12.2.2 Design of El Siete No.2 Power Station Civil Structures

The civil structures comprising El Siete No.2 Power Station are as follows:

- El Siete No.2 Intake Dam

Type	:	Concrete gravity
Height	:	35 m
Crest length	:	146 m
Volume	:	60,000 m^3
Design flood	:	1,260 m^3/s
High water level	:	1,070 m
Avilable drawdown	:	0 m
Maximum intake water	:	3 m^3/s

- El Siete No.2 Sedimentation Basin

Type	:	Double tank
Length	:	41.5 m
Width	:	18.0 m
Depth	:	3.5 m
Capacity	:	2,300 m^3

- El Siete No.2 Headrace Tunnel

Type	:	Pressure
Length	:	9,108.85 m
Inside diameter	:	3.6 m
Cross section	:	Circular
Gradient	:	1/1,000
Capacity	:	28 m^3/sec

- El Siete No.2 Surge Tank

Type	:	Ristricted oriffice vertical shaft
Height	:	48.2 m
Inside diameter	:	9 m
Cross section	:	Circular
Port inside diameter	:	1.3 m

- El Siete No.2 Penstock

Type	:	Surface, rocker bearing
Number of lines	:	1 - 2 (after branched)
Capacity	:	28 m^3/sec
Inside diameter	:	3.40m - 1.25 m
Steel thickness	:	10 mm - 40 mm
Length	:	1,045.17 m
Type of branch	:	Y-branch

- El Siete No.2 Powerhouse

Type	:	Surface
Width	:	18 m
Length	:	52 m
Height	:	17.8 m
Turbine	:	Vertical-shaft Francis x 2 units
Generator	:	Vertical-shaft synchronouse x 2 units
Turbine center elevation	:	685.00 m
Tailwater level	:	687.00 m

- El Siete No.2 Outdoor Switchyard

Area	:	8,100 m^2
Width	:	79.00 m
Length	:	102.50 m

(1) El Siete No.2 Intake Dam

No.2 Intake Dam is a dual purpose structure, to carry out a maximum intake of 3.0 m^3/s from the discharge of the remaining catchment area of 41.6 km^2 between El Siete No. 1 Dam (catchment area: 256.3 km^2) and No.2 Intake Dam (catchment area: 297.9 km^2), and to conduct discharged water of a maximum of 25 m^3/s after use at the No.1 Power Station through a conduit inside the intake dam, to cross the Rio Atrato main stream and then conduct the water to the No.2 Power Station.

El Siete No.2 Intake Dam is to be provided on the Atrato River approximately 160 m upstream of the No.1 powerhouse and is designed with appurtenant spillways for a high water level of 1,070 m, and the discharge of a design flood of 1,260 m^3/s.

The dam height would be 35 m from the relations with the described appurtenant structures, while the dam crest length is to be 146 m in consideration of deposits distributed at the right bank. (See Dwg.-34.)

The dam type, in consideration of discharging the design flood of 1,260 m^3/s, dam height, appurtenant structures, etc., is to be a concrete gravity type.

1) Spillway

The design flood at the El Siete No.2 Intake Dam site is to be 1,260 m^3/s, as stated in 8.4. The spillways, similarly to El Siete No.1 Dam, are to be a combination type with a normal-use spillway and an emergency spillway, discharging floods with the two.

The normal-use spillway is a free overflow type with overflow at surcharge water level, with the capability to discharge up to 230 m^3/s corresponding to past maximum flood without the operation of gates.

The emergency spillway would be composed of two sluice gates 8.50 m high and 10.00 m wide, and is designed to be discharge the design flood of 1,260 m^3/s in combination with the normal-use spillway in the event of a flood exceeding 230 m^3/s.

The reason for adopting combination type spillways is to minimize the frequency of gate operation and prevent gate operation errors. The design was also made considering unforeseen floods from landslides occurring upstream of the dam and discharging such floods naturally without requiring gate operation.

The spillway section would be 52 m and occupy 36 percent of the 146 m dam crest length. (See Dwg.-34.)

2) Sediment will be deposited at the river bed upstream of El Siete No.2 Intake Dam. The sediment yield will not only be from the remaining catchment area, but also include sediment flushed down from El Siete No.1 Regulating Pond.

This deposited sediment is to be disposed by partially opening the two spillway gates to flush down, simultaneously to flood discharge.

3) Dam Foundation Treatment

According to the results of geological investigations of the right-bank side of the dam, there is a thick distribution of deposits, and it is estimated that weathering extends deep into the bedrock. Regarding the dam foundation, rather than excavate to a perfectly fresh rock, the design calls for excavation to rock where bearing power would be adequate, and cut-off was applied for foundation treatment concerning the permeability problem with a dam height of 35 m.

4) Care of River

River diversion during construction was done considering the dam crest length of 146 m, river width, and the distribution of river deposits, and it was decided to adopt the river-bed release method. The locations of the spillways and intake appurtenant to the dam were therefore laid out to make it possible for construction to be performed by this method.

The sequence would be for the spillway with gates to be constructed first, then used as the river diversion channel, followed by construction of the right bank section.

5) No.2 Intake and No.2 Sedimentation Basin

El Siete No.2 intake and No.2 sedimentation basin were designed to be a three-dimensional structure to effectively utilize the structure of the dam and to economize on the concrete volume.

The maximum intake from the remaining catchment area was set at 3 m^3/s, and was designed for particles 0.1 mm and larger to be settled out at the No.2 sedimentation basin. The system of the sedimentation basin is for two parallel sedimentation tanks each 41.50 m long, 8.00 m wide, and 3.50 m in average depth of water. Flushing of sediment settled in the tanks would be achieved by operating one of the two parallel tanks, fully or partially opening a partitioning gate installed at the upper part of the intermediate partitioning wall, causing the water conducted in to overflow to the other empty tank, utilize the force of the falling water to agitate the sediment settled in the tank to make it into slurry form, and then discharge into the Atrato River through drain holes provided at the two sides of the tank.

After settling the water is to be temporarily stored at the end of the tank, intaken by a morning-glory type intake, and joined with the No.2 headrace tunnel via a connecting conduit.

6) Conduit in No.2 Intake Dam Body

A 3.40-m inside diameter and 99.5-m long conduit to conduct the water discharged after being used at El Siete No.1 Power Station is to be provided inside the body of No.2 Intake Dam parallel to the dam axis. The conduit is to consist of steel pipe buried in the dam body.

(2) El Siete No.2 Headrace Tunnel

No.2 headrace tunnel is designed for 28 m^3/s maximum available discharge with a 3.60 m inside diameter, a length of 9,108.85 m, and a circular cross section. This will be a pressure tunnel. (See 12.1(3))

The No.2 headrace tunnel route would be provided parallel to the Atrato River and was selected as the shortest possible tunnel length to the El Siete No.2 Station while giving consideration to topography, geology, earth covering and work adits.

In consideration of experience with tunnel construction in Colombia, stability of the original ground, and the distribution of faults and seams, it was decided that the entire length is to be reinforced by a concrete lining. Consolidation grouting and high-pressure grouting are also to be performed as reinforcing work for stabilization of the original ground.

As work adits for construction, No.3 inclined shaft (L = 280 m) at the No.2 intake side, adit No.4 (L = 200 m) at Quitasuenos for excavation in both upstream and downstream directions, and adit No.5 (L = 265 m) for excavation in the upstream direction from the end of the headrace tunnel on the No.2 surge tank side are to be provided to facilitate tunnel work and shorten the construction period. The headrace tunnel gradient is to be 1/1,000 in consideration of drainage during excavation.

(3) No.2 Surge Tank

No.2 surge tank is to be provided at the end of No.2 headrace tunnel (L = 9,108.85 m). The surge tank is to be a restricted-orifice type in consideration of the topography and geology at the end of the tunnel and the conditions for work execution.

The vertical shaft inside diameter was made 9.00 m considering conditions for stability against surging vibrations (Thoma's conditions) and calculating the cross section for minimum construction costs.

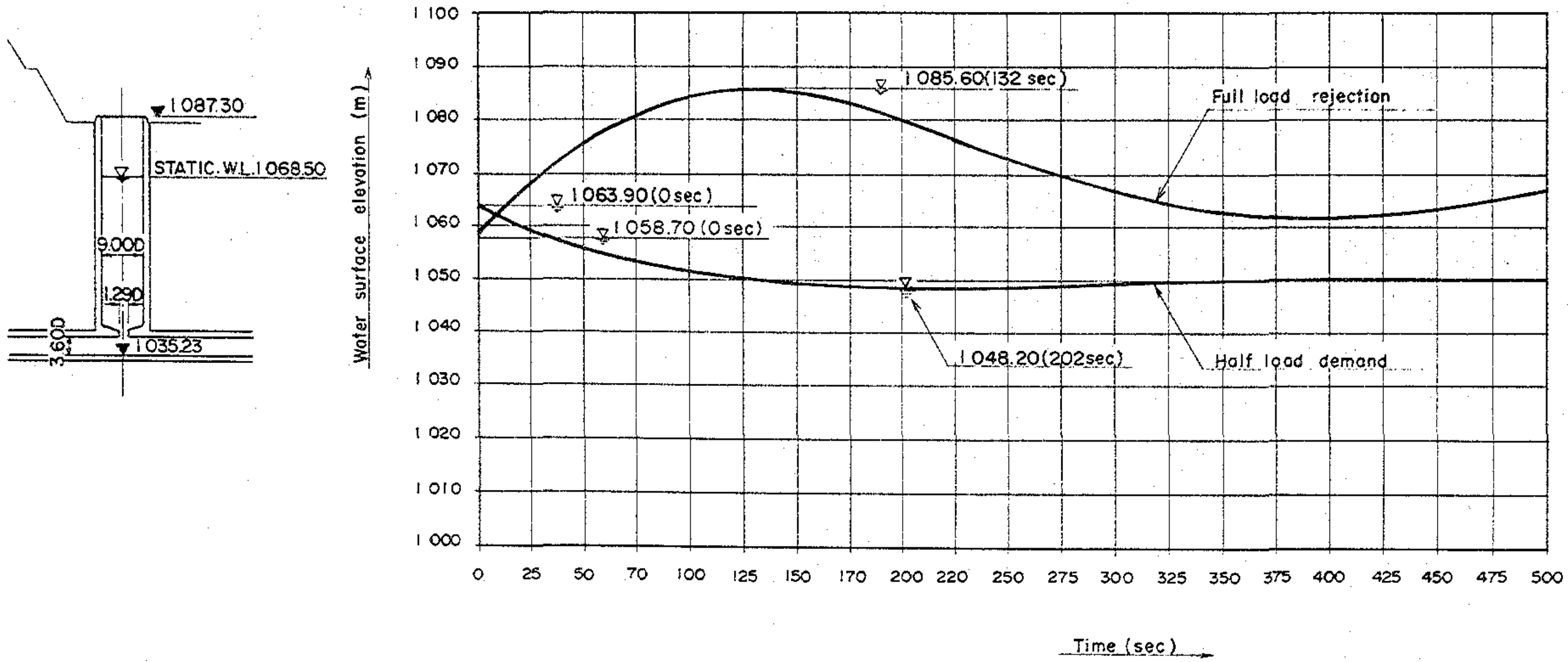
The inside diameter of the restricted orifice was made 1.30 m as a result of studying the critical flow of the restricted orifice and the optimum inside diameter at time of load breaking, and at sudden load increases.

The surge tank was designed for a height of 48.20 m, analyzing the upsurge water level at total load breaking (full closure from 28 m^3/s discharge) at water level of the clear water tank portion of the No.2 sedimentation basin, downsurge water level at half-load surging (sudden increase from 14 m^3/s discharge to 28 m^3/s discharge) at the same water level, and considering an upper allowance on top of the water level fluctuation range and an allowance at the bottom to prevent the intermixture of air.

The entire part the vertical shaft and bottom tunnel sections of the surge tank are to be lined with reinforced concrete. In consideration of work execution and the prevention of seepage into the ground, it will be reinforced with steel liner to a height of 4 m at the bottom of the vertical shaft and the bottom tunnel (L = 40 m).

The Runge-Kutta Formula was applied to surging design calculations, and calculations of damping waves were made employing an IBM S370-M 155 computer. The results are shown in Fig. 12-6.

Fig. 12-6 Surging Curve of No.2 Surge Tank



In the case of full load rejection

Q = 28 m³/s ⟶ 0 m³/s

n = 0.0110

ϵup = 1.2717

STATIC. W.L.= 1 068.50

In the case of half load demand

Q = 14 m³/s ⟶ 28 m³/s

n = 0.0150

ϵdown= 2.3647

(4) No.2 Penstock

Regarding the No.2 penstock, a study was made of the surface and underground embedment types. As a result, the more economic surface type, and with which work execution would be easier, and which enables a shortened construction period, was adopted. (See 12.1(4))

No.2 penstock route, connecting the surge tank and No.2 powerhouse was laid out on a ridge of the mountainside providing the shortest distance, a length of 1,045.2 m. Of this length, the horizontal 67 m section, corresponding to the connection with the surge tank was made an embedded tunnel type.

There would normally be one penstock line when the maximum available discharge of 28 m^3/s and penstock length are considered, and it was designed to connect to two turbines on bifurcation at the end of the penstock. The bifurcation pipe was made a Y-type as the direction of the penstock is orthogonal to the powerhouse axis.

As a result of economic comparisons of various inside diameters for the penstock, a starting point inside diameter of 3.40 m and an ending point (inlet valve) inside diameter of 1.25 m were selected. The variations in inside diameters between the two are shown in Dwgs.-39 and 40. (See 12.1(3))

The penstock surface is to be fixed by twelve anchor blocks with intervals provided support by rocker saddles, 12 m apart. Connection of individual pipe lengths is to be by field welding.

The pipe shell material is to be SM 50 (JIS specifications) or ASTM A 440 in consideration of pipe thickness and field welding. The individual pipe thickness were decided calculating water hammer pressures. The results are shown in Dwg.-40.

The water hammer pressure rise at the turbine inlet will be 46 percent of hydrostatic pressure.

(5) El Siete No.2 Powerhouse

Two vertical-shaft Francis turbines were adopted for the El Siete No.2 powerhouse in consideration of efficiency, annual utility factor, and operation. A comparison study was made of the two cases of surface and underground types for the powerhouse, and the surface type, providing better economics was adopted. (See 12.1(4))

It was decided to locate the El Siete No.2 powerhouse at the right bank of the Atrato River upon consideration of the geology and condition of the river bed of the Atrato River. The powerhouse was designed taking into consideration the 1,360 m^3/s design flood discharge at the powerhouse location in addition to the dimensions of the turbines and generators.

This flood water level would be at EL. 689.60 m and the elevation of the powerhouse lot was selected at 695.00 m. The powerhouse lot is to be secured entirely by open excavation, but as it will be necessary to excavate below the river water level for the foundations, cofferdam construction will be required.

The powerhouse building is to be a reinforced concrete surface type construction, the required dimensions being 18.00 m wide, 52.00 m long, and 17.80 m high.

Two Francis turbines and generators, an erection bay, control room, cable handling room, storeroom, office room, etc. are to be accomodated in this building.

The powerhouse foundations are to be provided on bedrock by open excavation below the lot at EL. 695 m. Two vertical-shaft Francis turbines, draft tubes, and appurtenant equipment are to be accomodated in the foundation, and an afterbay is to be provided facing the Atrato River. (See Dwgs.-41 and 42)

An access road is to be constructed for access to the powerhouse, from the national road (Medellin City - Quibdo City) and heavy equipment such as generators, turbines, and transformers are to be transported. This access road is designed to be 6 m wide.

(6) El Siete No.2 Outdoor Switchyard

The El Siete No.2 outdoor switchyard, when stepping up the voltage at the No.2 Power Station to 230 kV and taking out to the No.1 outdoor switchyard and the existing 115-kV line to Quibdo are considered, will require a lot 79 m wide, 102.5 long and area of 8,100 m^2.

This lot is to be developed by open cut and banking at a point 320 m upstream along the Atrato River from the powerhouse site. The elevation of this lot is to be at 715 m, which would be unaffected by flood.

The powerhouse access road can be utilized connection between No.2 outdoor switchyard and No.2 powerhouse. The cable duct to control this outdoor switchyard is to be laid parallel to the powerhouse access road.

12.3 Turbines, Generators

Both Pelton and Francis turbines can be adopted for the El Siete No.1 and No.2 power stations when the maximum available discharges and effective heads are considered. However, when the Francis type is to be adopted, care will be needed in design since generator rotor speed will be fairly high.

The Survey Mission considered the following items in selecting the turbine types for El Siete No.1 and No.2 Hydroelectric Power Projects:

a) The El Siete No.1 and No.2 Power Station waterway systems are in series, and stoppage of the No.1 power station means stoppage of the No.2 power station also.

b) The effective storage capacity at the No.1 regulating pond amounts to 6 hours' worth in comparison with the maximum available discharge of the of No.1 power station. In effect, when considered in relation to natural discharge of the stream, both No.1 and No.2 power stations would be classified as run-of-river types.

c) Sediment inflow of the Atrato River and inspection and maintenance frequency

d) Difference in costs of turbines and generators according to turbine type

e) Difference in construction cost of powerhouse building according to turbine type

f) Difference in available energy production according to turbine type

Study of Economic comparison on Alternative Turbine Types

Name of Project	Unit	El Siete No.1		El Siete No.2	
Type of turbine		Pelton	Francis	Francis	Pelton
Intake water level	m	1,445.00	1,445.00	1,068.50	1,068.50
Tail water level	m	1,071.00	1,071.00	687.00	693.00
Gross head	m	374.00	374.00	381.50	375.50
Less of head	m	21.00	18.00	24.00	351.50
Effective head	m	353.00	356.00	357.50	351.50
Maximum discharge	m^3/sec	25.0	25.0	28.0	28.0
Installed capacity	MW	75.0	75.6	85.0	83.6
Annual energy production	GWh	508.0	512.3	588.3	578.4
Annual benefit (B)	10^3US$	21,354	21,535	24,056	23,652
Construction cost	"	134,740	137,678	114,771	122,270
Annual cost (C)	"	16,169	16,521	13,772	14,672
Unit energy cost	mil US$/kWh	32.81	33.24	24.13	26.15
B - C	10^3 US$	5,185	5,014	10,283	8,980
B/C	-	1.321	1.303	1.747	1.612

Based on the results of the above study the principal specifications of turbines, generators, and main transformers for El Siete No.1 and No.2 Power Stations are selected as follows:

	El Siete No.1	El Siete No.2
Turbine		
Type	V. Pelton Turbine	V Francis Turbine
Output	38,300 kW	43,300 kW
Max. Discharge	12.5 m^3/s	14.0 m^3/s
Effective Normal Head	354.6 m	361.2 m
R.P.M	300 rpm	600 rpm
No. of Units	2	2
Generator		
Type	V. AC Generator	V. AC Generator
Capacity	41,600 kVA	47,000 kVA
Voltage	13,800 V	13,800 V
Power Factor	0.9	0.9
R.P.M	300 rpm	600 rpm
No. of Units	2	2
Transformer		
Type	FOA	FOA
Capacity	41,600 kVA	47,000 kVA
Voltage	230/13.8 kV	230/13.8 kV
No. of Units	2	2

12.4 Design of Outdoor Switchyard Equipment

The connecting system for the main circuit of the outdoor switchyard was determined as follows to enable localization and speedy restoration in the event of an accident to the linking transmission lines or to the main circuit of the generators, ensuring operation safety at times of maintenance and localization of the power stopage section as much as possible, as well as the simplicity of the equipment and the reduction of construction costs.

12.4.1 El Siete No.1 Power Station

The No.1 power station outdoor switchyard is to be located on the opposite bank at EL 1,081 m above sea level. As a consequence, because of the decline in voltage resistance capacity due to the drop in air density, it is necessary to compensate for the flush-over voltage and select the clearance of bus and the number of insulators for the bus support. It is also essential to effect a harmonization of the insulation coordination so that it is not less than the BIL of the switchyard equipment.

(1) Required Number of Insulators for Switching Surge

Nominal Voltage	230 kV
Maximum Permissible Voltage (Um)	245 kV
Switching Surge Multiple (n)	2.8
Switching Surge Voltage $Um \times \sqrt{\frac{2}{3}} \times n$	560 kV
Insulation Reduction Coefficient	1.2(sea level around 1,000m)
Required Insulation Strength for Insulator	672 KV
Required Number of Insulators (A)	12
Number of Insulator Required for Maintenance (B)	1
Number of Insulators Installed (A+B)	13
Flush-Over Voltage of 50% of Insulators	1,185 kV
BIL	900

(2) Insulation Tolerance for Insulator to Abnormal Power Frequency Voltage

Nominal Voltage	230 KW
Maximum Permissible Voltage (Um)	245 kW
Abnormal Voltage Multiple (n)	0.8
Insulation Reduction Coefficient (m)	1.2(sea level around 1,000m)
Required Insulation Strength of Insulators Um x n x m	235 kW
Required Number of Insulators	13
Power Frequency Insulation Strength at Wet Test of Insulators	420 kW
Insulation Tolerance	1.8

(3) Clearance of Bus

In deciding on the clearance of phase to phase and phase to earth for bus, consideration was given to the insulation so that the bus would not flush over before the flush over of switchyard equipment. That is to say, the following values were adopted.

Phase to earth clearance	Above 2,500 mm
Phase to phase clearance	Above 3,500 mm

As the space for the construction of the outdoor switchyard for the No. 1 power station is relatively sufficient, it has been decided to construct it with the conventional switchyard equipment. Due to the adoption of a double bus system, it is possible to avoid stopping the generators for the inspection and maintenance of the outdoor switchyard equipment or transmission lines. SF_6 gas circuit breaker has been applied for switchyard circuit breaker.

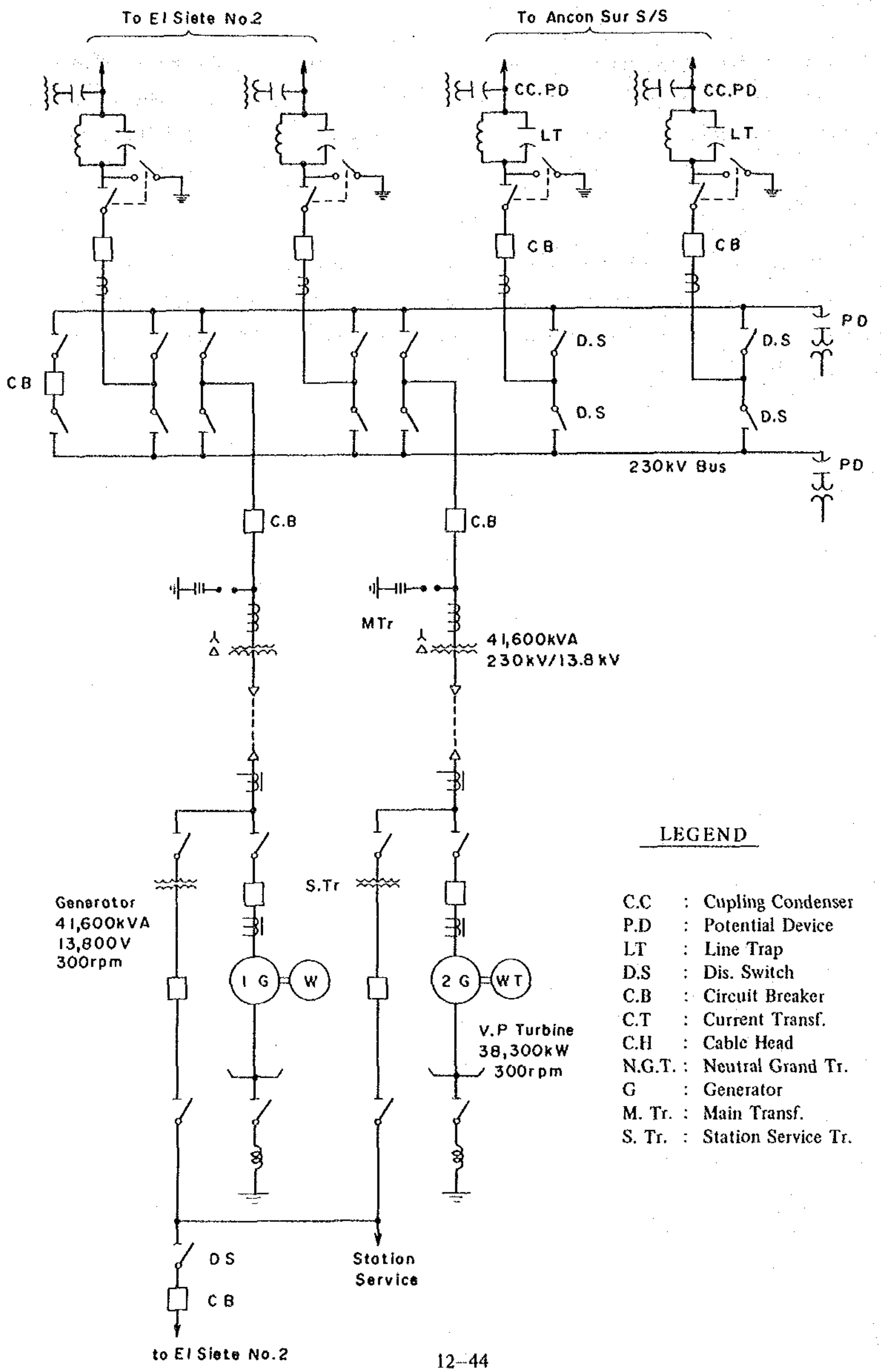
12.4.2 El Siete No.2

The outdoor switchyard for the No. 2 power station is to be located on the right bank. However, because of the space, a relatively flat position has been selected about 100 m upstream from powerhouse. This position is EL 715 m above sea level, which is 370 m lower than for the outdoor switchyard for the No. 1 power station. The design criteria, for the clearances of bus, number of insulators, bus system and the outdoor switchyard equipment, however, are the same as those for the No. 1 power station.

