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REHABILITATION OF THE TAISHAKUGAWA DAM WITH THE AIM OF IMPROVING FLOOD DISCHARGE CAPACITY AND SEISMIC STABILITY [*]

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1. INTRODUCTION

Upgrading or rehabilitation of existing dams has lately attached world-wide attention from the situations of progress in ageing of dams, the lack of sites suitable for dam construction, the rising tide for the environmental preservation and etc.

The Chugoku Electric Power Co., Inc., one of the major electric utilities in Japan, executed the rehabilitation of an old concrete gravity dam with the aim of improving flood discharge capacity and seismic stability.

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[*] *Réhabilitation du barrage de taishakugawa dans le but d'améliorer la capacité d'évacuation des crues et la stabilité sismique*

This dam (The Taishakugawa dam) had been playing an important role in stable supply of electric power (4.4MW) and the role as the sightseeing resources in local area after the completion in 1924. However, as the reasons bellow, the Taishakugawa dam was planed to improve to be a modern dam by the drastic rehabilitation together with the re-developing existing hydropower station.

- About 80 years had passed since the completion and therefore the dam was getting older.
- An insufficient flood discharge capacity of the spillway had restricted the operation of the reservoir.
- There was an unused head of about 35 m in the maximum and effective utilization of valuable water resource was not performed enough.

The rehabilitation work of the Taishakugawa dam commenced in June 2003 and was completed in June 2006.

Fig. 1

Site Map of the Taishakugawa dam

Carte du site du barrage de Taishakugawa

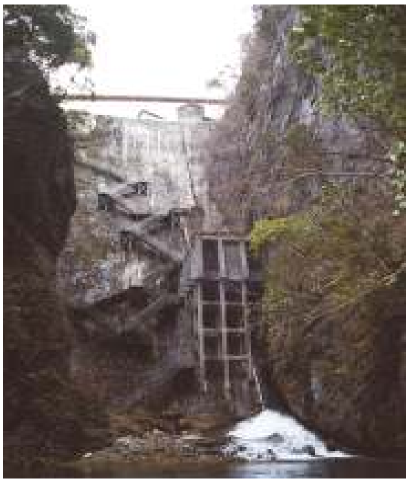

Fig. 2

The Taishakugawa dam
(Before rehabilitation)

Le barrage de Taishakugawa
(avant la réhabilitation)

2. OUTLINE OF THE REHABILITATION WORK OF THE TAISHAKUGAWA DAM

2.1. GENERAL DISCRIPTION

The rehabilitation work of the Taishakugawa dam is outlined in Fig. 3. The upper part of the existing dam body was cut off so that the overflow type spillway was installed on the top of the dam for the improvement of flood discharge capability and new concrete was added on the downstream face of existing dam body for the improvement of seismic stability. Table 1 shows the dimensions of the Taishakugawa dam before and after rehabilitation.

Table 1
Dimensions of the Taishakugawa dam
Dimensions du barrage de Taishakugawa

	Before rehabilitation	After rehabilitation
Dam type	PG	PG
Dam height (m)	62.1	62.43
Dam volume (m^3)	31,000	45,000
Effevtive storage capacity (m^3)	13,000,000	7,500,000
Flood discharge capacity (m^3/s)	720	1,610

