A proposal to realize sustainable development of large hydropower project

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Hydropower is one of desirable energy resources to reduce CO_2 emission and to realize low-carbon society. However, the development of hydropower projects occasionally causes serious environmental negative impacts. In order to develop hydropower projects sustainably without serious environmental negative impacts, it is important to find out sites with high effective head and good geological conditions as well as desirable environmental friendly conditions. It is required to develop and apply new technologies in order to conquer technical problems due to high water pressure. It is also essential to make various efforts to avoid serious environmental negative impacts.

Kannagawa Pumped Storage Power Project, one of hydropower projects with extremely high water head in Japan, is introduced as an environmental friendly hydropower project.

1. Introduction

The higher water head is, the more compact and the more environmental friendly hydropower facilities become. That is, in the case of hydropower projects with high water head, dam, waterway system and electro-mechanical equipments can be made smaller than those with lower water head, provided generation of the same electric power and energy.

In order to develop hydropower projects sustainably without causing serious environmental negative impacts, it is important to find out sites with high effective head and good geological conditions as well as desirable environmental friendly conditions.

It is necessary to develop and apply new technologies in order to conquer technical problems due to high water pressure. It is also essential to make various efforts to avoid serious environmental negative impacts. I would like to introduce environmental and social considerations and new technologies applied for dams, penstocks etc.

Kannagawa Pumped Storage Power Project (PSPP), one of hydropower projects with extremely high effective head in Japan, will be introduced as an environmental friendly hydropower project.

Kannagawa PSPP has been constructed since 1997 by the Tokyo Electric Power Company Inc. (TEPCO).

The project has the maximum output of 2,820MW (six 470MW units), the maximum plant discharge for generation of 510 m3/s and the effective head of 653m. TEPCO put Unit No.1 of the plant into operation in 2005.

The Unit capacity, which consists of a generator-motor with 525MVA and a pump-turbine with 482MW, is the largest in Japan.

2. Development history of hydropower projects after World War II

Reservoir type hydropower projects and regulating pond type hydropower projects had been developed actively from postwar rehabilitation period in 1945 through years of high economic growth of 1950s in order to meet high growth of electric power demand.

However, the general trend of power development shifted from hydropower projects to thermal power projects characterized by shorter construction period and lower power generation cost after the mid of 1950s.

Basically, thermal power projects are less economical as a power supplier at the peak times of power demand, and are characterized by operational disadvantages of less capability of ancillary services such as spinning reserve, non-spinning reserve, replacement reserve and regulation of frequency which are required for ensuring reliability of the power system.

In line with decrease in economical hydropower potential sites with rich river flow, large scale pumped storage power projects came to be developed, which are characterized by a very small river flow into regulating reservoirs after 1970s.

From the viewpoint of best fuel mix of power sources, unit construction cost per kilowatt of pumped storage power projects needs to be low as suitable for a peak supplier. In pursuit of economies of scale, water head and unit capacity of pumped storage power projects has been higher and larger year by year (Fig.2.1, Fig.2.2 and Fig.2.3).

At present, power generation system is composed of pumped storage power plants as a peak supplier, thermal power plants as a middle supplier and nuclear power plants as a base supplier.

