The hydroelectric power generating facilities in Japan, moreover, are mainly owned by the following three parties:

(1) General Electric Power Utilities (9 companies)

There are nine electric power companies in each of the national districts (9 districts). They are selling general consumers both electricity which they have generated in house and have purchased from other electric power utilities.

As far as the maximum output is concerned, these nine companies have occupied approximately 66% of all the conventional hydroelectric power generating facilities in Japan. (Another electric power utility does exist (Okinawa Electric Power Company) but does not have any hydroelectric power generating facility.)

(2) Wholesale Electric Power Utilities

Falling in this category are public electric utilities in 33 prefectures and in 1 city, Electric Power Development Co., Ltd. and other private enterprises. All of them are selling their in-house generated electricity to general electric power utilities. As far as the maximum output is concerned, they occupy approximately 27% of all the conventional hydroelectric power generating facilities in Japan.

(3) Private Power Plants

The electricity generated is used as the power to be supplied for the private use only, including a factory or the like. As far as the maximum output is concerned, the private power plants occupy approximately 7% of all the conventional hydroelectric power generating facilities in Japan. (the term, private power plant, however, means a facility with a capacity of 100 kilowatts or more only.)

A breakdown of the conventional hydroelectric generating facilities referred to above is given on Table 2 below.

Table 2 A breakdown of the Pure Hydroelectric Power Generating Facilities

Division of Owners	Number of Hydro Plants	Installed Capacity (kW)	Annual Generation (MWh)
General electric power utilities	1,125	13,811,734 (66%)	61,046,289 (68%)
Wholesale electric power utilities	359	5,635,849 (27%)	20,315,761 (23%)
Private power plants	250	1,398,515 (7%)	7,814,316 (9%)
Total	1,734	20,846,098 (100%)	89,276,366 (100%)

* As for private plants, adding up power plants with a capacity 100 kilowatts or more only.

1.2 General Method of Working out a Development Plan

In Japan, a hydroelectric power development plan is generally worked out by the methods and steps as referred to below.

(1) Schematic Plan

Based on the existing data, geographical chart and the like, a schematic route is selected on a drawing to work out a schematic plan of an individual power plant site, taking into account the findings of a rough water system survey and of a field exploration.

(a) Rough Water System Survey

Both water system and river to be covered by a development plan are surveyed concerning the river from, outline of its basin, water utilization facilities already obtained, etc., based on the data already available. And the findings of this survey are used as the data fundamental to the plan.

(b) On-drawing Plan

A plan is worked out, based on the existing data (a topographic map to a scale of 1/50,000, etc.) and on the findings of rough water system survey.

1) Determining a power plant type

A hydroelectric power plant may take one of three types according to the power supply functions' characteristic of that power plant. To proceed with a development plan, it is necessary to preselect an optimum type beforehand. Three types about power plant are described below.

- Run-of-river type power plant:

  A power plant of this type does not have a storage pond, in particular, but uses natural stream discharge of a river directly to generate electric power without making any adjustment of the discharge.

- Poundage type power plant:

  Demand for electric power fluctuates remarkably in a day or in a week the natural stream-discharge of a river remains nearly constant in a day or in a week. A storage pond, therefore, is located in a dam or in the midcourse of a headrace. In the midnight or on a holiday when the electric power demand is low, the stream discharge is stored in pond so that the water so stored can be used when the electric power demand is high. Thus, the power plant is capable of responding properly to a fluctuation of electric power demand.

- Reservoir type power plant:

If the power is hydroelectrically generated while resorting merely to natural stream discharge of a river, the quantity of power generated will fluctuate from season to season in a year, resulting in an instable supply of power. As a solution to this problem, a dam is constructed to store the discharge in a wet season and to use the stored water in a dry season. As a result, the power plant can obtain an averaged quantity of water throughout the year by increasing the doughty water-discharge.

2) Calculating an Output and a Quantity of Power Generation

Both output and power generation are arithmetically obtained from a total head available on a topographic map and from a stream discharge at the water intake. A stream discharge data collected for the latest decade are to be used.

A maximum output available may be obtained as under.

$$P = 9.8 \cdot Q_{max} \cdot He \cdot \eta$$

where, P : maximum output (in kilowatts)

η : total efficiency ($\eta = \eta_t \cdot \eta_g$) with η_t and η_g standing for turbine efficiency and generator efficiency, respectively

Q_{max} : maximum usable stream discharge (in cubic meters per second)

He : effective head (in meters)

Described below is how to prepare a stream discharge data, which are fundamental and most important to work out a power generation plan, in particular.

- Preparing a stream discharge data:

To hydroelectrically generate power, neither possible power generation nor storage reservoir size can be determined without accurately knowing the stream discharge. A river has the stream discharge vary with the meteorological, topographical and geological features. it is necessary, therefore, to precisely gage the stream discharge for a period of long years.

For a gaging period, a stream discharge data gathered during the latest decade are used to work out a power generation plan in Japan. For the Japanese Government (Ministry of International Trade and Industry) to permit or authorize a power generation plan, any data that may have been gathered for a period of less than one decade are not recognized as the official data for a hydroelectric power development.

The Electric Enterprises Act, therefore, provides that those who have installed a hydroelectric power plant must gage the stream discharge of a river on which such power plant has been installed and that they must report the results of such gaging to the government. The equipment to gage the stream discharge and the method of gaging a stream discharge have been established in a governmental order.

Currently in Japan, there are 720 gaging stations, which have been gaging stream discharges in response to an order from the Ministry of International Trade and Industry. Except some gaging stations under direct control of the Ministry of International Trade and Industry, electric power utilities have been gaging stream discharges. If the sites where gaging were done in the psst are added, the gaging stations existing in Japan reach approximately 1,800 sites. To obtain a permit or authorization for an electric power development, it is necessary to use the stream discharge data collected in the gaging stations referred to above.

At a gaging station, a daily stream discharge is gaged every day, and accumulated and stored as the stream discharge data valuable for a hydroelectric power development.

To prepare a stream discharge data at a site planned to be hydroelectrically developed, the stream discharge data at an existing gaging station are multiplied by a simple catchment area ratio to calculate a discharge if such existing gaging station is located near the planned hydroelectric power development site. And the discharge so calculated is taken for the stream discharge data.

This calculation is to be made by the use of an expression as follows:

$$Q_A = \frac{CA_A}{CA_B} \times Q_B$$

where, Q_A : stream discharge at the planned site
Q_B : stream discharge gaged at a gaging station nearby
CA_A : catchment area at the planned site
CA_B : catchment area at the gaging station

The maximum usable discharge is generally taken at such a level that the capacity factor will reach approximately 45 through 60% in a run-of-river type power plant.

The capacity factory may be obtained as follows:

Capacity factor =

$$\frac{\textit{Annual possible power generation in kilowatt-hours}}{\textit{Maximum output in kilowatt} \times 8{,}760\ \textit{hours}}$$

Based on this maximum usable discharge, the maximum output is obtained. In addition, the annual possible power generation is calculated.

3) Roughly Integrating a Construction Cost

Based on a roughly estimated quantity, various expenses are integrated for main power plant structures, land compensation and construction to roughly estimate the construction cost.

4) Studying Economic Aspects

A rough construction cost per generation in kilowatt-hours at the planned construction site is calculated. And the economic aspects of the plan are evaluated, based on the construction cost so calculated.

Cost per generation in kilowatt-hours =

$$\frac{\textit{Total cost}}{\textit{Annual possible power generation in kilowatt-hours}}$$

(2) Field Surveys

Based on the schematic plan, field surveys are carried out concerning the topographical, geological and environmental features at the site to work out a power generation plan.

(a) Topographical Surveys

An aerophotographical survey is carried out around the site where main power plant structures are scheduled to be installed at the planned location. And a topographical map to a scale of 1/1,000 or 1/5,000 is prepared.

(b) Geological Survey

A surface geological survey is first of all carried out around the site where main power plant structures are scheduled to be installed. And the portion or portions considered necessary as a result of such surface geological survey is subjected to a seismic prospecting and a boring survey.

(c) Environmental Survey

Surveys are carried out concerning current water quality at the site where water is scheduled to take in, including the distribution and living conditions of animals and vegetables around the planned site. And in case the planned site is in a national park area, it is necessary to survey the influences to the environments.

(3) Power Generation Plan

A power generation plan is worked out in detail, based on the schematic plan and on the findings of the field surveys.

(a) Layout of Civil Engineering Facilities

The locations of main power plant structures and the route of a headrace are determined, with consideration given to the findings of the field surveys, etc.

(b) Determining a Size

Based on the findings of field surveys and on the existing data and so on, main power plant structures are roughly designed. To make this design, it is necessary to positively adopt the new technologies, in addition to the observance of the "engineering Standards relating to Water Power Facilities for Power Generation" (A ministerial ordinance of the Ministry of International Trade and Industry).

A output is calculated from the stream discharge data already referred to plus the effective head (total head -

loss of head) and total efficiency of both hydraulic turbine and generator.

The monthly quantity of power generation is calculated based on the past near ten-year stream discharge datas. As for the output and quantity of power generation, more accurate values than those in the schematic plan are calculated.

(c) Integrating Construction Costs

Construction costs are integrated on an item by item basis as shown in **Table 3.**

The construction costs referred to herein must be a more detailedly highly accurate value than that in the schematic plan.

Table 3 Integration Construction Costs

Items		Reference
(1) Land compensation		Compensation for sunk area and so on
(2) Building of power station		
(3) Civil engineering works	Waterway	Dam, Intake, Settling basin, Headrace, Headtank, Spillway, Penstock, Tailrace, Outlet, and Spoil-bank and so on
	Storage pond or Reservoir pond	Dam, Flood spillway
	Facilities	Foundation of machinery, Access road, Tree planting and son on
	Temporary facilities	Road for construction, Bridge, Temporary building and son on
(4) Turbine and electric facilities		Turbine, Generator, Transformer facilitiesand so on
(5) Management of construction work		Personnel expenses, Electric expenses for construction, Fixtures and so on
(6) A share of dam cost		This cost is added up in case multipurpose dam
(7) Interest during construction term		
(8) Expenses of instructing office		
(9) Sundry expenses		Reserve cost preparing for accidents during construction term
(10) Compensation for abolished plant		Compensation for plant which are subjected to influence of newly developments

(d) Evaluating Economic Aspects of the Plan

From the power generation and construction cost calculated as referred to (b) and (c) above, the construction cost per power generation (in kilowatt-hours) is calculated. And the value so calculated is used to evaluate economic aspects of the plan.

Cost generation in kilowatt-hours =

$$\frac{\textit{Total cost}}{\textit{Annual possible power generation in kilowatt-hours}}$$

The construction cost per generation in kilowatt-hours, meanwhile, must be obtained as a more detailedly highly accurate value than that in the schematic plan.

2.1 New Hydroelectric Power Development Techniques

As a research into the development techniques to promote hydroelectric power development, the New Energy foundation (NEF) has been conducting the following surveys as consigned by the Ministry of International Trade and Industry:

(1) 5th Hydroelectric Power Resources Potential Survey

This survey was carried out as a six-year plan starting in 1980 and ending in 1985.

(a) Objective

As part of the governmental policy to promote the diversification of power supplies aimed at getting rid of petroleum, the survey had an objective of clarifying the entirety of hydroelectric power resources potential in Japan and of promoting a reasonable development of the hydroelectric power resources which can be secured most stably out of the resources reserved in the country.

(b) What was Surveyed

Sites hydroelectrically undeveloped were surveyed as described below and a power generation plan was worked out at every site surveyed.

- Schematic plan
- Field survey
- Power generation plan
- Evaluating economic aspects of the plan

(c) Findings

As a result of the surveys, it could be gathered that 2,811 sites were found applicable to conventional hydroelectric power developments, having a potential of 13.01 million kilowatts and an annual power generation potential of 49.7 billion kilowatt-hours for undeveloped hydroelectric power potential. And Japan was found having a total hydroelectric power potential as shown in a **Table 4**, including the hydroelectric power plants both in operation and under construction. These surveys have clarified the entirety of hydroelectric power resources potential in Japan. Based on the findings successfully gathered, reasonable hydroelectric power developments have been being promoted here in Japan.

Table 4 Hydroelectric Power Potential in Japan

Installed Capacity (kW)	Annual Generation (GWh)
32,746	130,924

* The Figures are as of March 31, 1985.

(2) Survey into Techniques of Developing Miniature Hydroelectric Power Plants

This survey was carried out as a four-year plan starting in 1986 and ending in 1989.

(a) Objective

To make effective use of the scastteringly distributed water energies by developing private hydroelectric power generation, thereby contributing to promotion in a region.

(b) What was Surveyed

Hydroelectric power characteristics, such as a supply fluctuation due to a change in stream discharge, and demand characteristics in farm and mountain areas, including local industries, were analyzed. And a survey was carried out into the techniques to harmonize demand and supply for miniature hydroelectric power generation mainly with a capacity of 1,000 kilowatts or less, including the means of using the power so generated.

(c) Findings

A manual was prepared, showing the steps involved in the techniques to develop a miniature hydroelectric power plant. Findings of this survey have accelerated the development of private miniature hydroelectric power, especially contributing to regional promotion.

(3) Survey into Series Developments to Reduce Construction Cost

This survey was carried out as a six-year plan starting in 1985 and ending in 1990.

(a) Objective

Recently, hydroelectric power development sites have been being smaller and smaller sized, precluding an expectation of scale merits. As a result, a construction cost has turned relatively high. As a solution to this problem, a technique was established to reduce the construction cost by conducting developments in series, aiming at a significant decrease in cost.

(b) What was Surveyed

1) Setting our eyes on the fact that sites hydroelectrically undeveloped have similar characteristics, a number of sites in a similar size located nearby or existing in an identical water system were grouped to bring about some cost reduction effects as enumerated below. Thus, the survey was carried out to decrease a construction cost by making effective use of such effects.

- Standardize the specifications of headrace and headtank structures, construction equipment, etc.
- Standardize the specifications of hydroelectric power equipment (hydraulic turbines and generators).
- Jointly and otherwise properly apply construction machinery and falseworks.
- Centralize the supervision of works (so that every work can be supervised in a single construction work office).

2) The survey was carried out to decrease a construction cost by taking reasonable design with new technologies.

(c) Findings

It was found that developments in series would allow a construction cost to be saved by approximately 5% as compared with an individually designed development.

It was found that a reasonable design with new technologies employed would allow an approximately 15% decrease in construction cost as compared with a conventional design.

And some sites have been already developed by making effective use of the findings in this survey. And it could be expected much that a future hydroelectric power development would be accelerated in a great measure.

(4) Survey into Methods of Effectively Gaging Stream Discharge at a Developing Site From an Existing Gaging Station

This survey was carried out as a five-year plan starting in 1986 and ending in 1990.

(a) Objective

In Japan, stream discharge data relating to a point to be hydroelectrically developed have been being prepared through a direct calculation of the stream discharge from a nearby gaging station if it is located near the point. Despite the fact that there are many gaging stations all over the nation, however, there are also many points about which the important stream discharge data cannot be calculated for a study of the development size and economic aspects because there is no gaging station nearby. This survey, therefore, was made into the methods of converting and calculating stream discharge also from the data relating to any gaging stations other than the one nearby.

(b) What was Surveyed

This survey did not only build up a stream discharge data collected at gaging stations all over the nation but developed a method of calculating stream discharge.

A hydroelectrically developing point has its stream discharge calculated and prepared through a conversion from the stream discharge data obtained in an existing gaging station nearby with a catchment area ratio (a ratio of the catchment area at a gaging station to the catchment area at a point to develop). The survey, however, employed another method of correcting the stream discharge with a rainfall ratio (a ratio of the catchment rainfall at a gaging station to the one at a developing point) so that a conversion could be made from the data gathered at not only a newly gazing station but also every one.

(c) Findings

In addition to the conversion with a catchment area ratio, converting a stream discharge with a rainfall ratio was found improving the accuracy in calculating the stream discharge. As a result, one gaging station has had a range of its applications expanded, allowing us to expect that a reasonable stream discharge can be calculated through the new technique in the future.

(5) Survey into Methods of Calculating Stream Discharge at a Developing site, Using Remote Sensing Data

This survey has been currently carried out as a three-year plan starting in 1991.

(a) Objective

Concerning those points whose stream discharge could not be calculated through the survey referred to in (4) above, this survey is being made into the methods of correcting a calculated stream discharge with remote sensing data.

(b) What is being Surveyed

A stream discharge data relating to a point to be hydroelectrically developed are calculated and prepared by converting the stream discharge data gathered at an existing gaging station with a catchment area ratio. Although an applicable range of a gaging station has been expanded by the survey referred to in (4) above, this survey is being made into a method of correcting a stream discharge with the remote sensing data, in addition to the rainfall ratio correction method.

For remote sensing, LANDSAT data are used. Based on these data, the plant situations around the basin of a river are taken to grasp the characteristics of each catchment. Another remote sensing (weather satellite NOAA, etc.) is utilized to grasp the snowfall in the catchment of a river. At the same time, methods are also studied to convert and calculate a streamed discharge.

(6) Survey into Techniques of Redeveloping a Power Plant in Operation

This survey has been being currently carried out as a three-year plan starting in 1990.

(a) Objective

An old power plant generally is not making satisfactory use of the hydroelectric power energy that a river has, since it has a small working stream discharge. From the viewpoint of effective hydroelectric power energy utilization, therefore, the survey is aimed at establishing a technique of redeveloping such an old power plant.

(b) What is being Surveyed

This survey covers four items as specified below. From a new point of view, a redevelopment technique tries to be established, based on those items:

- A fact-finding survey into conventional hydroelectric power plants both in operation and under construction.
- A study of the techniques for evaluating the redevelopment, with consideration given to the effective use of both water power resources and existing equipment.
- A study to rationalize the design and work execution plan of a redevelopment.
- Working out a development planning manual to determine what redevelopment should be carried out, judging from the actual situations of an existing power plant.

(7) Survey to Establish a Power Generation Design Support System by Use of Computer Systems

This survey has been being currently carried out as a four-year plan starting in 1990.

(a) Objective

To support a prompt design for a power generation by establishing a detail power generation design system with computers utilized.

(b) What is being Surveyed

Those surveys which have been already carried out, including the fifth hydroelectric power resources potential survey and the ones referred to above, are to be configured into a data base to establish a computer-aided power generation design system, which will make effective use of the needs in detail power generation designs.

