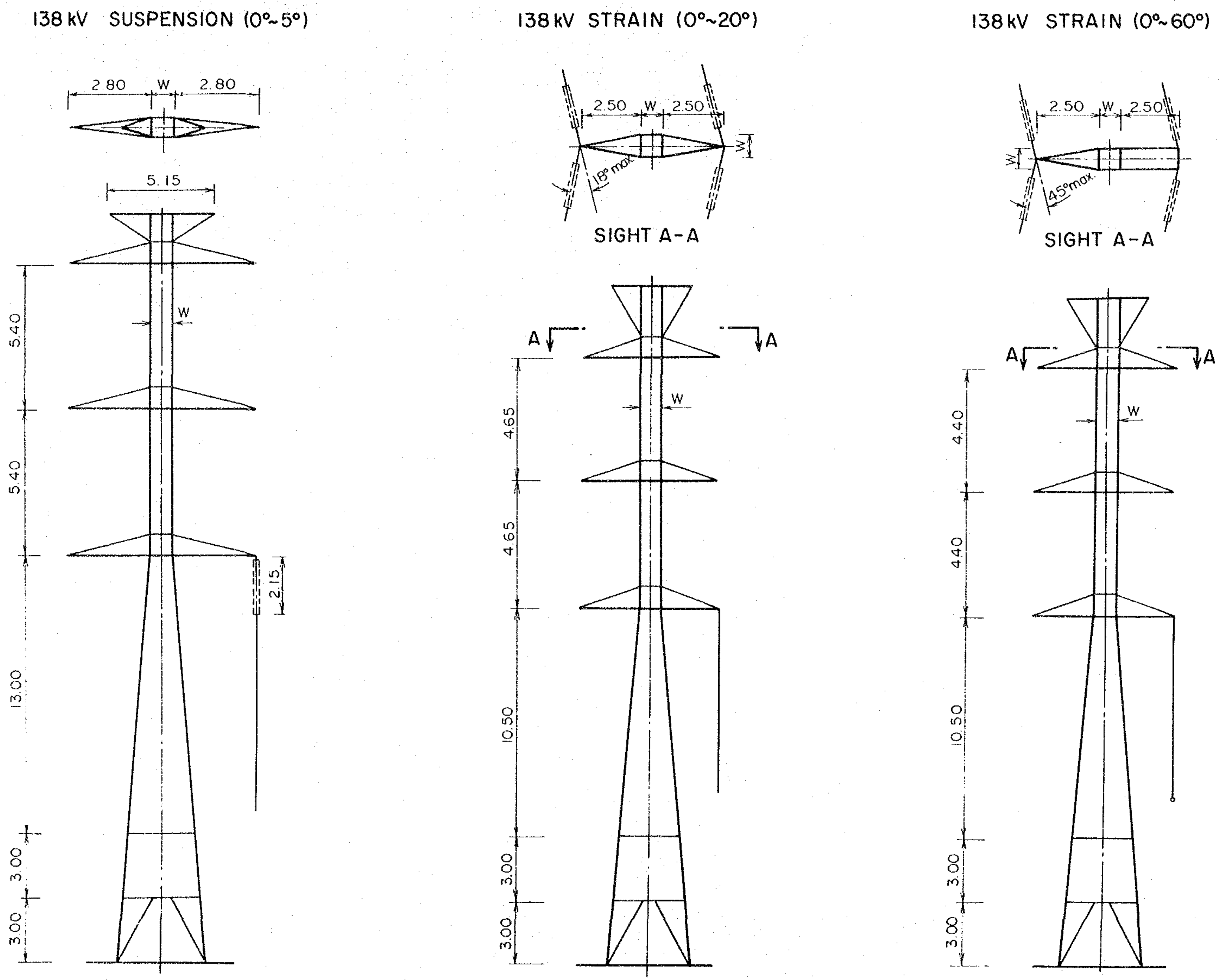
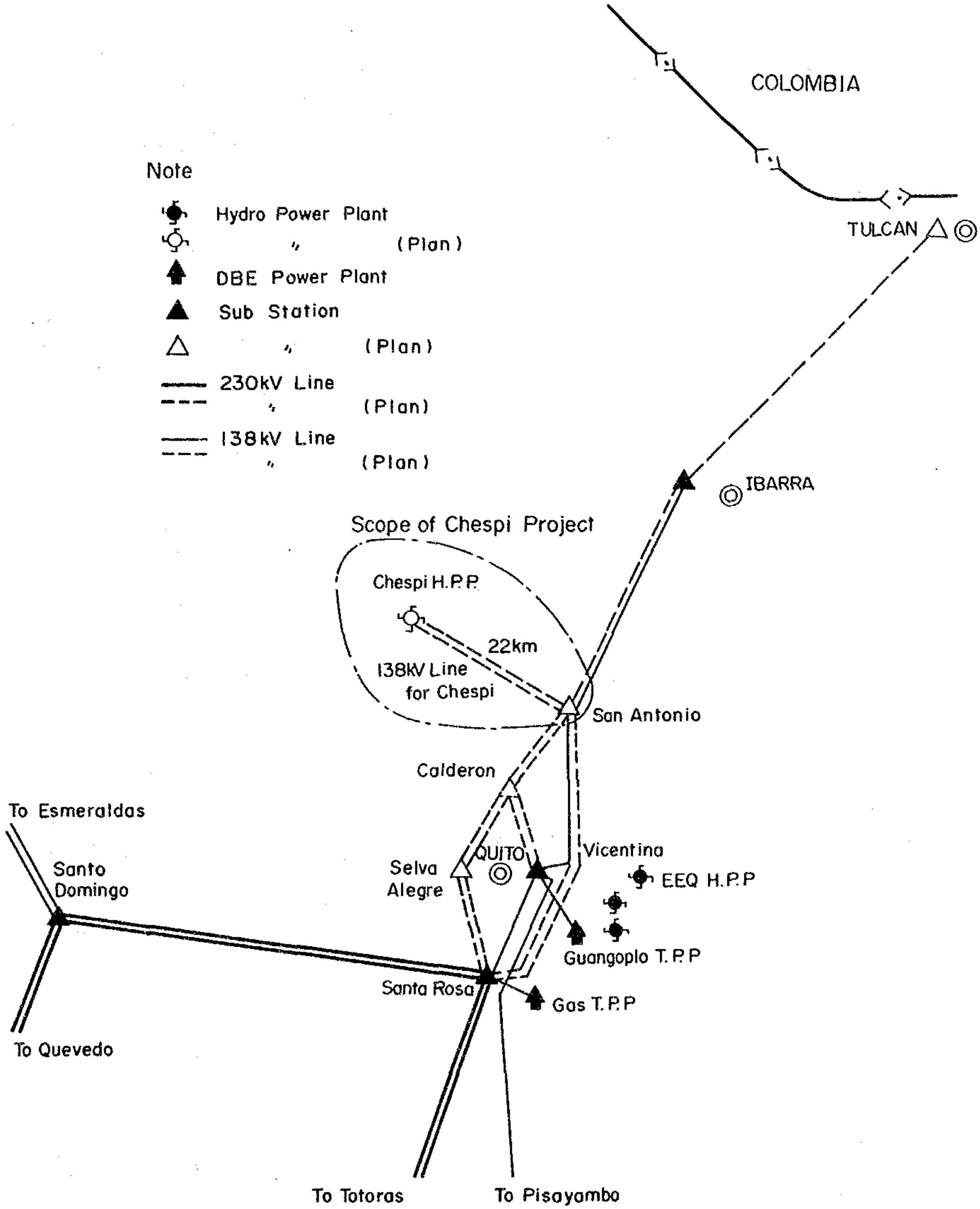
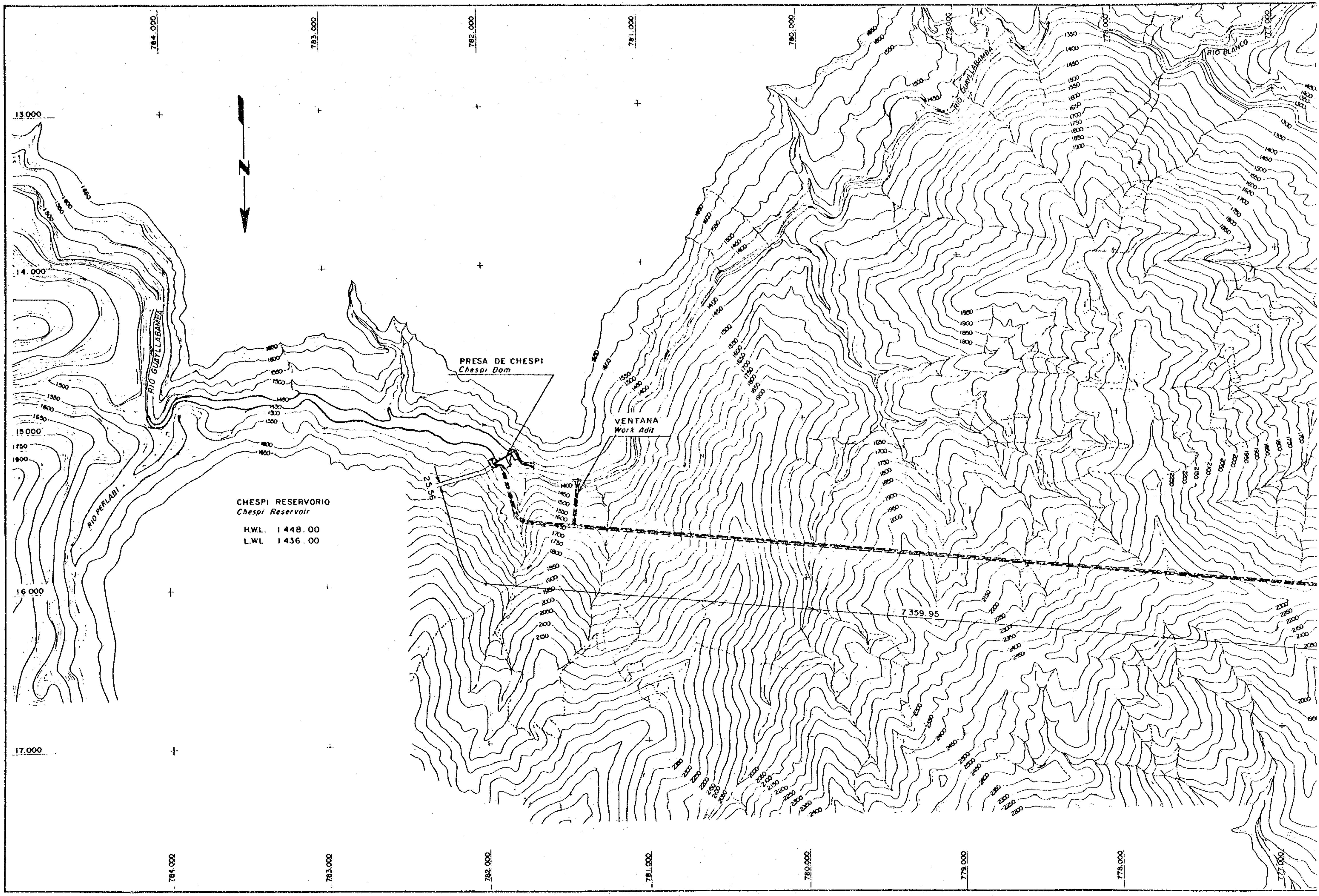


Fig. 7–29 Transmission Plan of Quito Region (in 1985)





PRESA DE CHESPI
Chespi Dam
VENTANA
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CHESPI RESERVORIO
Chespi Reservoir
H.WL. 1448.00
L.WL 1436.00
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RIO PERLABI
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N
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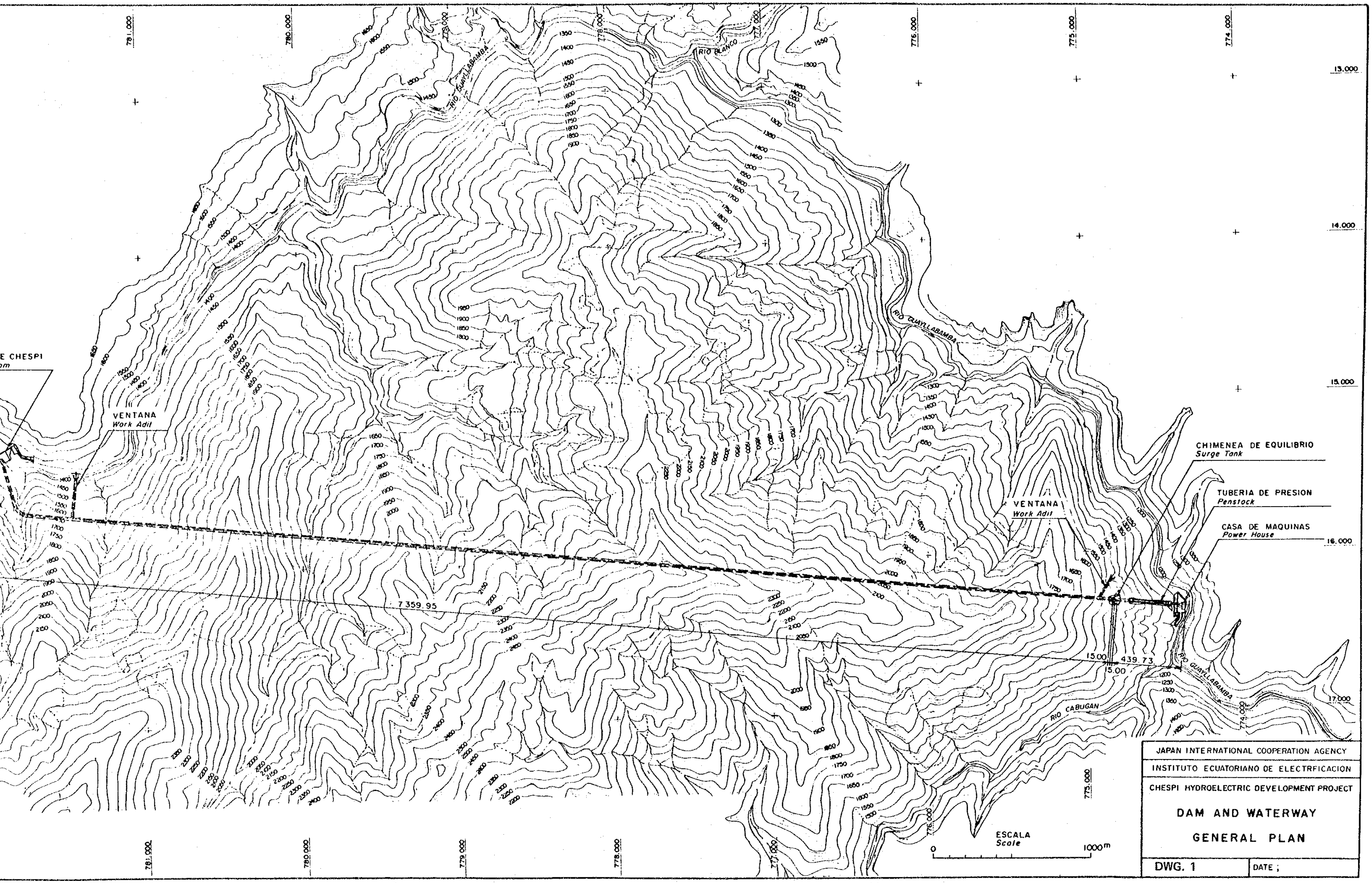
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VENTANA
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VENTANA
Work Adit
CHIMENEA DE EQUILIBRIO
Surge Tank
TUBERIA DE PRESION
Penstock
CASA DE MAQUINAS
Power House
RIO GUAYLLABAMBA
RIO BLANCO
RIO CABUGAN
7 359.95
15.00
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ESCALA
Scale
0
1000m
JAPAN INTERNATIONAL COOPERATION AGENCY
INSTITUTO ECUATORIANO DE ELECTRIFICACION
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
DAM AND WATERWAY
GENERAL PLAN
DWG. 1
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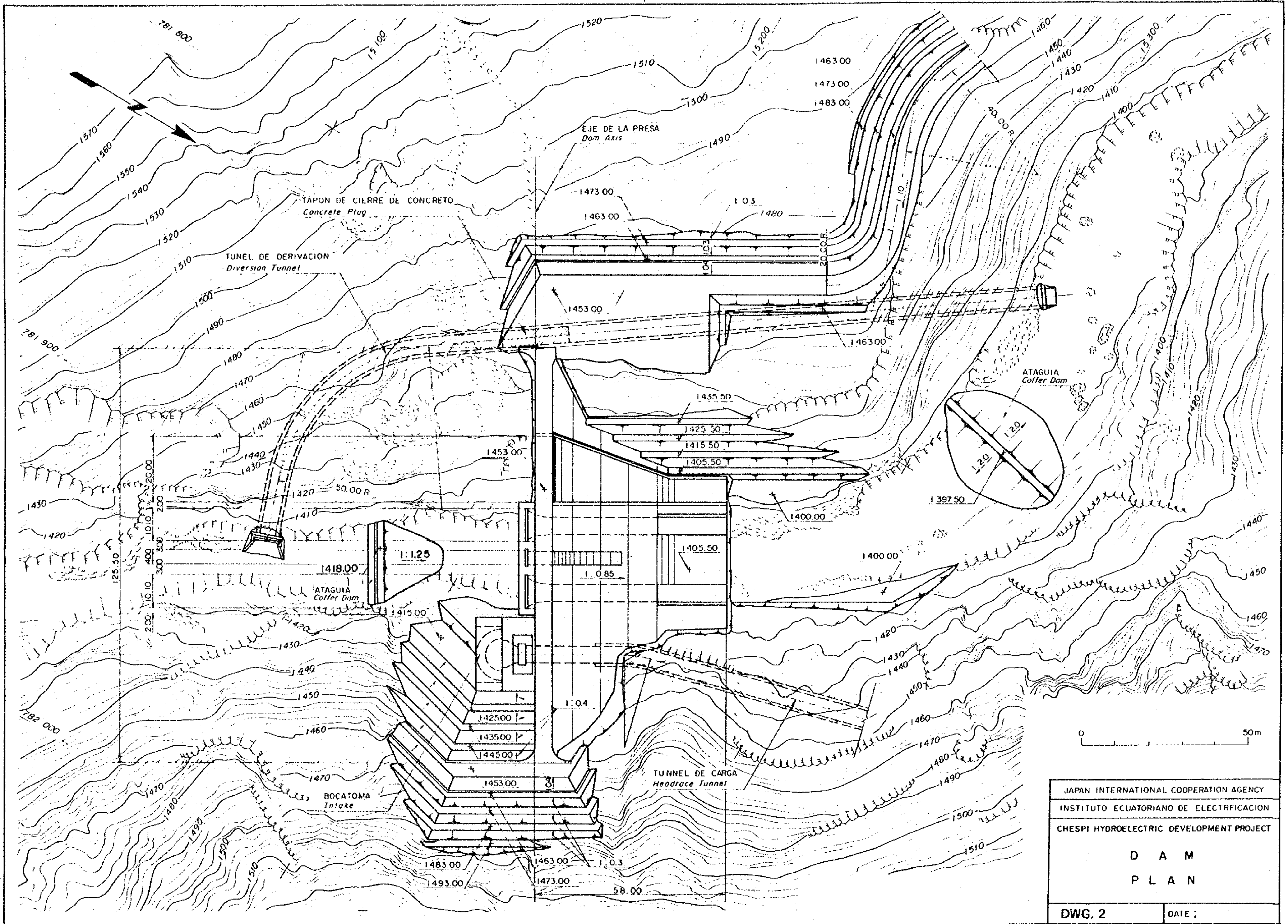
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CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
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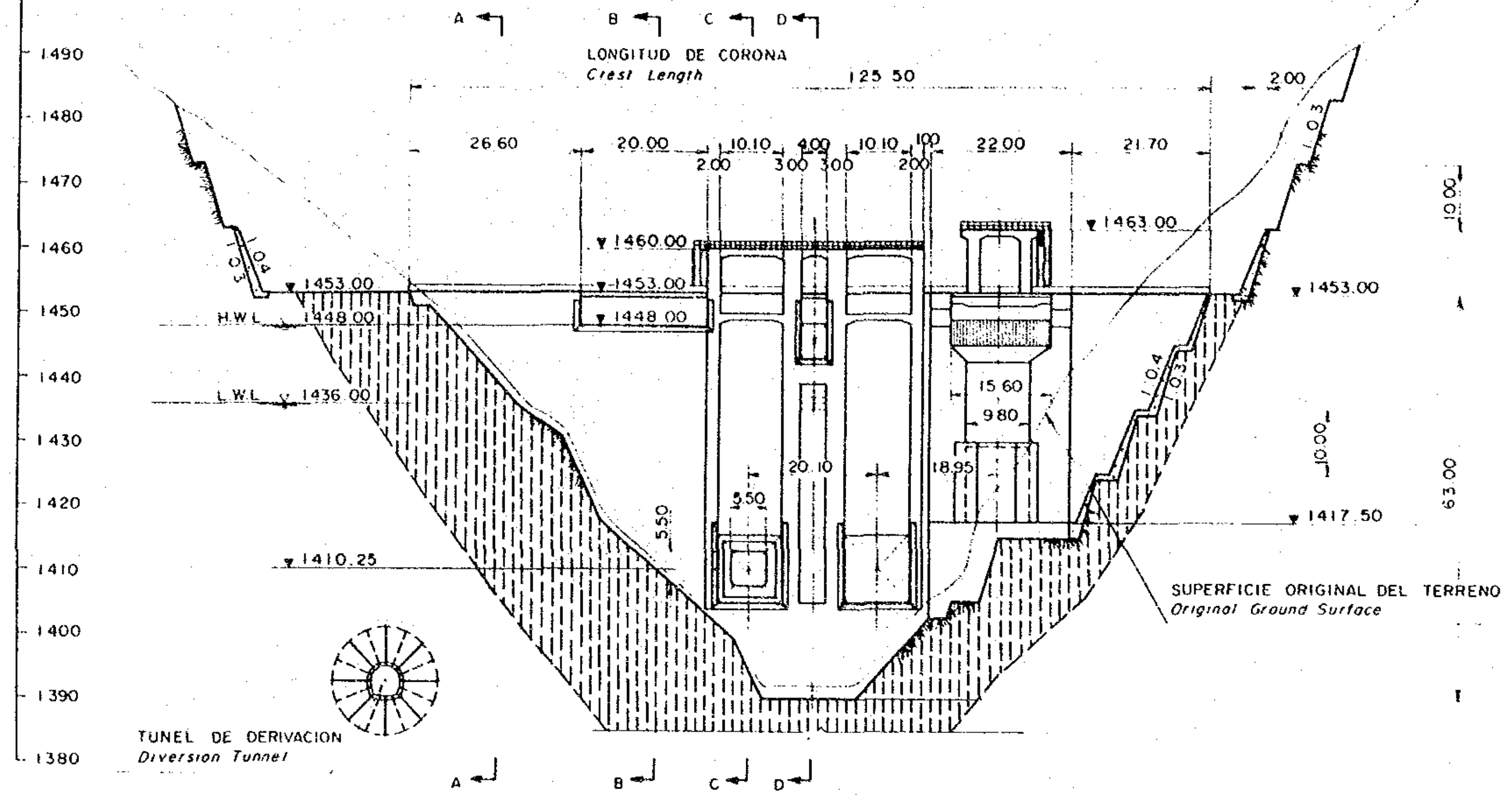
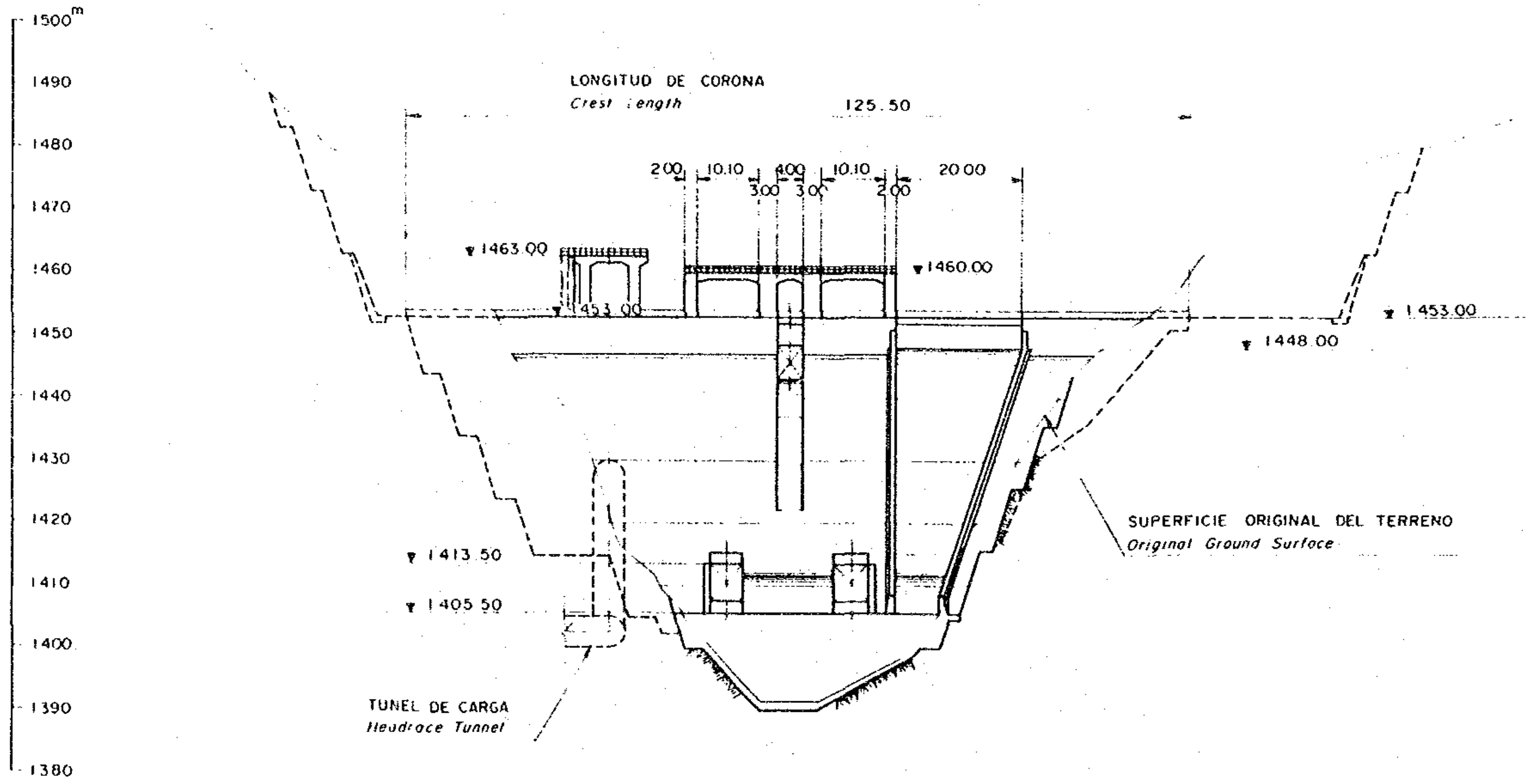
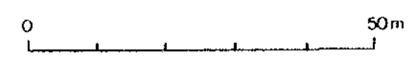
DATE ;
EJE DE LA PRESA
Dam Axis
TAPON DE CIERRE DE CONCRETO
Concrete Plug
TUNEL DE DERIVACION
Diversion Tunnel
ATAGUIA
Coffer Dam
BOCATOMA
Intake
TUNNEL DE CARGA
Headrace Tunnel
0
50m