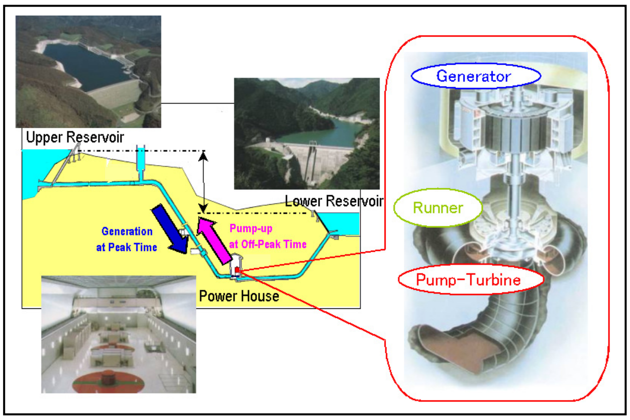

Fig.2.1 Function of Pumped Storage Power

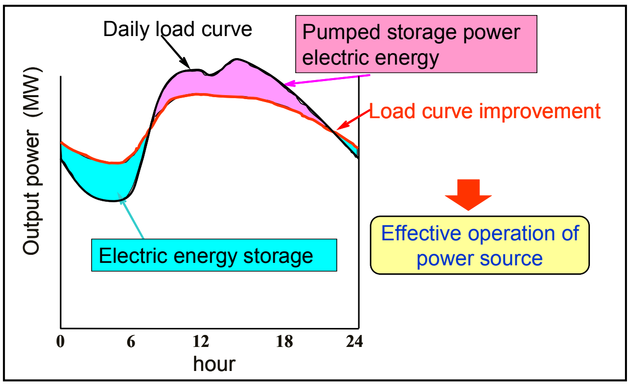

Fig.2.2 Shifting Peak Demand

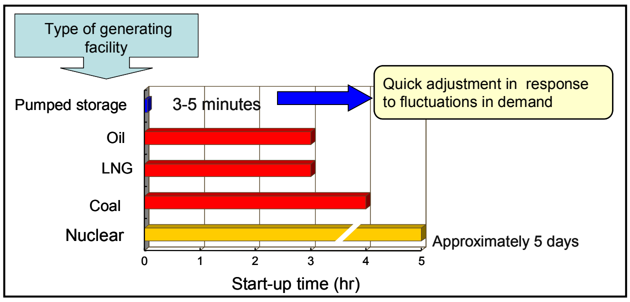

Fig.2.3 Start-up time after 8-hours shutdown

In the future, it is desired for power generation system to be composed of mainly nuclear power plants and hydropower plants including pumped storage power plants, because fossil fuel reserve will decrease or fossil fuel price will hike significantly.

3. History of technical development of penstocks

In terms of site selection of hydropower projects, it is important to select the most rational and economical scheme. One considerable point is to select smaller L/H. L means the length of waterway and H means the effective head. In general, the smaller L/H is, the more economical the project is.

Waterway is composed of intake, headrace, penstock, tailrace and outlet. Since penstock is made from steel pipe, penstock is more expensive than other waterway facilities. In the case of hydropower project with high water head, penstock is one of considerable facilities.

The development history of penstocks of hydropower projects in Japan is introduced as follows.

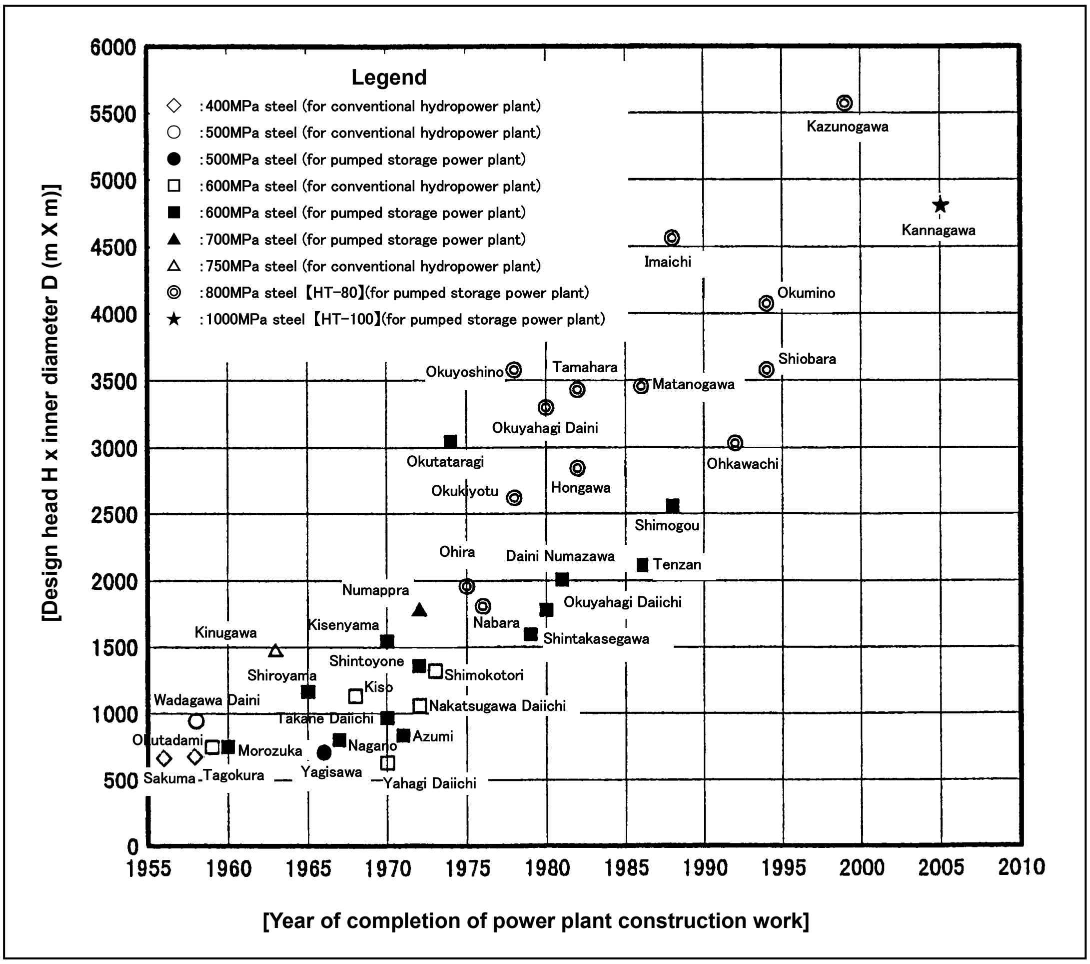

Fig. 3.1 Transitions scale of penstock

Transitions of the penstock scale in hydropower projects constructed after 1955 are shown in Fig.1.