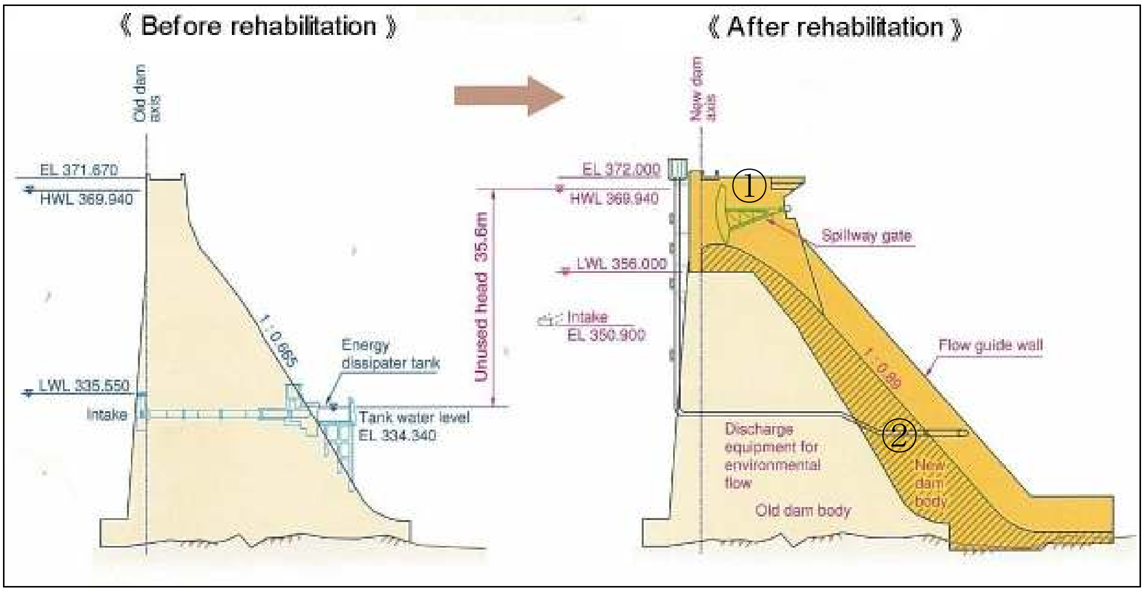

Fig. 3
Cross section of the rehabilitation work
Coupe du chantier de réhabilitation

1 Installation of additional spillway	*1 Installation du déversoir supplémentaire*
2 Placing of new concrete	*2 Mise en place de nouveau béton*

2.2. NECESSITY FOR THE IMPROVEMENT OF FLOOD DISCHARGE CAPACITY

The existing spillway is tunnel type, located separately from the dam body with flood discharge capacity of 720m^3/s. As the possibility of flooding far greater than the discharge capacity of existing spillway was confirmed by the runoff analysis based on the recent torrential rainfall records, reservoir level had been lowered during flood seasons. However, for the drastic solution of insufficiency of the discharge capacity, conclusion was reached that the top of the existing dam body needed to be cut off, so as to install an overflow type spillway on the top of it.

2.3. NECESSITY FOR THE IMPROVEMENT OF SEISMIC STABILITY

The Taishakugawa dam was designed and constructed over 80 years ago and therefore does not satisfy the specific safety requirements (seismic stability) of the current design criteria in Japan. In order to satisfy the safety level of the new dam, it was planned that the new concrete was placed on the downstream face of existing dam body.

3. HISTORY AND FEATURES OF THE TAISHAKUGAWA DAM

The Taishakugawa dam is located in Hiroshima Prefecture in western Japan (See Fig. 1). This dam is a concrete gravity dam that was completed with the aim of hydropower generation in 1924, and with the height of 56.4m (About 6m in height was raised in 1931, and the final height is 62.1m). At that time, it was one of the highest dams in Japan. The dam is located on a narrow part in the river with the steep cliffs of limestone on both banks, and it has a unique shape such that its length is only half of its height and it looks like a wedge from an anterior view, as shown in Fig. 2. Therefore, it is a remarkable feature in view of excellent water storage efficiency that reservoir capacity is 14,278,000 m^3, where the volume of dam is 31,000 m^3.

The upstream slope and downstream slope of the dam were 1:0.0745 and 1:0.665 respectively and masonry facing was put on the surface of the dam body. The dam formed a slightly arched shape in a plane view. Moreover, no joints had been installed.

It was one of the features that spillway was installed at another position beside the dam as the tunnel type and that the dam was non-overflow type without spillway, as already mentioned in Chapter 2.2.

The dam and its surroundings are situated within a Quasi-National Park (Class 1 Special Area) and a district of officially-designated beauty spots. The dam and reservoir are located at the center of a Quasi-National Park where is one of the most famous tourist spots in Hiroshima Prefecture and tourist businesses are operated such as sightseeing boats in the reservoir. So, the dam and reservoir are the treasurable tourism resources for local people.

4. TOPOGRAPHICAL AND GEOLOGICAL FEATURES AROUND THE DAM SITE

The Taishakukyo Valley where the Taishakugawa dam is located is a deep valley that was formed with the erosion by the Taishakugawa River flowing at the center of the Taishakudai Plateau. As for the surrounding area of the dam, the extremely steep cliffs made of limestone are consecutive, as shown in Fig. 4.

