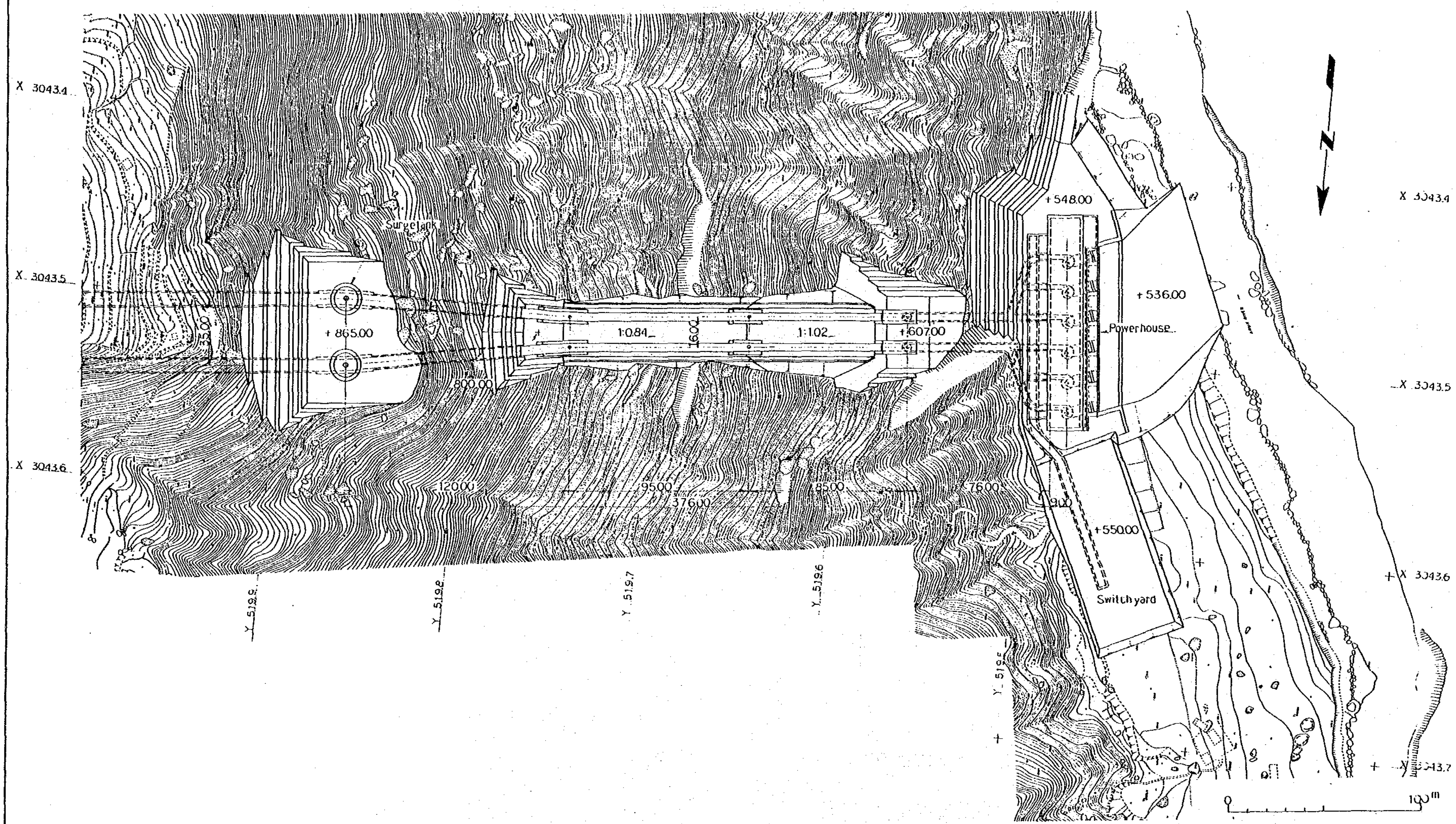


ARUN 3 HYDRO POWER PROJECT

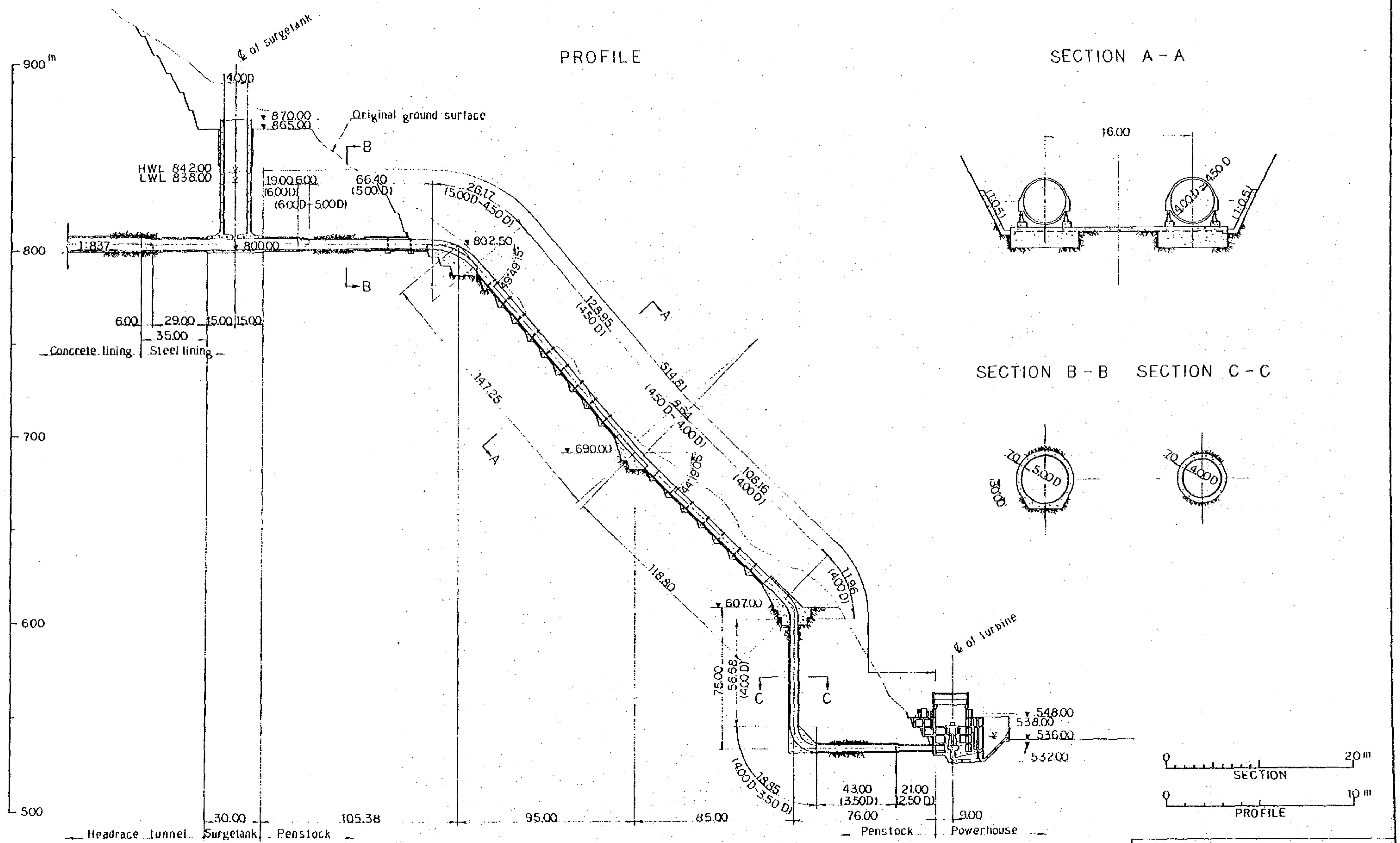
FEASIBILITY STUDY

ALTERNATIVE PENSTOCK

OUTDOOR TYPE

PLAN

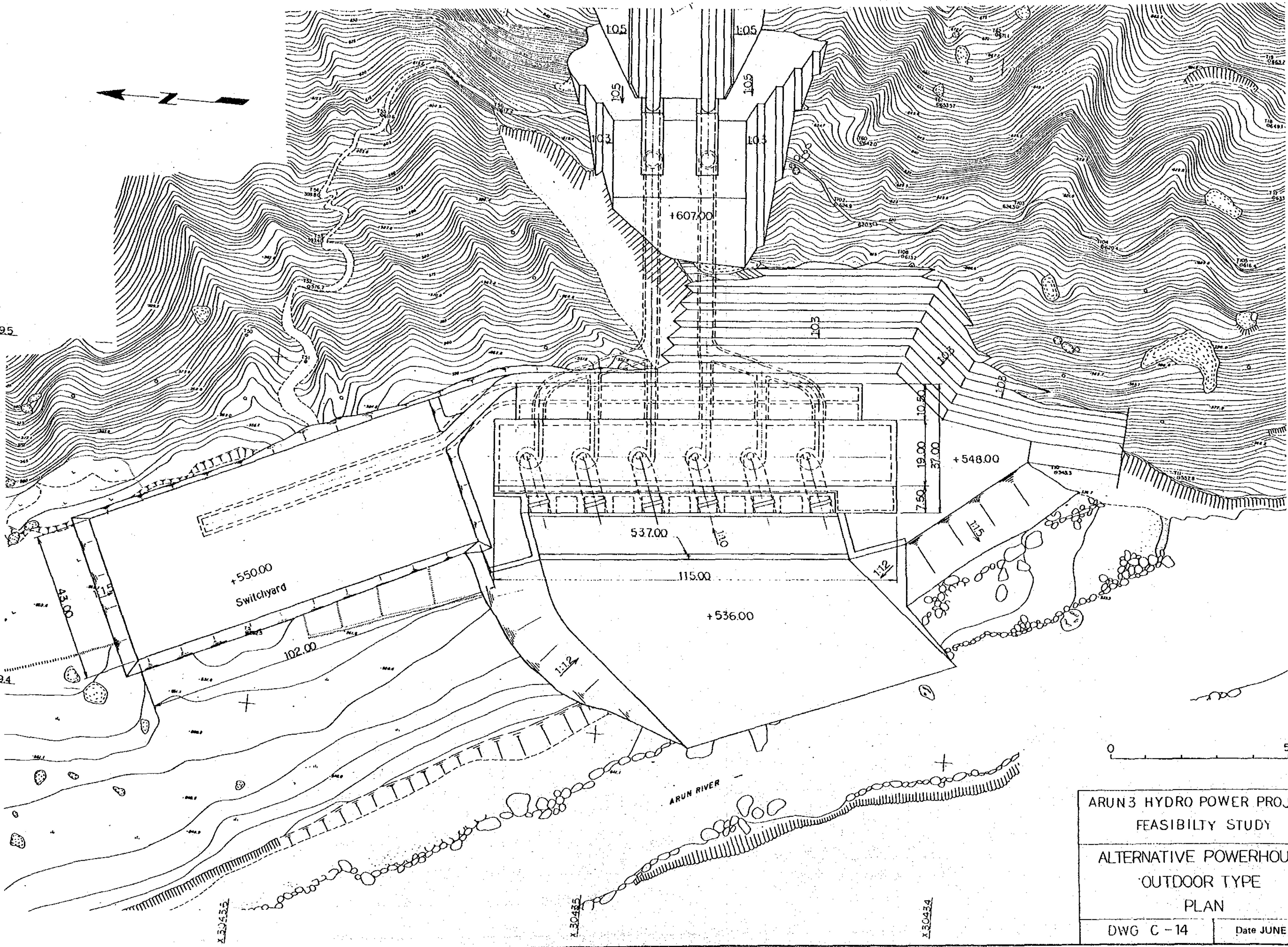
DWG. C-12	Date JUNE 1987



ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

ALTERNATIVE PENSTOCK
OUTDOOR TYPE
PROFILE AND SECTIONS

DWG. C -13 | Date JUNE 1987

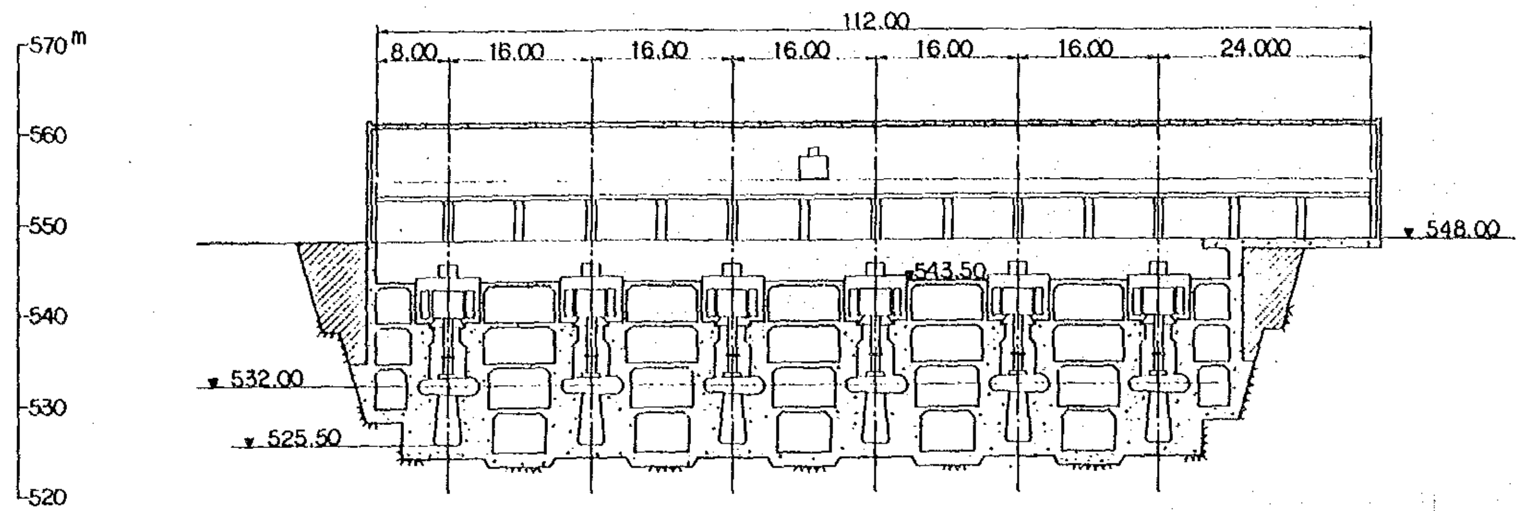


ARUN3 HYDRO POWER PROJECT
FEASIBILTY STUDY

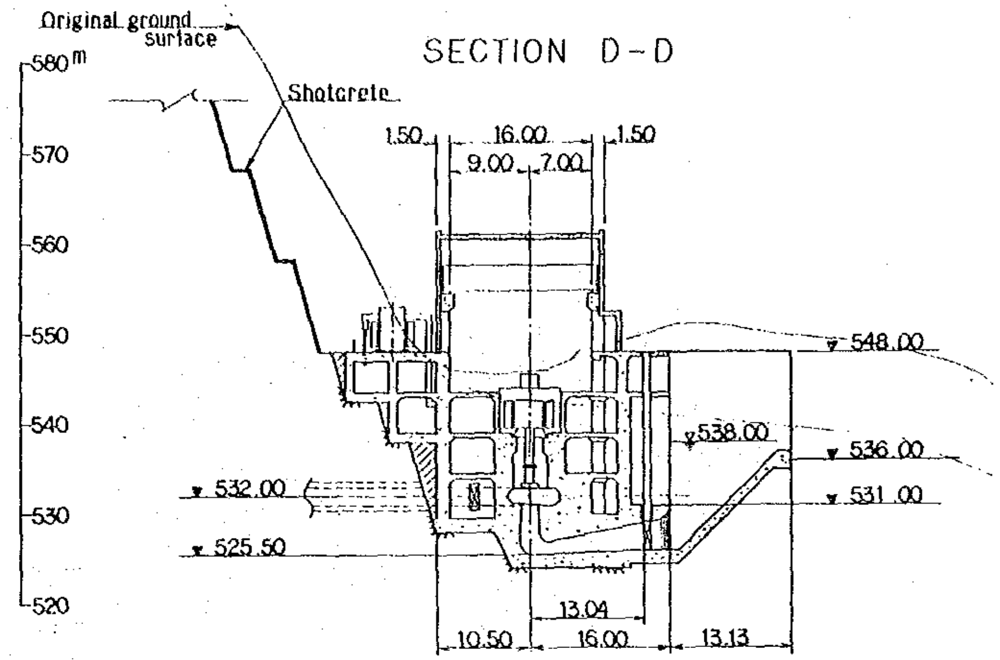
ALTERNATIVE POWERHOUSE
OUTDOOR TYPE
PLAN