ELEVACION DE AGUAS ARRIBA
Upstream Elevation



ELEVACION DE AGUAS ABAJO
Downstream Elevation





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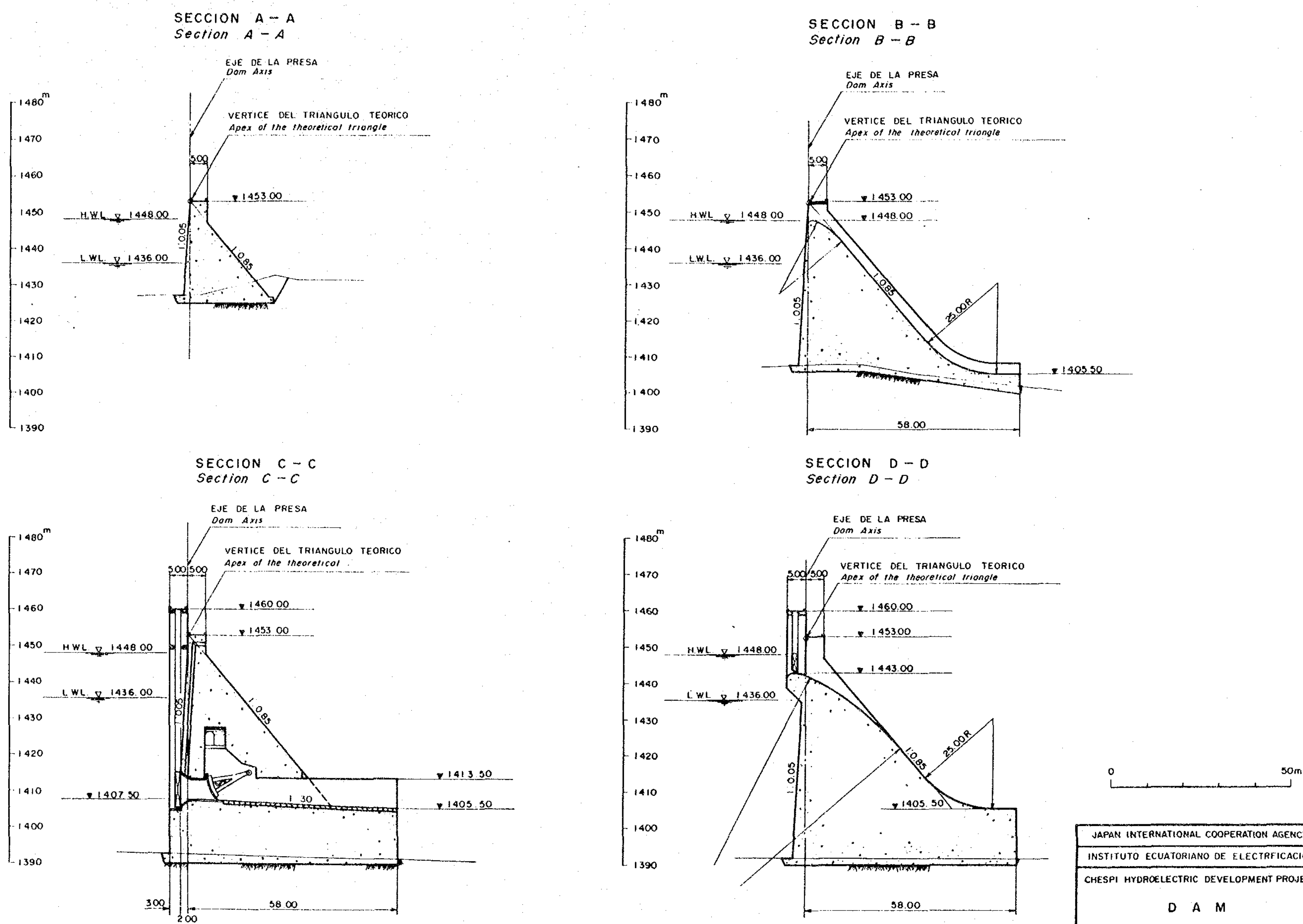

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CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

D A M

TYPICAL CROSS SECTION

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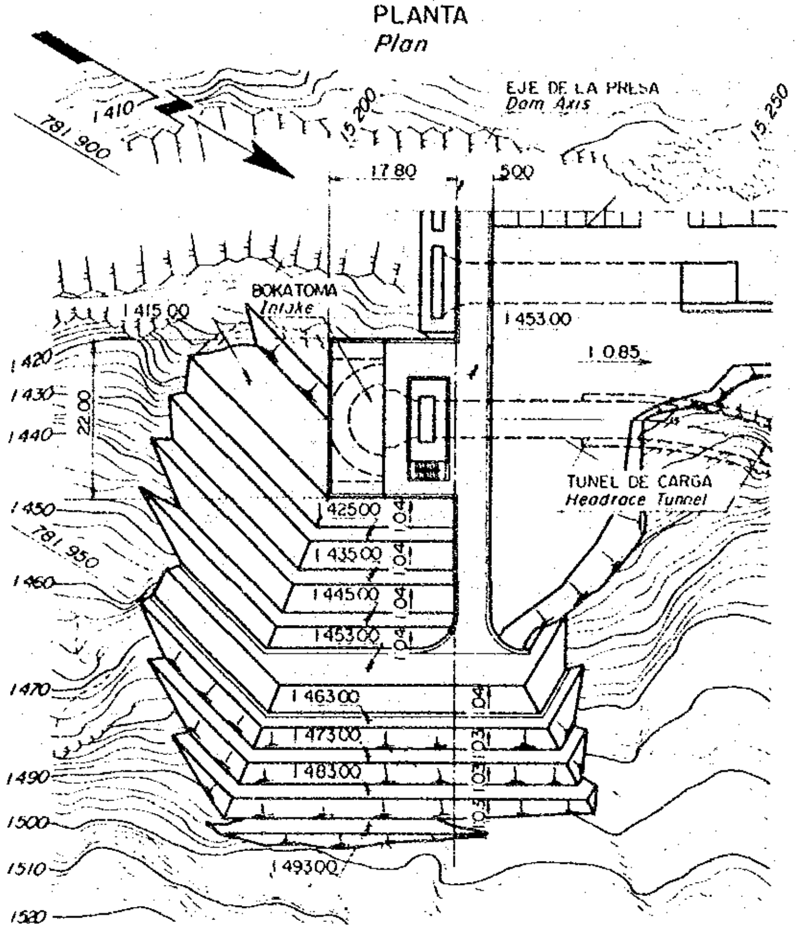

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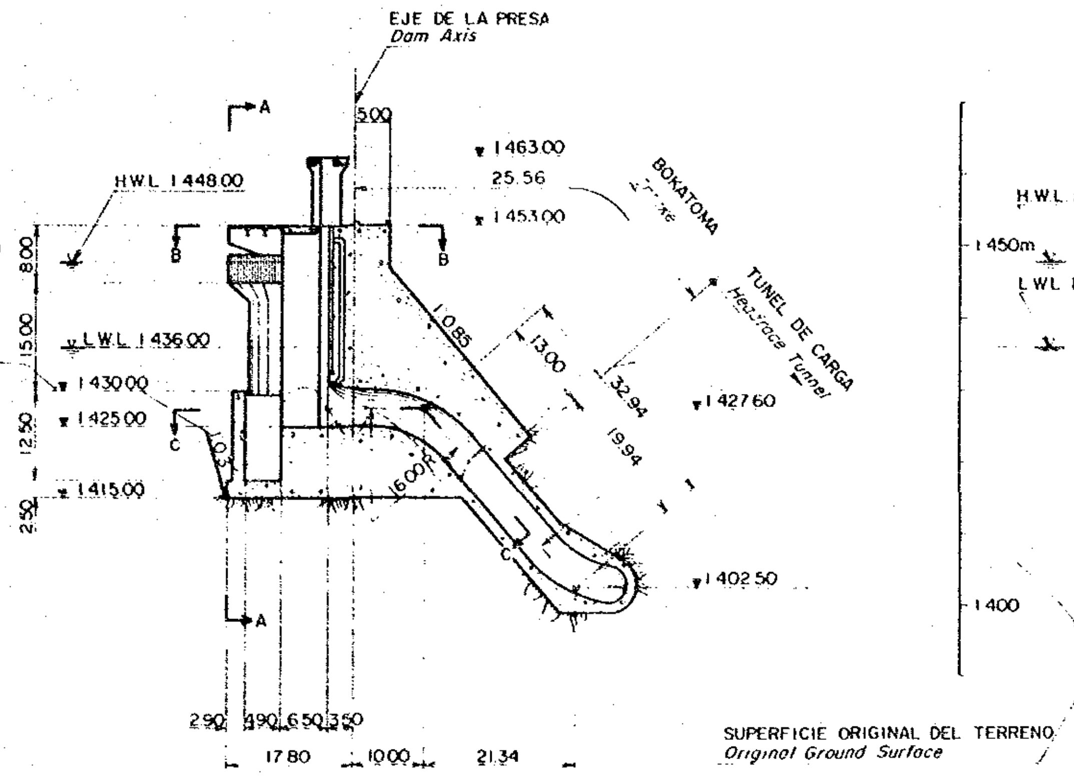

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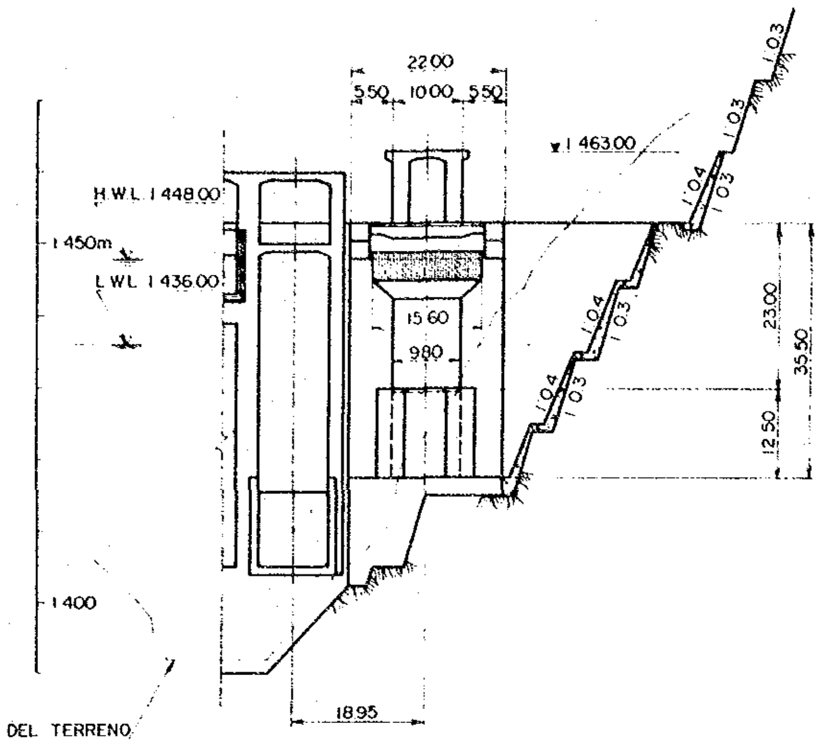

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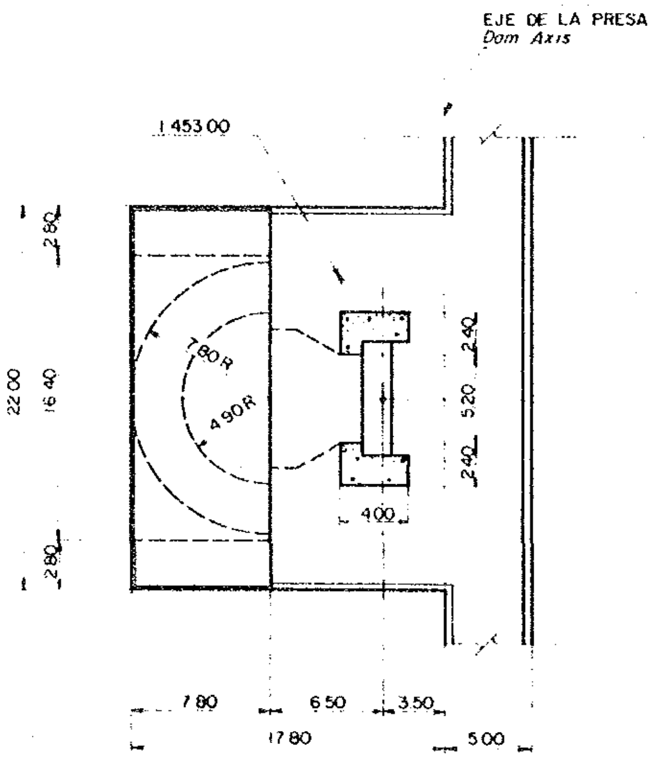

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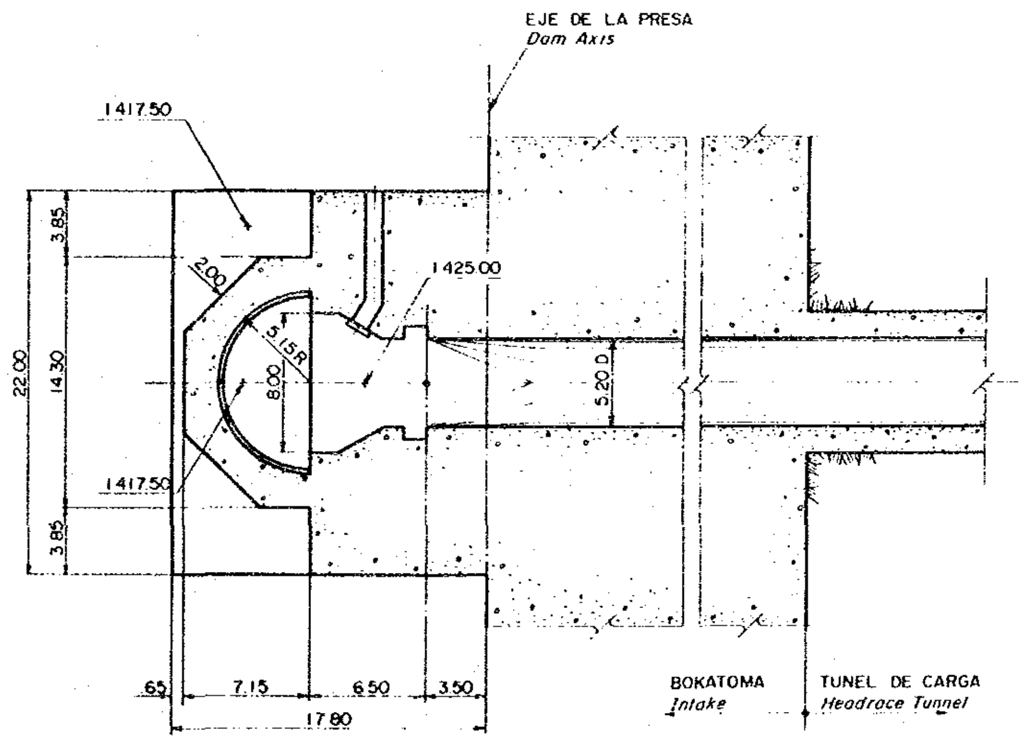