(8) Survey to Evaluate Environmental Effects of a Power Plant Installation in a Water-reduced Level Section of a River

This survey has been being carried out as a seven-year plan starting in 1985 and scheduled to end this year (1992).

(a) Objective

To establish a system allowing use to forecast and evaluate the effects of a hydroelectric power plant installation upon the aquatic creatures, water qualities, natural landscapes, etc. in a water-reduced level section, thereby promoting the location of hydroelectric power plants while paying due consideration to the preservation of environments.

(b) What is being Surveyed

At hydroelectrically undeveloped site, a fact-finding survey is being carried out into the ecosystem of aquatic creatures, water qualities and natural landscapes in a section whose water level has been lowered. And a study has been being made to clarify what effects a water level reduction has brought about or concerning evaluation methods involved and evaluation manuals.

2.2 Measures to Reduce Costs through Technical Developments

To reduce the construction costs incurred on hydroelectric power generation by rationalizing and saving the labor for the medium-and small-sized hydroelectric power generating equipment and work execution, the New Energy Foundation has been making a new technology development survey into the equipment, work execution and new materials as referred to below as consigned by the Ministry of International Trade and Industry.

(1) Utilization Technology for Inflatable Rubber Weir

A bag made of synthetic rubber is made to rise and fall, with water or air filled or discharged under pressure. This allows us to remove the effects of back ware and deposited sand on the upstream of a weir.

Besides, the weir permits the cost to be reduced as compared with the concrete one. (For details, see "**NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT**")

An outline of the inflatable weir is shown in Fig. 3.

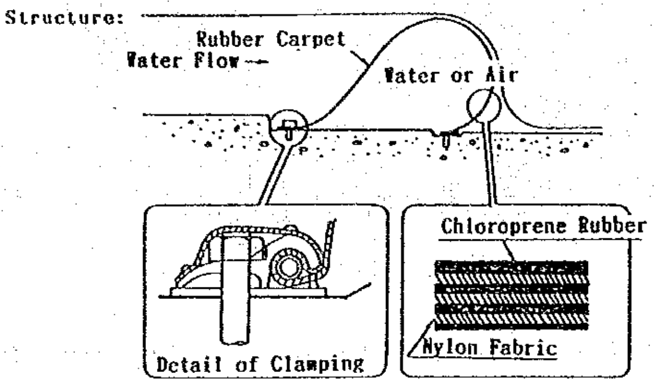

Fig. 3 Inflatable Rubber Weir

(2) Rationalization of Dam Foundation Treatment in Low-head Project

Two foundation treatment engineering processes have been developed; one is the dam foundation treatment engineering process with an underground wall made of concrete mixed with bentonite and the other is a foundation treatment engineering process with wet minute cement (WMC) grouted.

These engineering process permit us to reduce their costs for constructing an intake dam. (For detailed, see "**NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT**")

Fig. 4 depicts a comparison of the conventional engineering process with the new technology for a dam foundation treatment.

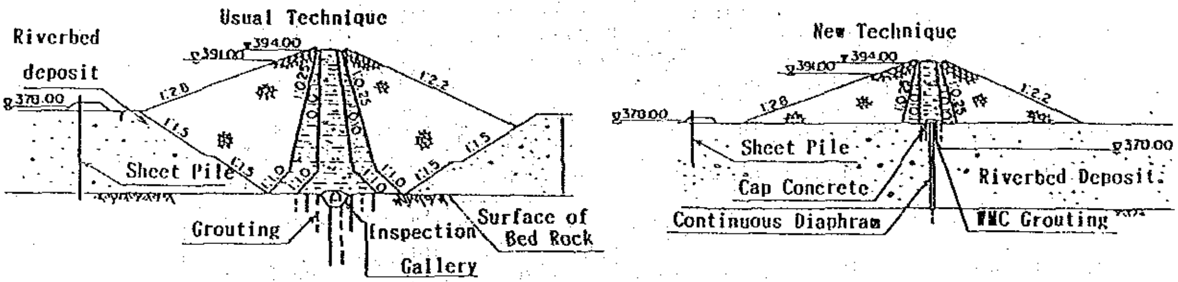

Fig. 4 Comparison of the Conventional Engineering Process with the new Technology for a Dam Foundation Treatment

(3) Adoption of the TBM Method

An all-geology type TBM (Tunnel Boring Machine) is capable of excavating three or four times as compared with the existing blasting method. As a result, it is possible to reduce both term of work and costs, with labor saved. (For detailed, see "**NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT**")

Fig. 5 shows a tunnel boring machine.

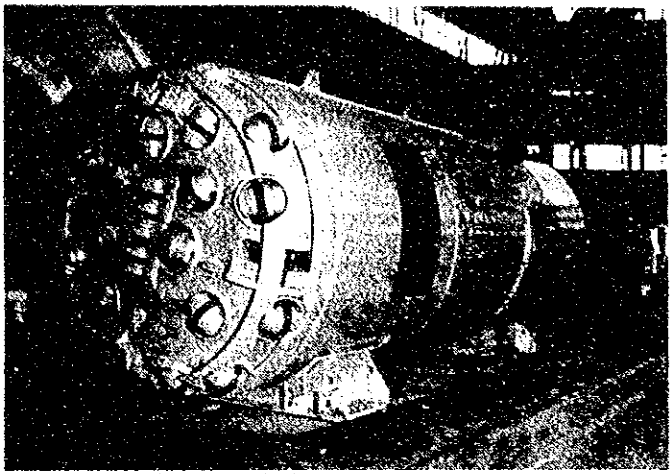

Fig. 5 TBM (Tunnel Boring Machine)

(4) Rationalization of Civil Facilities Such as Elimination of Spillways

In the case of a Francis hydraulic turbine, spillways are omissible by discharging the ware through a discharge valve located in the lower part of a penstock and by operating at the intake gate.

In the case of a Perton hydraulic turbine, spillways are also omissible by establishing deflector and operating the intake gate. (For details, see "**NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT**")

(5) Application of FRPM Pipe to Penstock

An FRPM (Fiber-glass Reinforced Plastic Mortar) pipe is highly resistant to both acids and corrosives. Applying this pipe is aimed at creating the fallibility to a displacement of the ground, reducing the penstock weight and penstock equipment.

Fig. 6 shows an FRPM pipe.

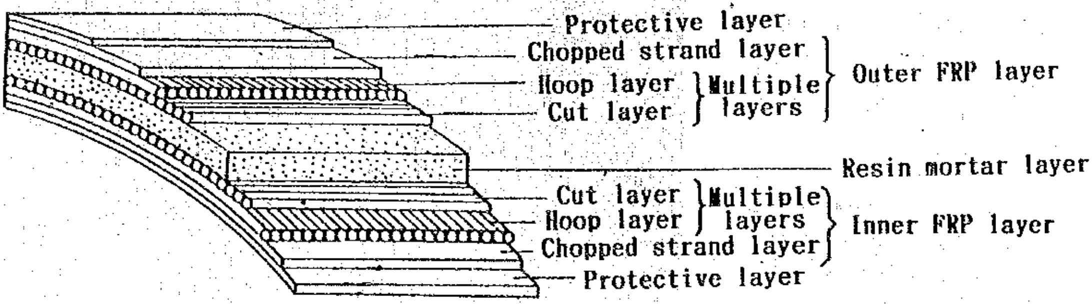

Fig. 6 FRPM Pipe

(6) Mechanical Joints for Penstock

The penstock has been conventionally joined by welding. With a mechanical joint of bolting applied, however, the penstock is capable of flowing a settlement of the ground with safety. This permits us to expect of a reduction of both term and cost for installation of the penstock.

(7) Package Turbine Generator

This generator is applicable at an effective head of 3 through 20 meters, stream discharge of 0.5 through 4.0 cubic meters per second and output of 10 through 600 kilowatts. The turbine unit comprises a fixed vane propeller, a fixed guide vane, and a squirrel cage type induction generator. Rotors are incorporated on the circumference of the runner vanes of a hydraulic turbine. And they are turning jointly on a concentric circle.

The generator is aimed at reducing costs by simplifying and standardizing the equipment. (For details, see "**SMALL SCALE HYDROELECTRIC POWER GENERATING FACILITIES OWNED BY LOCAL PUBLIC ORGANIZATION IN JAPAN**)

Fig. 7 shows a package turbine generator.

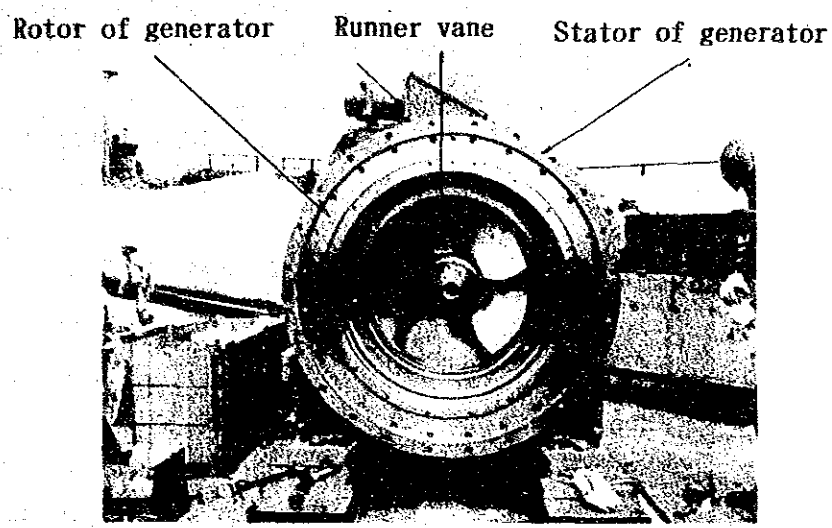

Fig. 7 Package Turbine Generator

(8) Light-load Francis Turbine

This hydraulic turbine is applicable to a run-of-river type power plant with a medium-high head (approximately 50 through 300 meters) and with stream discharge fluctuating in a great measure.

This power plant is operable in a zone with a low stream discharge. A light-load Francis turbine of low specific speed (150 meter-kilowatts) type is operable up to a stream discharge of 25% on the maximum usable discharge. And a high specific speed (200 meter-kilowatts) type is operable up to 40% of the maximum usable discharge.

This hydraulic turbine itself is costly and aimed at reducing the cost per unit power generation by increasing the quantity of power generated.

(9) Very-low-head Hydroelectric Power Generating Facility

A power plant is to be developed, which employs a straight-flow turbine shaped into a flow channel applicable to a very low head.

The very-low-head hydroelectric power plant is applicable to the site which satisfies the following conditions:

Head : 2 through 25 meters
Working discharge : 30 through 100 cubic meters
Output : 500 through 21,000 kilowatts

(10) Others

2.3 Fostering and Assisting Developers

To promote the development of hydroelectric power, the New Energy Foundation has been conducting the following projects with the fiscal subsidies granted from the Ministry of International Trade and Industry:

(1) Technical Guidance for Medium- and Small-scale Hydroelectric Power Development (to Develop a Power Plant with an Output of 50,000 kilowatts and below)

To foster and strengthen the public electric utilities and private power generating installation developers, the New Energy Foundation has been conducting a guidance relating to technical and managerial challenges, etc. concerning those hydroelectric power development plants which are considered promising or likely to succeed in their project. In addition, a fiscal subsidy is granted to cover a certain percentage of the costs required for planning and/or surveying for such project.

(2) Interest subsidy System for Construction of Hydroelectric Power Development

Those public electric utilities and other electric enterprises, which try to install medium- and small-scale hydroelectric power plants, are subsidized with the interest payable for construction costs for a certain period following a startup of hydroelectric power plant operations. Thus, the system is aimed at promoting the hydroelectric power development by reducing the initial power generating cost, with a burden of the interest lightened.

In addition, the New Energy Foundation has been opening hydroelectric power-related training courses as one of the Foundation's autonomous projects.

Outlined above are the actual trends of hydroelectric power development in our country, including the measures taken for the promotion of such development. From now on, it will be essentially necessary to develop the hydroelectric power which is clean and renewable from a global point of view.

In Japan, the National Government make five times hydroelectric power potential surveys starting in 1910 to clarify the entirely of hydroelectric power development sites all over the nation. As a result, a reasonable development has been being promoted. And the findings of the surveys have been considerably supporting the development still at the present. Japan, moreover, is a minor country from the viewpoint of natural resources. As a result, the Japanese Government has been taking a wide variety of measures for developments.

To promote an immense extension of the development from now on, the Provincial Government of Saba is also recommended to develop hydroelectric power reasonably, with state-of-the-art technologies introduced. To this end, a hydraulic power potential survey should be preferably made to establish a comprehensive development plan, first of all, with the future taken into consideration.

NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT

Summary

This paper will give some examples of new technology adopted for small scale hydroelectric power development. One is the example for typical run-of-river project in Japan which includes: (a) an inflatable rubber weir; (b) Burried underground penstocks; (c) Adoption of a tunnel boring machine; (d) Turbine-generators with different sizes.

The other is a low head power project with a reregulating pondage. The project was constructed on deep alluvial deposits and the technologies adopted include: (a) Bentonite concrete diaphram cut off wall; (b) Wet milled cement; (c) A large size tubular turbine.

Some examples out of Japan include: (a) A L-shape waterway layout; (b) Adoption of a tunnel boring machine; (c) Elimination of an head tank; (d) Fiber reinforced plastic penstocks.

NEW TECHNOLOGY FOR SMALL SCALE HYDROELECTRIC POWER DEVELOPMENT

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Between 1984 and 1989 he was in charge of planning of small-scale hydroelectric power projects as an assistant manager of the planning section. In 1985, he was involved in the Pahang Small-Scale Hydroelectric Development Study in Malaysia. He has been actively involved in feasibility studies of hydroelectric power projects in Lao P.D.R., Myanmar, Thailand and Vietnam since 1989.

1.1 Outline of the Power Project

The Kurotani Hydroelectric Project is a run-of-river power development project with an installed capacity of 19,600 kW, located on the Kurotani River, a small tributary of the Ina River, itself a tributary of the Tadami River in the Agano River System.

The Kurotani Intake Dam, made of a large-scale inflatable rubber weir of 6 m high is located at a point approximately 16 km upstream from the confluence of the Kurotani River and the Ina River. The project consists of three intake dams, a 8,200 m long headrace tunnel, a 450 m long penstock, and a semi-underground powerhouse. Its installed capacity is 19,600 kW with maximum discharge of 12 m^3/s and effective head of 194 m.

The power generated is to be interconnected with the bus of the Tagokura Power Station of EPDC by a transmission line (66 KV, 1 cct, length approximately 13 km). The energy is to be supplied to Tohoku Electric Power Co., Inc. for distribution.

The project located in a heavy snowfall area (accumulated average annual snow-fall is more than 15 m), and access to intake dam site during snow season from December to April is very difficult. This is one reason that we adopted a small size tunnel boring machine to excavate the longest tunnel in length of 4,850 m. The tunnel will be excavated from a head tank side and it makes the tunnel excavation works during snow season possible.

In order to construct a economical and functional project in harmony with environment some interesting technology such as an inflatable rubber weir, a buried underground penstock, and omission of spillway is adopted.

1.2 Topography and Geology of the Project Area

The Kurotani River having total length of 25 ~ 30 km originates from mountainous area at elevation of 1,400 ~ 1,800 m and runs from south to north. The project is located in the area 6 ~ 16 km upstream from the confluence of the Kurotani River and the Ina River. The project area is in topographic maturity and its valley is narrow and steep.

The bed rock of the project area consists of Permian slate interpolated by granite and gabbro. Dikes consists of rhyolite, porphyrite, diabase, and liparite are also distributed in small area. The slate is black and hard, being developed by block-form joints. The granite which is hard is distributed in the downstream area of the waterway. The granite is deeply weathered at low elevation in the downstream area of the waterway.

1.3 Construction Schedule and Plan

The construction works begun in May 1991 and the project is expected to be commissioned in May 1994. The construction period is very limited because of heavy snowfall from December to April. The construction work will be stopped during the snow season except the TBM tunnel excavation work.

Efforts not to disturb natural condition by the construction work were made. A cable crane and incline facilities were adopted as substitutions for construction roads. The newly constructed roads are a road for No. 3 Intake Dam and a road for penstocks.

1.4 Inflatable Rubber Weir

In order to keep the river bed in natural condition as much as possible, a 6 m high inflatable rubber weir will be constructed on the main river. Compared with a steel gate having similar functions, in inflatable weir has the following features:

- Safe and sure automatic deflation and automatic erection through adoption of a multiplex mechanism
- Easy maintenance due to less trouble because of a simple operating mechanism and no necessity for painting
- Excellent weather resistance and durability against impact of boulders
- Shortening of construction period is possible because of light weight which makes delivery and installation easy.
- Prevention of water level rise upstream of dam, as no backwater caused by the dam and sedimentation

Other important features include:

- A settling basin and a desilting gate can be omitted, because sediment flowing into the pond can be removed naturally by deflating the weir.
- Manpower, connected with the maintenance and operation such as sand flushing, can be saved.

1.5 Buried Underground Penstock

A penstock of 2.2 m in diameter will be buried underground 1 m below the surface. The underground penstock has the following advantages compared with a surface penstock:

- Supporting structures such as saddles for penstock are not necessary because the penstock will be supported and restrained by the surrounding ground and backfilld earth. Anchor block concrete can be reduced as the horizontal forces on anchor blocks are alleviated.
- There is less susceptibility to effects of natural phenomena such as air temperature and snowfall.
- There is safety against external impacts from avalanches, rockfall, etc.
- Scenery can be maintained through greening after burying the penstock.

Consequently, by burying penstocks at sites of severe natural environment such as cold and heavy snowfall areas, there will be even more merits gained from the point of view of long-term maintenance.

It is unavoidable that the shell thickness of a buried penstock will be slightly greater compared with a surface penstock, considering the earth pressure of the surrounding backfield earth besides the internal pressure. However, a reduction in overall construction costs can be expected, because supporting structures are not necessary.

1.6 Omission of Spillway

(1) Outline

Most of the medium- and small-scale hydraulic power plants are generally planned as small run-of-river types, and are not usually economical. However, in most cases, it can be made economical by ingenuity and new technology because the total construction cost is not so high. One of the means of reducing construction expenses is an economical design that omits the spillway that leads the spilled water from the head tank to the river and adds a discharge valve tapped from penstock just upstream side of inlet valve instead.