DWG C - 14	Date JUNE 1987

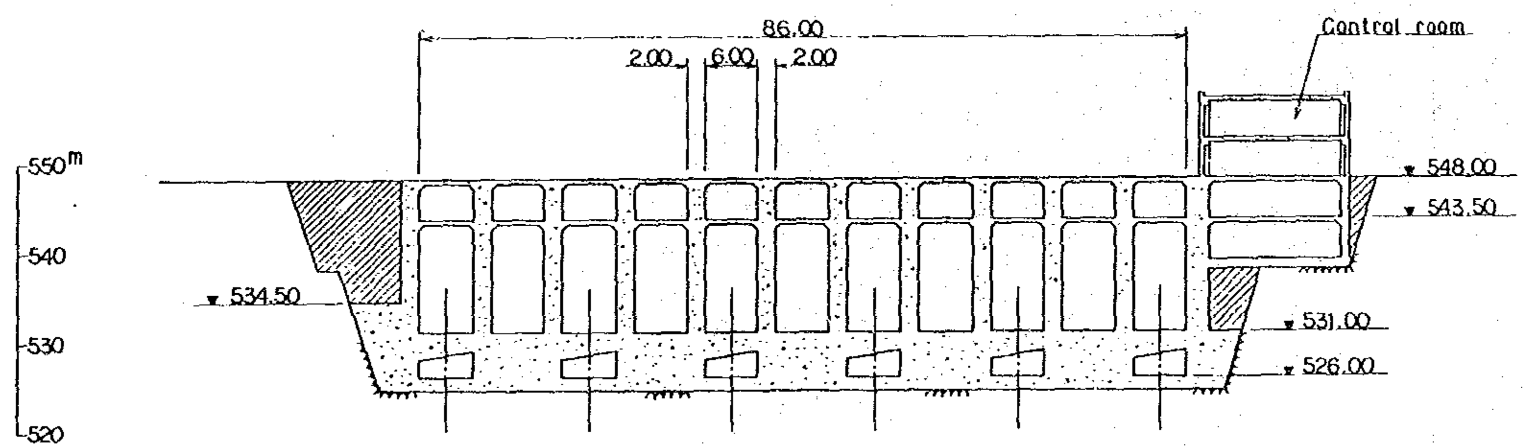
SECTION A-A



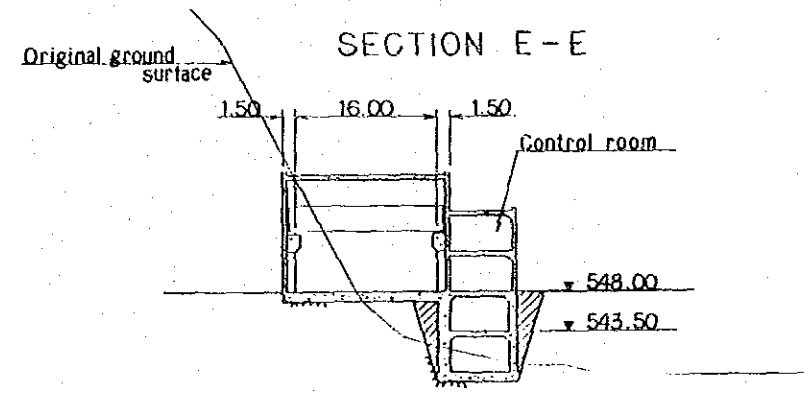
SECTION D-D



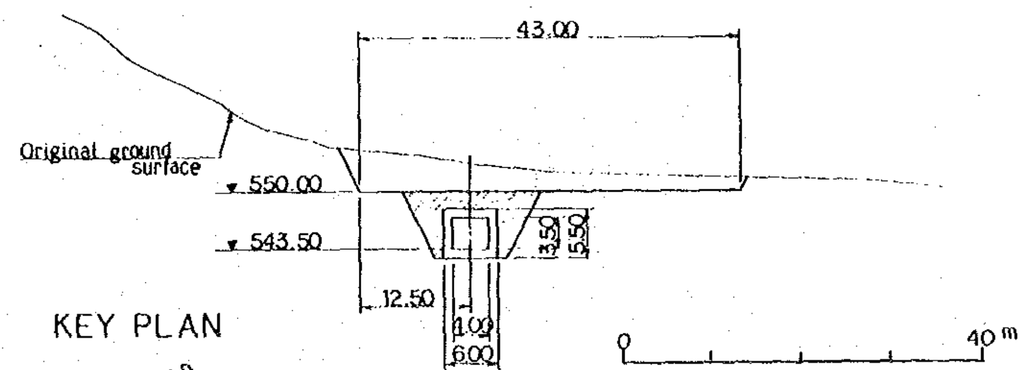
SECTION B-B



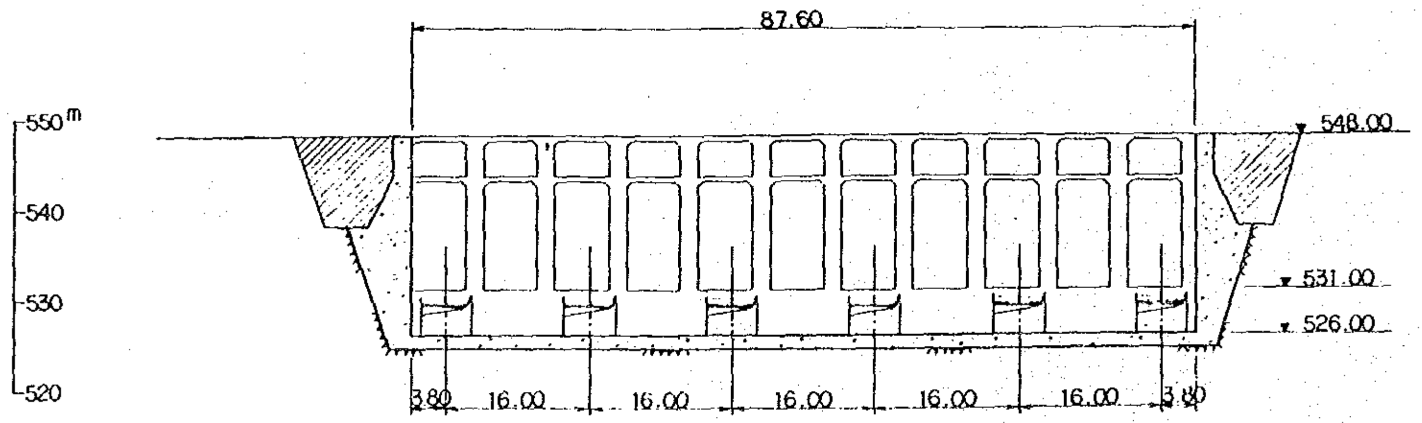
SECTION E-E



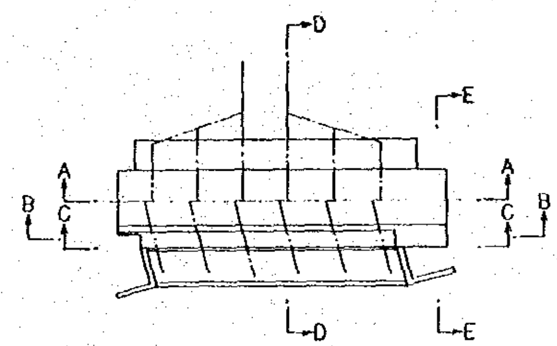
SECTION OF SWITCHYARD



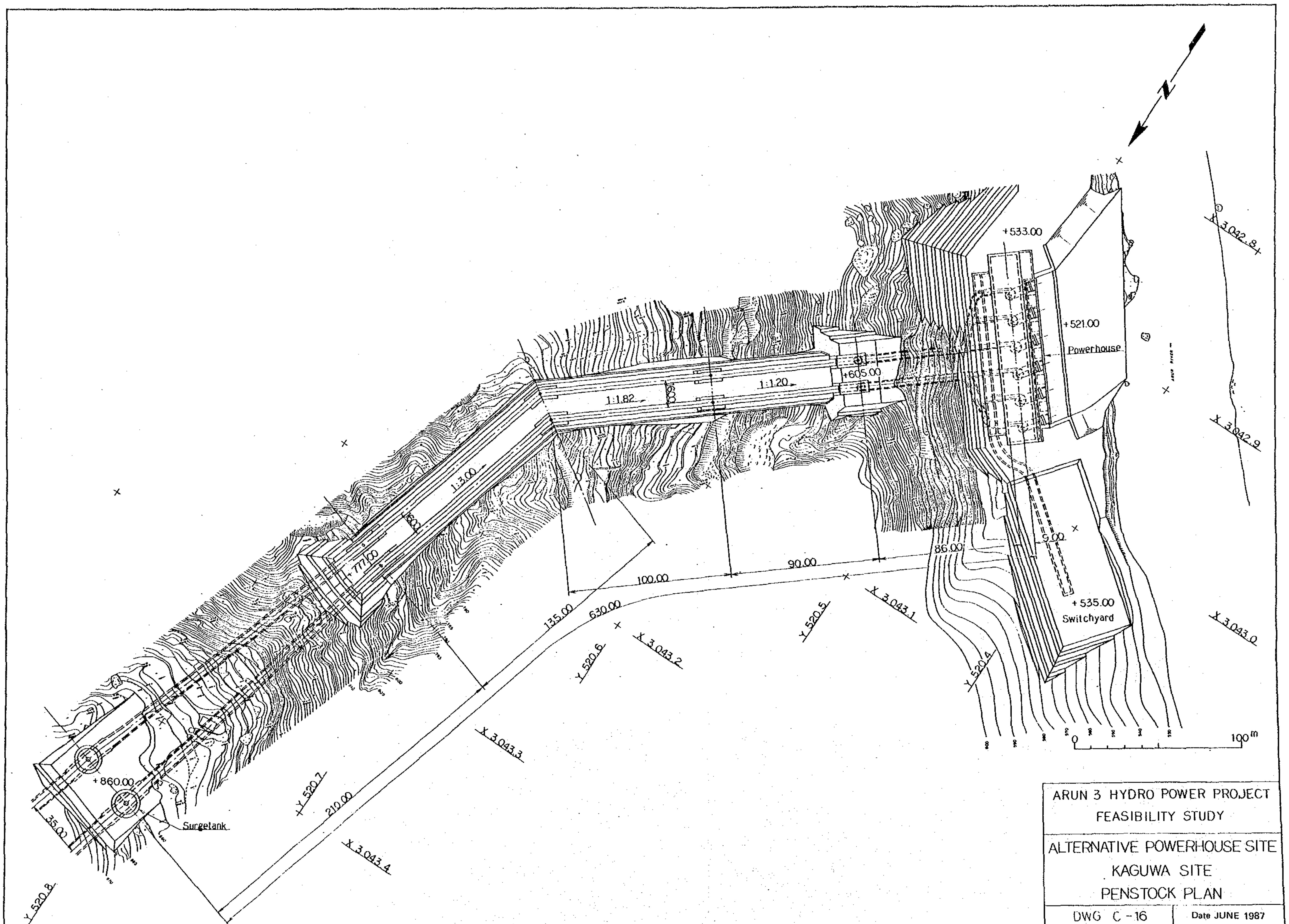
SECTION C-C



KEY PLAN



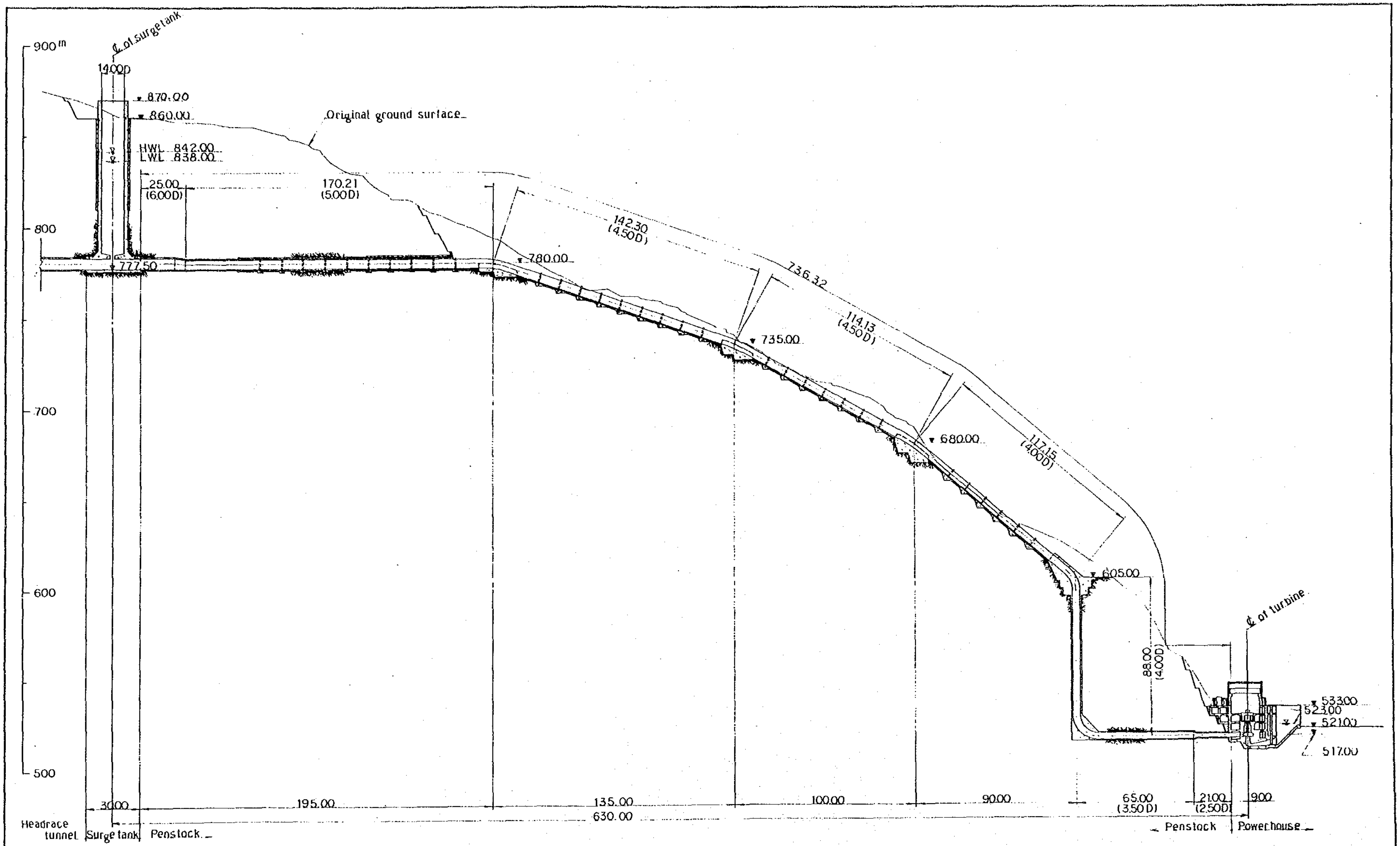
ARUN 3 HYDRO POWER PROJECT FEASIBILITY STUDY	
ALTERNATIVE POWERHOUSE OUTDOOR TYPE SECTIONS	
DWG C -15	Date JUNE 1987



ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

ALTERNATIVE POWERHOUSE SITE
KAGUWA SITE
PENSTOCK PLAN

DWG C-16	Date JUNE 1987



ARUN 3 HYDRO POWER PROJECT
FEASIBILITY STUDY

ALTERNATIVE POWERHOUSE SITE
KAGUWA SITE
PENSTOCK PROFILE

DWG. C-17 | Date JUNE 1987

9.2 Electromechanical Equipment

9.2.1 Powerhouse

(1) Comparison of Francis and Pelton Turbine

Either Francis or Pelton turbines are applicable for the Arun 3 power station in view of the range of head and power discharge. Therefore, in this study, comparison of Francis and Pelton turbines is made from both technical and economic viewpoints in order to select the optimum turbine type.

(i) Comparisons of designs and costs of turbines and generators

(a) Ratings and dimensions of turbines and generators

Comparative designs of Francis and Pelton turbines are made using identical intake water level, tailrace water level and maximum power discharge, and the ratings given in Table 9-8 are selected.

Preliminary designs of turbines and generators are made using these rated values and the results are given in Fig. 9-11. As clearly observed in this figure, the dimensions of the Pelton turbine-generator are very large compared with the Francis turbine-generator and as shown in Figs. 9-12 and 9-13, the dimensions of the powerhouse will be also very large in case of Pelton turbine (Comparison is made for outdoor type powerhouse). As for the turbine centers of the two types, they will be 6 m below the tailrace water level in case of the Francis turbine and 4 m above in case of the Pelton turbine. The center of the Francis turbine is selected in such a manner as to give the suction head (submergence, Hs) larger than the normal value for the Francis turbine, in consideration of the effect of suspended load as described later in (iii). On the other hand, in case of the Pelton turbine, the turbine center will be high, hence since there is no draft tube, the effective head will become lower compared with the Francis turbine, and this will be the disadvantageous aspect of smaller output. Further, in case of the Pelton turbine, if it is to be operated during flood, it will be necessary to make the turbine center even higher, thus causing further decrease in head.

(b) Turbine efficiency characteristics

The relative efficiency characteristics of Francis and Pelton turbines are compared in Fig. 9-14. This figure clearly shows that the efficiency characteristics of the Francis turbine is better with larger output, while in a range of small output, the Pelton turbine is superior. Especially, with a Pelton turbine, it is possible to increase efficiency at light load time by switching the nozzle number from four to two in an operating range of less than about one-half of rated capacity.

However, it is considered that operation at light load of less than 60 percent of rated capacity will not be so often from the reasons given below. In order to check the balance of daily demand and supply in Nepal after the Arun 3 power station will have been commissioned, the estimated daily load demand curve for the day of the maximum load in the case of January 2002 (3 unit operation) and January 2006 (6 unit operation) as representatives and the operating pattern of the Arun 3 power station according to this load curve are predicted as shown in Figs. 9-15(1) and 9-15(2) (on precondition that the base load is to be supplied from other generating facilities). According to this figure, if the number of units operated and operation at equal output are to be controlled at Arun 3 power station, the operating pattern per unit of main equipment will be as follows:

(January 2002, 3 unit operation)

90% - 100% output 3 hours
80% - 90% output 5 hours
70% - 80% output 2 hours
60% - 70% output 3 hours

(January 2006, 6 unit operation)

90% - 100% output 8 hours
80% - 90% output 12 hours
70% - 80% output 2 hours
60% - 70% output 2 hours

As a result of the above, it is expected that the operating pattern of the Arun 3 power station will be such that case of operation at large output of 70 percent of rated capacity or higher will be predominant, and it is considered that large-output, high-efficiency operation with Francis turbine will have much more advantage than operation with Pelton turbine. Furthermore, it is thought that large-output, high-efficiency operation will be possible for the various load patterns conceivable by suitably selecting the number of units operated at the Arun 3 power station, while when export of power in excess of the domestic demand of Nepal is taken into account, this trend will become even stronger, and it is considered that adoption of Francis turbine with which more electric energy can be produced will be advantageous.

(c) Turbine and generator costs

The comparisons of costs for turbines and generators including auxiliary control equipment are estimated to be as follows:

(Unit: US$$10^3$)

	Francis Turbine, Generator (6 units)	Pelton Turbine, Generator (6 units)
Turbine	20,160	22,980
Generator	17,040	19,740
Total	37,200	42,720

This clearly shows that Francis turbine-generator will be more advantageous.

(ii) Economic comparison of different turbine types (In case of outdoor type powerhouse)

Comparisons of total construction costs in case with power export, including construction costs for power-house and dam, and power transmission and substation equipment according to different types of turbines, and comparisons of energy production and benefits are presented below.

	Francis Turbine, Generator	Pelton Turbine, Generator
Installed Capacity (MW)	67 x 6 = 402	64 x 6 = 384
Total Annual Energy Production (GWh/Yr)	2960.3	2832.4
Salable Domestic Energy (GWh/Yr)	1863.2	1782.7
Salable Export Energy (GWh/Yr)	920.8	881.0
Surplus Energy (GWh/Yr)	176.3	168.7
Present Value of Construction Cost, C (10^6US$)	258.11	263.56
Present Value of Benefit, B (10^6US$)	364.79	352.48
B-C (10^6US$)	106.68	88.92
B/C	1.413	1.337

According to this table, both B - C and B/C will be higher for the Francis turbine-generator than the Pelton turbine-generator and the former is economically superior. Furthermore, if the comparison is made for underground type powerhouse, the Francis turbine-generator is obviously far more advantageous in economy than the Pelton turbine-generator.

(iii) Design and operation and maintenance of Francis turbine considering influence of suspended load

(a) Water quality

According to the results of water quality analyses obtained in this study as described in detail in preceding paragraph 3.5.3., the content of suspended solids is approximately 80 mg/lit on average and 810 mg/lit at maximum which are not very large in quantity. However, as the Arun 3 power station has high head of around 300 m, it will be desirable to give consideration to measures against abrasion of the turbine due to suspended load.

Acid which has a great influence on corrosion of metals is not a problem in particular since pH is around 7, while SO_4^- is low at about 6 to 17 mg/lit also giving no problem, but since Cl^- is high at 90 to 140 mg/lit, it will be necessary to pay further attention to selection of metal plate thickness, combinations of different metals, paintings, etc., regarding the high-tension steel and other turbine materials to be used.

In this study, the points below are considered as suspended load countermeasures in turbine design. With these in practice it is considered that the maximum suspended grain size of 0.3 mm after the desilting process will not cause any adverse effects in turbine operation.

(b) Points to be considered in turbine design

a. Applicable revolving speed

Considering the applicable head and available discharge for the Arun 3 power station, either of the rated revolving speed of 429 rpm and 500 rpm of turbine and generator can be applied, while from viewpoint of measures against abrasion from suspended load, it will be desirable to design the revolving speed as low as possible.

The revolving speed of 429 rpm is selected in view of the facts that differences in dimensions and efficiency characteristics of turbine and generator are not great between 429 rpm and 500 rpm machines, and that there will be no special difficulties in transportation of equipment (refer to paragraph 9.2.5).

b. Suction head (H_s)

Since damage from sediment abrasion will cause composite damage together with cavitation effect, it is judged desirable to select the suction head of about 2 to 3 m deeper than normally adopted in order to prevent cavitation, and in this study, H_s = -6 m (when all units in operation) is set up.

c. Runner

Adoption of high Ni 13Cr stainless steel which can be welded and repaired, and which excels in cavitation-resistant characteristics will be reasonable for runner taking into account the measures for resistance to abrasion from sediment, and further, the research and development by manufacturers on runner materials and configurations of better sediment abrasion-resistant characteristics will be looked into.

It is desirable to provide the power station with spare runner(s). With regard to replacement with spare runner or runner repairs, it is thought that the work can be done at almost the same level of ease for both Francis turbine and Pelton turbine as described in (c) below.

d. Guide vane

For guide vane materials, as in the case of runner, it will be appropriate to adopt high Ni 13Cr stainless steel which can be repaired and which excels in cavitation-resistant properties. For inspection and repair of guide vanes, it will be desirable to have such structure that the turbine pit is 1 m higher than normal and the head cover is hoisted and held up inside the turbine pit without disassembling the turbine and generator. The guide vanes can be taken out utilizing the space under the head cover to carry out necessary welding and repairs. It will also be desirable to provide the power station with spare guide vanes.

e. Runner seal, main shaft seal

Materials excelling in abrasion resistance should be selected, with gaps made slightly on the large side so that easy replacement of seal can be done.

(c) Operation and maintenance of turbine and generator

Damage to turbine runner due to sediment abrasion is caused by the combined action of cavitation and other factors. Consequently, it is desirable that light load operation below 50 percent is to be avoided as much as possible. As described previously, it will be possible to keep large-output, high-efficiency operation at the Arun 3 power station through selection of the number of units operated and equal-output operation. From the standpoint of countermeasures against sediment abrasion, the operation mode stated above of this power station is thought to be favorable.

With regard to turbine inspection, particularly to runner inspection and repair, there is not very much difference between Francis and Pelton turbines concerning the intervals and time needed for inspection and repair. Likewise, there is not much difference with respect to damage due to suspended load, but in case of Francis turbine, dewatering of draft tube is required and hence, inspection and repair of Pelton turbine can be done more easily.

However, except for dewatering of draft tube, the inspection and repair methods are almost the same for both Francis and Pelton turbines. The following can be considered as inspection and repair methods for runner of Francis turbine.

a. Disassembly of turbine and generator

   The method is to use crane to hoist the generator rotor to take out runner from the top (generator side), and is very common for inspection and disassembly. It requires relatively longer time for inspection and disassembly compared with other methods.

b. Adoption of intermediate shaft

   This is a method which consists of providing an intermediate shaft of about 2 m long between the generator and the main shaft to remove runner without dismantling the generator and this intermediate shaft is to be removed first for taking out the runner from the top (refer to Fig. 9-11). With this method, the axial length of the entire turbine-generator will be about 1 m longer compared with other methods. It will be necessary to give more consideration to the aspect of stable operation compared with other methods in connection with the turbine and generator of the Arun 3 power station which is relatively high speed machine.

c. Removal of runner from bottom (draft tube side)

As shown in Figs. 9-11 and 9-16, this is a method of removing runner from the bottom (draft tube side) without dismantling the generator and without adopting an intermediate shaft. With this method, upper and lower cones of removable structure are provided to draft tube so that draft tube liner can be disassembled. Parts around these cones are not to be embedded with concrete. As shown in Fig. 9-16, the inspection and repair method will be almost the same as for Pelton turbine runner, with the exception of dewatering inside the draft tube.

It should be noted, however, that the height from turbine center to bottom of draft tube liner and the powerhouse dimensions will be slightly larger.

As described in the foregoing, there are advantages and disadvantages among the different methods of inspection and repair of turbine runner. It would be best to await the results of detailed studies of water quality including grain-size distribution of sediment at the advanced stage of design. In case the adverse effects of suspended load on turbine are not very great, the most common method of abovementioned a, that is, the method of disassembling the generator and taking out runner from the top should be adopted, while when the effects of suspended load are great, the method of c, that is, removal of runner from the draft tube side, or the method of adopting an intermediate shaft should be considered.

In this study, the powerhouse dimensions and layout which allow all of the above three turbine inspection and repair methods are considered. The turbine design and powerhouse layout should be studied based on the results of further detailed analyses of suspended load.

(iv) Conclusions

Pelton turbine was considered in the Pre-feasibility study because of the ease of turbine inspection and repair, but it is desirable to adopt Francis turbine from technical and economic viewpoints as mentioned before considering appropriate turbine design, power station operation, and turbine inspection and repair methods, even though turbine damage and a great degree of abrasion due to suspended load may be expected.

(2) Special Functions and Equipment required for Arun 3 Power Station

As indicated in the power system analysis shown previously in paragraph 8.6, this power station shall have the special functions as stated below.

(i) Condenser operation

At off peak load time during night, the transmission line voltage on the load side (power receiving side) rises because the capacitor induced to the transmission line is large especially in case of 220 kV operation and therefore, it is necessary to provide condenser operation function with the turbine and generator (leading operation) to suppress the line voltage rise.

Meanwhile, lagging operation which compensates for line voltage drop at peak load time will not be specially required at the Arun 3 power station if static condensers are provided on the power system side as shown by the results of power system analysis. It is considered that provision of three units having function of condenser operation will be satisfactory, however, it will be required to carry out condenser operation for many hours because of the characteristics of electric power system.

The methods of condenser operation are that of spinning the turbine in water, and that of depressing the water surface inside the draft tube using air compressor and spinning the turbine in air. Continuous spinning in water is not a very desirable method considering that (1) the effect of reaction torque forced to the turbine is great and power loss occurs, (2) water temperature inside the draft tube rises under the condition that guide vanes are closed and further, (3) vibration produced by the turbine is relatively large. Thus, for carrying out stable condenser operation for long, spinning in air will be desirable even though the cost for auxiliary equipment to depress the water surface will be additionally needed.

(ii) Trial line charging

The Arun 3 power station will play very important role in the electric power system of Nepal and its influence is extremely great. Hence, in the case that the transmission line is to be operated again after it has been shut down due to maintenance work or fault, it will be necessary to charge the transmission line from the Arun 3 power station to Hetauda or Kathmandu. Especially, regarding the route to Kathmandu after the commencement of operation at 220 kV, the study is made on possibility of the trial line charging from the Arun 3 power station since the transmitting voltage is considerably high and the line distance long. The result, as described in preceding paragraph 8.6.4, is that trial line charging of 220 kV, 1 cct to Kathmandu will be possible with one generator of the Arun 3 power station coordinating with power transmission and substation facilities.

(iii) Black start

In connection with (ii) above, in order to carry out trial line charging from the Arun 3 power station, it is necessary to start the main equipment at the power station itself, namely, so-called "black start" is required. Therefore, it is scheduled to provide an emergency diesel engine generator to secure power supply for auxiliary equipment required for starting the main equipment. This diesel engine generator will be used not only for black start, but also for securing power supply for telecommunication facilities, ventilation system, controls, etc.

9.2.2 Switchyard Equipment and Others

The main equipment to be provided to the Arun 3 power station is as shown in the single line diagram of Fig. 9-17. The main features of major equipment other than turbine and generator are described below.

As described previously in paragraph 8.4 on the power transmission and substation plan, the transmission and substation facilities will be operated at 220 kV from the time of commissioning of the No. 3 unit in September 1998, whereas before that, the operation will be at 132 kV, and it will be necessary to make plan and design of outdoor switchyard equipment including transformers, paying attention to this point.

(1) Main Transformer and Station Service Transformer

The main transformers are to be of indoor type, oil-immersed and water-cooled, while, the station service transformer outdoor type, oil-immersed and air-cooled. Taking into account the installation space for equipment, it is desirable to adopt 3-phase transformers rather than single-phase ones. However, when transportation limits are considered, the weight of an ordinary 3-phase type will be about 60 tons which are considered too heavy to transport. Therefore, it is desirable to adopt special 3-phase type in which the upper tank only is used in common and transportation and assembly in unit of single phase is possible so as to reduce the transportation weight.