Regarding the geological features around the dam site, it is consisted of the limestone formed from the Carboniferous to the Permian in Palaeozoic Era. Relatively sound bedrock is exposed on the surface around the dam site. According to the results of the boring tests, foundation rock of the existing dam is found to be sound. There is no cavern confirmed at the dam site, but in the surrounding area of the dam, there are a few small-scale caverns made by the erosion of the surface water and underground water. Totally, permeability around the dam site is low.

Fig. 4

Steep cliffs of limestone around the dam site

Falaises de calcaire autour du site du barrage

5. SOUNDNESS OF EXISTING DAM BODY

The most important technical issue of the rehabilitation of an old dam is the evaluation of the soundness of existing dam body.

According to the records, the existing dam was built by boulder concrete, that is, at first boulders were put and concrete was placed on them, and after that compaction was done. It is said that there was a lot of leakage of water when it was completed. However, in these days, the leakage volume is constantly less than a few litters per minute after the repeated countermeasure works such as grouting in the dam body and sprayed concrete on the upstream face of the dam.

Exhaustive examinations on the records of past countermeasure works of the dam body were carried out and the effect of countermeasure works was grasped by the results of over 100 borings shown in Fig. 5.

Test results of boring core showed that compressive strength and unit weight were approximately 20 N/mm and 2.34 g/ cm^3 on an average respectively, and it was assured that carbonation was not seen by the effect of the masonry facing on the surface of the dam body.

Judging from the results above mentioned, the concrete of existing dam body had enough properties such as watertightness, strength and unit weight required for dam concrete. Consequently, it was proved that the existing dam concrete could be used continuously as a part of new dam.

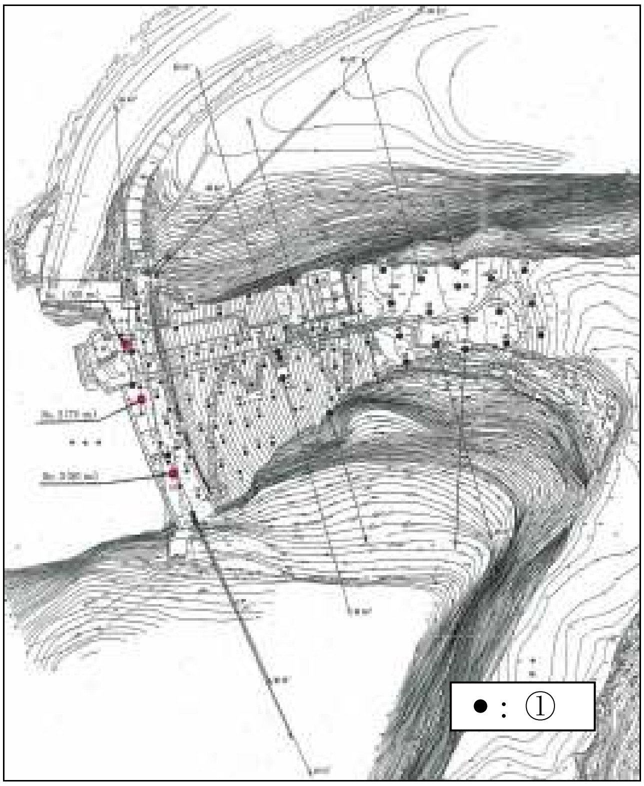

Fig. 5

Borings for the evaluation of the soundness of existing dam body

Forages pour l'évaluation de la tenue du corps de barrage existant

1	Position of boring	*1*	*Position du forage*

6. DESIGN

6.1. DESIGN OF SPILLWAY

6.1.1. Design Flood Discharge

According to the Japanese criteria, maximum possible flood discharge (estimated by Creager's specific flood discharge curve : 1,610 m^3/s) should be set as a design flood discharge, which is the largest discharge among 200-year flood discharge, largest recorded flood discharge and maximum possible flood discharge (estimated by Creager's specific flood discharge curve) . This is more than the double of the existing capacity.

6.1.2. Method of Flood Discharge

Design flood discharge 1,610 m^3/s should be discharged by the existing tunnel type spillway and newly-built overflow type spillway with the capacity of 720 m^3/s and 890 m^3/s respectively.

6.1.3. Features of Spillway Design

For the following reasons, an energy dissipater such as an auxiliary dam was omitted to reduce the range of environmental impact and reduce the construction costs.

- According to the hydraulic model test, it was confirmed that the local topographical features limited the impact of flood discharging up to the area aroud 200m below the dam.
- A geological survey revealed that firm bedrock was exposed on both downstream sides so that flood discharge would not be likely to cause much damage to the riversides
- Neither private houses nor vital structures are located within several kilometres of the area below the dam.