The omission of the spillway is made by two methods: that is, one is by using civil engineering facility and the other is by the deflector discharge of the Pelton turbine. In Japan, several power plants that were developed by these methods are operating now.

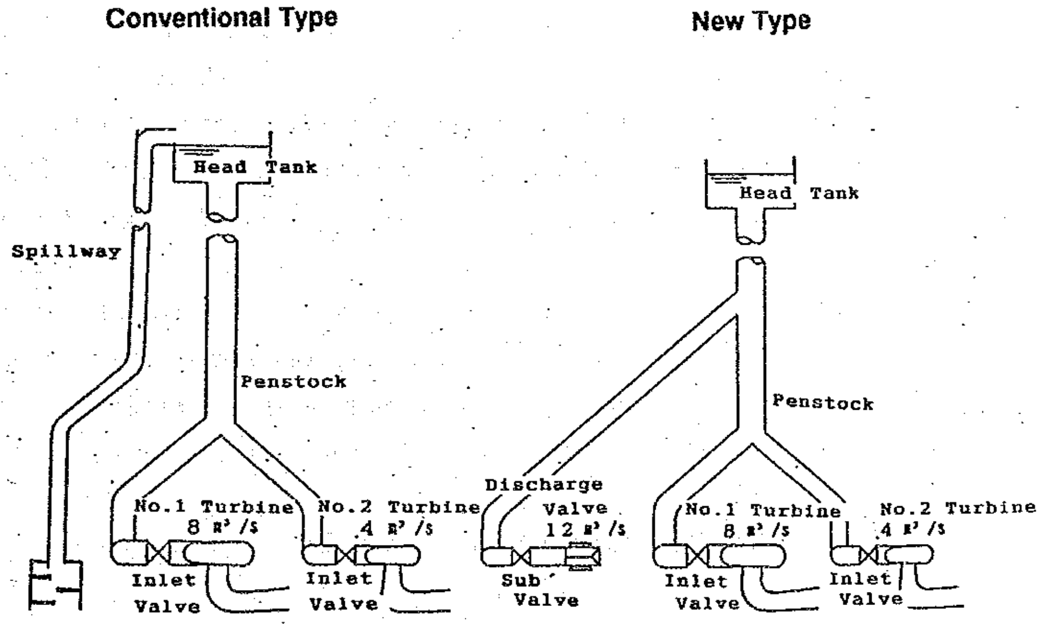
These power plants usually have a small discharge, under 4 m^3/s, to generate electricity and only one main machinery. In the case of a deflector discharge, only the Pelton turbine is allowed to be used. As the Kurotani Power Plant has a relatively large discharge of 12 m^3/s and two Francis turbine units, many problems have to be examined to use a discharge valve instead of the spillway.

The omission of the spillway in the Kurotani Power Plant was made possible by research including the improvement of the valves, making the penstock discharge valve system applicable for discharge above 4 m^3/s.

Fig. 1.1 shows a conceptional drawing of an ordinary power plant and the Kurotani Power Plant where the spillway was omitted by adding the penstocks discharge valve.

In an ordinary power plant, at load rejection by failure of transmission line and/or generating equipment, the level of the water in the head tank rises and spills, and the spilled water is discharged into the river through a spillway tapped from the tank. The spillway is usually provided parallel to the penstock and most of them are expensive. The system applied this time detects the rise of water level in head tank caused by load rejection and discharges water in an amount proportional to spilled water to the downstream bypassing through a discharge valve.

Fig. 1.1 Omission of Spillway



The penstock discharge valve system is activated at the time of the load rejection and discharges water not to spill from head tank. For this purpose, the investigation and research, such as the evaluation of the reliability, the control system linked with the hydraulic turbine, the backup method in the case of mulfunctioning, were conducted and the application to actual plant was realized.

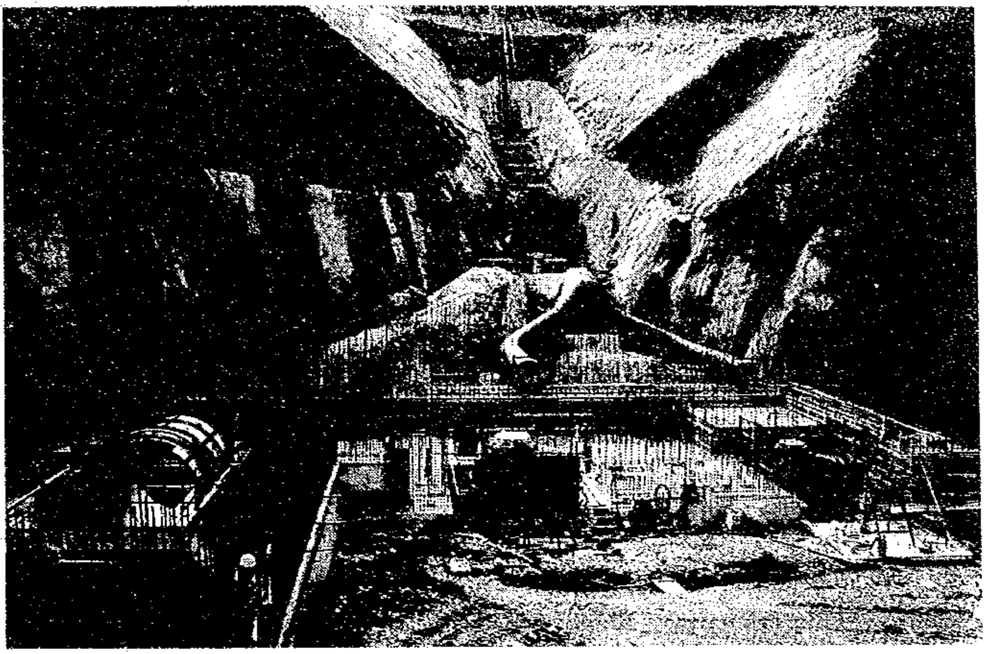
(2) Selection of discharge valve

Five kinds of valves, that is, a cone valve (H.B.V.), a hollow jet valve (H.J.V.), a jet flow valve (J.F.V.), a needle valve (N.V.), and a pressure-regulator-type valve (R.T.V.) were selected, examined, and evaluated for the penstock discharge valve.

The examinations were performed for 12 items, such as structural design, operation and control performance, flow characteristics, energy-absorbing effect, etc.

As the result of the overall evaluation of those valves, the cone valve (H.B.V.) with a small operating force, a large energy absorbing effect of the valve itself, simple structure, and least maintenance, was adopted. It has to be noted that the hollow jet valve (H.J.V.) has advantages that has self-opening characteristics when water pressure is applied to its body and that it has high operational reliability owing to it's operation mechanism capable of using pressure oil system of hydraulic turbine as stand-by.

The following photograph shows how it is installed.



1.7 Selection of Turbine Type and Unit Discharge

To select the type of hydraulic turbine for the Kurotani Power Plant, the following three cases were examined for economic efficiency.

(a) 6 + 6 m^3/s vertical shaft Francis turbine
(b) 8 + 4 m^3/s vertical shaft Francis turbine
(c) 9 + 3 m^3/s vertical shaft Francis turbine

The vertical shaft Pelton turbine was also examined as an alternative, although evidence was given that it is not economical to use because of its higher machinery cost and a larger housing space requited for installing spiral case with not less than four nozzles.

The annual run off and it's period, which was calculated from the run off-duration curve, for the power generation scheme are roughly as follows. (The river flow required for downstream and not to be used for power generation is subtracted. May to November: 0.5 m^3/s / 100 km^3, December to April: 0.25 m^3/s /100km^3)

12 m^3/s or more usable	80 days/year
8 m^3/s or more usable	90 days/year
6 m^3/s or more usable	110 days/year
4 m^3/s or more usable	160 days/year
3 m^3/s or more usable	210 days/year
2 m^3/s or more usable	300 days/year
1 m^3/s or more usable	365 days/year

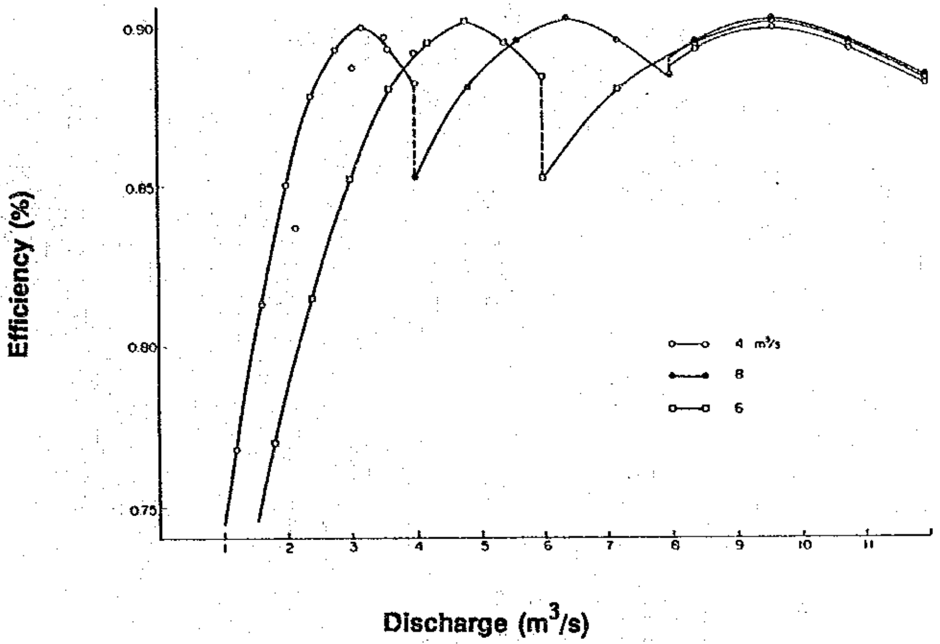
For the medium and small scale run-of-river plants without a regulating capacity, the annual energy production shall be maximized especially considering minimum operation limit of turbine in dry season.

Therefore, the hydraulic turbine, which can be operable at around 1 m^3/s flow (25 - 30% Q_{max}), was selected for this plan.

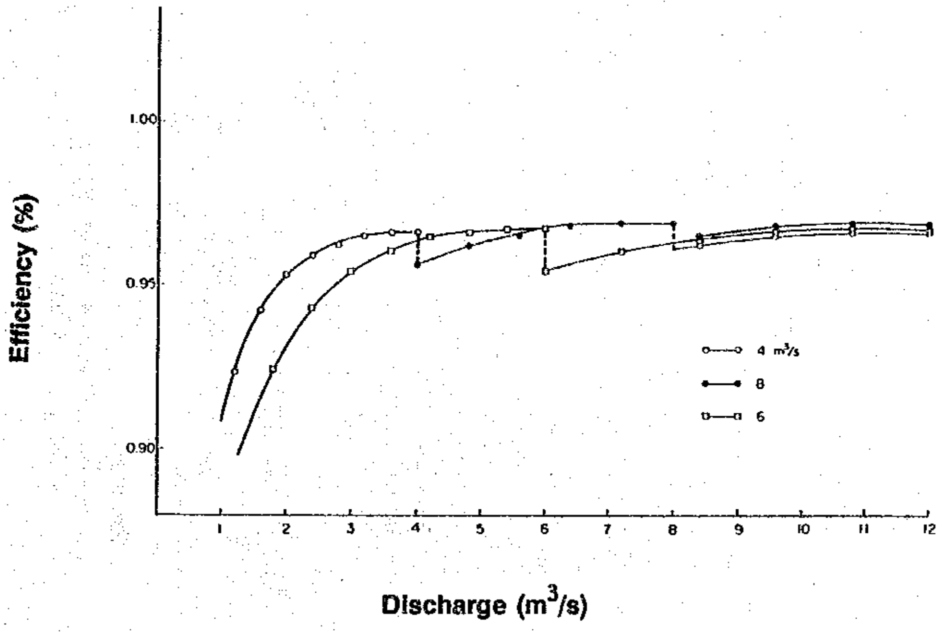
The energy production was calculated based on the efficiencies of the hydraulic turbine and generator in the attached data.

In conclusion, the adoption of the b) plan, hydraulic turbine, is most economical, as a result of comparing specific data, energy production and rough construction cost per kWh for three cases.

Turbine Efficiency Characteristic



Generator Efficiency Characteristic



Project Feature of Kurotani Project

Characteristics

River

Agano river - Kurotani river
- Ohyuzawa river
- Koyuzawa river

Average Runoff	7.08 m^3

Catchment area

- Kurotani river	52.8 km^2
- Ohyuzawa river	23.7 km^2
- Koyuzawa river	6.5 km^2
Total	83.0 km^2

Intake Level	678.0 m
Tail Water Level	465.50 m
Effective Head	194.30 m
Maximum Discharge	12.00 m^3/s
Installed Capacity	19,600 kW
Annual Energy Production	72 GWh

Main Equipment

Turbine

- Type	Vertical Francis
- Power	13,500 kW (1st unit), 6,900 kW (2nd unit)

Generator

- Type	Synchronized Generator
- Capacity	13,800 kVA (1st unit), 7,000 kVA (2nd unit)

Main Structures

Dam

- Kurotani Intake Weir	
Type	Inflatable Rubber Weir
Dimension	11.6 m high x 50.3 m long
- Ohyuzawa Intake Weir	
Type	Concrete Gravity
Dimension	12.0 m high x 56.0 m long
- Koyuzawa Intake Weir	
Type	Concrete Gravity
Dimension	11.0 m high x 32.0 m long

Waterway

- Type	Non-pressure tunnel
- Width	2.2 ~ 3.3 m
- Height	2.1 ~ 3.3 m
- Length	8,162.43 m

