REHABILITATION OF AN OLD CONCRETE GRAVITY DAM AND ITS COUNTERMEASURES FOR ENVIRONMENTAL PRESERVATION

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Abstract: The Chugoku Electric Power Co., Inc. rehabilitated an old concrete gravity dam, which was completed in 1924, with the aim of improving flood discharge capacity and seismic stability, together with the re-development of existing hydropower station.

In this rehabilitation, an additional spillway was installed, and the new concrete was placed on the downstream face of existing dam body.

Furthermore, as the dam and its reservoir are located in a Quasi-National Park, countermeasures for environmental preservation were needed stringently. We took appropriate countermeasures for environmental preservation under the guidance of pertinent organization and experts.

Outline of this dam rehabilitation and countermeasures for environmental preservation are described in this paper.

Key words: dam rehabilitation, flood discharge capacity, seismic stability, environmental preservation

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 named Taishakugawa dam with the aim of improving flood discharge capacity and seismic stability in addition to supplemental hydropower generation by developing the unutilized energy.

Fig. 1 The Taishakugawa dam (Before rehabilitation)

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.

- 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.

2. Outline of the rehabilitation work of the Taishakugawa dam

2.1 General description

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.

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 current safety level of the dam, it was planned that the new concrete was placed on the downstream face of existing dam body.