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(Plan, Profile and Section A-A)
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(SECCION B-B, C-C)
(Section B-B, C-C)
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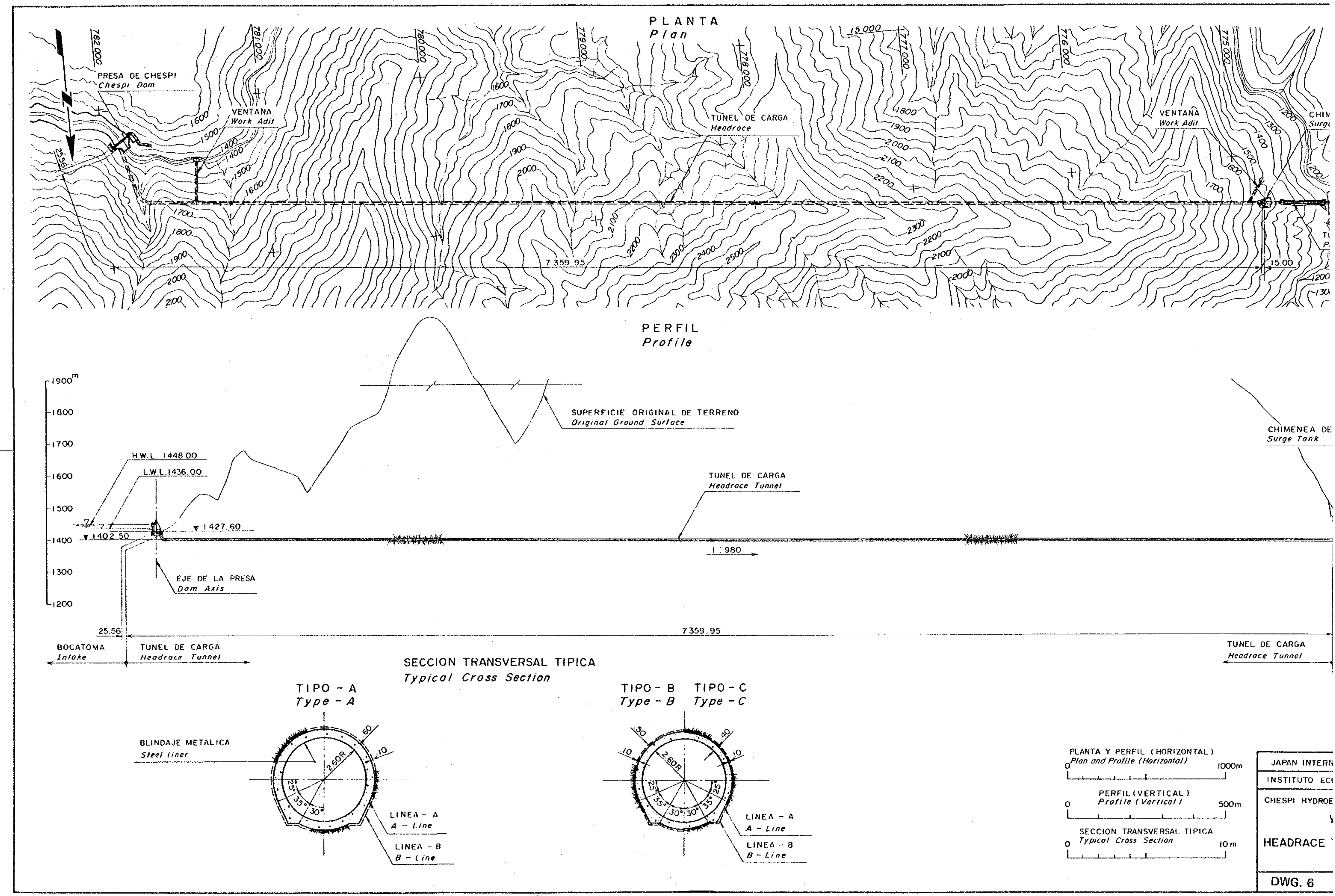
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

WATERWAY

INTAKE PLAN, PROFILE AND SECTION

DWG. 5 | DATE :



PLANTA
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PRESA DE CHESPI
Chespi Dam
VENTANA
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TUNEL DE CARGA
Headrace
VENTANA
Work Adit
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PERFIL
Profile
SUPERFICIE ORIGINAL DE TERRENO
Original Ground Surface
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TUNEL DE CARGA
Headrace Tunnel
1 : 980
EJE DE LA PRESA
Dam Axis
CHIMENEA DE
Surge Tank
25.56
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BOCATOMA
Intake
TUNEL DE CARGA
Headrace Tunnel
TUNEL DE CARGA
Headrace Tunnel
SECCION TRANSVERSAL TIPICA
Typical Cross Section
TIPO - A
Type - A
BLINDAJE METALICA
Steel liner
2.60R
LINEA - A
A - Line
LINEA - B
B - Line
TIPO - B TIPO - C
Type - B Type - C
2.60R
LINEA - A
A - Line
LINEA - B
B - Line
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PERFIL (VERTICAL)
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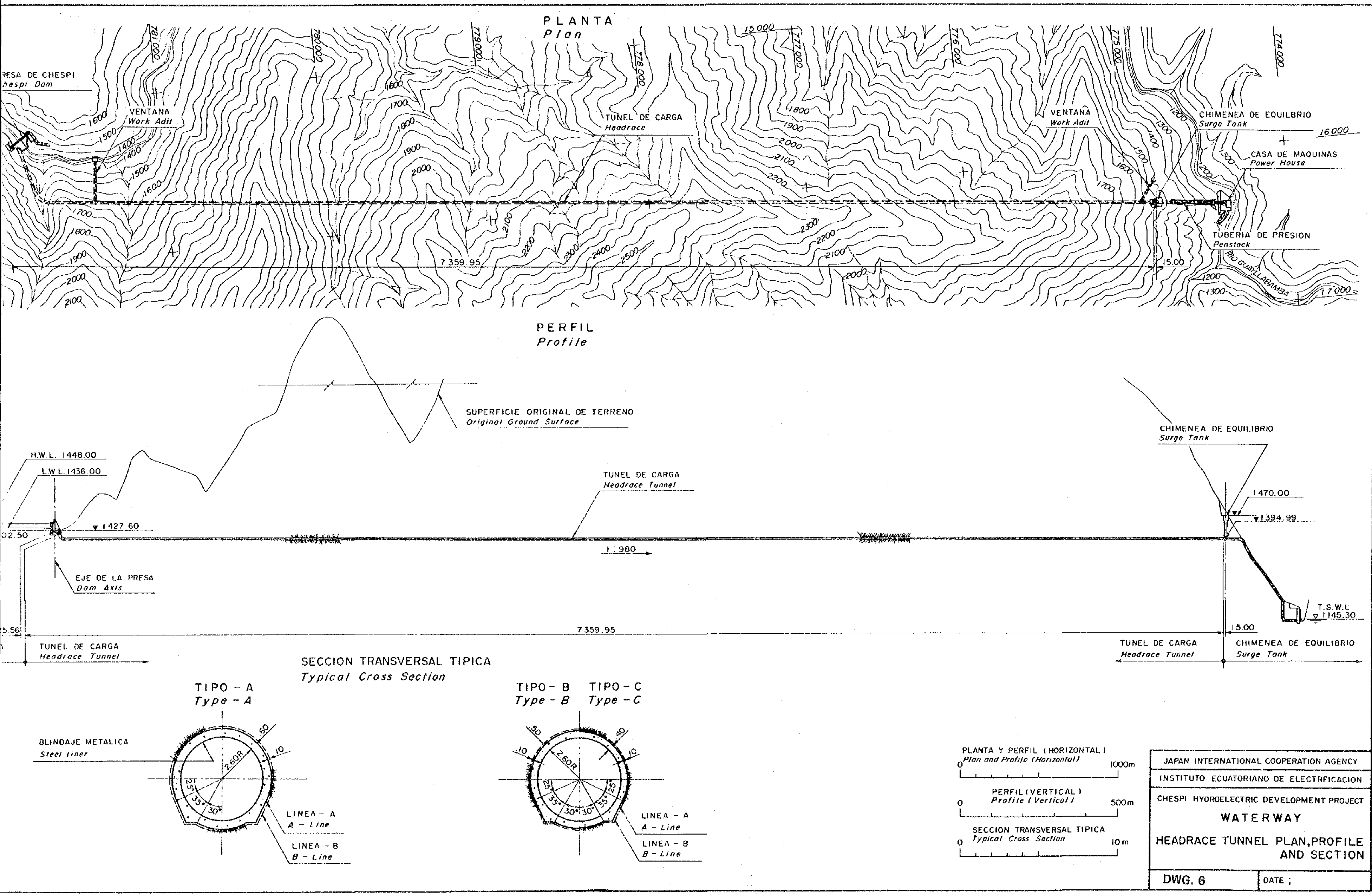
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VENTANA
Work Adit
TUNEL DE CARGA
Headrace
VENTANA
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CHIMENEA DE EQUILBRIO
Surge Tank
CASA DE MAQUINAS
Power House
TUBERIA DE PRESION
Penstock
RIO GUAYLLABAMBA
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SUPERFICIE ORIGINAL DE TERRENO
Original Ground Surface
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Headrace Tunnel
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EJE DE LA PRESA
Dam Axis
CHIMENEA DE EQUILIBRIO
Surge Tank
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7 359.95
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TUNEL DE CARGA
Headrace Tunnel
TUNEL DE CARGA
Headrace Tunnel
CHIMENEA DE EQUILIBRIO
Surge Tank
SECCION TRANSVERSAL TIPICA
Typical Cross Section
TIPO - A
Type - A
TIPO - B TIPO - C
Type - B Type - C
BLINDAJE METALICA
Steel liner
2.60R
LINEA - A
A - Line
LINEA - B
B - Line
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PERFIL (VERTICAL)
Profile (Vertical)
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SECCION TRANSVERSAL TIPICA
Typical Cross Section
0 10 m
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CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
WATERWAY
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PLANTA
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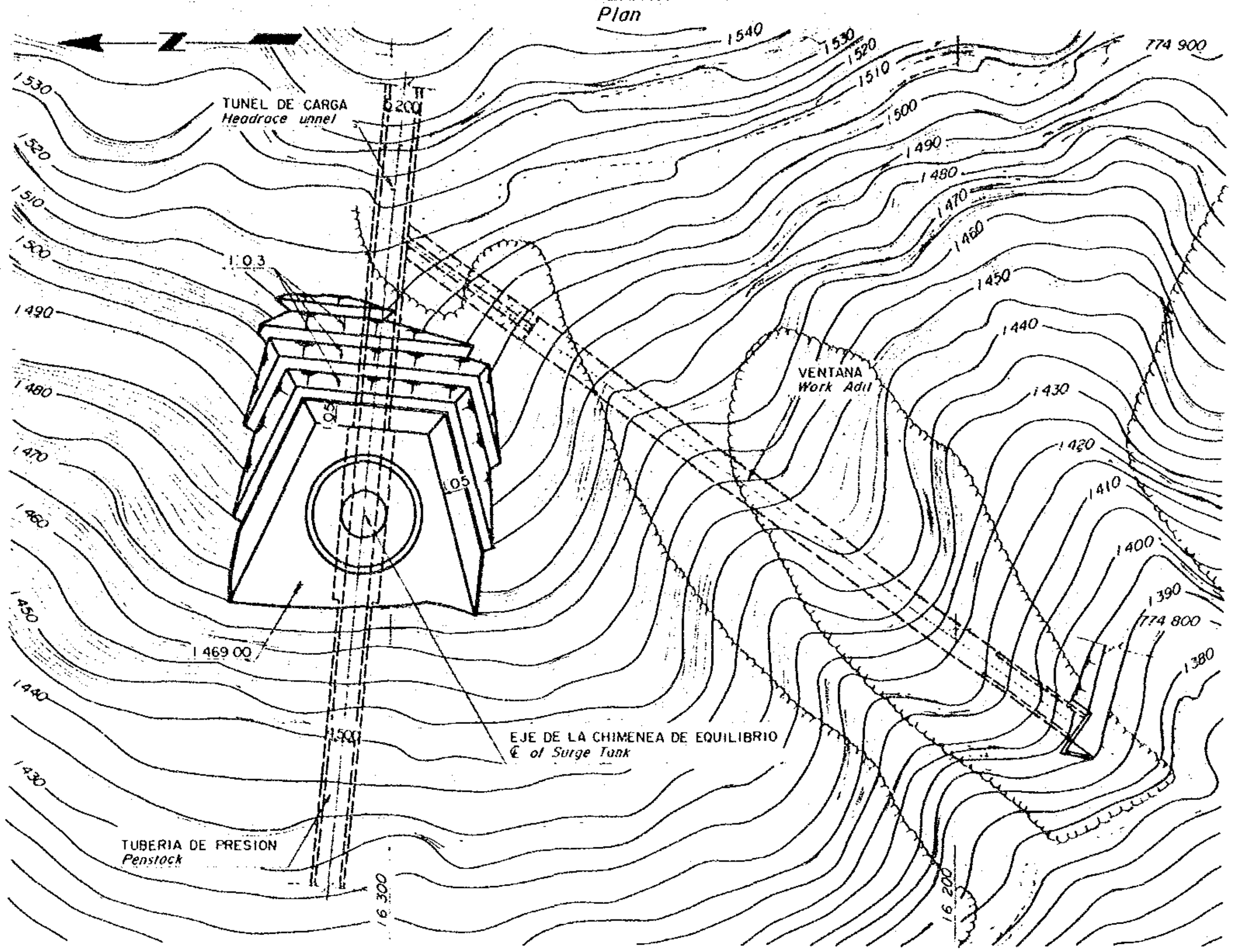

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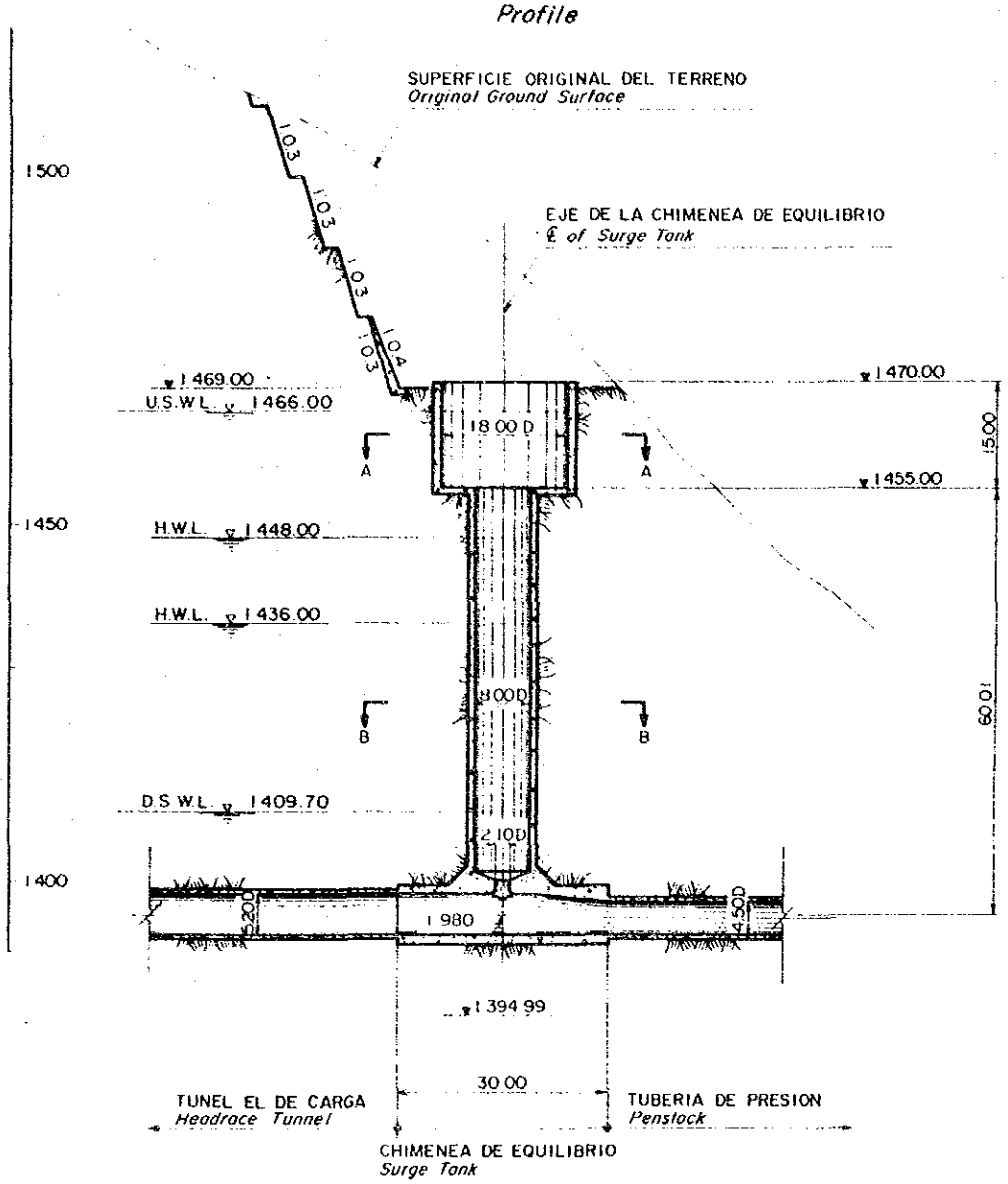

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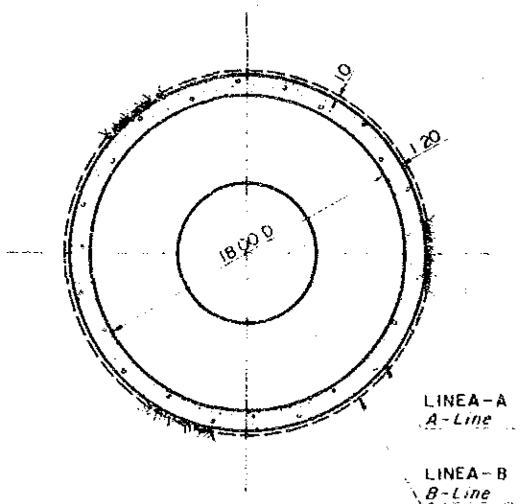

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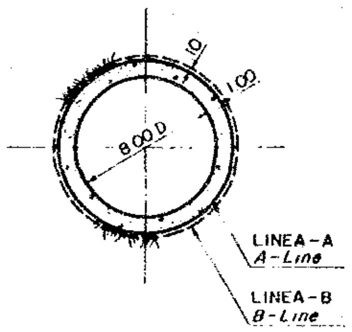