A system in which a single main transformer is shared by plural number of generators is also conceivable, but in consideration of the ease of inspection and maintenance, it is suitable to adopt a unit system in which a main transformer is provided to each generator.

In consideration of the importance of the Arun 3 power station in the electric power system, the station service power should be supplied not only from the generator circuits but also from the station service transformer to be installed outdoors.

(2) Switchyard Equipment

As shown in the single line diagram of Fig. 9-17, a high-voltage synchronized system is adopted. Since a very large switchyard space will be required for conventional type switchgear as shown in Fig. 9-19, it is aimed to reduce the required space adopting compact type gas insulated switchgear (GIS) (Fig. 9-18). 3-phase separate type GIS is considered in this study but 3-phase integrated type which reduces the cost has recently been adopted at many places throughout the world. It is necessary to study the possibility of adoption of this type in the detailed design stage. If adoption of vertical type circuit breaker is considered together with adoption of the abovementioned 3-phase integrated type GIS (whereas horizontal type circuit breaker is considered in this study), the required space shown in Fig. 9-18 can be reduced even more. Hence, it will be necessary to study this aspects in detail also.

(3) Power Cable

Oil-filled cable (OF cable) was generally adopted in the past as power cable connecting transformers and switchyard equipment, but a world-wide trend recently has been to adopt cross-linked polyethylene insulated vinyl sheath cable (CV cable), and therefore, it is desirable to adopt CV cable which permits easier maintainance than OF cable for 220 kV circuits in the Arun 3 power station.

(4) Overhead Travelling Crane

The heaviest equipment will be the generator rotor estimated at about 170 tons, and in consideration of ease of equipment installation and shortening of installation time, two cranes with rated load capacity of 90 tons respectively are to be installed.

(5) Telecommunication Facility

An outline of the telecommunication facility is described later in 9.2.3(3). Although duplex system consisting of microwave link and power line carrier (PLC) apparatus has been considered here, it is necessary to further examine this system in detail.

9.2.3 Substation and Switchyard

The single line diagrams and equipment arrangements for the Dubi substation, the Dhalkebar switchyard and the New Kathmandu substation are shown respectively in Figs. 9-20, 9-21, 9-22, 9-23, 9-24 and 9-25. The outlines of the main equipment are as shown in these figures, while the basic concepts of major equipment are as described below.

(1) Substation and Switchyard Equipment

Conventional equipment arrangements applying SF_6 gas circuit breaker and aluminum pipe bus are considered in this study, but since the Dubi substation and the Dhalkebar switchyard are to be expanded and the New Kathmandu substation is to be newly constructed in the capital city of Kathmandu, difficulties will possibly be encountered in securing space for installation of equipment. There is a possibility that a necessity will arise to consider application of GIS in such case, and therefore it will be necessary in the future to carry out field investigation of substations and switchyard to be expanded or newly constructed to set up optimum designs.

(2) Bus Configuration

Double-bus system with high reliability is adopted in this study taking into account the important role of 220 kV substation and switchyard.

(3) Telecommunication Facility

With regard to planning and designing of telecommunication facility, the future conception of NEA should be taken into account and coordination with existing facilities should be kept in mind. Furthermore, (i) telephone channel for load dispatching, (ii) telephone channel for security, (iii) telemeter circuit for load dispatching, (iv) signal transmission system for carrier protective relay, (v) information transmission channel for remote control, (vi) VHF mobile radio facility and VHF radio base station, (vii) transmission line fault locator, (viii) telecommunication power supply facility and (ix) location of repeater station for microwave link are to be considered. It will be necessary to examine the system in detail through the detailed design to be made in the future. With regard to planning of telecommunication facility, formulation of plan should be done incorporating the concept of the future supervisory control and data acquisition system (SCADA), and this SCADA concept should also be studied at an early stage.

In the present feasibility study, it is planned to link the load dispatching center at Kathmandu, the Arun 3 power station, the Dubi substation, the Dhalkebar switchyard and the New Kathmandu substation with telecommunication facility on the premise that supervisory remote control will be done from the load dispatching center. With regard to telecommunication link, duplex system consisting of power line carrier (PLC) and microwave is considered in consideration of enhancing reliability, while regarding power line carrier equipment, it is desirable to adopt line-connected telecommunication link (metallic return method) for load dispatching and security with high reliability.

9.2.4 Transmission Line

(1) Transmission Line Route

The outline of transmission line route of the project is shown in Fig. 9-26.

(i) Arun 3 Power Station - Dubi Substation (Section A, 120 km)

Regarding the route between the Arun 3 power station and the Dubi substation, except for approximately 10 km of rice paddies in the vicinity of Dubi, the greater part of the route is in mountainous area and the maximum altitude is about 1,800 m in the vicinity of Hile.

From the Arun 3 power station to Hile, a route generally parallel to the access road along the Arun river for the construction of dam and powerhouse is selected. The topography along the route is relatively flat, but there is a mountainous area around Hile with many ups and downs.

Between Hile and Dubi, a route running generally to the south along the existing road is selected.

(ii) Dubi Substation - Dhalkebar Switchyard (Section B, 146 km)

The route between Dubi and Dhalkebar is selected in generally parallel with the existing 132 kV transmission line. The major concern from technical point of view in this section will be the crossing of Sapt Kosi. In setting up of this route, the Kosi Tappu Wild Life Reserve is kept away so as not to cause the environmental impact. The crossing is to be made upstream of the existing transmission line.

(iii) Dhalkebar Switchyard - New Kathmandu Substaion (Section C, 120 km)

The route between Dhalkebar and Kathmandu is a mountainous area, but the topography is more or less flat. It is thought that the existing road will be amply utilized with addition of an access road. A mountain pass at elevation of about 1,800 m will be crossed over at roughly the midpoint of this route. These are not considered to be great obstacles to establish the route in this section, but it will be necessary to select the optimum route based on field investigations at the detailed design stage.

(2) Transmission Voltage and Number of Circuits

As described in Chapter 8 on the power transmission and substation plan, 220 kV, 2 cct will be eventually required for stable power transmission of the total output of 400 MW from the Arun 3 power station. However, the operation is to be done provisionally at 132 kV at the beginning.

(3) Optimum Conductor Size

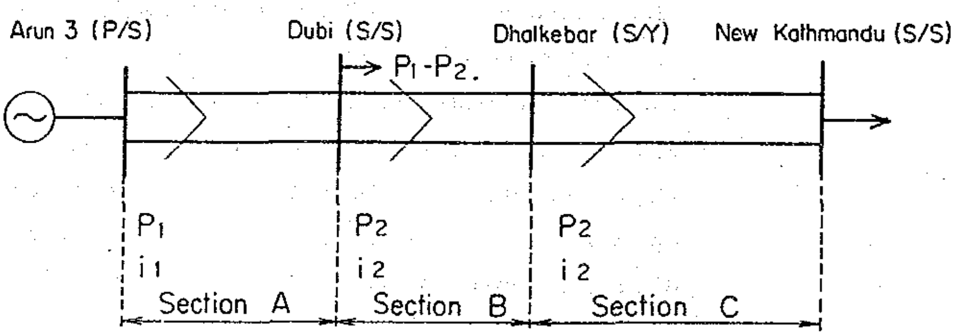
(i) Transmission pattern and power flow

In selecting the optimum conductor size, studies on operation and transmission pattern of the Arun 3 power station at F.Y. 2001/02 (3 units operation) and F.Y.

2007/08 (6 units operation) are made taking into account the construction schedules of power station and transmission/substation facilities.

Transmission line route is as described below and it is planned to operate the 220 kV transmission line of 1 cct up to F.Y. 2001/02 and 2 cct up to F.Y. 2007/08 between the Dubi and the New Kathmandu substations through the Dhalkebar switchyard taking into account the suspension of power export.

As shown in power system analysis in paragraph 8.6, power flows at the peak load in F.Y. 2001/02 and F.Y. 2007/08 are P_1 = 200 MW, P_2 = 80 MW and P_1 = 400 MW, P_2 = 216 MW, respectively.



The currents (i_1, i_2) of the individual sections are obtained as follows:

<u>F.Y. 2001/2002</u>

(Section A)

$$i_1 = \frac{0.5P_1}{\sqrt{3}\ V\ \cos\theta} = \frac{100}{\sqrt{3} \times 220 \times 0.95} = 0.28\ (kA/\phi.cct)$$

where, $\cos\theta$: load power factor = 0.95

(Section B, C)

$$i_2 = \frac{P_2}{\sqrt{3}\ V\ \cos\theta} = \frac{80}{\sqrt{3} \times 220 \times 0.95} = 0.22\ (kA/\phi.cct)$$

F.Y. 2007/2008

(Section A)

$$i_1 = \frac{0.5P_1}{\sqrt{3}\ V\ \mathrm{Cos}\theta} = \frac{200}{\sqrt{3} \times 220 \times 0.95} = 0.55\ (kA/\phi.cct)$$

(Section B, C)

$$i_2 = \frac{0.5P_2}{\sqrt{3}\ V\ \mathrm{Cos}\theta} = \frac{108}{\sqrt{3} \times 220 \times 0.95} = 0.30\ (kA/\phi.cct)$$

(ii) Conductor size

From the standpoint of maintenance, it is desirable to use the unified size of conductor in Section A, B and C. When the current capacity, mechanical strength and corona characteristics meeting the electric power generated in this project are considered, the proper sizes will be as presented below. Namely, the following three cases and their combinations will be presented on condition that 1 cct transmission line is capable of transmitting power of 400 MW in section A and 216 MW in sections B and C respectively.

	(Section A)	(Section B, C)
Case 1 ...	330 mm^2 ACSR x 2C	330 mm^2 ACSR x 1C
Case 2 ...	400 mm^2 ACSR x 2C	400 mm^2 ACSR X 1C
Case 3 ...	410 mm^2 ACSR X 2C	410 mm^2 ACSR X 1C

The optimum conductor size will be selected out of the above cases based on comparative studies of cost and power loss.

The results of economical comparisons of the above three cases are as shown in Tables 9-9(1) and 9-9(2) for the fiscal years

2001/02 and 2007/08, respectively. As clearly observed therein, Case 1 and Case 2 are the most economical ones for the fiscal years 2001/02 and 2007/08 respectively, while, the Case 1 gives the worst result in F.Y. 2007/08. Case 1 and Case 2 have no remarkable difference from the economical point of view at F.Y. 2001/02, and thereafter the economic nature of Case 1 declines compared with Case 2. Hence, it is concluded that the conductor size taken in Case 2 will be the optimum one. The selected conducter sizes are as shown below.

Arun 3 P/S - Dubi S/S (Section A) 400 mm^2 ACSR x 2C

Dubi S/S - Dhalkebar S/Y (Section B) 400 mm^2 ACSR x 1C

Dhalkebar S/Y - New Kathmandu S/S (Section C) 400 mm^2 ACSR x 1C

The specifications of 400 mm^2 ACSR conductor will be as follows:

"Condor" 795 MCM ACSR (ASTM Standard)

Outside diameter: 27.73 mmø (cross-sectional area 402.6 mm^2)

Unit weight: 1.522 kg/m, R20 = 0.07173Ω/km

(4) Lightning-proof Design

The IKL (isokeraunic level) in the project area is about 50, and it is aimed at 100 percent shielding against lightning through provision of two overhead ground wires of 70 mm^2 GSW with shielding angle within 20 deg.

(5) Type and Number of Insulators

Insulation design for the 220 kV transmission line is considered under the condition of an effective grounding system at the maximum system voltage of 240 kV and altitude under 2,000 m along the route.

The route of this transmission line will be an inland one and the number of insulators will be decided by abnormal voltage of switching surge, but in consideration of interconnection with a neighboring country, some allowances are to be provided for coordination, and the standard is to be of suspension type insulators of 250 mmϕ consisting of 14 discs.

(6) Supports

According to the design of the existing facilities, the standard wind pressures are 80 kg/m^2 for conductor and 230 kg/m^2 for steel tower, and these are thought to be reasonable design conditions in view of meteorological data and operating performance so far.

(7) Special Design for Crossing Sapt Kosi

It is considered that the transmission line route for crossing the Sapt Kosi river will be upstream of the existing 132 kV transmission line, and the width of the river at this point is estimated to be from 6 to 8 km. Therefore, it is necessary to have a special design for this section in the same manner as that for the existing transmission line. In effect, a special conductor will be specified for reducing the steel tower height to lower the construction cost, while it is necessary to apply special foundations to river crossing, giving every consideration to maintenance and operation of facilities. The facilities, in outline, will be as follows:

Conductor:	330 mm^2 AACSR
Steel tower:	Span 800 m, height 70 m, approx.
Foundation:	Well-type special foundation

Details such as the type of foundation, span length, etc. will be decided based on the results of field investigations such as geological investigations and surveys to be carried out in the future at the detailed design stage.

9.2.5 Transportation

The weights and dimensions of large or heavy equipment to be transported are estimated as follows:

	L x W x H (m)	Weight (ton)
(Turbine)		
Main shaft	3.7 x 1.4 x 1.4	13
Inlet valve disc	4.7 x 2.9 x 2.9	14
(Generator)		
Stator (divided into 4 pieces)	2.3 x 3.6 x 5.1	25
(Main Transformer)		
	3.1 x 2.7 x 3.3	30

Table 9-8 Comparison of Main Ratings between Francis and Pelton Turbine-Generator

Item	Unit	Francis	Pelton
(Hydrology)			
Intake Water Level	(m)	840	840
Tail Water Level	(m)	538	538
Max. Discharge per Unit	(m^3/S)	26.7	26.7
Gross Head	(m)	302	302
Loss Head	(m)	14	20
Effective Head	(m)	288	282
(Turbine)			
Type		V. Francis Turbine	V. Pelton Turbine
Output	(kW)	69,000	66,000
Revolving Speed	(rpm)	429	200
Specific Speed	(m-kW)	95.0	22.2 (per nozzle)
Nozzles	(No.)	-	4
Units	(No.)	6	6
(Generator)			
Type		V. AC Generator (Suspended or Semi-Umbrella)	V. AC Generator (Semi-Umbrella)
Capacity	(kVA)	79,000	75,000
Voltage	(kV)	13.8	13.8
Revolving Speed	(rpm)	429	200
Frequency	(Hz)	50	50
Power Factor	(%)	85	85
Units	(No.)	6	6
(Main Transformer)			
Type		FOW (Indoor)	FOW (Indoor)
Capacity	(kVA)	79,000	75,000
Voltage	(kV/kV)	13.8/220	13.8/220
Units	(No.)	6	6

Table 9–9 (1) Economic Comparison for Selection of Conductor Size (For F.Y. 2001/2002)

	Case 1				Case 2				Case 3			
	Section A	Section B	Section C	Total	Section A	Section B	Section C	Total	Section A	Section B	Section C	Total
Line Route Length (km)	120	146	120	386	120	146	120	386	120	146	120	386
Conductor Size (mm^2) x No. of Conductors	330 x 2	330 x 1	330 x 1	-	400 x 2	400 x 1	400 x 1	-	410 x 2	410 x 1	410 x 1	-
Resistance of Single Conductor at 60°C (Ω/km)	0.052	0.1030	0.1030	-	0.042	0.0832	0.0832	-	0.041	0.0814	0.0814	-
Resistance of Single Conductor at 60°C, R (Ω)	6.24	15.04	12.36	33.64	5.04	12.15	9.98	27.17	4.92	11.88	9.77	26.57
Load Current, i (kA/Phase·cct)	0.28	0.22	0.22	-	0.28	0.22	0.22	-	0.28	0.22	0.22	-
Total Power Losses (MW), $6i^2R$ (for A), $3i^2R$ (for B,C)	2.94	2.18	1.79	6.91	2.37	1.76	1.45	5.58	2.31	1.72	1.42	5.45
*1 Annual Total Energy Losses (GWh)	8.37	6.21	5.10	19.68	6.75	5.01	4.13	15.89	6.58	4.90	4.04	15.52
Annual Cost due to Transmission Line Losses												
*2 Power (kw) Losses (10^3US$) ... (1)	199.9	148.2	121.7	469.8	161.2	119.7	98.6	379.5	157.1	117.0	96.6	370.7
*2 Energy (kwh) Losses (10^3US$) ... (2)	527.3	391.2	321.3	1239.8	425.3	315.6	260.2	1001.1	414.5	308.7	254.5	977.7
Total (1) + (2) (10^3US$) ... (3)	727.2	539.4	443.0	1709.6	586.5	435.3	358.8	1380.6	571.6	425.7	351.1	1348.4
Construction Cost (10^3US$)	21600	14010	11400	47010	23200	14800	12100	50100	24400	15700	12700	52800
*3 Annual Construction Cost (10^3US$) ... (4)	2592	1681	1368	5641	2784	1776	1452	6012	2928	1884	1524	6336
Total Annual Cost (3) + (4) (10^3US$)	3319.2	2220.4	1811.0	7350.6	3370.5	2211.3	1810.8	7392.6	3499.6	2309.7	1875.1	7684.4

Note: *1 Annual energy losses (kwh losses) are calculated taking into account the loss factor (Lr) which is the ratio of average power losses to peak power losses obtained from experimental equation of Buller-Woodrow.

$Lr = 0.3 \times (\text{Annual Load Factor}) + 0.7 \times (\text{Annual Load Factor})^2$, Annual Load Factor : 0.50

*2 Cost for power losses and energy losses

(a) 68 US$/kW/year
(b) 0.063 US$/kwh

*3 Annual cost rate of 0.12 is adopted.

Table 9–9 (2) Economic Comparison for Selection of Conductor Size (For F.Y. 2007/2008)

	Case 1				Case 2				Case 3			
	Section A	Section B	Section C	Total	Section A	Section B	Section C	Total	Section A	Section B	Section C	Total
Line Route Length (km)	120	146	120	386	120	146	120	386	120	146	120	386
Conductor Size (mm^2) x No. of Conductors	330 x 2	330 x 1	330 x 1	-	400 x 2	400 x 1	400 x 1	-	410 x 2	410 x 1	410 x 1	-
Resistance of Single Conductor at 60°C (Ω/km)	0.052	0.1030	0.1030	-	0.042	0.0832	0.0832	-	0.041	0.0814	0.0814	-
Resistance of Single Conductor at 60°C, R (Ω)	6.24	15.04	12.36	33.64	5.04	12.15	9.98	27.17	4.92	11.88	9.77	26.57
Load Current, i (kA/Phase-cct)	0.55	0.30	0.30	-	0.55	0.30	0.30	-	0.55	0.30	0.30	-
Total Power Losses, $6i^2R$ (MW)	11.33	8.12	6.67	26.12	9.15	6.56	5.39	21.10	8.93	6.42	5.28	20.63
*1 Annual Total Energy Losses (GWh)	32.26	23.12	18.99	74.37	26.05	18.68	15.35	60.08	25.42	18.28	15.03	58.73
Annual Cost due to Transmission Line Losses												
*2 Power (kw) Losses (10^3US$) ... (1)	770.4	552.2	453.6	1776.2	622.2	446.1	366.5	1434.8	607.2	436.6	359.0	1402.8
*2 Energy (kwh) Losses (10^3US$) ... (2)	2032.4	1456.6	1196.4	4685.4	1641.2	1176.8	967.1	3785.1	1601.5	1151.6	946.9	3700.0
Total (1) + (2) (10^3US$) ... (3)	2802.8	2008.8	1650.0	6461.6	2263.4	1622.9	1333.6	5219.9	2208.7	1588.2	1305.9	5102.8
Construction Cost (10^3US$)	21600	17800	14600	54000	23200	18900	15400	57500	24400	19900	16300	60600
*3 Annual Construction Cost (10^3US$) ... (4)	2592	2136	1752	6480	2784	2268	1848	6900	2928	2388	1956	7272
Total Annual Cost (3) + (4) (10^3US$)	5394.8	4144.8	3402.0	12941.6	5047.4	3890.9	3181.6	12119.9	5136.7	3976.2	3261.9	12374.8

Note: *1 Annual energy losses (kwh losses) are calculated taking into account the loss factor (Lr) which is the ratio of average power losses to peak power losses obtained from experimental equation of Buller-Woodrow.

$Lr = 0.3 \times (\text{Annual Load Factor}) + 0.7 \times (\text{Annual Load Factor})^2$, Annual Load Factor : 0.50

*2 Cost for power losses and energy losses

(a) 68 US$/kW/year
(b) 0.063 US$/kwh

*3 Annual cost rate of 0.12 is adopted.

