COMMISSION INTERNATIONALE
DES GRANDS BARRAGES

VINGT-CINQUIÈME CONGRÈS
DES GRANDS BARRAGES
Stavanger, juin 2015

STRENGTHENING THE FLOOD DISCHARGE CAPACITY OF KANOGAWA DAM (*)

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1. INTRODUCTION

The Ministry of Land, Infrastructure, Transport and Tourism (hereinafter called "MLIT") has planned a large-scale tunnel spillway with internal diameter of 11.5m and total length of approximately 450 m in order to drastically strengthen the flood discharge capacity of Kanogawa Dam [1]. This tunnel spillway will have the following four unique technical features. Firstly, because the gate and operating room will be installed near the outlet of the tunnel spillway, the tunnel will be a pressure tunnel acted on throughout its length by maximum external water pressure of about 0.9 MPa dependent on the ground water level of the natural ground and by maximum internal water pressure of about 0.4 MPa dependent on the reservoir water level. Secondly, in order for the maximum discharge flow rate to be 1,000 m^3/s, its maximum flow velocity will be higher than

(*) *Renforcement de la capacité d'évacuation de crues du barrage de Kanogawa*

10m/s. Thirdly, in order to install an inflow channel and a vertical shaft inside the reservoir of Kanogawa Dam and excavate a tunnel along the reservoir, it is important to take countermeasures against reservoir leakage. Fourthly, in order to minimize the impact on the downstream river, the energy dissipator will be a horizontally contractive type with a stepped energy dissipator, which narrows in the downstream direction.

This report presents an overview of strengthening of the flood discharge capacity of Kanogawa Dam.

2. OVERVIEW OF KANOGAWA DAM AND HIJIKAWA RIVER FLOOD CONTROL PROJECT

Kanogawa Dam (Fig.1) is a multipurpose dam performing flood control and generating hydropower constructed by MLIT in 1959.

Fig. 1
Kanogawa dam
Barrage de Kanogawa

Hijikawa River has a trunk channel with length of 103 km and a drainage basin with area of 1,210 km^2, 90% of which is occupied by mountains. The drainage basin, which is shaped like the palm of a person’s hand, includes the upstream Ozu Basin, where many tributaries converge, while downstream, the riverbed gradient becomes gentler as the river enters a narrow section enclosed by mountains on both banks, lowering the river’s flood discharge capacity. Thus, during recent floods, the water level has risen extremely high in Ozu Basin, triggering flood damage. MLIT began river improvement work in 1944, and built

Kanogawa Dam in its middle reaches in 1959 and Nomura Dam upstream in 1982. But repeated flood damage continues to occur frequently on Hijikawa River.

MLIT has, therefore, enacted a new flood control plan in order to radically increase the level of safety from flooding on Hijikawa River. Under the river improvement plan, which is the present flood control plan, the target flow rate is set as 5,000 m^3/s as the peak flow rate corresponding to actually recorded flow after the Second World War. Under the fundamental river management policy, which is the long-term flood control plan, the target flow rate is set as 6,300 m^3/s, which is a rate that occurs once every 100 years. The dam and river course improvements including Kanogawa Dam Improvement Project are being implemented in order to achieve these target flow rates.