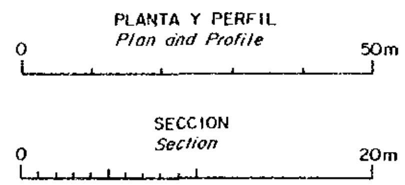

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CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
WATERWAY
SURGE TANK PLAN, PROFILE AND SECTION
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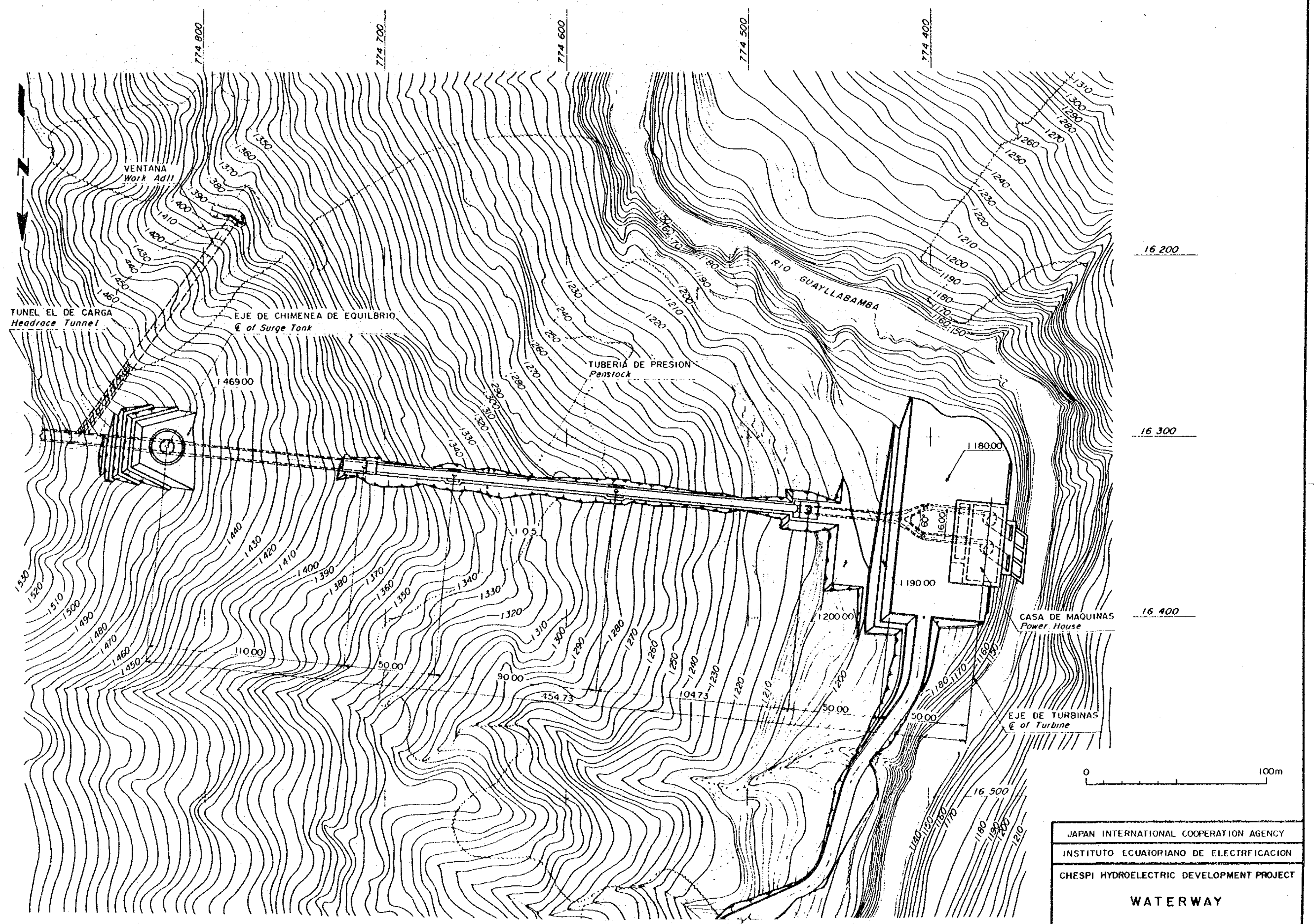

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WATERWAY

PENSTOCK PLAN

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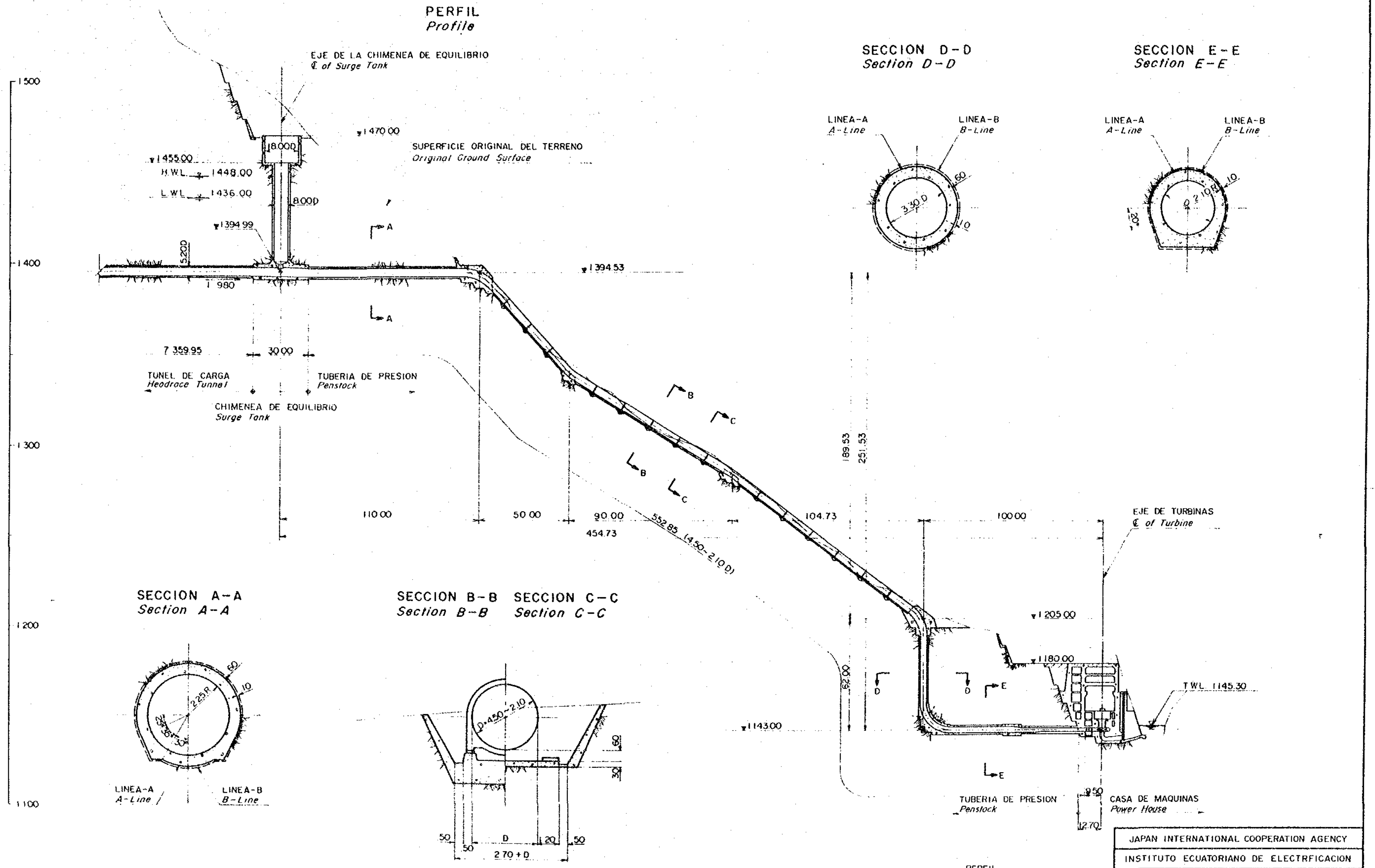

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WATERWAY
PENSTOCK PROFILE AND SECTION
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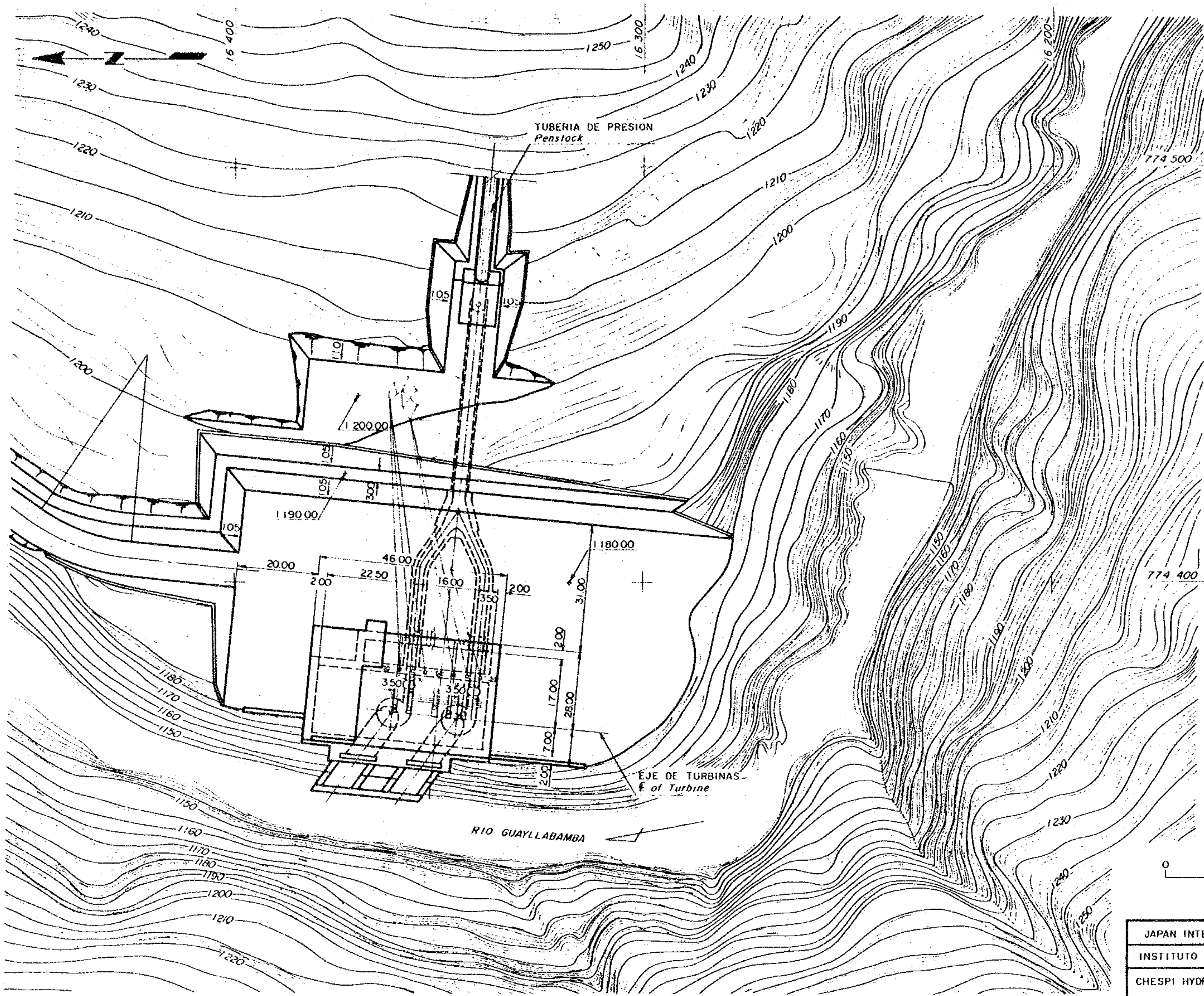

JAPAN INTERNATIONAL COOPERATION AGENCY

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CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

POWER HOUSE

PLAN

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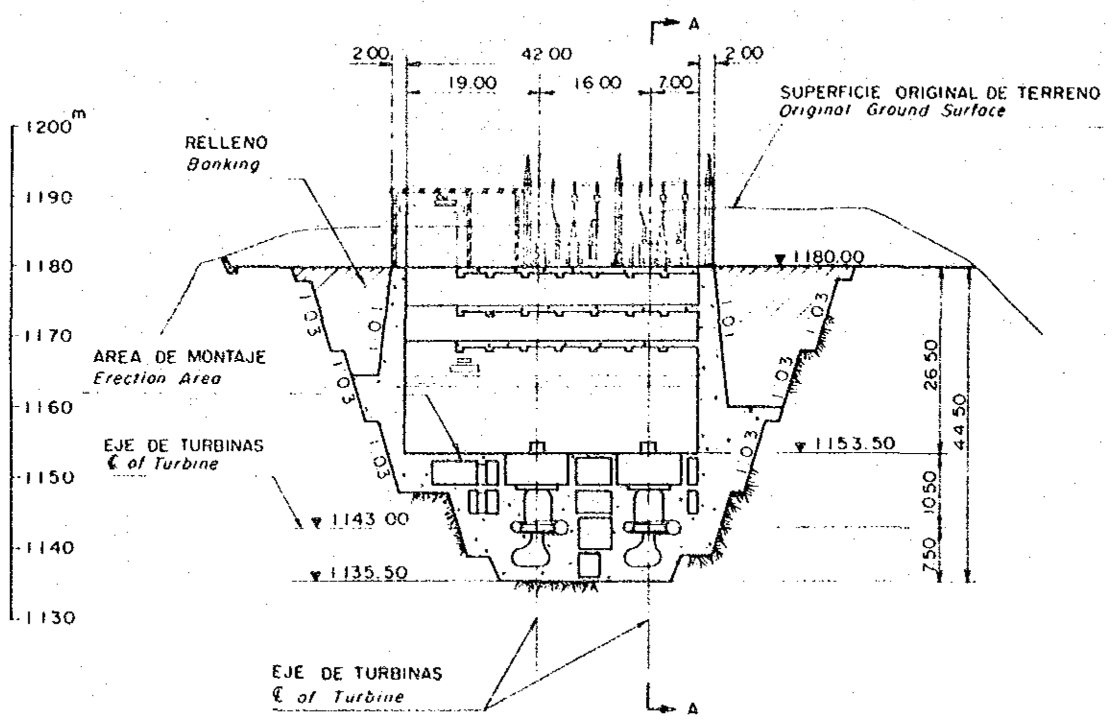
Profile



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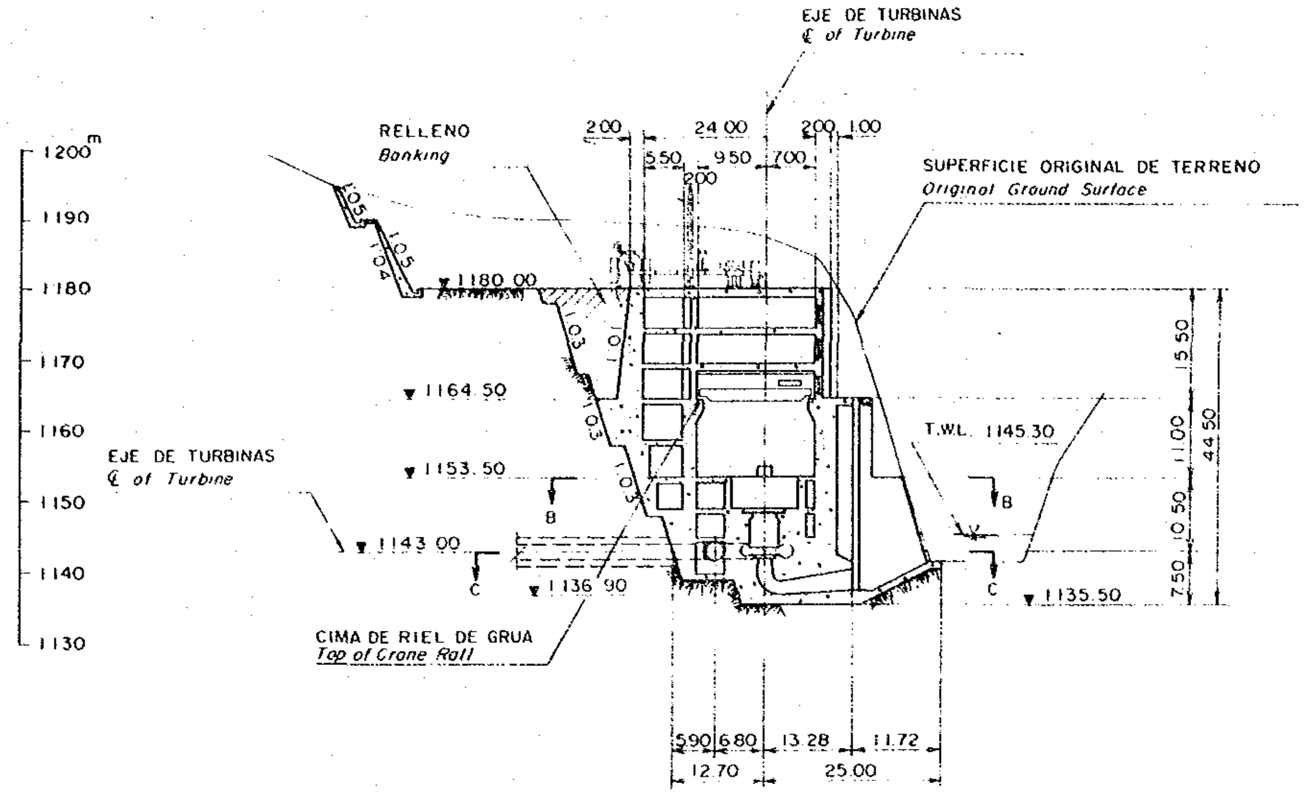
Section A – A



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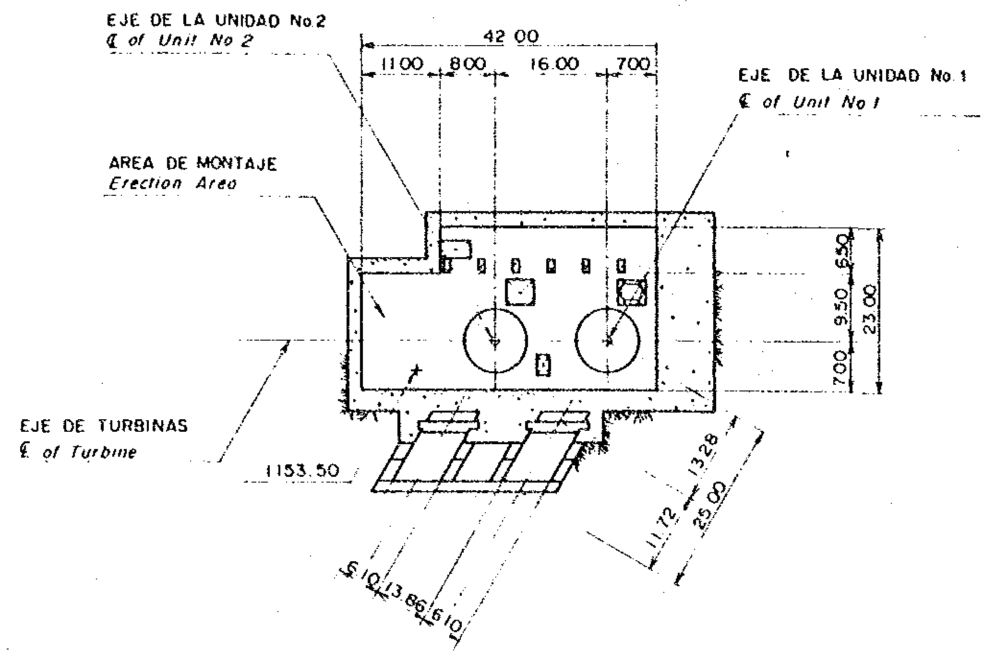