Table 1 Dimensions of the Taishakugawa dam

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

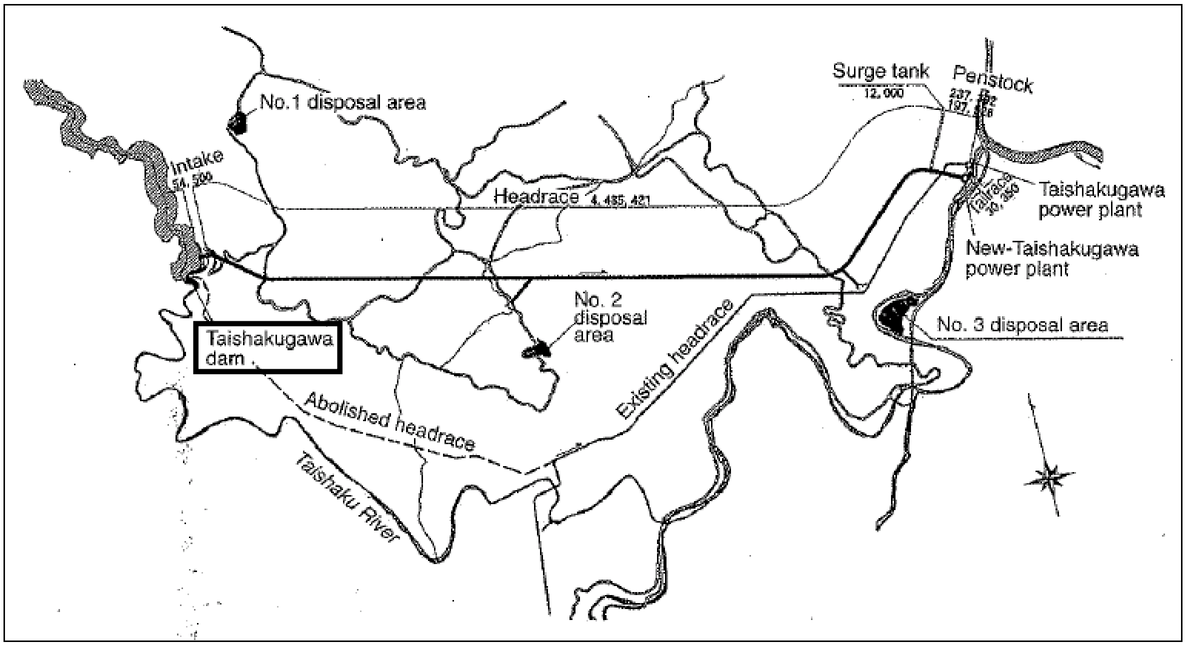

Fig. 2 Plan of Shin-Taishakugawa hydropower project

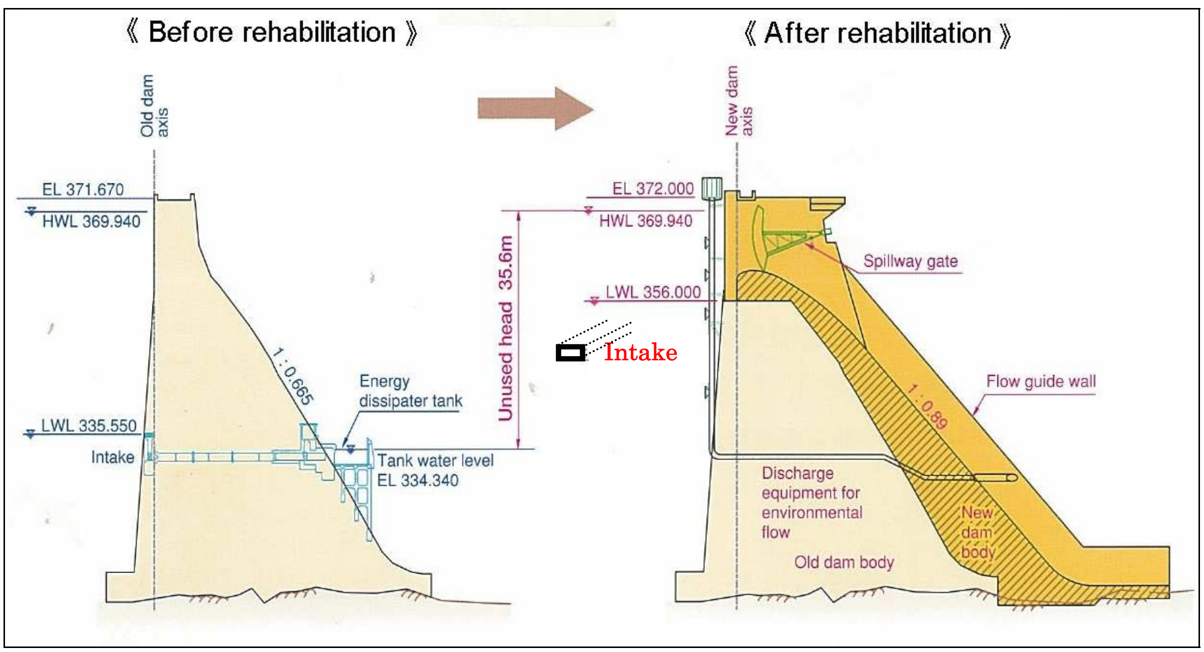

Fig. 3 Cross section of the dam rehabilitation work

3. History and features of the Taishakugawa dam

The Taishakugawa dam is located in Hiroshima Prefecture in western Japan. 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. 1. 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 (See Fig.4). So, the dam and reservoir are the treasurable tourism resources for local people.

Fig.4 Reservoir and a sightseeing boat

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. 5.

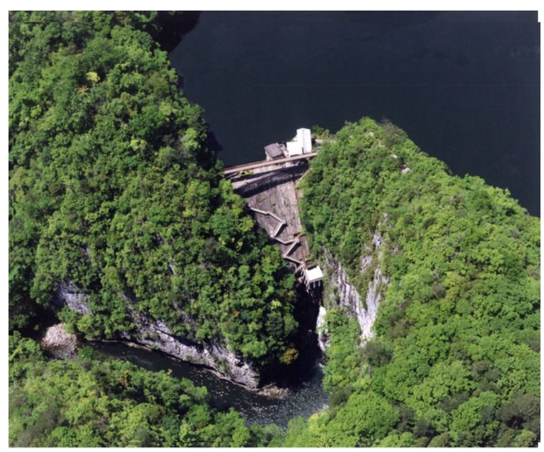

Fig. 5 Steep cliffs of limestone around the dam

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.

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.

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.

6. Features of design and construction works

6.1 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 Design theory and unification of existing and new dam bodies

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.

Accordingly, unification of existing and new dam bodies 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. Moreover, 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.

6.3 Adoption of ready-mixed concrete and maximum aggregate size of 40 ㎜

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.

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.

6.4 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 (See Fig.6). Moreover, the dam concrete was placed by setting up similar steel-made temporary stage (43m in maximum height) on the downstream of the dam (See Fig.7), and by using 80t crawler crane.

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. 6 Steel-made temporary road in the reservoir

Fig. 7 Steel-made temporary stage on the downstream of the dam

7. River environmental preservation measures

7.1 Outline of the river environment

Taishakugawa River where the Taishakugawa dam is located is expected relatively clean water quality by the environmental criteria of Japan. As the results of water examinations, BOD is 0.6 mg/l on the average, which satisfies the water quality standard of 2.0mg/l.

The length of the area affected by river diversion is about 11km, and the situation of the river is divided by the junction of the tributary (Hukumasugawa River). In the upstream area, the extremely steep cliffs made of limestone are consecutive, where people cannot easily access, and the width of the river is narrow (See Fig.8). On the other hand, in the downstream area, the river is wider, and the roads, houses, cultivated lands can be seen on the both banks like ordinary rivers (See Fig.9).