The vertical axis of Fig.3.1 represents design head multiplies inner diameter as an indicator of penstock scale.

Significant efforts were made to develop large scale reservoir type hydropower projects and regulating pond type hydropower projects before 1960. And the steel plates used for penstocks had a tensile strength of 400-500MPa. After that, the tensile strength steels used for became 600MPa.

These high tensile strength steels were used in the projects of both the conventional hydropower and pumped storage power projects. HT-80 (a tensile strength of 800MPa) was firstly used for penstock in 1975. Since then, this high tensile strength steel has been used for penstocks of pumped storage power projects characterized by large scale and high water head.

Application of HT-100 (a tensile strength of 1,000MPa) was firstly attempted in Cleuson Dixence hydropower project in Switzerland.

Thickness of the applied steel plates has increased in line with advance of steel producing technology, welding technology and nondestructive test technology.

Under these circumstances, it was required to develop and apply new higher tensile strength steel of HT-100.

Kannagawa PSPP is introduced as an example of hydropower projects with high water head, applying HT-100 for a material of penstocks.

4. Case study by Kannagawa PSPP

4.1 Site selection and outline

The project comprises construction of an upper

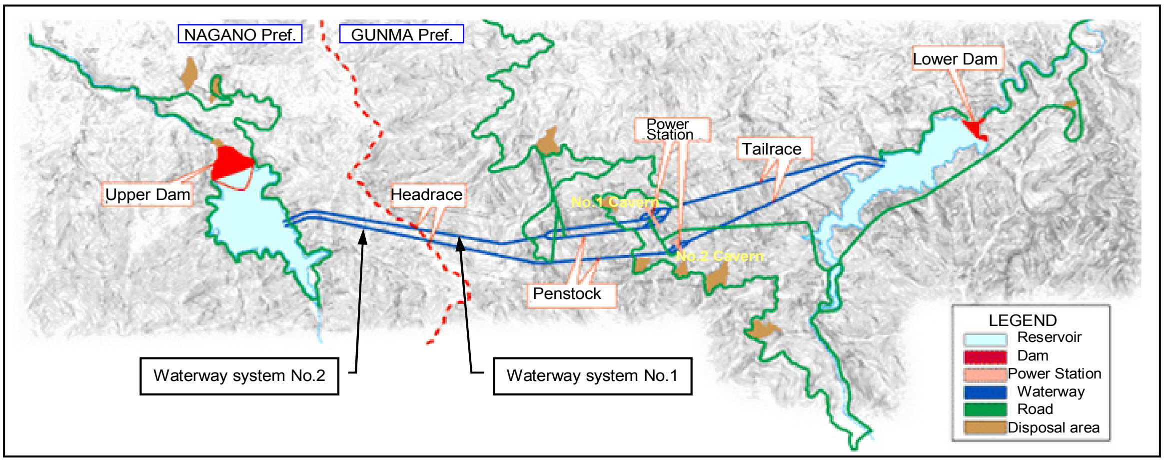

Fig.4.1 General Plan of the Project

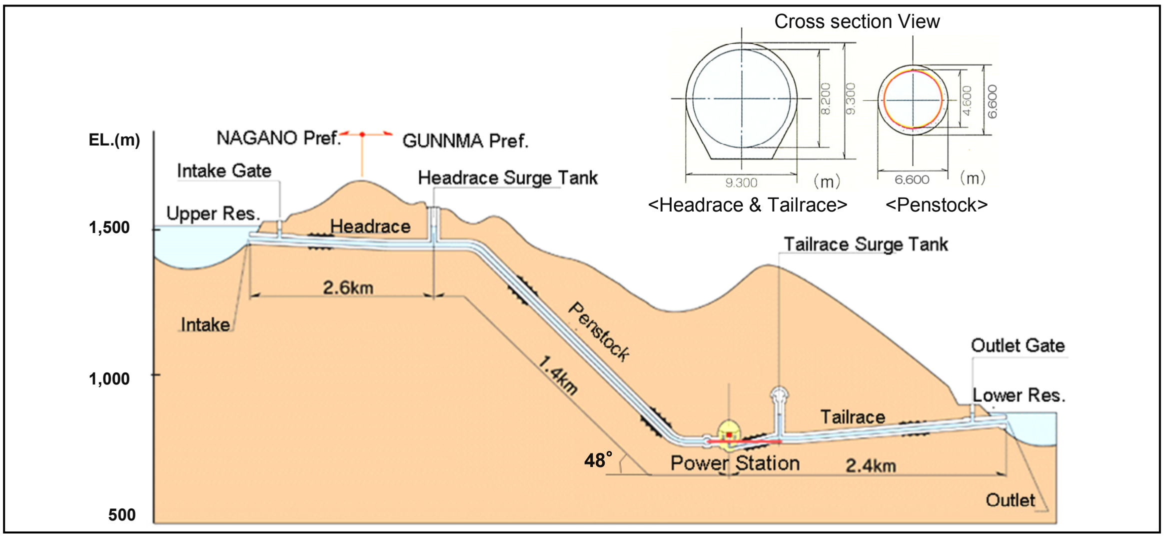

Fig.4.2 Profile of Waterway System No.1

dam at the most upstream area of the Shinano river system in Nagano Prefecture and a lower dam at the most upstream area of the Tone river system in Gunma Prefecture to construct upper and lower regulating reservoirs, which are connected with conduit tunnels of about 6 km in length as shown in Fig.4.1, Fig.4.2 and Table 4.1.

Most of the project area is not designated as a national park or a natural conservation area.

The construction site of lower dam and around half of the lower reservoir are located in privately owned woodlands, and the rest of the project site is located in the state owned land.

The value of L/H of the project is relatively small as 9.7.

Construction work started in 1997 and Unit No.1 commenced commercial operation in 2005.

Table 4.1 Power Plant Profile

	Upper Dam	Lower Dam
Name	Minamiaiki Dam	Ueno Dam
Type	Rock fill dam with center core	Concrete gravity dam
Name of River	Minamiaikigawa	Kannagawa
Catchment area	6.2 km^2	31.2 km^2
Reservoir area	0.59 km^2	0.56 km^2
Total storage capacity	19.17×10^6 m^3	18.40×10^6 m^3