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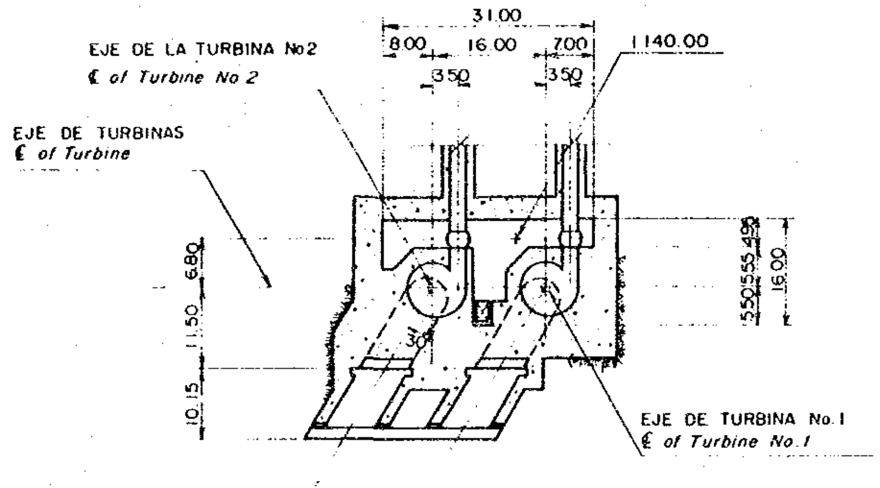
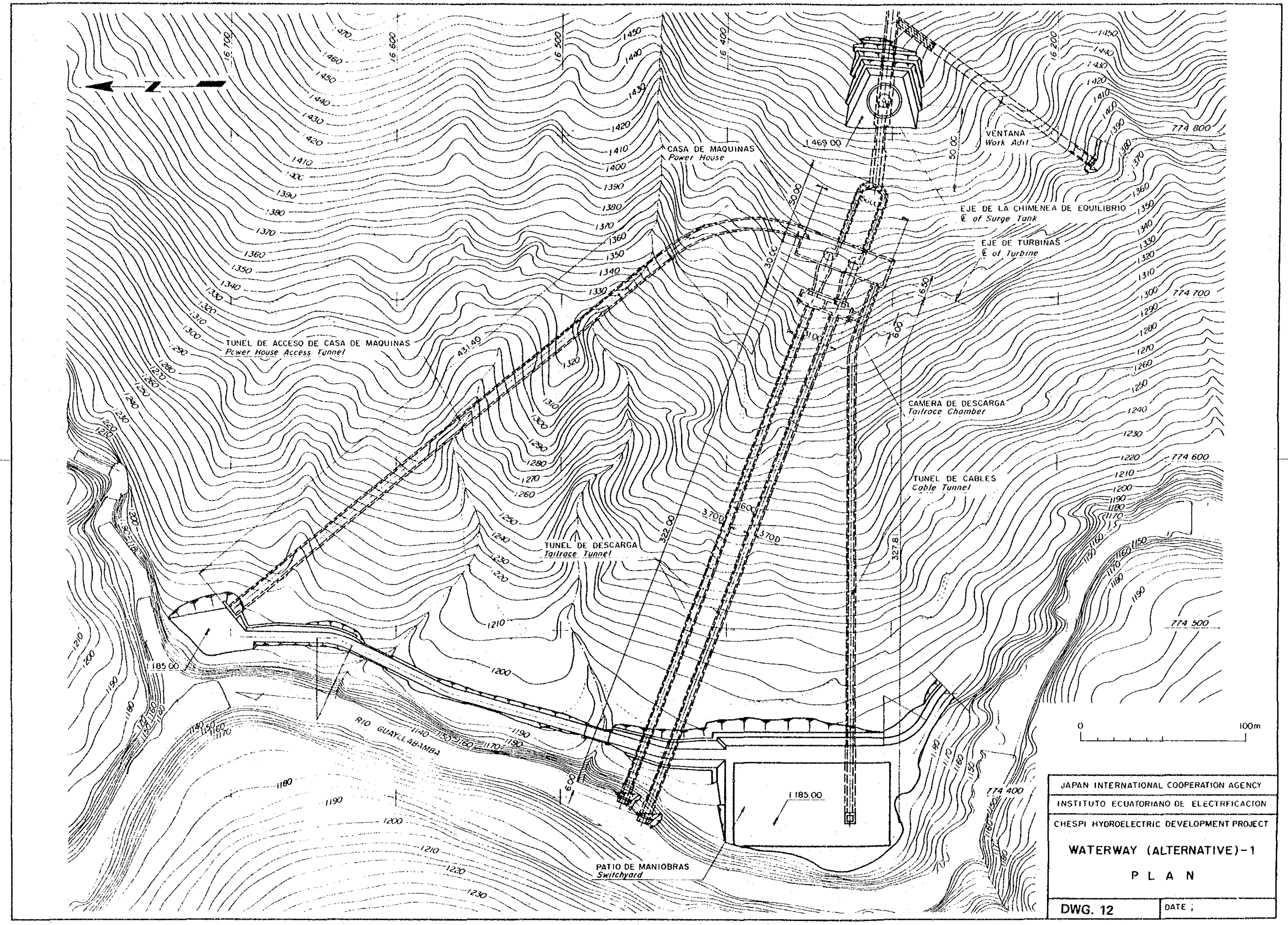
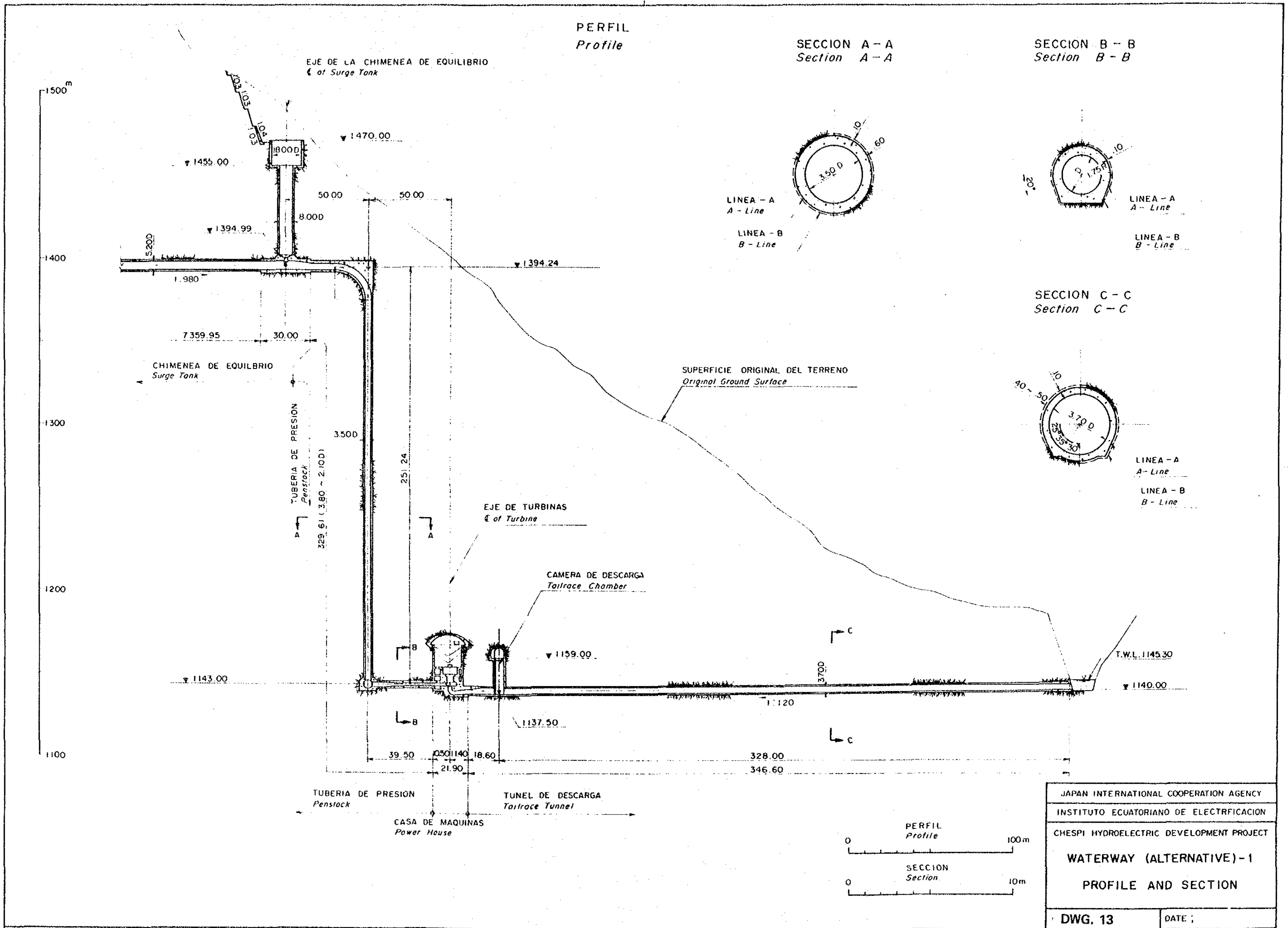


JAPAN INTERNATIONAL COOPERATION AGENCY
INSTITUTO ECUATORIANO DE ELECTRFICACION
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
POWER HOUSE PROFILE AND SECTION
DWG. 11 — DATE ;



CASA DE MAQUINAS
Power House
VENTANA
Work Adit
1469.00
EJE DE LA CHIMENEA DE EQUILIBRIO
℄ of Surge Tank
EJE DE TURBINAS
℄ of Turbine
TUNEL DE ACCESO DE CASA DE MAQUINAS
Power House Access Tunnel
CAMERA DE DESCARGA
Tailrace Chamber
TUNEL DE CABLES
Cable Tunnel
TUNEL DE DESCARGA
Tailrace Tunnel
1185.00
RIO GUAYLLABAMBA
PATIO DE MANIOBRAS
Switchyard
774 800
774 700
774 600
774 500
774 400
0
100m
JAPAN INTERNATIONAL COOPERATION AGENCY
INSTITUTO ECUATORIANO DE ELECTRFICACION
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
WATERWAY (ALTERNATIVE)-1
PLAN
DWG. 12
DATE :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Profile
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Section A – A
SECCION B – B
Section B – B
SECCION C – C
Section C – C
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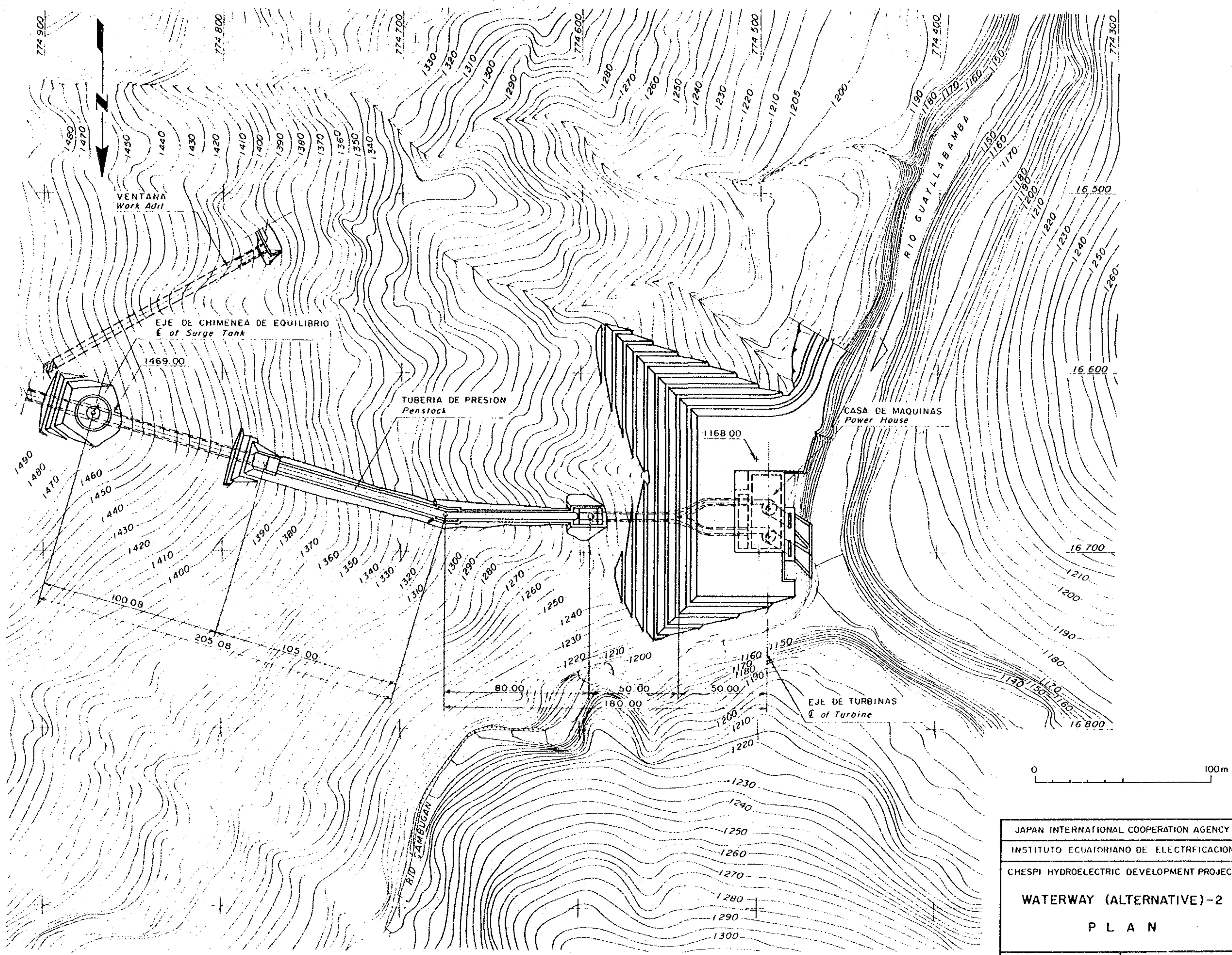
▼1470.00
▼1455.00
▼1394.99
▼1394.24
▼1159.00
▼1143.00
▼1140.00
1137.50
T.W.L. 1145.30
1500m
1400
1300
1200
1100
50.00
50.00
8.000
5.200
1.980
7.359.95
30.00
3.500
251.24
329.61 (3.80 ~ 2.100)
3.700
1:120
39.50
10.50
11.40
18.60
21.90
328.00
346.60
CHIMENEA DE EQUILBRIO
Surge Tank
TUBERIA DE PRESION
Penstock
SUPERFICIE ORIGINAL DEL TERRENO
Original Ground Surface
EJE DE TURBINAS
℄ of Turbine
CAMERA DE DESCARGA
Tailrace Chamber
TUBERIA DE PRESION
Penstock
CASA DE MAQUINAS
Power House
TUNEL DE DESCARGA
Tailrace Tunnel
LINEA – A
A – Line
LINEA – B
B – Line
3.50 D
1.75 R
3.70 D
PERFIL
Profile
0
100m
SECCION
Section
0
10m
JAPAN INTERNATIONAL COOPERATION AGENCY
INSTITUTO ECUATORIANO DE ELECTRFICACION
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
WATERWAY (ALTERNATIVE) - 1
PROFILE AND SECTION
DWG. 13
DATE :



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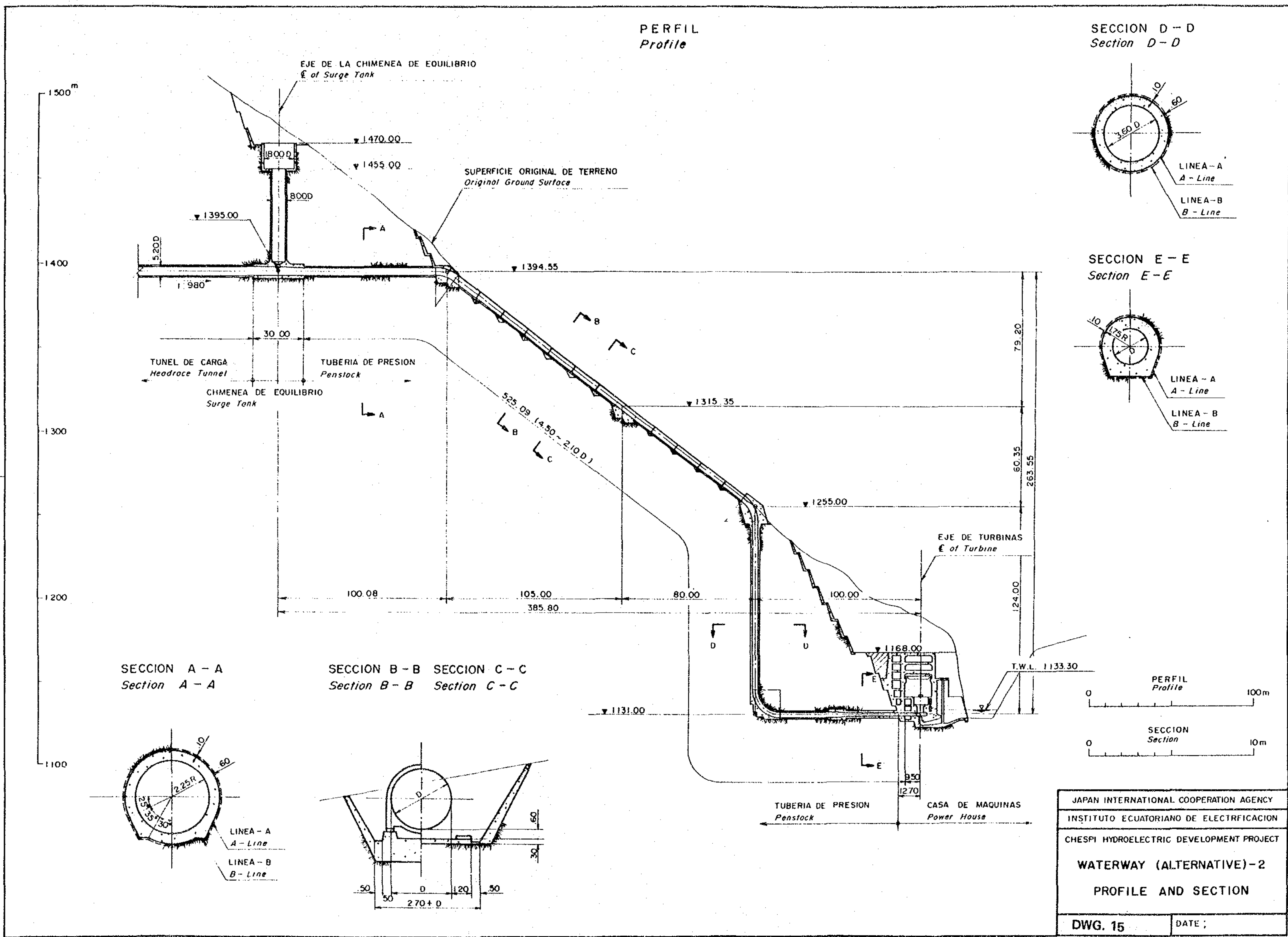
INSTITUTO ECUATORIANO DE ELECTRFICACION

CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

WATERWAY (ALTERNATIVE)-2

PLAN

DWG. 14 | DATE ;