Penstock

- Type	burried underground
- Inner diameter	2.2 ~ 0.78 m
- Length	453.83 m

Powerhouse

- Type	semi-underground
- Width	12.2 m
- Length	28.9 m
- Height	24.8 m

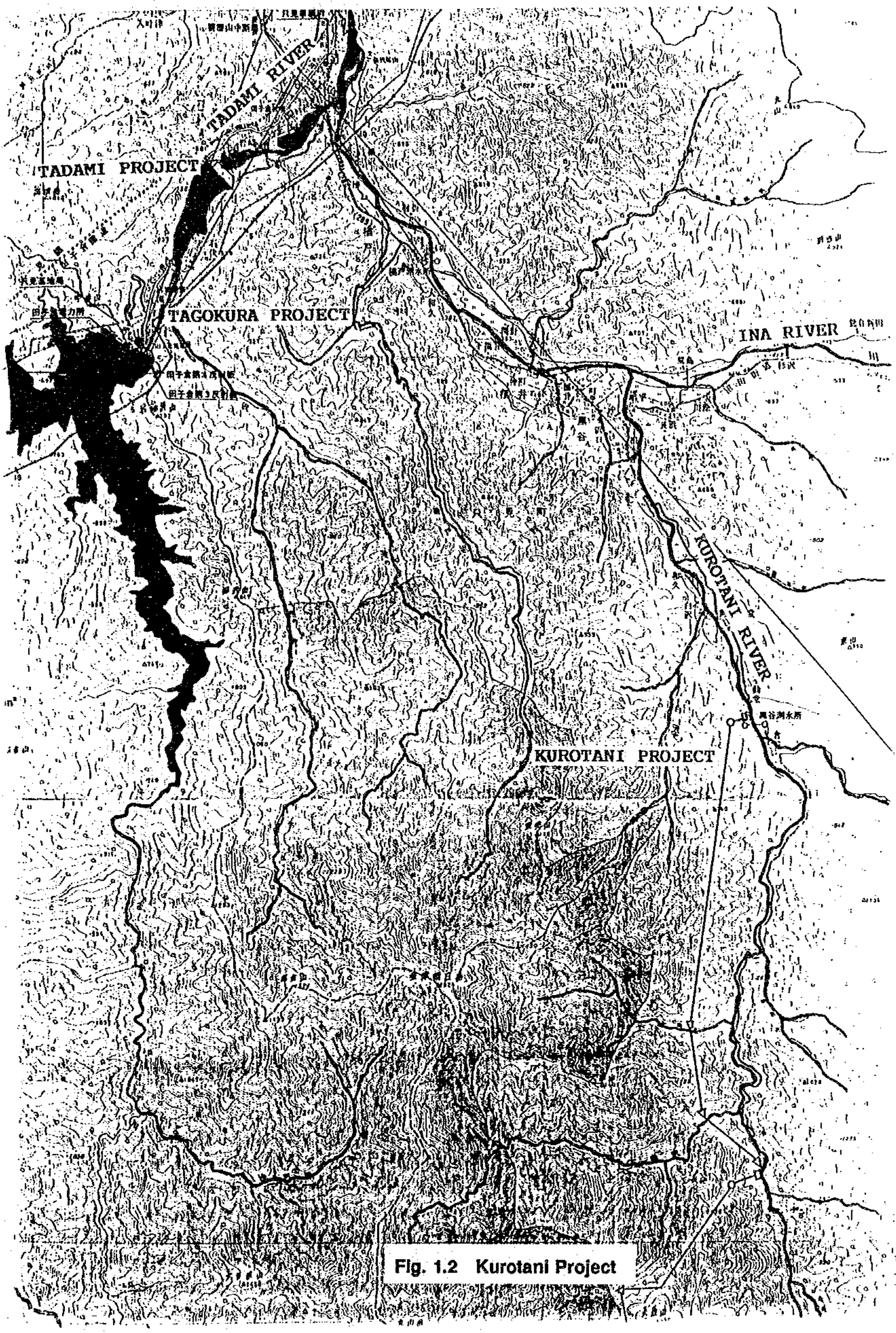


Fig. 1.2 Kurotani Project

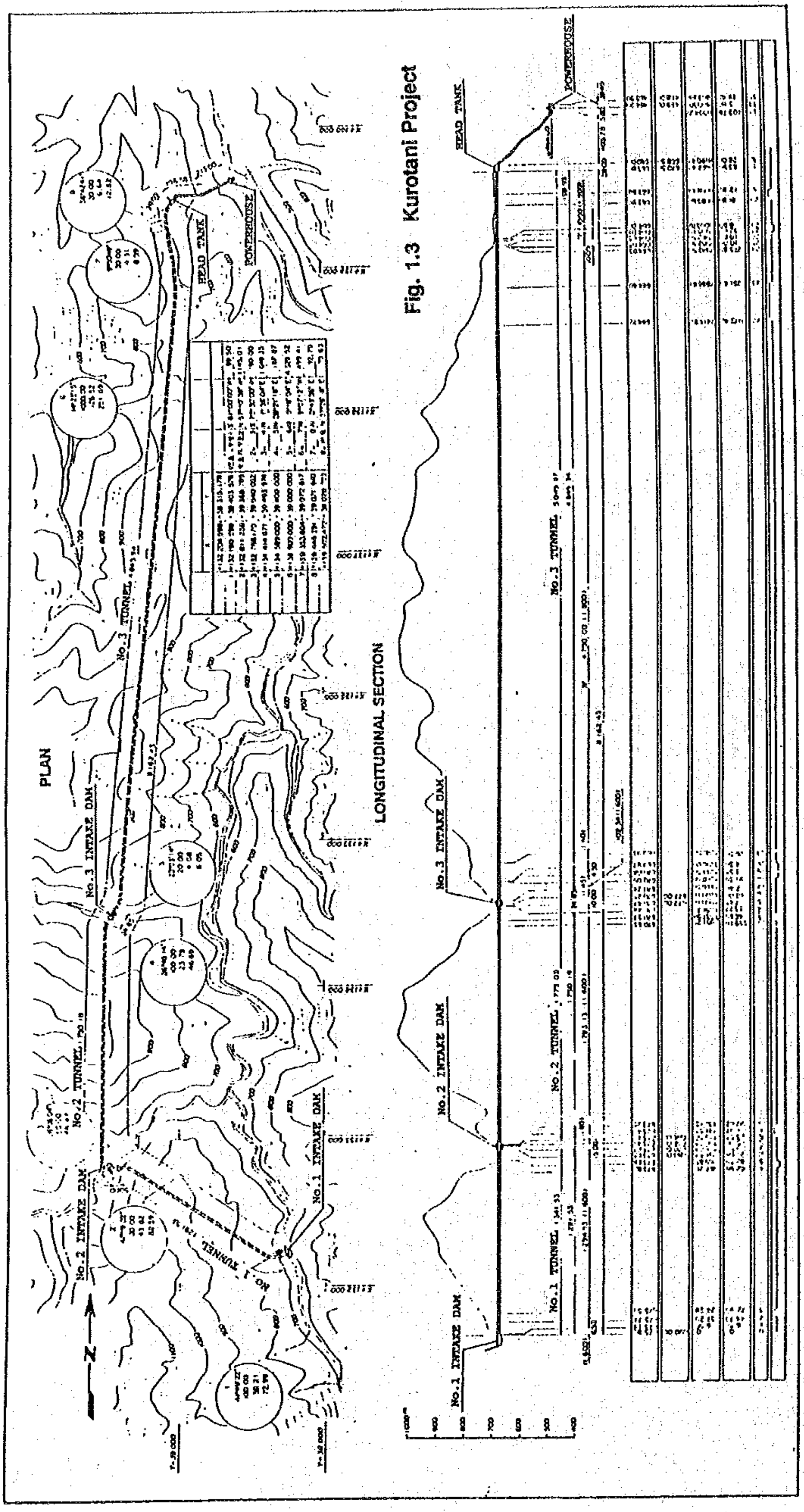


Fig. 1.3 Kurotani Project

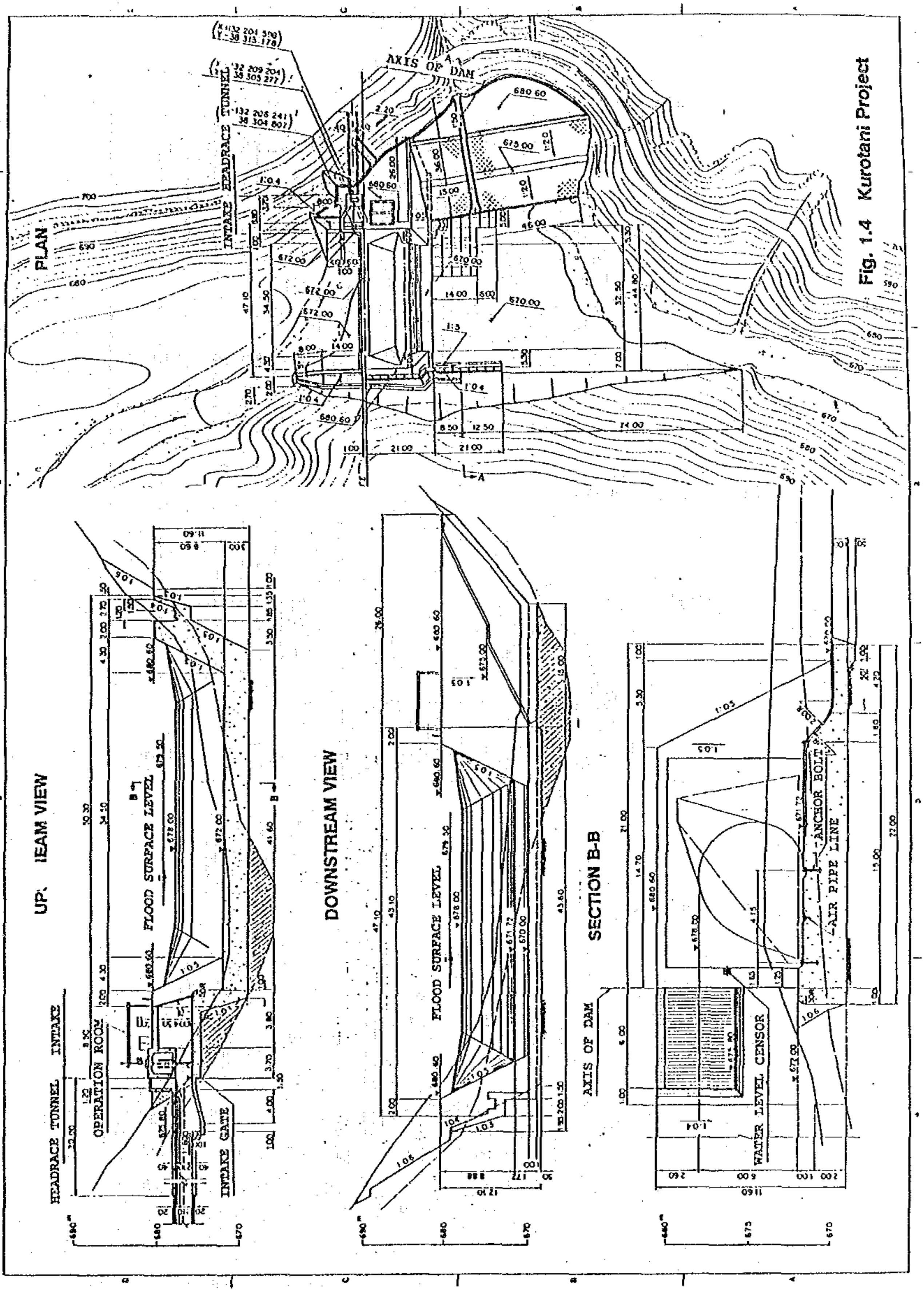


Fig. 1.4 Kurotani Project

Fig. 1.5 Inflatable Rubber Weir

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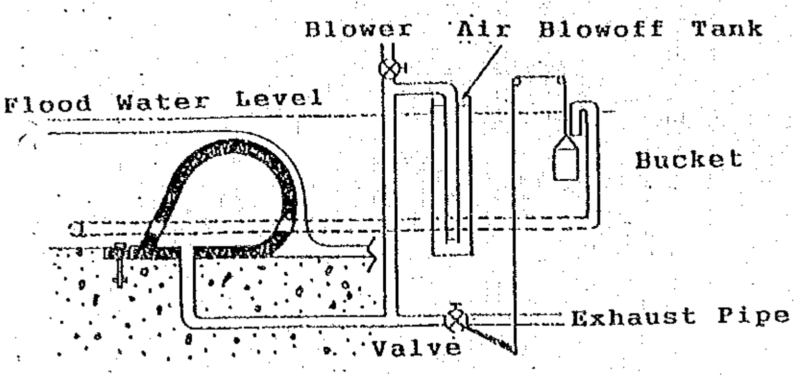
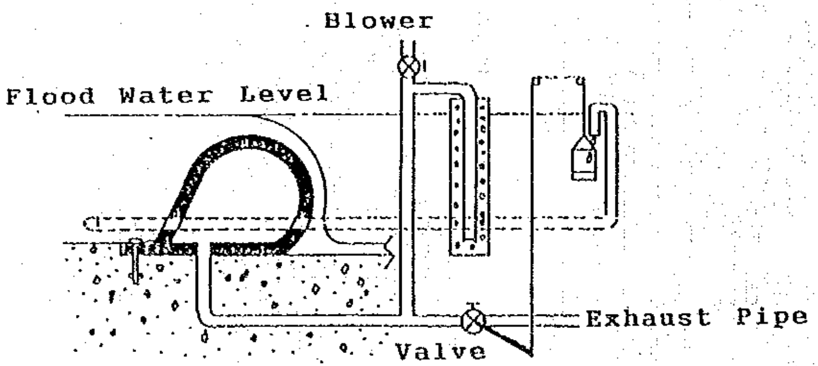
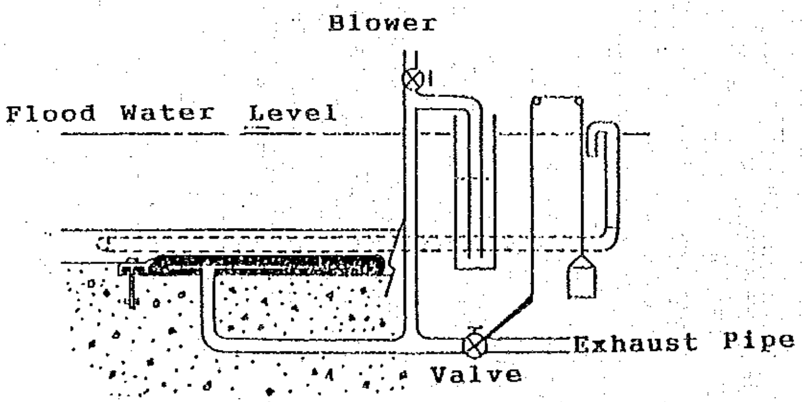


Beginning of Deflation



After Deflation



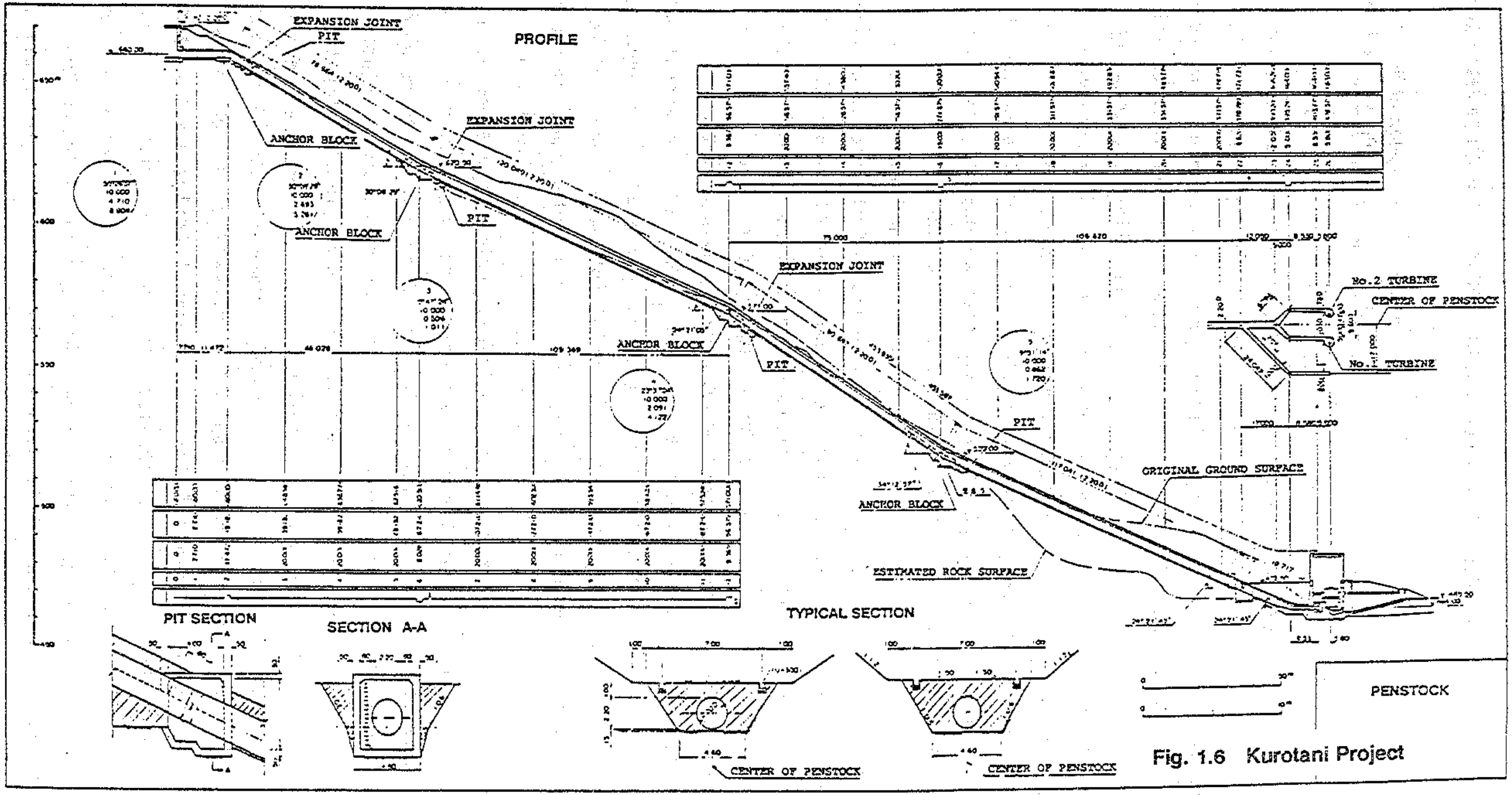


Fig. 1.6 Kurotani Project

2.1 Outline of the Project

Tadami Dam is a facility for power generation located 3 km downstream of Tagokura Dam built earlier by Electric Power Development Co., Ltd. (EPDC) on the Tadami River of the Agano River System. At Tadami Hydroelectric Power Station electric power of a maximum output of 65 MW is generated using a maximum power discharge of 375 m^3/s, taking advantage of the effective head of 19.8 m made available by a regulating pond having an effective storage capacity of 2 hm^3 created by this dam and a tailrace canal 2.2 km in length.

At power station sites of low head located of the middle or downstream stretches of rivers such as the Tadami site, the widths of the rivers are broad and alluvial deposits exist in many cases. Excavation and fill volumes will tend to be large using conventional construction methods that core bases are based directly on foundation bedrock, while care of the river would be of enormous scale making dam construction by such methods difficult for practical purposes. Consequently, to construct dams directly on alluvial deposits and to carry out foundation treatment rationally assume extremely great importance.

The river width at the dam site is approximately 180 m, and is more than 450 m when the terrace portions at the right and left banks are included. Therefore, Tadami Dam was laid out to have a main dam portion from the left bank to the present river channel (crest length 354 m), and next to it a spillway and a power intake structure (total width 74 m), while further on the right-bank side there is a side dam (crest length 154.5 m), the total length of the river structures including the spillway being 582.5 m. The main dam is a central impervious core rockfill dam constructed directly on alluvial deposits approximately 20 m in thickness.

The side dam (height 24.0 m) at the right-bank side adjacent to the spillway and power intake structure is also a central impervious core rockfill dam. This side dam was based directly on the bedrock as the alluvial deposits were thin at the right-bank side.

The embankment volume of the main dam and the side dam together was approximately 450,000 m^3.

The new technology for foundation treatment of alluvial deposit and for low head utilization was developed in this project.

2.2 Foundation Treatment for Alluvial Deposit

The alluvial deposits at the Tadami site are comparatively well-compacted with the void ratio approximately 25 percent, the deformation modulus being about 1,700 kgf/cm^2 according to plate bearing tests. The maximum particle size of the sand and gravel is roughly about 60 cm. Coefficients of permeability tend to become successively higher going from the right-bank side to the left-bank side, with values of the orders of 10^{-3} cm/s and 10^{-2} cm/s indicated at the right and left-bank sides, respectively. Whereas the alluvial deposits at this site contain few boulders so that excavation is easy, there are many parts where coefficients of permeability are low for sand-gravel deposits so that improvement by grouting methods is difficult and the diaphragm cut off wall method is more advantageous economically compared with grouting methods.

The diaphragm cut off wall at Tadami Dam is of a construction for cutting off water acting integrally with the impervious soil core, and therefore, the location of the diaphragm wall was arranged underneath the impervious core to form a continuous cut off wall which would be based directly on the bedrock existing at a depth of approximately 20 m. Thicknesses of diaphragm cut off walls normally range between 60 and 100 cm, and 80 cm was selected in this case giving consideration to the maximum particle size of the alluvial deposits, scale of the dam, and performances of construction equipment. Bentonite concrete which shows properties close to the deformability of the surrounding alluvial deposits was adopted as the material for the diaphragm wall.

The connection of the diaphragm wall and the impervious soil core was where the hydraulic gradient would be a maximum, so that blanket grouting using wet milled cement (WMC) grout was performed along the entire width of the impervious core aiming to suppress seepage flow velocity.

(1) Bentonite Concrete Diaphragm Cut Off Wall

Bentonite concrete is a material with its deformability increased taking advantage of the water-retentive properties of bentonite. A deformability approximately the same as the alluvial-deposit foundation is exhibited, while since the water cut off property is good, bentonite concrete is extremely logical as a diaphragm was material making structural design of the dam easy. EPDC has actively worked to develop this concrete. Mix designs of bentonite concrete are for unit cement contents in a range of 75 to 200 kg/m^3 with about 10 to 30 kg/m^3 of bentonite added to concrete, and water-cement ratios from 1.20 to 3.50, appropriate proportions required to be selected depending on the use and construction method.

The mix proportions of bentonite concrete were selected giving consideration to approaching the deformability of the surrounding alluvial deposits while securing water cut off property, stability of quality, and workability. A standard mix design of bentonite concrete is given in table below.