3. OVERVIEW OF KANOGAWA DAM IMPROVEMENT PROJECT

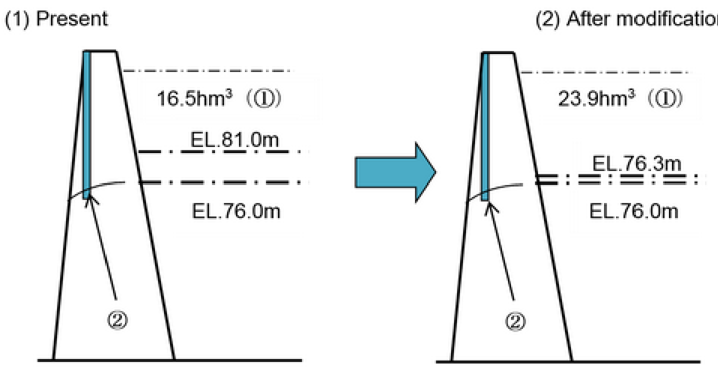


Fig. 2
Capacity allocation charts
Graphique de répartition de la capacité

1 Flood regulation capacity	*1 Capacité de régulation en cas de crues*
2 Crest gate	*2 Vanne de crête*

Fig. 2 shows reservoir capacity allocation charts before and after Kanogawa Dam Improvement Project. At the present Kanogawa Dam, during the period from July 1 until September 30, which is the flood season, the reservoir level is kept at the normal flood season water level of EL. 84.0m. When a flood occurs, a preliminary discharge lowers the reservoir level to EL. 81.0 m, ensuring flood regulation capacity of 16.5 hm^3. After improvement of Kanogawa Dam, part of the electric power generation capacity will be transferred to flood control capacity and the normal flood season water level will be changed to EL. 80.0 m. When a flood occurs, the reservoir water level will be lowered to the new preliminary discharge water level of EL. 76.3 m, ensuring flood regulation capacity of 23.9 hm^3. In other words, Kanogawa Dam Improvement Project is intended to increase the flood regulation capacity of Kanogawa Dam about 1.4 times from 16.5 hm^3 to 23.9 hm^3, so that this capacity can be used effectively to prevent or mitigate flood damage in the downstream area.

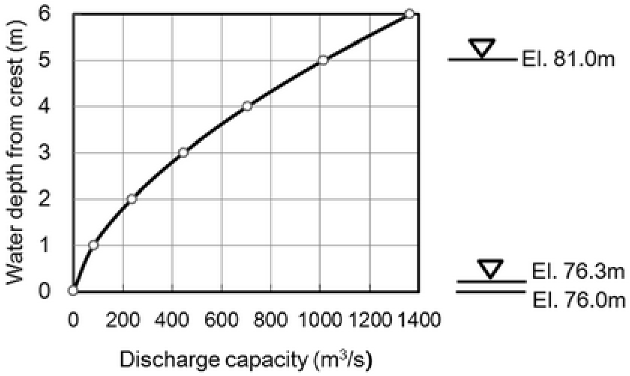


Fig. 3
Relationship of water depth with discharge capacity of four crest gates (full open)
Rapport entre la hauteur d'eau et la capacité de décharge des quatre vannes de crête (totalement ouvertes)

In order to effectively use the 23.9 hm^3 flood regulation capacity after improvement, while the dam inflow rate is low, the flood is discharged instead of being stored by the dam, conserving its flood regulation capacity. So, at the new preliminary discharge water level of EL. 76.3 m, under the present flood control plan, until the dam inflow reaches 600 m^3/s, the flood is discharged without being stored. And under fundamental river management policy (the long-term flood control plan), until the dam inflow reaches 1,000 m^3/s, the flood is discharged without being stored at the dam. The present overflow crest with four radial gates that are 12.0 m wide and of 10.3 m high, is situated on EL. 76.0 m. The discharge capacity at the preliminary discharge water level of EL. 76.3 m is only about 40m^3/s including 23 m^3/s for power generation shown in Fig. 3. Therefore, in order to achieve the goals of these two flood control plans, Kanogawa Dam must be improved to radically increase its discharge capacity.

4. SELECTING THE KANOGAWA DAM IMPROVEMENT METHOD

The design condition set for the newly constructed spillway is that it must have 1,000 m^3/s discharge capacity at the preliminary discharge water level of EL. 76.3 m in order to satisfy both flood control plans. A comparative study of the following four proposals for improvement methods to strengthen the discharge capacity while maintaining the present flood regulation function of Kanogawa Dam was carried out.