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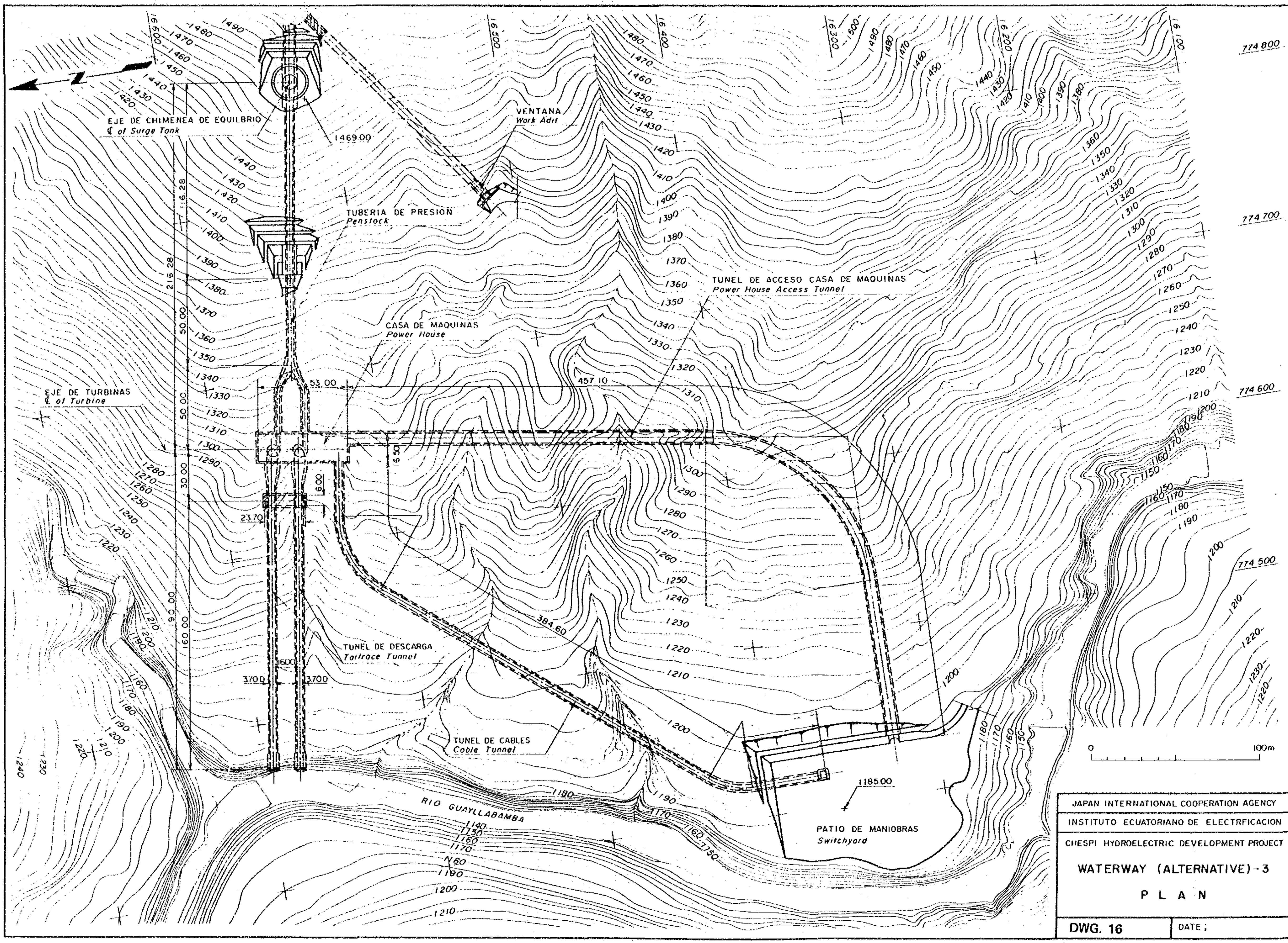
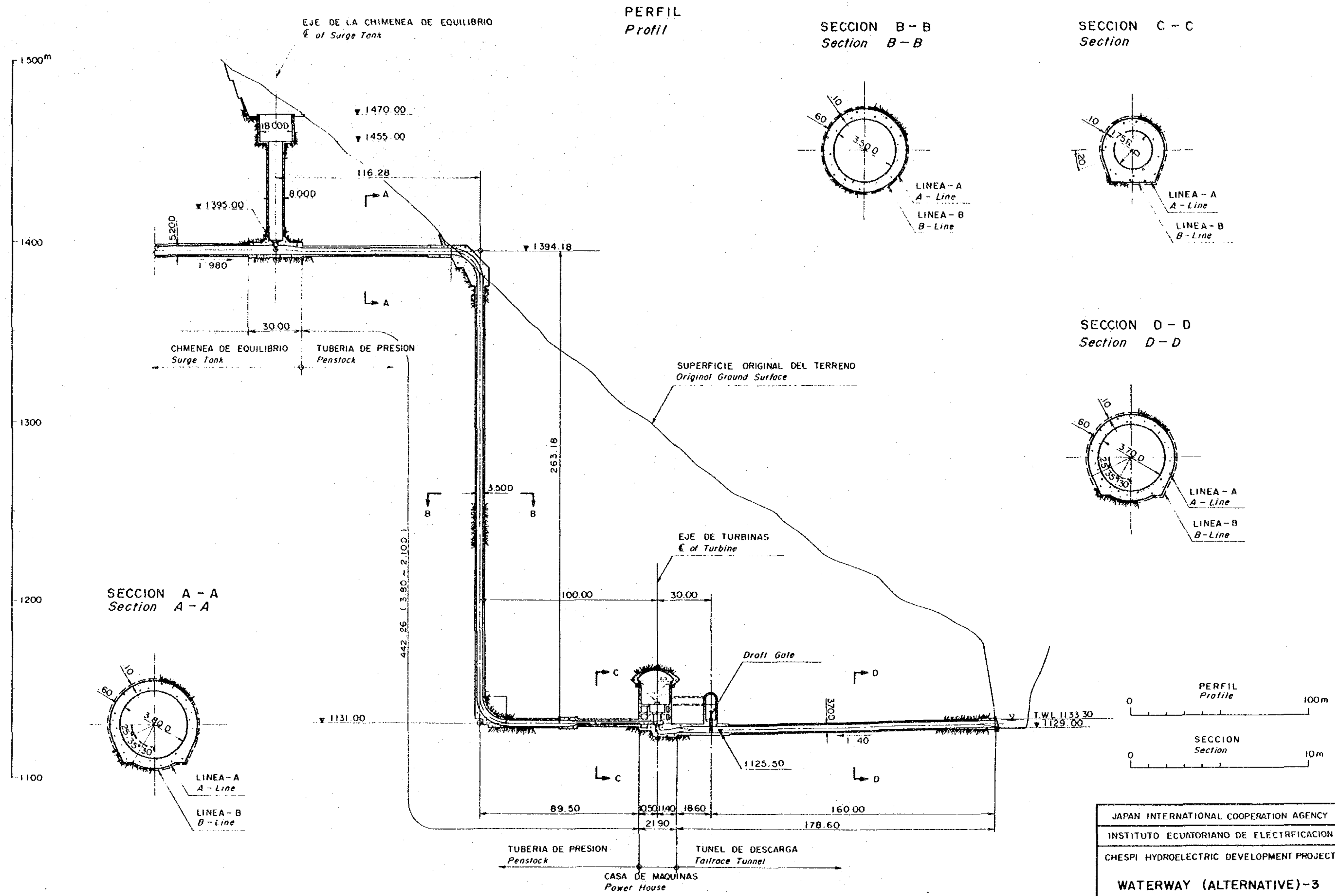
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

WATERWAY (ALTERNATIVE)-2

PROFILE AND SECTION

DWG. 15 | DATE ;


EJE DE CHIMENEA DE EQUILBRIO
℄ of Surge Tank
1469.00
VENTANA
Work Adit
TUBERIA DE PRESION
Penstock
TUNEL DE ACCESO CASA DE MAQUINAS
Power House Access Tunnel
CASA DE MAQUINAS
Power House
EJE DE TURBINAS
℄ of Turbine
53.00
457.10
16.50
16.00
23.70
384.60
TUNEL DE DESCARGA
Tailrace Tunnel
16.00
37.00
37.00
TUNEL DE CABLES
Cable Tunnel
1185.00
PATIO DE MANIOBRAS
Switchyard
RIO GUAYLLABAMBA
116.28
216.28
50.00
50.00
30.00
190.00
160.00
774 800
774 700
774 600
774 500
16 600
16 500
16 400
16 300
16 200
16 100
0
100m
JAPAN INTERNATIONAL COOPERATION AGENCY
INSTITUTO ECUATORIANO DE ELECTRFICACION
CHESPI HYDROELECTRIC DEVELOPMENT PROJECT
WATERWAY (ALTERNATIVE)-3
PLAN
DWG. 16
DATE ;



JAPAN INTERNATIONAL COOPERATION AGENCY

INSTITUTO ECUATORIANO DE ELECTRFICACION

CHESPI HYDROELECTRIC DEVELOPMENT PROJECT

WATERWAY (ALTERNATIVE)-3

PROFILE AND SECTION

DWG. 17	DATE :

CHAPTER 8 PLAN OF TRANSMISSION LINE AND SYSTEM ANALYSIS

CHAPTER 8 PLAN OF TRANSMISSION LINE AND SYSTEM ANALYSIS

CONTENTS

TABLE LIST

FIGURE LIST

CHAPTER 8 PALN OF TRANSMISSION LINE AND SYSTEM ANALYSIS

8.1 Outline of Electric Power System

The electric power systems in Ecuador are being linked into a National Interconnected System by INECEL with the objective of integrated operation throughout the country. In structuring the National Interconnected System, INECEL has adopted 230 kV for main transmission lines and 138 kV for interconnection with provincial areas.

At present, the principal load areas of the north and south, a distance of approximately 330 km, are interconnected by 230-kV transmission lines. It is scheduled for a 230-kV loop system to be structured in 1987. With this loop, the power flow of the transmission line which is toward the north-bound only at present will be corrected, and the outlook is for stability to be improved.

The National Interconnected System in 1987 is shown in Fig. 8-1.

8.2 Power Transmission Scheme

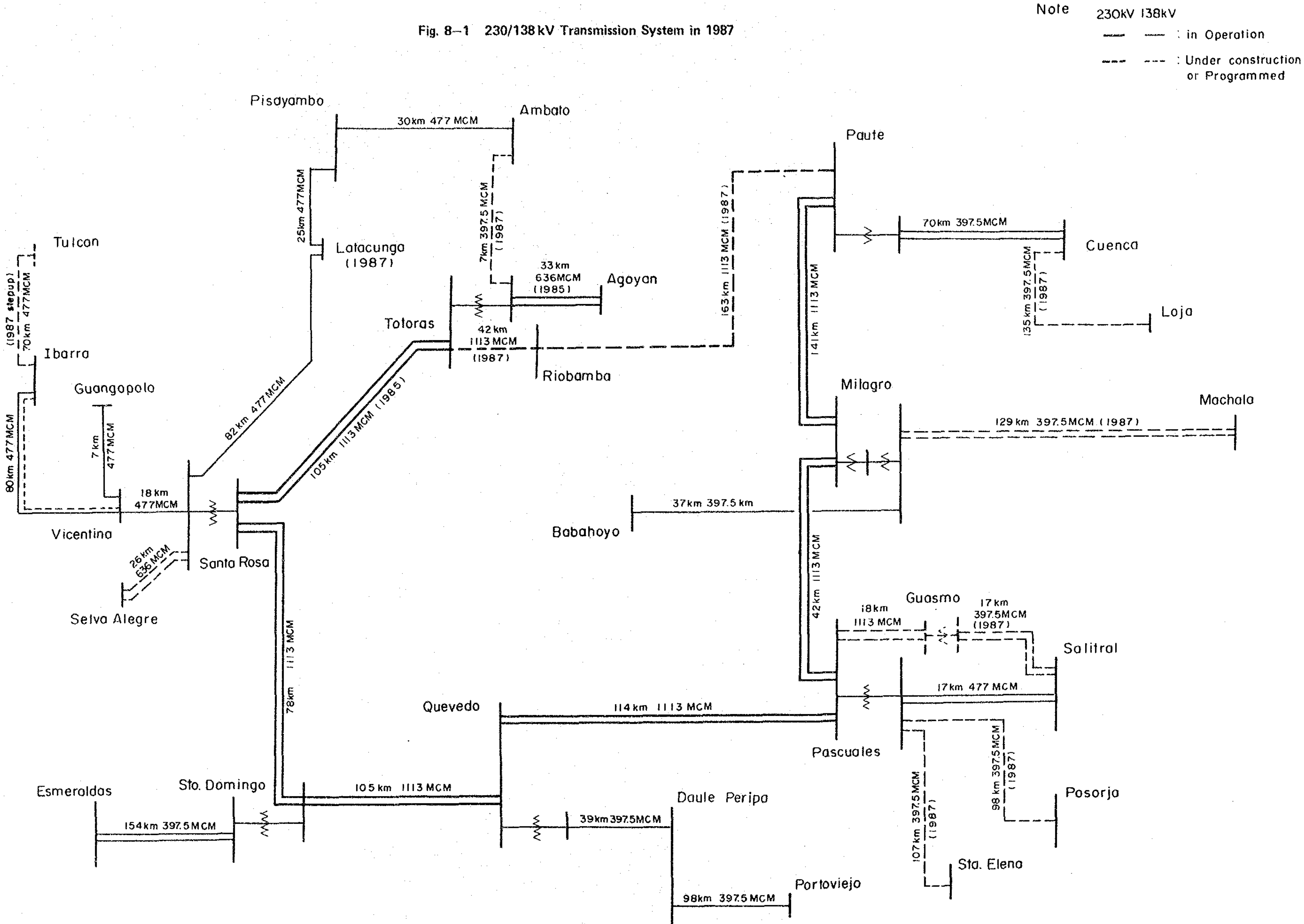
8.2.1 Background of Power Transmission Scheme

Chespi Hydroelectric Power Station is to be located geographically close to the north end of the capital city area.

The demand in the service area of Empresa Electrica Quito S.A. (EEQ) consisting of the capital city of Quito and environs was 215 MW in 1985 and is forecast to reach 386 MW in 1995, these figures both corresponding to 26 percent of maximum demand of the entire country. The installed power generating capacity of the company is presently 187.5 MW (including 85.7 MW of hydro).

On the other hand the demand in the service area of Empresa Electrica Regional del Norte S.A. consisting of the Northern Region was 31 MW in 1985 and is forecast to be 60 MW in 1995, while the power generating facilities of the company amount to 25 MW (including 15.2 MW of hydro).

Fig. 8-1 230/138 kV Transmission System in 1987



Of the power generating facilities owned by the abovementioned two companies the greater part of the thermal facilities consists of medium- to small-sized diesel power plants which are scheduled to be successively scrapped in the future. Electric power matching the demand increase will be purchased at substations of the National Interconnected System of INECEL.

With the situation being such, the 167-MW output of Chespi Hydroelectric Power Station would meet 37.4 percent of the abovementioned demand in 1995.

These circumstances were taken into consideration in formulation of the power transmission plan, along with which transmission voltage, conductor size, number of circuits, etc., were studied in accordance with the transmission line design standards of INECEL.

8.2.2 Examination of Power Transmission Scheme

The examination was carried out according to the items below. An examination of power system analysis is made in 8.3.

a) Selection of Power Transmission Pattern

INECEL is presently studying an expansion plan for the National Interconnected System, and ther is a necessity for the Chespi Transmission Line to be in conformity with this plan. Although the present situation is that INECEL's future plans have not yet become definite, the six locations below are conceivable for lead-in of the Chespi Transmission Line in view of geographical location and other transmission plans, and the six patterns described below were selected.

1 Santa Rosa Substation
2 Selva Alegre Substation
3 Calderon Substation
4 San Antonio Substation
5 Ibarra Substation
6 Santa Rosa (230 kV)

It was considered that 3 to 5 would be new substations constructed by INECEL with interconnection with EEQ made by connecting lines.

Before start-up of Chespi Power Station, it is scheduled for five new sections of transmission lines to be built for stable power supply to the capital city of Quito and environs and to the Northern Region. (Table 8-1)

Table 8-1 Example of Transmission Plan

Section	Distance (km)	Voltage (kv)	Number of Unit	Conductor (MCM)
Santa Rosa ~ San Antonio	42	138	2	477
Santa Rosa ~ Selva Alegre	26	138	2	636
Selba Alegre ~ Calderon	20	138	2	636
Calderon ~ San Antonio	8	138	2	636
Vicentina ~ Calderon	18	138	1	477

b) Selection of Voltage and Conductor Size

At present, the conductor sizes by voltage adopted by INECEL which can transmit the power generated at Chespi are as follows:

138 kV: 266 MCM, 397.5 MCM, 477 MCM, 636 MCM
230 kV: 477 MCM, 556 MCM, 636 MCM, 1113 MCM

In the present study, the economics and local nature of demand, etc., were considered, and 138-kV transmission lines were adopted.

i) Number of Circuits

According to the standards of INECEL multiple conductors are not to be used. Consequently, from the standpoint of transmission line thermal capacity, 138 kV was made double circuit and 230 kV single circuit.

ii) Study of Economics of Conductor

The conductor to be applied to the Chespi Transmission Line was selected upon comparisons of construction costs and transmission losses. (Table 8-2)

Furthermore the conductor adopted was one that was according to the use criteria of INECEL.

1 Conductor Types Studied and Constants

	(100 MVA Base)
. 397.5 MCM (201 mm^2)	0.084 % /km.cct
. 477 MCM (242 mm^2)	0.070 % /km.cct
. 636 MCM (322 mm^2)	0.050 % /km.cct

2 Transmission Line Construction Cost and Annual Cost Factor

. 397.5 MCM	US$76.94 x 10^3/km
. 477 MCM	US$86.85 x 10^3/km
. 636 MCM	US$106.6 x 10^3/km

Annual cost factors were all assumed to be 10 percent.

3 Transmission Loss Evaluation Unit Cost

The unit costs as of March 1985 employed by INECEL were used.

. kW loss unit cost	US$125.80/kW/yr
. kW loss unit cost	US$64.97/MWh

4 Transmission Loss Factor and Load Factor

- Load factor Ld = 0.95
- Loss factor Ls = 0.3 Ld + 0.7 Ld^2

Table 8-2 Comparison of 138 kV Transmission Cost

(10^3 U S $)

Item	Transmission Length	MCM 397.5	MCM 477	MCM 636
Transmission losses	22.0km	1095	912	653
Transmission Anual Cost	22.0km	169	191	235
Total Anual Cost	22.0km	1264	1103	888

Note) The unit construction costs employed by INECEL were used for the annual cost of the transmission line, and calculations were made with annual cost factor as 10 percent.

Based on the above study, the transmission line conductor selected was the economically advantageous 636 MCM.

8.2.3 Selection of Optimum Transmission Scheme

The results of studies on the various transmission patterns are shown based on Table 8-3. Further, comparisons of system stability are shown below, but there are not problems of stability due to operation of Chespi Power Station in the various patterns.

(Pattern 1)

This is a plan for leading in 138 kV, 2 cct, at Santa Rosa Substation in the outskirts of Quito. This pattern is of poor economic nature since the transmission line length is greatest.

(Pattern 2, Pattern 3)

In both cases, a substation is to be provided by INECEL in the neighborhood of an EEQ substation and electric power supplied by 138 kV, 2 cct. In this case, including Pattern 4, there will be the following advantages from the standpoint of the power system.

In effect, the National Interconnected System of INECEL is composed mainly of hydroelectric power stations in the southern and central part of the country and large-scale thermal power stations in the coastal region with Paute Molino Power Station as the big station, power supply to the capital area and the Northern Region being done through Santa Rosa Substation at the south end of Quito City. Under such circumstances, in the event there should be a major fault at Santa Rosa Substation or the 230-kV system, the capital area and the Northern Region would suffer a total power failure, and it is feared that the functions of the national capital city would be paralyzed.

To counter this, if Chespi Hydroelectric Power Station were to be connected to a 138-kV transmission line in the vicinity of the capital Quito, it will be possible for important loads of the capital city area to continue to be supplied by Chespi alone or together with hydroelectric power stations of EEQ even if a system fault such as mentioned above were to occur.

However, the systems of Pattern 2 and Pattern 3 would be separated from the National Interconnected System (SNI) of INECEL, which would hinder integrated operation of the SNI, and therefore, this will be undesirable.

The length of transmission line between Chespi and Calderon is a little long because of being shifted to avoid the equator monument, the quarry site, the villages and so on.

(Patter 4)

A substation would be provided at San Antonio in the northern part of the the capital and a national interconnected transmission line, and 138 kV, 2 cct, from Chespi Power Station are to be taken in. In this case, there would be the advantages in system operation mentioned above and also the advantage that loads of Ibarra and northern parts can be met. Furthermore, the annual cost is the lowest of the six patterns.

(Pattern 5)

This is a plan to bring in 138 kV, 2 cct, to the existing Ibarra Substation in the northern part of the capital. In this case, there will be the advantage that loads of Ibarra and further north can be met most effectively, but the transmission distance would be long and the annual cost would be the second highest of the six patterns.

(Pattern 6)

This is a plan for leading in 230 kV, 1 cct, at Santa Rosa substation in the outskirts of Quito. This pattern is of poor economic nature since the transmission line length is greatest, and the effect on this system will be great at time of faulting.

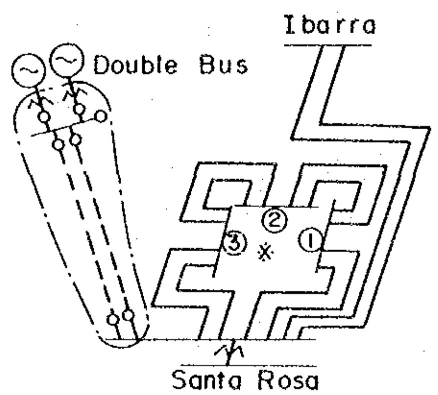
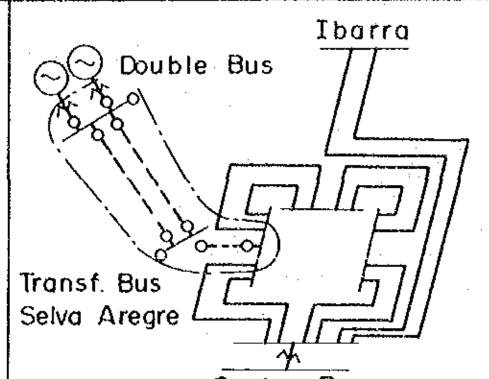
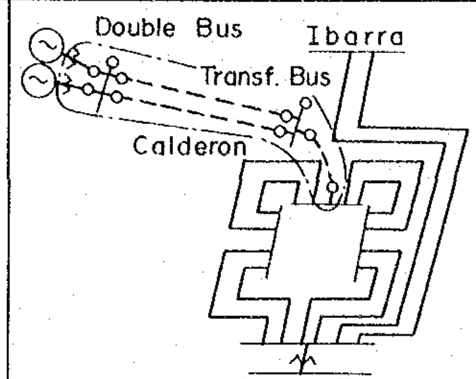
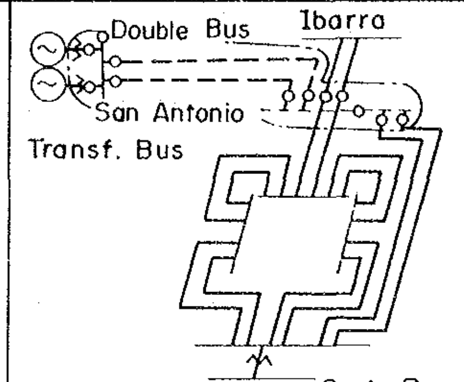
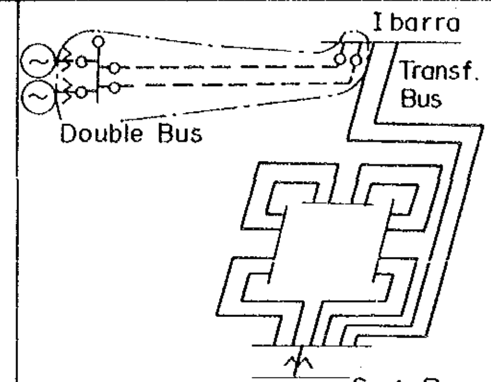
As a result of the above study, Pattern 4, which is the most favorable from the standpoint of system operation and is of the lowest annual cost, is recommended as the transmission line for Chespi.