Fig. 9–12 (1) General Arrangement of Powerhouse in case of Francis Turbine (Sectional View)

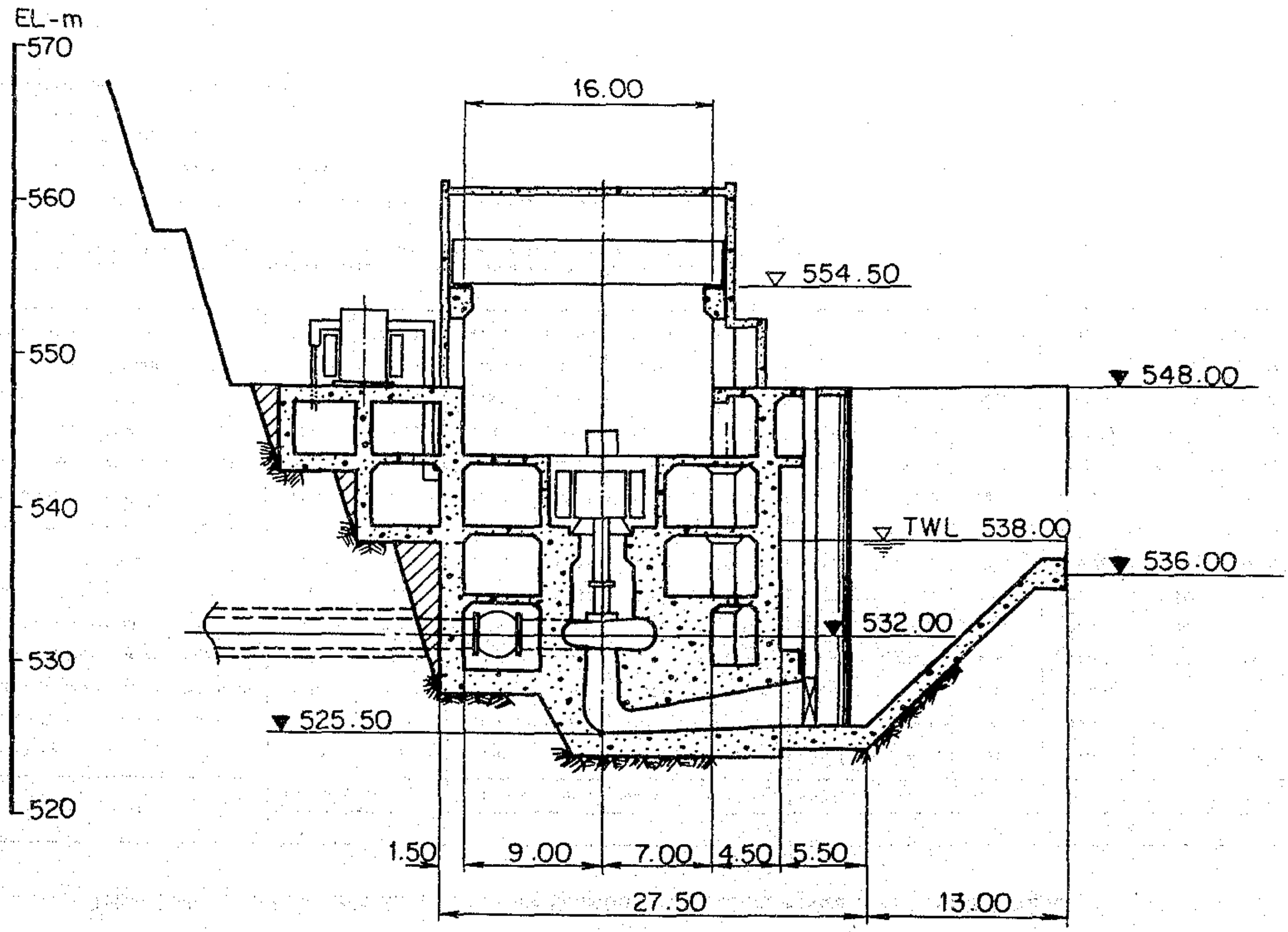


Fig. 9–13 (1) General Arrangement of Powerhouse in case of Pelton Turbine (Sectional View)

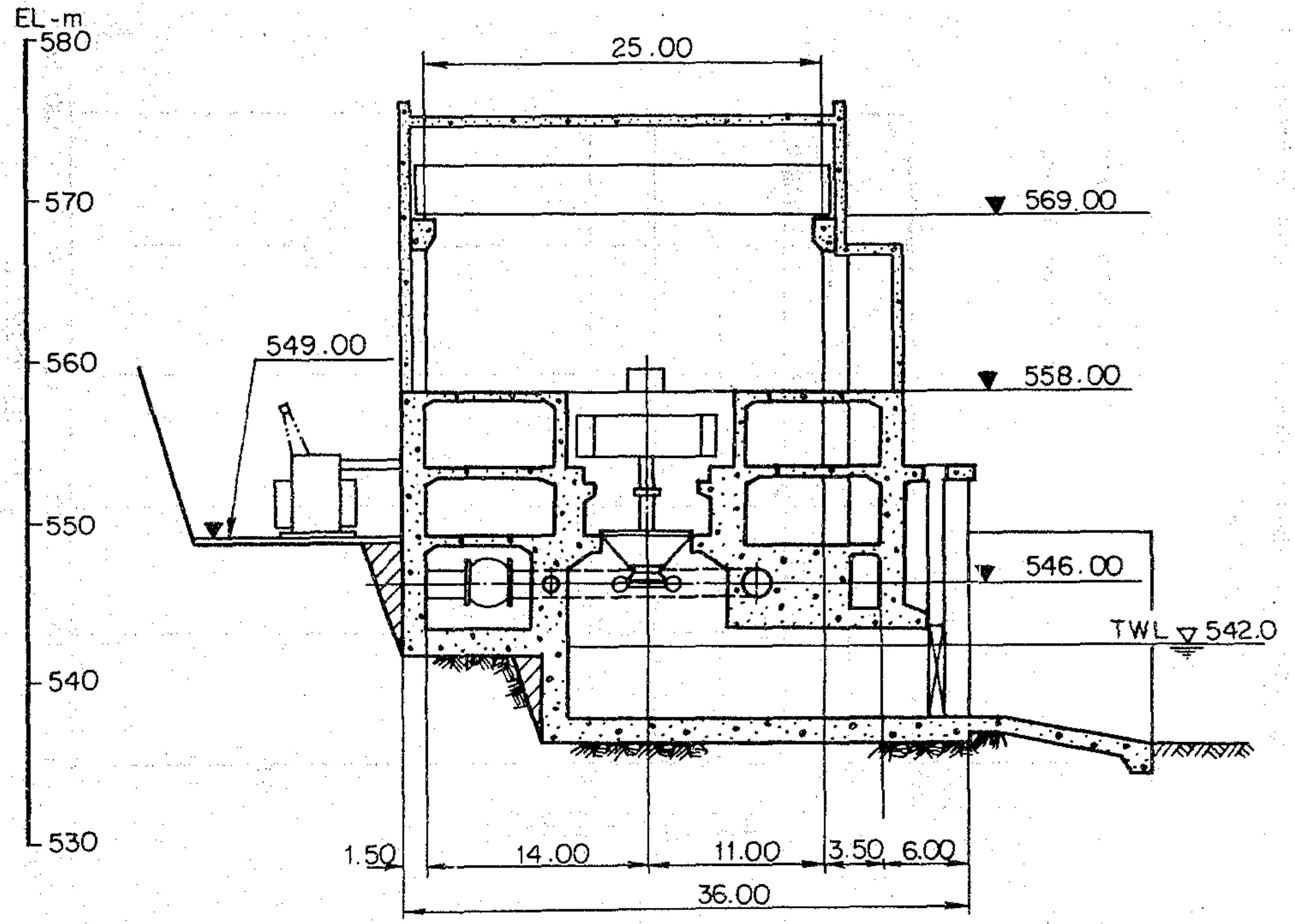


Fig. 9—14 Comparison of Turbine Efficiency between Francis and Pelton Turbine

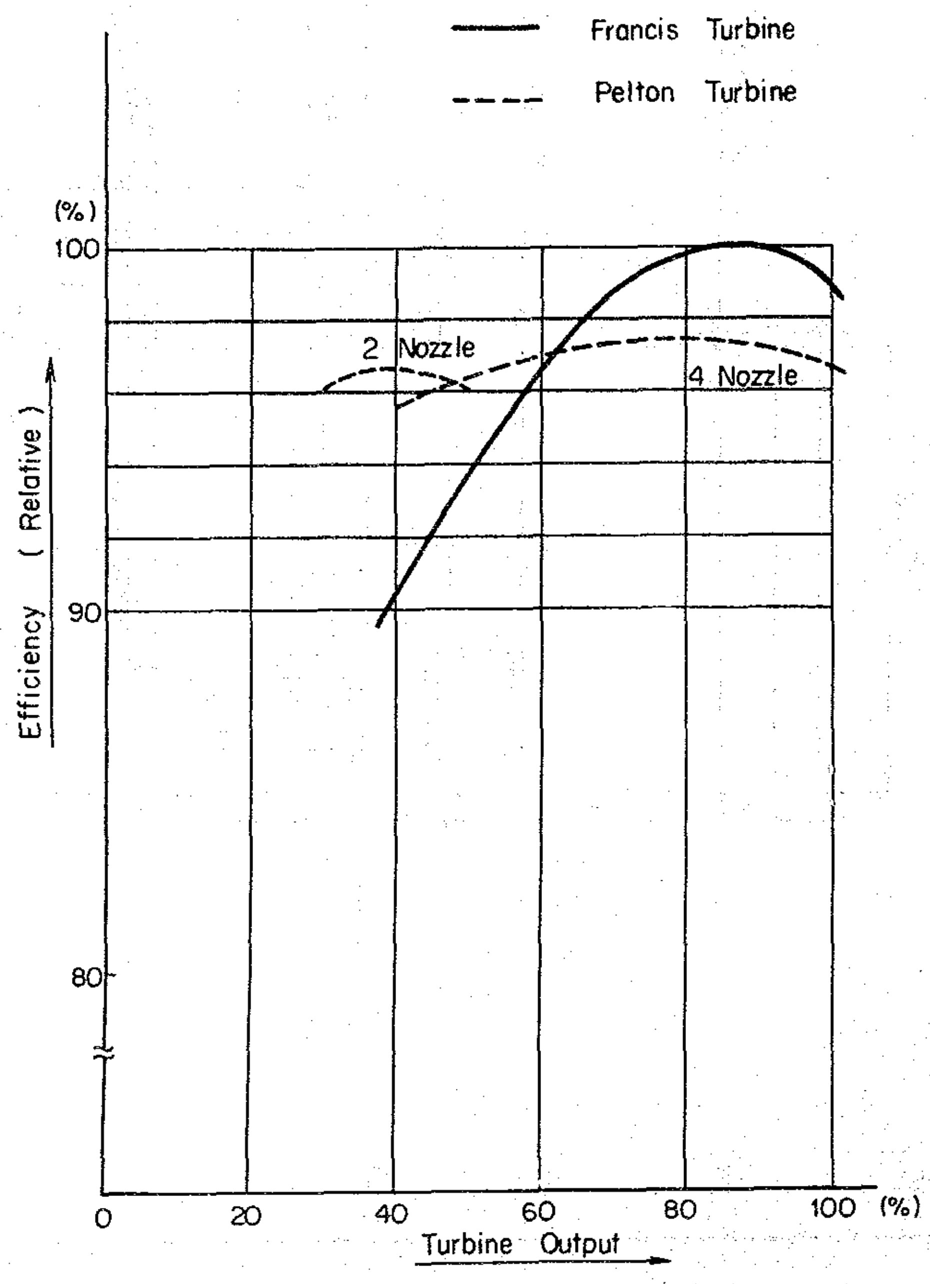


Fig. 9–15 (1) Daily Peak Load Forecast and Arun 3 Operation Rule in Jan. 2002

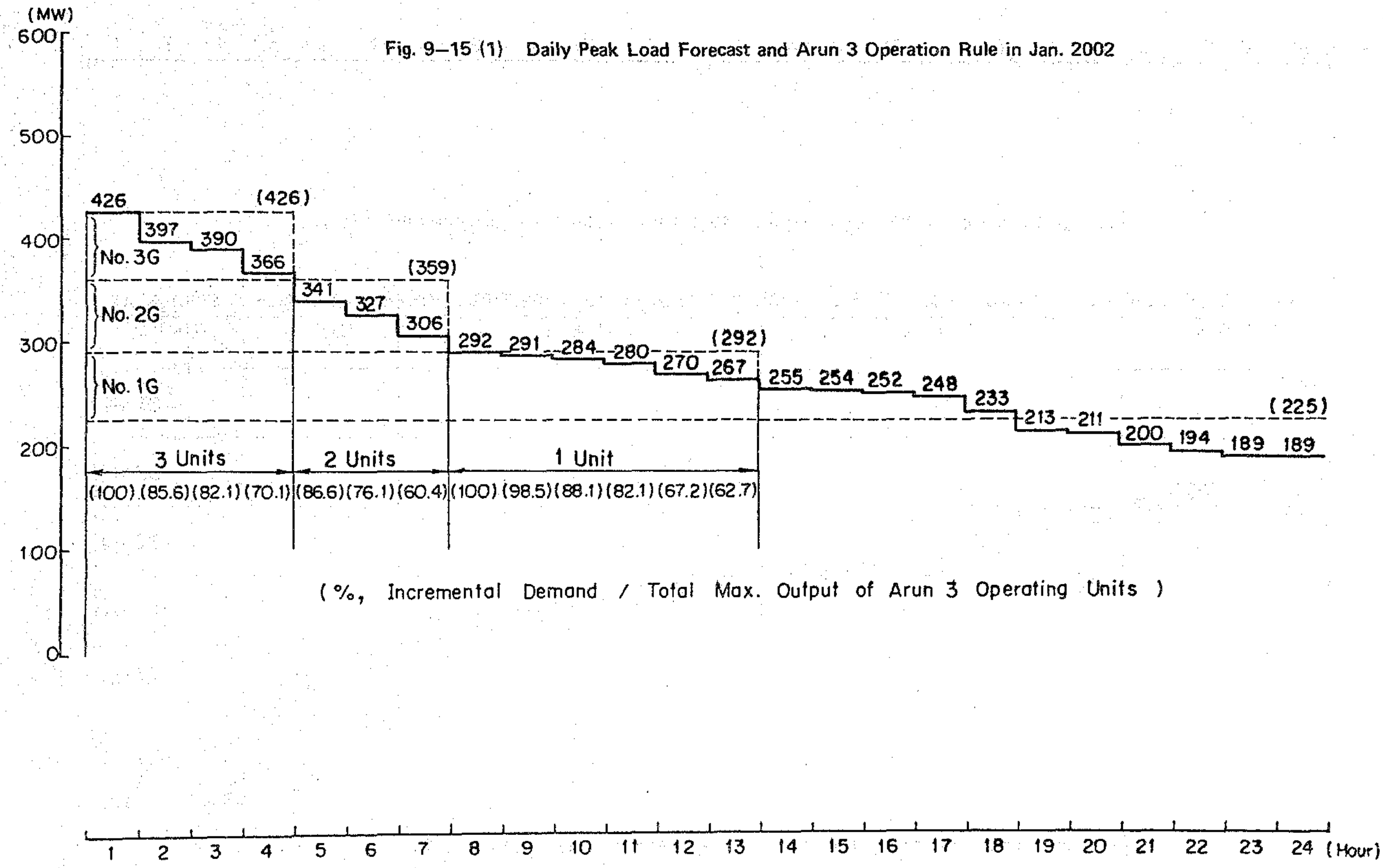


Fig. 9–15 (2) Daily Peak Load Forecast and Arun 3 Operation Rule in Jan. 2006

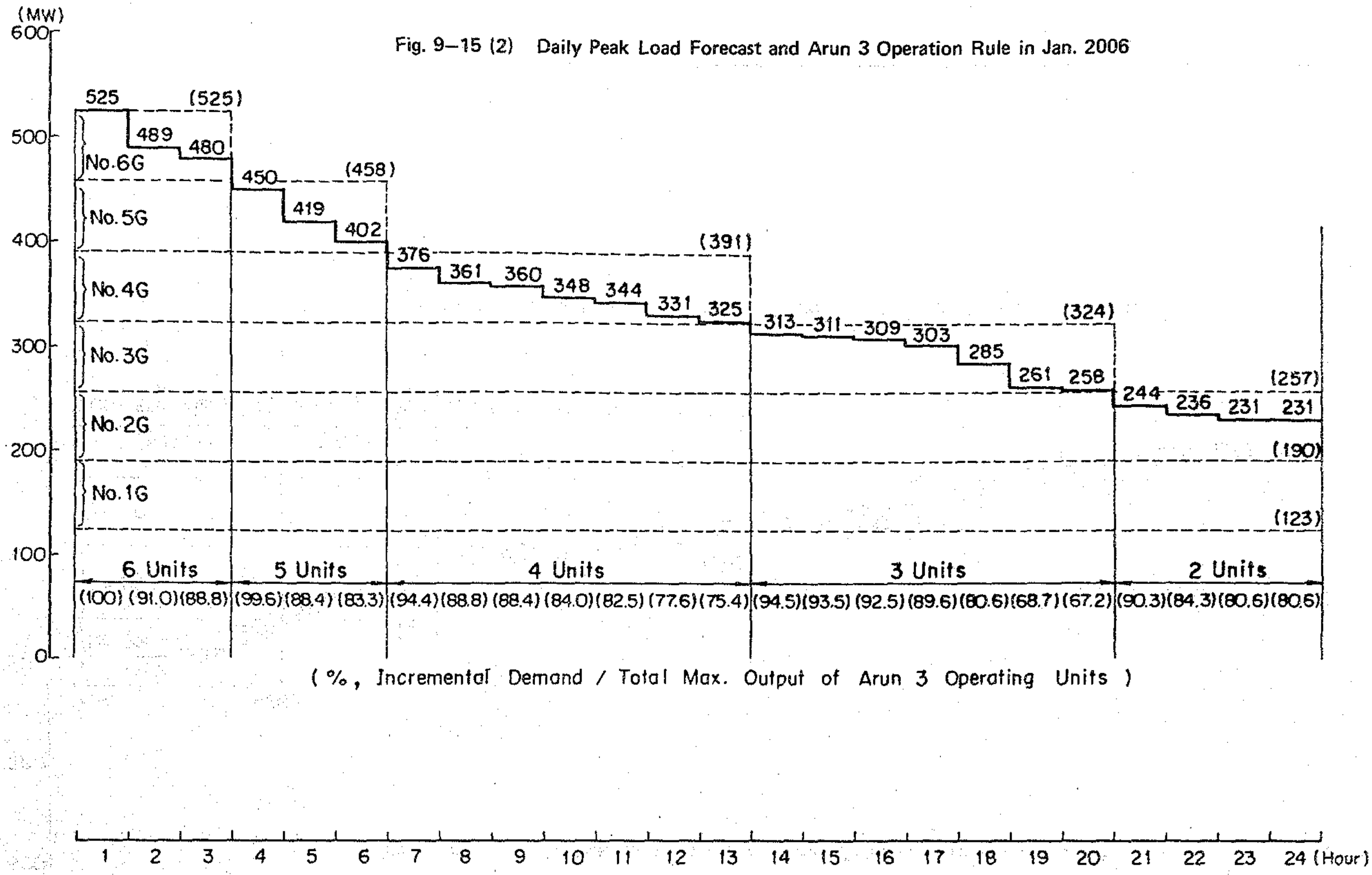
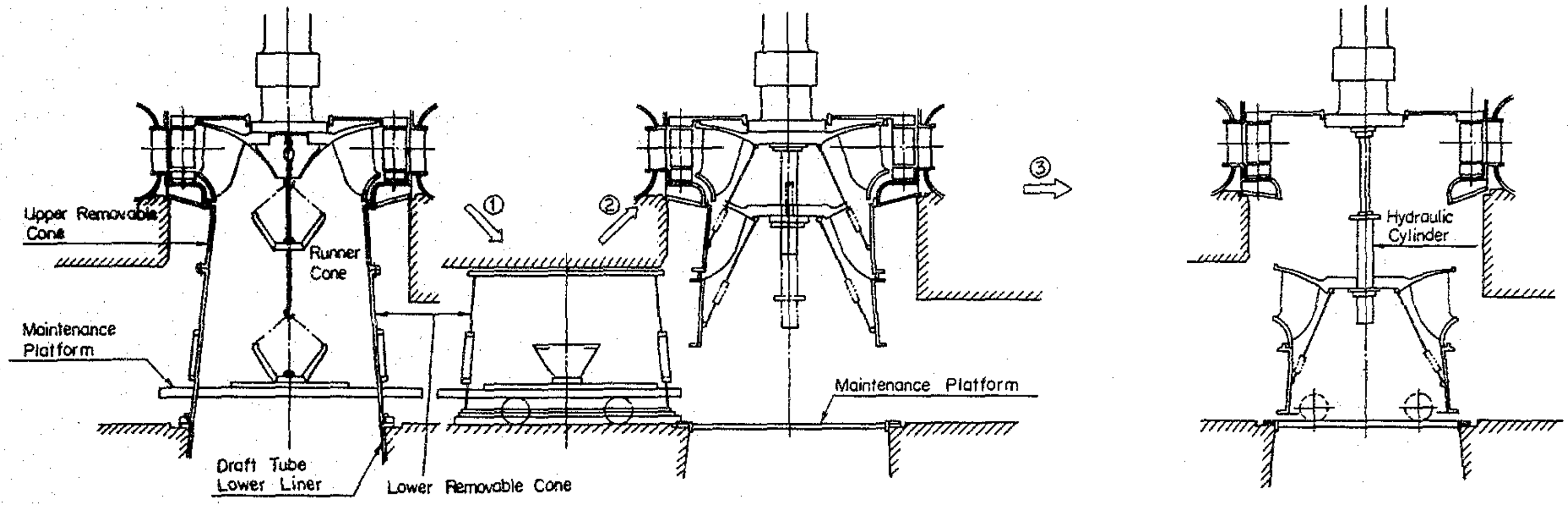
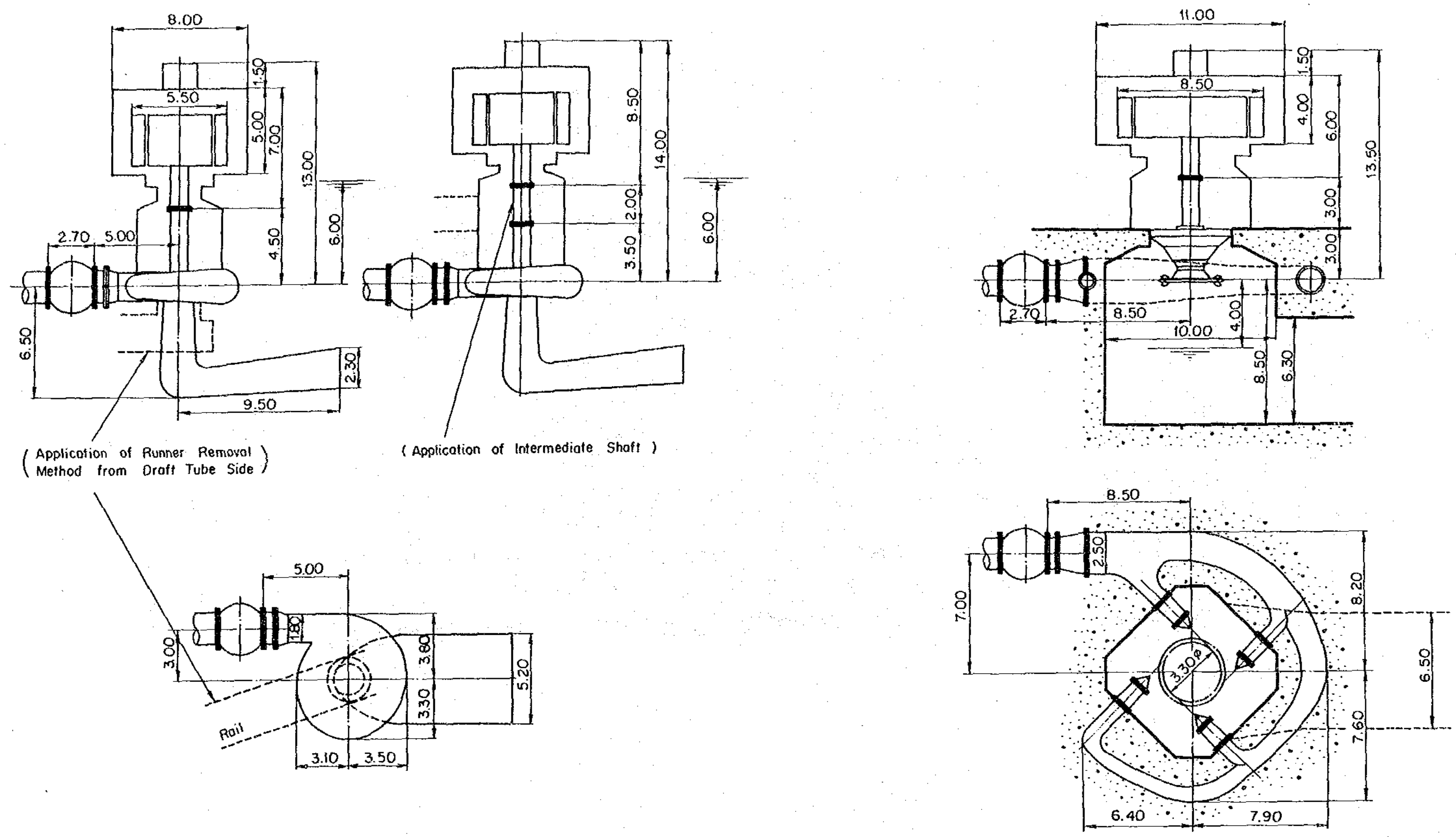


Fig. 9–16 Example of Runner Removal Method for Francis Turbine





Francis Turbine - Generator

Pelton Turbine - Generator

Fig. 9–11 Comparison of Main Dimensions between Francis and Pelton Turbine-Generator