A 15 MVA three-phase transformer with terminal voltage of 230 kV/ 115 kV is installed in the outdoor switchyard of the No. 2 power station, therefore, it will be possible to supply electricity to Quibdo City in Choco by connecting the existing 115 kV transmission line to this tie transformer.

Fig. 12-7 - (1) and (2) show the diagram of the main circuit for the No. 1 and No. 2 power stations, and Fig. 12-8 - (1) and (2) show the arrangements for the outdoor switchyard equipment of the No. 1 and No. 2 power stations.

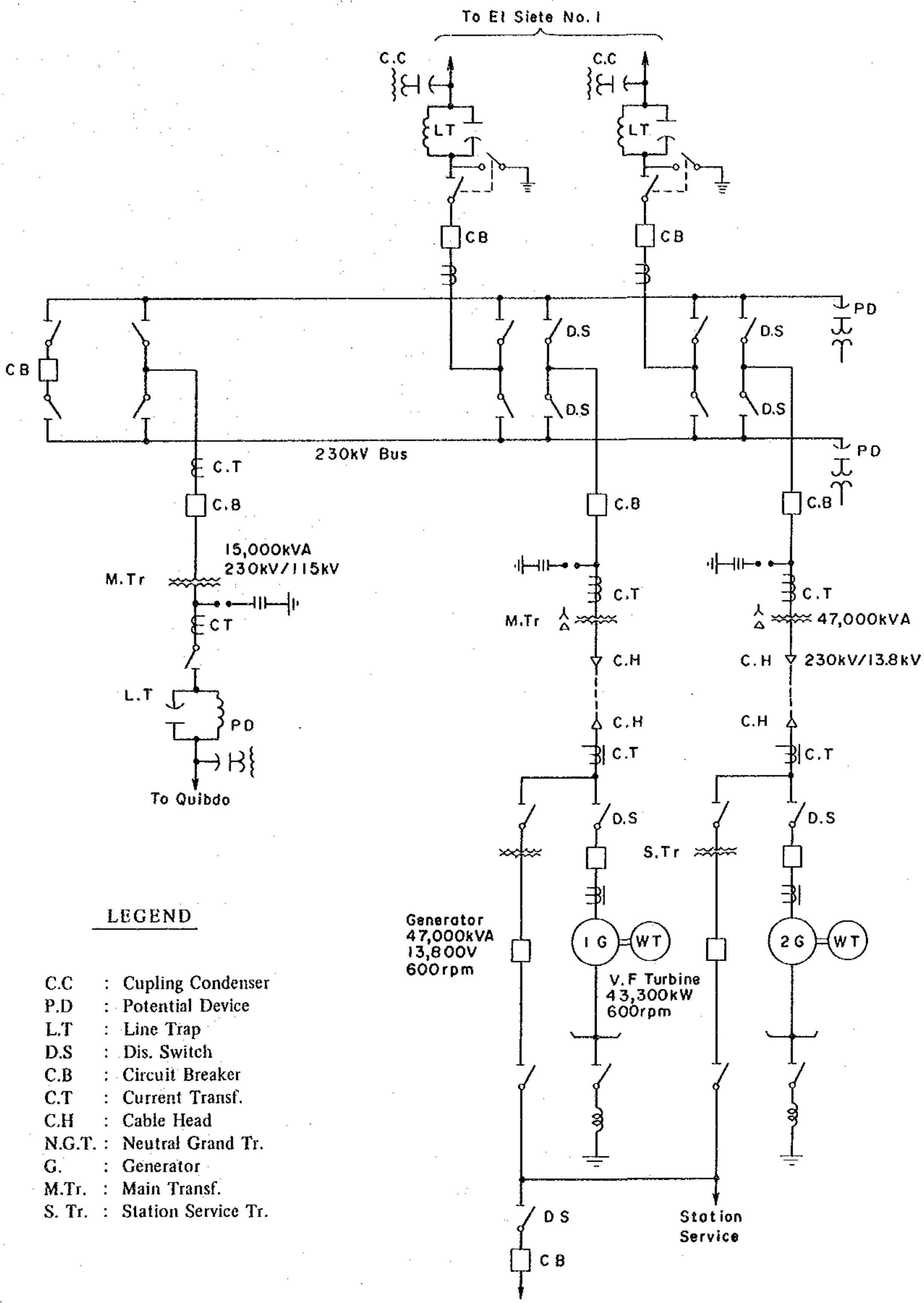
Fig. 12-7 (1) Single Line Diagram for El Siete No.1 P.S.



LEGEND

C.C : Cupling Condenser
P.D : Potential Device
LT : Line Trap
D.S : Dis. Switch
C.B : Circuit Breaker
C.T : Current Transf.
C.H : Cable Head
N.G.T. : Neutral Grand Tr.
G : Generator
M. Tr. : Main Transf.
S. Tr. : Station Service Tr.

Fig. 12-7 (2) Single Line Diagram for El Siete No.2 P.S.



LEGEND

C.C : Cupling Condenser
P.D : Potential Device
L.T : Line Trap
D.S : Dis. Switch
C.B : Circuit Breaker
C.T : Current Transf.
C.H : Cable Head
N.G.T. : Neutral Grand Tr.
G. : Generator
M.Tr. : Main Transf.
S. Tr. : Station Service Tr.

Fig. 12-8 (1) 220 kV Switchyard for El Siete No.1 Power Plant

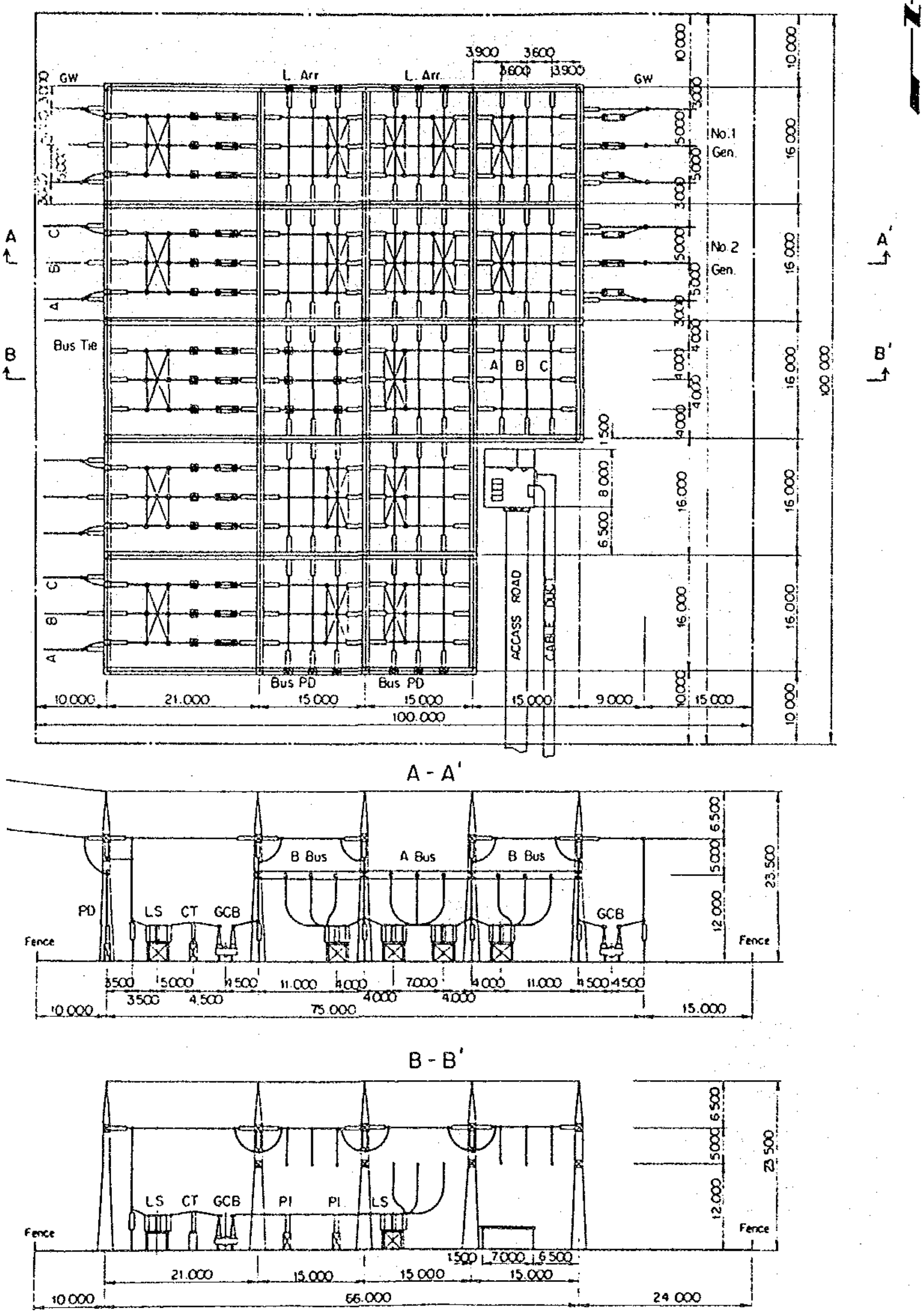
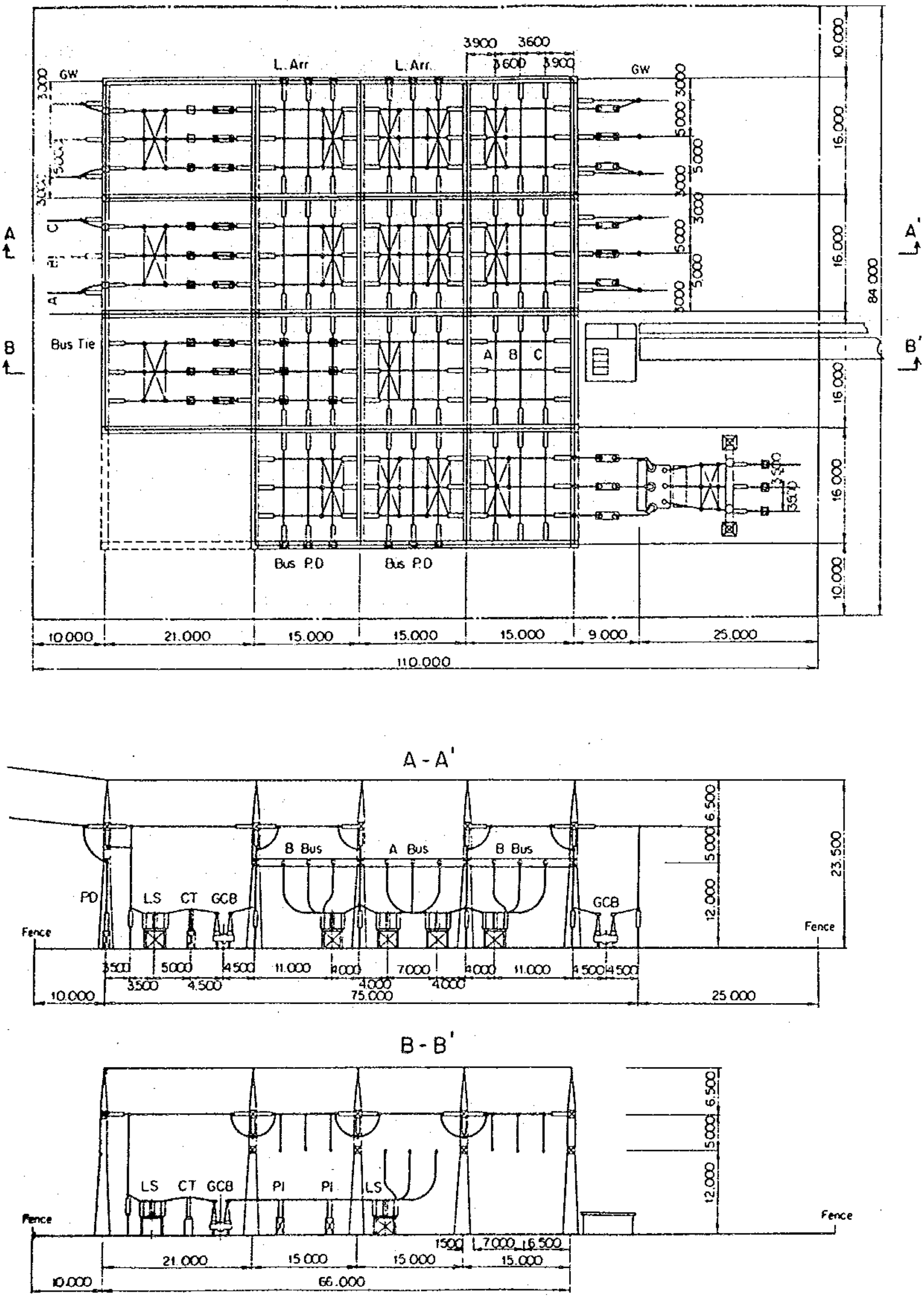


Fig. 12-8 (2) 220 kV Switchyard for El Siete No.2 Power Plant



12.5 Design of Telecommunication Equipment

12.5.1 Design Conditions

The configuration of Telecommunication equipment required for this project has been designed based on the following conditions.

(1) El Siete No. 1 and No. 2 Power Stations will be connected by 230-kV transmission lines to the Ancon Sur substation and most of the generated power will be supplied to the EPM power company in Medellin.

All load-dispatch instructions for El Siete No. 1 and No. 2 Power Stations will be issued from the EPM load-dispatching office in Medellin.

(2) El Siete No. 2 Power Station will be capable of remote-control operation from the El Siete No. 1 Power Station.

(3) The telecommunication circuit for administration use will be established between the El Siete No. 1 Power Station and the ICEL head office in Bogota through the Ancon Sur Substation.

However, the construction of circuits to form a telecommunication system from the Ancon Sur Substation to ICEL is not within the scope of this project.

(4) Since the existing 115-kV power line between the Bolombolo Substation and the Quibdo Substation will be changed as part of this project's system modifications and power will instead be supplied to the Quibdo Substation from the El Siete No. 2 Power Station, a maintenance telephone circuit will be established between the Quibdo Substation and El Siete No. 2 Power Station.

(5) The maintenance office for the 230-kV transmission line linking El Siete No. 1 and No. 2 Power Stations and the Ancon Sur substation will be located at El Siete No. 1 Power Station.

12.5.2 Configuration of Telecommunication Circuit

(1) Power Line Carier Circuit

The required telecommunication circuits for load dispatching, administration use and maintenance use will be constructed by means of the high reliable PLC circuit with metallic-circuit coupling method and inter-circuit coupling method taking the compatibility with the existing telecommunication system into consideration.

The telecommunication line sections and the required number of circuits for each section are listed below.

a) Between El Siete No. 1 Power Station and Ancon Sur Substation

Telephone lines for load-dispatch instructions:	1 cct.
Telephone lines for maintenance:	2 ccts.
Telemetry line for load dispatching:	1 cct.
Transmission lines for carrier protection:	2 ccts.

If these circuits need to be extended beyond the Ancon Sur Substation, a separate plan must be made to incorporate such extended lines into the existing and planned telecommunication line systems of EPM and ISA.

b) Between El Siete No. 1 and No. 2 Power Stations

Data transmission lines for remote control:	2 ccts.
Telephone lines for maintenance:	2 ccts.
Transmission lines for carrier protection:	2 ccts.

The data transmission lines for remote control will be a dual-route configuration consisting of one 1L (No. 1 transmission line) power line and one 2L (No. 2 transmission line) power line carrier circuits.

c) Between El Siete No. 2 Power Station and Quibdo Substation

Telephone line for maintenance :	1 cct.

d) Between El Siete No. 1 and VHF base station

Line for control of VHF base station: 1 cct.

The line will be connected to mobile radio circuits used for maintenance.

(2) Mobile Radio Circuits for Maintenance

A VHF base station will be established near the peak of la Manza to serve the formation of a mobile radio circuit used for maintaining a radio service area along the transmission lines linking El Siete No. 1 and No. 2 Power Stations and the Ancon Sur Substation.

The VHF base station will be controlled by El Siete No. 1 Power Station using the power line carrier circuit.

12.5.3 Outline of Telecommunication Equipment

(1) Power line carrier equipment

The following power line casrrier devices and coupling devices will be installed for the following sections as part of the power line carrier circuit configuration described in section 12.5.2 (1) above.

Section	Coupling System	Carrier Capacity
El Siete No. 1/Ancon Sur	Phase to phase	1 CH (Speech + singnal operation) x 3 sets
El Siete No. 1/No. 2	Phase to phase	1 CH (Speech + signal operation) x 3 sets
El Siete No. 2/Quibdo	Phase to Earth	1 CH
El Siete No.1/VHF base	Phase to phase	1 CH

(2) Signal transmission equipment for carrier protection relays

Transmission lines constructed under this project will be protected by one of two systems: the directional comparison method for the section between El Siete No. 1 Power Station and the Ancon Sur Substation and the

TFT (Transfer Trip) method for the section between El Siete No. 1 and No. 2 Power Stations. FS type signal ransmission equipment for carrier protection relays which sends the relay signals over the power line carrier circuits will be installed at El Siete No. 1 and No. 2 Power Stations and at the Ancon Sur Substation.

(3) Data transmission equipment

Digital-transmission type data transmission equipment will be installed at El Siete No. 1 and No. 2 Power Stations to enable transmission of the required supervisory and control signals for remote-control operation of El Siete No. 2 Power Station.

In addition, data transmission equipment will be installed at the Ancon Sur substation to enable display of operating conditions at El Siete No. 1 and No. 2 Power Stations.

(4) VHF mobile radio equipment

Press-to-tolk VHF mobile radio equipment will be installed at the VHF base station. Portable and car-mounted mobile radio equipment will be provided to El Siete No. 1 Power Station.

(5) Fault locators for transmission line

Fault locators for transmission line will be installed to speed repair of malfunctions and other accidents occurring on the 230-kV transmission line (about 100 km long) between El Siete No. 1 Power Station and the Ancon Sur Substation.

These fault locators will be of the pulse radar type and will be installed at El Siete No. 1 Power Station. No fault locators are needed for the line section between El Siete No. 1 and No. 2 Power Stations since they are only about 8 km apart.

(6) Telephone equipment

Common-battery system or tone-ringer (selective calling) system telephones for load-dispatch instructions and telephone switching equipment for maintenance telephones will be installed at El Siete No. 1 Power Station.

This teleophone equipment will be connected by power line carrier circuits via the Ancon Sur Substation to the EPM load dispatching office and to ICEL's PAX telephone network.

(7) Power supply equipment for telecommunication equipment

DC no-break power supply equipment consisting of floating charge devices and batteries will be installed at El Siete No. 1 and No. 2 Power Stations, the Quibdo Substation, and the VHF base station.

Separate power supply equipment may be installed at the Ancon Sur Substation, however such equipment is not within the scope of this project.

Because the VHF base station will be located in an area where it is difficult to receive commercially supplied power, it will receive power from a PD coupling to the transmission line between El Siete No. 1 Power Station and the Ancon Sur Substation.

Fig. 12-9 Telecommunication System

Note: The equipment surrounded by dotted line will be transfered from that of ATRATO Project Construction Site and BOLOMBOLO S.S, which will have been used for construction administration use.

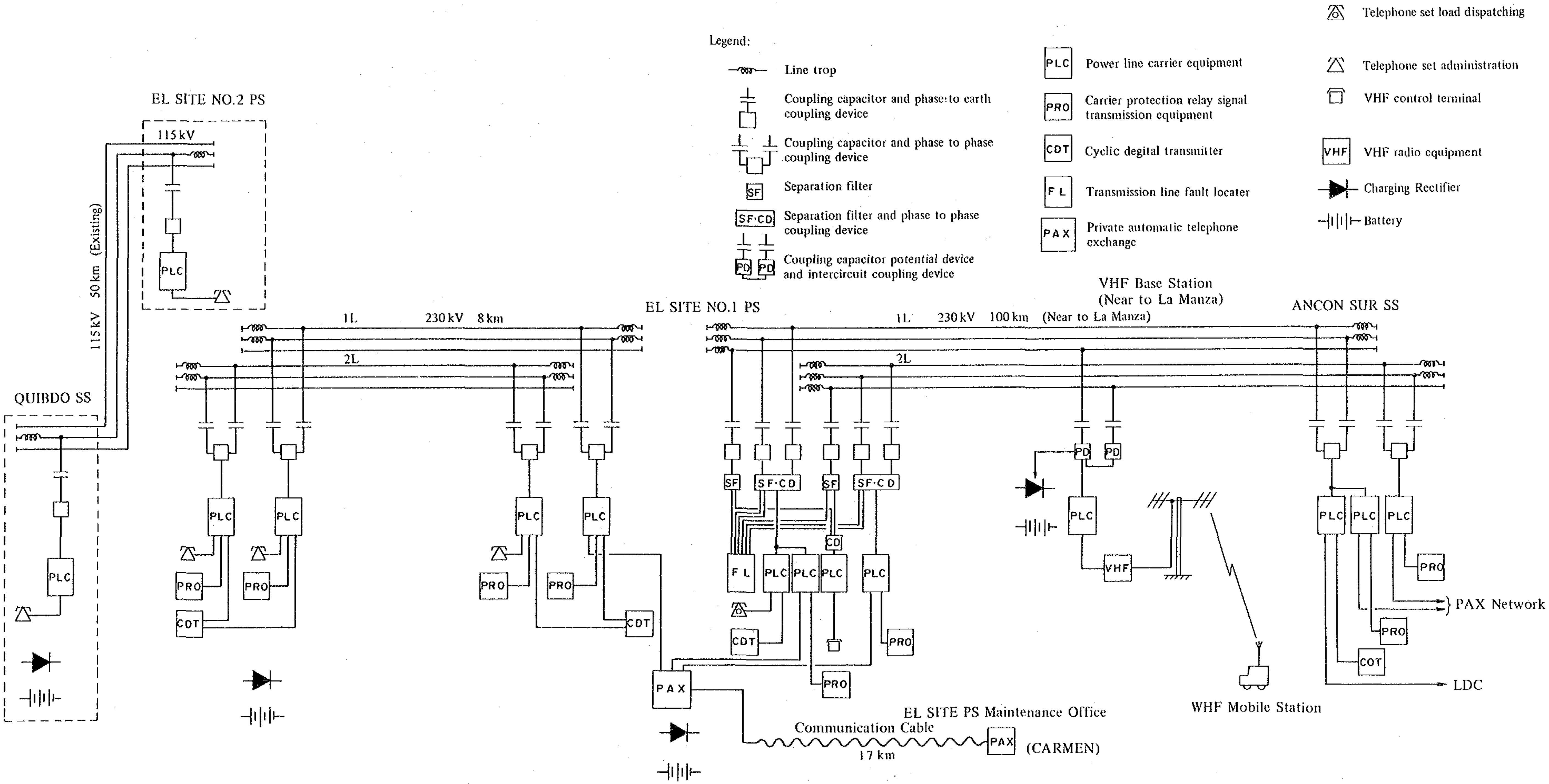
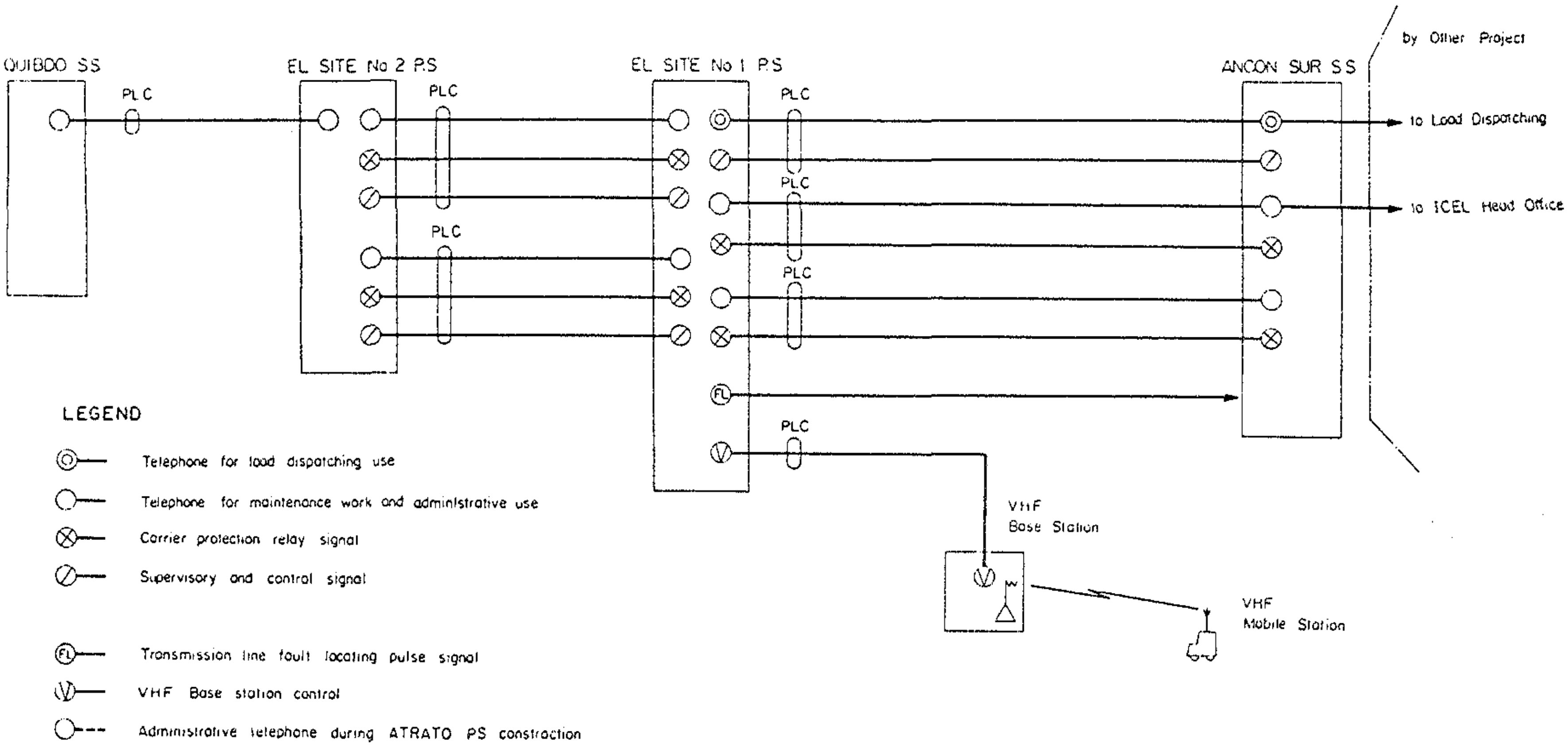


Fig. 12-10 Telecommunication Circuit



CHAPTER 13. TRANSMISSION PLAN AND POWER SYSTEM ANALYSIS

CHAPTER 13 TRANSMISSION PLAN AND POWER SYSTEM ANALYSIS

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CHAPTER 13. TRANSMISSION PLAN AND POWER SYSTEM ANALYSIS

13.1 Transmission Line Plan

The total power to be generated by the Atrato Project is 160 MW, of which 75 MW is to be provided by El Siete No. 1 Power Station and 85 MW by El Siete No. 2 Power Station.