As the results of environmental surveys, 42 species of fishes, 107 species of aquatic insects, and 10 species of benthos were confirmed in the project area, which included the 3 precious fishes of Oncorhynchus masou ishikawae, Tanakia lanceolata, and Liobagrus reini.

As there is a series of dams owed and operated by the Chugoku Electric Co., Inc. in the downstream area of Shin-Taishakugawa hydropower station, ascending fishes such as salmon and trout cannot ascend the river. Main fish for the fishery is sweetfish, which is planted in the river.

Fig. 8 The area affected by river diversion (Upstream area)

Fig. 9 The area affected by river diversion (Downstream area)

7.2 Discharge of river maintenance flow

In order to preserve the environment of the area affected by river diversion, river maintenance flow is discharged from the Taishakugawa dam at the rate of $0.687m^3/s$ (from December to March) or $0.360m^3/s$ (from April to November). Discharge of river maintenance flow is determined by Japanese regulation, considering fishery, scenery, preservation of flora and fauna, and etc.

7.3 Flush discharge

Influence on the ecosystem of the river would hardly be seen by the discharge of river maintenance flow. But, the flatness of the river discharge cannot be avoided according to the storage by the dam.

To improve the infection of the flatness of the river discharge, Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) is attempting flush discharge, which means the small-scaled artificial flood, on some dams.

For the first time in Japan for dams of hydropower, flush discharge with rate of $4.7m^3/s$ has been regularly executed in the Taishakugawa dam after the completion of construction works.

Fig. 10 Flush discharge at the dam site

Although this flush discharge executed in the Taishakugawa dam is small-scaled compared with that of MLIT, frequency (16 times per year) is much higher than that of MLIT. Therefore, this flush discharge is regarded as the new attempt to give the variations in the river discharge.

To confirm the effect of flush discharge, monitoring of the river has been continued from 2002. Sediment on the riverbed was confirmed to move by flush discharge. But, the effect on the river environment including ecosystem cannot be confirmed at the present moment because of the short time from the beginning of the operation. Therefore, the accumulation of surveys should be needed to grasp the effect of flush discharge accurately.

8. Other environmental preservation measures

8.1 General description

As the dam and its surroundings are situated within a Quasi-National Park and a district of officially-designated beauty spots, stringent regulations are applied to development actions in the area for the purpose of protecting its flora and fauna and preserving its scenery. Accordingly, surveys of the current situation regarding vegetation, wildlife, river water quality, noise, vibration and landscapes in the site's surrounding area were carried out so as to assess the project's environmental impacts and thereby be able to take appropriate environmental preservation measures during the construction period. These measures were taken under the guidance of pertinent organizations and experts.

8.2 Measures to protect precious bird species

Environmental surveys revealed the presence of hawk eagle, a rare bird of prey, in the surroundings of the construction areas. Accordingly measures below were taken to protect this bird and continuous surveys were carried out to determine its habitat and breeding situations during the construction period.

- Bedrock excavation work within areas where the hawk eagle could be impacted was suspended during the bird's breeding season which lasts from January to July.
- Low-noise type construction machinery was used wherever possible. Further, soundproofing doors/sheets and similar were used to keep the noise from blasting down to the lowest level possible.
- Monitoring of hawk eagle's habitat and breeding situations continued throughout the construction period, and the results of monitoring were reported to the expert periodically.

Owing to these measures, no impact on bird's habitat or breeding was found.

Fig.11 A brace of hawk eagles

8.3 Measures to protect flora and fauna

Taishakukyo-valley where the Taishakugawa dam is located is known by rich natural environment and a variety of precious flora and fauna. A lot of precious flora and fauna were confirmed around the dam by the environmental surveys, and basically they had been moved or transplanted to the safety area that would not be impacted by the project before construction works were started, and they were also monitored when under construction. The results of monitoring were reported to the experts periodically.

As the results of monitoring, it was confirmed that most of moved or transplanted flora and fauna were sound.

Fig.12 An example of precious fauna (Stereophaedusa costifera)

8.4 Landscape architecture design

Landscape architecture design was employed with the guidance of an expert in harmony with rich natural environment around the dam, as shown in Fig.13.

Fig.13 Landscape architecture design (CG)

9. 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.

Moreover, the environmental preservation measures were carried out effectually in consideration for the rich natural environment.

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.14 The Taishakugawa dam after rehabilitation

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