- Proposals to add a new spillway to the dam body:
  1. Conduit gate proposal
  2. Crest gate proposal
- Proposal to construct a new dam downstream from the existing dam
  3. New dam body construction proposal
- Proposal to construct a new spillway outside the dam body
  4. Tunnel spillway proposal

The crest length of Kanogawa Dam is 167.9 m. There are four crest gates in the center of the dam body. An intake tower for the electric power plant stands on the left bank side. It is obvious that there is insufficient space on the dam to install a new spillway.

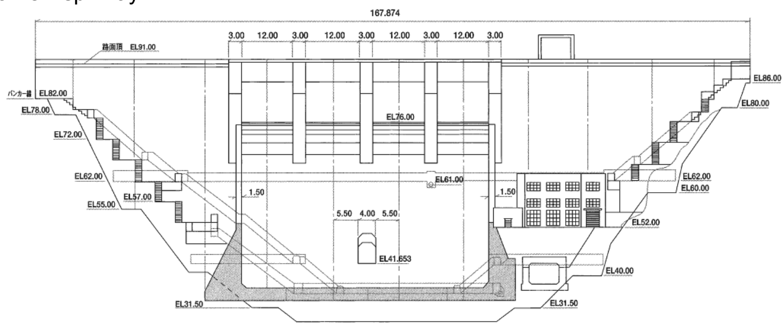


Fig. 4
Downstream surface of Kanogawa dam
Surface aval du barrage de Kanogawa

Fig. 4 shows the downstream surface of Kanogawa Dam.

1. In the proposed conduit gate, the dam is to be bored for four discharge pipes 4.2 m diameter to be installed at EL. 55.0 m. Because there is insufficient space on the dam, they would be laid directly under the crest gate piers, and it would be difficult to place the gate control house inside the dam, so it would have to be installed on the downstream side of the dam. Thus, installing a new

spillway on the overflow part of the existing dam would be difficult. Furthermore, construction during the flood period from July to September would also be difficult. So a long construction period should be necessary. The construction plan would become extremely complex. For example, a necessary large-scale cofferdam in the reservoir would be removed partially to ensure flood discharge capacity during the flood period.

2. In the proposed crest gate, the installation of a large gate with height of 25 m and width of 12 m would be installed on the right bank side of the dam. As Kanogawa Dam is designed three-dimensionally, the excavation of the dam body would entail measures to thicken the downstream side of the dam with concrete to improve dam safety. Furthermore, detailed study of the design and construction would also be necessary in order to preserve the stability of the dam body left on the right bank side during excavation of the existing dam. It would also be necessary to construct a large deep cofferdam on the upstream side of the dam. During the flood period, it would be difficult to thicken the downstream side of the existing dam or to construct the downstream part of the spillway, possibly resulting in a complex construction plan and prolonged construction period.
3. In order to ensure the present flood discharge capacity of 4,000 m^3/s during the improvement work, the new dam construction proposal requires an extremely complex construction procedure. It would have great impacts on the social environment by, for example, requiring the replacement of the arterial national road on the left bank side, the shutting down of the hydroelectric power plant, and the relocation of local residents.

Each of the above three proposals would require the construction of the improvement work while ensuring the flood discharge capacity of the present Kanogawa Dam, making the construction planning extremely complex, so it would have been very difficult to adopt any of them.

4. The tunnel spillway proposal will entail the construction of an inlet inside the reservoir and connecting the reservoir to the downstream river with a large section tunnel with inner diameter of 11.5 m. The construction work has been carried out at a location separate from the dam, permitting construction while maintaining the flood regulation and electric power generation functions of the dam. This approach will have little social impact such as replacing the national road on the left bank side, shutting down the hydroelectric power plant, or moving local residents.

For the above reasons, the tunnel spillway proposal was adopted.

5. FEATURES OF THE DESIGN OF THE TUNNEL SPILLWAY

Fig. 5 is a conceptual view of the tunnel spillway. The inlet will be on the right bank side of the reservoir, and the outlet gate control house and the energy dissipator will be on the downstream right bank side of the dam.