Effective storage capacity	12.67×10^6 m^3	
Available drawdown	27 m	29.4 m
High-water level	EL. 1,527 m	EL. 843.4 m
Height	136 m	120 m
Crest length	444 m	350 m
Volume	$7,300\times10^3$ m^3	720×10^3 m^3

Installed capacity		2,820MW(470MW×6)
Discharge for generation		510 m^3/sec
Effective head		653 m
Waterway System No.1	Headrace	Length 2,445 m Inner diameter 8.2 m
	Penstock	Inner diameter 2.3 – 8.2 m Length No.1&No.2 1,398 m No.3&No.4 1,366 m
	Power House	Underground cavern Height 52 m Width 33 m Length 216 m
	Tailrace	Length 2,270 m Inner diameter 4.1－8.2m
	Pump Turbine	Vertical Francis type pump-turbine, 482MW×4
	Generator Motor	3-phase A.C. synchronous generator motor, 525MVA×4

The total output of the project will be the largest in Japan when fully completed. The generator-motor unit capacity and the pump-turbine unit capacity are also the largest in Japan.

4.2 Geology

The geology of the site consists of sedimentary rocks of Paleo-Mesozoic Era in which sand stone, chert, basic tuff, basalt, and limestone are mixed in matrix of mudstone as olistoliths.

The olistoliths are rock masses that was deposited in the Paleozoic and Mesozoic Eras before the Jurassic Period, when the matrix of mudstone was deposited and the olistostrome was formed.

The Paleo-Mesozoic Era layer in the site is one of the oldest strata in Japan (which was formed 200 to 300 million yeas ago) and is sound and hard.

4.3 Environmental and social considerations

Environmental assessment is a process by which a company surveys, forecasts and assesses the project that may have an impact on the surrounding environment. Environmental assessment has been conducted in Japan under Ministry of Economy, Trade and Industry (METI) and cabinet. The related laws require power companies to undertake certain arrangements before commencing construction works.

Although the area is not legally designated as a conservation area or a national park, some measures to conserve the environment have been taken during construction of the project.

4.3.1 Considering landscape

Development planners and designers should consider fully the environmental impacts by projects in the past, present and future.

Especially, landscape of the project must be a valuable asset for the local community. People of local community must be familiar with dams, reservoirs and a switchyard. Many cases were discussed eagerly about landscape with people of local community. Landscape planning is important, since landscape is local public goods (Fig.4.3, Fig.4.4). In Kannagawa PSPP, all surfaces of cut slope and deposit area above the water level was greened (Fig.4.5).