6.2. DESIGN OF DAM BODY

6.2.1. Technical Issues of Rehabilitation Work

Rehabilitation work of the Taishakugawa dam was almost the same as dam raising in the respect that new concrete was placed on the downstream of existing dam body. Therefore, technical issues of rehabilitation work were the same as those of dam raising basically.

Detailed studies on the technical issues of dam raising were carried in the Odomari dam, the Kuroda dam, the Shin-Nakano dam, etc., and the technical issues of dam raising can be focused to three points as follows.

- Stability of raised dam
- Unification of existing and new dam bodies, related to the stability of raised dam
- Thermal stress by the heat of hydration accompanied by concrete placing on the existing dam body

Moreover, peculiar conditions to the Taishakugawa dam had to be concerned as follows.

- Dam concrete includes the boulders of 30 to 50 cm for the coarse aggregate. How to consider this size of coarse aggregate when evaluating the existing concrete?
- The Taishakugawa dam has masonry facing on the surface of existing dam body. How to improve it ?

6.2.2. Design Theory and Calculation of Stability

This rehabilitation work was assumed to be executed with the water of reservoir stored in consideration of the importance of resources for tourism of reservoir, and the dam design was carried out, based on the idea of Kakitani Theory for dam raising that is able to consider the effect of storing water under construction.

Kakitani Theory is based on the hypothesis that existing dam body resists the loads when under construction, and new and existing dam bodies resist the loads which increase after the completion as one. Therefore, the unification of existing and new dam bodies is needed when designed by this theory. Most of raised dams were designed by this theory in Japan.

It is the water level under construction that it has a big influence on the decision of the downstream slope when stability is calculated by this theory. Keeping the water level lower is advantageous in respect of reduction of the construction costs and the range of environmental impacts because the downstream slope can be steepened by the lower water level when under construction, and excellent in respect of safety for the flood under construction. On the other hand, the lowest water level that the sightseeing boats can sail safely was EL.350m (lower from HWL by about 20m). Considering those mentioned above, the water level when under construction in the design was set EL.352m that added the allowance of 2m to keep the construction work even by the water level rise by small floods, and the downstream slope of the new dam was decided 1:0.89.

6.2.3. Unification of Existing and New Dam Bodies

From the hypothesis of Kakitani Theory, unification of existing and new dam bodies is needed for the resistance against loads, and it is an important technical issue in case of placing new concrete on the downstream of existing dam body. Therefore, the shear stress and tensile stress on the boundary between existing and new dam bodies generated from loads such as water pressure, seismic inertia force, etc. and the thermal stress by the heat of hydration of new concrete obtained by thermal stress analysis were calculated, and the safety was confirmed by comparison with the strength of the boundary of existing and new concrete.

The strength of the boundary of existing and new concrete can usually be estimated from the compressive strength of existing dam concrete, but considering that existing dam body is boulder concrete, it was confirmed by the in-situ shear tests using the existing inspection gallery.

Fig. 6 shows the result of in-situ shear tests. The shear strength of the boundary of existing and new concrete was estimated at least 2.0N/mm^2 from this figure, and the maximum stress calculated was 0.5N/mm^2. Therefore, unification of existing and new dam bodies was confirmed.

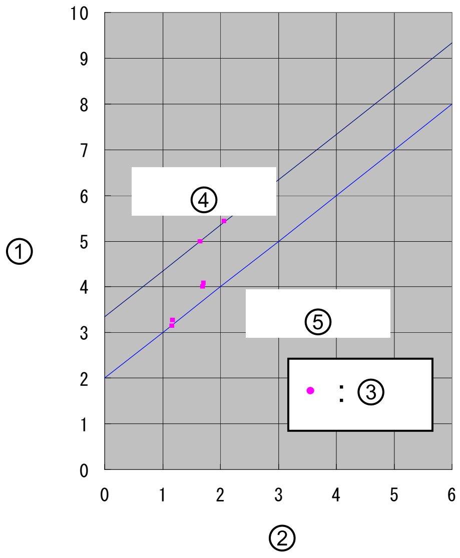

Fig. 6

The Result of the in-situ shear tests

Résultat des essais de cisaillement in-situ

1 Shear stress (N/mm^2)	*1 Contrainte de cisaillement (N/mm^2)*
2 Normal stress (N/mm^2)	*2 Contrainte normale (N/mm^2)*
3 Test data	*3 Données de l'essai*
4 Upper limit line : τ=3.3+tan45°	*4 Ligne de limite supérieure: τ=3.3+tan45°*
5 Lower limit line : τ=2.0+tan45°	*5 Ligne de limite inférieure: τ=2.0+tan45°*