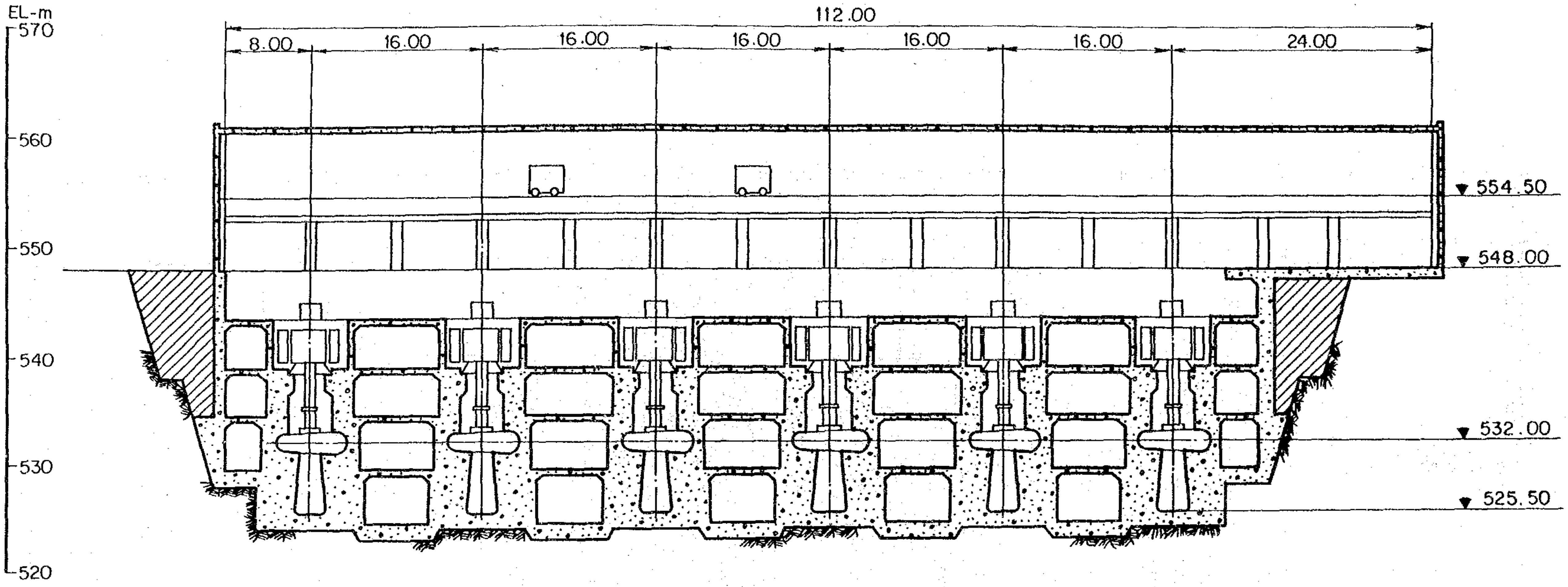


Fig. 9–12 (2) General Arrangement of Powerhouse in case of Francis Turbine (Longitudinal View)

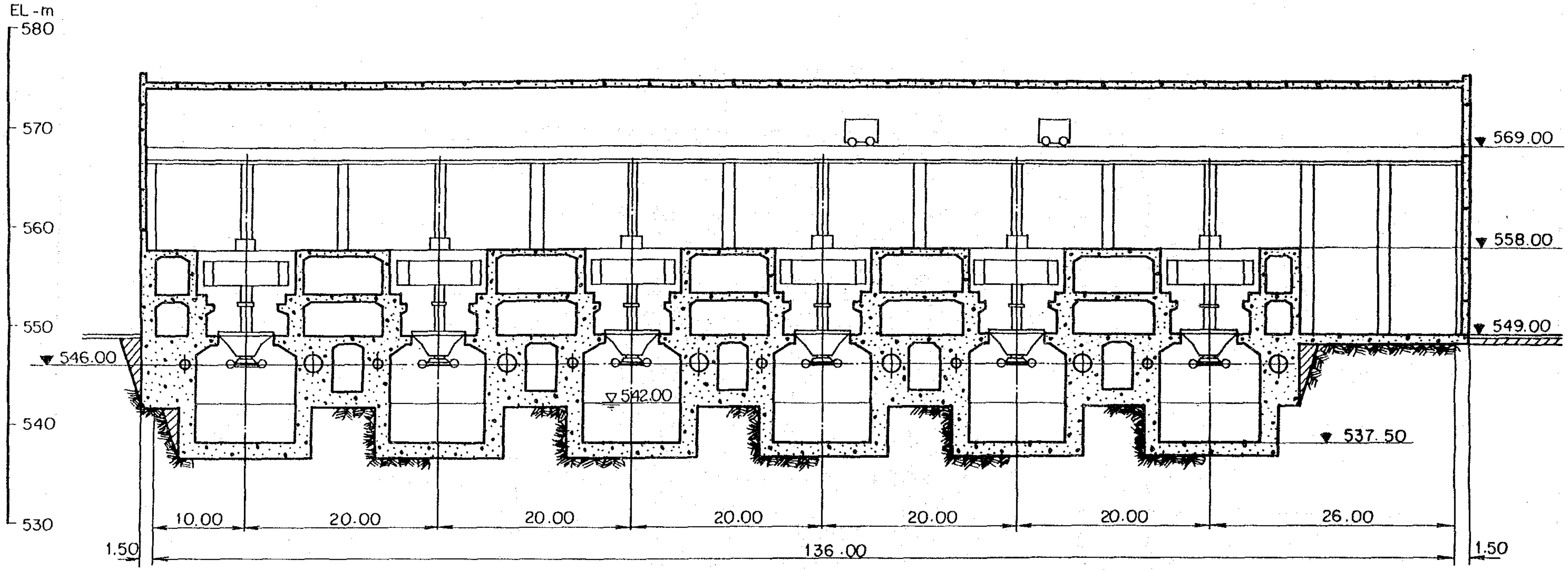


Fig. 9–13 (2) General Arrangement of Powerhouse in case of Francis Turbine (Longitudinal View)

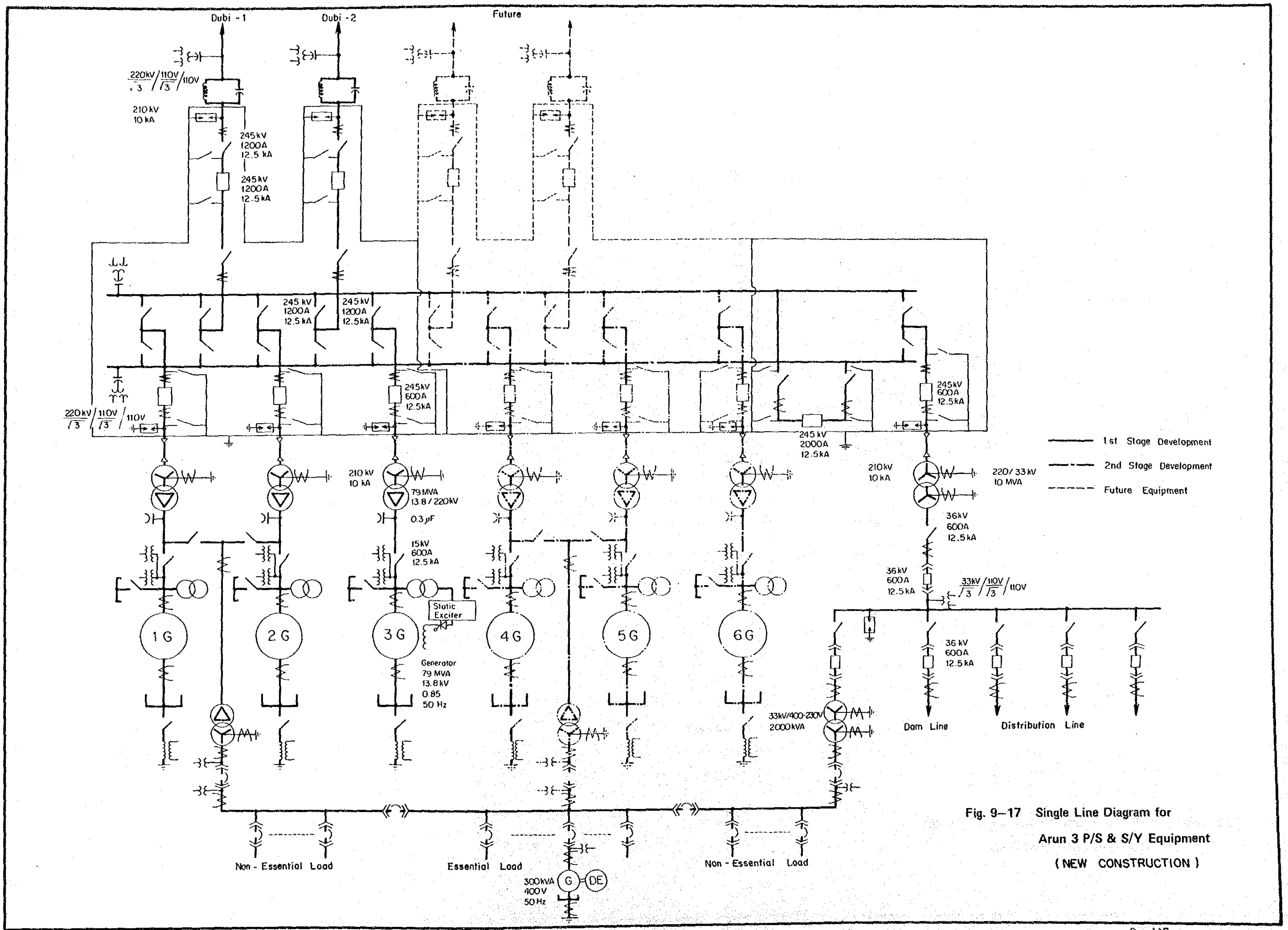
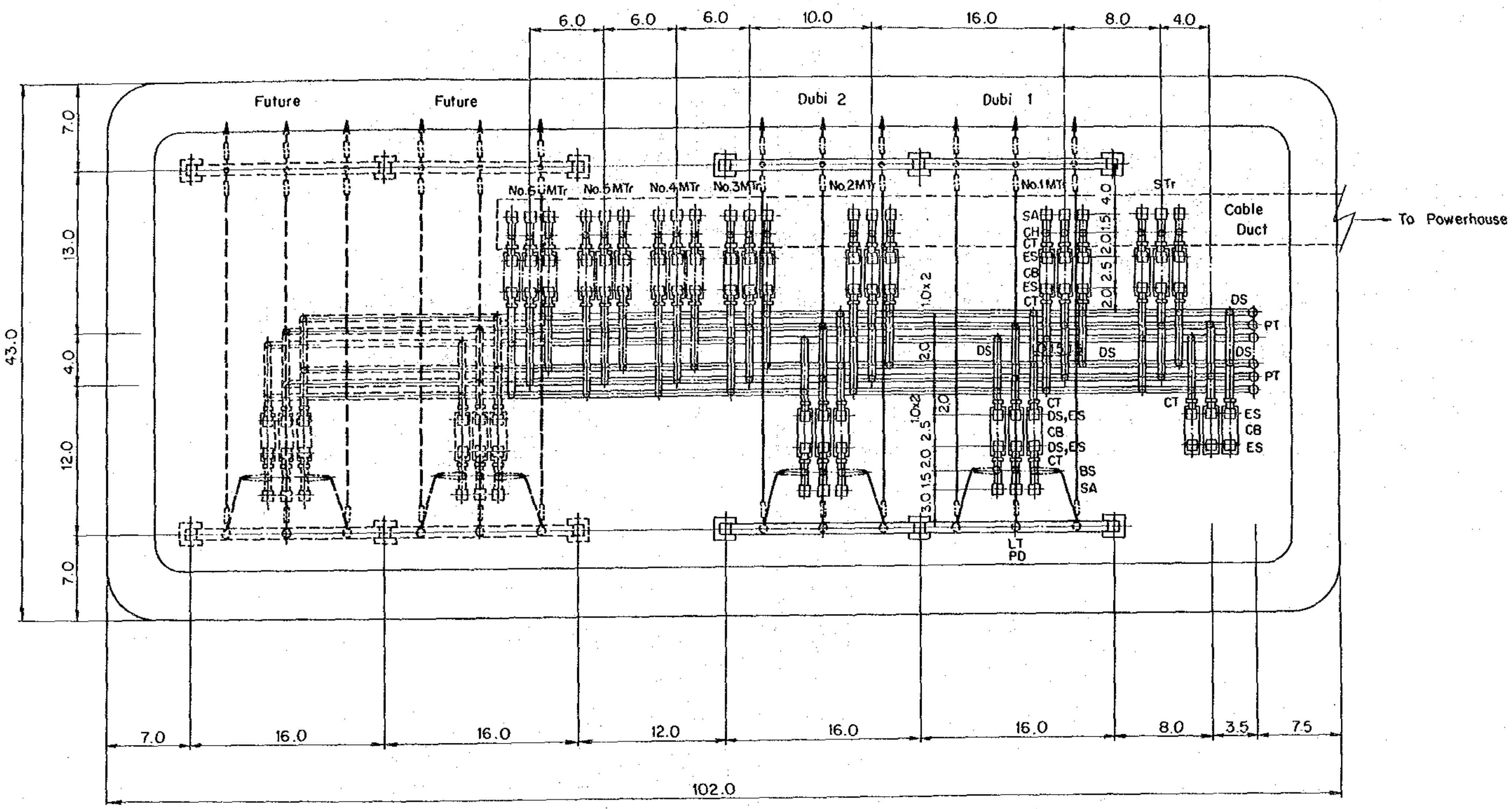


Fig. 9–17 Single Line Diagram for Arun 3 P/S & S/Y Equipment (NEW CONSTRUCTION)



LEGEND

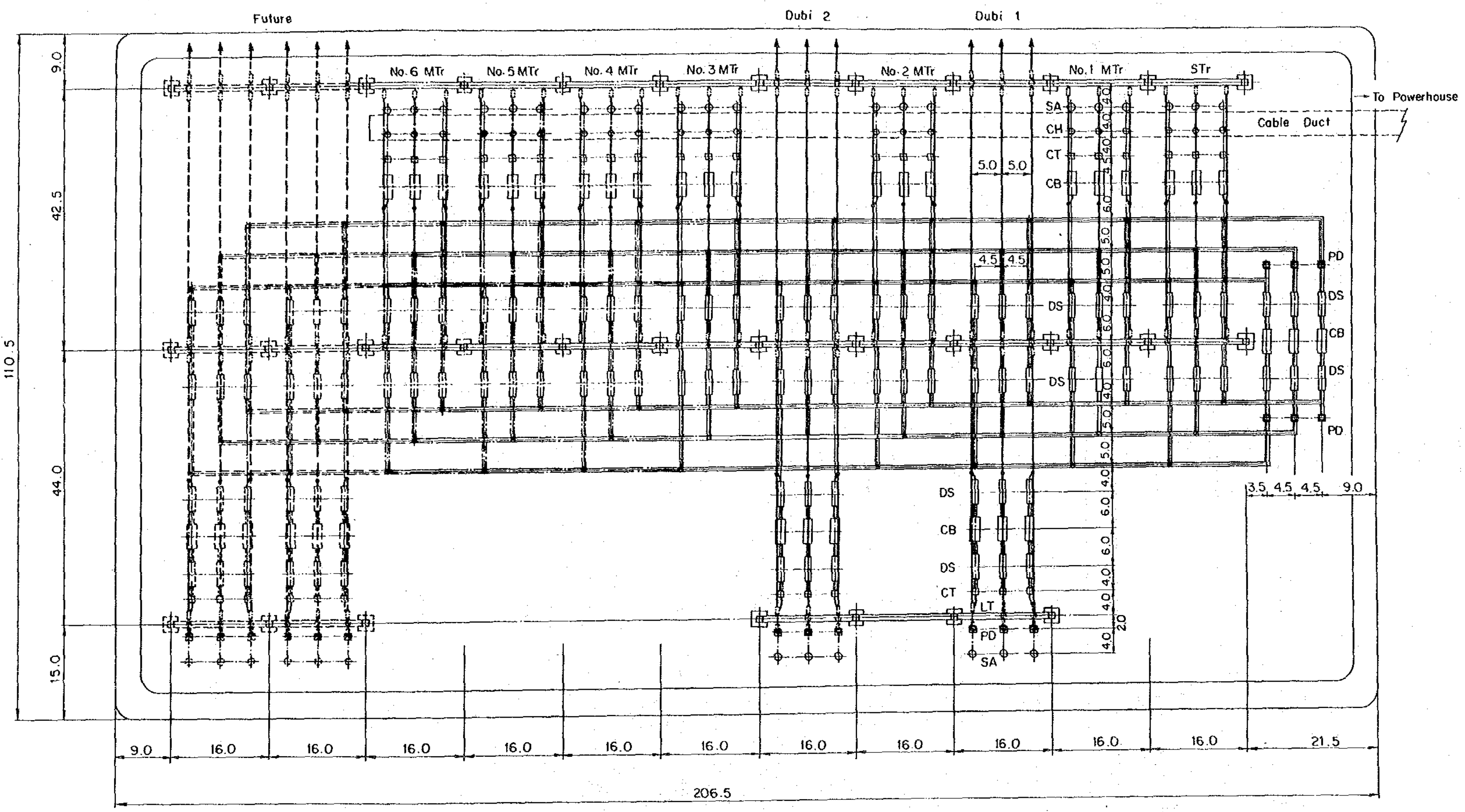
SA	Surge Arrester
CH	Cable Head
CT	Current Transformer
ES	Earthing Switch
CB	Circuit Breaker
DS	Disconnecting Switch
BS	Air Bushing
PT	Potential Transformer
LT	Line Trap
PT	Potential Transformer
MTr	Main Transformer
STr	Station Service Transformer

——— 1st Stage Development

—·—·— 2nd Stage Development

- - - - Future Equipment

Fig. 9–18 General Arrangement of Arun 3 Switchyard (In Case of GIS Equipment)



LEGEND

SA	Surge Arrester
CH	Cable Head
CT	Current Transformer
CB	Circuit Breaker
DS	Disconnecting Switch
LT	Line Trap
PD	Potential Device
MTr	Main Transformer
STr	Station Service Transformer

——— 1st Stage Development

—·— 2nd Stage Development

------ Future Equipment

Fig. 9–19 General Arrangement of Arun 3 Switchyard

(In Case of Conventional Type Equipment)

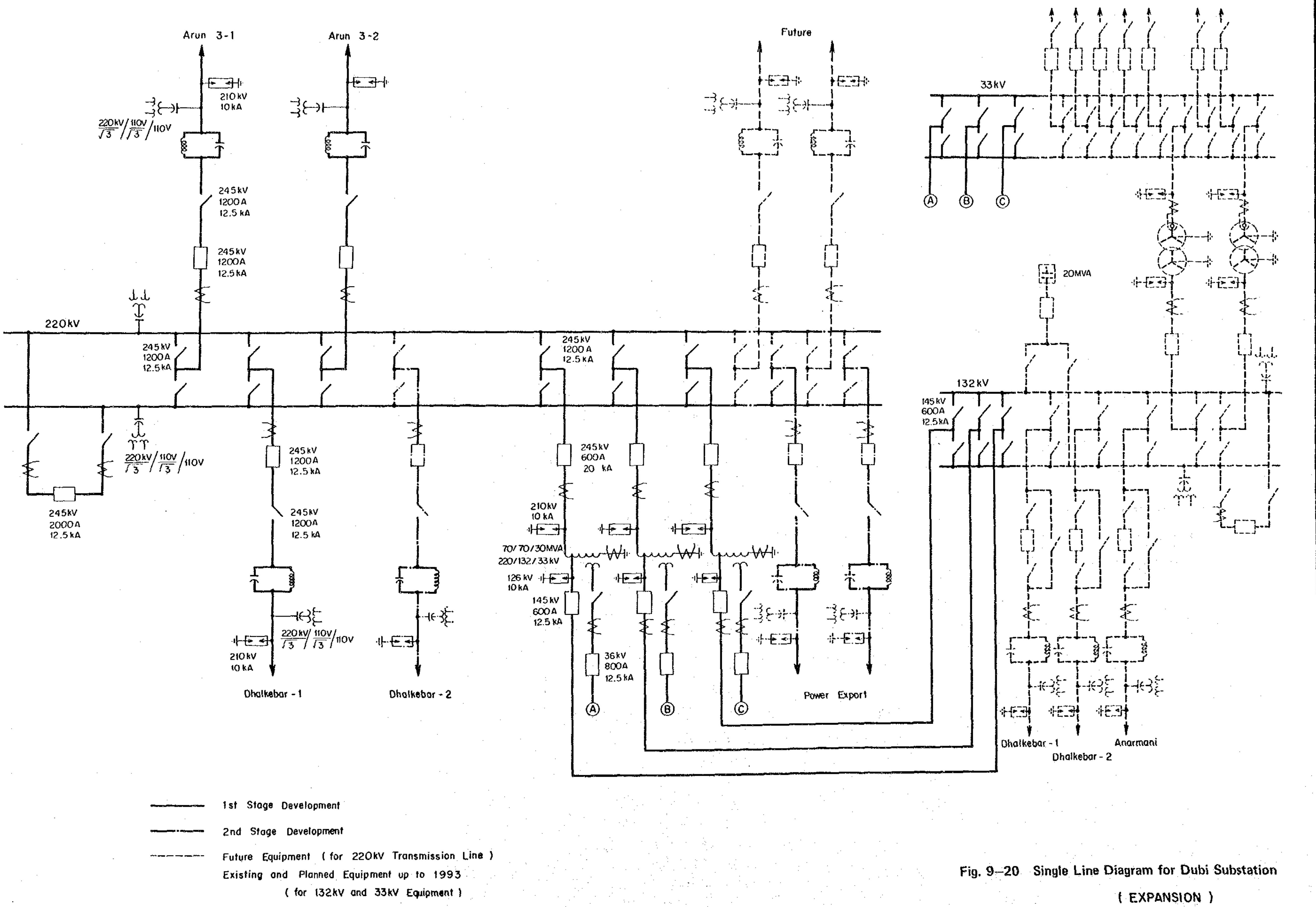


Fig. 9–20 Single Line Diagram for Dubi Substation
(EXPANSION)