Fig.4.3 Landscape Planning (a)

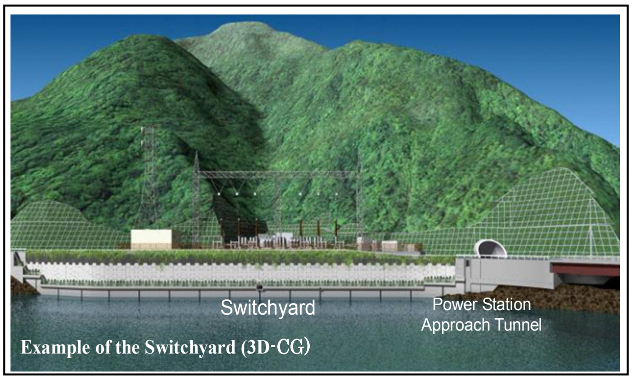

Fig.4.4 Landscape Planning (b)

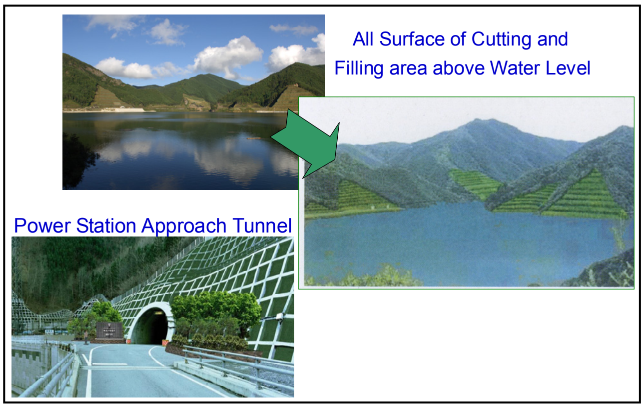

Fig.4.5 Greening

4.3.2 Minimizing alteration area of ground surface

It was possible to minimize construction area by selecting the project site with high effective head.

All facilities except for dams, reservoirs and a switchyard are laid out in the underground for environmental conservation (Fig.4.6).

Access roads were constructed by utilizing existing roads as much as possible or excavating tunnels in order to minimize alteration area of ground surface.

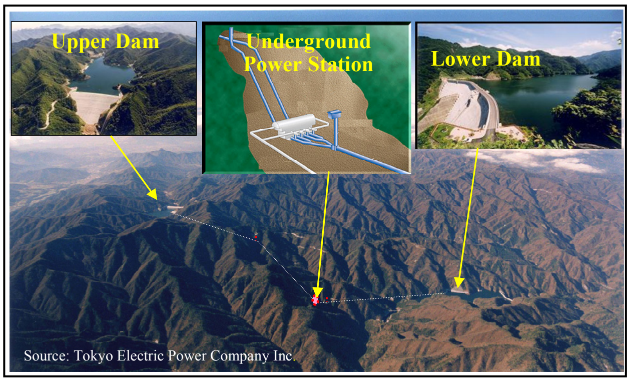

Fig.4.6 Setting in the underground except dams, reservoirs and switchyard

The upper dam was constructed by using rocks and soil materials excavated from the reservoir area in order to protect forests except core materials.

The lower dam was constructed by using sound rocks excavated from dam foundation, underground cavern and tunnels as aggregates for concrete in order to mitigate environmental negative impacts (Fig.4.7).

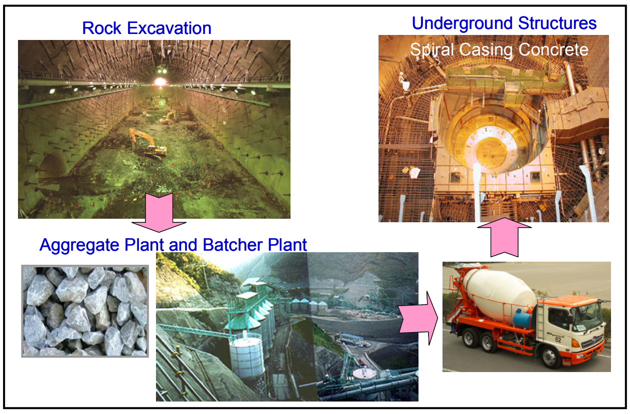

Fig.4.7 Recycle of Excavated Rock

In addition, the excavated areas and the construction areas are planted with local various trees to conserve natural environment.

4.3.3 Protecting river environment

The project generates electric power using water stored in the lower dam. Water that flows into the upper dam is not stored and discharged to the downstream of the dam. .

In order to mitigate environmental negative impacts on the river by construction of the upper dam to avoid changes of water temperature and turbid water, inflow from the mountainous area is designed to discharge to the downstream of the dam directly.

Water channels with a discharge capacity, equivalent to 10-day inflow, were constructed around the upper reservoir to conserve the aquatic environment that might be lost by construction of the dam, and to restore the habitats of its aquatic organisms (Fig.4.8).

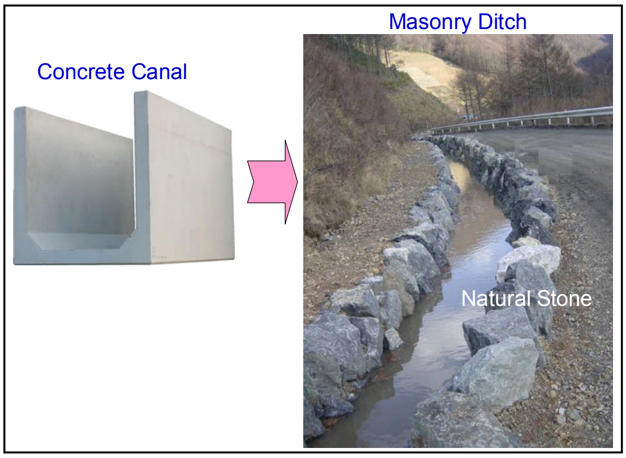

Fig.4.8 Environment-Friendliness

The water channel was constructed along the left bank of the lower reservoir (Fig.4.9).