8.3 System Analysis

8.3.1 Objective

Calculations for selecting the optimum power transmission method and detailed calculations concerning the method selected are to be performed regarding transmission of the maximum 167 MW of electric power generated at Chespi Hydroelectric power Station.

Table 8—3 Economic Comparison of Transmission Patterns

Transmission pattern / Item	(Pattern-1) 138 kV Chespi - Santa Rosa	(Pattern-2) 138 kV Chespi - Selva Aregre	(Pattern-3) 138 kV Chespi - Calderon	(Pattern-4) 138 kV Chespi - San Antonio	(Pattern-5) 138 kV Chespi - Ibarra	(Pc Ch
Power System Diagram						
Transmission line Voltage Length to be constructed Number of circuits Size of conductor	138 kV 67.5 km 2 cct 636 MCM	138 kV 43.5 km 2 cct 636 MCM	138 kV 33.5 km 2 cct 636 MCM	138 kV 22 km 2 cct 636 MCM	138 kV 56.5 km 2 cct 636 MCM	
Construction cost Annual cost	7195 x 10^3 720 x 10^3	4637 x 10^3 464 x 10^3	3571 x 10^3 357 x 10^3	2345 x 10^3 235 x 10^3	6023 x 10^3 602 x 10^3	
Station equipments Step-up Transf.	1050 x 10^3	1050 x 10^3	1050 x 10^3	1050 x 10^3	1050 x 10^3	
138kV outline feeder	1650 x 10^3	2270 x 10^3	2270 x 10^3	2740 x 10^3	1650 x 10^3	
Construction cost Annual cost	2700 x 10^3 324 x 10^3	3320 x 10^3 398 x 10^3	3320 x 10^3 398 x 10^3	3790 x 10^3 455 x 10^3	2700 x 10^3 324 x 10^3	
Transmission losses Peak power loss Annual energy loss	4.71 MW 593 x 10^3 21785 MWh 1415 x 10^3	3.03 MW 381 x 10^3 14028 MWh 911 x 10^3	2.34 MW 294 x 10^3 10823 MWh 703 x 10^3	1.53 MW 193 x 10^3 7080 MWh 460 x 10^3	3.94 MW 496 x 10^3 18220 MWh 1184 x 10^3	2.C 957
Annual cost	2008 x 10^3 (1712 x 10^3)	1292 x 10^3 (1102 x 10^3)	997 x 10^3 (851 x 10^3)	653 x 10^3 (556 x 10^3)	1680 x 10^3 (1433 x 10^3)	
Total Construction Cost	9895 x 10^3	7957 x 10^3	6891 x 10^3	6135 x 10^3	8723 x 10^3	
Total Annual Cost	3052 x 10^3 (2756 x 10^3)	2154 x 10^3 (1964 x 10^3)	1752 x 10^3 (1606 x 10^3)	1343 x 10^3 (1246 x 10^3)	2606 x 10^3 (2359 x 10^3)	(

Note : (1) : Scope of construction cost for economical comparison.

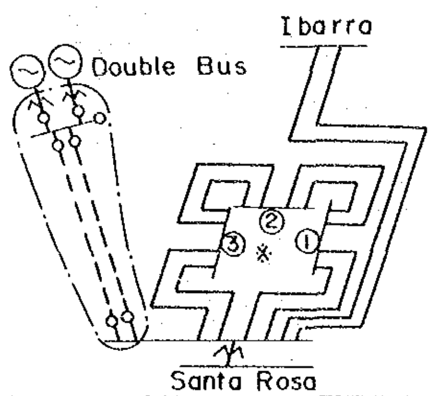
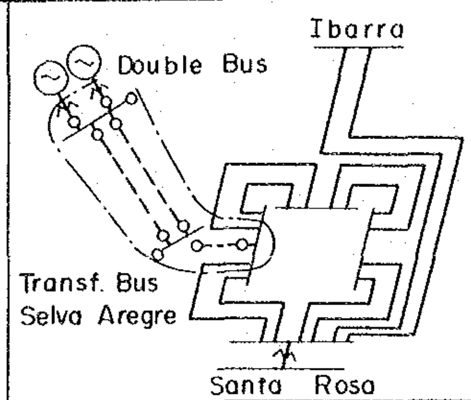
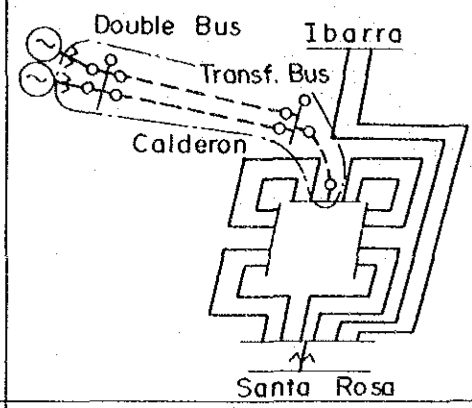
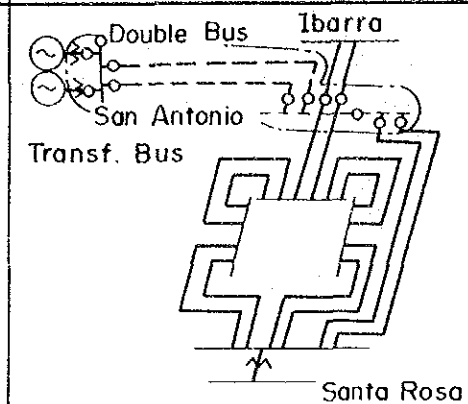
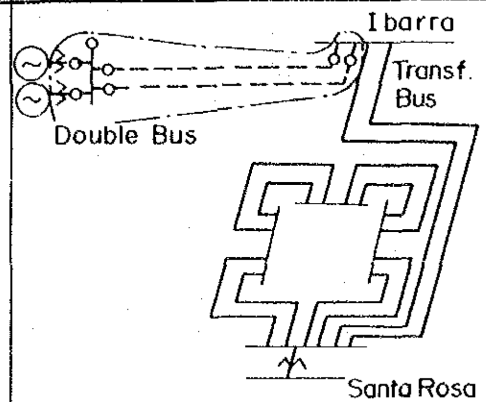
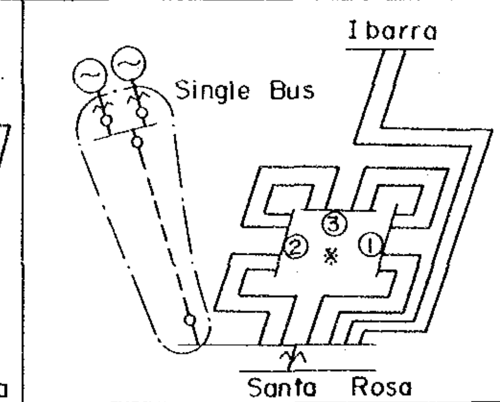
(2) Annual factor
transmission line 10%
station equipment 12%

(3) Cost of power loss and energy loss
125.80 US$/kW/year (120.45 US$/kW/year
64.97 US$/MWh 52.56 US$/MWh)

※ ① Vicentina S.S (INECEL)
② Selva Alegre S.S (EEQ)
③ Calderon S.S (EEQ)

Table 8–3 Economic Comparison of Transmission Patterns

(US$)

smission pattern	(Pattern-1) 138 kV Chespi - Santa Rosa	(Pattern-2) 138 kV Chespi - Selva Aregre	(Pattern-3) 138 kV Chespi - Calderon	(Pattern-4) 138 kV Chespi - San Antonio	(Pattern-5) 138 kV Chespi - Ibarra	(Pattern-6) 230 kV Chespi - Santa Rosa
er System gram						
ne						
	138 kV	138 kV	138 kV	138 kV	138 kV	230 kV
onstructed	67.5 km	43.5 km	33.5 km	22 km	56.5 km	675 km
rcuits	2 cct	2 cct	2 cct	2 cct	2 cct	1 cct
ctor	636 MCM	636 MCM	636 MCM	636 MCM	636 MCM	1,113 MCM
cost	7195×10^3	4637×10^3	3571×10^3	2345×10^3	6023×10^3	6466×10^3
	720×10^3	464×10^3	357×10^3	235×10^3	602×10^3	647×10^3
nts						
sf.	1050×10^3	1050×10^3	1050×10^3	1050×10^3	1050×10^3	1350×10^3
feeder	1650×10^3	2270×10^3	2270×10^3	2740×10^3	1650×10^3	1440×10^3
cost	2700×10^3	3320×10^3	3320×10^3	3790×10^3	2700×10^3	2790×10^3
	324×10^3	398×10^3	398×10^3	455×10^3	324×10^3	335×10^3
osses						
oss	4.71 MW 593×10^3	3.03 MW 381×10^3	2.34 MW 294×10^3	1.53 MW 193×10^3	3.94 MW 496×10^3	2.07 MW 260×10^3
loss	21785 MWh 1415×10^3	14028 MWh 911×10^3	10823 MWh 703×10^3	7080 MWh 460×10^3	18220 MWh 1184×10^3	9574 MWh 622×10^3
	2008×10^3	1292×10^3	997×10^3	653×10^3	1680×10^3	822×10^3
	(1712×10^3)	(1102×10^3)	(851×10^3)	(556×10^3)	(1433×10^3)	(752×10^3)
ion Cost	9895×10^3	7957×10^3	6891×10^3	6135×10^3	8723×10^3	9256×10^3
Cost	3052×10^3 (2756×10^3)	2154×10^3 (1964×10^3)	1752×10^3 (1606×10^3)	1343×10^3 (1246×10^3)	2606×10^3 (2359×10^3)	1864×10^3 (1734×10^3)

(1) : Scope of construction cost for economical comparison.

(2) Annual factor
transmission line 10%
station equipment 12%

(3) Cost of power loss and energy loss
125.80 US$/kW/year (120.45 US$/kW/year
64.97 US$/MWh 52.56 US$/MWh)

※ ① Vicentina S.S (INECEL)
② Selva Alegre S.S (EEQ)
③ Calderon S.S (EEQ)

8.3.2 System Calculation Conditions

The conditions for performing system calculations were set as follows:

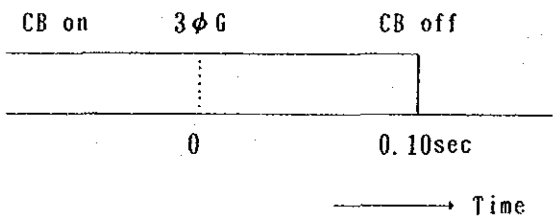
a) Power Flow Voltage Calculations

System voltage: 95 - 105%
Generator operating voltage: 100±5%
Transformer tap ratio: 100±10%
Load power factor: 0.95

b) Stability Calculations

Calculations of stability were performed applying the conditions of 3-phase line-to-ground fault (3ϕG) and no reclosing in accordance with the standards of INECEl.

- Fault sequence



c) Short Circuit Current Calculation

Generator reactance: transient reactance (Xd)
Transformer tap ratio: 100%

Generator parallel condition: case of all generators parallel as shown in Table 8-4.

d) System Structure

The system structure was considered to be the transmission network planned by INECEL for 1995. The impedance map is shown in Fig. 8-16. Regarding the generator constants, it was not possible to obtain them from INECEL, but since there would be little effect on results, general values of Japan were used.

Table 8-4 Load Forecast for Each Substation of S.N.I.
(Peak Power Demand)

Substation	Voltage (kV)	1985		1995	
		MW	MVav	MW	MVav
TULCAN	138/69	31.5	10.4	13.3	4.4
IBARRA	138/34.5			21.4	7.0
IBARRA	138/69	–	–	25.7	8.4
STA ROSA	138/46	214.8	55.6	196.3	64.5
VICENTINA	138/46				
SELVA ALEG	138/46	–	–	63.3	20.8
CALDERON	138/46	–	–	126.2	41.5
LATACUNGA	138/69	–	–	30.2	9.9
AMBATO	138/69	69.3	22.8	15.9	5.2
TOTORAS	138/69	–	–	27.0	8.9
RIOBAMBA	23.4 230/69	–	–	61.6	20.2
STO DOMINGO	13.3 138/69	13.0	4.3	23.9	7.9
ESMERALDAS	138/69	25.0	8.2	45.3	14.9
QUEVEDO	138/69	8.8	2.9	15.6	5.1
PORTOVIEJO	138/69	40.1	13.2	66.5	21.9
PASCUALES	138/69	68.0	22.4	151.3	49.7
SALITRAL	138/69	274.8	90.3	240.0	8.0
GUASMO	138/69	–	–	248.1	81.5
STA ELENA	138/69	–	–	40.0	3.1
POSORJA	138/69	–	–	7.8	2.6
MILAGRO	230/69	26.4	8.7	34.4	11.3
BABAHOYO	138/69			16.9	5.6
MACHALA	138/69	–	–	47.4	15.6

Substation	Voltage (kV)	1985		1995	
		MW	MVav	MW	MVav
C U E N C A	138/69	47.0	15.4	70.7	23.2
L O J A	138/69	–	–	22.0	7.2
L I M O N	138/69	–	–	6.2	2.0
Total	–	818.7	254.2	1617.0	531.3

e) Demand

Power demands at the principal substations were considered with power factor of 0.95, and estimates were made as shown in Table 8-4 based on the forecasts of INECEL.

8.3.3 Results of Power Transmission Pattern Calculations

System calculations were performed on the various power transmission patterns described in 8.2 in order to select the optimum power transmission scheme.

a) Power Flow and Voltage Calculations

The results of calculations on power flows and voltages of the various patterns are given in Fig. 8-2.

In case of transmission according to Pattern 1, all of the power generated at Chespi will be transmitted to Quito, and none of it would be sent out to the 230-kV system. The loads of the 230/138-kV transformers will be increased approximately 150 MW compared with the other patterns. Since the present transformer capacity is 375 MVA (FOA), it will be necessary to increase this capacity. In this case, the voltage at Ibarra Substation will be 93.0 percent, the lowest in all patterns, and a measure to maintain voltage will become necessary.

In the cases of Patterns 2 and 3, there will be no problem with either voltage or power flow, but since the transmission distances wil be long compared with Pattern 4, the capacity to maintain voltages in the system north of Quito will be lowered.

The case of Pattern 5 is advantageous from the standpoint of voltage at Ibarra Substation. The transmission loss of Chespi will be greatest until demand north of Ibarra Substation increases.

b) Stability Calculations

The location of 3-phase line-to-ground fault occurrence applied to transient stability calculations was taken to be the outgoing end of Chespi Power Station for every one of the patterns. Further, the basic generators were taken to be Paute A, B (Molino) for all patterns.

The fault locations and swing curves of generators in the various patterns are shown in Figs. 8-3 to 8-8.

According to transient stability calculations, the swing of Chespi Power Station will be affected by transmission line impedance, and the swing is greatest in Pattern 5, but is in the range of maximum amplitude 44.5 to -24.1 at initial phase angle -4.8, and hence there will be stability. The swing of Pattern 4 is the smallest and provides favorable results. Swing amplitudes are small for generators in the other patterns and since synchronous states are maintained, it may be said there is no problem about stability with the transmission patterns compared.

8.3.4 Analysis of Chespi Power Transmission System

Calculations were made of the electric power system of lead-in of the Chespi Transmission Line to San Antonio Substation by 138 kV, 2 cct, and verification of the transient stabilities of the individual generators was done.

a) Power Flow Calculations

The National Interconnected System (SNI) of Ecuador presently extends north-south in the form of interconnection with the Quito district which is the major load area, while it is scheduled for a loop to be structured with a 230-kV transmission line to be completed in 1987. Because of this, in spite of demand having increased by 1995, the transmission line power flow will be lessened and exceeding of installed capacity will not occur (Figs. 8-9,8-10).

Fig. 8–2 Power Flow Diagrams of Chespi Transmission Patterns

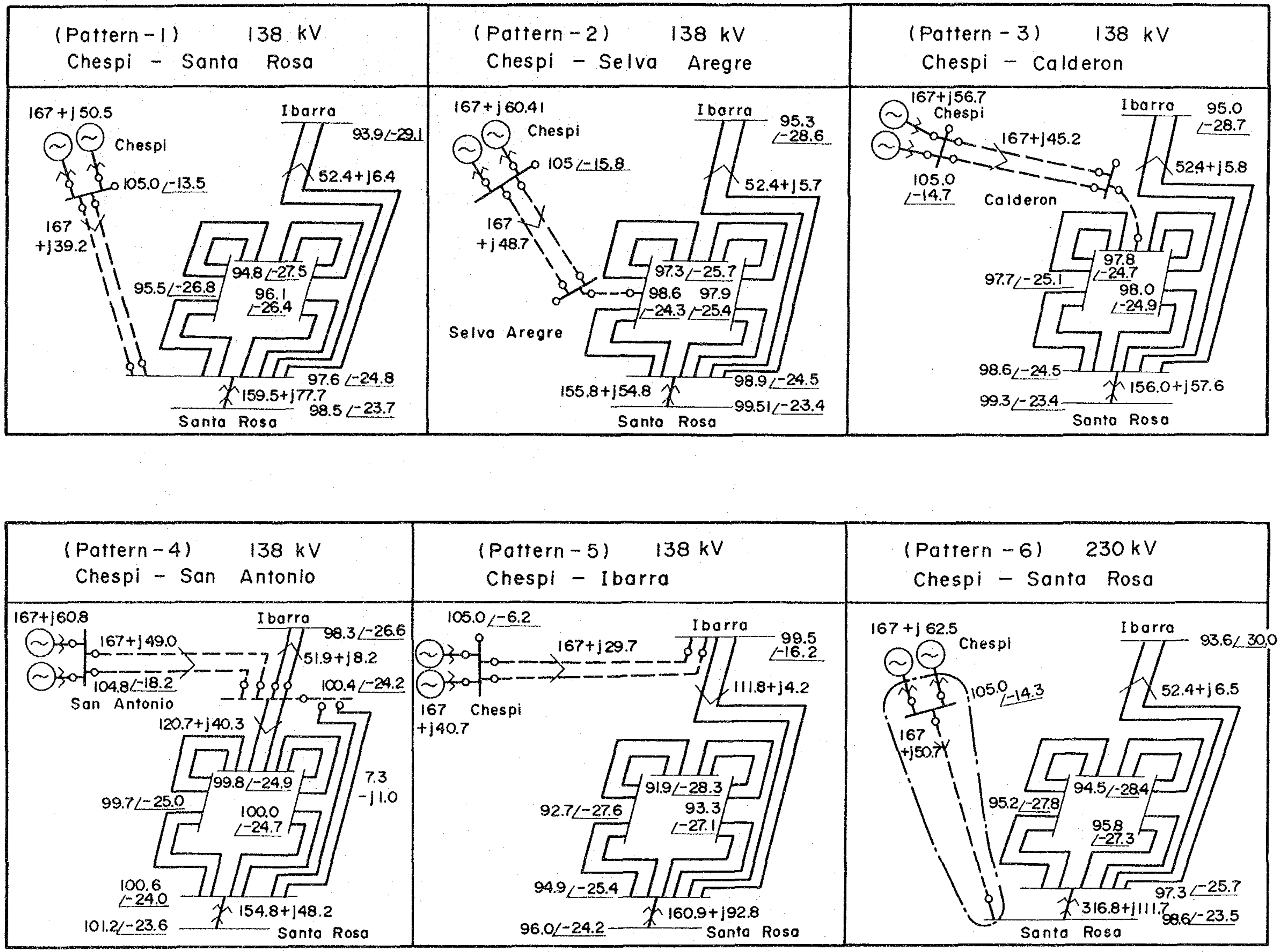
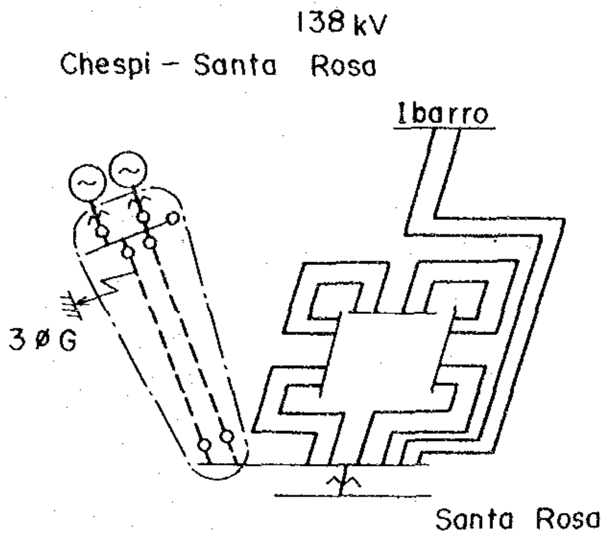