6.2.4. Thermal Stress Analysis

The existing dam body is subject to a huge heat load when new concrete is placed on it. It is known that the temperature change of dam body according to this heat load generates the thermal stress peculiar as the tensile stress on the upstream of existing dam body, and it was an important technical issue in the project that was equal to the unification of existing and new dam bodies. Therefore, the thermal stress analysis using two-dimensional FEM was executed and the countermeasures were examined.

As a result, it was confirmed that shrinkage by the cooled heat of new concrete generated peculiar tensile stress to the vicinity of the boundary between existing and new dam bodies and the upstream of existing dam body, as shown in Fig. 7.

If concrete cracks at these places, it would have a big influence on the watertightness of the dam. So, on the boundary between existing and new dam bodies in the uppermost part of existing dam body, reinforcement works with the reinforcing bars and waterstops in the direction of the dam axis were executed, as shown in Fig. 8.

As for the tensile stress in the upstream of existing dam body, generated stress was less than the tensile strength of existing dam body. But, considering the importance of watertightness of the dam, grouting in the upstream of existing dam body was executed to make doubly sure.

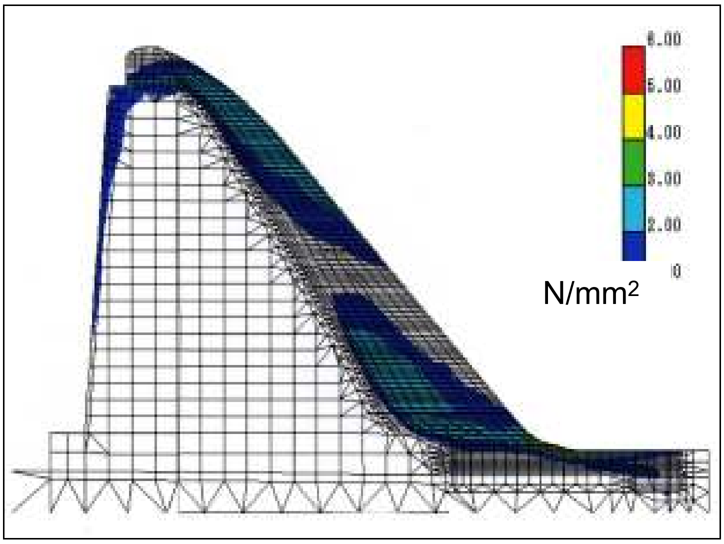

Fig. 7

Example of the results of thermal stress analysis

(Maximum tensile stress)

Exemple des résultats de l’analyse de contrainte thermique

(contrainte de traction maximum)

Fig. 8

Reinforcement works on the boundary of existing and new dam bodies

Travaux de renforcement sur les limites du corps existant et du nouveau corps

6.3. FOUNDATION TREATMENT

6.3.1. Consolidation Grouting

Consolidation grouting was executed only in the riverbed where excavation would be done for new concrete placing, because permeability of the foundation rock under the existing dam body was low, most of which were 2Lu or less.

6.3.2. Curtain (Rim) Grouting

Curtain (rim) grouting was not executed, because of the reasons below.

- The maximum water level was not changed after the rehabilitation of the dam
- The results of the trial storage to the maximum water level before the rehabilitation work showed that there was no conspicuous leakage around the dam that would wreck the stability of the dam and the function of storage.
- There was no possibility of seepage failure such as piping because the foundation rock around the dam was sound limestone.

6.4. DAM CONCRETE

6.4.1. Method of Concrete Placing

Extended Layer Construction Method (ELCM) was adopted in consideration for the narrowness of the concrete placing area, and the placement lift was set to be 1m in principle.

6.4.2. Adoption of Ready-Mixed Concrete

In recent years in Japan, small-scale dams that utilize existing ready-mixed concrete plants have been increasing in number. In this project, ready-mixed concrete was adopted because the gross volume of concrete was relatively small (about 15,600m^3). Before the concrete work started, detailed investigations such as the manufacturing capacity, the transportation time from the concrete plant to the dam and the influences on the concrete supply to general users, etc. had been done, and a remarkable cost reduction was achieved by the adoption of ready-mixed concrete.