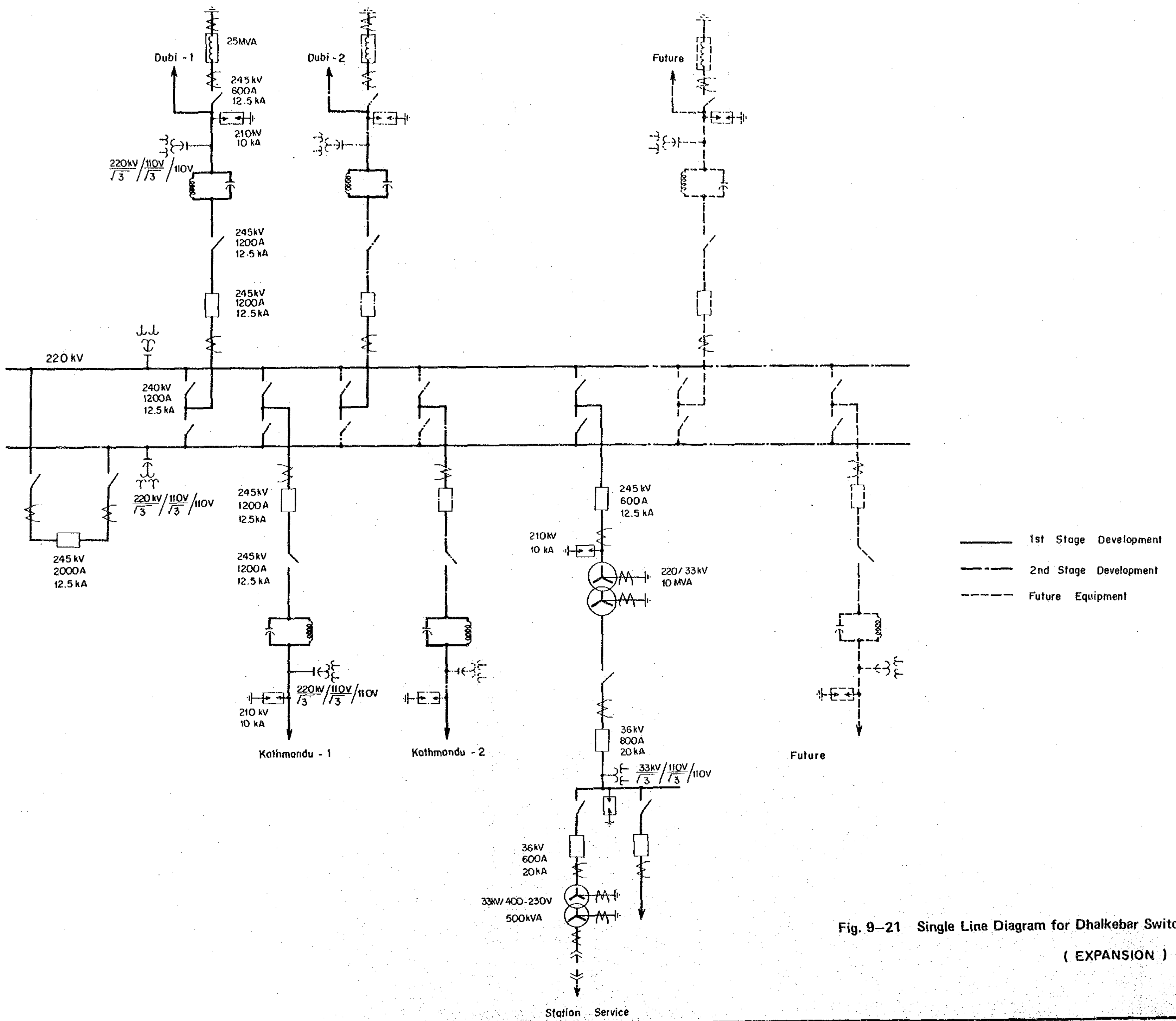


Fig. 9–21 Single Line Diagram for Dhalkebar Switchyard

(EXPANSION)

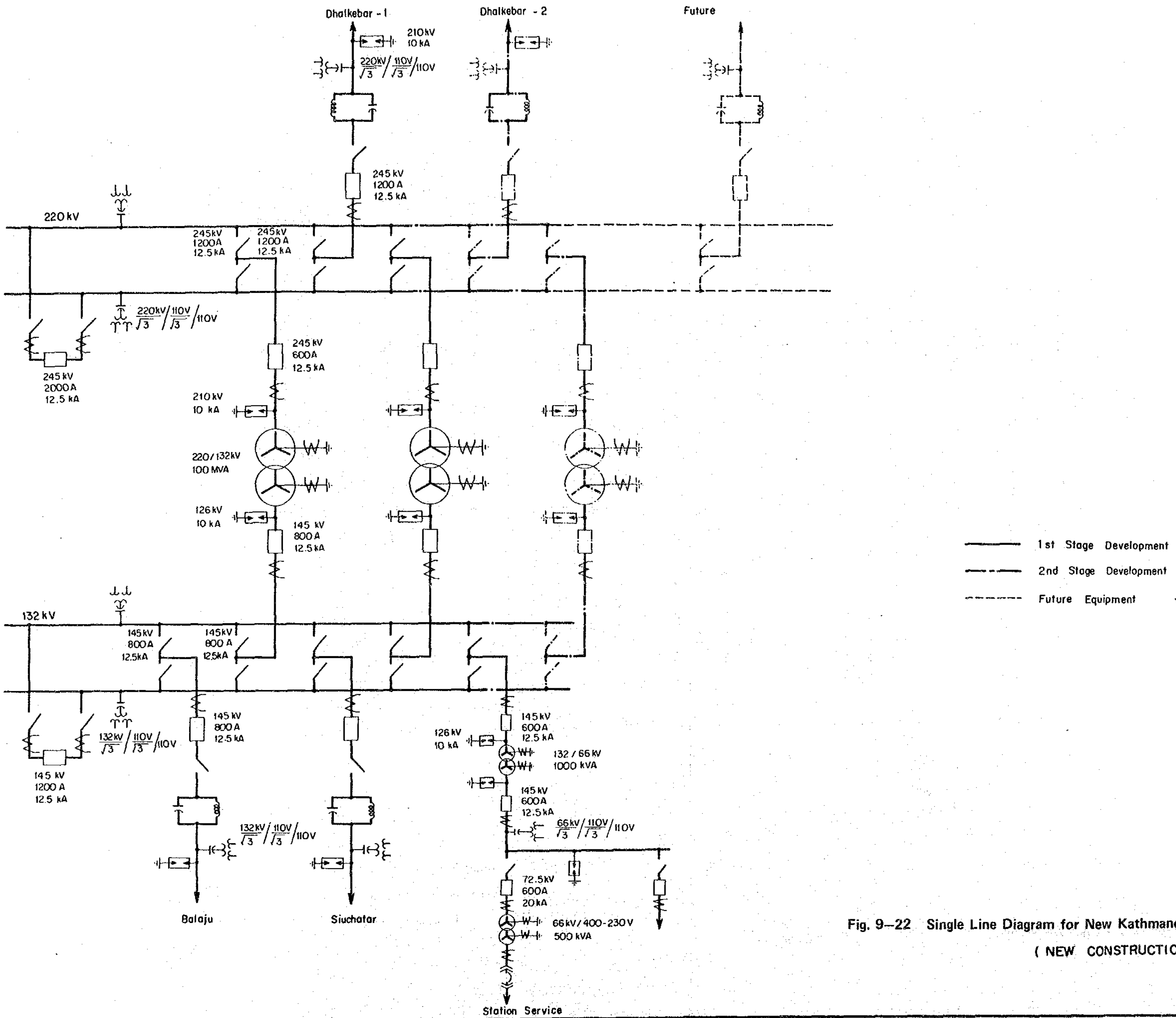
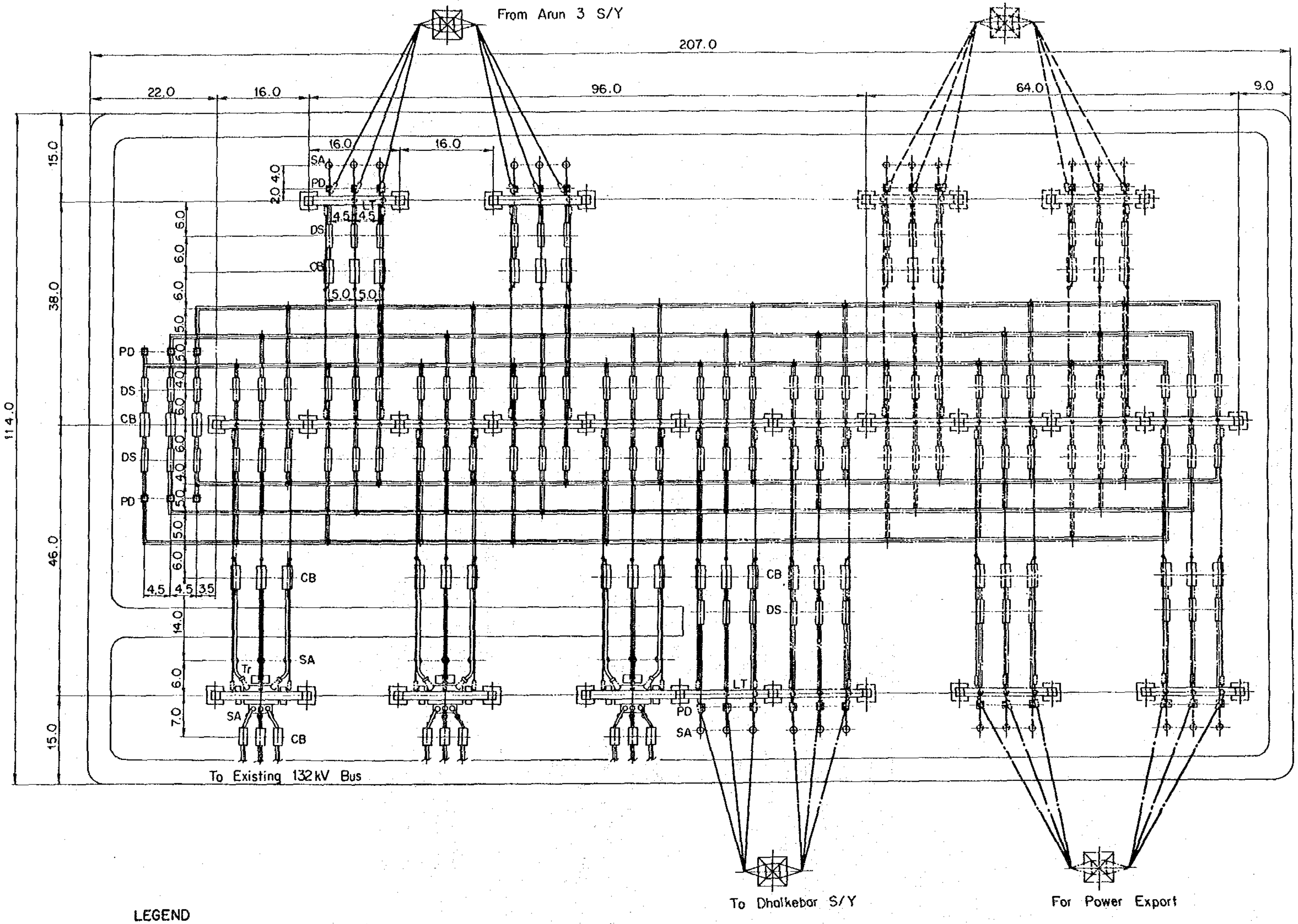


Fig. 9–22 Single Line Diagram for New Kathmandu Substation

(NEW CONSTRUCTION)



LEGEND

DS	Disconnecting Switch	————	1st Stage Development
SA	Surge Arrester	—·—·—	2nd Stage Development
PD	Potential Device	-------	Future Equipment
CB	Circuit Breaker		
LT	Line Trap		
Tr	Transformer		

Fig. 9–23 General Arrangement of Dubi Substation

(EXPANSION)

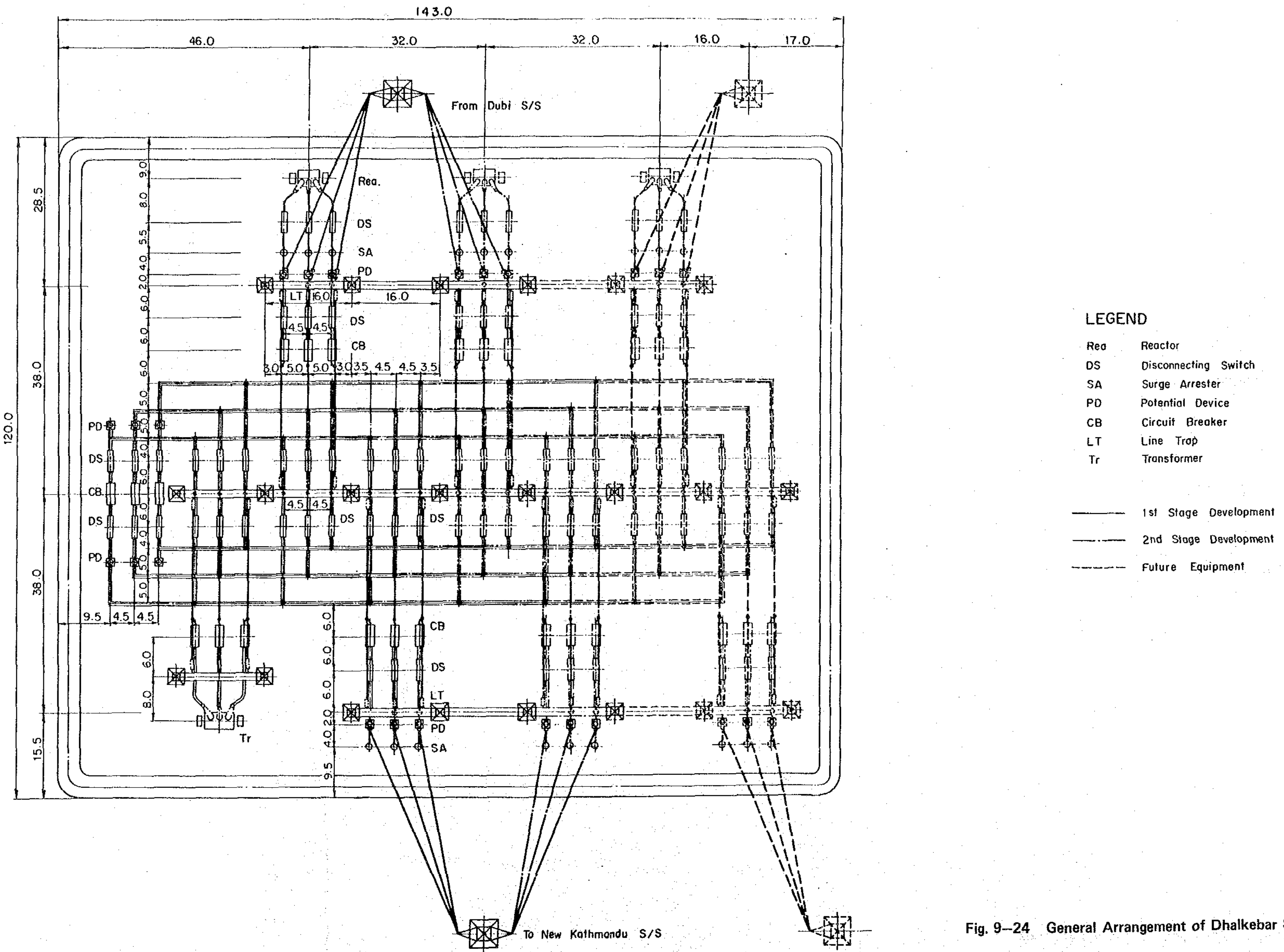
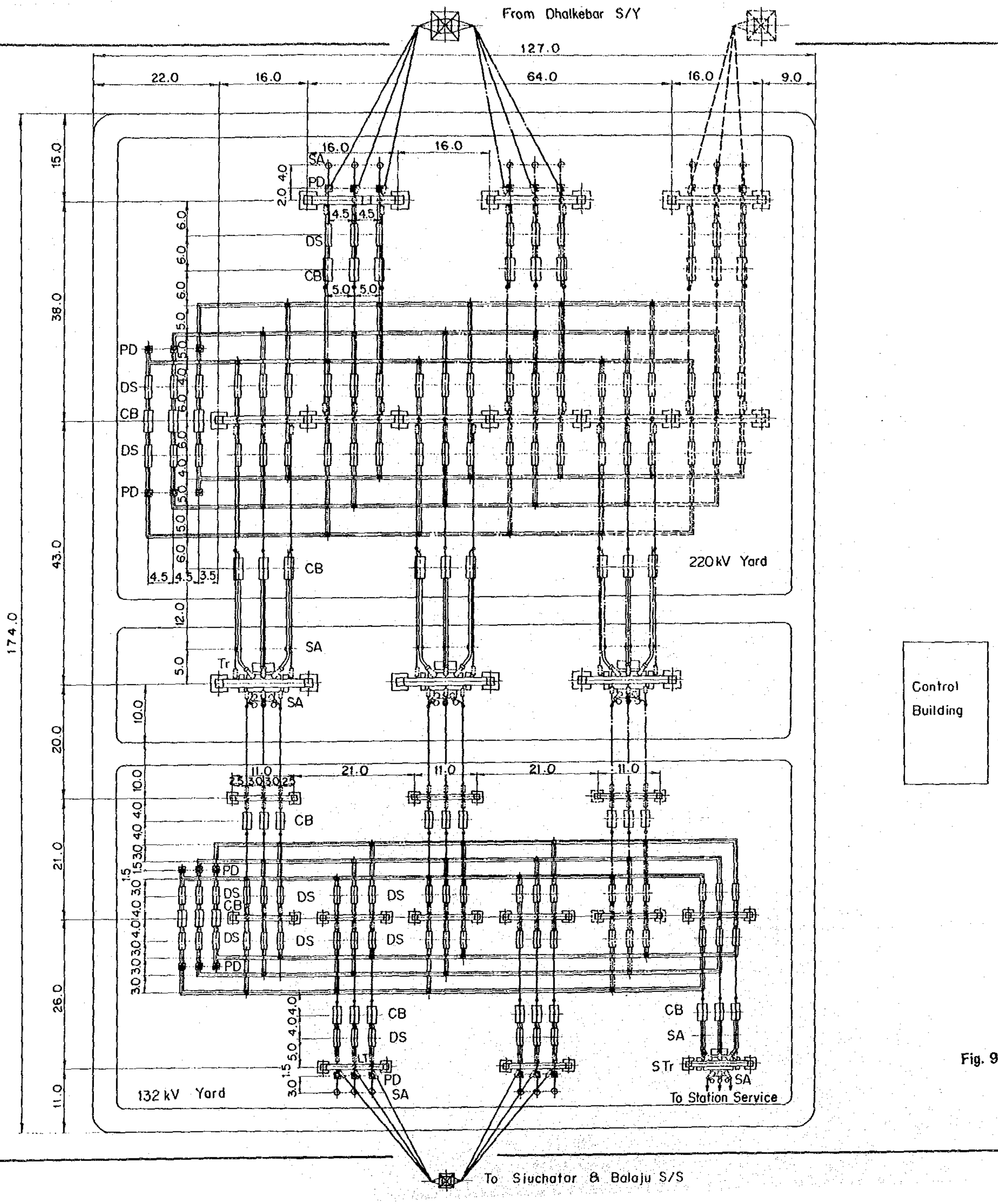


Fig. 9–24 General Arrangement of Dhalkebar Switchyard

(EXPANSION)



LEGEND

DS	Disconnecting Switch
SA	Surge Arrester
PD.	Potential Device
CB	Circuit Breaker
LT	Line Trap
Tr	Transformer
STr	Station Service Transformer

——— 1st Stage Development

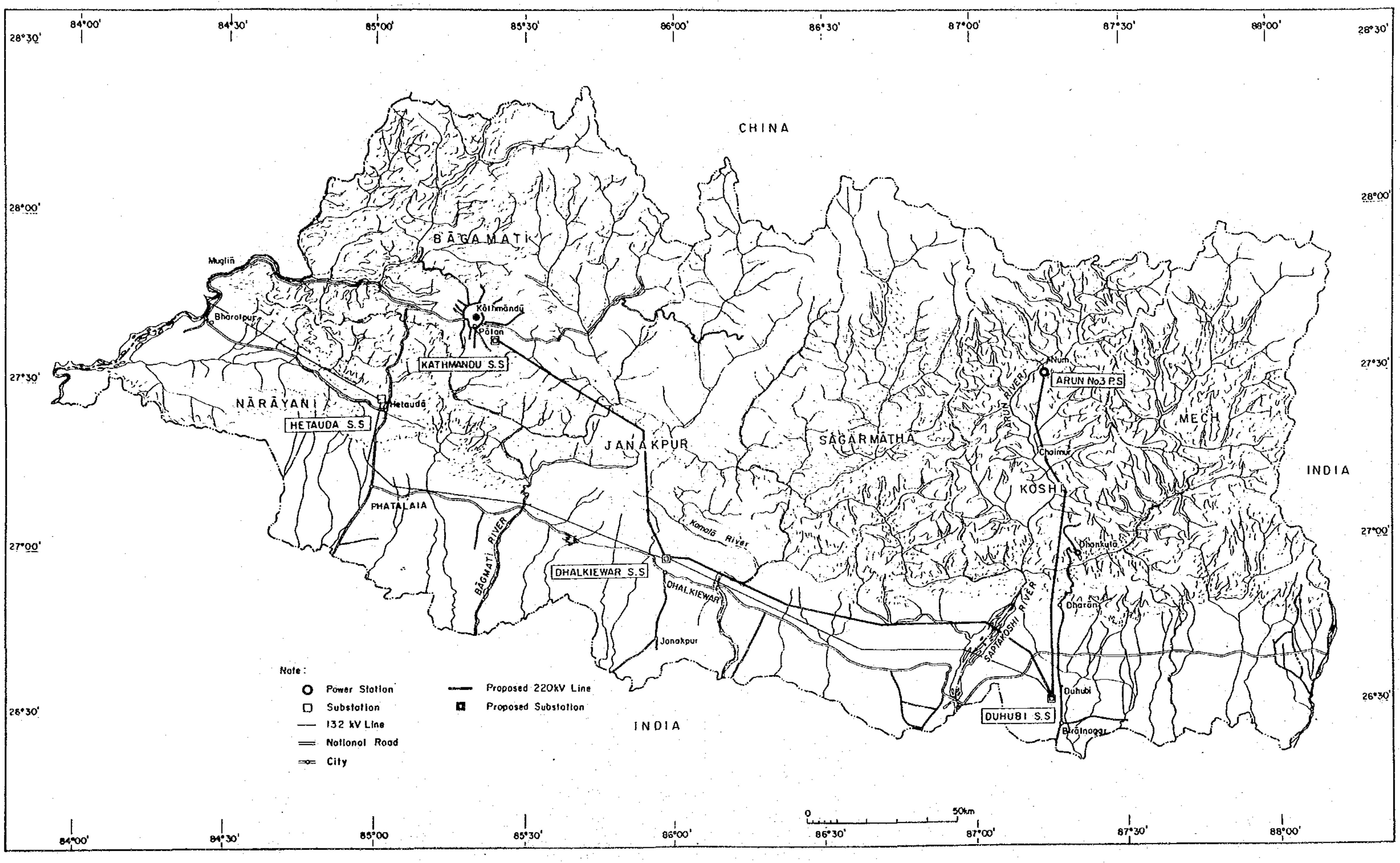
—·—·— 2nd Stage Development

– – – – Future Equipment

Fig. 9–25 General Arrangement of New Kathmandu Substation

(NEW CONSTRUCTION)

Fig. 9–26 Transmission System of Arun 3 Project



CHAPTER 10. CONSTRUCTION PLANNING

CHAPTER 10. CONSTRUCTION PLANNING

LIST OF TABLES

LIST OF FIGURES

CHAPTER 10. CONSTRUCTION PLANNING

10.1 General

The Arun 3 hydroelectric power project is planned to be developed in two stages, namely, the first stage construction of the installed capacity of 201 MW to cope with domestic power demand in Nepal after the middle of 1990s and the second stage construction for power export, and the final installed capacity is scheduled to be 402 MW.

As stated in 2.5.2, the first stage construction is aiming at completion of units No. 1 and No. 2 (67 MW each) and unit No. 3 (67 MW) in 1994 and 1998 respectively. Accordingly, the construction plan is to be built in conformity with the above schedule. Construction plan of transmission line and substation also made in accordance with the schedule of related generating facilities. Very long access road and headrace tunnel being the character of this project are planned and the construction schedules of these works govern the overall schedule of implementing the Arun 3 hydropower project.