Standard Mix Design Of Bentonite Concrete

Water-Cement ratio W/C (%)			223
Sand percentage s/a (%)			47
Unit weight (kg/m^3)	Bentonite	B	25
	Cement	C	125
	Water	W	279
	Fine aggregate	S	792
	Coarse aggregate	G	928

The structural study of the diaphragm wall was made by a linear finite element method giving consideration to the embankment and water impoundment processes. As a result, the amounts of settlement of the diaphragm wall and the river deposits at completion of embankment were 2.1 cm and 2.5 cm, respectively, the difference in the variation being 0.4 cm. It was decided that the examination of stresses in the diaphragm wall would be done by element safety factor, with 2.0 to be secured as the element safety factor at this site throughout embankment and impounding, and during earthquake. As a result of analysis, it was found that the maximum stress occurring inside the diaphragm wall was in the vicinity of the embedded part of the wall, and the element safety factor at this time was 2.3. By adopting a bentonite concrete diaphragm wall, the difference in settlement amounts between diaphragm wall and alluvial deposits was practically eliminated, while stress-wise, large concentrations of stresses did not occur, and a rational design was made possible.

Regarding the structure of the connection between diaphragm wall and impervious soil core, model experiments were conducted in view of the extreme importance of this part from the standpoint of water cut off, and the safety was confirmed. Also, in-situ tests were performed before actual construction of the bentonite concrete diaphragm cut off wall, and confirmations were made of constructibility, deformability, watertightness, and response properties at time of earthquake.

Confirmation of the water cut off properties of the diaphragm was done by permeability tests by the packer method utilizing test holes of ø 66 mm made in the wall. As a result of the tests the coefficient of permeability was found to be an average of 4.4×10^{-7} cm/s. The control criterion for coefficient of permeability of the wall is 1.0×10^{-6} cm/s or under, so that the permeability test results all satisfied the criterion, and it was ascertained that ample watertightness had been secured.

(2) Wet Milled Cement (WMC) Blanket Grouting

Ordinary cement which has been conventionally used for grouting bedrock is a material which excels in the aspects of handling, strength, durability, costs, etc., but there are often limits occurring with respect to practicle size in grouting of alluvial deposits. EPDC focused on the fact that cement grout is used in the form of a slurry and carried out research on the WMC grouting method aiming for increased efficiency of pulverization by switching the milling process of cement from the conventional dry system to a wet system. This grouting method is featured by the fact that injection can be done changing the quality of the grout micropulverizing cement effectively, and moreover, to any desired particle size with simple facilities incorporating a wet milling process in the conventional process of injecting cement grout.

The wet micromilling apparatus (hereinafter referred to as "micromill") is a device consisting of a vessel in which steel beads are filled with the beads rotated at high speed and cement particles passing through the voids in the beads pulverized by forces such as friction, compression, and shear.

The alluvial deposits at the Tadami site are generally fine-particled and difficult to improve by grouting, but it was judged that by manufacturing and injecting WMC of the finest size, it would be possible for representative sand-gravel layers, needless to say, and even silty-sand layers having minute voids existing at parts to be improved.

Results Of Studies On Groutability Ratios

Sample No	Particle size of deposits (mm)		Groutability ratios			
			Ordinary cement		WMC	
	D15	D10	D15/G85 (≥15)	D10/G95 (≥8)	D15/G85 (≥15)	D10/G95 (≥8)
1	8.0	4.3	229	86	1,778	614
2	0.45	0.3	34	6	267	40
3	1.2	0.18	14	4	111	26
4	0.07	0.06	2	1	16	9

Note: Ordinary cement G95 = 0.05 mm, G85 = 0.035 mm
WMC G95 = 0.007mm, G85 = 0.0045 mm

The target permeability was made 5 Lu since the grouting was to be blanket grouting; the range of injection was along the entire bottom surface of the impervious soil core with the depth of improvement to be 5 m. The injection pattern was that of two rows at 1.5 m spacings on both upstream and downstream sides of the diaphragm wall with grout hole intervals in the direction of the dam axis 2.5 m.

At the difficult-to-improve right-bank side, since adequate improvement effects were not obtained with primary injection, secondary injection and additional grout hole injection were performed. As a result, the probability of non-exceedence at 5 Lu became 88 percent to attain the target.

At the left-bank side of comparatively high coefficient of permeability, the improvement target was more or less reached with primary injections. As a result of permeability tests after a slight amount of additional grouting, the probability of non-exceedence at 5 Lu became 93 percent.

The relationships of amount of grout injected and improvement effect according to the right and left-bank side are summarized in table below.

Relationships of Amount of Grout Injected and Improvement Effect According to the Right and Left-bank Sides

Location	Left bank side	Right bank side
Coefficients of perme-ability before injection (cm/s)	1.7×10^{-2}	2.3×10^{-3}
Coefficients of perme-ability after injection (cm/s)	2.3×10^{-5}	2.2×10^{-5}
Probability of non-exceedence at 5 Lu (%)	93	88
Amounts of grout per valve (ℓ)	623	456
Amounts of cement per length (kg/m)	346	204

2.3 Bulb Turbine

(1) Introduction

The bulb turbine generating unit is the optimum unit for electric power generators at low head sites under large flow conditions. Owing to the cylindrical and linear arrangement of the casing and draft tube which comprise the water passage, the bulb turbine has the following advantages in comparison with the vertical shaft Kaplan turbine:

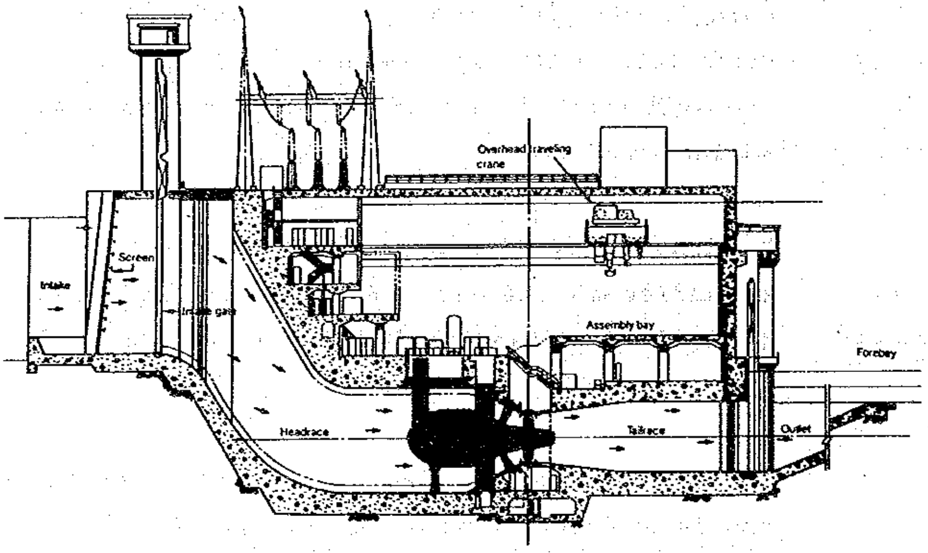
- Higher efficiency due to less head loss
- Smaller machine size due to higher unit speed
- Requires less excavation than elbow type draft tube and volute type casing

The EPPC's Tadami Project is typical under those circumstances and is applied advanced technology.

In order to pursue the features of low head and large capacity machines, careful feasibility studies were made between the Kaplan type unit and the bulb type unit in terms of the efficiency, size of the power house building, required excavations, maintainability and so on and finally the bulb type was selected making points for its less construction cost and more energy production.

The power station is partially underground as shown in Fig. 2.1.

Fig. 2.1 Sectional View of the Tadami Powerhouse



A 1,700 kW S-type tubular unit is installed side by side with the 65 MW bulb unit so that, at any time, the released water 8 m^3/s, to protect natural condition of the river, can be discharged bypassing the bulb unit.

(2) Features and Construction

Table 2.1 lists the specifications of bulb turbine and S-type tubular turbine.

Table 2.1 Specifications of Turbine and Generator Units

Type Bulb Turbine	Bulb Turbine	S-type Tubular Turbine
No. of units	1	1
Capacity (M/W)	65.8	1.75
Head (m)	20.7	24.2
Speed (rev/min)	100	600
Specific speed (m-kW)	614	468
Submergence (horizontal) center of rotating parts (m)	-8.5	-3.45

Type Generator	Bulb Turbine	S-type Tubular Turbine
Capacity (MVA)	67.2	1.7
Voltage (kV)	11	6.6
Frequency (Hz)	50	50
No. of poles	60	10
Speed (rev/min)	100	600
Power factor	0.95	0.98

Features of the Tadami bulb unit are described below.

(a) Runner and Wicket Gate

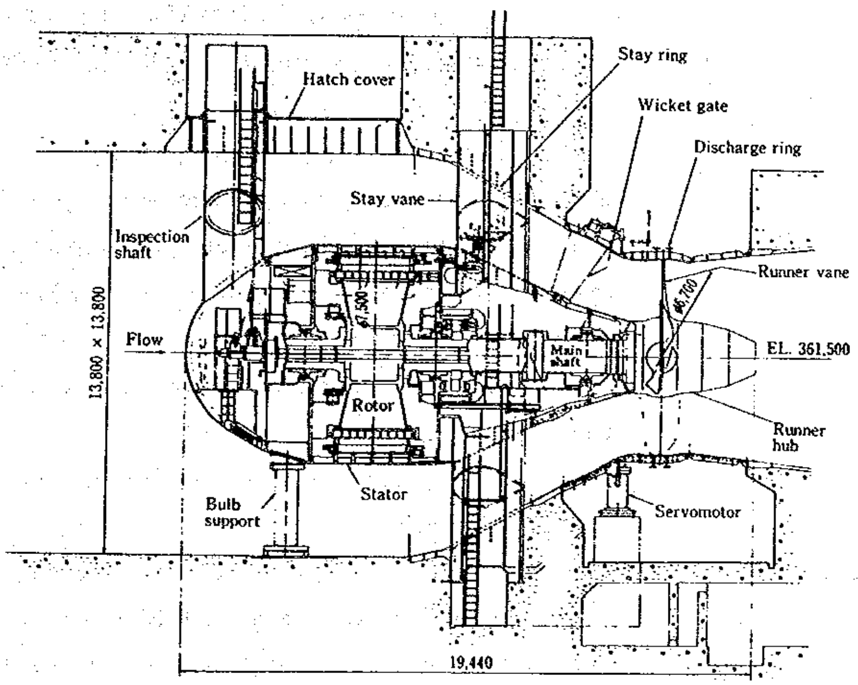
A five-blade runner was used, in view of the rather high head of 20.7 m, and a high nickel content 13-chromium stainless steel casting was used to assure high fatigue strength in water and good weldability.

Twenty wicket gates, made of 13 chromium stainless steel casting, were conically arranged and supported by cylindrical stem bearings.

(b) Bulb Supporting System

This system has six stay vanes, two horizontal supports and a bulb support, which support the various loads; hydraulic thrust, bulb weight, buoyancy, generator driving torque, generator thermal load, seismic force, fluctuating hydraulic force and seasonal thermal load. The above loads are all carried to the surrounding concrete by the stay vanes and the support.

Fig. 2.2 Cross Section of the Bulb Unit



Therefore, their reliability is very important. The fishtail shape six stay vanes are hollow. These stay vanes are spaced at equal pitch around the bulb body to reduce the share load on the surrounding concrete.

The large top and bottom stay vanes are hollow for maintenance access and to accommodate generator leads and piping. A bulb support is at the bottom of the generator and two horizontal supports are on each side of the generator. The stiffness of these supports, with longer pipes and fixed ends, is selected so that the bending stress caused by forced displacement cannot increase. These longer pipe supports do not need a large concrete pier and spherical bushings at each end. Therefore, maintenance is easier and less concrete work is required, and hydraulic head loss at the large concrete pier is reduced. The two horizontal supports must each be preloaded using pre-set hydraulic rams, so that at any time, the support can maintain the minimum required compressive load.

The stay vanes and supporting structures are designed to be rigid enough to withstand the various loads, to assure smooth operation without excessive deformation, to withstand frictional force at each bearing and vibration, and to be safe enough to withstand low and high cyclic loads.

(c) Bearing System

Three guide bearings are provided in view of the machine's large size and capacity and these bearings are forcibly lubricated by a gravity head from an upper oil tank. The Thrust bearing is close to the stay vanes so that it can be supported rigidly. The thrust load is thereby transmitted directly from the stay vanes to the concrete foundation.

For the thrust bearing, a Hitachi pivot-spring type thrust bearing is used. This bearing has both the advantages of good oil film formation and good load balancing through the pivot spring operation. This bearing structure minimizes thermal distortion through the use of double-layer thrust bearing pads.

(d) Cooling Method for Generator

The bulb generator must be designed to have adequate ventilation for cooling in the closed and limited diameter of the bulb casing. Also, the design of the ventilation channels must be simple so that the generator can be easily maintained. For the Tadami bulb generator and efficient cooling effect was achieved by improving the construction of the stator frame. A non-pressurized cooling method was adopted.

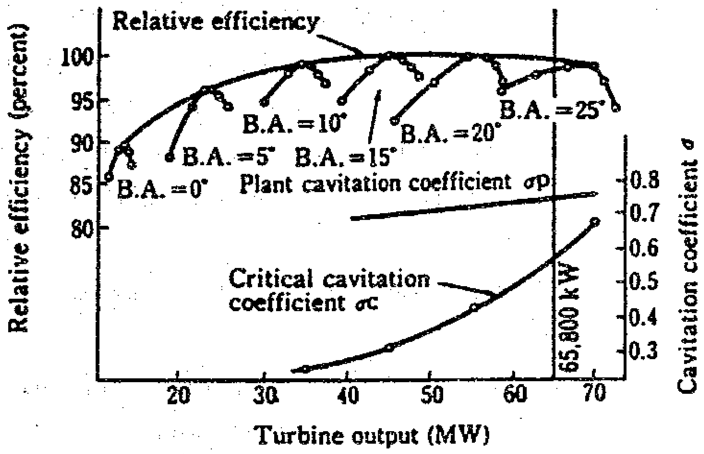
(3) Special Model Tests

(a) Hydraulic Performance Model

The water passage and the stay ring were optimized to have a accelerated at their outlet. The runner blades were developed using F.E.M. flow analyses.

A flat, high efficiency, over the entire output range was achieved, as shown in Fig. 2.3.

Fig. 2.3 Characterics of the Turbine



(b) Cavitation characteristics

The relationship between the critical cavitation coefficient and the plant cavitation coefficient is shown in Fig. 2.7, where the cavitation margin at the maximum turbine output of 65.8 MW is approximately 25 percent. Runner vanes were developed, which assured a no-bubble condition over the entire operating range.

(c) Scale Model of the Stay Ring

To assure reliability in construction before manufacturing the prototype machine, a 1/8 scale model was built, comprised the stay vanes, the surrounding concrete, a bulb support, two horizontal supports, and the rotating parts of the turbine and generator. Model tests were tested int he laboratory using a 1,200 ton capacity testing machine and a 20 ton vibration testing stand.

(4) Manufacture and Installation

(a) Stay Ring

The stay ring was divided into 12 pieces for easier transportation. The pieces were connected at the site using coupling bolts and seal welding. This coupling method is considered a good way to reduce the large amount of deformation caused by welding heat.

(b) Shop Assembly of the Bulb Turbine

Shop assembly was performed, including the turbine rotating such parts as runner, shaft, etc. All clearances, gate opening, deformation of the shaft and major components, load acting on the turbine bearing, operation of the runner blades, etc., were tested and compared with the design values.

(c) Shop Assembly of the Bulb Generator

The generator was fully assembled and rotating tests were performed in the shop. Guaranteed performance was confirmed at a satisfactory value. All clearances, deformation, stress and temperature rise of major components were measured and compared with the design values.

(d) Site Installation

Most of the construction of the Tadami powerstation has been completed. Installation of the turbine embedded parts (stay ring, hatch cover, draft tube liner, etc.) have already been finished. To get a highly reliable stay ring, which is the most important part of the bulb generating unit, an adjustable spider bracing was used during installation to maintain the accuracy of the machined face. A deformation of 0.3-0.8 mm per 10.2 m diameter was less than the allowable deformation 1.5 mm. The runner, generator rotor and other main part were installed successfully.