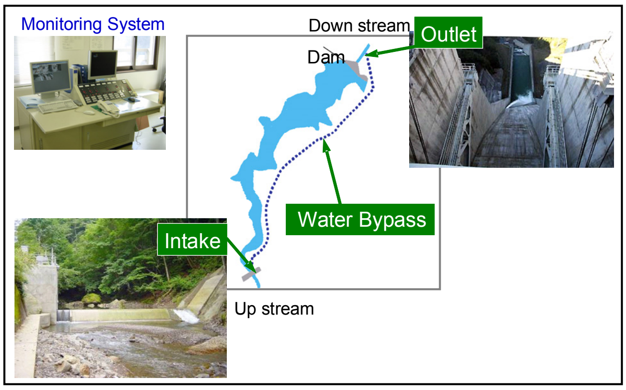

Fig.4.9 Water Bypass (in Operation)

The selectable discharge facility, which enables to adjust the depth of outflow from a reservoir, aims at preventing low-temperature or turbid water of the reservoir from outflowing to the downstream of the dam (Fig.4.10).

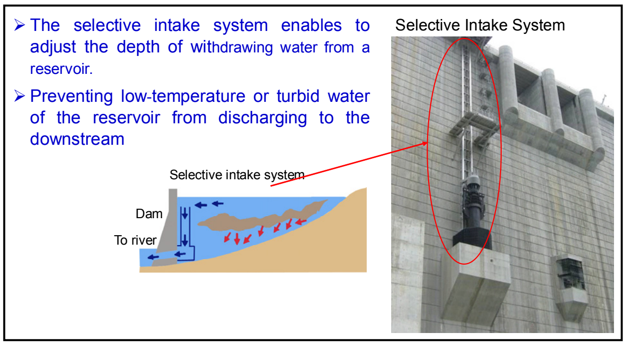

Fig.4.10 Water Quality Control

4.3.4 Adopting environmental management system

The project became the first large-scale construction project in Japan, which obtained certification of Environmental Management System International Standard ISO 14001. And it attracted our attention to its continuous efforts to mitigate the environmental loads of whole construction area.

Especially, in terms of prevention of river pollution and conservation of water quality, as well as efficient utilization of by-products from construction, the quality of water discharged from the project area has been strictly controlled.

To control pollution of river water, temporary drains were constructed to isolate waste water produced in the construction site form river water (Fig.4.11).

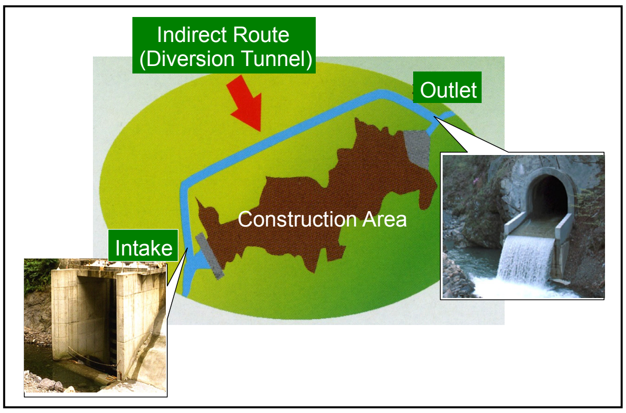

Fig.4.11 Water Bypass (Under Construction)

In order to prevent pollution of the river, temporary sewage lines were constructed to isolate waste water yielded in the construction site.

Sewage from accommodation of workers was purified by sewage disposal facilities installed in each accommodation, and the quality of disposed water is monitored and controlled based on the original quality standards.

4.3.5 Cooperating with local community

The project is aiming at a disclosed power plant, communicating much data about the project to the local community and welcoming numerous observers.

Environmental partnership between TEPCO and local community was established to work together as an equal partner through mutual cooperation and appropriate role allocation of each activity, sharing the common objectives to solve environmental problems in a community or society.

In environmental partnerships, it is important for participants to be equal partner based on appropriate role allocation, instead of provision of one-way support or cooperation.

To establish partnership on common elements, both parties must share in advance common perceptions on the objectives of joint works and on its advantages for each party.

In addition, before cooperating in activities with mutual respect, each actor must confirm is own objectives and philosophy and carry out substantial activities.

Without conducting its own activities, it would be difficult for any actor to provide others the results and know-how, and further deepen a relationship based on mutual trust.