Fig. 5
Conceptual view of the tunnel spillway of Kanogawa dam
Vue conceptuelle de l'évacuateur de crue en tunnel du barrage de Kanogawa

5.1. PRESSURE TUNNEL

5.1.1. Adoption of the pressure tunnel method

The tunnel spillway will be installed on the right bank side, because a national road is on the left bank side and the relocation of residents living in the left bank side would be necessary, resulting in severe social impacts. To decide the locations of the spillway gate, control house and the energy dissipator, two proposals were compared.

1. Locating them inside the tunnel
2. Locating them downstream outside the tunnel

1. Locating them inside the tunnel

In proposal 1, the gate control house would ensure the space for gate installation and maintenance, necessitating the construction of a large underground space with width of 20 m, length of 25 m, and height of 40 m near the center of the tunnel route. For the energy dissipator to be inside the tunnel directly downstream from the gate control house, the tunnel would require a large section with width of 20 m and height of 20 m. This would involve constructing a large section underground space. It would be necessary to design and execute it cautiously to ensure the stability of this space.

2. Locating them downstream outside the tunnel

In contrast, locating them downstream from the tunnel will not require a large space, sharply reducing the area of the downstream tunnel. So, this proposal was adopted.

5.1.2. Tunnel sectional design

Because the gate control house will be installed near the tunnel outlet, the tunnel spillway will be a pressurized tunnel throughout its length. Three external forces will act on the tunnel: the external water pressure (approximately 0.9 MPa) acting on the outside of the tunnel as hydrostatic pressure dependent upon the ground water level, internal water pressure (approximately 0.4 MPa) acting on the inside of the surface of the lining of the tunnel dependent upon the reservoir water level, and the self-weight of the lining concrete. To design the tunnel section, the case where only the self-weight and external water pressure act during tunnel inspection was hypothesized, and it was also assumed that the internal water pressure will act at the surcharge water level. The shape of tunnel section is circular because it is a pressure tunnel subject to the action of internal and external pressures.

The lining thickness is structurally estimated at 80 cm for the concrete with compressional strength of 24 N/mm^2. However, it will be modified to 90 cm for the high strength concrete of 30 N/mm^2 and allowance for wear of 10 cm, because the flow velocity inside the tunnel will be high at approximately 10 to 12 m/s.

5.2. HIGH FLOW VELOCITY

5.2.1. Design flow velocity

The design flow velocity inside an aqueduct tunnel must ensure tunnel maintenance. In Japan, the design flow velocity for an aqueduct tunnel is often from 2 to 5 m/s in the case of an aqueduct tunnel with a constant flow, and it is often between 4 to 7 m/s or less in an aqueduct tunnel where the flow temporarily rises. In a case where the internal flow velocity of an aqueduct tunnel with bend exceeds 10 m/s in particular, it is possible for the pressure to decline to below the allowable pressure. It is necessary to estimate the flow velocity by performing hydraulic experiments.

For the Kanogawa Dam tunnel spillway, the design flow velocity is set between 10 and 12 m/s assuming that;

- There is little possibility of the inflow of sediment and bottom mud from the reservoir unlike most tunnel rivers.
- A divider wall will be installed at the inflow part as a measure taken to prevent the inflow of sediment or bottom mud.
- The radius of bend curvature will ensure 7D (D: internal diameter of the tunnel) or larger.
- Adequate consideration will be given to the lining concrete thickness, concrete strength, and other aspects of the tunnel structure.

The inlet of the tunnel spillway has been designed in order to prevent the generation of negative pressure near the start point of the bell mouth of the inlet, which might cause the formation of eddies and entraining of air during flood discharge.