Fig. 8-3 Transient Stability of Pattern — 1



CHESPI PROJECT 1995 PATTERN-1

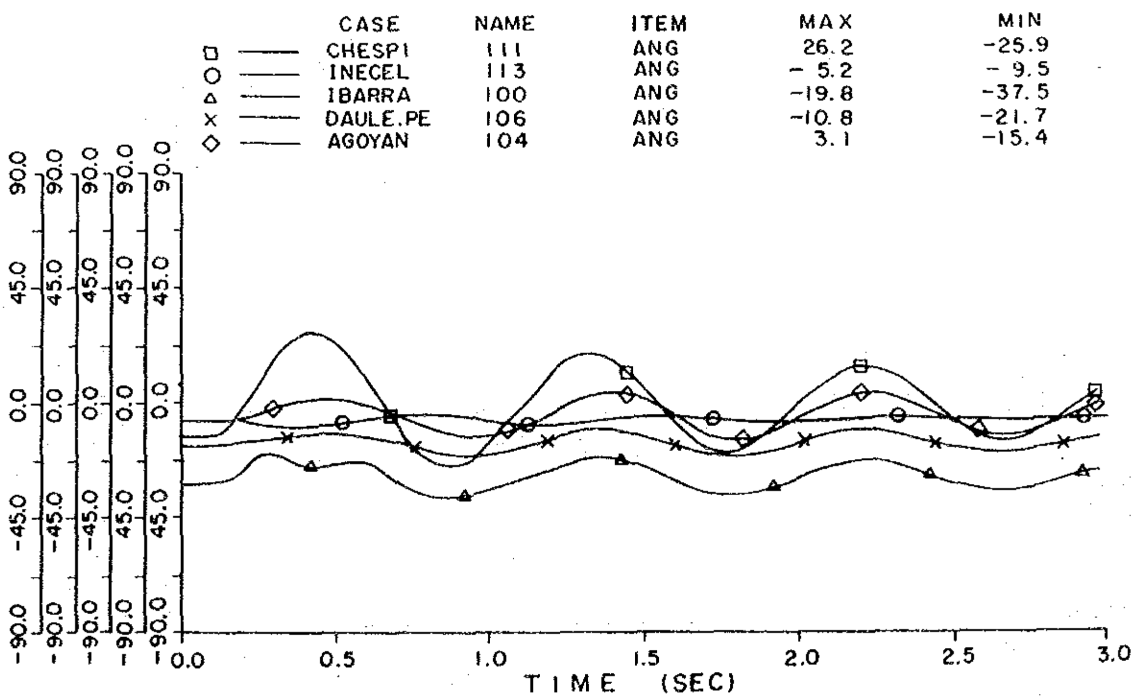
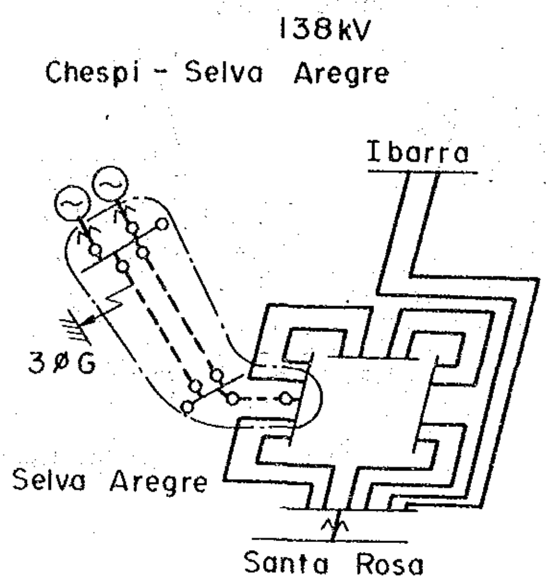


Fig. 8-4 Transient Stability of Pattern – 2



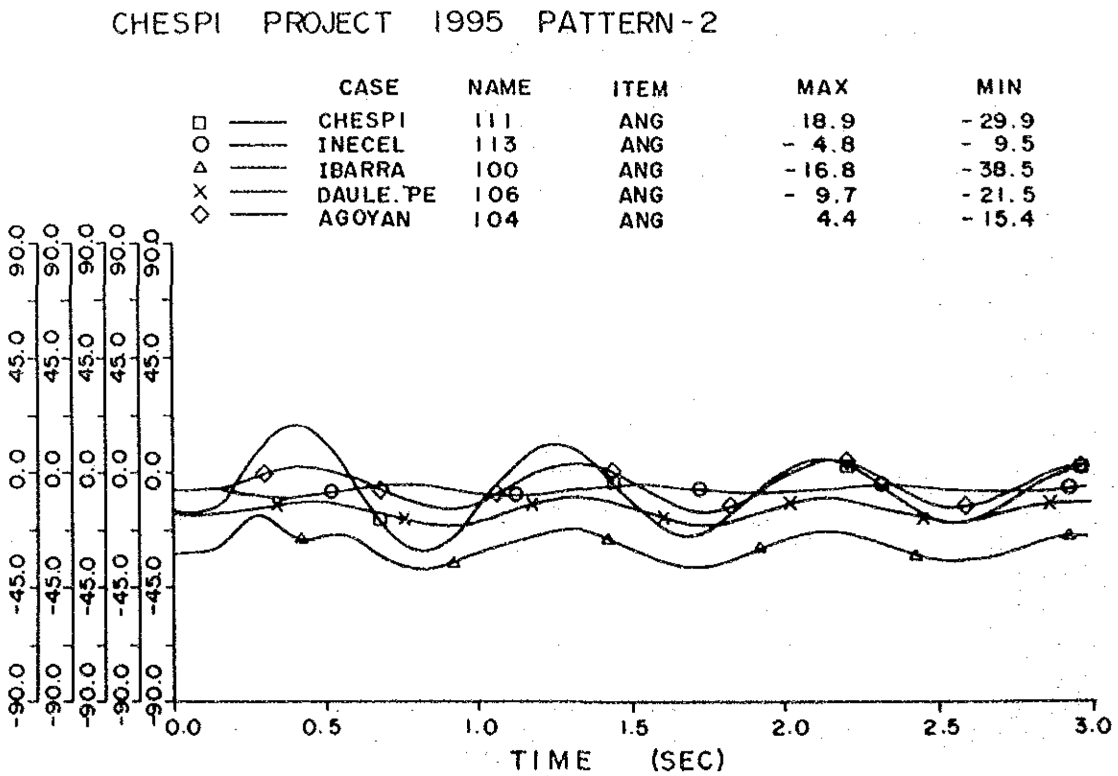
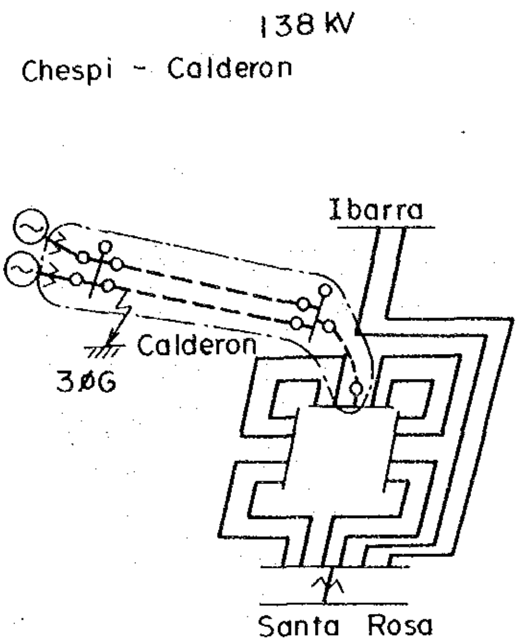


Fig. 8–5 Transient Stability of Pattern – 3



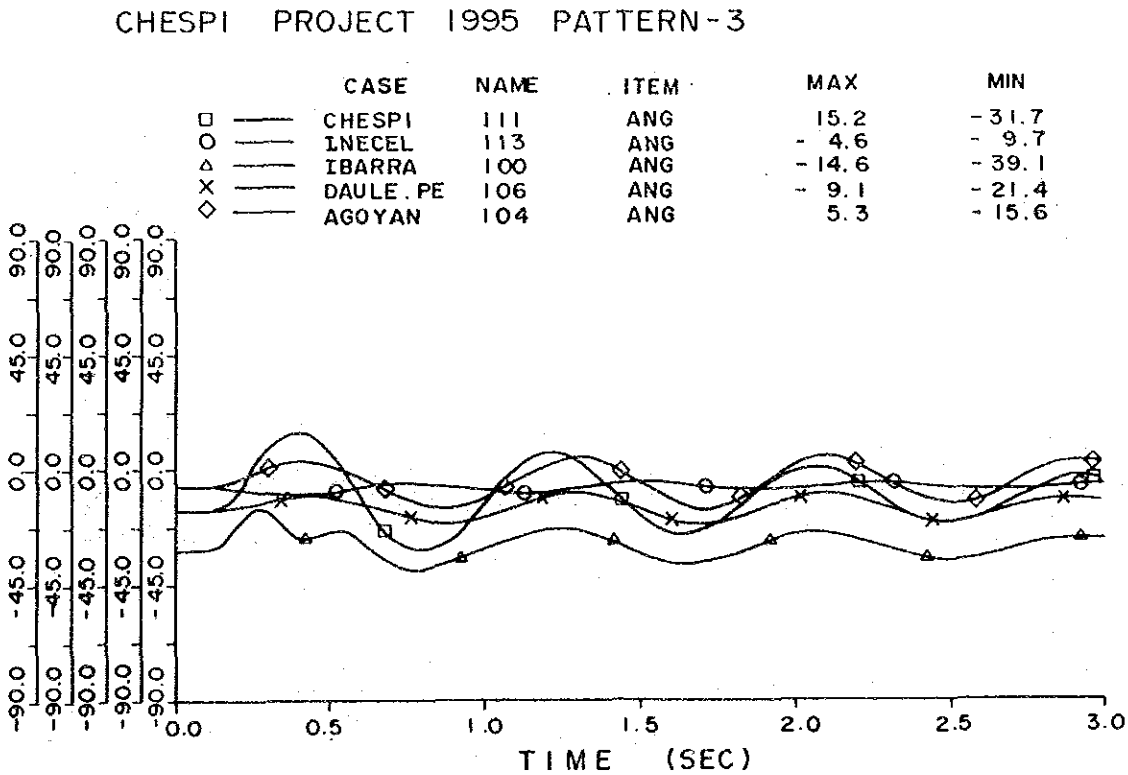
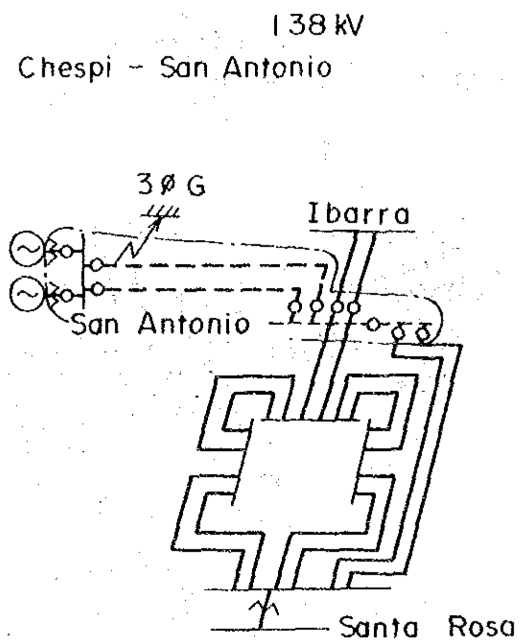


Fig. 8–6 Transient Stability of Pattern – 4



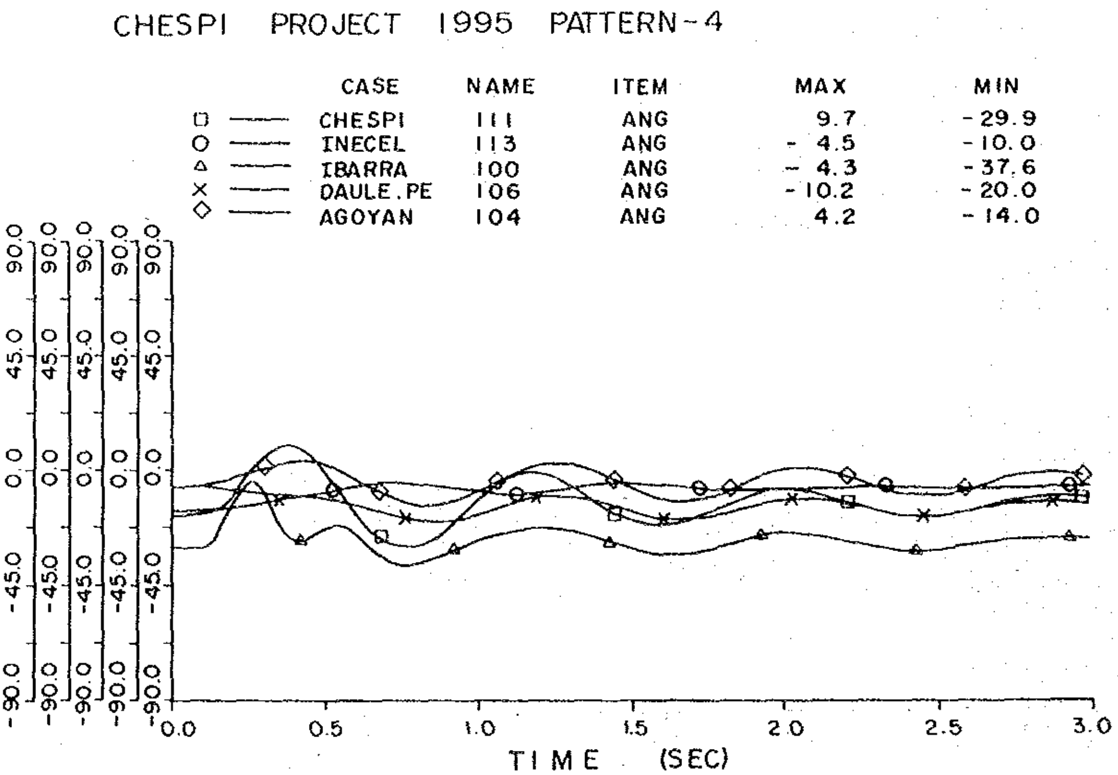
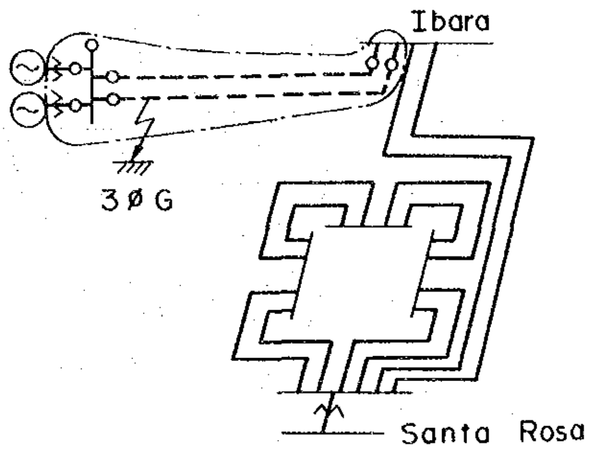


Fig. 8–7 Transient Stability of Pattern – 5

138 kV

Chespi - Ibarra



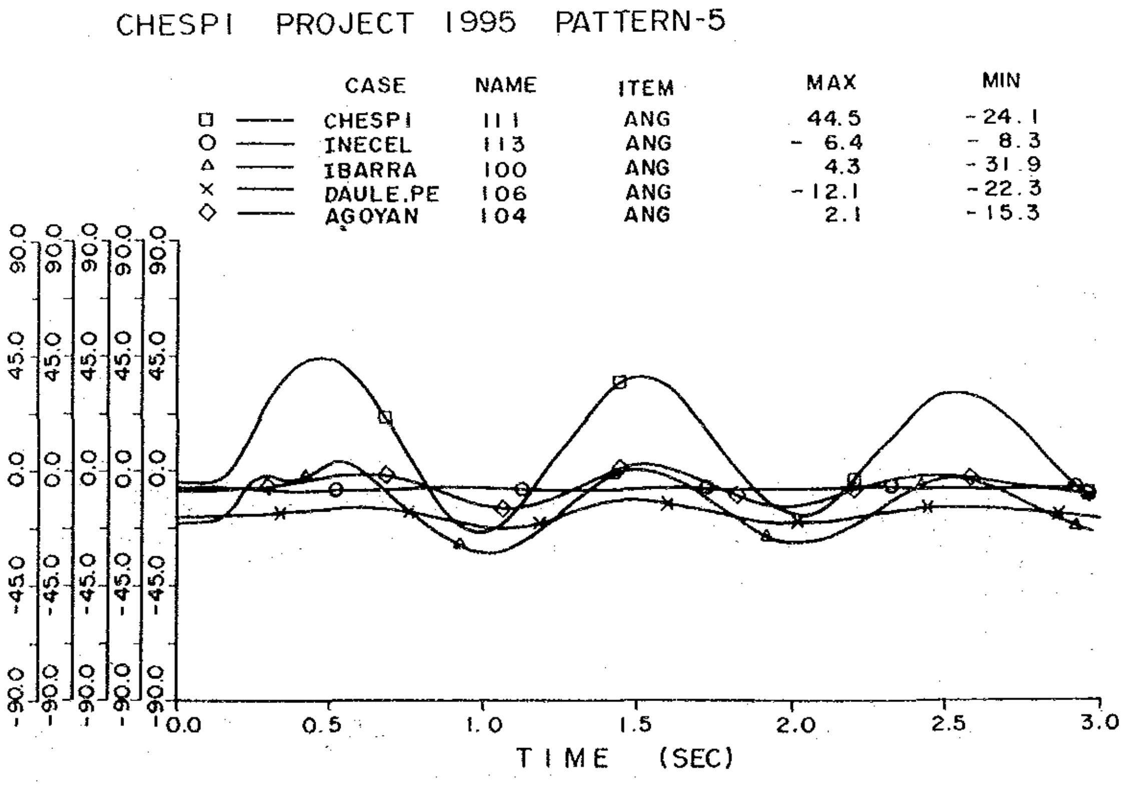
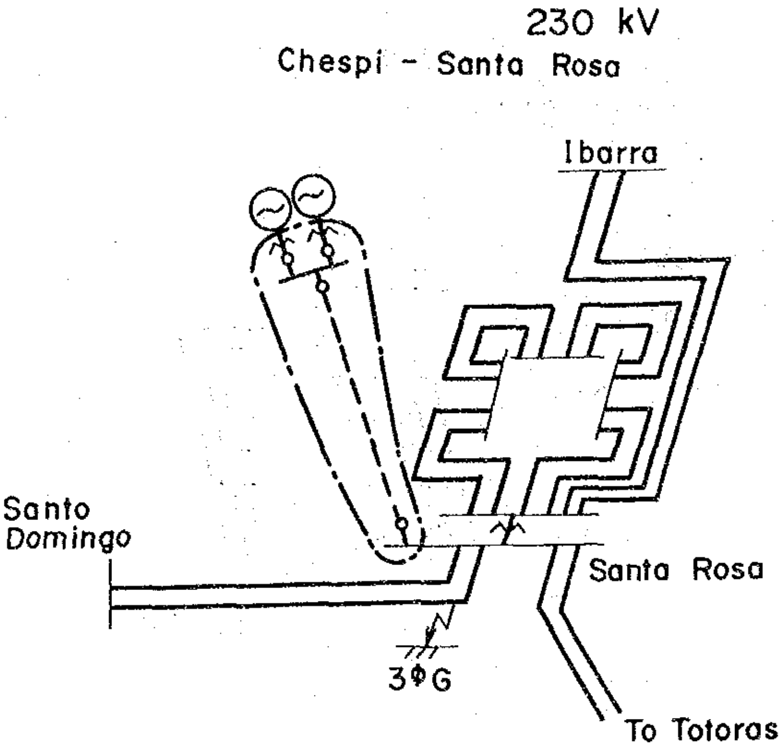


Fig. 8–8 Transient Stability of Pattern–6



CHESPI PROJECT 1995 PATTERN-6

	CASE	NAME	ITEM	MAX	MIN
□ ——	CHESPI	111	ANG	6.4	-27.5
○ ——	INECEL	113	ANG	-1.6	-13.5
△ ——	IBARRA	100	ANG	5.1	-42.9
× ——	DAULE.PE	106	ANG	-10.0	-21.0
◇ ——	AGOYAN	104	ANG	10.6	-19.8