4.4 Profile of principal facilities

4.4.1 Upper dam

The upper dam is a rock fill type dam with earth center core. The dam is 136m high, with a crest length of 444m and dam volume of 7.3 million m^3 (Fig.4.12).

This type of dam was selected based on the topographic conditions of the dam site, the properties of the foundation rock, and availability of embankment materials near the dam site.

Most of embankment materials for the upper dam were collected from the quarry and borrow area near the dam site. Those areas were submerged in the reservoir. Only the embankment material for the earth center core, its volume of 0.8 million m^3, were collected from the downstream area near the dam site.

The upper dam is a very compact dam in the mountainous area (Fig.4.13).

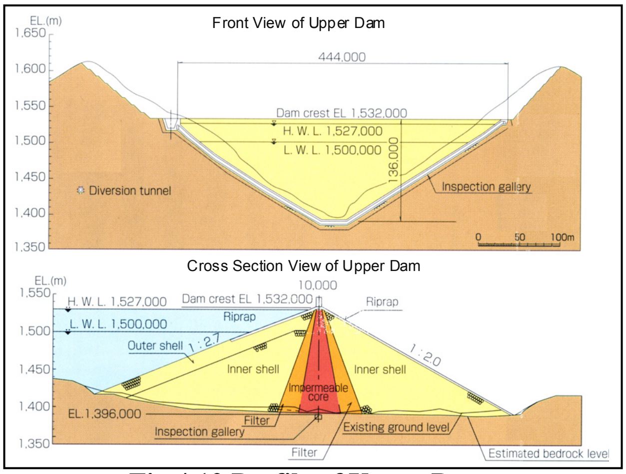

Fig.4.12 Profile of Upper Dam


Fig.4.13 Bird's-eye View of Upper Dam

4.4.2 Headrace and tailrace tunnels

The headrace and tailrace, 2,445m and 2,270m long respectively, are circular pressure tunnels which inner diameter is 8.2m. And the maximum flow rate is $340m^3/s$ and the maximum flow velocity is 6.3m/s.

These tunnels were excavated by bench construction method using the New Austrian Tunneling Method for supporting system. High pressure consolidation grouting was applied around the concrete lining. Sound rocks from tunnels were used for aggregates of concrete and materials of road foundations.

4.4.3 Penstock

Fig.4.14 shows underground structures image around the power station.

The penstock, inner diameter of 8.2m to 2.3m and length of 1,398m, is all-welded steel pipe embedded in concrete.

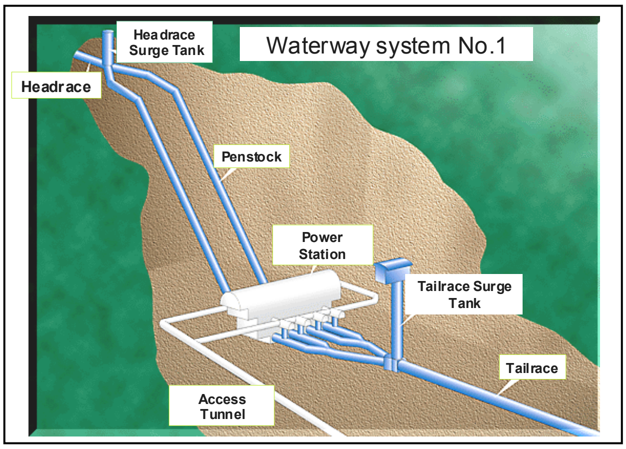

Fig.4.14 Underground Structures Image Map

A full-face tunnel boring machine (TBM) was applied to excavate the inclined tunnel section, inclination of 48 degree, length of 961m and diameter of 6.6m for the first time in Japan.

The design inner pressure of steel penstock drastically varies by section from about 1MPa at the base of headrace surge tank to about 11MPa at the inlet valve.

The penstock was designed to change the sort of steel and plate thickness in order to minimize the construction cost. A part of the inner pressure is designed to be supported by surrounding rock, since the bedrock surrounding penstock is sound and hard.

In the project, high tensile strength steel of HT-100 was applied for penstock for the first time in Japan (Fig.4.15).

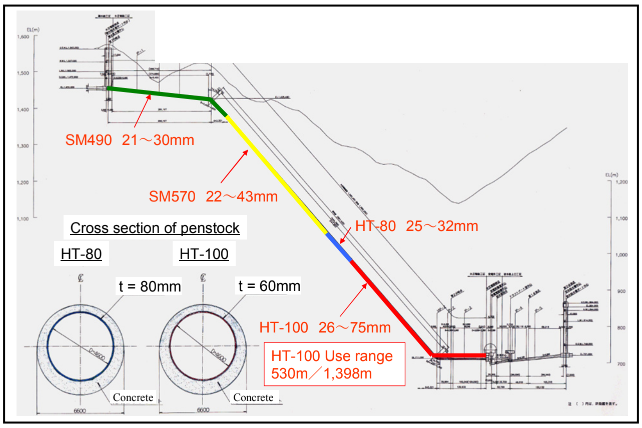

Fig.4.15 Application of HT-100 for Penstock

4.4.4 Power station

The powerhouse was designed to locate so that the entire cavern is accommodated in hard and fresh rock mass and within the depth of 500m under the ground surface. The cavern is 52m high, 33m wide and 216m long. The cross section area of the cavern is 1,400m^2.