5.2.2. Longitudinal alignment

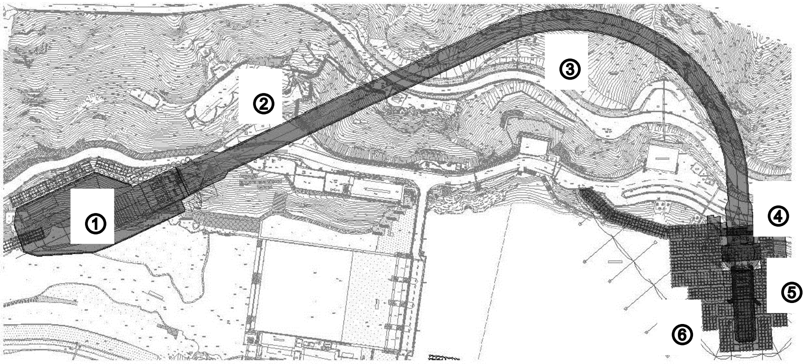


Fig. 6
Plane view of tunnel spillway
Vue d'en haut du déversoir en galerie

1 Outlet works	*1 Ouvrages de fuite*
2 Conduit	*2 Conduite*
3 Tunnel	*3 Tunnel*
4 Shaft for roller gate	*4 Puits de la vanne roulante*
5 Entrance channel	*5 Canal d'entrée*
6 Temporary work yard	*6 Site des travaux temporaires*

The horizontal alignment of the tunnel spillway was set to satisfy the following three conditions.

1. The discharge nappe is smoothly connected to the downstream river course.
   The tunnel spillway will discharge at the maximum discharge rate of 1,000 m^3/s. In order to prevent harmful impacts on the downstream river course section, the alignment of the outlet side of the tunnel spillway is designed to conform to the normal line of the downstream river course.
2. The flow is stable under the high flow velocity inside the tunnel.
   The tunnel spillway includes a long bend and the flow velocity inside the tunnel is high at about 12 m/s. It is feared that in the bend section, the pressure will decline or the flow regime will be destabilized by centrifugal force. In order to stabilize the flow regime inside the tunnel, in the bend section of the tunnel, the radius of curvature is 7 or more times D, which is the tunnel diameter. The Inner diameter D is constant at the straight section from the inlet to the bend section of the tunnel.
3. The longitudinal alignment of the tunnel must avoid the foundation treatment range of Kanogawa Dam.
   The distance from the center of the tunnel to the edge of curtain grouting will be equal to 3 or more times the tunnel diameter D. The impermeability of the dam foundation must be maintained after the improvement works.

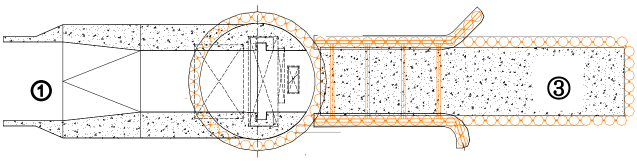
The five horizontal alignment proposals which satisfy the above conditions were compared to select the best one from the viewpoints of surrounding social environment conditions, geological conditions, economic conditions, and completion period. Social and environmental conditions include road traffic, boat courses and other use of lake surfaces, natural parks, fishery, noise pollution, construction vibration, water quality, etc. The degree of impact on these were investigated.

Geological conditions are elements of great importance when selecting the route of a tunnel spillway. The geology around Kanogawa Dam where is an accretionary wedge formed from the Triassic to the Jurassic eras (from about 250 Ma to 150 Ma), consists mainly of sandstone, mudstone, chert, greenstone and other old sedimentary rocks. The geology around the tunnel spillway consists of greenstone and mixed rock. In the mixed rock, sandstone, greenstone etc. are mixed in blocks, with argillaceous rock as the matrix. The rock from the outlet to the center of the tunnel is mainly greenstone, and on the upstream side of the tunnel, mixed rock dominates, while the geology near the inlet is a sandstone block. The overall geological structure near Kanogawa Dam is a monocline structure with the strike in roughly the dam's upstream-downstream direction and an incline of about 45° on the right bank side. According to the results of a past geological survey, in the foundation rock along the tunnel route, hard rock is distributed except at the surface. The deformation modulus is estimated to be 1,000MPa or higher and there are few problems regarding strength. There are no large-scale fractured zones along the tunnel route.