Project Feature of Tadami Project

MAIN STRUCTRUES	Main Dam	Sub Dam
Dam		
Type	Rockfill with center impervious core	Rockfill with center impervious core
Height	29.0 m	19.0 m
Crest Length	354.0 m	154.5 m
Crest Width	10.0 m	10.0 m
Volume	310,000 m^3	90,000 m^3
Slope Gradient		
Upstream	1 : 2.8	1 : 2.8
Downstream	1 : 2.2	1 : 2.2
Spillway		
Type	Controlled	
Dimension	Width : 14.0 m	
Discharge Capacity	6,000 m^3/s	
Number of Gate	Roller Gate x 3 Width : 14.0 m Height : 17.0 m	
Outlet Works		
Type	Controlled	
Dimension	Conduit pipe ϕ1,100 - ϕ600 Length : 21.5 m	
Discharge Capacity	2.5 m^3/s	
Power Intake		
Type	Reinforced concrete	
Dimension	Height : 24.0 m Width : 20.5 m	
Power House		
Type	Semi-Underground	
Dimension	Width : 20.5 m Height : 43.0 m Length : 74.0 m	
Tailrace		
Type	Open	
Dimension	Width : 45.0 m - 87.2 m Length : 2,200.0 m	

MAIN STRUCTRUES	Main Dam	Sub Dam
MAIN MACHINARY		
	Main Turbine	Sub Turbine
Turbine		
Type	Bulb turbine	S-type tubular turbine
Output	65,800 kW	1,750 kW
Number	1	1
Generator		
Type	Three phase AC synchronous generator, horizontal shaft	Three phase AC synchronous generator, horizontal shaft
Capacity	67,200 kVA	1,750 kVA
Number	1	1

Fig. 2.4 PLAN OF DAM

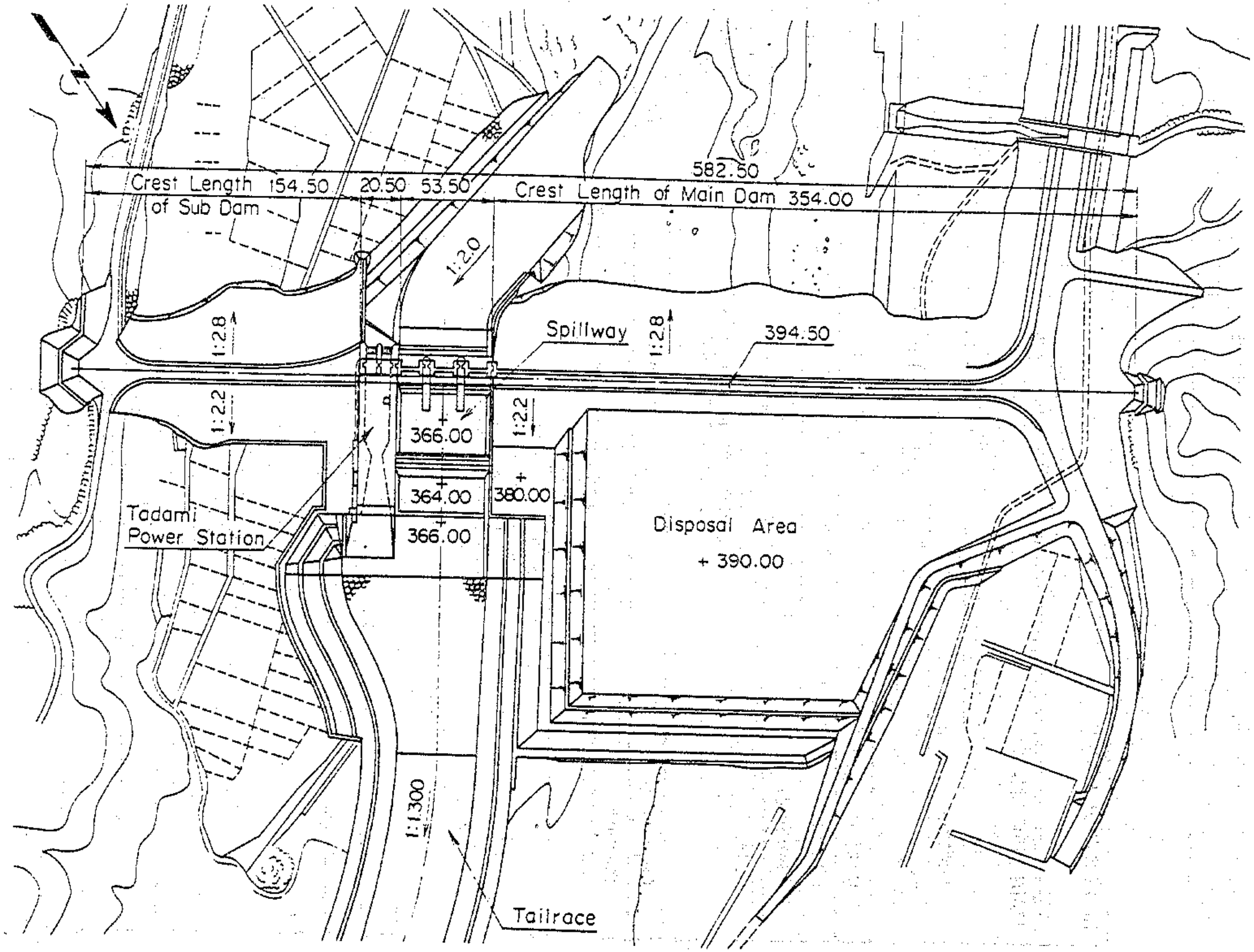
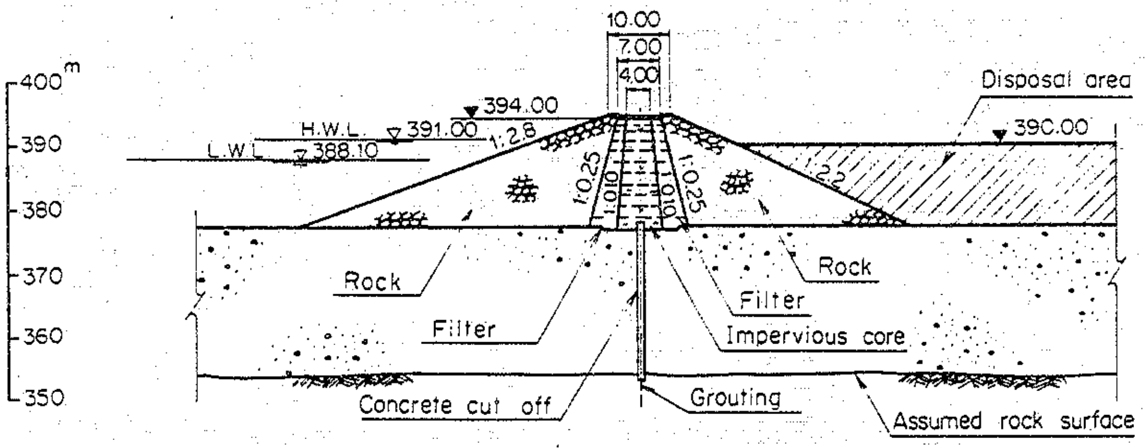


Fig. 2.5 TYPICAL SECTION OF DAM

CONCRETE CUT OFF SECTION



GENERAL SECTION

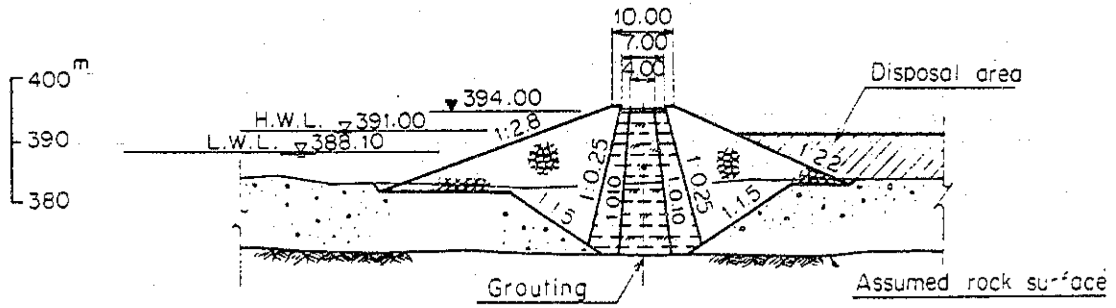
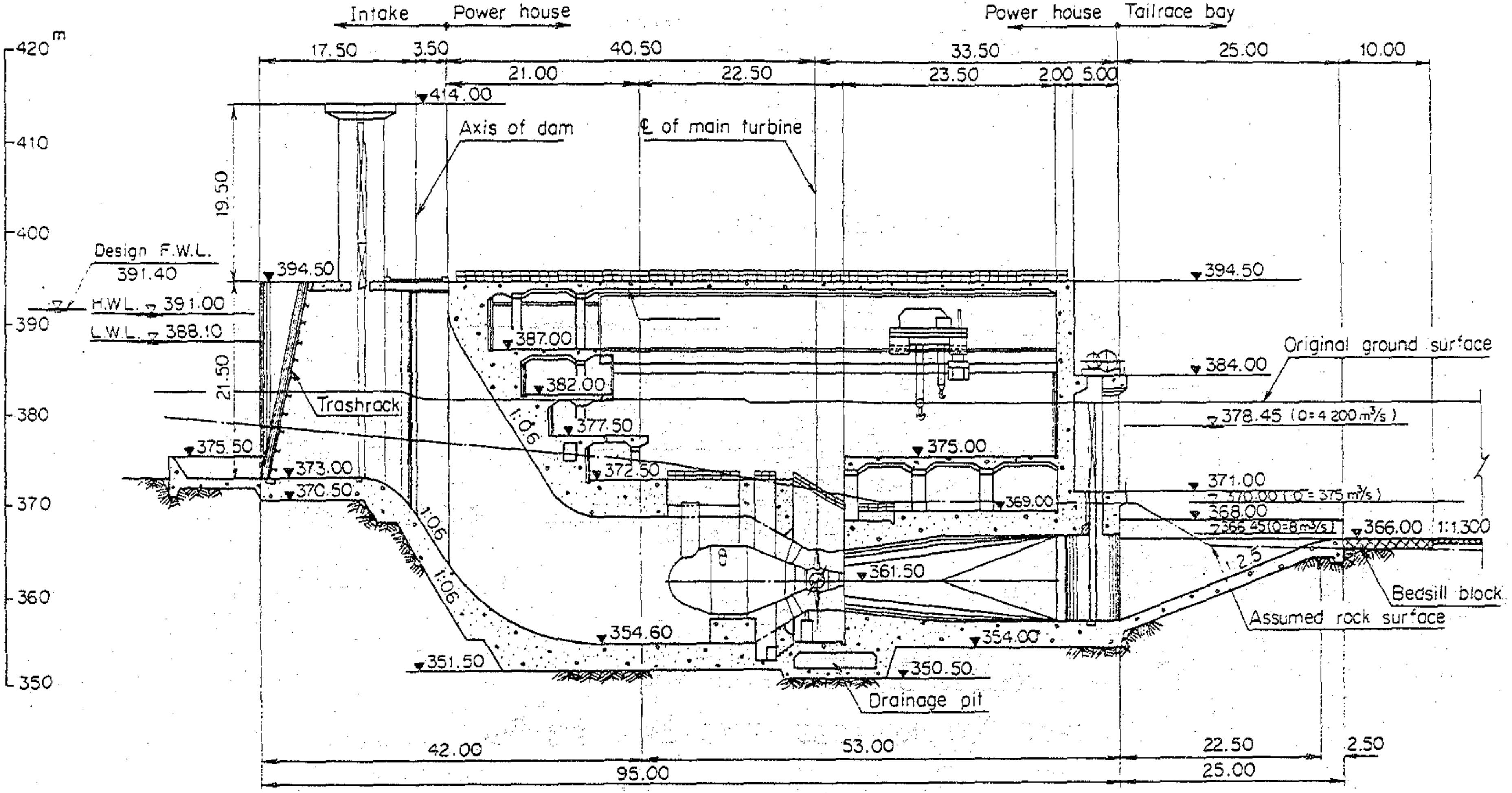


Fig. 2.6 PROFILE OF POWER HOUSE



3.1 Outline of the Project

This project is a small scale run-of-river hydroelectric power project, comprises a 4,200 m pressurized headrace tunnel and a 8,100 kW powerhouse, and generates 39 GWh annually. A L-shaped profile tunnel layout was adopted to prevent a long penstock and distruction of environment.

The project intends to use a tunnel boring machine (TBM) in the construction work of a tunnel. An adoption of a L-shaped profile tunnel makes omission of a head tank and a spillway possible.

3.2 TMB Method

The TBM methods are adopted for the project construction sites for the following reasons:

(1) The progress of the overall construction work in each scheme depends almost entirely on the progress of the tunnel work. By adopting a TBM, the rate of the tunnel work can be stepped up, thus securing an early start to the commercial operation of the power stations while at the same time providing the economic advantage of generating incomes through the production of electric power that much earlier.

(2) The tunnel length is 4,200 m. Tunnels of such a length can be excavated by the TBM method at lower costs than by the conventional method.

(3) The geology of the tunnel at each construction site is estimated to consist of a homogeneous granitic rock in the deeper layer, whereas the surface layer is weathered. In this case the TBM method is suitable.

(4) All the tunnels can be excavated starting from the power station side. It is easy to transport construction machinery to any of the power stations through the well-maintained roads of access to the said powerhouses provided that parts of these access roads are improved. In the powerhouse area exists flat land providing a suitable assembly yard for a TBM.

(5) The TBM method is a method desirable from the viewpoint of environmental aspect because its unidirectional work does not require any intermediate work adits, construction roads and disposal areas. It can be executed without destroying the forest above the tunnel section.

3.3 Construction Work of Shafts by Raise Borer

(1) A vertical shaft is intended to be excavated with a raise borer. The use of the raise borer makes it possible to execute the construction work of a shaft safely and in a short period of time.

(2) A raise borer is generally composed of the main body (drill unit, control unit, valve unit, power unit, switch unit) and tools (drill rod, pilot bit, reaming bit, etc.), and in a broader sense comprises also water and air supply equipment.

(3) The excavation of a shaft will be executed after completion of the excavation of horizontal tunnel by installing the main body aboveground and executing pilot drilling downward from the top

using a pilot bit with a small diameter of 250 to 300 mm, until the pilot bit reaches the horizontal tunnel where a switch-over to a reaming bit takes place to start reaming upward from the bottom.

(4) The rate of excavation by a raise borer depends on the characteristics of the bedrock in question. The Project at hand has been planned with the following rates of excavation in mind based on the records of similar works:

Pilot drilling	10 m/day
Reaming	8 m/day

These standards are provisional and therefore must be reviewed after conducting a detailed geological investigation at the definite design phase.

Project Feature of A-Project

Items	Unit	Sempam
Planning Dimensions		
1. Catchment Area	km^2	78.0
Main (Inter basin)	km^2	78.0
2. Annual Mean Inflow	10^6m3 (m^3/s-day)	82.2 (951.3)
3. Maximum Discharge	m^3/s	4.5
4. Firm Discharge	m^3/s	1.2
5. Intake Water Level	E.L. m	440.5
6. Turbine Center	E.L. m	216.0
7. Gross Head	m	224.5
8. Effective Head	m	217.5
9. Installed Capacity	kW	8,100
10. Dependable Capacity	kW	2,200
11. Annual energy	10^3kWh	39,270
Facilities		
1. Diversion Dam		
Type		Concrete
Dimensions	Hm x Lm	7.50 x 51.50 7,630
Concrete Volume	m^3	
2. Waterway		
Type	P. or Non-P	Pressure
Vertical Shaft	L x D	125.5 x 1.75
Horizontal	L x D	4,200 x 2.80
Penstock	L x D	200 x 1.15 - 0.85
Tailrace	L x D	T. Culvert 71
3. Powerhouse		
Type		Surface
Turbine		V.Pelton, 4N
Outer Sizes	m x m	19.3 x 20.5
Concrete	m^3	1,790