6.4.3. Concrete Composition

Regarding the adoption of the maximum aggregate size of 40 ㎜, by which remodelling the aggregate plant was not needed, detailed investigations of the thermal stress analysis and tests of concrete placing, etc. were executed as the use of an existing ready-mixed concrete plant was adopted (The aggregate plant was established as an annex).

As a result, adopting the maximum aggregate size of 40 ㎜ was proved to have little problem although a part of countermeasures against the thermal stress were needed.

Moderate heat fly-ash cement at the fly-ash substitution rate of 30% was employed.

There were two kinds of concrete composition for the dam body (composition for the external part) and for the structure, and design compressive strength for the dam body was assumed to be 20N/㎜^{2} from the necessity for the same level as the strength of the existing dam body, and 21N/㎜^{2} for the structure such as guide wall.

7. CONSTRUCTION WORKS

7.1. FEATURES OF CONSTRUCTION WORKS

As the Taishakugawa dam is located in extremely steep topographical features where steep cliffs peculiar to limestone was consecutive, and also in the Quasi-National Park (Class 1 Special Area), rational and environmental-friendly layout of construction programme was stringently needed.

According to the circumstances above mentioned, Steel-made temporary road of about 170m was set in the reservoir because there was no road by which the vehicles for construction was able to access to the dam site. Moreover, the dam concrete was placed by setting up similar steel-made temporary stage (43m in maximum height) on the downstream of the dam, and by using 80t crawler crane. Fig. 9 and 10 show the steel-made temporary road in the reservoir and the steel-made temporary stage on the downstream of the dam respectively.

Moreover, it is one of the features that the construction works were carried out with the reservoir stored in consideration that the reservoir is the treasurable resource for tourism.

Fig. 9

Steel-made temporary road
in the reservoir
Route temporaire en acier
dans le réservoir

Fig.10

Steel-made temporary stage
on the downstream of the dam
Palier temporaire en acier
en aval du barrage

7.2. FOUNDATION EXCAVATION

Outcrop of sound rock could be seen around the dam site, and it was judged to be a good condition for dam foundation rock of a gravity dam as it was because of its enough strength and stability. So, the excavation work of foundation was carried out only for the part where loosening of the rock was seen and the part with vegetation partially.

7.3. REMOVAL WORK OF EXISTING DAM BODY

From the viewpoint that ensured the unification of existing and new dam bodies, removal of masonry facing and the chipping on the surface of existing dam body were carried out with a concrete breaker in parallel with new concrete placing, as shown in Fig.11.

To install the spillway gates newly on the top of the dam, the upper part of existing dam body of about 16m (concrete amount about 5,000m^3) was removed. This removal work was carried out by the wire sewing method (See Fig.12) , which is one of the concrete cutting methods by turning the diamond-encrusted wire continuously, together by a concrete breaker using the nonexplosive demolition agent.

Fig. 11

Removal work of masonry facing and chipping

Démolition du masque en maçonnerie frontal et burinage

Fig. 12

Removal work of existing dam body by wire sewing saw

Retrait du corps existant du barrage avec la méthode de la piqûre au fil métallique

7.4. DAM CONCRETE PLACING

7.4.1. Construction Equipments

Construction work using a lot of large-scale construction equipments, which has come into general use in dam construction in Japan, was impossible, because of the topographical features around the dam site extremely steep and narrow, etc. Construction works were carried out step by step using the construction equipments suitable for the dam site and sometimes relying on manpower, and dam concrete of 62m was placed in one year and nine months

Because the aggregate is stirred easily by the vibrator for the dam of φ150 ㎜ accompanied by the adoption of the maximum aggregate size of 40 ㎜ and the construction area was extremely narrow compared with usual dam construction sites, the small-scale vibrator vehicle of the special specification of which the vibrator was φ60 ㎜ was developed aiming at the rationalization of construction, as shown in Fig. 13.