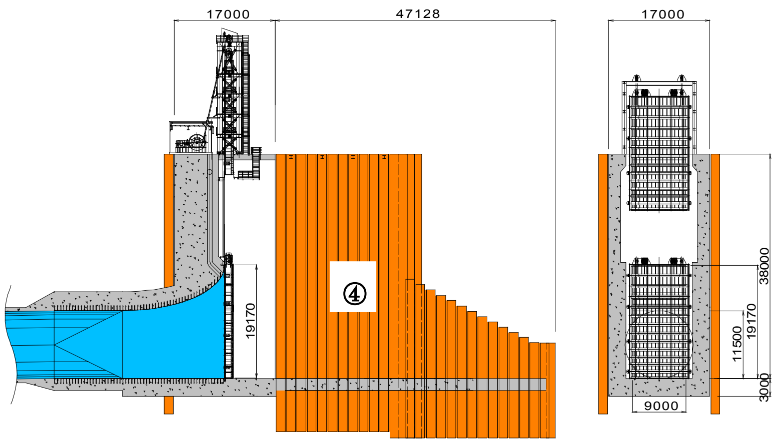
Fig. 7
Hydraulic experiment of the tunnel spillway
Essai hydraulique de l'évacuateur de crue en tunnel

Regarding the alignment proposal which was finally adopted as shown in Fig. 6, hydraulic model experiments were performed to confirm that the discharge capacity satisfies the planned discharge quantity, that negative pressure will not appear in the section where the high velocity flow occurs, that air will not be entrained, and that the flow will not show eccentricity in the bend section. Fig. 7 shows a hydraulic experiment model.

Fig. 8
Conceptual view of the Inlet of the tunnel spillway of Kanogawa dam
Vue conceptuelle de l'entrée de l'évacuateur de crue en tunnel du barrage de Kanogawa



(1) Plane view



(2) Longitudinal profile and cross section

Fig. 9
Intake facility of tunnel spillway
Installation d'entrée du déversoir en tunnel

1 Tunnel spillway	*1 Déversoir en tunnel*
2 Shaft for roller gate	*2 Puits de la vanne roulante*
3 Entrance channel	*3 Canal d'entrée*
4 Steel pipe sheet-pile	*4 Paroi tuyaux acier*

There are two methods of providing the cofferdam needed to build the vertical shaft; excavating the natural rock above the reservoir water level to use the natural rock as a cofferdam and driving steel pipe sheet-piles in a cylindrical shape inside the reservoir to form the cofferdam. Because Kanogawa Dam is in the designated region where community roads for nearby residents are ensured and the land around the reservoir is designated under the Natural Parks Law, the steel pipe sheet-pile method was adopted to absolutely minimize the change of the topography outside the reservoir area.

5.3. LEAKAGE PREVENTION MEASURES

Fig. 8 shows a conceptual view of the inlet. The inlet consists of the inflow channel and the inlet vertical shaft as shown in Fig. 9. At the inflow channel, the side walls of the inflow channel will be laid out with the steel pipe sheet-piles so that it protrudes about 6 m from the reservoir slope in order that reservoir bottom sediments, which have a maximum thickness of 2.0 m, are not drawn in. Because the inlet vertical shaft will be inside the reservoir, it requires reliable water-proofing treatment in order that stored water does not leak from the inlet. According to the results of the geological survey, sandstone blocks near the inlet are highly permeable. Two or three layers of curtain grouting and consolidation grouting are planned as the waterproofing measures.

As the tunnel passes through near the reservoir, measures to prevent the water in the reservoir from leaking into the tunnel must be taken. According to the past geological survey, the permeability of the foundation rock along the most of 60m of rock cover from the ground surface is as low as 5 Lugeon or less.

Fig. 10
Temporary work yard at intake facility
Site des travaux temporaires au niveau des installations d'entrée du déversoir

As waterproofing measures to keep water from leaking into the tunnel, waterproof sheets will be installed over the entire periphery of the tunnel. Around the tunnel outlet where the internal water pressure of the tunnel will exceed the external water pressure, waterproofing measures using collar braces will be taken to prevent water from leaking from the tunnel into the natural rock. Curtain grouting with fan borings will be executed on the upstream side of the lining pipe, preventing leaking along the waterproof sheets in the concrete lining section.