The Arun 3 project is the large scale development scheme including construction of concrete gravity dam of 65 m in height, pressure type headrace tunnels of each 11.4 km in length, big underground powerhouse, etc. Out of all structures of the project, such part as will be required to cope with the domestic power demand is to be carried out as the first stage construction together with simultaneous construction of a part of the civil works such as waterway and powerhouse to be operated for power export.

This chapter gives the outline of access road, transportation method, temporary power source, procedures of constructing various facilities, etc. and also the construction schedule to complete various facilities in conformity with the above requirement.

10.2 Transportation

10.2.1 Road Network

(1) Existing Road

The Arun 3 project is located approximately 100 km upstream of the junction of 3 rivers; the Sunkosi, Arun and Tamur rivers in the eastern region of Nepal. The existing roads available for transportation of construction materials are the road from Kathmandu to Dhankuta via Hetauda and Dharan of 490 km and from Calcutta (India) to Dhankuta via Biratnagar and Dharan of 710 km. Railway from Calcutta to Forbesganj (India near the border) is also available. These two routes are the main roads available for transporting construction materials required for construction of the Arun 3 project. General layout of transportation road is shown in Fig. 10-1.

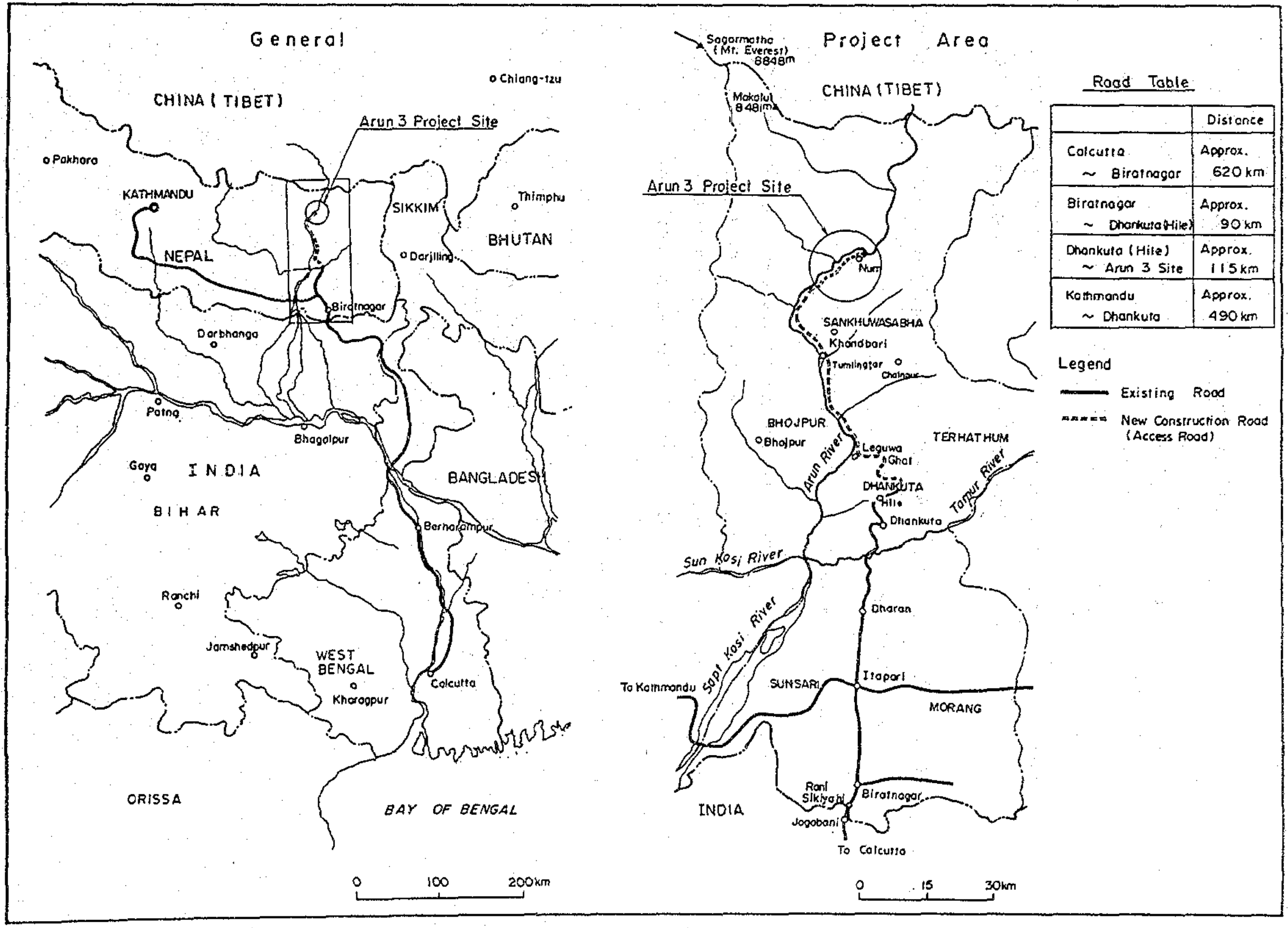
(2) Access Road

Since there is no existing road reaching the Arun 3 project site from Dhankuta for wheeled transport, it is indispensable to construct the new access road for transportation of construction materials as well as permanent equipment. The access road for the Arun 3 project will be approximately 115 km long and its first phase construction has to be completed for wheeled transport by the end of 1989 when the main works of the Arun 3 project will be commenced. The route, preliminary design, construction plan, etc. of the access road are described in Vol. II "Access Road" separately.

10.2.2 Transportation Method

For construction of the Arun 3 hydroelectric power project, a huge amount of materials and equipment such as construction machines and materials, hydraulic equipment (gates and penstock), electromechanical equipment (turbines and generators), transmission and substation facilities, etc. will be brought into the site.

Fig. 10–1 Transportation Route



Road Table

	Distance
Calcutta ~ Biratnagar	Approx. 620 km
Biratnagar ~ Dhankuta(Hile)	Approx. 90 km
Dhankuta (Hile) ~ Arun 3 Site	Approx. 115 km
Kathmandu ~ Dhankuta	Approx. 490 km

The heaviest part and the longest part of the above are estimated as shown below.

	The Heaviest Part	The Longest Part
During construction	Cutterhead support of TBM Approx. 40 t (divided into two: if necessary)	Rail Approx. 10 M
Generating facilities	Main transformer Approx. 30 t	Generator stator Approx. 5 m (ht)

Transportation of these materials and equipment will be divided into the following two categories.

(1) Imported Materials and Equipment

The majority of the imported materials and equipment including construction materials will be unloaded at the Calcutta harbour and thereafter, they will be transported to Biratnagar and then to the project site by trucks or trailers.

(2) Domestic Materials

Materials available at the domestic markets are to be in-land transported by trucks from Kathmandu and other parts of the country.

10.3 Power Source for Construction

(1) General

For construction of the Arun 3 project, a big amount of electric power is required for operation of temporary plants, construction machines, etc. There will be two methods of securing the required power source, namely, (1) power receiving from the existing Dubi substation by means of advanced construction of the permanent transmission line and (2) construction of new diesel engine generators.

The power requirement estimate and comparative studies on the above two methods are as described below. It is noted that the electric power needed after June 1994 is to be supplied from the Arun 3 project as the unit No. 1 will be put in service at this time.

(2) Estimate of Power Requirement for Construction Use

The maximum power to be supplied for construction use is calculated on the basis of the installed capacities of plants, machines and equipment to be operated during construction multiplied by the demand factors. The total installed capacity is estimated at 6,100 kW and the required maximum power to be supplied is calculated as shown below.

$$\text{Max. power req'd} = \frac{\text{Installed capacity x Demand factor}}{\text{Power factor}}$$

$$= \frac{6{,}100 \times 0.65}{0.8} = 5{,}000 \text{ kVA } (4{,}000 \text{ kW})$$

While, the energy consumption varies depending upon the construction plants and equipment to be operated with the progress of the construction activities. The monthly energy consumption estimated in accordance with the construction schedule (Fig. 10-6) will be as shown in Fig. 10-2 and the total energy consumption during the period from commencement of the main civil works to the first commissioning of unit No. 1 will be approximately 27 GWh as shown in Table 10-1.

Fig. 10–2 Monthly Energy Consumption

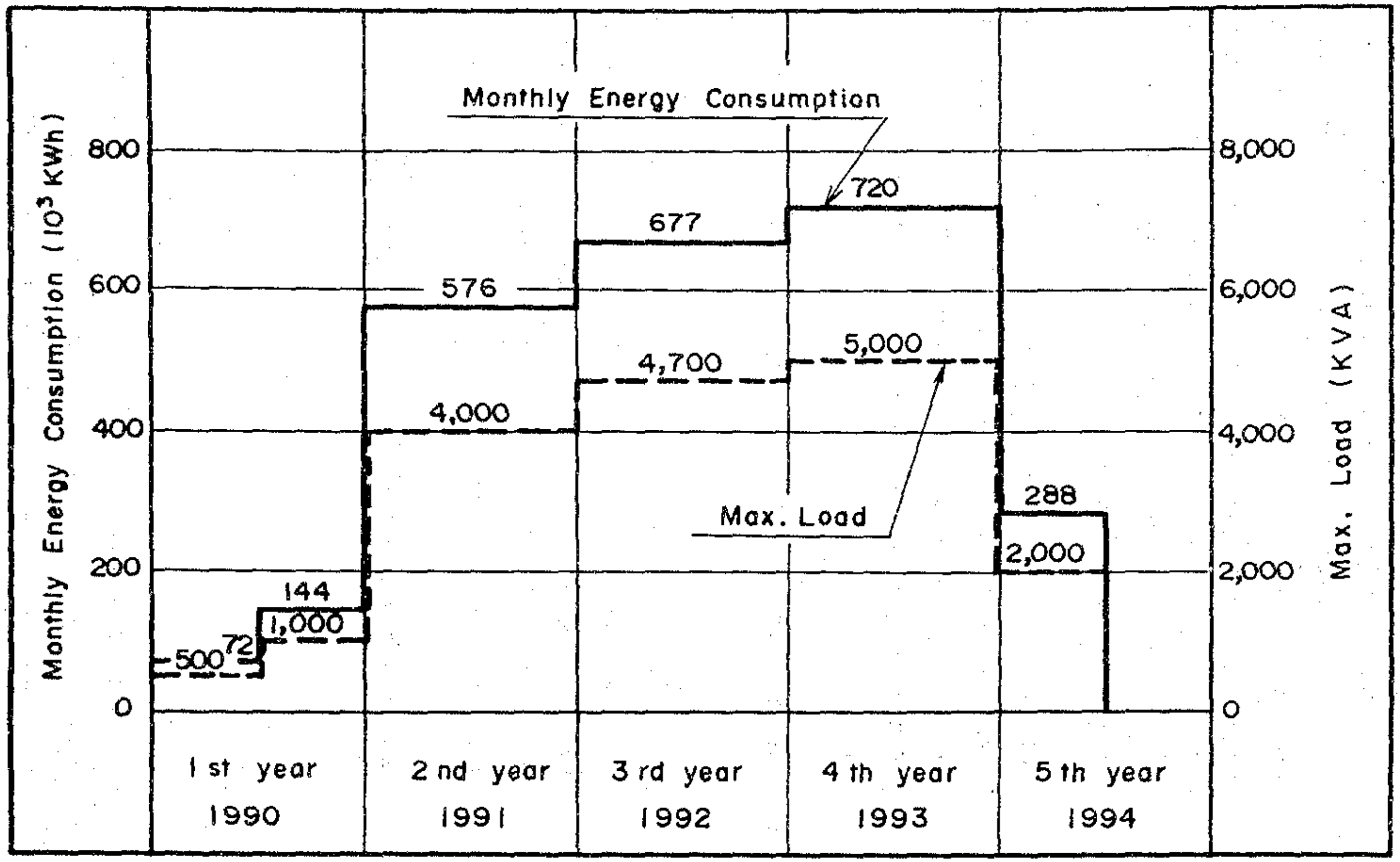


Table 10–1 Estimated Energy Consumption

Year	Max. Load (KVA)	Month	Day/Month	Hour/Day	Time Factor	Load Factor	Power Factor	Premium Factor	Energy (kWh)	Monthly Energy (kWh/Month)
1st	500 1,000	6 6	25 25	24 24	0.5 0.5	0.5 0.5	0.8 0.8	1.20 1.20	432,000 864,000	72,000 144,000
2nd	4,000	12	25	24	0.5	0.5	0.8	1.20	6,912,000	576,000
3rd	4,700	12	25	24	0.5	0.5	0.8	1.20	8,120,000	677,000
4th	5,000	12	25	24	0.5	0.5	0.8	1.20	8,640,000	720,000
5th	2,000	6	25	24	0.5	0.5	0.8	1.20	1,728,000	288,000
Total									26,696,000 (= 27,000,000)	

(3) Comparative Study on Power Sources

The results of comparative study on two plans for securing the power source; advanced construction of permanent transmission line and installation of diesel engine generator are as shown in Table 10-2 and Fig. 10-3. Since permanent transmission line will be constructed along access road, its construction schedule is governed by that of access road and further, the time required for construction of transmission line is quite long and accordingly, it will be difficult to start the construction of the main civil works as scheduled.

On the other hand, diesel engine generator can be provided in rather short time and the cost therefor including fuel cost is still almost equal to the incremental cost required for advanced construction and operation of permanent transmission line. In view of the above, it is decided to adopt diesel engine generator as the power source.

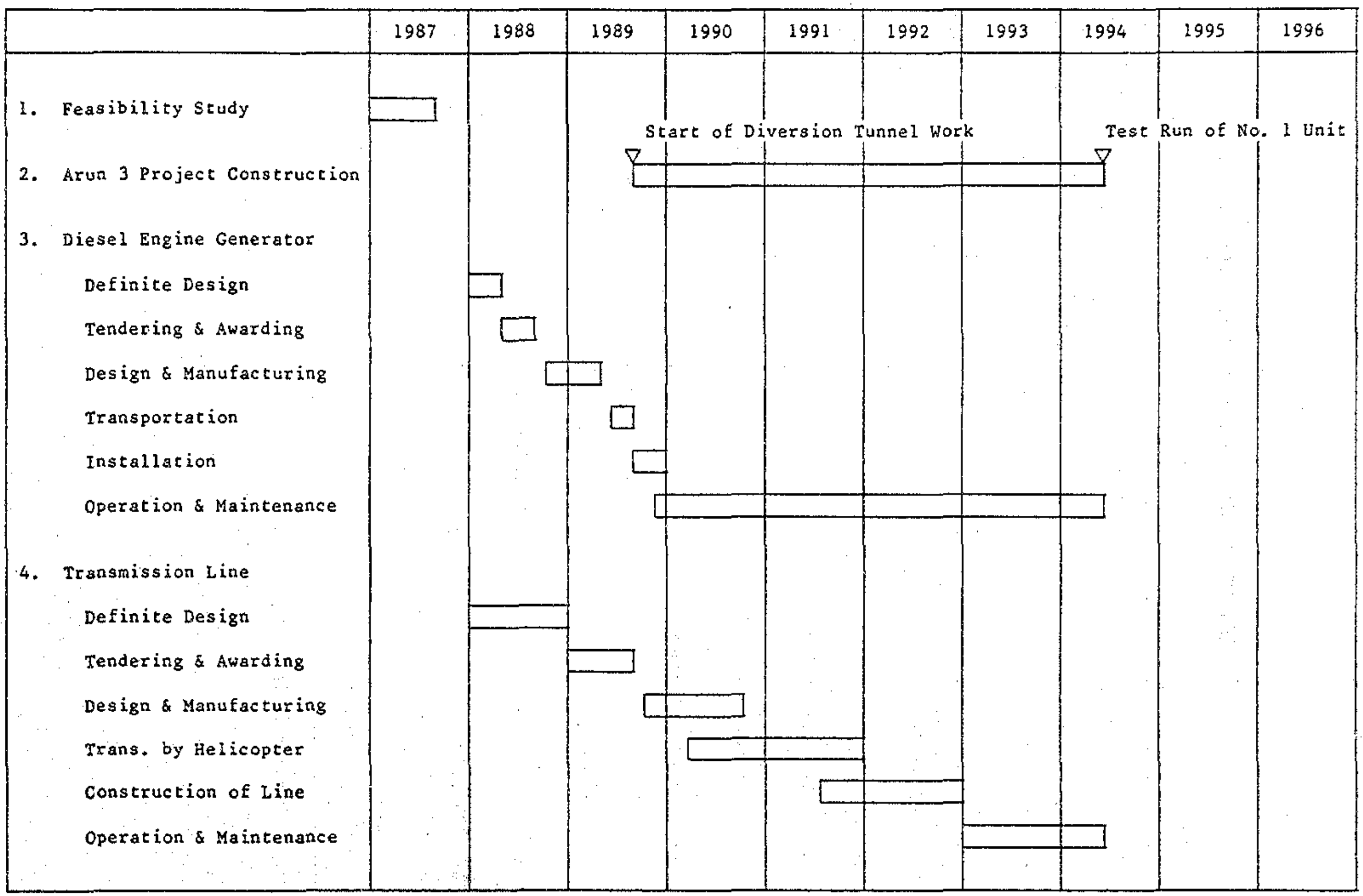
In the case of diesel engine generator, it is recommendable to install 5 units of 1,000 kVA to take advantages of easy transportation and installation and also reliability on steady operation. It is also preferable to adopt air-cooling system.

Table 10–2 Comparison of Power Sources

Unit: 1,000 US$

Items	Diesel Engine Generator		Transmission Line	
	Unit	Total	Unit	Total
Equipment Cost	640US$/kVA	3,200	-	-
Incremental Cost of Materials for Transmission Line due to 1 CCT Stringing	-	-	-	4,500
Helicopter Fee-Normal Transportation Fee (for transmission line facilities)	-	-	-	1,090
Re: [Normal Transportation Fee / Helicopter Rental Fee]	-	-	[8,000US$/km / 750US$/hour]	560 / 1,650
Operation & Maintenance				
Fixed	2% of Capital	64	1.5% of Capital	244
Variable	0.015US$/kwh	405	-	-
Fuel Cost (27 GWh)	0.0132US$/kWh	3,564	-	-
Grid Charge	-	-	0.050US$/kWh	1,350
Total	-	7,233(A)	-	7,184(B)
Difference (A - B)	49			

Fig. 10–3 Construction Schedule of Power Sources



10.4 Construction Procedure of Respective Works

10.4.1 Supporting Facilities

The supporting facilities are composed of the following items.

- Access road (new construction, 115 km)
- Existing road (improvement)
- Camp facilities
- Telecommunication system
- Power source (diesel engine generator: 5,000 kVA)

Out of these items, the construction plan of new access road is described separately in Vol. II "Access Road" in detail and the repair works of the existing road include partial improvement of surface conditions, curves, etc. of the existing road between Dharan and Dhankuta to facilitate smooth traffic for transportation of the construction materials and equipment.

Concerning the items other than access road, they shall be worked out in short time immediately after completion of access road or even in parallel with access road construction by means of transporting the required materials and equipment with helicopter, in order not to cause any obstructions for commencement of the works of diversion tunnel.

10.4.2 Diversion Tunnel and Cofferdam

(1) Diversion Tunnel

Diversion tunnel is of horseshoe shape, 7.00 m in diameter and 354.50 m in length. Its scheduled commencement and completion dates are November 1989 being the end of the rainy season of the first year of the construction activities and October 1990, respectively. The tunnel will be driven with full-face blasting excavation method and the expected monthly progress is 120 m/month. The entire length of tunnel is to be concrete lined. 12 months will be needed for construction of diversion tunnel including inlet and outlet structures, and concrete in diversion tunnel is to be produced at a small mixing plant separately provided.

(2) Khoktak Khola Diversion Tunnel

A tunnel for diverting the Khoktak Khola situated on the left bank of the Arun river and immediately downstream of dam axis is designed to facilitate construction of desanding basin and headrace tunnel. Tunnel is of horseshoe shape, 3.00 m in diameter and 270 m in length. After completion of excavation works in diversion tunnel stated (1) above, all excavation equipment is to be shifted for excavation of Khoktak Khola diversion tunnel. The construction period for this work including coffering will be limited to 8 months which permit the commencement of works in desanding basin as scheduled.

(3) Cofferdams

Cofferdams are to be constructed immediately after completion of diversion tunnel. Concerning the type of upstream cofferdam, both concrete dam and fill-type dam will be considered, however, the fill-type dam is selected in this study based on the following considerations; (1) river deposit at the dam site is rather deep and (2) suitable embankment materials are available in the vicinity thereof. Crest elevation of upstream cofferdam is set at EL. 815.0 m taking into account the design flood discharge for diversion tunnel of 490 m^3/s (flood discharge for return period of 10 years in dry season).

Since the Arun river discharge fluctuates considerably in an year as shown in Table 10-3, it is required to construct diversion tunnels with large diameter for diverting the river flows throughout the year. While, the river discharge during the dry season from November to April is small and steady, permitting easy care of river. Considering the above characteristics of the Arun river discharge, it is planned that the floods are permitted to pass over cofferdam during the wet reason and cofferdam is reconstructed in the succeeding dry season. Thus, it is scheduled to suspend the construction works in dam for a certain period.

Table 10-3 Probable Flood Discharge at Arun 3 Dam Site

(Instantaneous Peak)

Return Period	Annual Flood	Monthly Probable Flood Discharge											
		Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
2	2,211	167	177	221	289	611	1,379	2,010	1,895	1,623	965	340	241
5	2,553	196	217	283	371	788	1,708	2,419	2,373	2,197	1,379	430	375
10	2,778	214	243	324	428	905	1,924	2,688	2,690	2,579	1,653	490	465

10.4.3 Dam and Spillway

(1) Dam

The quantities of the main work items in dam are as shown below.

. Foundation excavation 108,300 m^3

. Foundation treatment 8,600 m
(consolidation and curtain grouting)

. Dam concrete 160,700 m^3

The sound rock foundation will be available in view of wide distribution of gneiss at both banks and river bed portion as described in Chapter 4 "Geology". Especially, the left bank is characterized with very steep slope having many outcrops of gneiss rock and thin overburden.

Excavation at dam foundation is to be carried out immediately at the end of wet season of the first year. Excavation at both banks will be carried out by means of bench-cut method using crawler type drilling machines. Mucks produced at the upper benches will be thrust to the lower portion prepared for loading and hauled to disposal area as much as possible with tractor shovels, dump trucks, etc. Excavation at the river bed section is to be carried out after diverting the Arun river discharge into diversion tunnel, and all river bed deposit and weathered rocks are to be removed to obtain the fresh rock foundation.

Dam concrete is to be placed during the dry season over three years. In the first year, dam concrete will be placed upto EL. 790 m corresponding to dam concrete volume of 27,000 m^3 after completion of foundation excavation at the river bed section. In the second year, dam concrete will be placed upto EL. 815 m (81,000 m^3) after reconstruction of cofferdam and in the third year, upto EL. 846 m (52,700 m^3). For placing dam concrete, cable cranes of 9 tons (3 m^3) and 6 tons (2 m^3) are planned and dam concrete placing will be completed in 18 months approximately.

Details of the dam concrete placing plan are shown below.