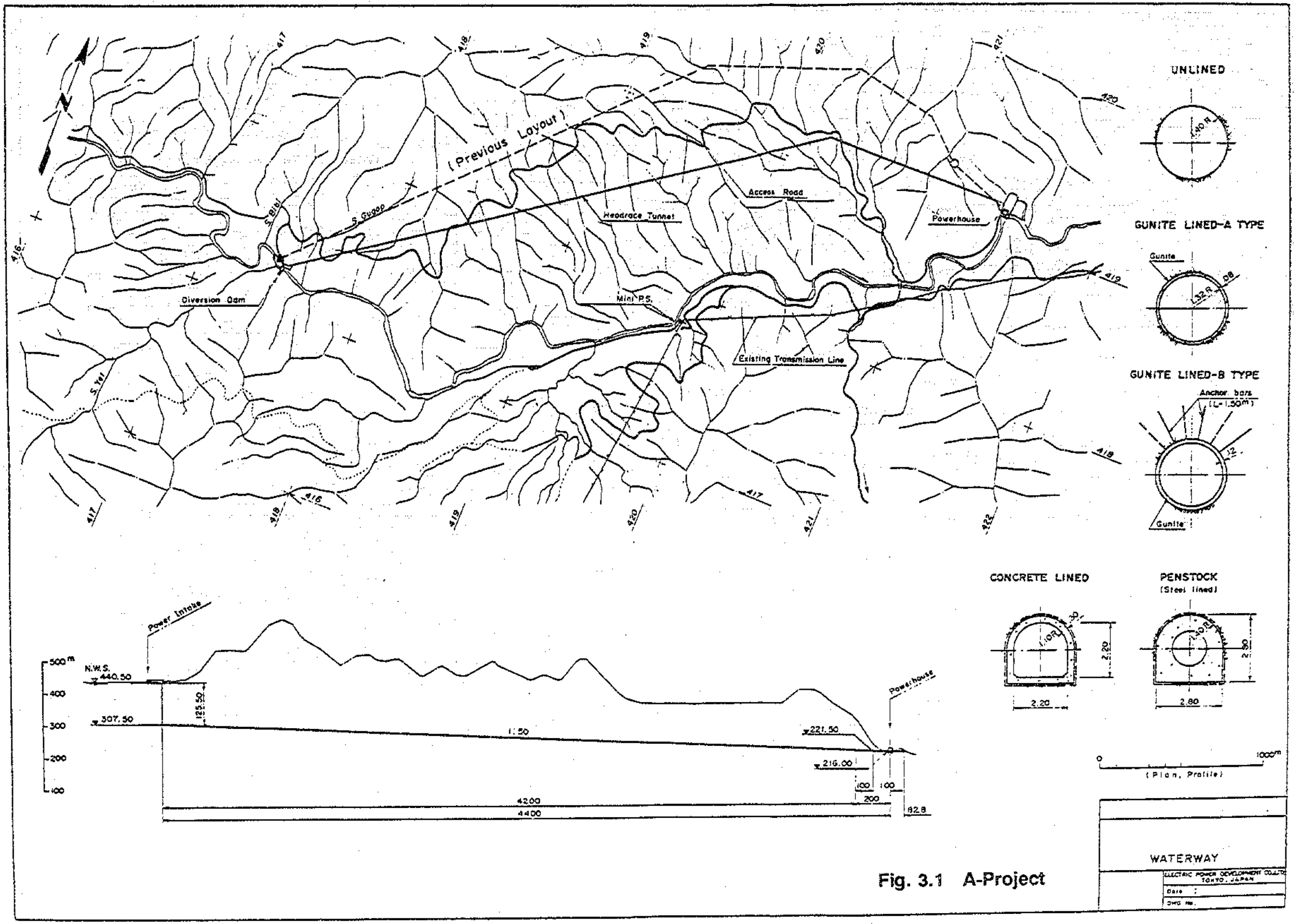


Fig. 3.1 A-Project

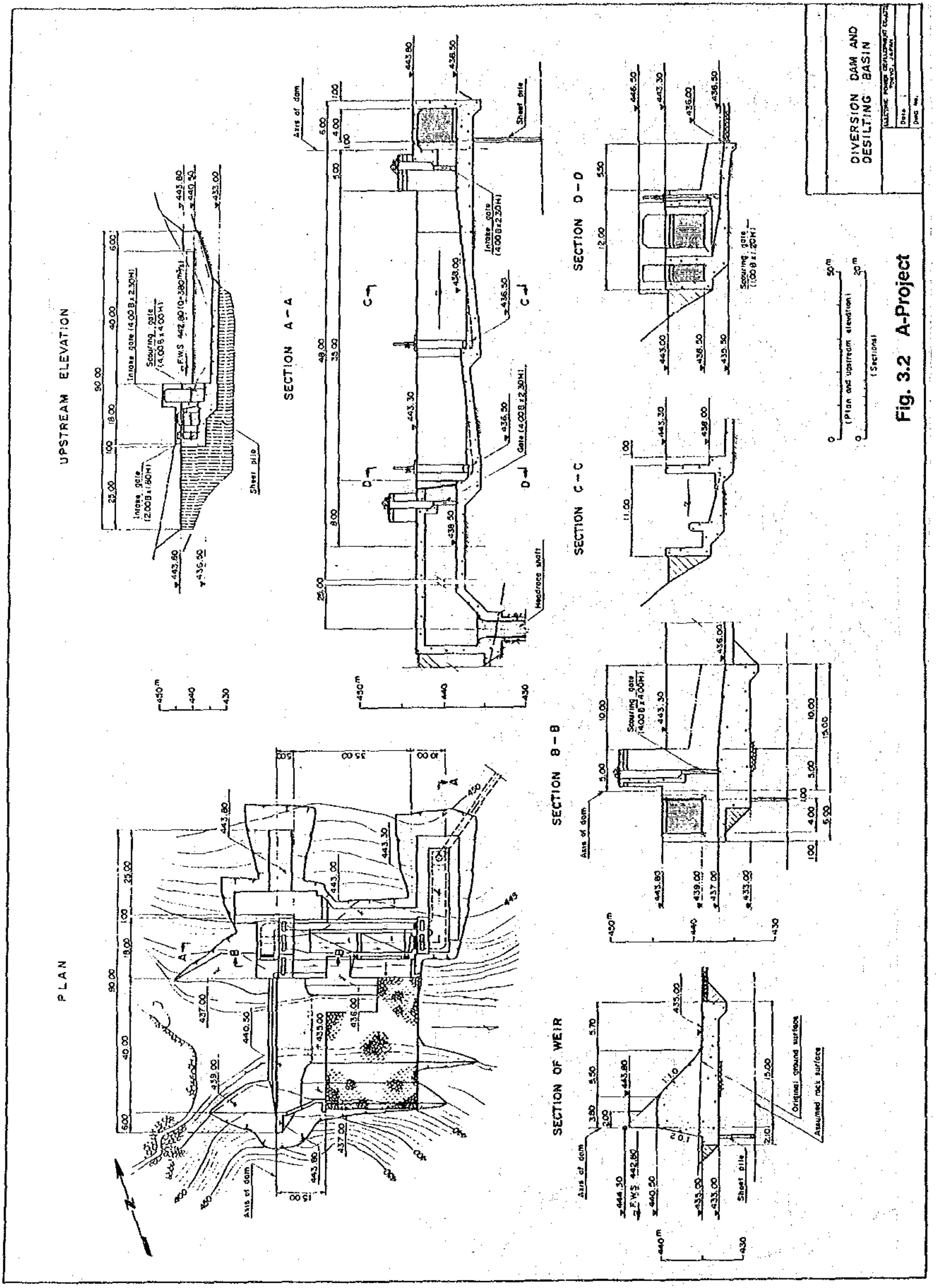


Fig. 3.2 A-Project

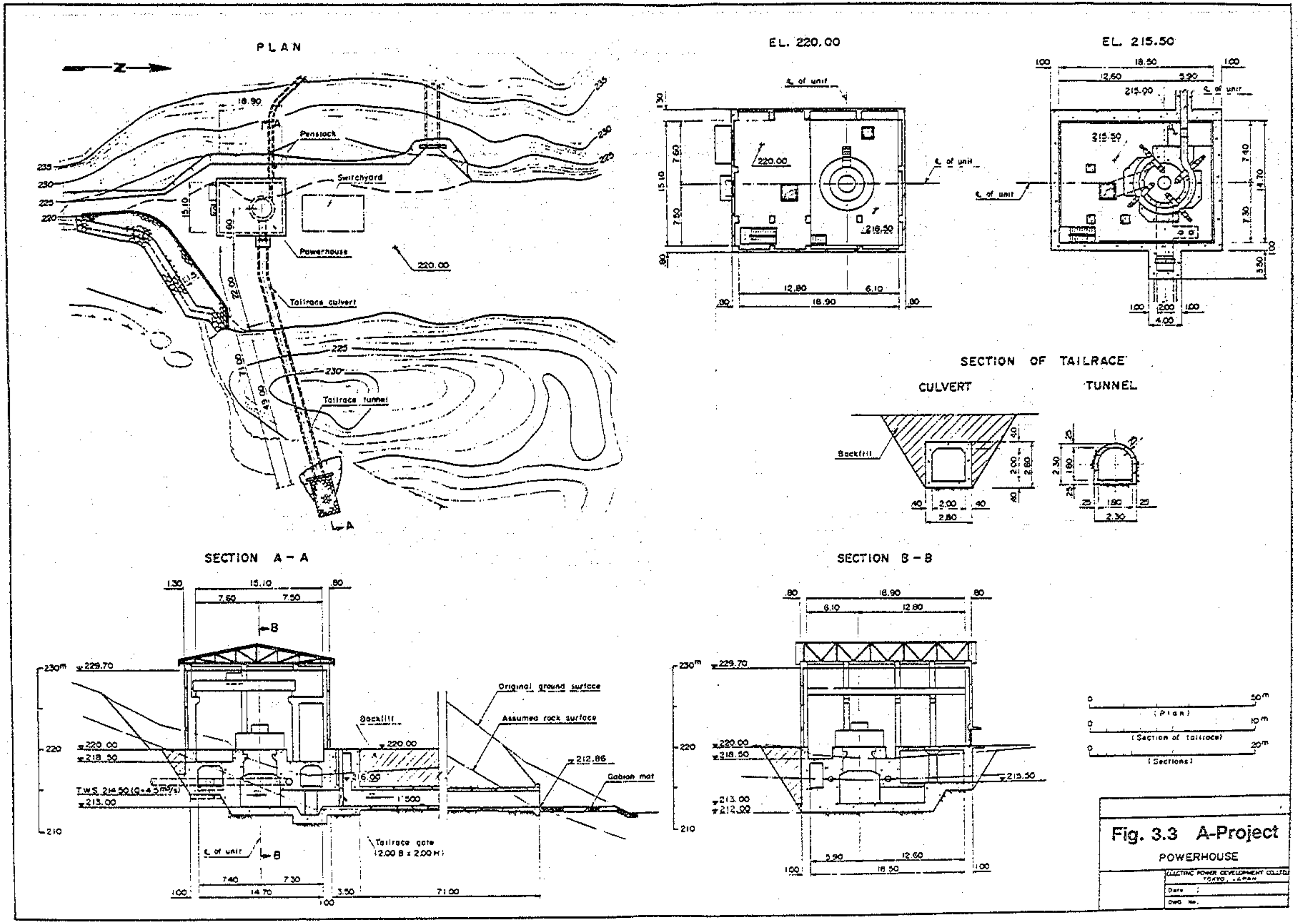
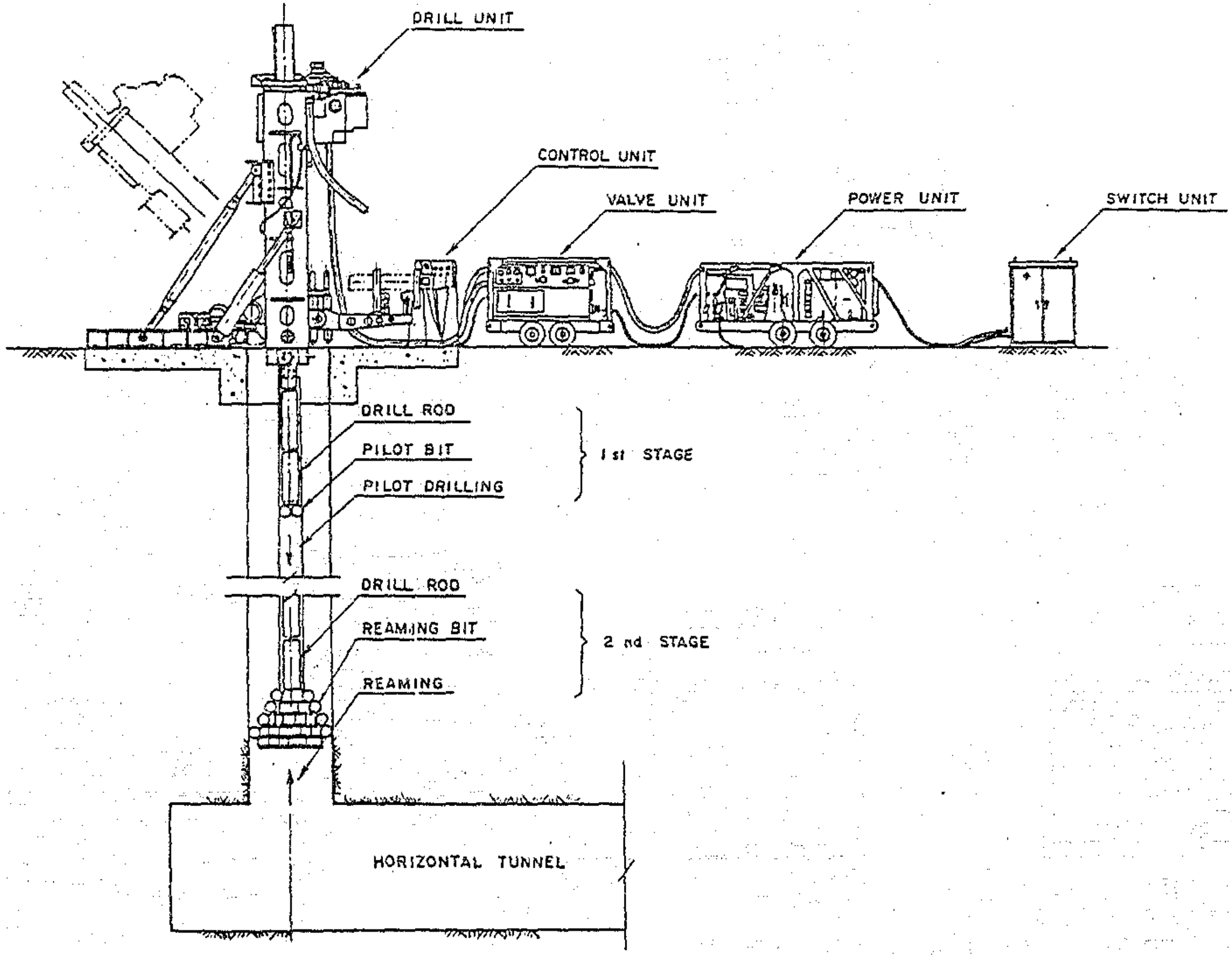


Fig. 3.3 A-Project

POWERHOUSE

Fig. 3.4 RAISE BORER SYSTEM



4.1 Outline of the Project

This project is a small scale run-of-river hydroelectric power project to supply energy in isolated remort area. The project consists of an intake dam 8.6 m in height, a 342 m pressurized headrace tunnel, two penstocks in 337 m and 290 m in length and a 6,000 kW powerhouse, and generates 40 GWh annually.

Because a headrace tunnel was very short, a settling basin is designed to have a function of a head tank, and a head tank and a spillway could be eliminated. The fiber reinforced plastic (FRP) pipes are used as penstocks and some parts of penstocks are buried underground.

4.2 Omission of Head Tank or Surge Tank

Generally speaking, a surge tank is installed on a pressurized headrace when the headrace is long and very large water hammering can occur, in order to absorb the surge effect and protect the tunnel

In the case of this project, the length of headrace channel is 417.89 m, and the length of penstock is 311.788 m, and the total length of 731.678 m is a relatively short headrace channel. The surge tank may be omitted when the water channel is short. In addition, as Pelton turbines are used in this case, the magnitude of water hammering is small.

A Pelton turbine has the needle which controls the spouting water (jet steam) that impact the runner, and the deflector to control the direction of the water jet that impacts the runner, and the outstanding feature of this type of turbine is that it can control or shut off the force of water that acts on the runner without changing the water flow that enters the powerhouse. That is, the rate of flow entering the powerhouse can be adjusted by the needle, and the water that acts on the runner can be adjusted or shut-off by the deflector. Therefore, when the turbine-generator has to be stopped urgently due to mechanical or electrical fault on the powerhouse equipment electrical fault on the transmission line, the power generation unit can be shut down without abruptly changing the rate of inflow to the powerhouse. This is an advantage because the rise of water pressure due to shutting off of water flow can be suppressed to a low value.

Generally speaking, the needle is operated from the full open position to the full close position in 30 to 60 seconds, and the deflector can be fully closed from full open position within 1 to 4 seconds.

As discussed above, there is no serious problem concerning the pressure rise in pressure tunnel and penstock because the Pelton turbine is adopted. Therefore, it has been decided for this Project not to install a surge tank at the end of the headrace tunnel in order to reduce the total construction cost.

4.3 Adoption of FRP Pipe

It was decided to mainly use the FRP pipe, which is being remarked recently as a new material replacing the conventional steel pipe, with the objective of reducing the construction cost and construction period. However, steel pipes will be used for the sections which are buried into concrete and for branches and curved sections.

The FRP pipe has the following features.

(1) FRP pipes having design pressure of up to 250 m can be manufactured.

(2) The standard of FRP pipe Association is applied to the fiber reinforced plastic pipes, and structurally stable products can be obtained.

(3) In comparison to general grade steel pipes, the total cost is low, and the workability is superior as FRP pipes are light weighted. They have many advantages, i.e., good performance in connecting to pipes of other types, capability to stand outside pressure at low cost, superior erosion resistance, superior hydraulic characteristics, and the lack of need of painting.

(4) At present, there are many examples of applications in construction work. EPDC has selected FRP pipes for the penstock (2.4 m in diameter, 338.14 m long, with maximum static water pressure of 177.0 m) for Okinawa Sea Water Pumped Storage Power Plant (30 MW) which is under construction.

4.4 Continuous Foundation for Penstock

The methods of supporting FRP penstock can be broadly divided into the saddle support type foundation and the continuous foundation. In the former case, the pipe is supported at both ends, at intermediate 2 points, 3 points, 4 points, etc.

With the continuous support method, the bending force in the direction of the pipe axis and the shear become zero, and the stress generated are only the bending force in the circumferential direction, tensile strength caused by internal pressure, and the stress in the direction of pipe axis. As the total stress is reduced, the pipe was thickness can be reduced.

In this design, the curved section is fixed by anchor blocks, and other straight sections are supported by continuous concrete foundation. The

FRP pipe used has 6.0 m unit length, and the joint is an inserting type T-joint. Therefore, the load is distributed to each pipe unit, and the load does not transmit continuously as in the case of steel pipe. This makes it possible to save the volume of anchor block concrete. In addition, as the pedestal type saddle support is eliminated to choose the continuous foundation, the pedestal form having complicated shape is not required, and the workability is improved. In particular, in the lower section of the penstock, where the slope is gentle (15° to 30°) and it is covered by talus which is ten plus several meters thick, the surface ground will be excavated for a depth of 3 to 4 meters to expose the stable natural ground, and continuous concrete foundation will be constructed (the bearing force of the foundation ground is estimated at approximately 18 t/m^2), thereby distributing the load of penstock.

This continuous concrete floor foundation are provided with expansion joints at locations of the joints of FRP pipes, so that even when a foundation of a unit pipe moves, the stress concentration will not be created in the pipe except for the pipe joint owing to this independent foundation blocks.

4.5 Adoption of Buried Type Penstock

The downstream section of the penstock will be placed on a gentle slope having a longitudinal gradient of 15° to 30°. According to boring surveys, this area is covered with talus cones which are ten plus several meters deep, and it is difficult to place anchor blocks on the bed rock. In addition, chasms created by surface water during rainy season cross the route of the penstock. Therefore, if the penstock is placed in an open cut channel with slope treatment, the rain chasms will be regenerated in a heavy rain, to erode the slope and bury the penstock with debris. For this reason, it has been decided to bury the penstock in this section. At the same time, drain channels will be provided on both sides of penstock to prevent ingress of surface water.

The burial of the penstock has the effect of preventing extension/contraction of FRP pipes due to temperature change of this region, and protecting the penstock from impact of fallen rock or gun bullet. Also, the forest fire in the vicinity will be prevented, and help people travel for hunting and fishing.