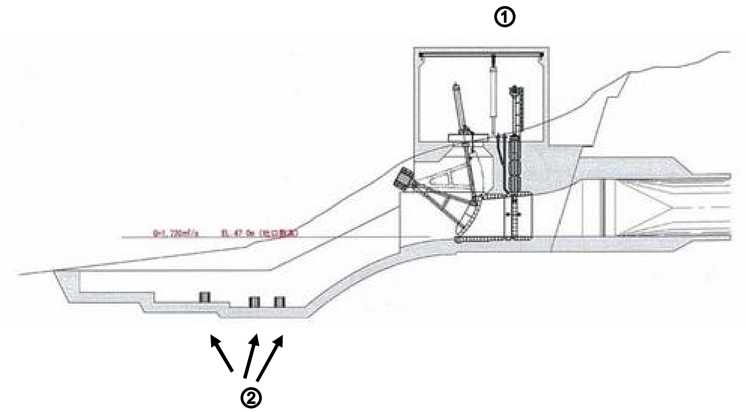


Fig.11
Stepped energy dissipator: longitudinal section
Dissipateur d'énergie étagé : coupe longitudinale

1 Gate control house	*1 Salle de contrôle des vannes*
2 Baffle block	*2 Blocs déflecteurs de réduction de pression*

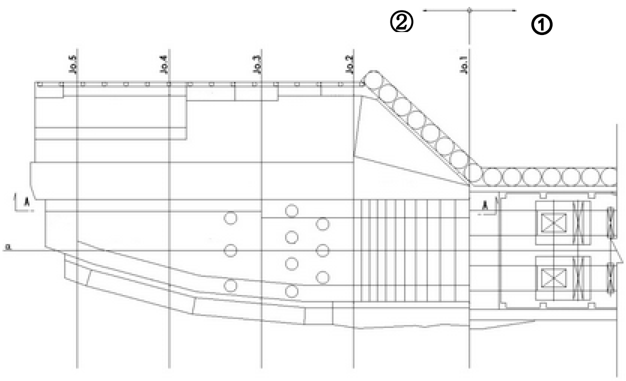


Fig. 12
Stepped energy dissipator: plane view
Dissipateur d'énergie : vue du dessus

1 Gate control house	*1 Salle de contrôle des vannes*
2 Stepped energy dissipator	*2 Dissipateur d'énergie étagé*

In order to prepare for the appearance of springs during tunnel excavation, at the same time, advance boring of about 50 m has been executed, clarifying geological conditions and predicting spring locations on the planned tunnel route.

A temporary work yard was built by LIBRA-S (Libra(L); the Balance) construction method for the construction work of the inlet as shown in Fig. 10. The temporary work yard had to be set up to water depth of 40 m. The assembly of braces for fixing the steel pipes also had to be unsafe underwater work. In this method, braces have been assembled above ground and sunk into the reservoir resulting in avoiding underwater work.

5.4. STEPPED ENERGY DISSIPATOR

Fig. 11 and Fig. 12 show the longitudinal cross section and plane view of the stepped energy dissipator, respectively. The energy dissipator would, as initially planned, protrude into the downstream river. But in order to minimize the impact on the downstream river environment, the construction work was changed to remain in the range of the present sandbar.

In order to mitigate the impact of the discharged water from the crest gate of Kanogawa Dam, the energy dissipator was gradually contracted in the downstream direction based on the hydraulic model experiment results. That system gradually dissipates energy from the downstream area of the gate control house, and steps will be formed towards the downstream end in order to stabilize the flow regime. Furthermore, a cylindrical baffle pier will be installed inside the energy dissipator to stabilize the hydraulic jump location. Fig.13 is a view of the hydraulic experiments concerning the energy dissipator. Fig.14 shows the outlet works under construction.