This power will be supplied to regional network through the national interconnected power systems.

The project site is located 100 km to the southwest of Medellin, and the ISA network is interconnected to the EPM network at Medellin.

Thus, considering the power transmission distance from the project site to the network receiving the Atrato Project out put, the most suitable plan for this project is to provide an interconnection with the ISA network at Medellin.

The Medellin district, to which the electric power is supplied from the EPM network, is the largest load center, next only to Bogota, the capital City.

The peak power demand on the EPM network in 1993, the year the Atrato Project is to be completed, is expected to be 1,700 MW. (Refer Table 7-5, Chapter 7.)

(1) Receiving Substation

As the Medellin district receiving substation, the ISA's Ancon Sur Substation and the EPM's Evingado Substation are conceivable. In comparing these two substations, Ancon Sur Substation is more advantageous for the following reasons:

- In the present power system configurations, Ancon Sur Substation is operated as the interconnection point for each power company's network, and hence functions better for power exchanges.

- Ancon Sur Substation is also located in the outskirt's of Medellin City, and would provide less environmental impact when connecting a new transmission line to the substation.

- As Ancon Sur Substation is now under construction, space can be provided in the substation for the future connection of the Atrato transmission line.

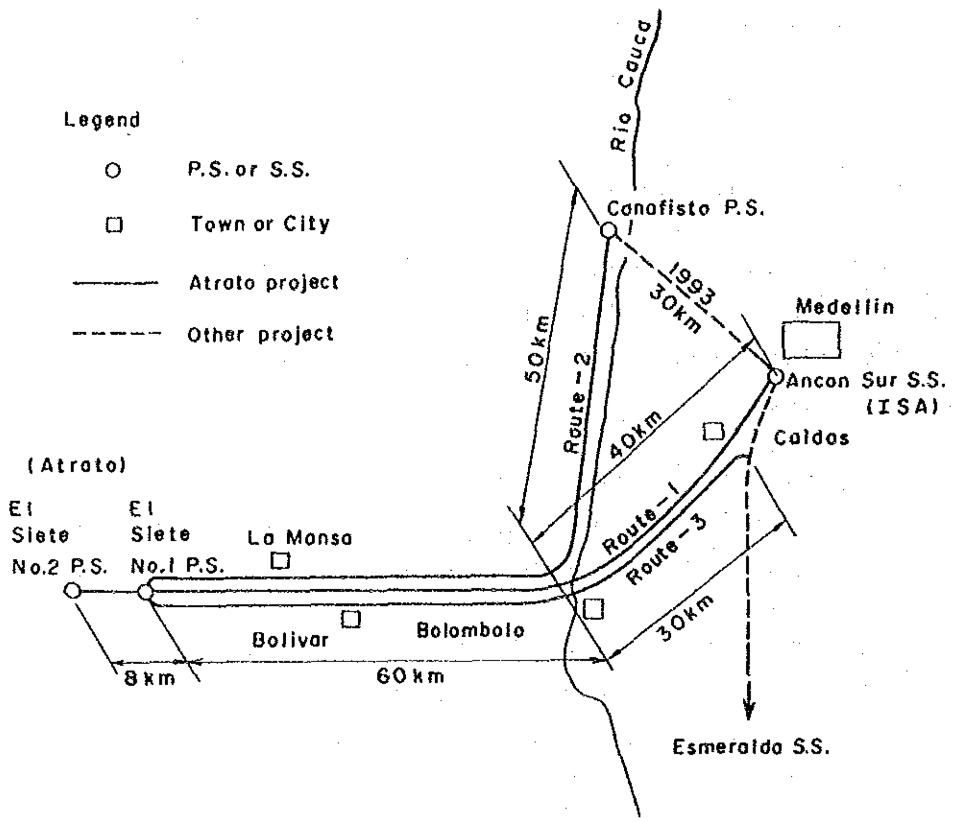
(2) Transmission Line Route

The following 3 routes are conceivable for power transmission to the EPM network.

Route 1: Atrato to Ancon Sur Substation
Route 2: Atrato to Canafisto Power Station
Route 3: Atrato to the transmission line between Ancon Sur and Esmeralda

The relative advantages of these 3 routes have been studied, and it has been concluded that Route 1 is the best. A conceptual map of each route is presented in Fig. 13-1. As illustrated in the figure, the geography and conditions for the construction work dictate that the proposed transmission line from the Atrato Site to Bolombolo will be built on the same path in all three of the above route plans.

Fig. 13-1 Alternative Route of Atrato Line



The advantages and disadvantages of the proposed three routes are outlined below.

1) Route 1: Atrato to Ancon Sur Substation

In this plan, the transmission line will run from the Atrato Site (El Siete No. 1 Power Station) to Ancon Sur Substation, passing through the towns of Bolivar, Bolombolo, Amaga and Caldas. The total length of the transmission line will be approximately 100 km. This transmission line will run almost in paralled with the existing 115 kV transmission line which supplies power from EPM's Ancon Sur Substation to Quibdo. In terms of the power system configuration, this plan is the simplest of all other alternatives, and the power system operation will be easier. Also, the transmission line construction schedule will not be affected by the degree of progress of other projects, as the new transmission line will be directly connected to the existing substation.

2) Route 2: Atrato to Canafisto Power Station

In this plan, the transmission line route will be the same with Route 1 for the section of the line from the Atrato Site (El Siete No. 1 Power Station) to Bolombolo. From Bolombolo, the line runs north along the Cauca River to the Canafisto Power Station. The transmission line length is the longest of the three alternative routes, and the construction cost the highest.

In the present plan, Canafisto Power Station will be connected to Ancon Sur Substation by a 30 km long 230 kV lines and is scheduled to be completed in 1993. The total length of the lines from Atrato to Ancon Sur Substation through Canafisto will be 140 km with the largest transmission losses of the three alternative plans.

There is also constraint on the construction schedule, where in construction of the line must coincide with the completion of the Canafisto Project.

3) Route 3: Atrato to transmission line between Ancon Sur and Esmeralda

In this plan, the transmission line route is the same for the section from the Atrato Site (El siete No. 1 Power Station) to Caldas, and the line will be connected to the Ancon Sur-Esmeralda transmission line (to be completed in 1988) at a location near Caldas. The line will be approximately 90 km long, 10 km shorter than the Route 1 line, or the shortest of the three alternatives.

In this plan, the Atrato transmission line will be directly connected to the Ancon Sur-Esmeralda transmission line, without circuit breakers. This scheme realizes certain economic advantage, but the lack of circuit breakers makes the power system operation less flexible. Whenever a network configuration is complicated, the power system reliability will be reduced.

To summarize the above studies, Route 2's transmission distance is the longest, and power system operation is relatively difficult for Route 3.

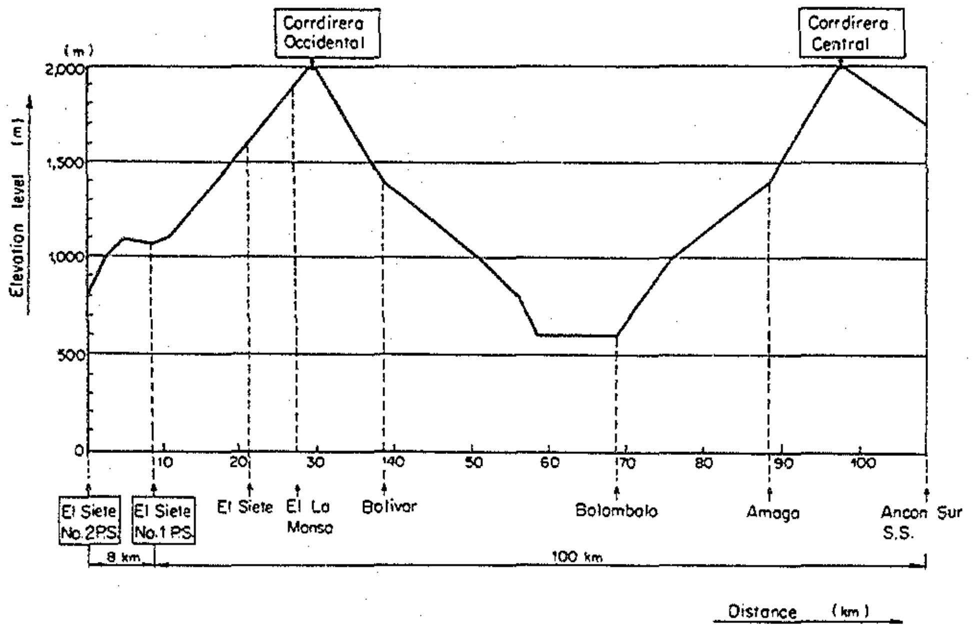
As the transmission distance is short and the system operation is simple, Route 1 can be regarded as the most advantageous.

(3) Transmission Route Geography

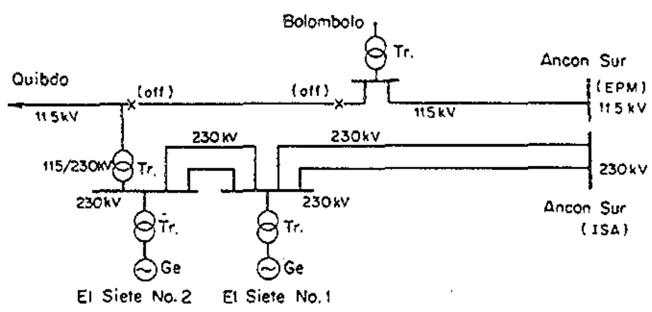
The total length of the Atrato transmission line will be 108 km, comprising 100 km from El Siete No. 2 Power Station to El Siete No. 1 Power Station and 8 km from El Siete No. 1 Power Station to Ancon Sur Substation. The transmission line will run from the over the Corrdireo Occidental ridges with altitudes of 2,000 m, goes down to the Cauca River, and again climbs the Corrdireo Occidental to reach Ancon Sur Substation at an altitude of 1,700 m.

Throughout the route, altitude's vary from 600 to 2,000 m. (see fig. 13-2(a).) The transmission line lengths for the altitude ranges are given below.

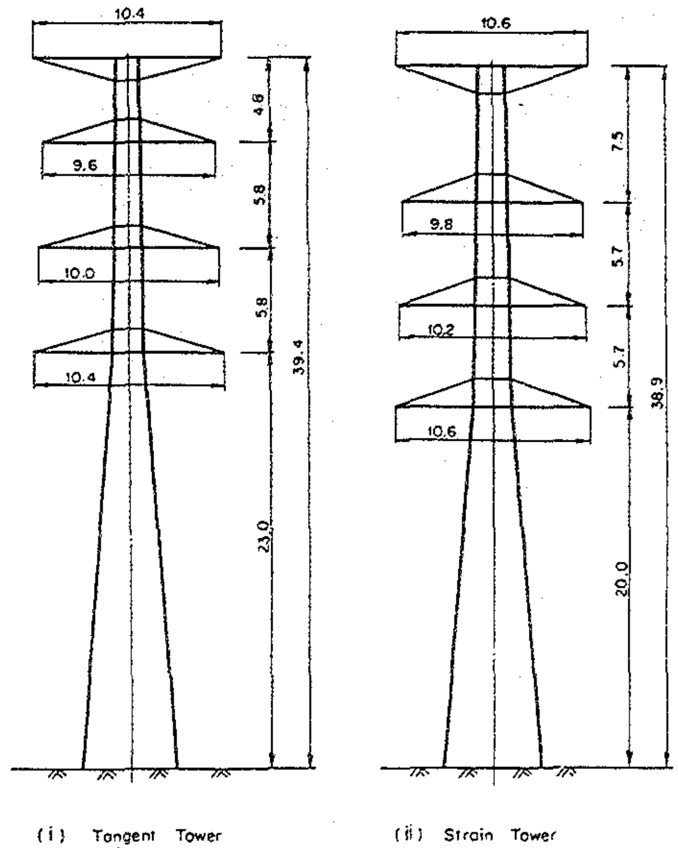
Fig. 13-2 Layout of Transmission Lines



(a) Profile of Transmission Line



(b) Switching of Quibdo Line



(c) 230kV Line Steel Tower, Standard Type

Altitude	Cumulative Length
2,000 m (maximum)	2 km
1,000 m to less than 2,000 m	76 km
600 m to less than 1,000 m	30 km
Total	108 km

A section of the line as long as 78 km, or approximately 72% of the total length, runs at altitudes more than 2,000 m. For this section, insulation strength and critical corona voltage are reduced.

There is a national road along the transmission route connecting Medellin to Quibdo, and towns such as El Siete, La Mansa, Bolivar, Bolombolo and Amaga are scattered.

(4) Transmission Voltage Selection

In the Republic of Colombia, the primary network consists of 500 kV and 230 kV lines, while the secondary network is formed by 115 kV lines.

The 500 kV transmission lines however, are presently operated with 230 kV. But their operating voltage will be raised to 500 kV by the time El Siete No. 1 and No. 2 Power Stations commence operations.

The Atrato transmission line voltage is to be selected from the existing voltage classes, based on the amount of power to be transmitted (160 MW) and the transmission distance (108 km).

As a 500 kV transmission line normally has a carrying capacity of more than 2,000 MW, the 500 kV voltage class has not been considered in this study, because construction of such a transmission line would apparently be an excessive investment. Voltage selection studies were conducted on 230 kV and 115 kV, with 230 kV being finally selected.

The results of the 230 kV line and 115 kV line are studies presented below.

Plan 1: 230 kV Transmission Line

In this plan, 230 kV lines will be constructed connecting El siete No. 1 and No. 2 Power Stations to the ISA's Ancon Sur Substation 230 kV bus.

Plan 2: 115 kV Transmission Line

In this plan, the existing 115 kV single circuit transmission line between the EPM's Ancon Sur Substation and Quibdo Substation is utilized.

It's conductor size is ACSR 336 MCM, with a carrying capacity limit of around 90 MW.

In the plan, two 115 kV lines will be newly constructed, and together with the existing line, El Siete No. 1 and No. 2 Power Stations will be connected to Ancon Sur Substation 115 kV bus by three 115 kV lines.

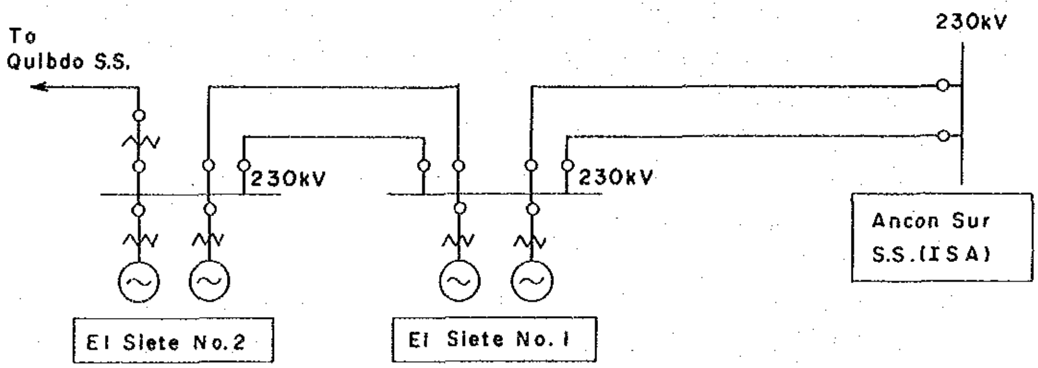
The power system configuration in these two plans are presented in Fig. 13-3. In both plans, the systems were designed so that a power of 160 MW can be transmitted even with single line shut down, provided both systems have the same supply reliability.

Under this criterion, 3 lines are required for the 115 kV plan, and 2 lines for the 230 kV plan.

Economic comparison study on these two plans were made,by calculating the annual costs of the transmission lines, transformers switching equipments and transmission losses.
The study results are given in Table-13.1.

Fig. 13-3 Alternative Transmission Voltage, 230 kV α 115 kV

a. 230 kV Lines



b. 115 kV Lines

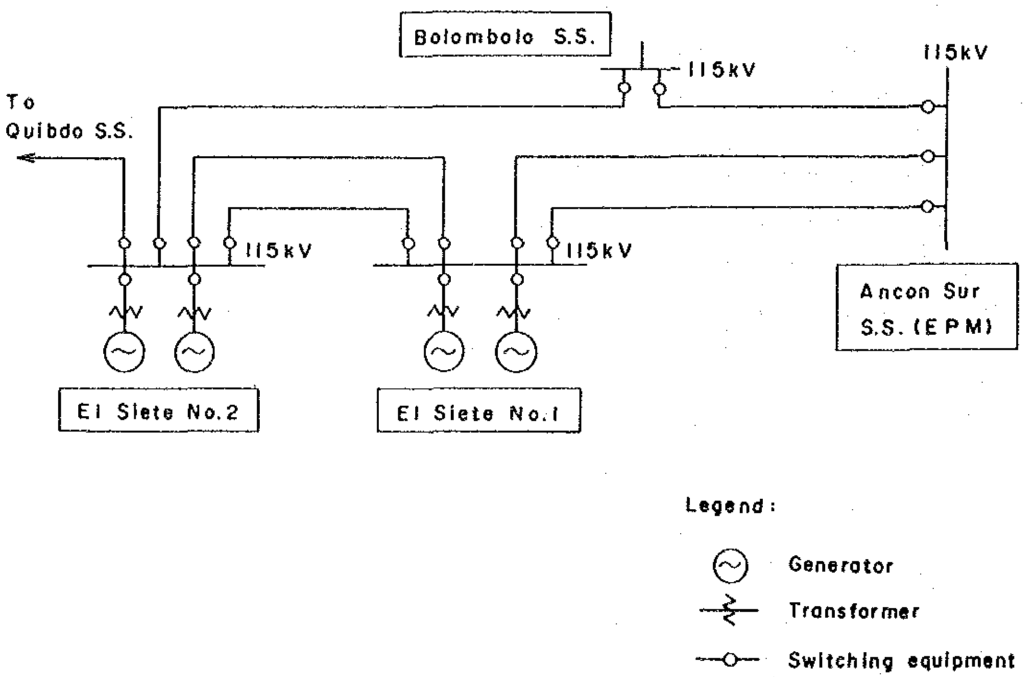


Table-13.1 Economic Comparison of Transmission Voltages

Items \ Voltage	230 kV	115 kV
Construction costs (Thousand US$)		
Transmission lines	13,392	8,705
Transformers	2,568	1,048
Switching equipment	5,672	4,352
Total	21,632	14,105
(1) Annual cost	2,596	1,693
Transmission losses		
Peak power loss (kW)	2,950	7,080
Annual energy loss (GWh)	17.13	41.12
Power loss (Thousand US$)	456	1,095
Energy loss (Thousand US$)	382	917
(2) Annual cost	838	2,012
Total of annual cost (1) + (2) (Thousand US$)	3,434	3,705 (271)

Note: (1) Annual factor is 0.12 of construction cost for transmission line, transformer and switching equipment.

(2) Cost for power loss and energy loss
(a) 154.7 US$/kW/year
(b) 0.0223 US$/kWh

The results show that the 230 kV plan is economically superior to the 115 kV plan.

In terms of construction costs only, 115 kV is less expensive, but the transmission loss in the 115 kV is less expensive, but the transmission loss in the 115 kV plan is 2.4 times that of the 230 kV plan. As a result, overall annual costs in the 230 kV plan is US$271 thousand less than that in the 115 kV plan.

Therefore, 230 kV voltage was chosen for the projected transmission line.

The results of power flow and voltage calculations of these two plans are presented in 13.4 (4). The calculation of the transmission losses in the economic comparison is based on these power flow calculations.

(5) Conductor Size Selection

In selecting the conductor size, a study was carried out taking into account the corona disruptive critical voltage and the current carrying capacity.

Three types of conductor size, ACSR 330 mm^2, 410 mm^2 and 520 mm^2 were studied, with ACSR 410 mm^2 being selected.

The contents of this study are presented below.

1) Corona disruptive Critical Voltage

As described in paragraph (3), the Atrato transmission line route runs through mountainous areas at altitudes ranging from 600 to 2,000 m. As altitude increases, the disruptive critical voltage at which the corona is started is reduced, due to reduced relative air density. For this reason, conductor size must be selected with which the corona is not generated at the normal operating voltage of the line.

The corona disruptive critical voltages, for conductor sizes ACSR 330 mm^2, 410 mm^2, and 520 mm^2 are given in Table 13-2.

Corona disruptive critical voltage was studied for altitudes 2,000 m and 1,500 m, assuming both fair and rainy weather conditions.

Table-13.2 Conductor Size and Corona Voltage

Corona voltage & conductor size / Elevation & Climate	Maximum voltage gradient on the conductor surface G (kV/cm)			Gradient of the corona distruptive critical voltage Ego (kV/cm)			Corona distruptive critical voltage V (kV)		
	330 mm²	410 mm²	520 mm²	330 mm²	410 mm²	520 mm²	330 mm²	410 mm²	520 mm²
Case-A H = 2,000 m t = 20°C Fair weather	16.5	14.9	13.7	19.9	19.6	19.4	277.1	302.2	325.1
Case-B H = 2,000 m t = 15°C Rainy weather				*1 16.1	15.8	15.7	*2 223.9	244.2	262.7
Case-C H = 1,500 m t = 25°C Fair weather				20.4	20.1	19.9	283.9	309.7	263.2
Case-D H = 1,500 m t = 20°C Rainy weather				*1 16.4	16.1	16.1	*2 229.3	250.1	269.2

Note: 1) *1 : Ego < G
2) *2 : V < System voltage 230 kV

The study results indicated that for the conductor ACSR 330 mm^2, the gradient of the corona disruptive critical voltage (Ego) is below the maximum voltage gradient (G) on the conductor surface, and corona is generated in rainy weather at the 1,500 m altitude as well as at 2,000 m.

With this conductor size, the corona disruptive critical voltage is 223.9 kV at 2,000 m altitude, and 229.3 kV at 1,500 m altitude, both of which are below 230 kV.

This means that the conductor size must be ACSR 410 mm^2 or larger, from the corona disruptive critical voltage point of view.

2) Carrying Capacity

The current carrying capacities of the three types of conductors, ACSR 330 mm^2, 410 mm^2, and 520 mm^2 are presented below.