The conduit tunnels connecting the cavern and the intake and the outlet were designed to be as short as possible.

Sound rocks from the cavern were used for aggregates of concrete.

To reduce the construction cost of the pumped storage power station, both effective head and unit capacity of generators needed to be increased.

The Splitter Runner was developed and applied for the first time in Japan. The number of blades is increased from six or seven blades of conventional types to ten blades (Fig.4.16).

It could improve the efficiency of pump-turbine by arranging long blades and short blades. The power generation and pumping operation efficiency

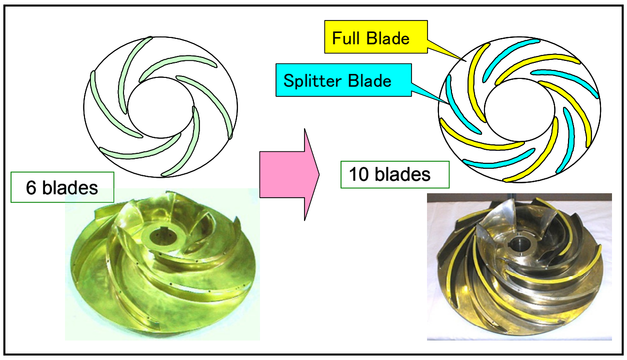

Fig.4.16 Development of New-Type Pump-Turbines

could increase by approximately 4%. The power generation capacity per unit could increase from 450MW of the original plant to 470MW.

4.4.5 Lower dam

The lower dam is a concrete gravity type dam, with height of 120m, crest length of 350m and dam volume of 0.72 million m^3 (Fig.4.17).

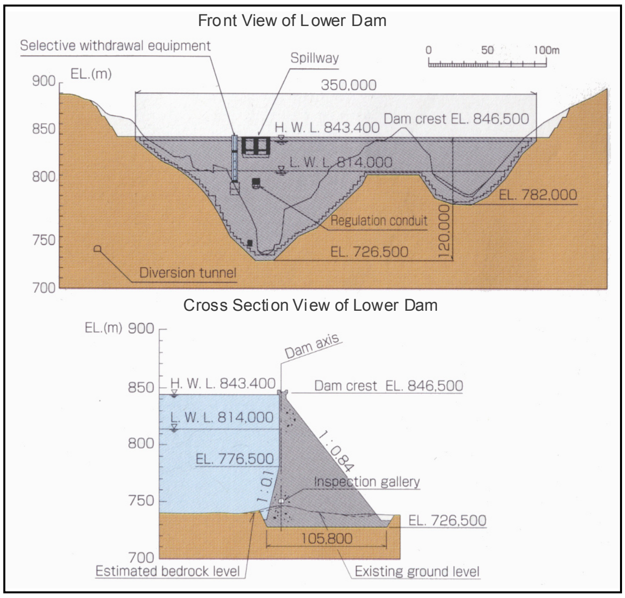

Fig.4.17 Profile of Lower Dam

The concrete gravity type dam was selected because the topography of site is formed of steep V-shape valley.

Materials of aggregates for concrete were collected from quarries at the right upstream of the dam site and sound rocks excavated from lower dam foundation, underground cavern and tunnels were reused.

The lower dam is a very compact dam in the mountainous area (Fig.4.18).

Fig.4.18 Bird's-eye View of Lower Dam

5. Conclusion

About thirty years ago, TEPCO developed Sintakasegawa pumped storage power project. Its output is 1,280MW, discharge is 644m^3/s and effective head is 229m. The height of upper dam is 176m which was the highest in Japan. The dam volume is 11.6 million m^3. The discharge is so large that large reservoir is required. The lower dam is 125m high and the dam volume is 7.4 million m^3. L/H of the project is 13.7.

The effective head of Kannagawa PSPP of 653m is higher than that of Sintakasegawa. Although the output is two times larger, both dam volumes are smaller. L/H of the project is 9.7 and smaller than Takasegawa. Generally speaking, Kannagawa PSPP may be better than Takasegawa in the viewpoint of site selection.

It is our great pleasure to resolve technical problems of hydropower projects by developing and applying the new technologies in order to conquer high water pressure.

We can apply new technologies developed for pumped storage power projects to conventional hydropower projects.

We would like to realize sustainable development of hydropower projects without serious environmental negative impacts by adopting new technologies under environmental and social considerations.

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