Fig.13

Concrete placing

Déposition du béton

7.4.2. *Artificial Cooling (Pre-Cooling)*

Reflecting the result of the thermal stress analysis, concrete pre-cooling by liquid nitrogen (LN_2) was carried out considering the influence of thermal stress by placing concrete in summer. LN_2 plant was installed at the ready-mixed concrete plant and LN_2 was put into concrete during the mixing. The concrete temperature when it was placed in the site was aiming at 20℃. Moreover, to prevent the concrete temperature rising by heat as much as possible, the heat insulator cover was installed in the agitating truck. Because of the circumstances around the ready-mixed concrete plant, concrete placing in the night-time in summer was abandoned.

Fig.14

LN_2 plant installed at the ready-mixed concrete plant

Centrale de LN2 installée dans l'usine de béton

Fig.15

Heat insulator cover installed in the agitating truck

Isolants thermiques installés dans le camion malaxeur

7.4.3. Measurement With Buried Gauges

To observe the behavior of existing and new dam bodies in the concrete placing period and after completion, various measuring gauges such as strain gauges, thermal gauges and etc. were set in the dam body. It has shown an expected behavior from the construction period to the present, and the remarkable problem has not occurred.

CONCLUSIONS

It is expected that upgrading or rehabilitation of existing dams for life prolongment, improvement of safety, and effective utilization will increase from the situations of progress in ageing of existing dams, lack of sites suitable for dam construction, rising tide for environmental preservation and etc. The rehabilitation works of the Taishakugawa dam covered the majority of technical issues on the rehabilitation works of concrete gravity dam. It is assured that the rehabilitation of the Taishakugawa dam will be the model case of dam rehabilitation as the integration of systemized technologies in the future.

Fig. 16

The Taishakugawa dam after rehabilitation

Le barrage de Taishakugawa après la réhabilitation

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SUMMARY

The Taishakugawa dam was completed with the aim of hydropower generation in1924. Its tunnel type spillway is located separately from the dam body and discharges at a rate of 720m^3/s. As the possibility of river floods far greater than the discharge capacity of the existing spillway was confirmed recently, reservoir level had been lowered during flood seasons. However, for a permanent solution to the insufficiency of the discharge capacity, conclusion was reached that the top of existing dam body needed to be cut off, so as to install an overflow spillway on the top of it. The design flood discharge has been set at the Creager rate of 1,610m^3/s, which is more than double the existing capacity.

The existing dam was designed and constructed over 80 years ago and therefore does not satisfy the specific safety requirements (seismic stability) of the current design criteria in Japan. In order to satisfy the safety level of the new dam, it was planned that the new concrete was placed on the downstream face of the existing dam body, and at the same time, the new spillway was constructed on the dam crest.

The rehabilitation work of the Taishakugawa dam commenced in June 2003 and was completed in June 2006.

The rehabilitation works of the Taishakugawa dam covered the majority of technical issues on the rehabilitation works of concrete gravity dam. It is assured that the rehabilitation of the Taishakugawa dam will be the model case of dam rehabilitation as the integration of systemized technologies in the future.

RÉSUMÉ

Le barrage hydroélectrique de Taishakugawa a été achevé en 1924. Son déversoir de type à tunnel est aligné séparément du corps du barrage et possède une capacité d'évacuation de 720 m³/s. La possibilité d'une crue largement supérieure à la capacité d’évacuation du déversoir existant ayant été récemment confirmée, le niveau du réservoir a été abaissé durant les saisons de crue. Cependant, pour avoir un remède permanente à l’insuffisance de la capacité d’évacuation, il a été conclu que le corps supérieur existant du barrage devait être découpé afin d’y installer un déversoir libre au-dessus. La crue de projet a été fixée à 1 610 m³/s, soit plus du double de la capacité existante.

Le barrage existant a été conçu et construit il y a plus de 80 ans et il ne satisfait donc pas aux exigences de sécurité spécifiques (stabilité sismique) des critères de conception actuellement en vigueur au Japon. Afin de satisfaire le niveau de sécurité du nouveau barrage, il a été prévu de disposer du nouveau

béton sur la face aval du corps existant du barrage et de construire en même temps un nouveau déversoir sur la crête du barrage.

Le chantier de réhabilitation du barrage de Taishakugawa a débuté en juin 2003 et a été achevé en juin 2006.

Les travaux de réhabilitation du barrage de Taishakugawa ont couvert la majorité des problèmes techniques liés aux travaux de réhabilitation du barrage-poids en béton. Il est certain que la réhabilitation du barrage de Taishakugawa servira d’exemple de réhabilitation de barrage lors de l’intégration de technologies systémiques à l’avenir.