Conductor size (mm^2)	Allowable Current (kA/line)*1	Carrying Capacity (MW) *2
ACSR 330	0.720	272/line, 544/2 lines
ACSR 410	0.830	314/line, 628 2 lines
ACSR 520	0.965	365/line, 730/2 lines

*1: At the continuous operating temperature of the conductor of 90°C

*2: The calculation of the thermal carrying capacity P is based on the following equations.

$$P = \sqrt{3}\ V\ I\ \text{Cos}\theta \qquad \text{(MW)}$$

where;

V = transmission voltage (= 230 kV)

I = allowable current of the conductor

$\text{Cos}\theta$ = power factor of power flow in conductor (assumed to be 0.95)

From the corona disruptive critical voltage point of view, the minimum conductor size allowed is ACSR 410 mm^2. The carrying capacity of the ACSR 410 mm^2 conductor is 314 MW/line, providing sufficient margin for the transmission of the total output of El Siete No.1 and No.2 Power Stations, which is 160 MW.

(6) Number of Lines

Studies on the supply reliability and economic comparison were performed for selection of the number of lines, and the 2-lines system was selected. The contents of these studies are presented below.

1) Supply Reliability

As the El Siete No.1 and No.2 Power Station dams are designed for daily regulations, the storage capacities are small and the power plant operation periods are long.

This design makes the capacity factor of the two power plants as high as 77 to 79%. The dams would immediately overflow, should the power stations or transmission line stop for any reason.

It is therefore required to design the transmission line that constraints on power station operations by the transmission line are as little as possible. From the supply reliability point of view, it is worthwhile to design the transmission line with two circuits, and provide sufficient capacity to each circuit to continue power generation and power transmission even when the other circuit is out of service.

2) Economic Comparison

An economic comparison study was conducted on the single line and double line plans, in terms of annual costs arising from transmission construction costs and transmission losses.

The study results are given in Table-13.3.

Table-13.3 Economic Comparison of Number of Line

(Thousand US$)

Costs \ Number of Line	1 Line	2 Line
Construction costs		
Transmission line	9,180	13,392
Switching equipment	1,440	2,880
Total	10,620	16,272
Annual costs		
Transmission line	1,102	1,607
Switching equipment	173	346
Power loss	471	236
Energy loss	394	197
Total	2,140	2,386 *(246)
kWh loss/day (caused by the interrupted line)	70.0 *246 is equivalent to 3.5 days of the interrupted line	

Note: (1) Annual factor is 0.12 of construction cost for transmission line and switching equipment.

(2) Cost for power loss and energy loss
(a) 154.7 US$/kW/year
(b) 0.0223 US$/kWh

The study indicated that the annual cost of the single line plan is US$246 thousand below that of the double line plan.

However, with a single line, the dam cannot store the inflow and spills water, as described in the preceding paragraph, when the line is shut down for routine maintenance.

The loss ocurred by transmission line shutdown for a period of only one day amounts to US$70 thousand per day, meaning the advantage of US$246 thousand in the annual cost, previously cited, would be written off by only 3 or 4 days of transmission line outage.

Transmission line outage frequency is dependent to geographical and meteorological conditions. Especially, transmission line fault by lightning strokes is most frequent, accounting for 60 to 80% of the total fault, although the frequency does depend on regional conditions.

According to the IKL map, the IKL (Isokeraunic Level) in the Republic of Colombia is 60, which is a relatively high value. Transmission line's fault statistics indicate that the fault frequency is 5 times/100km/year in an area where IKL is 20.

Applying these statistics to the Colombia's area of IKL 60, the fault frequency can be calculated as 15 times/100km/year, implying that the 108 km long Atrato transmission line will be subjected to an average of 16 lightning strokes per year.

Other than fault by lightning, the line must be shut down for routine maintenance works. Based on these factors, it is expected that the transmission line will be out of service for at least 3 days or more per year.

From these considerations, selection of the double line is not regarded as an excessive investment.

(7) Alterations of Existing 115 kV Quibdo Line Connections

The existing 115 kV line (160 km), which runs from the EPM's Ancon Sur Substation to Quibdo Substation through Bolombolo Substation, happens to pass the Atrato project site. This transmission line is currently used to send power from the EPM's Ancon Sur Substation to Bolombolo and Quibdo Substations.

It is planned that the Atrato line (108 km) for this project is connected to the ISA's Ancon Sur Substation, located near the EPM's Ancon Sur Substation.

As a result, the existing 115 kV Quibdo line and the 230 kV Atrato line run parallel on the same route, and the direction of power flows on both lines are reversed to each other for the 108 km section.

To alleviate these reverse power flows, the existing 115 kv Quibdo line can be connected to El Siete No.2 Power Station, and power can be supplied directly to Quibdo Substation. In this scheme, section of the 115 kV line from El Siete No.2 Power Station to Bolombolo Substation is to be separated from the operating power system (See Figure 13-2 (b)). This system configuration alteration provides the following effects.

- Power supply reliability to Quibdo Substation is increased.
- Transmission losses in the existing Quibdo line and the new Atrato line are reduced.
- Maintenance costs with the existing Quibdo line is reduced.

(8) Outline of Transmission Line Facilities

The basic design parameters of this project's new transmission lines are outlined below.

1) El Siete No.2 Power Station to El Siete No.1 Power Station.

Length:	8 km (E.L. 800 to 1,100 m)
Voltage:	230 kV
Number of circuits:	2
Conductor:	ACSR 410 mm^2

Ground wire:	GSC 55 mm^2 x 2
Insulator:	250 mm suspension insulators, 16 - 17/string
Type of towers:	Angle steel tower

2) El Siete No.1 Power Station to Ancon Sur Substation of ISA

Length:	100 km (E.L. 600 to 2,000 m)
Voltage:	230 kV
Number of circuits:	2
Conductor:	ACSR 410 mm^2
Ground wire:	GSC 55 mm^2 x 2
Insulator:	250 mm suspension insulators, 16 - 17/string
Type of towers:	Angle steel tower

3) El Siete No.2 Power Station to existing 115 kV Quibdo line. (Section for change)

Length:	0.5 km (E.L. 800 to 1,000 m)
Voltage:	115 kV
Number of circuits:	1
Conductor:	ACSR 170 mm^2 (equivalent to ACSR 336MCM)
Ground wire:	GSC 38 mm^2 x 1
Insulator:	250 mm suspension insulators, 10 - 11/string
Type of towers:	Angle steel tower

4) Structural Design of Tower

The structural outline of a typical 230 kV line steel tower is illustrated in Fig. 13-2 (c).

13.2 Power System Analysis

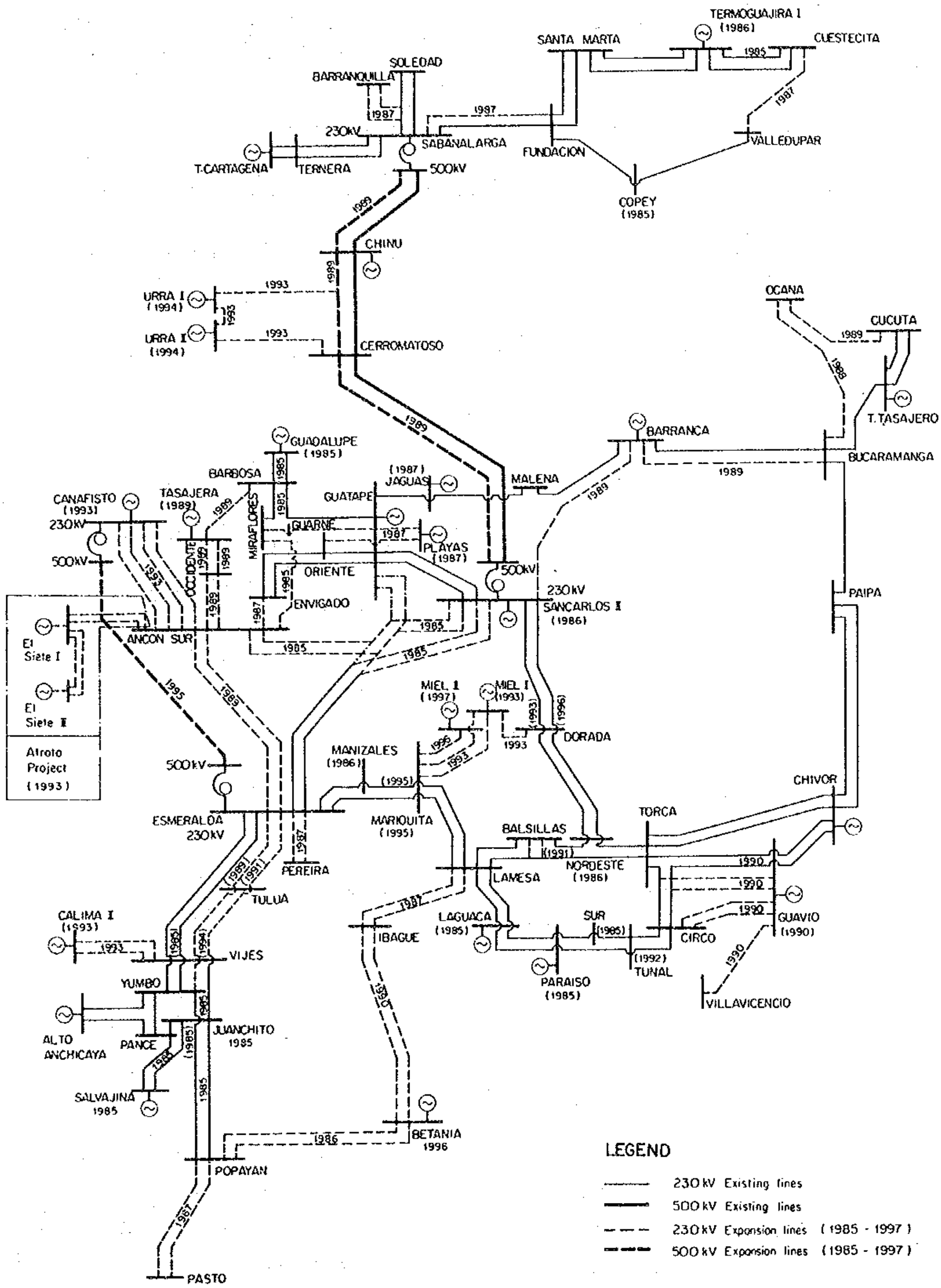
(1) Outline of poqwe system

The power system in the Republic of Colombia is being organized as a unified network that consists of a 230 kV for the primary network and a 115 kV for the secondary network. 500 kV lines to interconnect between the CORELCA network in the northern area and the central and southern networks, consisting of EPM, EEEB, CVC and ICEL networks, was constructed in 1982 and are being operated at present with 230 kV.

Furthermore expansion of 500 kV transmission lines are planned for Urra No.1 and No.2 Power Stations. After the 500 kV lines are put into practice, operating with the rated voltage, the primary network will consist of 500 kV and 230 kV lines.

National primary network is illustrated in Dwg.-03 and Fig. 13-4.

Fig. 13-4 National Primary Network



(2) Analytical theme

The power system analysis have been carried out to examine the stable power transmissin and the characteristics of the power system related to the development of El Siete No.1 and No.2 Power Stations and transmission line planning for them.

The objective themes for the analysis are as follows:

- System calculation for voltage selection of Atrato transmissin line

- Examination of the power system stability associated with El Siete No.1 and No.2 Power Stations

- Examination of the characteristics in the primary network

- Short-circuit current of the primary network

(3) Premise for calculations

Premise for the power system analysis are set as follows.

1) Objective years and items of calculations

i) Objective years

- 1993 as El Siete No.1 and No.2 Power Stations will be in operation.

ii) Items of calculations

- Power flow and voltage calculation
- Power system calculation
- Short-circuit current calculation

2) Conditions for the calculations

i) Power flow and voltage calculation

To keep the balance of the power supply and demand in the network for the power flow calculation, about 80% of the installed generating capacity in EEEB, EPM, CVC, CORELCA and ICEL networks must be in service and its shortage power is supplied by ISA's generators.

The power flow and voltage calculations are carried out by setting the operational conditions of power system as follows:

- System voltage to maintain	95% - 105% of the rated voltage
- Operating voltage of generator	100 ± 5% of the rated voltage
- Operating power factor of generator	Above 0.85
- Tap ratio of transformer	1.00 ± 0.075
- Power factor of feeder load	0.85
- Power system load	about 8,000 MW at peak hours

In order to maintain the system voltage within the range mentioned above, static condensers or shunt reactors are to be applied to the appropriate substation buses.

The power system load and the operating generators of each regional network are given in Table 13-4.

Table-13.4 List of Power Stations and Power Demand Used for the Calculations

Power System	Power Demand (MW)	Paralleled Power Stations		
		Rated Capacity (MVA)	Rated Output (MW)	Output at peak hr. (MW)
EEEB				
Salto, Coleg.		531	425	400
Paraiso, Guaca		750	600	600
Sub total	2,040	1,281	1,025	1,000
EPM				
G. Lupe, Trone.		680	550	440
Guatape		700	560	480
Playas		250	200	170
Tasajera		375	300	260
Sub total	1,640	2,005	1,610	1,350
CVC				
Alto Anchi.		430	345	340
Calima		450	360	310
Salvajina		337	270	270
Sub total	1,000	1,217	975	920
ICEL				
Rio Negro, etc.		314	251	200
El Siete No.1		93	75	75
El Siete No.2		106	85	85
Paipa		210	170	170
Barranca		120	97	80
Tasajero		188	150	150
Sub total	1,740	1,031	828	760
ISA				
Chivor		1,250	1,000	860
Chinu		166	133	50
San Carlos		1,550	1,240	848
Jaguas		210	170	160
Betania		625	500	480
Guavio		1,250	1,000	860
Sub total	0	5,051	4,030	3,258
CORELCA				
Sub total	1,550	1,240	992	780
Grand Total	7,970	11,825	9,460	8,068

3) Stability calculation

Power system stability calculations directing at the generators of El Siete No.1 and No.2 Power Stations are carried out in the following conditions.

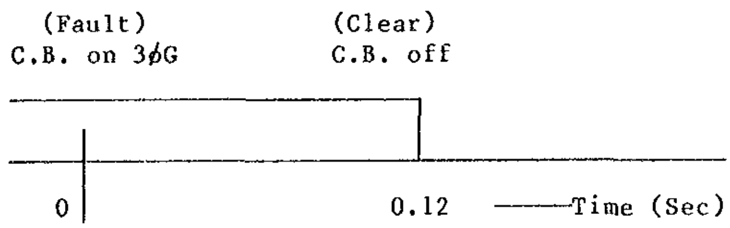
As a disturbance on the power system, three-phase ground fault (3ϕG-F) is applied on the Atrato Line and the perturbations of all generators after the disturbance is examined.

For giving a severe impact on the power system, the following conditions are added to the preceding situation:

- The fault resistance at the fault point is considered as zero
- The function of AVR and GOV for generator and turbine is ignored
- Reclosing the fault line is not simulated

Fault sequence applied to the line is shown in the following illustration.

For the fault clearing time, 0.12 seconds are used provided that the protective relays operate normally.



4) Short-circuit current

The capacities of generators used for the short-circuit calculation are the same that are used for the power flow study in 1993's peak load.

The total capacity of the operating generators is 12,000 MVA since that the system load is 8,000 MW. The list of generators capacities in the each regional network is given in Table 13-4. For the generator reactance, the direct-axis transient reactance Xd' is used.

5) Network configuration

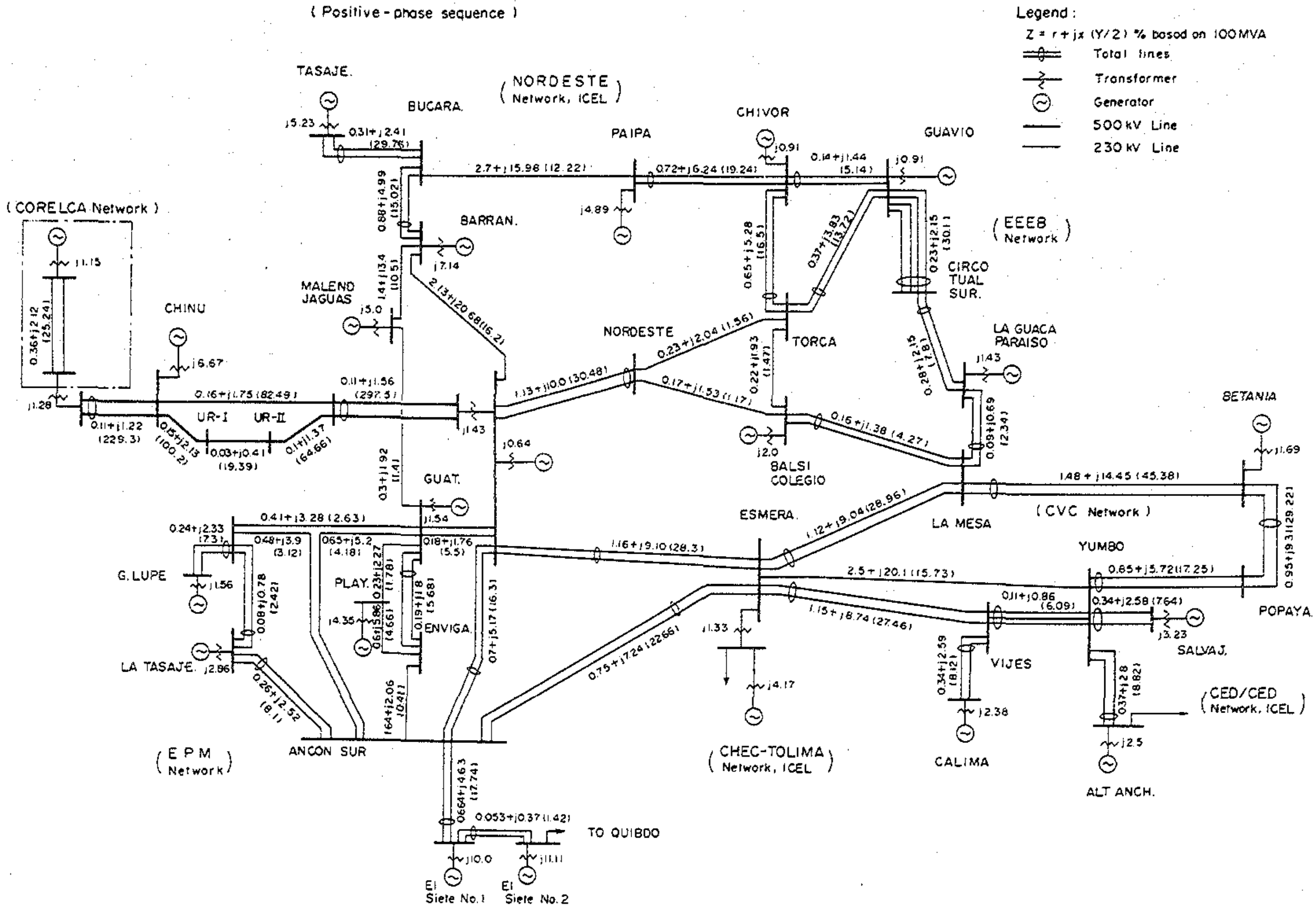
The scope of the calculation network is the same as for the primary network which consists of 500 kV and 230 kV lines.

The primary network spreads more than 1,000 km between the north and the south and encomposes a huge mesh system, so that the regional networks are simplified for the calculations. Particularly, the CORELCA network which is the greatest distance from the Atrato site is simulated as a one-machine system.

Few differences between the simplified network and the detailed network arises, so that it can be considered that there is no problem on the power system calculation method, because this calculation is limited only for analysing the Atrato project. The system configuration and line impedance used for the calculation are shown in Fig. 13-5.

Fig. 13-5 Impedance Map in 1993 Network

(Positive - phase sequence)



(4) Results of Analysis

1) Power Flow and Voltage Calculation

a) Voltage comparison of Atrato Line

For selection of the Atrato Line voltage, the power system characteristics were compared for 230 kV and 115 kV lines by calculating the system voltages and power flows.

The system configurations for each voltage are illustrated in Fig. 13-3.

i) 230 kV transmission line

The power flows in the 230 kV line system are presented in Fig. 13-6 (a) and (b).

The case in (a) is the normal system status with both 230 kV line circuits operating throughout all sections.

In case (b), one 230 kV line circuit is stopped throughout all sections, and operations are handled with only one circuit.

The difference of bus voltages between El Siete No.2 Power Station and ISA's Ancon Sur Substation is 2.8% with both circuits of the 230 kV line operating, and 3.7% in the severest condition, or with only one circuit operating. Both of these values are in the allowable range.

With the 230 kV design, it is possible to supply reactive power from El Siete No.1 and No.2 Power Stations to the primary network to maintain power system voltages.

Transmission loss is 2.95 MW in the normal state of line operaiton. This loss value includes the transmission loss of the 115 kV line between EPM's Ancon Sur Substation and Bolombolo Substation, in order that the transmission loss is compared with that of the 115 kV transmission plan on the same basis.

ii) 115 kV transmission line

The power flows of 115 kV transmission line are illustrated in Fig. 13-7 (a) and (b). In case (a), the three transmission line circuits are operating throughout all sections, and (b) is the case in which the power flow of the main transmission line is the heaviest, with the transmission line from El Siete No.2 Power Station and Bolombolo shut down.

The voltage difference between El Siete No.2 Power Station and EPM's Ancon Sur Substation is 4.3% in the normal transmission line operation, and 5.3% in the severest case, or with one line shut down. Although these voltage difference values are relatively large, the 115 kV bus of El Siete No.1 and No.2 Power Stations can be operated at voltages below 105%, if the 115 kV bus voltage of EPM's Ancon Sur substation can be kept in a range of 10% from the rated voltage.

With the 115 kV transmissin line, the bus voltages of El Siete No.1 and No.2 Power Stations rise substantially if it is attempted to supply reactive power from these power stations. Thus these stations are not expected to contribute to the system voltage regulation.

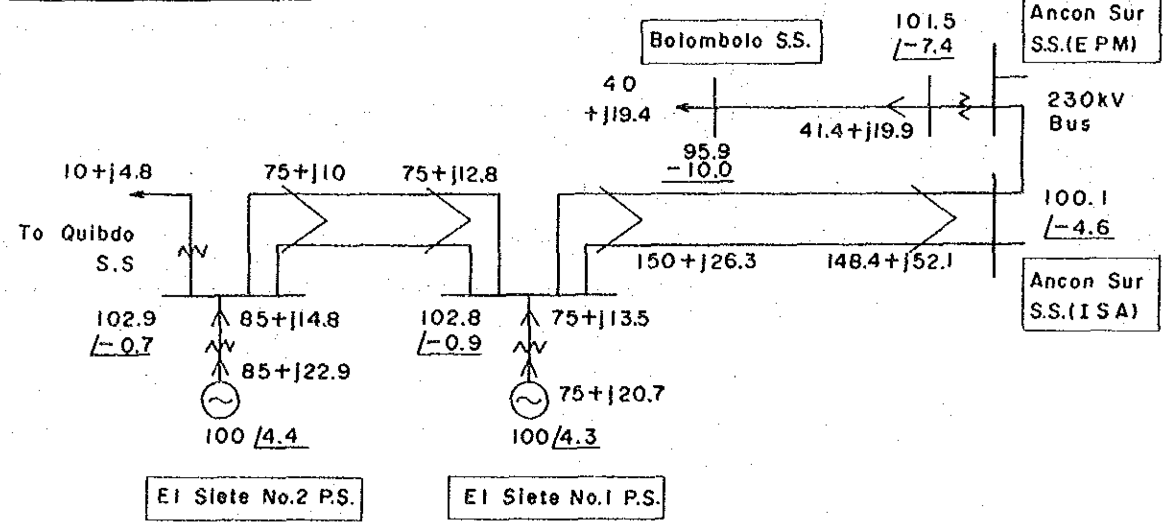
The transmission loss is 7.08 MW in normal operation of the lines.