° Maximum required concrete placing capacity (second year)

Monthly average	: 81,000 m^3 ÷ 6 months	= 13,500 m^3/month
Monthly maximum	: 13,500 m^3 x 1.3 1/	= 18,000 m^3/month
Daily maximum	: 18,000 m^3 ÷ 25 days	= 720 m^3/day
Hourly maximum	: 720 m^3 ÷ 14 hours 2/	= 51 m^3/hour

° Batcher plant

Unit capacity	: 1.5 m^3 2 units required
Production rate	: 1.5 m^3 x 2 x 60 min/3 min. 3/ = 60 m^3/hour

° Cable crane

Type	: 9t both end traveller 1 set	
Bucket capacity	: 3 m^3	
Ability	: 3 m^3 x 60 min./3 min.	= 60 m^3/hour
Actual ability	: 60 m^3/hour x 0.85 4/	= 51 m^3/hour

° Sub crane

A sub cable crane (6 t) of a fixed type is to be installed for carriage of forms, concrete, materials and etc.

1/ : Premium factor

2/ : Daily working time in 2 shifts

3/ : Cycle time of batcher plant

4/ : Working factor of cable crane

As demonstrated in the above mentioned estimations, the required dam concrete placing works for the 1st year through the 3rd year can be accomplished within 6 months during the dry season of each year.

Accordingly, the construction plans for the diversion tunnel and cofferdam shown in 10.4.2 (1), (3) are adequate.

In advance of placing dam concrete, it is required to provide temporary construction facilities such as aggregate plant, batching plant, cable cranes, water supply system, etc.

As to the foundation treatment, consolidation grouting and curtain grouting which are to be executed before and after placing dam concrete respectively, are planned.

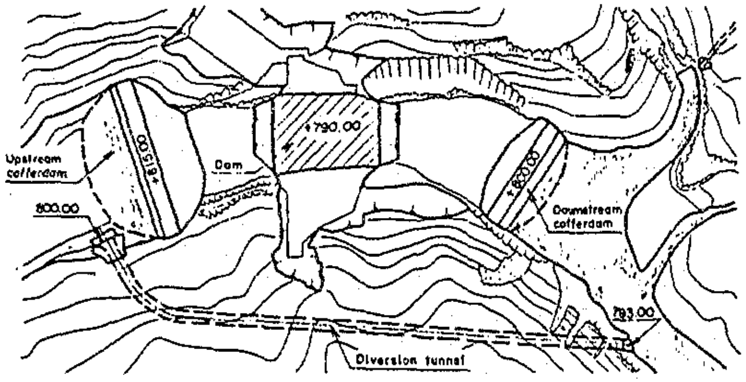
Fig. 10-4 shows the chronological features of care of the Arun river correlated with dam construction works.

(2) Spillway

Spillway is composed of five radial gates which are to be installed during the dry season of the fourth year after completion of placing concrete at dam crest of overflow section and piers. Gate leaf will be divided into several pieces and carried to the designated places by crane and then installed. Anchorages and gate frames are to be installed and embedded with the progress of placing dam concrete.

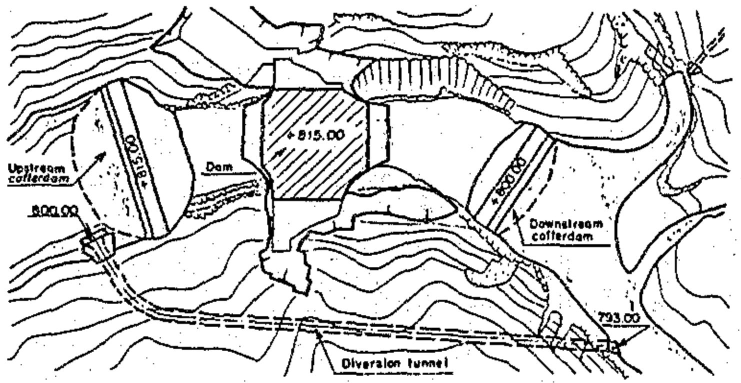
Fig. 10–4 River Diversion and Dam Construction

1st year (Nov.～Apr.)



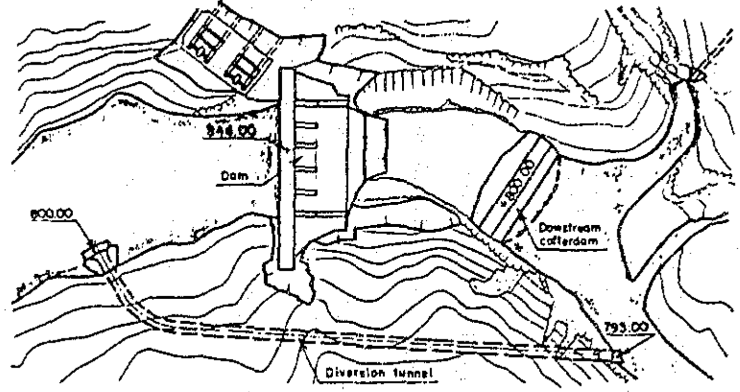
Main Works in 1st year
Construction of coffer dams
Excavation of dam foundation
Consolidation grouting
Placing dam concrete up to EL.790.00

2nd year (Nov.～Apr.)



Main Works in 2nd year
Reconstruction of coffer dams
Consolidation & curtain grouting
Placing dam concrete up to EL.815.00

3rd year (Nov.～Apr.)

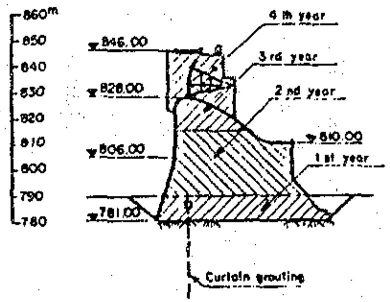


Main Works in 3rd year
Consolidation & curtain grouting
Placing dam concrete up to EL.846.00

4th year (Nov.～Apr.)

Main Works in 4th year
Installation of spillway gate

Typical Section of Dam



Note:
1) Design flood of diversion tunnel
$Q = 490\ m^3/s$
2) Max. flood during dam construction
$Q = 2,600\ m^3/s$

10.4.4 Intake and Desanding Basin

(1) Intake

The intake structure is located adjacent to dam on the left bank and foundation excavation is to be carried out together with dam excavation simultaneously. Since the intake structure directly faces the reservoir, it is difficult to carry out the extension of intake structure for the second stage development in the future. Accordingly, all works including excavation, concrete placing, installation of gate, etc. for No. 1 and No. 2 intakes are to be carried out at the same time as the 1st stage.

(2) Desanding Basin

Desanding basins of underground type are located immediately downstream of the intake structure in favourable rock foundation composed of sound gneiss. Since desanding basins are designed close to the dam and intake structures, it is planned to construct both No. 1 and No. 2 basins at one time similarly to the case of intake.

The total excavation in desanding basins amounts to 163,000 m^3 which will be all worked from the Khoktak Khola side. Firstly, upper work adit continued to access tunnel is to be driven for excavation at the cavern arch portion, while, bottom tunnel is to be driven at the same time. Then, several glory holes connecting upper and bottom tunnels are to be provided for cavern excavation. After completion of cavern excavation, intake tunnels between desanding basin and intake are to be excavated. It is scheduled to complete all the above excavation works within 18 months.

The total volume of concrete in intakes and desanding basins is estimated at approximately 43,000 m^3 which will be produced at the batching plant for placing dam concrete and placed by concrete pumps. The time required for concrete work is scheduled to be 12 months.

10.4.5 Headrace Tunnel

(1) Headrace Tunnel No. 1

Only headrace tunnel No. 1 of 7.00 m in diameter and 11.4 km in length is to be constructed for the first stage. The above tunnel length is planned to be divided into two sections by the work adit located downstream of the Suki Khola, namely, the upstream section of 7.7 km long and downstream section of 3.7 km long.

(i) Upstream section

As stated in 4.4, the rock foundation along the tunnel is composed of gneiss, granite and mica schist in this order from the upstream side. Mica schist distributes over 2.6 km of tunnel, and gneiss and granite the remaining 5.1 km.

As described in 4.4 (3), the compressive strengths of gneiss and granite ranges from 440 kg/cm^2 to 600 kg/cm^2. The compressive strength of mica schist is assumed to be approximately 100 kg/cm^2. Taking the above mentioned rock characters of soft to medium strength, difficulty of planning closely spaced work adits required for the conventional tunneling method due to the topographical constraint and shortening the construction schedule into consideration, the tunnel boring machine (TBM) is planned for driving the upstream section of the headrace tunnel. Gneiss and granite occupying a greater part of the tunnel alignment is considered to be a sort of rock best suitable for TBM, therefore, high excavation progress is expected. On the other hand, a lower progress is expected for the mica schist since the fine grained material of the soft rock will be adhered easily to the TBM cutter head. Accordingly, it is desirable to adopt a fully vesatile TBM to cope with both medium strength and soft rocks at the project. Selection of the TBM cutter head and other mechanical options should be based on the detail studies of the geotechnical information from exploratory adit.

The monthly progress of tunnel excavation by mean of TBM is expected to be around 280 m/month considering 300 m/month for gneiss and granite and 250 m/month for mica schist. Total excavation period is planned 30 months including some allowance for unforeseen trouble.

Many records of tunnel driving successfully by TBM through the similar rock formation have been reported as stated in 4.4.3 (3).

TBM is to be assembled at the yard prepared in front of work adit and drawn into the site of excavation. TBM will be taken out at the upstream end of upstream tunnel section when tunnel excavation is completed. A sample of tunnel boring machine system is given in Fig. 10-5.

The standard specifications of TBM applicable for driving the proposed headrace tunnel will be as shown below.

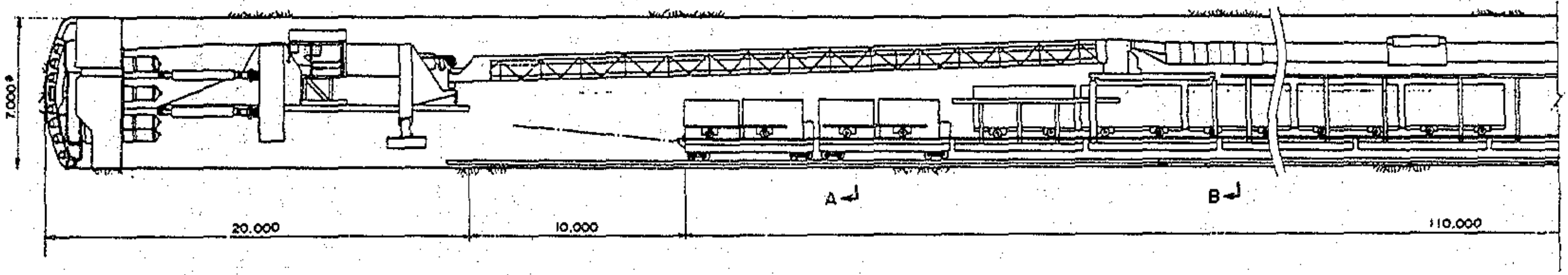
Excavation diameter	:	7,000 mm
Stroke	:	1,500 mm
Cutter head motor	:	400 V, 1,200 kW
Power source	:	6,600 V
Max. unit weight	:	40 tons approx.
Average excavation speed	:	280 m/month

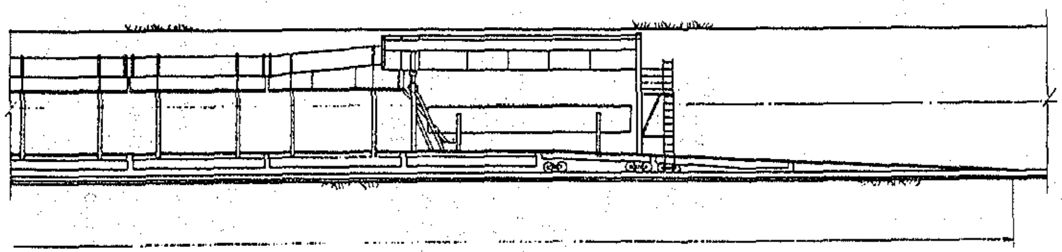
As stated in Chapter 9 "Feasibility Design" in detail, lining works to be applied to the upstream tunnel section are planned as shown below taking into consideration the geological conditions along the tunnel as well as application of TBM for excavation. In these lining works, shotcreting shall be applied after excavation immediately. The time required for execution of lining works is expected to be 24 months.

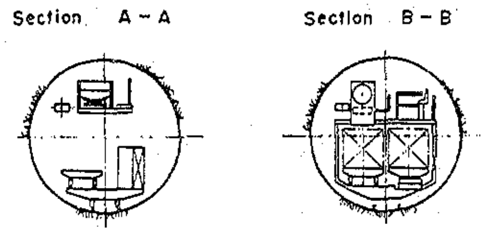
Geological condition	Type of lining	Length & percentage	
Sound gneiss and granite	Un-lined	2,000 m	27%
Mica schist, moderate gneiss & granite	Shotcrete lined	3,200 m	45%
Mica schist at thin overburden & sheared zone	Concrete lined	2,100 m	28%

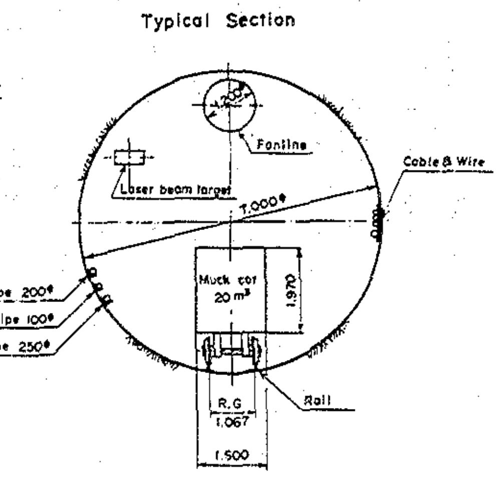
When the sheared zone is encountered, shotcreting shall be applied as support work immediately after excavation and concrete lining will be further worked. It is required to take adequate measures especially at the sheared zone which is deemed to cause possible troubles in driving the headrace tunnel No. 2 (the second stage construction) in connection with filling of the headrace tunnel No. 1.

Fig. 10–5 Tunnel Boring Machine System









Salient Features

Bore diameter	7.000 mm
Cutter	φ394 (15 1/2") x 47
Stroke	1.500 mm
Cutter head motor	1.200 KW (150 KW x 8)
Total weight	400 t

(ii) Downstream section

Geological conditions along the downstream section is similar to those of the upstream section, consisting of mica schist continued from the upstream section, gneiss and granite.

It is planned to apply the conventional blasting method (CBM) to driving tunnel in consideration of its short length of 3.7 km. Full-face excavation with hydraulic jumbos will be applied. Assuming work progress of 120 m/month, excavation of entire tunnel length will be completed within 30 months.

Lining works to be applied to the downstream section are planned as shown below, taking into consideration the geological conditions and also application of blasting operation. In the lining works, shotcreting shall be applied after excavation immediately.

Geological condition	Type of lining	Length & percentage	
Mica schist, moderate gneiss & granite	Shotcrete & invert concrete	1,300 m	34%
Mica schist at thin overburden & sheared zone	Concrete lined	2,400 m	65%
Section upstream of surge tank	Steel lined & filling concrete	35 m	1%

It is scheduled to complete the lining works including filling concrete at steel lined portion within 30 months. When sheared zone is encountered, adequate measures shall be taken as stated in previous upstream section.

(2) Headrace Tunnel No. 2

It is planned to construct headrace tunnel No. 2 as a part of the second stage subsequently. The construction method of headrace tunnel No. 2 is almost the same as that of No. 1, however, it is important to pay careful attention to the geological information obtained during execution of headrace tunnel No. 1 works and to adopt the modified construction method, if deemed effective.

10.4.6 Surge Tank

Surge tank No. 1 is the vertical shaft having innerdiameter of 14.00 m and height of 70 m, partly steel lined. As there distributes highly weathered surface layer in the vicinity of surge tank, this portion is to be removed by open excavation. While, sound rock foundation composed of granite and gneiss exists underneath the above-stated layer and accordingly, it will be considered adequate to excavate the vertical shaft portion by pilot shaft of around 2 m by 2 m from the bottom followed by enlargement from the top. Steel lining and concrete lining are to be worked from the bottom after completion of shaft excavation.

For execution of construction works of surge tank, it is required to prepare access roads reaching the top and bottom portions of surge tank. Out of these roads, the lower road is connected with work adit which will be used for various works of surge tank, penstock shaft and downstream section of headrace tunnel.

Surge tank No. 2 is to be constructed separately as the second stage and it is important to carefully observe the records of construction activities and geological information obtained during construction of surge tank No. 1 and to improve the work procedure for surge tank No. 2.

10.4.7 Penstock

Penstock is underground type steel conduit and divided into the upper horizontal portion, vertical shaft portion and lower horizontal portion including branches. Along the penstock route, there distributes homogeneous gneiss rock without sheared zone. Only penstock No. 1 which trifurcates into three branch pipes at its end is to be constructed as the first stage. The works for penstock include excavation of upper and lower portions, shaft excavation, installation of steel penstock pipes followed by placing of back-fill concrete.

(1) Excavation of Upper Horizontal Portion

Upper horizontal tunnel is of 5.80 m in diameter and 35 m in length between the bottom portion of surge tank and penstock vertical shaft. Tunnel excavation is to be carried out by full-face excavation with conventional blasting method same as the case of downstream section of headrace tunnel, through upper work adit.

(2) Shaft Excavation

Vertical penstock shaft is of 4.50 m to 4.00 m in diameter and 271 m in height. Shaft excavation is to be carried out by pilot shaft of around 2 m by 2 m from the bottom upto upper horizontal portion followed by enlargement from the top, through lower work adit. Cranes or winches will be needed for moving excavation machines and workers during enlargement works as well as installation of penstock pipes to be performed thereafter.

The time required for shaft excavation is expected to be 4 months for pilot shaft excavation, 6 months for shaft enlargement and 2 months for unforeseen troubles, 12 months in total.

(3) Excavation of Lower Horizontal Portion

Lower horizontal portion is the section between the bottom of vertical shaft and powerhouse and trifurcates into branch pipes No. 1 to No. 3. Tunnel excavation is to be carried out through lower work adit and partly, from the powerhouse side. The time required for excavation of this portion including large excavation at the trifurcation is expected to be 4 months.

(4) Installation of Penstock Pipes and Placing of Backfill Concrete

Installation works of penstock steel pipes are to be carried out immediately after completion of excavation in upper and lower horizontal portions as well as shaft portion. Steel pipe at the lower bend will be first installed and extended toward shaft portion and then upper horizontal portion, through upper work adit. Steel pipes for lower horizontal portion is to be installed from the lower bend and also downstreammost branch pipes through lower work adit. The time required for installation of penstock pipes including trifurcation is expected to be 18 months.

10.4.8 Powerhouse

The Arun 3 powerhouse is mainly composed of underground type machine hall of 18 m wide, 41.50 m high and 122 m long (excavated size), underground type transformer room of 9.20 m wide, 15.00 m high and 122.2 m long (excavated size), switchyard of outdoor type and control building. In addition to the above, access tunnel, cable tunnel, etc. are to be constructed too. As described in Chapter 4, it is considered that sound homogeneous gneiss rock is widely distributed around the powerhouse giving favorable conditions for construction of underground structures. It is planned to construct all the civil structures for the second stage simultaneously with those for the first stage, except for those to be worked with installation of turbines, generators, etc. for the second stage.

(1) Machine Hall

Excavation of machine hall cavern is to be carried out in three stages; arch portion, upper and lower cavern portions.

Excavation of arch portion will be carried out in the order of excavations of work adit branched off at access tunnel and lead to arch portion, top or bottom headings and connection tunnel, and arch section followed by center core section remained. Excavation and placing concrete at arch portion will be performed alternately. As arch portion is of 122 m long, this will be divided into 3 sections, thus permitting excavation work at arch portion to be completed in 8 months.

Upper cavern portion is above EL. 543.50 m at which access tunnel is to be provided. Excavation is to be carried out by bench cut method and all mucks will be pushed off to access tunnel through glory holes provided between arch portion and access tunnel, and then transported through access tunnel by dump trucks.

Lower cavern portion is below EL. 543.50 m and bench cut method will also be applied. All mucks will be pushed off to tailrace tunnel through glory holes provided between access tunnel and tailrace tunnel, and transported through tailrace tunnel by dump trucks.

The time required for cavern excavation including the portion to be used for the second stage development is expected to be 18 months. After completion of cavern excavation, placing of base concrete, column concrete, etc. shall be started immediately, followed by installation of draft tube, turbine, etc. A part of the concrete works will be performed with the progress of installation of each turbine, generator unit.

(2) Main Transformer Cavern

All the works to be carried out at transformer cavern are almost the same as those described for machine hall cavern, provided that this cavern will be divided in two portions;

arch and main cavern portions. Works at arch portion are to be carried out through work adit branched from cable tunnel and all mucks will be transported through access tunnel. Connection tunnel with machine hall and bus bar tunnels are also worked during the same time. After completion of civil works, main transformers are to be installed.

The time required for execution of civil works at transformer cavern is expected to be 16 months.

(3) Access Tunnel

Access tunnel is 4.00 m wide and 324 m long from access road to erection bay at EL. 543.50 m. This road is the main access to be used for all works in powerhouse in addition to transportation of main equipment. It is, therefore, required to complete this tunnel in advance of starting excavation works in machine hall cavern. Tunnel will be driven by the full-face conventional blasting method and lined at its entire length.

(4) Cable Tunnel

Cable tunnel connecting main transformer cavern with outdoor switchyard is of 3.50 m wide and 173 m long. Since this tunnel will provide a part of access to be used for the initial stage of powerhouse works such as excavation of arch portion of machine hall cavern and ventilation, it is required to excavate this tunnel before execution of the above-mentioned access tunnel. Cables are to be laid after completion of the related civil works. It is desirable to excavate this tunnel to further investigate the rock conditions around powerhouse during the detailed design stage.

10.4.9 Tailrace Tunnel and Outlet

(1) Tailrace Tunnel

Tailrace tunnels are 5.80 in diameter and 270 m in length including branch tunnels of 3.50 m in diameter.

For the first stage construction, only tailrace tunnel No. 1 and related branch tunnels are to be constructed. Since the foundation rock along tailrace tunnel is considered to be composed of sound homogeneous gneiss similarly to the case of powerhouse, the full-face conventional blasting method is to be applied to driving tailrace tunnel. Tailrace tunnel will be used for transportation of mucks from powerhouse excavation and thereafter concrete lined at its entire length.

(2) Tailrace Outlet

As tailrace outlets No. 1 and No. 2 face the Arun river, both of them are to be constructed in one time as the 1st stage. Tailrace gates No. 1 and No. 2 are also to be installed at the same time and it is considered that the closure of gate No. 2 will secure the safe construction of tailrace tunnel No. 2 separately as the second stage.

10.4.10 Transmission Line

All steel tower materials, conductors, ground wires and insulator strings as well as materials for tower foundations such as cement and reinforcing bars except aggregate are to be imported. These materials are to be transported through the existing road and new access road to several stockyards selected along the transmission line route. Other access roads for the purpose of construction of transmission line only will also be prepared where deemed necessary.

In order to keep the construction schedule of the project, the transmission line route will be divided into 10 sections or so and simultaneous construction works will be executed at these sections. Prior to starting excavation works at tower foundations,