Project Feature of B-Project

Items	Unit	Sempam
Planning Dimensions		
1. Catchment Area	km^2	290
2. Annual Mean Inflow	10^{6}m^3 (m^3/s-day)	307.9 (3,564)
3. Firm Discharge	m^3/s	1.11
4. Intake Water Level	E.L. m	489.0
5. Turbine Center	E.L. m	306.7
6. Gross Head	m	161.5
7. Effective Head	m	158.0
8. Installed Capacity	kW	6,000
9. Dependable Capacity	kW	1,400
10. Annual energy	10^{3}kWh	40,299
Facilities		
1. Diversion Dam		
Type		Concrete
Dimensions	Hm x Lm	8.6 x 77.0
2. Waterway		
Type		Pressure
Headrace	L x D	342.3x2.0
Penstock	L x D	336.8x0.9~0.5 290.1x2.0~1.1
3. Powerhouse		
Type		Surface
Turbine		V.Pelton, 4N 1,000kWx2 2,000kWx2

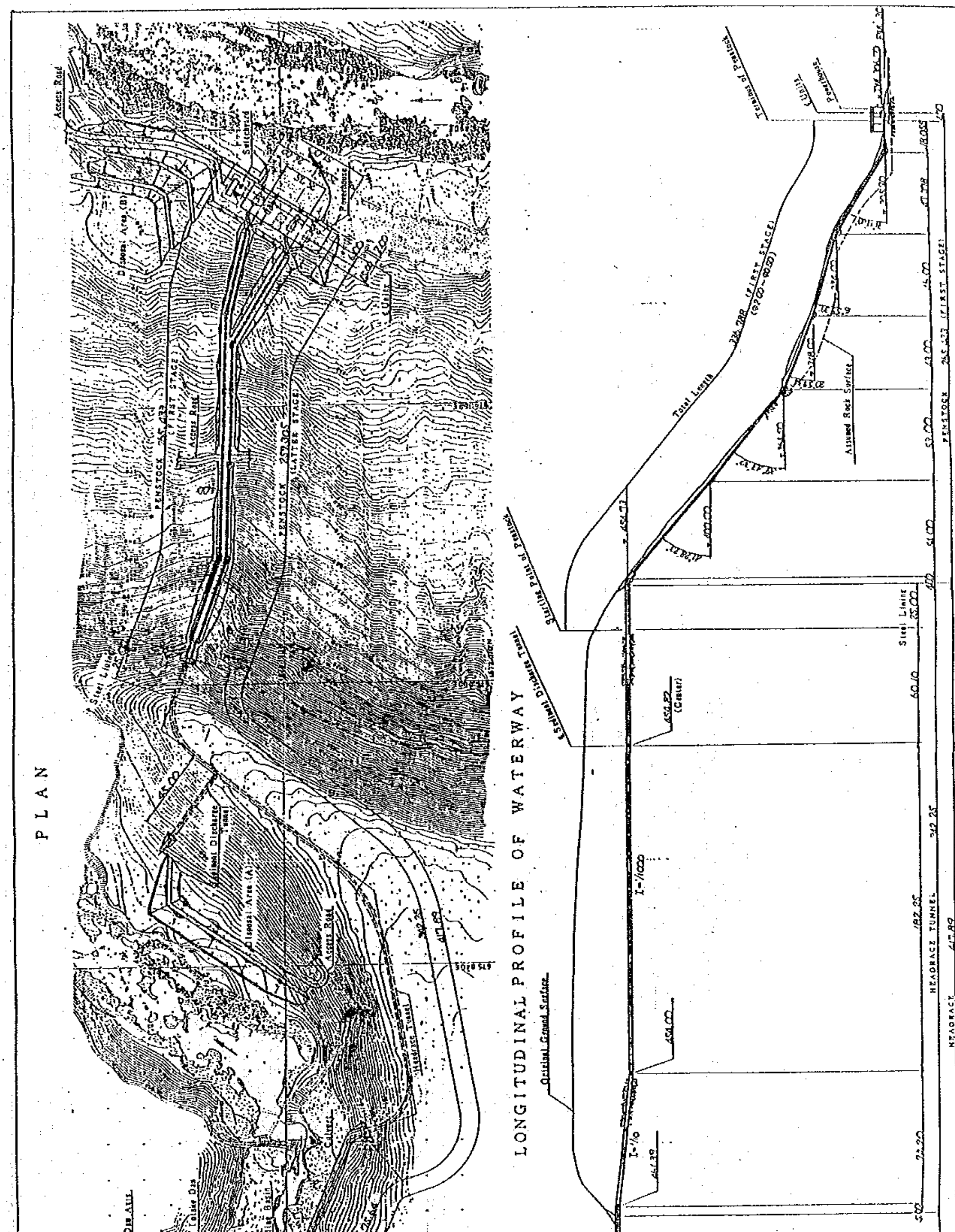


Fig. 4.1 B-Project

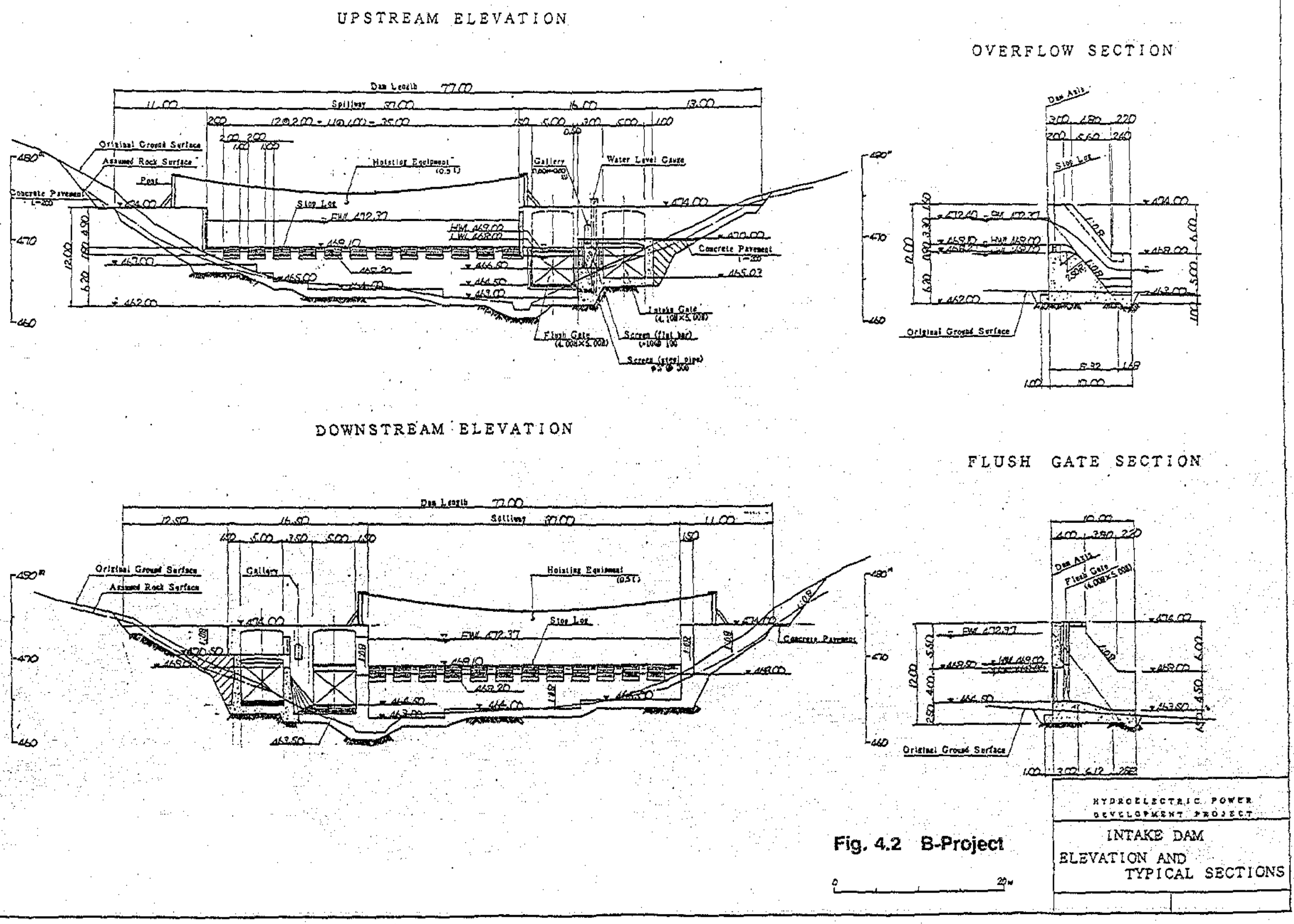


Fig. 4.2 B-Project

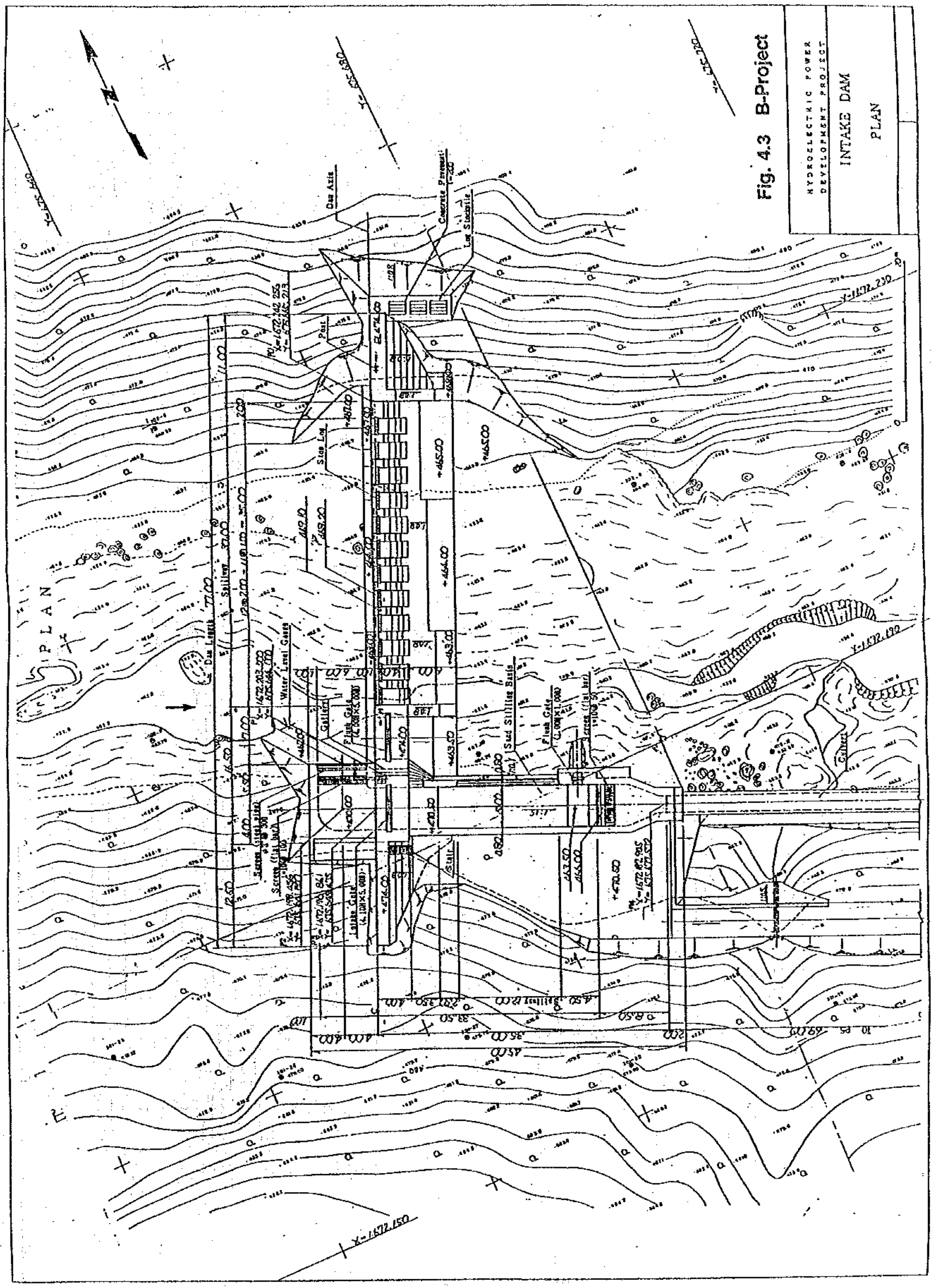


Fig. 4.3 B-Project

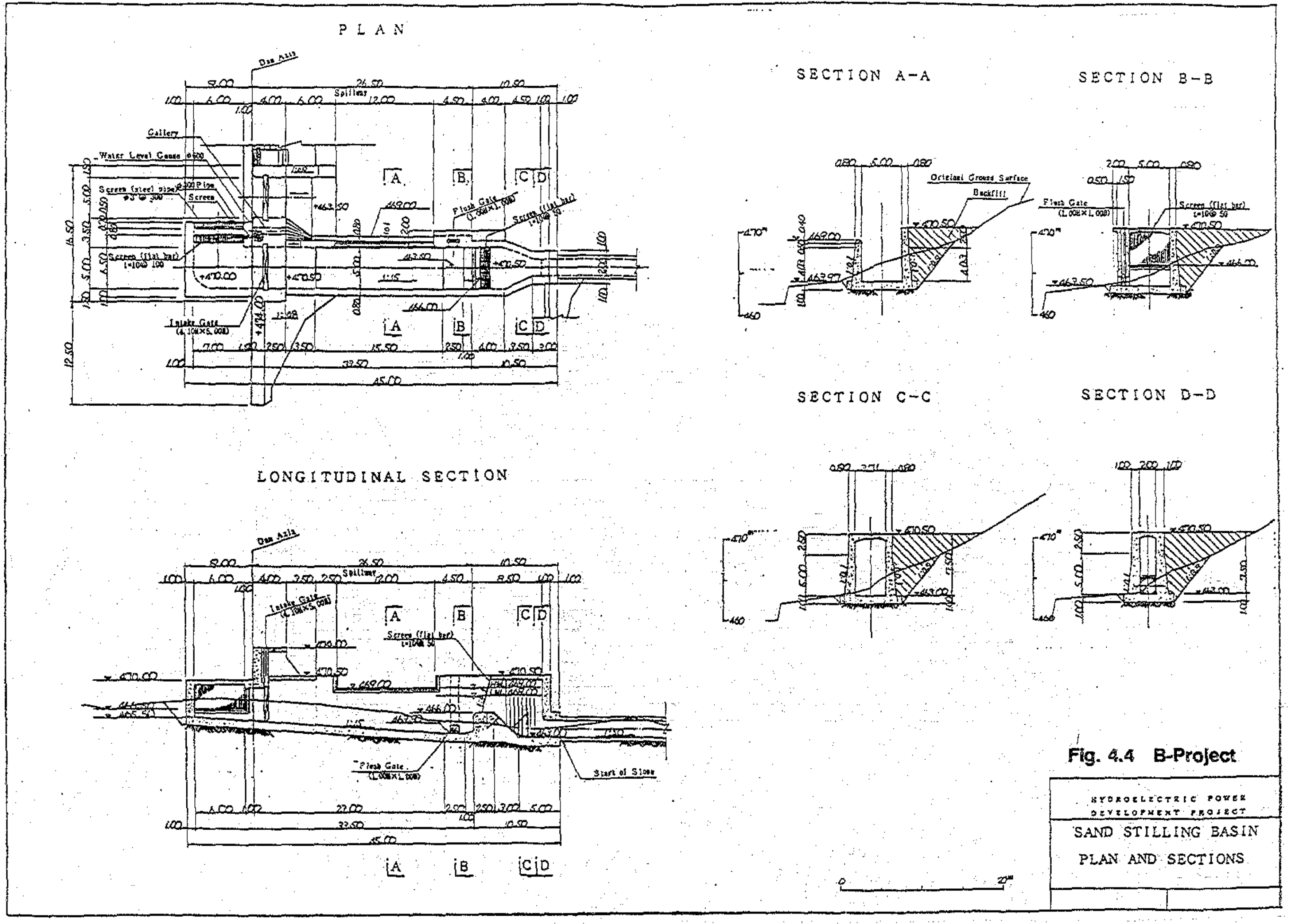


Fig. 4.4 B-Project

HYDROELECTRIC POWER DEVELOPMENT PROJECT

SAND STILLING BASIN
PLAN AND SECTIONS

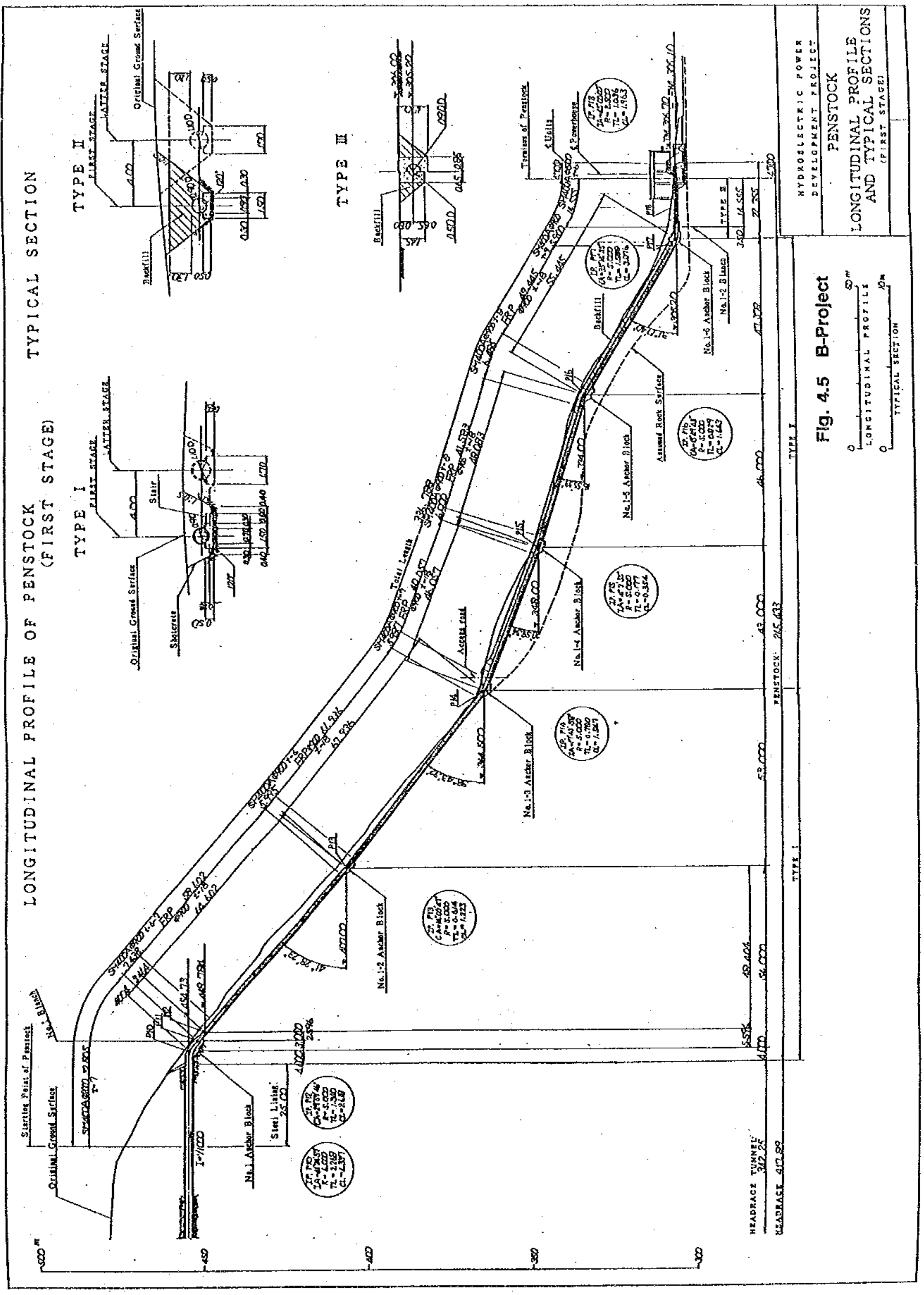


Fig. 4.5 B-Project

JICA