The 230 kV lines have the following merits compared with 115 kV lines:

- To have abilities for maintaining the system voltage
- To decrease the transmission losses

Fig. 13-6 Power Flow of 230 kV Atrato Lines

(a) Normal operation



(b) 2-Lines are out of service

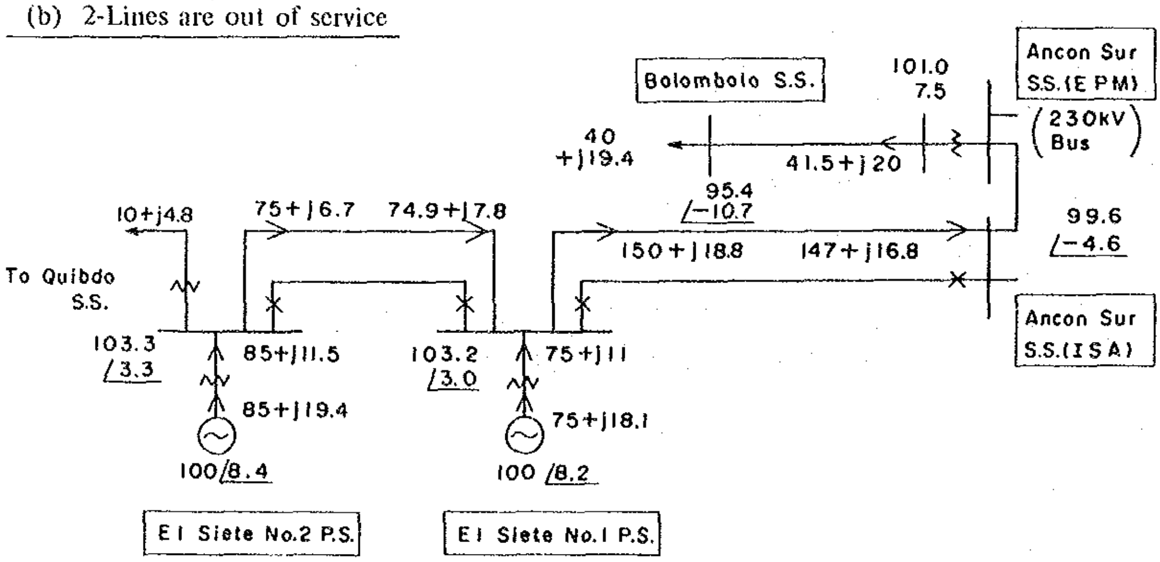
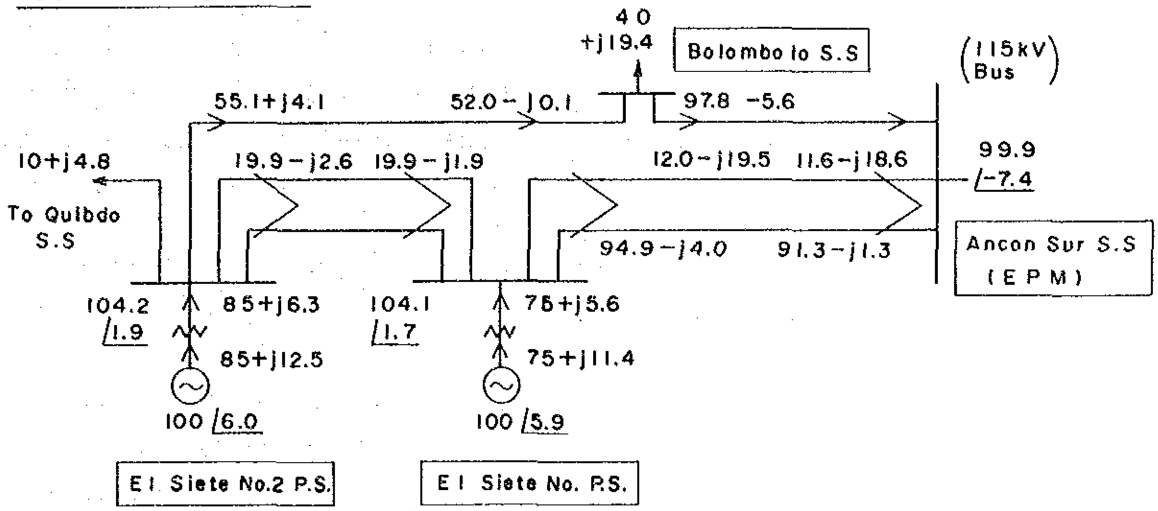
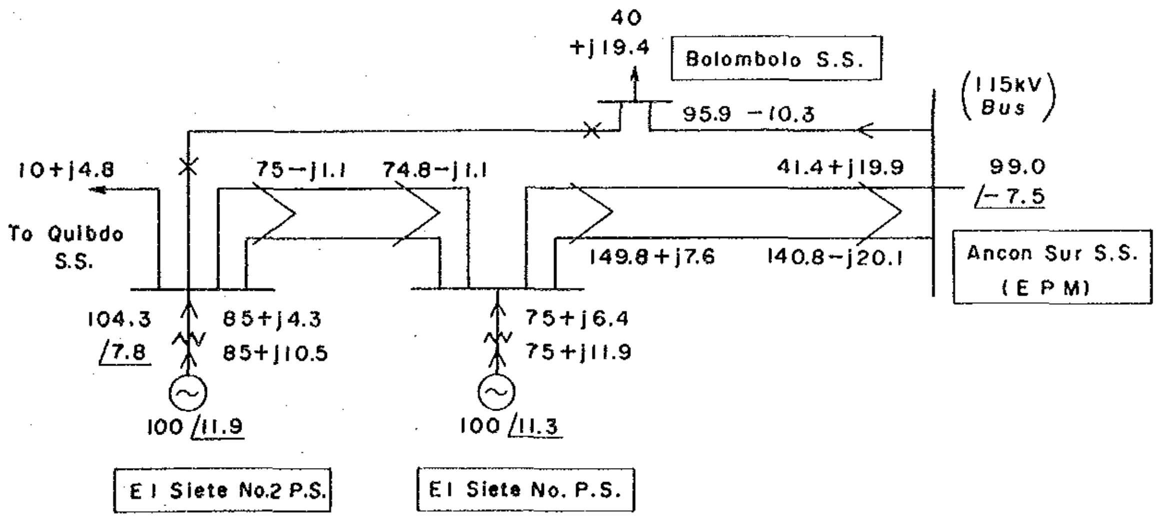


Fig. 13-7 Power Flow of 115 kV Atrato Lines

(a) Normal operation



(b) 1-Line is out of service



b) Primary network

The primary network power flow diagram is presented in Fig. 13-8. As the outstanding characteristic of the primary network, the following voltage characteristics are noted:

- The CVC network bus voltages in the south are lower than in other network. This is because the distance from the major power stations and the load center is large in the CVC system, causing large voltage drops.

- Due to the Ferranti effect of the 500 kV transmission line between the San Carlos Substation in the central district and the Sabanalarga Substation in the northern district, the voltages in the 230 kV network near the 500 kV network, as well as the 500 kV network itself, tend to rise. Shunt reactors are required in the 500 kV network to suppress this voltage rise. (663 MVA of shunt reactors in the case in Fig. 13-8). As the voltage rise in the 500 kV system in the light-load time would be even severer than in peak times, overall planning and operation guides will be required to suppress voltage rise as the primary network is expanded.

  This Ferranti effect is associated with the characteristics of the primary network, and is caused irrespective of the Atrato project.

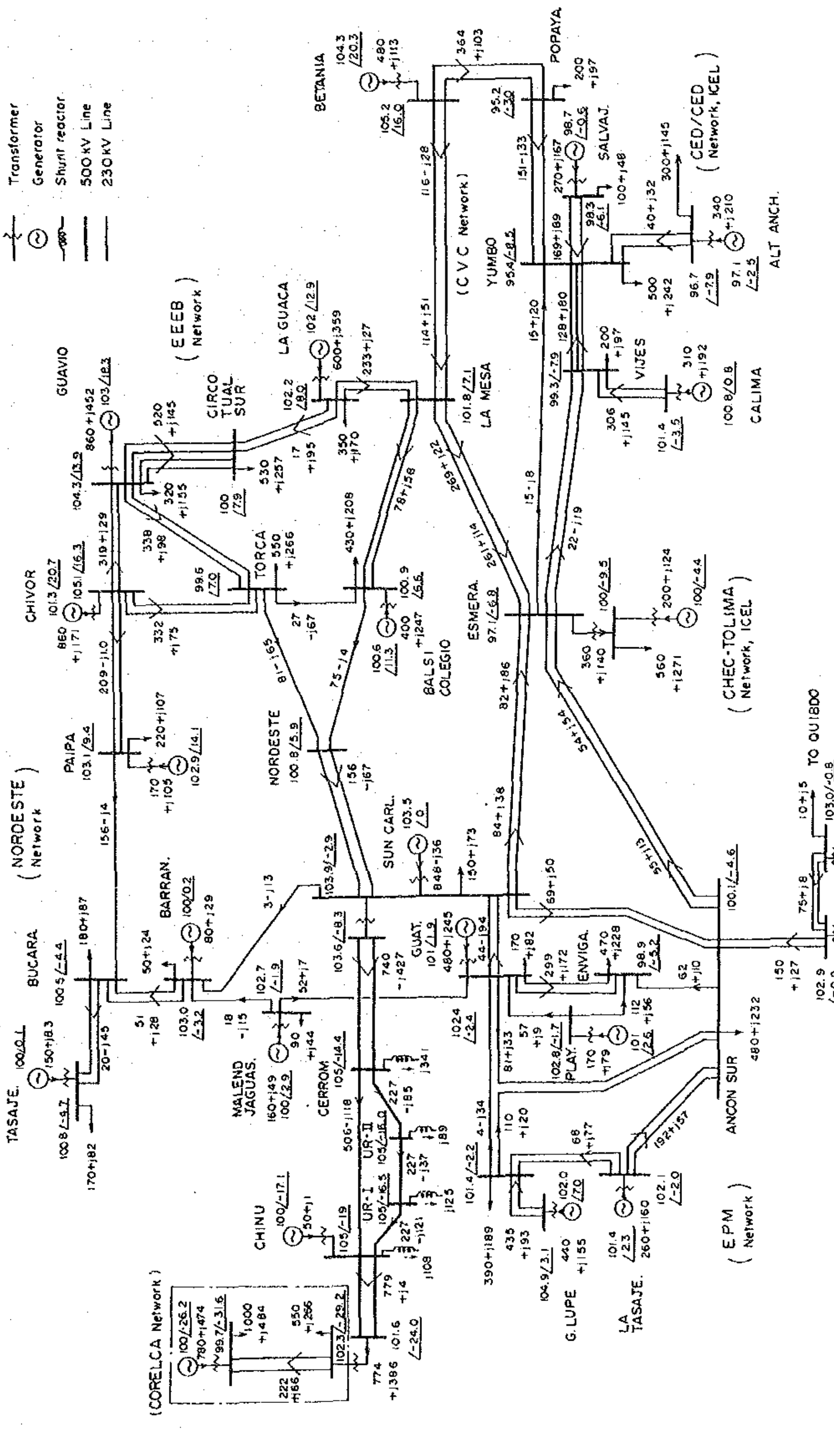


Fig. 13-8 Power Flow Diagram

(Peak hours in 1993)

2) Power system stability

Fig. 13-9 and Fig. 13-10 show the swing curves of generators as a result of power system stability calculation.

Fig. 13-9 shows the case of applying the disturbance to Atrato line between El Siete No.1 and NO.2 Power Stations, the closest point of El Siete No.1 Power Station's bus, and after one of the two lines is isolated.

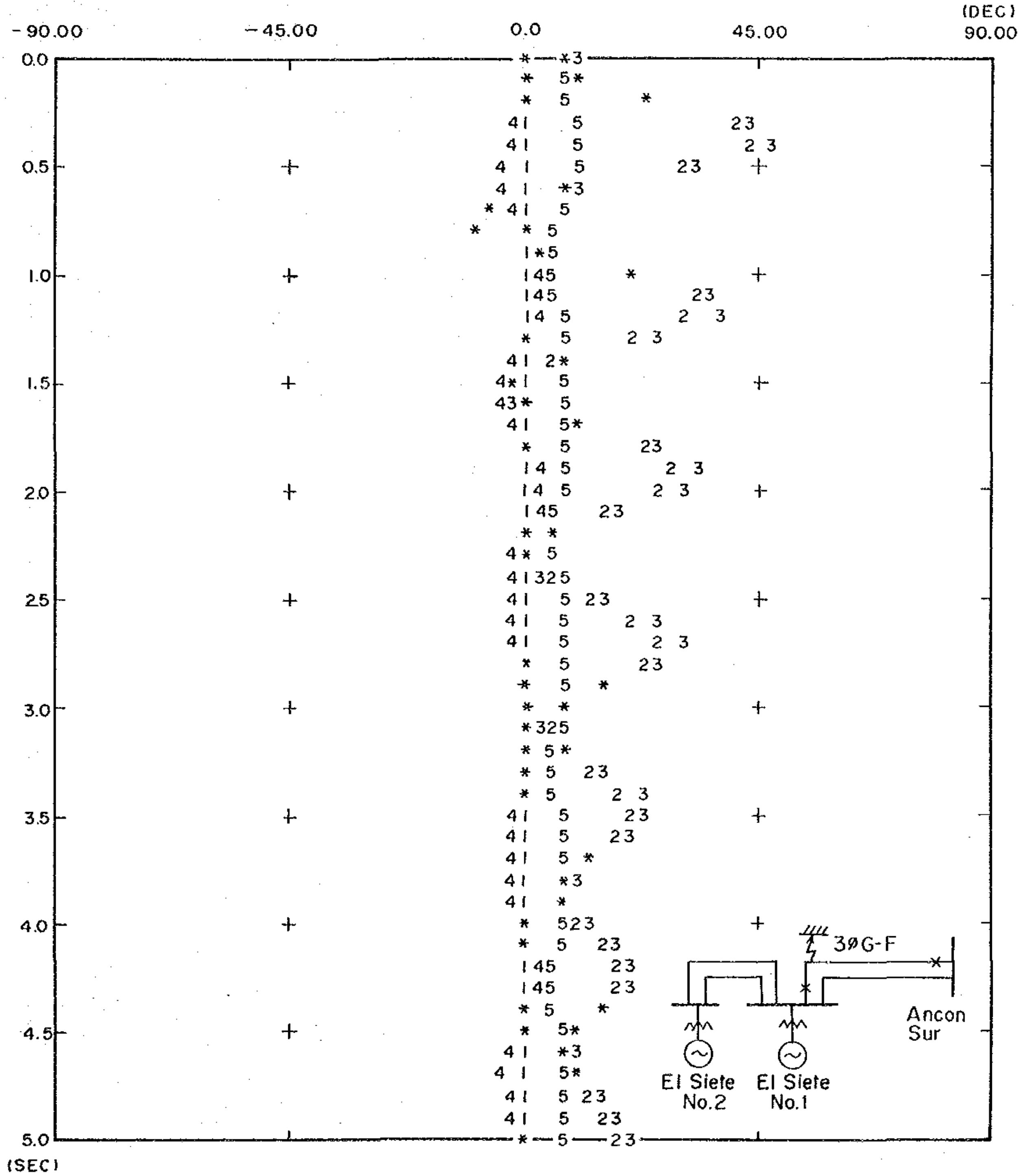
Fig. 13-10 shows the case of applying the disturbance to the closest point of Ancon Sur Substation's bus and after one of the two lines is isolated.

In both cases, the generators of El Siete No.1 and No.2 Power Stations are very stable as well as the other related networks.

The phase angle of El Siete No.1 and No.2 Power Stations' generators gain 30-40 degrees after the disburbance, but the affection of three perturbations for the related network is very slight because the generator's perturbations converge in 3.0 to 4.0 seconds.

Stability calculation applying the disturbance on the Atrato line between El Siete No.1 and No.2 Power Stations was not carried out, because the line length of this is very short and its power flow is a light. Therefore, the phase angle difference between the both terminals of the line is under 1 degree, so that a system statbility problem will not occur in it.

Fig. 13-9 Dynamic Stability Swing Curve after 3ø G-Fault at El Siete No.1 P.S.

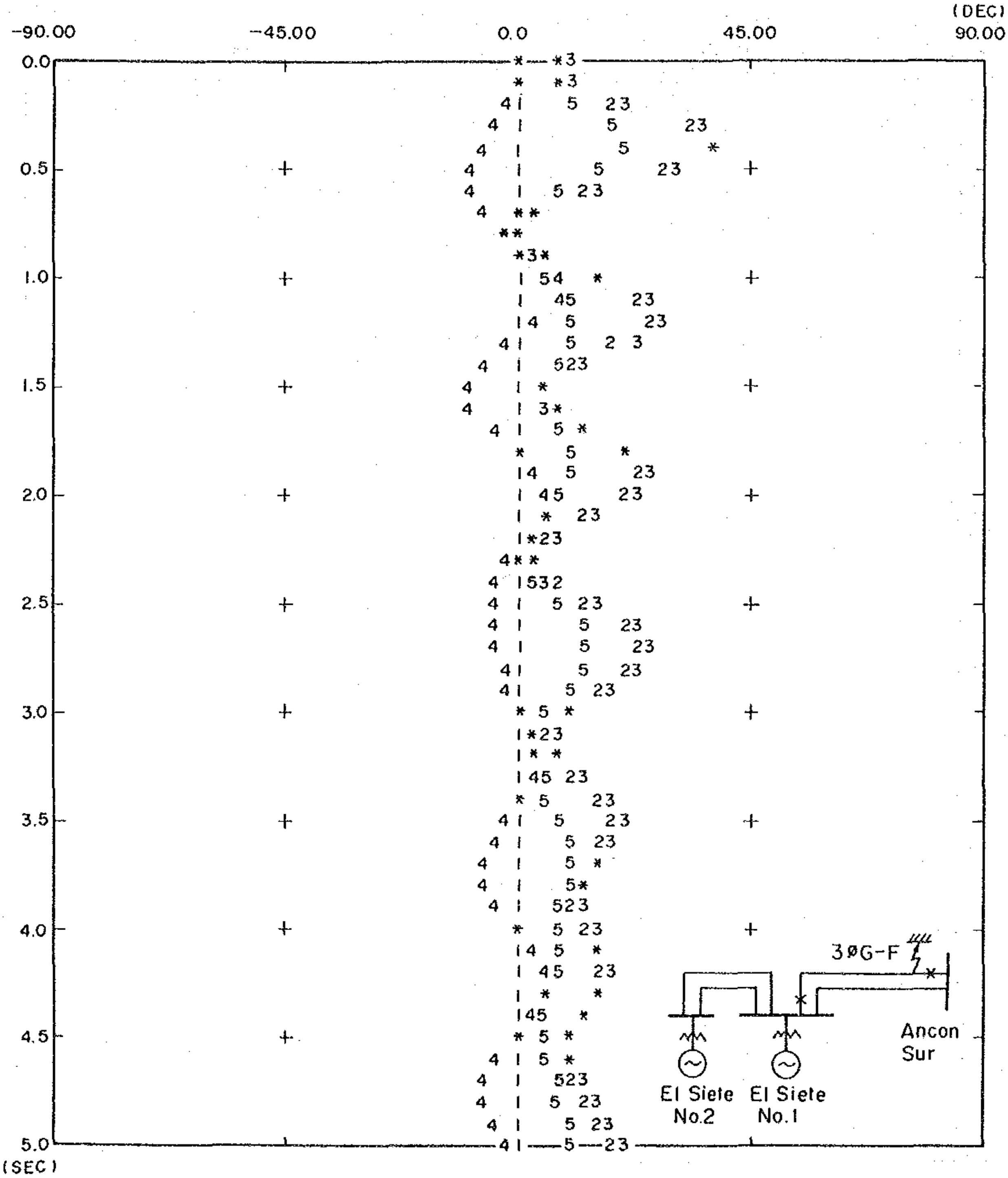


Symbol Generator:

1 = San Carlos (Base) 2 = El Siete No.1 3 = El Siete No.2

4 = Calima 5 = Guadalupe

Fig. 13-10 Dynamic Stability Swing Curve after 3ø G-Fault at Ancon Sur S.S.



Symbol Generator :

1= San Carlos (Base) 2 = El Siete No. 1 3 = El Siete No. 2

4= Colima 5 = Guadalupe

3) Short-circuit current

The result of the calculations is shown in Fig. 13-11 in the form of 3-phase short-circuit current of the bus in each substation.

The short-circuit currents of the buses connected to Atrato Line are as follows:

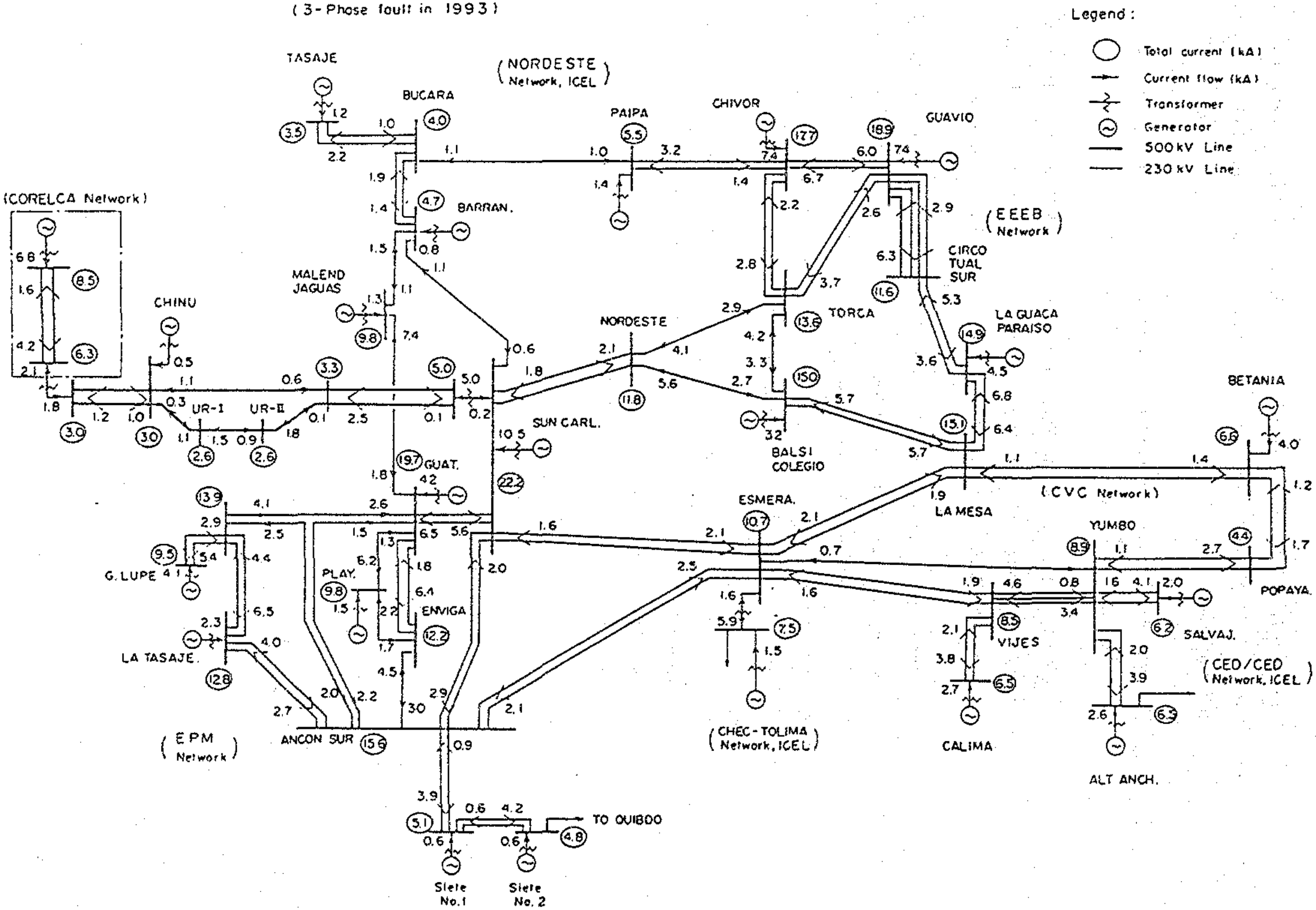
230 kV bus of El Siete No.1	:	5.1 kA (2,020 MVA)
230 kV bus of El Siete No.2	:	4.8 kA (1,911 MVA)
230 kV bus of Ancon Sur	:	15.6 kA (6,215 MVA)

Short-circuit current value is 0.9 kA that flows into the bus of Ancon Sur Substation from El Siete No.1 and No.2 Power Stations through Atrato Lines. Impact of this increased short-circuit current is a negligible level to the power system equipment in Ancon Sur Substaion.

Therefore, there is no need to take any measures for the equipment in Ancon Sur Substation against the increased short-circuit current.

Fig. 13-11 Short-Circuit Current

(3-Phase fault in 1993)



4) Frequency Deviation

El Siente No.2's generator is larger than El Siete No.1's with a 42.5 MW capacity. This capacity is very small relative to the power system's total load, and for this reason, frequency deviation is trivial, should one of the generators be dropped.

In this study, frequency deviation was checked by assuming a case wherein both Atrato line circuits are stopped while El Siete No.1 and NO.2 Power Stations are operating at the rated output (160 MW), that is, a dropout of 160 MW supply from the system.

It is projected that the peak system load will be approximately 8,000 MW in 1993, and the midnight load 3,200 MW (assumed to be 40% of the peak).

The frequency deviations be caused by a dropout of 160 MW supply from the system will be 0.2 Hz (59.8 Hz system frequency) at peak load time and 0.5 Hz (59.5 Hz system frequency) at midnight light-load time, based on apporoximate calculations.

The effect of the frequency deviation of these magnitudes is almost negligible and this project does not create a cause which may produce substantial system frequency deviations.

CHAPTER 14. CONSTRUCTION WORK PROGRAM

CHAPTER 14 CONSTRUCTION WORK PROGRAM

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CHAPTER 14. CONSTRUCTION WORK PROGRAM

14.1 Conditions for Construction Execution in Project

The following points are considered as for work execution conditions in the El Siete No. 1 and No. 2 Hydroelectric Power Development Projects.

(1) Road Situation

The project site is 120 km from Medellin, the capital city of Departamento de Antioquia and 80 km from Quibdo, the capital city of Departamento de Choco.

The two cities are connected by a national road, along which the project site is located.