Fig.13
Hydraulic experiment to test the tunnel spillway energy dissipator
Essai hydraulique du dissipateur d'énergie
de l'évacuateur de crue en tunnel

Fig.14
Outlet works
Ouvrages de fuite

CONCLUSION

In Japan, the flood discharge capacity of concrete gravity dams has often been strengthened by one of two methods: adding discharge pipes by boring holes in the dam body or by adding a spillway by forming a notch in the dam crest. At Kanogawa Dam, the tunnel spillway method was adopted because it would have been difficult to install a large-scale spillway with large intended flow rate by improving the existing dam body. It was necessary to overcome technical challenges posed by three facts: it will be a pressure tunnel with a large section over its entire length, the discharge will flow at high velocity, and it will be necessary to execute innovative energy dissipation in order to conserve the river environment of the river downstream from the outlet.

To build the Kanogawa Dam tunnel spillway, preparatory work such as the temporary approach road for construction work was started in 2012, and the entire work will be completed by the end of March 2016. Fig. 15 shows the entire construction work to build the tunnel spillway concerning the inlet and outlet facilities under construction.

Fig. 15
Bird-eye view of tunnel spillway under construction
Vue aérienne du déversoir en tunnel durant les travaux de construction

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[1] HARADA, M., TAKASU, S., YOSHIDA, H. and IKEDA, T. (2012), Overview of the Planning of Kanogawa Dam Tunnel Spillway, *International Symposium on Dams for a Changing World*, ICOLD 2012 Kyoto, CD-ROM

SUMMARY

The Ministry of Land, Infrastructure, Transport and Tourism has planned a large-scale tunnel spillway with inner diameter of 11.5 m and total length of approximately 450 m in order to drastically strengthen the flood discharge capacity of Kanogawa Dam. This tunnel spillway will have the following four unique technical features. Firstly, because the gate and control house will be installed near the outlet of the tunnel spillway, the tunnel will be a pressure tunnel acted on throughout its length by maximum external water pressure of about 0.9MPa dependent on the ground water level of the natural ground and by maximum internal water pressure of about 0.4 MPa dependent on the reservoir water level. Secondly, its maximum discharge flow rate will be 1,000 m^3/s, and its maximum flow velocity will be as high as 10 m/s or more. Thirdly, in order to minimize the impact on the downstream river course, the stepped energy dissipator adopted is a contractive type. Fourthly, in order to install an inflow channel and vertical shaft inside the reservoir of Kanogawa Dam and to excavate the tunnel in the natural rock on the right bank of the reservoir, measures to prevent leaking from the reservoir was an important matter that was thoroughly investigated.

RÉSUMÉ

Le Ministère du territoire, des infrastructures, des transports et du tourisme a planifié la construction d’un évacuateur de crue en galerie de grande envergure présentant un diamètre interne de 11,5 m et une longueur d’environ 450 m afin de renforcer considérablement la capacité d’évacuation des crues du barrage de Kanogawa. Cet évacuateur de crue en galerie aura les quatre caractéristiques techniques originales suivantes. Premièrement, puisque la salle d’exploitation et de contrôle des vannes sera installée à proximité de la sortie de l’évacuateur de crue en tunnel, le tunnel sera une galerie en charge sur toute sa longueur avec une pression d’eau externe maximale d’environ 0,9 MPa dépendant du niveau de la nappe phréatique et une pression d’eau interne maximale d’environ 0,4 MPa dépendant du niveau d’eau du réservoir. Deuxièmement, le débit maximal des eaux évacuées sera de 1000 m^3/s avec une vitesse maximale d’écoulement élevée qui dépassera 10 m/s. Troisièmement, en vue de minimiser l’impact sur le cours de la rivière en aval, le dissipateur d’énergie sera de type étagé en se resserrant vers l’aval. Quatrièmement, la mise en place d’un canal d’entrée et d’un puits vertical dans le réservoir du barrage de Kanogawa et d’un tunnel dans la roche naturelle sur la rive droite du réservoir a exigé des mesures en vue de prévenir les fuites provenant du réservoir.