This road greatly facilitates transportation of materials and equipment required for construction of the project, hauling of livelihood commodities, and the movement of laborers.

Running along the right-bank side of the damsite at the El Siete No. 1 dam site, at the opposite bank of the Atrato River at the El Siete No. 1 powerhouse site, and further on the powerhouse side at the El Siete No. 2 powerhouse site, it is extremely convenient for transportation. Although there are few paved sections, the condition of the road is generally good.

(2) Material Procurement

Seen from the locations of the project sites and road conditions it will be possible for principal materials (cement, reinforcing bars, steel, etc.) to be procured at Medellin throughout the construction period.

Regarding cement, both quality and quantity can be secured with domestic products. The closest cement plants to the project sites are those of the Argos company in Medellin City and the Cemento El Cairo company in Montevello.

Reinforcing steel can also be procured in Medellin City, similarly to cement.

It is however possible that there will be shortages, and partial imports should be considered.

Other than special items, procured in Medellin, but concern will remain about shortages.

It will be necessary for gasoline, lubricating oil, etc. to be purchased in bulk at Medellin and stored on site. There are gasoline stations at Bolivar and the town of El Siete, but these can only play supplementary roles.

(3) Construction Materials

It will be difficult for concrete aggregates such as sand and gravel to be obtained from river beds or river terraces in the project site vicinities.

The project site is located at the upper most reaches of the Atrato River. The river there is narrow, and the stream is swift so that river deposits are mainly boulders and cobbles. Smaller gravels and sand are not deposited in the neighborhood of the project site.

Accordingly, it will be necessary to seek an aggregate quarry in the project area, to collect rock in bulk, and to crush, screen and grade the rock at an aggregate plant, thus artificially manufacturing aggregate.

(4) Procurement of Water for Construction

It is necessary that water for construction purposes be clean in adequate quantities secured throughout the year.

As a result of the investigations of tributaries and mountain streams entering the project area, the Toro River and the Shiberia River are in the vicinity of the El Siete No. 1 dam site and water will not be a matter of concern.

Aguila Ravine at the El Siete No. 1 powerhouse site and the Rio Girardot River at the No. 2 intake dam site can be used for water.

The Piñon River flowing in immediately upstream fills the requirements for the El Siete No. 2 powerhouse for site water supply.

(5) Electric Power for Construction

A maximum of 6,000 kW of electric power would be required if construction of El Siete No. 1 and No. 2 Power Station were to be started simultaneously.

Fortunately, a 115-kV, 1-cct transmission line exists between Bolombolo and Quibdo and passes through the project area, and it will be possible to temporarily provide a project substation and receive power directly. In view of the power demand at Quibdo, there will be no problem about the capacity received.

(6) Land for Temporary Construction Facilities

Temporary construction facilities would consist of an aggregate manufacturing plant, concrete manufacturing plants, aggregate stockyards, water treatment plants, offices, quarters, warehouses, etc., for which sites will be required.

In the area of the El Siete No. 1 dam and the No. 1 auxiliary dam, the tableland at the right bank of the Toro River is comparatively gently sloped and has an adequately open space making it suitable for the installation of temporary facilities. This tableland is presently used for grazing.

In the El Siete No. 2 power station area, there is a large hilly table along the national road about 1.0 km downstream from the powerhouse site which can be used as space for temporary facilities.

However, in the case of the El Siete No. 1 power Station, the location as seen from the national road is on the opposite side of the Atrato River so that a permanent bridge will be needed to connect the national road and the powerhouse. A temporary bridge will also be required at the initial stage of construction.

The project supervision office and ICEL quarters would be provided at the town of Carmen de Atrato. This is a small town with a population of approximately 2,000, but is close to the Project and provides the necessary functions. It would be appropriate for the permanent quarters of the operation and maintenance personnel of the two power stations to be provided at Carmen de Atrato when living conditions are considered.

(7) Communications Situation

At present in the project area, there is a telephone office in the Carmen de Atrato town hall buuilding and calls can be made to principal cities such as Bogota and Medellin, but there are very few channels and communications are extremely poor.

The present situation is that in an emergency, one must go to the town of Bolivar de Antioquia (approximately 40 min by automobile) to make calls.

Radio communications are also not very good due to obstruction by the Cordillera Occidental.

Consequently, it will be necessary for the telecommunications situation to be improved to carry out construction of the Project.

(8) Meteorological Conditions

The greatest hindrance to construction of the two projects will be the area's meteorological conditions. As described in detail in Chapter 8, this area has extremely heavy rainfall and is very wet.

Rainfall records show this area to be a heavy rainfall zone with 3,000 mm/year at the El Siete No. 1 dam site, 3,500 to 4,000 mm/year at the El Siete No. 1 powerhouse site, and 4,000 to 4,500 mm at the El Siete No. 2 powerhouse site, as it rains practically every day of the year. Particularly, the 5-month period from April to October is a rainy season during which it is normal for rainfall to occur daily from the afternoon to the middle of the night. Even in the comparatively dry season of November to March, it is not very much different from the rainy season, and there is rainfall in the middle of the night even though for a short period of time.

Consequently, it will be necessary to exercise thorough care regarding measures against rain in construction of the two projects, particularly, in surface work and in excavated slope maintenance.

On the other hand, the area has a mean air temperature of 15 to 20°C and a minimum of 10°C which will not affect concrete manufacturing and placement.

(9) Labor Procurement

A maximum of about 4,500 laborers and other connected with the work at the peak of construction of the two projects will be required.

This labor force would be employed from Quibdo City in Departmento de Choco and from the prefecture in which the cities of Antioquia and Medellin are located.

Quibdo is a city with a population of 65,000, but its employment rate is low, and the greater part of common laborers will be employed from this city or its surroundings.

Skilled laborers will be procured from Medellin City and its surroundings where many people with experience in similar work live.

The only community from which it would be possible to commute from is Carmen de Atrato, and office helpers, including female employees, would be employed this town.

(10) Transportation of Generating Equipment and Heavy Articles

Imported materials and equipment required for the two projects would be unloaded at Santa Marta, Barranquilla, Cartagena, and Buenaventura which are Colombia's principal foreign trade ports.

There would be four routes as described below for the inland transportation of heavy articles such as generating equipment from these ports.

Route 1 : Buenaventura port —— Cartago —— La Pintada —— Cardas - Bolombolo —— Bolivar - project site

Route 2 : Barranquilla port or Cartagena Port —— Sincelejo —— Caucasia port —— Medellin —— Bolombolo - Bolivar - project site

Route 3 : Barranquilla port —— (transfer to barge) —— Rio Magdalena boat navigation —— Puerto Triunifo port —— Medellin —— Bolombolo —— Bolivar - project site

Route 4 : Barranquilla port - (transfer to barge) - Magdalena River and Cauca River boat navigation - Caucasia port - Medellin - Bolombolo - bolo - Bolivar - project site

Route 1 and Route 2 above are for road transportation from major ports via truck and trailere. Route 3 and Route 4 are transportation schemes using boats up the Magdalena River and the Cauca River from the port of Barranquilla and then switching to road transportation.

The features and the transportation weight limits of individual routes are described below.

1) Route 1

It is possible for 60,000-ton class ships to berth at the port of Buenaventura. The port is equipped with cranes with capacities up to a maximum of 45 tons. Accordingly, there will be no problem in loading and unloading. Buenaventura is Colombia's largest port, handling 50 percent of the imports and exports of the country.

The road from Buenaventura to the project site is 542 km long, and is 7 m wide. Most of the distance is concrete paved and the surface maintained in good condition.

Four long bridges cross the Cauca River, the Buga Bridge, La Virgina Bridge, La Pintada Bridge, and Bolombolo Bridge, all of which are 7.0 m wide with 60 ton load limits.

However, there are 5 road tunnels from 100 to 400 m in length between the port of Buenaventura and Buga.

These tunnels are 7.1 m wide and 6.0 m high so that load dimensions will be limited.

Heavy articles, including equipment for projects such as Quatape, San Carlos, Jaguas, and Guadalupe IV were transported by road over Route 1 .

There are two mountain passes along Route 1 , Alto Minas Pass (EL. 2,400 m) 327 km from Buga and La Manza Pass (EL. 2,000 m), which crosses the Cordillera Occidental.

Some sections of these passes are steeply graded and it will be necessary to provide assistance with other locomobile. (See Figs. 14-1 and 14-2.)

2) Route 2

The port of Barranquilla handles the largest volume of imports and exports and is the best-equipped of the ports facing the Caribbean Sea. The port is a river-mouth port utilizing the mouth of the Magdelena River. Piers are provided along the river banks and although five ships of 20,000-ton 30,000-ton class can be berthed, freighters of 50,000- to 60,000-ton class must be unloaded off-shore. Handling of heavy articles such as generators would be especially inefficient.

The road is 938 km long to the project site, and is 7.0 m wide. The section between Barranquilla and Cartagena is concrete paved and in good condition, but the section between Caucasia and Pto Valdivia is not well-maintained.

There are nine bridges along the route that will present transportation problems, the Suspension Bridge, Canal de Digue Bridge, San Jorge Bridge, Man Bridge, Taraza Bridge, Raya Bridge, Pugi Bridge, Cauca Bridge, and Bolombolo Bridge. (See Table-14.1)

The Canal de Digue Bridge is the longest at 284.3 m, with a 4.7 m limit height, and a maximum 30 ton load limit.

The San Jorge Bridge is 164 m long with a 4.5 m height limit, while the load limit is unknown.

The Raya Bridge is a truss type with a 4.2 m height limit and a 60 ton load limit. Consequently, the transportation limits are 30 ton load limits and 4.2 m heights. Transportation of extremely heavy articles and of large-sized cargo will be subject to restraints.

Route 2 was also partially used in past projects, with transportation carried out limited to these restrictions.

There are three mountain passes along the route, the Santa Rosa de Osos Pass (EL. 2,580 m), the Restaurante Monte Frio Pass (EL. 2,460 m), and the La Mansa Pass (EL. 2,000 m).

The 25-km section between Valdivia and Yarumal of the Restaurante Monte Frio Pass has a height differential of 1,350 m, a climb of 5.4 percent on the average. (See Figs. 14-1, 14-3.)

3) Route 3

Tugboat towed watercraft are utilized on the Magdalena River between the ports of Barranquilla and Puerto Triunifo.

However, these are not scheduled sailings, and trips are made whenever sufficient cargo is available.

In the low-water season, the Magdalena River's water level falls presenting draft problems which often hinders navigation.

This boat transportatin is suited to transporting very heavy articles and large size cargo but is normally used only for bulk shipment of cement, vegetables and fruit.

The road from the pvert of Triunifo to Medellin is approximately 200 km long and is 7.0 m wide with a 60 ton load limit.

The Samana Bridge located on this road has a 4.2 m height limit which restricts cargo dimensions.

From Puerto Triunifo (EL. 200 m) to Medellin (EL. 1,500 m), are the Santugo Pass (EL. 2,300 m) and the Guarne Pass (EL. 2,460 m) which present problems in respect to the gradient of the road. Severe grades are also located at other parts of this road. (See Figs. 14-1 and 14-2.)

4) Route 4

This is route utilizes boats on the Magdalena River and the Cauca River from the port of Barranquilla, while from the port of Caucasia to the project site is the same as Route 2 , Consequently, there will be the same 60 m load limit at bridges as on Route 2 after switching to road transportation. Also, navigation may be hindered in the low-water season due to lowering of the Magdalena River's water level as in the case of Route 3 .

On comparisons of the four routes described above, each presents advantages and disadvantages, but it is judged possible for sure transportation to be carried out throughout the year with Route 1 , partly because it has a performance record as a transportation road for heavy articles.

Consequently, it will be appropriate to select Route 1 as the principal transportation route for the El Siete No. 1 and No. 2 projects. However, depending on the port of arrival of imported articles, the weights and dimensions of the articles, and the season in which they arrive, routes, 2 , 3 , and 4 , are also to be used, thus supplementing Route 1 . (See Figs. 14-1, 14-2, 14-3, 14-4 and 14-5, Table-14.1.)

Fig. 14-1 Transportation Route Map

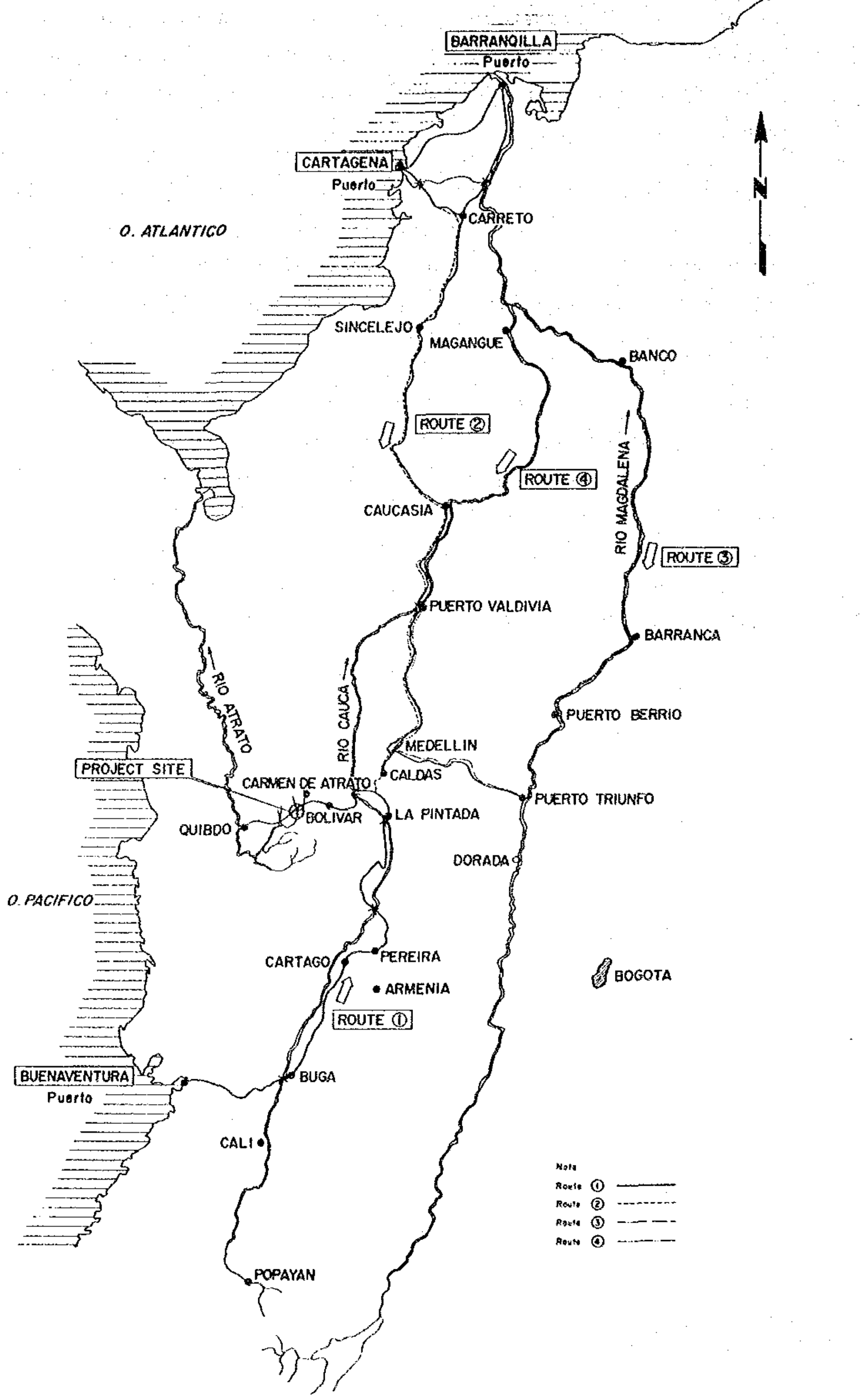


Fig. 14-2 Transportation Route of Heavy Machine and Equipment

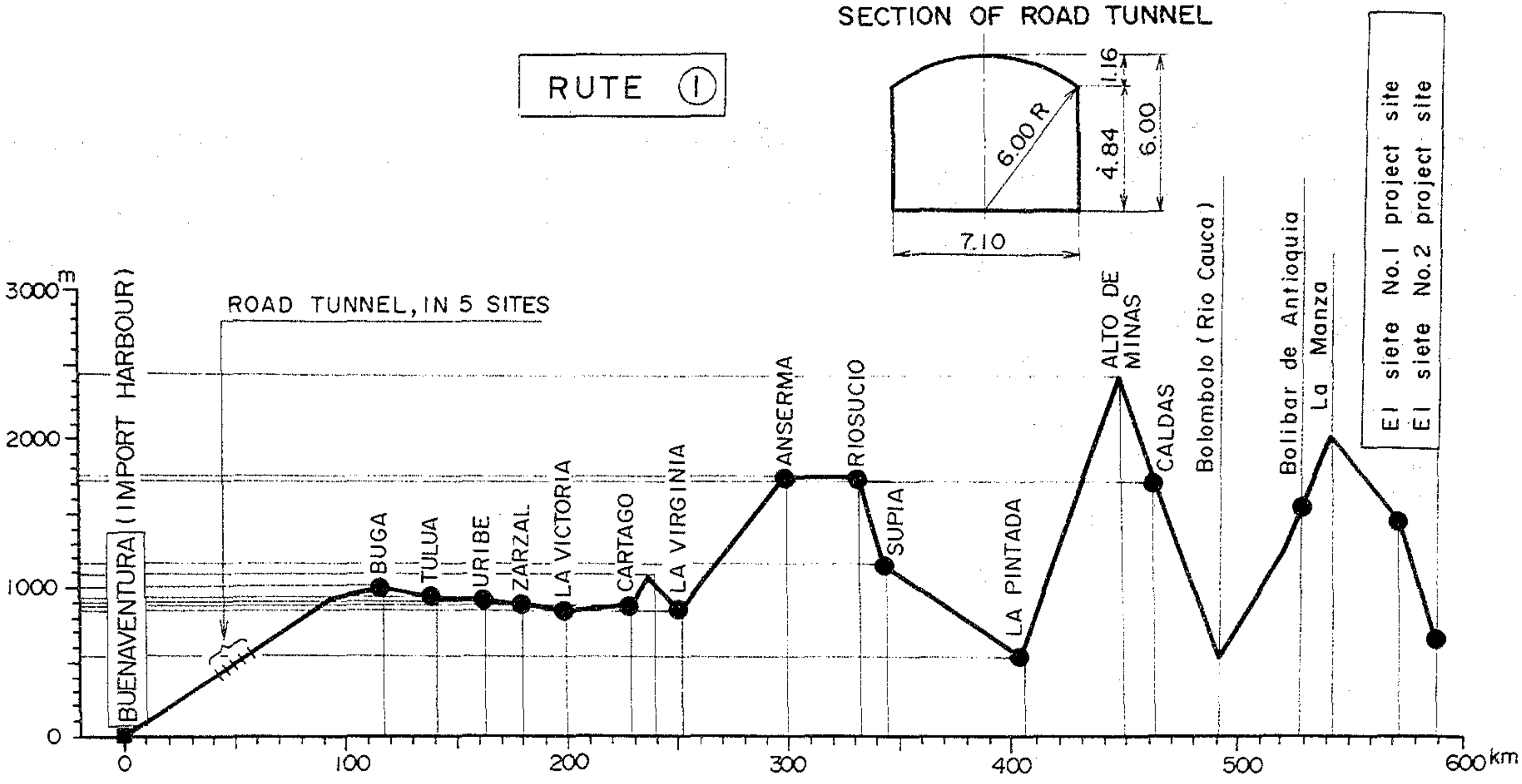


Fig. 14-3 Transportation Route of Heavy Machine and Equipment

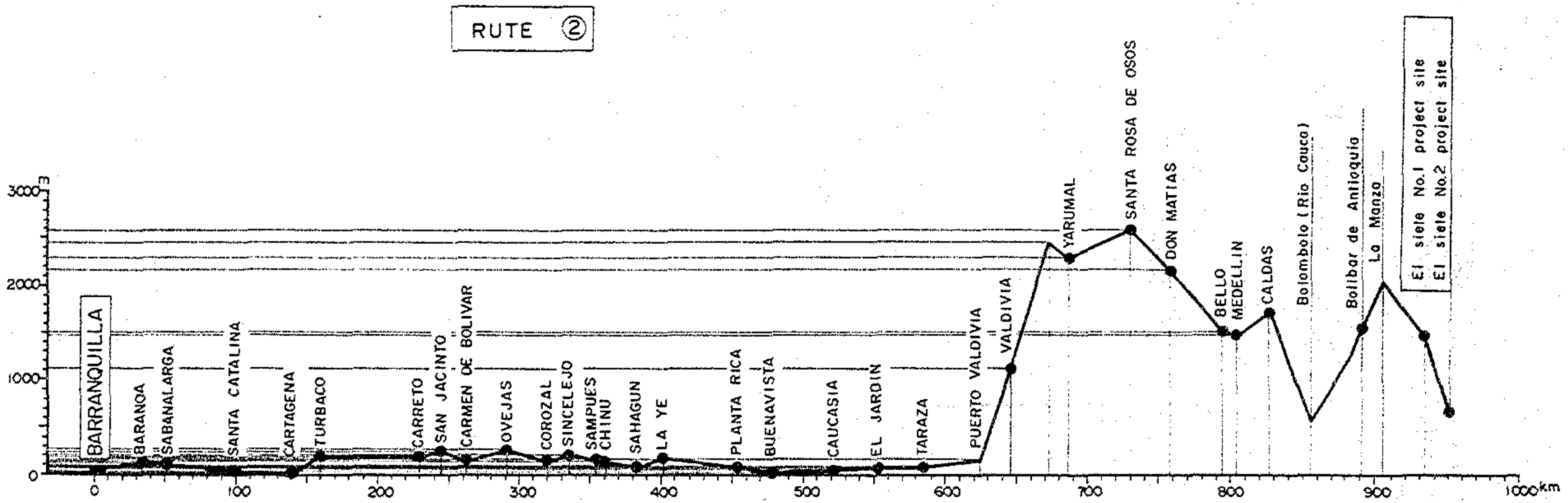


Table-14.1 Present Conditions of Bridges of Route 2

	Road					Bridge			Critical Bridge					
	Length (km)	Width (m)	Pave	Cap. (ton)	Condition	No.	Mater.	Length (m)	Name	Length (m)	Width (m)	Height Limit	Cap. (ton)	Mater.
Barranquilla Cartagena	142	7	Conc.	60	Good	15	Conc.	60-31	Suspiros	30.0	12.0		60	Conc.
Cartagena Sincelejo	188	7	Gravel	30	Common.	1 33	Steel Conc.	284.3 60-31	Canal de Dique	284.3	8.7	4.7	30	Steel
Sincelejo Caucasia	184	7	Conc.	-	Good	1 25	Steel Conc.	164 65-30	Rio San Jorge	164	6 0	4.5		Steel
Caucasia pto Valdivia	108	7	Conc.	60	Good	1 19	Steel Conc.	63-90						
pto Valdivia Medellin	176	7	Conc.	60	Good	1 6 9	Conc. Steel Conc.	9 241 60-90	Rio Man Rio Taraza Rio Rayo Rio Pugl Rio Cauca	61.6 90 50 63.0 241.0	6.0 7.5 7.5 4.6	4.5 4.6 4.3 4.6	60 60 60 60	Steel Steel Steel Steel
Medellin Project Site									Bolombolo					

Fig. 14-4 Transportation Route of Heavy Machine and Equipment

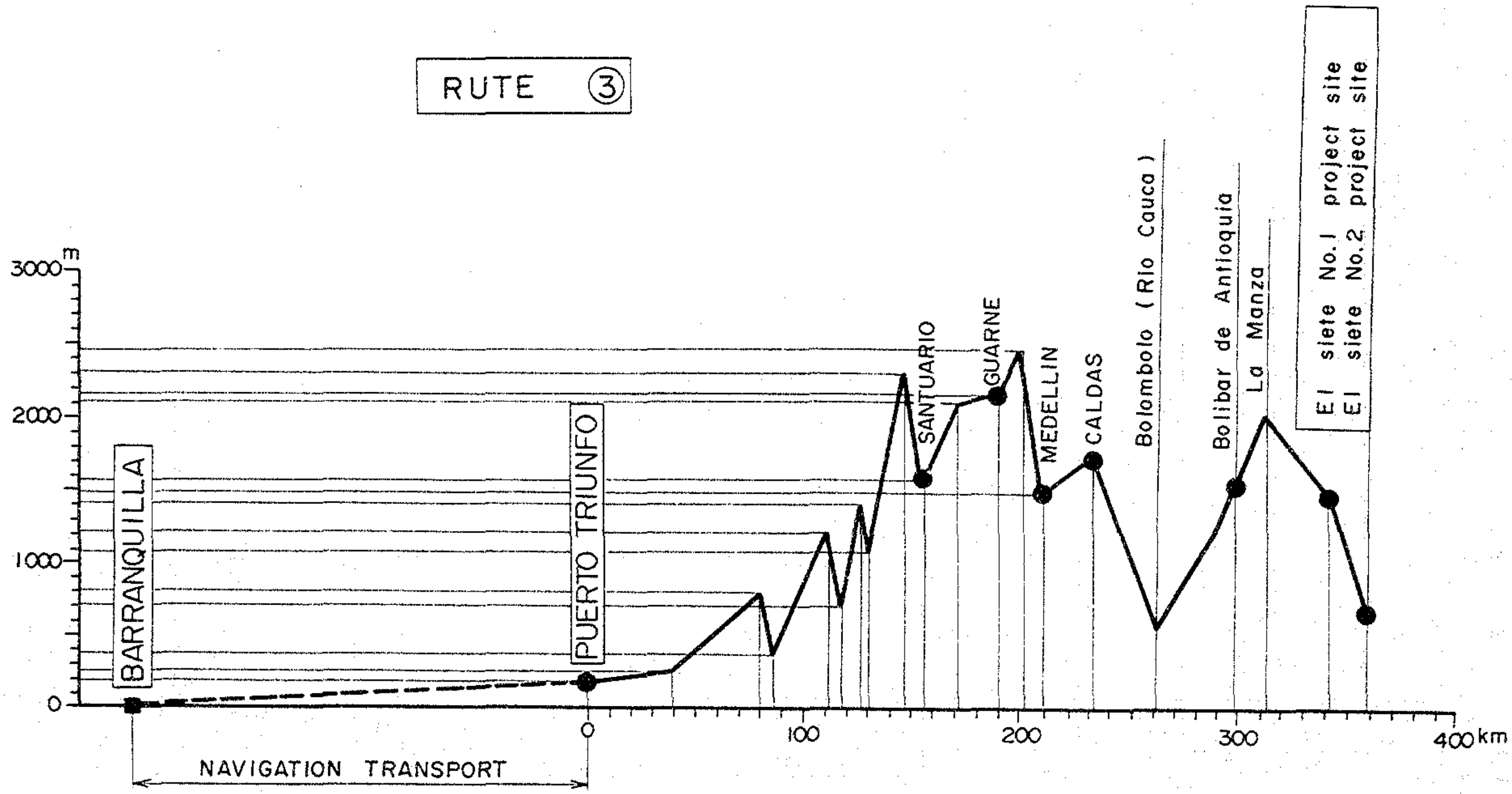
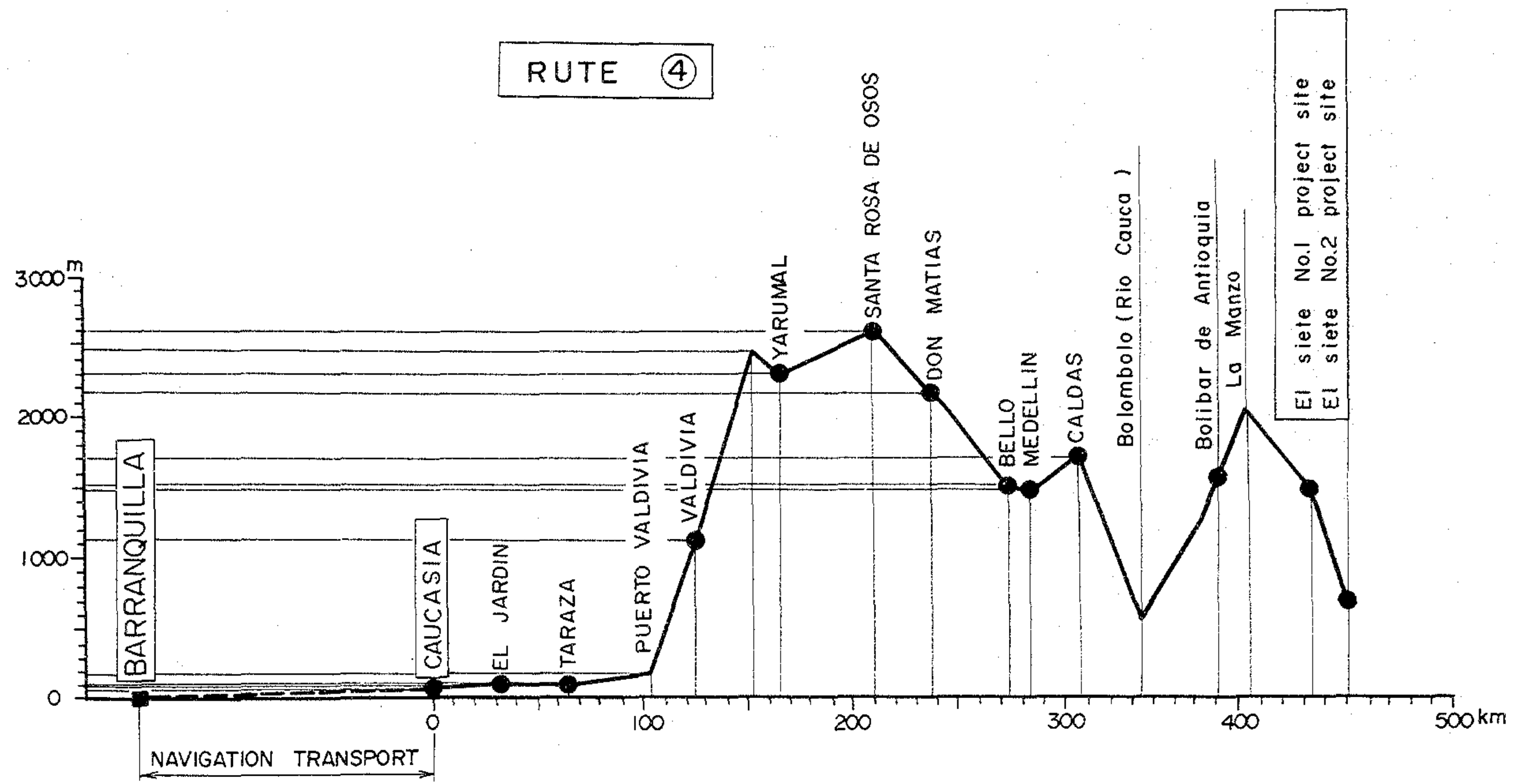


Fig. 14-5 Transportation Route of Heavy Machine and Equipment



14.2 Preparatory Works

Works and matters to be disposed of which should be completed beforehand as preliminary works prior to starting the main work for construction of the El Siete No. 1 and No. 2 power stations are as follows:

- Compensatin for submersion (purchase of land to be submerged, relocation of dwallings to be submerged)

- Relocation of national road (relocation of the parts of the national road on the right bank at the El Siete No. 1 damsite and the No. 1 auxiliary damsite, and the part of the national road crossing perpendicularly with the El Siete No. 2 power station penstock)

- Purchase of land for principal structures

- Construction work on power transformation, distribution facilities and telecommunications facilities

- Construction work for ICEL project supervision office and quarters

- Execution of additional investigation works

It is necessary for the above works to be implemented before starting the main works, with ICEL ordering from domestic constractors upon competitive budding.

14.3 National Road Relocation Work and Access Roads for Construction

The national road connecting Medellin and Quibdo passes through the lots of the principal structures of the El Siete No. 1 and No. 2 power stations, and it will be necessary to relocate a part of the national road.

This national road relocation work would be at the right bank of the El Siete No. 1 dam site, the right bank of the No. 1 auxiliary dam, and a part crossing the El Siete No. 2 power station penstock orthogonically, a total of 3 locations.

(1) At the El Siete No. 1 damsite, the high water level of the El Siete No. 1 regulating pond was planned at El. 1,450 m and the surcharge water level at EL. 1,451 m. As the existing national road is at a elevation lower than these water levels, the road would be submerged. Consequently, with the upstream side of the No. 1 Auxiliary Dam as the starting point, a new road would be built passing the tableland at the right bank of the Atrato River, crossing the Toro River by a bridge passing the open excavation site at the right bank side of the El Siete No. 1 Dam, and connecting to the existing road in the vicinity of the confluence with the Shiberia River. The route is shown in Dwg.-46. It is approximately 1.8 km long and 7.0 m wide. The sections before and after the connection are to be concrete paved.

(2) The El Siete No. 2 Power Station penstock will cross with the national road, and therefore it is necessary for the road to be relocated. This relocation, in view of the topography, is to be by tunnel work. The length would be 170 m, and the cross section is to be 7-m wide and 6.0-m high, making it possible to handle two lanes of traffic. (See Dwg. 40.)

(3) Construction of Access Road for Construction

The works of El Siete No. 1 Dam and the No. 1 auxiliary dam require access roads to reach the dam river beds. Temporary bridges to cross to the opposite banks will also be required. The layout is shown in Dwg. 46.

At El Siete No. 1 Power Station, it will be necessary for an access road branching from the national road and crossing the Rio Atrato by bridge.

This bridge is designed as a permanent structure, 95 m long, 5.0 m wide, with a 60 ton design load.

This access road is to be completely paved and used as an operation and maintenance road after completion of the Project.

It would be necessary El Siete No. 1 Power Station for this access road to be further extended and made into an access road passing the No. 1 penstock to the No. 1 surge tank. As this road connects to the surge tank, it will be as long as 3,800 m.

The access road to the No. 4 adit for the No. 2 headrace tunnel work can be easily branched from the national road and connected.

An access road to the No. 2 powerhouse and the No. 2 substation will also be required El Siete No. 2 Power Station. It will be necessary for this road to cross a creek and a concrete bridge 10 m long, 5.0 m wide is to be provided for this purpose.

It will also be necessary to have an access road from the national road to the No. 2 penstock, the No. 2 surge tank and the work adit of headrace tunnel for El Siete No. 2 Power Station.

The layouts of the above are provided in Dwg.-15, Dwg.-27, Dwg.-39 and Dwg.-46.

14.4 Temporary Facilities for Construction

The principal temporary facilities are an aggregate manufacturing plant, concrete plants, water treatment plants, power distribution facilities, and temporary telecommunications facilities.

The outlines of these temporary facilities are as follows:

(1) Aggregate Plant

562,000 m^3 of rock from the quarry is required at the agregate plant for construction of the various civil structures in the El Siete No. 1 and No. 2 Hydroelectric Power Project.

(Aggregate requirement; 1,016,000 tons, specific gravity of original rock 2.65 ton/m^3 x void ratio 0.95 = 2.52 ton/m^3, loss due to poor original rock 10%, quarrying and transportation loss 10%, aggregate plant loss 15%, required rock volume V = 1,016,000 ton x 1.10 x 1.15/2.52 ton/m^3 = 562,000 m^3)

As described in 15.1, it is not possible to secure the amount of aggregate required with natural aggregates. Consequently, rock for aggregate production is to be obtained from the quarry and to be artificially crushed, sorted and classified as aggregate. (Even when 50 percent of the muck from excavation of the headrace tunnel is diverted to aggregate, this would be approximately 100,000 m^3, and can only play an auxiliary role.)

The quarry for aggregate, described in 6.10 was selected at the El Copo area downstream of the El Siete No. 1 damsite. The geology of this site is basalt, and there is no problem in using it as raw material for aggregate (See Dwg.-46.)

On examination of the concrete placement schedules of the dam, tunnels, etc., it will be necessary to have an aggregate plant of approximately 500 ton/day.

(2) Concrete Manufacturing Plants

The total quantity of concrete, mortar grout, and shotcrete required for the El Siete No. 1 and No. 2 Power Station construction works will be 480,000 m^3. The quantities of concrete used for the various civil structures are as shown in Table 14-2.

It is scheduled for 236,000 m^3 corresponding to 51 percent of the total concrete volume to be placed in the area centered at El Siete No. 1 Dam and El Siete No. 1 Auxiliary Dam (Area 1), 153,000 m^3 corresponding to 33 percent in the area centered at El Siete No. 1 Powerhouse and El Siete No. 2 Intake Dam (Area 2), and 72,000 m^3 correponding to 16 percent in the El Siete No. 2 powerhouse are (Area 3).

These three areas are situated over a 12 km range, and a considerable amount of concrete wil have to be made in each area.

To locate a concrete plant centered at one of these areas would involve problems of quality control arising from concrete hauling. It was therefore decided that a concrete plant of a scale consistent with the volume of concrete to be placed would be located in each area.

(3) Treatment Plant for Water Used in Construction

Construction water will be required for aggregate production, concrete manufacture, concrete curing, construction equipment cleaning, foundation treatment, cleaning, grout, water chutes, etc. in construction projects of this type, and it will be economical to obtain such water in the neighborhood of the construction site. It will also be necessary to draw the water from a nearby mountain stream, settle out and chemically treat the water, and pipe this to the various plants or work sites using water.

At the two project sites, as described in 15.1, it is extremely easy to secure water, and there will be no concern about water supply throughout the year.

Area 1 : At the El Siete No. 1 Dam and the No. 1 Auxiliary Dam area, intake of water can be readily done by providing an intake weir on the Toro River which merges into the main stream of the Atrato River immediately upstream of the El Siete No. 1 dam site. The quantity of water secured will be adequate. It will not be necessary to chemically treat construction water to be provided, but potting water for offices and laborerers' quarters will need to be previsouly sterilized as grazing lands are scattered throughout the Toro River area upstream.

Area 2 : For the El Siete No. 2 Intake Dam and El Siete No. 1 powerhouse area, intake would be at the Girardot from where the water would be supplied by pipeline. The Girardot River has ample discharge, stable throughout the year. There are no dwellings in the area, which is covered by natural forest, and with no collapsed areas, the water is extremely clean. Accordingly, the natural water can be used for construction with simple filtering treatment adequate for drinking water.

Area 3 : At the El Siete No. 2 powerhouse area, ample water can be secured from Piñon Ravine. Water can be supplied to the construction site by natural gravity flow, but supply to the construction camp on the Pinon tableland, which includes quarters, will need chemical treatment and then pumped.

Table-14.2 Volume of Concrete

El Siete No.1

(Unit: m^3)

No.	Description	Concrete	Mortar Injection	Shotcrete
II-1	Care of River	4,870	360	
II-2	No.1 Dam	143,510	40	1,310
II-3	Auxiliary Intake Dam	35,780		240
III-1	Intake	5,810	20	
III-2	Auxiliary Sedimentation Basin	18,640	10	370
III-3	Auxiliary Connection Tunnel	5,060	880	
III-4	Headrace Tunnel	18,640	3,170	
III-5	Surge Tank	1,890	100	60
III-6	Penstock Line	12,080		230
III-7	Power Station	11,500		
III-8	Tailrace Tunnel	1,440	190	
III-9	Sub Station	1,350		
	Sub Total	260,570	4,770	2,210
	Others = 10%	26,430	530	290
	Total	287,000	5,300	2,500

El Siete No.2

(Unit: m^3)

No.	Description	Concrete	Mortar Injection	Shotcrete
II-1	Intake Dam	60,070		250
III-1	Sedimentation Basin	9,950	30	
III-2	Headrace Tunnel	63,110	9,140	
III-3	Surge Tank	2,430	100	40
III-4	Penstock Line	9,610		
III-5	Power Station	9,420		300
III-6	Sub Station	3,340		
	Sub Total	157,930	9,270	590
	Others = 10%	16,070	930	110
	Total	174,000	10,200	700
Grand Total (No.1 + No.2)		461,000	15,500	3,200

(4) Receiving and Distribution of Electric Power for Construction

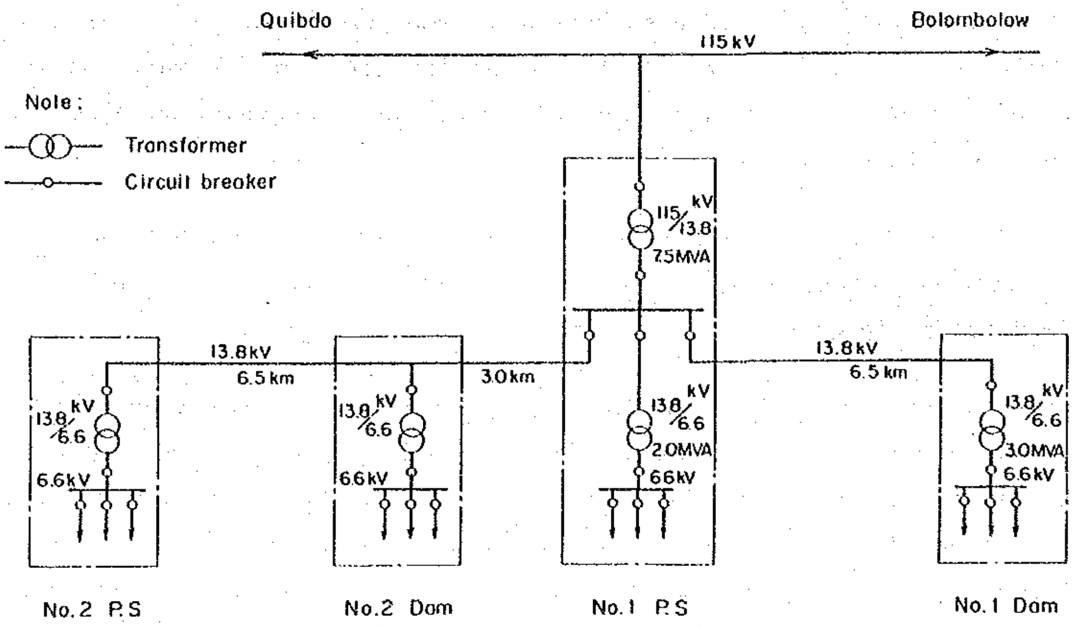
Where the two projects are simultaneously started, a maximum of 6,000 kW of electric power will be needed for construction when considered by project scale and construction schedule, and in comparison with actual records of similar projects.

It was considered that a 115/13.8-kV construction substation should be provided in the project area with power received from the existing 115-kV Bolombolo-Quibdo transmission line.

Either 13.8 kV or 6.6 kV is conceivable for the secondary voltage at the step-down transformer for receiving power from the 115-kV transmission line. When power distribution from the receiving substation to the individual work areas is done, and voltage drops in distribution are calculated, whereas it would be within 5.0 percent for 13.8 kV, it would be more than 10 percent for 6.6 kV. Because of this, 6.6 kV is unsuitable and 13.8 kV is to be adopted.

The construction substation layout is given in Fig. 14-6.

Fig. 14-6 Distribution circuit for Construction Work



(5) Construction Administration Use Telecommunication Facilities

To smoothly expedite the construction work of the Project, it will be necessary for close contact to be maintained between the construction site and Medellin City regarding construction material procurement and securing personnel.

It is also necessary to secure a communication channel with the ICEL head office in Bogota during the construction period.

For this purpose, a power line carrier facility is to be provided over the stretch from the Atrato project site to Bolombolo Substation to Ancon Sur Substation of the existing 115-kV transmission line from which receiving is done at the construction substation, to structure telephone channels for administrative communications required in connection with the Atrato construction sites.

Regarding telephone channels needed within the construction area, a handy-type telephone exchange is to be installed at the Atrato project site, and points inside the project area, the field office, and Carmen de Atrato are to be connected by a network of communication cables.

The communications facilities provided for construction according to the above would be used as the telecommunications lines necessary for operation and maintenance of the 115-kV system in accordance with the following:

- Project site to Bolombolo Substation

  The power line carrier apparatus would be transferred to the section of El Siete No. 2 Power Station to Quibdo Substation to structure a telephone channel for maintenance of this section.

- Bolombolo Substation to Ancor Sur Substation

  A telephone channel for maintenance is structured for the section of bolombolo Substation to Ancon Sur Substation.

Fig. 14-7 Construction Administration Use Telecommunication Circuit

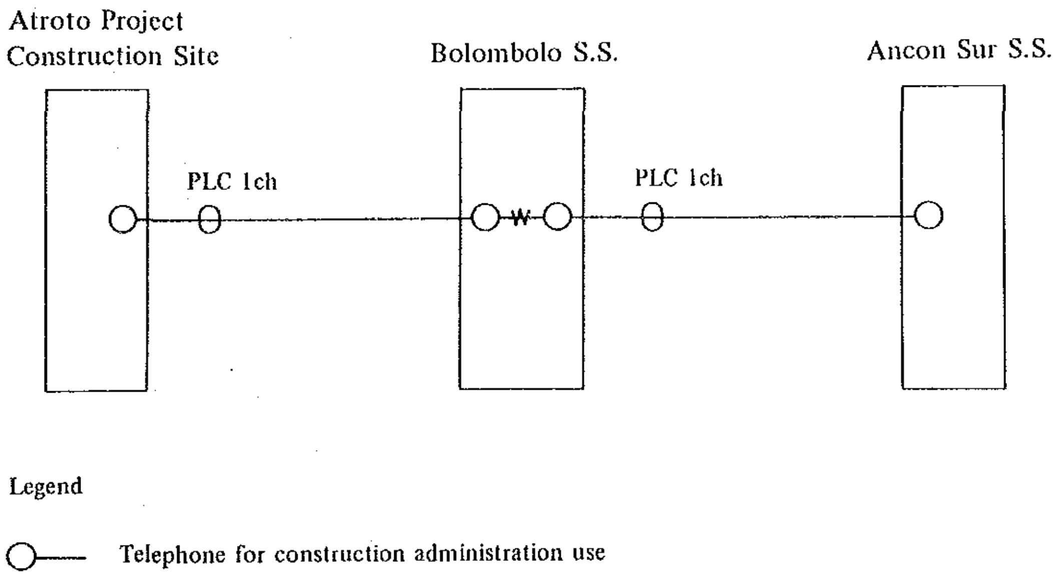
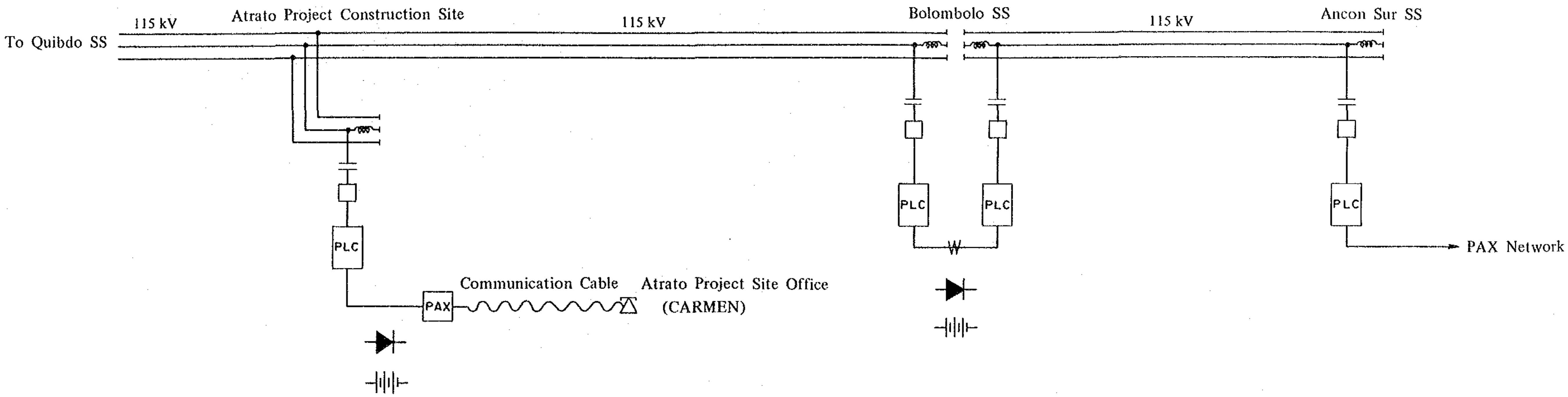


Fig. 14-8 Construction Administration Use Telecommunication Circuit



Legend

- Line trap
- Coupling capacitor
- Phase to earth coupling device
- PLC — Power line carrier equipment
- PAX — Private automatic telephone exchange
- Charging rectifier
- Battery

Note

1. The equipment to be installed between Atrato Project Construction Site and Bolombolo SS will be removed to El Siete No.2 PS and Quibdo SS for the purpose of power system maintenance
2. The equipment to be installed between Bolombolo SS and Ancon Sur SS will be available for power system maintenance use.

14.5 Execution of Civil Works and Installation of Hydraulic Equipment

Matters that should be attended with regard to execution of civil works and installation of hydraulic equipment in this Project are described below.

(1) Open Excavation

Open excavation works will amount to a total of 1,496 x 10^3 m^3, with a total of 1,065 x 10^3 m^3 for the El Siete No. 1 Hydroelectric Power Project and 31 x 10^3 m^3 for the El Siete No. 2 Hydroelectric Power Project.

The work can be done by normal stepped excavation, but as detailed in 15.1, Section 1, Chapter 15, since the excavation would be in a very rainy region according to meteorological observations, care should be exercised to protect slope surfaces and provide drainage ditches at the tops of slopes beforehand without fail.

Slopes should not be left untended for long periods of time, and when slope surfaces have stabilized, they should be covered with shotcrete to protect them against erosion from strong rain.

(2) Tunnel Excavation

Tunnel excavation work will be done at the bypass tunnel for El Siete No. 1 Dam, headrace tunnels, upper parts of penstocks, and tailrace tunnels, the total length amounting to 13,120 m.

The longest section to be worked from any work adit will be that section below Work Adit No. 4 with a length of 2,300 m.

Inner diameters of headrace tunnels are 3.4 m for the No. 1 tunnel and 3.6 m for the No. 2 tunnel.

The critical paths in the construction work schedule will be the penstock and powerhouse works, and therefore it will not be necessary to speed up excavation by adopting a tunnel boring machine (TBM). It will suffice to select an conventional excavation method.

Work adits numbered 1 to 5 would be provided so that there would be 6 working faces. Since the excavation work would be carried out simultaneously at all six, there will be a need for six sets of excavating equipment groups and steel forms to provide concrete linings.

(3) Mass Concrete for Dams

El Siete No. 1 Dam will have a height of 55 m and a volume of 143,000 m^3, and is designed to have transverse joints spaced at 15 m.

In concrete placement a 1.5 m lift height will be suitable. Consequently, maximum placement will be approximately 1,200 m^3.

Precooling by mixing with ice will be required when the regions air temperature is considered, because El Siete No. 1 Dam is a gravity type and consists of mass concrete, but since a sediment flushing duct and a gate chamber will be provided inside the dam due to sedimentation in the regulating pond, it will be necessary to obtain good quality concrete.

Waterstops (Eslon) are to be inserted at transverse joints, and contact grouting should further be executed. Steel forms are to be adopted in consideration of the quality of concrete at the surface.

(4) Structural Concrete

With concrete for civil structures in the El Siete No. 1 and No. 2 projects there will be no problem using normal construction methods.

Considered from the meteorological condition standpoint even if concrete were to be placed in the daytime, rain must be expected during the night. Therefore, attention must be paid to concrete to and the effects of rain.

(5) Penstock Pipe and Gate Installation

The El Siete No. 1 Power Station penstock is long at 1,301 m. Of this length, 178 m is to be installed buried in a tunnel section. The remaining 1,123 m section will be installed on saddles at 12 m intervals. Accordingly, for burial in the tunnel, 6 m pipe units are to be hauled sequentially from the tunnel outlet, joined by field welding from the inside, after which concrete is to be backfilled for complete embedding.

In installation on the ground surface, individual 12-m pipe units are to be set from four places, from the bottom upward starting at Anchor

Block No. 3, Anchor Block No. 7, Anchor Block No. 10, and Anchor Block No. 12 (bottom end), and are to be joined by field welding. The longest of these sections would be that between Anchor Block No. 10 and Anchor Block No. 7, the length being 317.86 m, consisting on 12 m of pipe units and this will govern the installation work period. (See Dwg.-27 and Dwg. 28.)

The El Siete No. 2 Power Station penstock is 1,045 m long and very little different from the former case. Of this length, 67 m will be installed buried inside a tunnel. The remaining 978 m would be installed on saddles on the ground surface at 12 m intervals.

Accordingly, tunnel burial would be done by the same method as at El Siete No. 1 with individual pipe units inserted sequentially from the tunnel outlet, joined by field welding from the inside, after which concrete is to be backfilled for complete embedding.

In installation at the ground surface, individual pipe units are to be set from three places, from the bottom upward starting at Anchor Block No. 12, Anchor Block No. 8, and Anchor Block No. 5, and are to be joined by field welding. (See Dwg.-38, Dwg.-39.)

In both cases, the steel pipes are to be hauled as 3-m pipe units by trailer and 2 each are to be welded in the field (temporary works yard) to fabricate into 6 m pipe units which are to be hauled to the installation site over the access road, hoisted by crane, and carried by platform cars travelling on rail tracks laid along the penstock route for setting at the installation site.

As for welding operations, welding efficiency will be affected by rain and humidity, and it will be necessary to provide countermeasures in consideration of the meteorological conditions at the two project areas, while X-ray weld joint inspection will also be required.

Spillway gates are 12 m high and 10 m wide at maximum. These are to be divided into three parts each at the factory for shipping by ocean going vessel, with transportation in Colombia by trailer to the project site. In the field, the gates, split into three blocks are to be hoisted into place and set sequentially for installation in their final integrated forms.

14.6 Construction Schedule and Construction Period

Followings are principal results of the studies for the construction schedule and construction period.

(1) Year of Commissioning

As studied and described under 7.3.5, so that both El Siete No. 1 Hydroelectric Power Project and El Siete No. 2 Hydroelectric Power Project would be completed by the end of 1992 and be supplying electric power at the beginning of 1993, it was planned for El Siete No. 1 Power Station to start commecial operation at the end of August 1992 and El Siete No. 2 Power Station at the end of December of the same year.

(2) Critical Path in Construction Schedule

The works to become critical paths governing the construction schedule would be the powerhouse work and the penstock in case of the El Siete No. 1 Hydroelectric Power Project. For the El Siete No. 2 Hydroelectric Power Project, it would be the headrace tunnel in case excavation is delayed through geological conditions or other causes.

(3) Preparatory Works

It was considered that the items and works given in 14.2 would be completed by ICEL before commencing the main construction work (the works ordered through international tendering and for which contractors take over responsibility).

The period for this is to be 10 months.

(4) Tendering and Contracting of Main Works

The priod for estimating after public notice of tendering was taken as 3 months. The period for evaluation and contract negotiation after submittal of tender estimates 4 months.

(5) Period for Detail Design and Preparation of Tender Documents

A period of 12 months is considered for this, but it was considered that design and preparation of tender estimates for preparatory works would also be done simultaneously during this period.

Construction schedules were considered for the individual works based on the various items above, the results of which are given in Dwg. 40 for the El Siete No. 1 Hydroelectric Power Project and Dwg.-49 for the El Siete No. 2 Hydroelectric Power Project.

Construction schedules were made in the form of bar charts in consideration of the wishes of ICEL. The principal works and their outlines by year from 1986 until the end of 1992, when both power stations are commissioned, will be as described below.

- 1986:

  In May, a Feasibility Study Report on the El Siete No. 1 and El Siete No. 2 Hydroelectric Power Projects would be submitted to the Government of Colombia and ICEL by the Government of Japan through diplomatic channels. ICEL should immediately study the said Report and obtain the decision of the Ministry of Mines and Energy regarding the priority as a development project in the Middle- and Long-Range Electric Power Development Program, and the time of commissioning, and also a permit to start the work.

- 1987:

  ICEL, while giving consideration to the matters recommended in the JICA Report, would start on detailed designing including supplementary investigation works and work on preparation of tender documents, aiming for completion in the 12 months until the end of the year.

  It will be necessary for the JICA Report and supplementary documents by ICEL to be submitted to an international financing institution, and also to the Government of Colombia in aiming to prepare and procure funds required for implementing the Project and to gain an outlook on procurement of funds for the Project by the end of the year.

- 1988:

ICEL should start preparations to tender for the main works based on the tender documents completed by the end of the preceding year, give public notice of tender in May and have contractors submit bids in August. The bids would then be evaluated and the contractor selected by the end of the year.

Preparatory works would be ordered to domestic contractors in February of the same year and the work started, and it would be necessary for these to be completed by the end of the year.

The principal preparatory works items would be compensation for submersion, relocation works for the national road, purchase of land for principal structures, temporary power transforming and distribution facilities and telecommunications facilities, and the construction of supervision office and quarters of ICEL.

- 1989:

In January, a contract would be signed with a contractor regarding the Project and ICEL would obtain the approval of the board of directors making it possible for the work to be started at once. The contractor would start work in the field after a 1 month preparatory period.

Relocation work on the national road, access roads from the national road diversion tunnel work at El Siete No. 1 Dam, disaster prevention work, and at other work sites, construction of access roads to tunnel work adits and excavation and concrete lining work in work adits, and open excavation works at the auxiliary dam, the No. 1 intake, the No. 1 auxiliary sedimentation basin, the No. 1 powerhouse and the No. 2 powerhouse, and the outdoor switchyards would be done.

In February, it would be necessary to complete the tendering and contracting of turbines and generators from among power generating equipment, and factory manufacturing to be started.

At the El Siete No. 1 powerhouse site it would be necessary for a permanent steel bridge (length 95 m, width 5 m) crossing the

Atrato River to the powerhouse to have constructed through order of ICEL to a local contractor, and this would be completed by March at least. In the event that this bridge is to be not started from 1989, the start of the main works, it would be necessary for a temporary bridge to be erected by the contractor at the El Siete No. 1 powerhouse site.

In October, it would be necessary to start manufacture of the No. 1 powerhouse overhead travelling crane and transmission line materials.

- 1990:

Foundation treatment grouting works would be completed at the beginning of the year at the No. 1 dam, the left bank portion of the No. 1 auxiliary dam, and the No. 1 auxiliary sedimentation basin, placement of structural concrete started, and 60 percent of the placement completed.

At the No. 1 headrace tunnel, excavation of work adits would be completed, and excavation of the main tunnel completed 50 percent.

At the No. 1 powerhouse, foundation concrete placement would be completed in the first half of the year, installation of the overhead travelling crane completed in August, and installation of turbines would be started.

Excavation of the No. 1 tailrace tunnel would also be completed. At the No. 1 outdoor switchyard, the greater parts of open excavation and embankment diverting the earth excavated would be completed.

Work on the transmission line would be started in August.

At the No. 2 dam intake, concrete placement for the right bank structure would be completed, the Atrato River diverted, and open excavation at the left bank started.

At the No. 2 headrace tunnel, excavation of the main tunnel would be in full progress, and approximately 70 percent of the excavation work completed during the year.

At the No. 1 and No. 2 surge tanks, most vertical shaft excavation and concrete lining works would be completed within the year.

At the No. 1 and No. 2 penstocks, tunnel excavation and open excavation would be completed, and concrete placement on parts of the foundations started.

Factory manufacturing of penstock pipe would have been started from January.

At the No. 2 powerhouse, foundation concrete placement would be completed and the installation of the overhead travelling crane completed in December.

In July, the order would be placed for the start of factory manufacture of gates, trash racks, etc.

- 1991:

At the No. 1 dam, concrete placement of the dam itself would be completed by the middle of the year, with curtain grout work and installation of spillway sediment flushing gates carried out in the latter half of the year.

At the No. 1 auxiliary dam, excavation of the right bank and placement of foundation concrete would be completed.

At the No. 1 auxiliary sedimentation basin, the structures would be completed, and in the latter half of the year installation of the appurtenant gate would be finished, thereby completing all structures.

At the No. 1 headrace tunnel, the first half of the year would consist of tunnel excavation work, while in the middle of the year the tunnel would be driven through. In the latter half of the year, concrete lining work would be carried out and the greater part completed.

At the No. 1 surge tank, finishing work such as grouting would be completed in the first half of the year.

At the No. 1 penstock, installation of the penstock would be started from the beginning of the year, and 70 percent of this installation work would be completed.

At the No. 1 powerhouse, installation of the generations would be started from the beginning of the year.

Finishing work on the building would be completed in the first half of the year.

At the No. 1 outdoor switchyad, equipment installation would start from October.

Transmission line field installation works would go on all through the year.

At the No. 2 intake dam, concrete placement at the left-bank side would be performed, and would be completed by the end of the year.

The structures of the No. 2 sedimentation basin appurtenant to the dam would also be completed by the end of the year.

At the No. 2 headrace tunnel, excavation work would be performed continuing from the previous year, and in October, the excavation work would be completed with the entire length worked from the various side adits completely driven immediately after this.

At the No. 2 surge tank, the first half of the year would be vertical shaft excavation, while in the second half, concrete lining work would be started.

At the No. 2 penstock, the installation of penstock pipe would be started from June with approximately 70 percent being pleted within the year.

At the No. 2 powerhouse, generator installation would be started from the beginning of the year. Finishing work would be performed on the building at the same time, and would be completed in the middle part of the year.

- 1992:

  At the various El Siete No. 1 Project structures, gate installation grouting work, remaining parts of penstock installation, generator installation, and equipment installation at No. 1 outdoor switchyard would be completed during the first quarter of the year.

  Equipment testing would be begun in succession from April. The test period would be for 4 months, while finishing work on civil structures would be performed in parallel. The El Siete No. 1 Power Station would go into operation from September.

  In the El Siete No. 2 Hydroelectric Power Project, the installation of gates spillway No. 2 dam would be completed in the first half of the year. Gate installation work would be performed simultaneously at the No. 2 sedimentation basin, and this would be completed within the first half of the year.

  At the No. 2 headrace tunnel, concrete lining work and grouting work would be completed by August, while the No. 2 surge tank would be completed by the end of May.

  At the No. 2 penstock, penstock pipe installation work would be completed by the end of August.

  At No. 2 powerhouse and No. 2 outdoor switchyard, equipment installation would be done by the end of July.

  The transmission line would be completed by the end of May.

  From September, the engineering group, after completing tests at El Siete No. 1 Power Station would move to El Siete No. 2 Power Station and equipment testing would be started.

  The test period would be 4 months, and El Siete No. 2 Power Station would go into operation from January 1993. (See Dwg. 45 and Dwg. 46 regarding the individual works.)

As described, the construction periods of this Project would be 44 months (3 yr 8 mo) for the El Siete No. 1 Power Station, and 48 months (4 yr) for the El Siete No. 2 Power Station, provided that the main construction works for the two are started in January 1989, the former would be completed at the end of August 1992, and the latter at the end of December 1992.

CHAPTER 15. CONSTRUCTION COSTS

CHAPTER 15 CONSTRUCTION COSTS

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TABLE LIST

CHAPTER 15. CONSTRUCTION COSTS

15.1 Fundamental Estimation Conditions

(1) Estimation System

The systems below may be applied to estimation of construction costs related to the El Siete No. 1 and No. 2 Projects.

Calculations were made based on "work quantity x unit price" for various civil works, "CIF cost + inland transportation cost + installation cost" for equipment and apparatus, and lump sum estimations for others.

Civil works quantities were estimated based on Dwg. 15 to Dwg. 45, and on supplementary figures.

CIF generating, transmitting, and transforming equipment costs were estimated from ratings, characteristics and dimensions.

Lump sum estimations were also applied for preliminary works, contingency costs, engineering and administration fees.

(2) Works Classifications

The El Siete No. 1 and No. 2 project structures were classified according to the items below and estimated in units of the items.

- No. 1 preparatory works (land, compensations, access road, bridge, power facilities for construction, camp facilities, telecommunications facilities for construction, other)

- No. 1 Dam (care of river)

- No. 1 Dam (open excavation, concrete, grout, metal works, drilling, protection of excavated surface, others)

- No. 1 Auxiliary Dam and Auxiliary Intake (open excavation, concrete, metal works, excavated surface protection, bridge, river care, others)

- No. 1 Intake (excavation, concrete, grout, metal works, drilling others)
- No. 1 Auxiliary Sedimentation Basin (excavation, concrete, metal works, excavated surface protection, others)
- No. 1 Headrace Tunnel (tunnel excavation, concrete, grout, metal works, drilling, others)
- No. 1 Surge Tank (excavation, concrete, grout, metal works, drilling, excavated surface, others)
- No. 1 Penstock (excavation, concrete, metal works, others)
- No. 1 Powerhouse (excavation, concrete, metal works, excavated surface protection, building, Qdo Aguila divertion cannel, bridge, others)
- No. 1 Tailrace Tunnel (tunnel excavation, concrete, metal works, others)
- No. 1 Substation (excavation, backfill, concrete, metal works, others)
- No. 2 Preparation Works (land, access road, bridge, electrical facilities for construction, construction camp, compensation, telecommunications facilities for construction, others)
- No. 2 Intake Dam and Intake (excavation, concrete, grout, metal works, drilling, excavated surface protection, river care, bridge, others)
- No. 2 Sedimentation Basin (excavation, concrete, grout, metal works, drilling, others)
- No. 2 Headrace Tunnel (tunnel excavation, concrete, grout, metal works, drilling, others)
- No. 2 Surge Tank (excavation, concrete, grout, metal works, drilling, excavated surface, protection, others)
- No. 2 Penstock (excavation, metal works, others)

- No. 2 Powerhouse (excavation, concrete, metal works ware, excavated surface protection, river care, others)

- No. 2 Substation (excavation, backfill, concrete, metal works, others)

The following classifications below were made for power generation equipment.

- No. 1 Turbine-Generator and Appurtenant Equipment

- No. 1 Hydraulic Equipment

- No. 1 Transforming and Switching Equipment

- No. 1 Transmission Line

- No. 2 Turbine-Generator and Appurtenant Equipment

- No. 2 Hydraulic Equipment

- No. 2 Transforming and Switching Equipment

- No. 2 Transmission Line

The above classifications, according to type of work, are normally applied to hydro power projects, and are also in accordance with internal ISA standards.

(3) Year of Estimation

In estimating construction costs it is necessary for the year of estimation to be fixed, such as for material commodity prices, labor wages, labor standards, laws and regulations, equipment prices, unit transportation price, foreign exchange rate, etc.

The Survey Mission was in Colombia from January 16 to February 25, 1985, and carried out investigations on the above costs and commodity prices. From discussions with ICEL, December 1984 was determined as the year of estimation.

(4) Currency Unit Applicable to Estimation

The currency unit to be applied in estimation was selected to be The US dollar, being extremely stable and which is accepted in the world economy, and which also has very strong influence on the Colombian economy, was selected as the corrency unit to be applied in estimation. It was decided that both local and foreign currency requirements would be expressed in terms of U.S. dollar. Therefore, for local materials and labor costs, the Colombian peso (COL$) was converted into the U.S. dollar at the December 1984 exchange rate and used.

(5) Work Quantity Units

The widely used and also metric system, applied in Colombia was adopted.

(6) Contingency Costs, Engineering and Administrative Costs

It was decided that contingency costs and engineering and administrative costs would be calculated by the ratio (%) to direct construction costs normally applied by ISA to hydro power projects.

- Contingency costs:
  Civil works cost x 15%
  Equipment cost x 10%

- General engineering and administrative costs
  (Civil works cost + contingency cost) x 10%
  (Equipment cost + contingency cost) x 8%

Note: Engineering and Administrative Costs include the administrative costs of advisers, inspectors, owner (ICEL) regarding reconnaissance, prefeasibility studies, feasibility studies, design, and construction supervision of the Project.

(7) Duty on Imported Item

Import duty is expressed by the ratio to CIF price and rates applicable as of December 1984 were as follows:

Empocol;	CIF x 4%
Ley 68;	CIF x 2%
Ley 50;	CIF x 10%
Other expenses;	CIF x 4%
Total;	CIF x 20%

The above import duty rate is also applied by ISA, and it was therefore decided to apply it to this Project.

(8) Transportation Insurance

Transportation insurance rates currently applied in Colombia are as shown below. These are applicable to both inland and marine transportation.

Table-15.1 Transportation Insurance

	Actual Insurance Costs	
	Inland transport	Marine transport
Common material	CIF x 0.276%	C&F x 0.225%
Machine and equipments	CIF x 0.276%	C&F x 0.225%
Steel materials	CIF x 0.276%	C&F x 0.225%
Detonator	CIF x 3.44%	C&F x 1.700%
Dynamite	CIF x 4.74%	C&F x 1.700%

The above transportation insurance costs will be included in the costs of the various works and equipment transportation cots.

(9) Unit Cost of Inland Transportation

Current unit costs below were applied to inland transportation of construction materials and imported equipment to the project site.

Construction materials	US$0.1/ton/km
Equipment	US$0.24/ton/km

The above transportation costs were included in the individual works costs.

(10) Local Currency, Foreign Currency

- Civil Works:

Civil works costs consist of labor costs, material costs, construction equipment costs, fuel costs, administrative costs, and profit.

Of labor costs, foreign engineers correspond to a part of the foreign currency requirements, the others being mostly local currency requirements.

Of materials costs, excavation works are 1:1 local currency versus foreign currency, while concrete works are 2.5:1.0 local currency versus foreign currency.

Construction equipment costs are mostly foreign currency requirements.

Civil works in this Project are 36.8 pecent foreign currency and 63.2 percent local currency. (See Table-15.11 and Table-15.12 for the allocations of local currency and foreign currency portions in the individual costs.)

- Equipment:

For equipment, gates and penstocks, FOB costs are all foreign currency requirements. Ocean freight, insurance, and inland transportation are all local currency requirements.

Installation work costs were divided into local and foreign currency requirements with percent (installation instruction) as a foreign currency requirement. Equipment would be 73 percent foreign currency and 27 percent local currency. Gates and penstocks would be 47 percent foreign currency and 53 percent local currency.

(11) Construction Material Costs

The unit price of construction materials applied in investigations and estimations in Colombia were as shown in the table below.

Table-15.2 Materials Unit Price

unit: US$

Materials	Units	Adopted unit price
Cement (50kg/sack)	sack	3.6
Reinforcement steel bar PDR60	ton	700
Reinforcement steel bar D-37	ton	650
Gasoline	lit.	0.25
Diesel oil, lubricating oil	lit.	2.8
Light oil	lit.	2.5
Dynamite	kg	3.2
Steel support	ton	2,800
Wooden form	m^2	6.0

- For the cost of cement at the site, the transportation cost for the distance of 119 km was added to the purchase price of cement at the cement plant of the Arcos firm at Medellin city.

- For reinforcing steel, the transportation cost was added to the purchase price from the Simesa company in Medellin City to obtain the on-site cost.

- The prices of gasoline, diesel oil, lubricating oil, light oil, and dynamite were obtained referring to the unit prices which ICEL and EPM apply to similar projects at the implementation stage.

- The prices of supports and wood forms were obtained referring to the unit prices which ICEL applys to similar projects.

(12) Unit Labor Costs

Unit labor costs applied to investigations and estimations in Colombia are as given below.

Table-15.3 Labor Wages

Unit: US$

Classification	Labor Wages
Foreign foreman	51.5
Foreman	44.3
Tunnel worker	23.3
Earth worker	18.7
Carpentor	23.3
Mason	23.3
Black smith	23.3
Operator A	32.7
Operator B	19.8
Mechanic	35.0
Electric	35.0
Reinforging bar worker	14.0
Assistant technician	23.3
Welder	14.0
Handy man	14.0
Common	14.0

Note: unit price as of Dec. 1984

These unit costs consist of indirect costs and social security costs added to direct personnel costs with the exchange rate from COL$ to US$ as COL$103/US$, and with direct personnel costs x 2.33.

Unit direct personnel costs were obtained referring to the unit estimating prices of a similar project, the Miel I Project, which ICEL is in the stages of preparing for implementation.

15.2 Unit Construction Costs

(1) Unit Construction Costs of Civil Works

Unit costs of civil works are composed of (A) direct costs (labor personnel cost + materials cost + construction equipment cost + other) and (B) indirect costs (administrative costs + profit). The term other includes the cost of motive power for construction.

The Survey Mission obtained unit estimating prices in accordance with individual types of work under civil works taking into consideration labor percentages, unit materials costs, unit costs of construction equipment, and ratios of indirect costs in similar projects.

The unit construction costs of similar hydro projects in Colombia in recent years were also referred.

The unit costs of the principal works applied to this Project are shown below.

Table-15.4 Principal Unit Price of Civil Works

unit: US$

Work item	Unit price
Open excavation (earth)	5.0/m^3
Open excavation (rock)	12.0/m^3
Tunnel excavation	85.0/m^3
Dam massive concrete	93.0/m^3
Tunnel linning concrete	158.0/m^3
Shotcreate (t: 10 cm)	250.0/m^3
Reinforcement steel bar	1,540.0/ton

(2) Unit Land Costs

The unit land costs ICEL applys for estimating similar projects are shown below.

Estimates were made for this Project applying these unit costs.

Table-15.5 Unit Land Cost

unit: COL$/ha

Land classification	Unit price
Plain less 12 deg. inclined	80,000
Inclined A 12 deg. to 25 deg.	65,000
Inclined B more 25 deg. inclined	45,000

(3) Unit Compensation Costs

Compensation items are forested mountains, agricultural crops, trees, pasturage and submerged dwellings. The unit prices applied by ICEL in similar projects are given below. Compensation costs were calculated by also applying these unit prices to this Project.

Table-15.6 Unit Compensation Cost for Forest Tree

Unit: US$/piece

Classification	Quality		
	good	common	low
Forested trees Young forest	0.6	0.45	0.23
Glowing forest	1.4	1.05	0.53
Adoptable wooden forest	4.0	3.0	1.5

Table-15.7 Unit Compensation Cost for Agricultural Crops

unit: US$/ha

Production kinds	Quallity	
	crowing	product
Corn	180	400
Toro, Poteto	300	700
Kidney bean	180	400

Table-15.8 Unit Compensation Cost for Timbe Tree

unit: US$/piece

Classification	Quality		
	good	common	low
Pine, Rose wood	50	35	15
Furniture wood	40	30	12
Log	5	3.5	2
Board wood	20	15	10

Table-15.9 Unit Compensation Cost for Pasturage

unit: US$/ha

Quality	Unit price
Good	300 - 400
Common	200 - 300
Low	120 - 200

- Submerged Dwelling Compensation

This is compensation to carry out relocation of dwellings to be submerged and land used for the Project. The computation method adopted by ICEL was used.

There are 37 classification points to be the computation items in this project area, the unit price being US$49/$m^2$. With an average 80 m^2 floor area per house compensation per house would be US$4,000.

8 dwellings would be submerged due to construction of El Siete No.1 Dam or to be paid compensation due to the work, if up to EL. 1,455 m is made the object of compensation.

(4) Unit Construction Costs of Relocated Roads and Access Roads

The standard unit construction costs applied to relocated roads and access roads in this Project are as follows: