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Large-scale Dam Body Drilling by Tsuruda Dam Redevelopment Project

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ABSTRACT:
The Ministry of Land, Infrastructure, Transport and Tourism is now redeveloping Tsuruda Dam. The objective of the project is to improve its flood control function by increasing its flood control capacity and installing 3 additional large outlets for flood control. Remarkable features of the project are its large scale: 6m diameter holes and 4.8m diameter outlet. And the height of the dam crest above the holes is more than 60m.

This work had to be executed while ensuring Tsuruda Dam's flood control and water supply functions, requiring the construction of a cofferdam in the reservoir before drilling the dam body. Because underwater work at the large depth was necessary, we developed a new type of floating cofferdam.

This report introduces an outline of large-scale dam body drilling at Tsuruda Dam redevelopment project.

Keywords: dam body drilling, dam redevelopment, floating cofferdam, vibration velocity

1. OUTLINE

It is considered that the necessity of projects to redevelop existing dams will become greater in the future in light of their merits compared with a new dam construction project. Redevelopment can [1] manifest flood control and water supply effects much earlier, [2] minimize impacts on the natural and social environments, and [3] can achieve economic purposes.

Figure 1. Conceptual drawing of completed redevelopment work（White colored parts are redeveloped.）

Tsuruda Dam is a 117.5m high concrete gravity dam completed in 1966. In 2006, record-breaking torrential rainfall occurred in its catchment, causing severe flood damage in the downstream basin, even though Tsuruda Dam made full use of its reservoir capacity to control the flood. The Ministry of Land, Infrastructure, Transport and Tourism is now redeveloping Tsuruda Dam. The objective of the project is to improve its flood control function by increasing its flood control capacity from 75 million m^3 to 98 million m^3, and at the same time, drilling the right side of the dam body to install 3 additional outlets for flood control (Fig. 1).

Remarkable features of this project are its large scale, the 6m diameter of the hole drilled and the 4.8m diameter outlet installed in the dam body. And the height of the dam crest above the holes is more than 60m.

At the design stage, we carried out detailed analytic study of the stress generated by the drilling of the dam body, and conducted a preliminary drilling test, too. During execution, we monitored vibration velocity to prevent the dam body drilling from harmfully effecting the dam body concrete. This work had to be executed while ensuring Tsuruda Dam's flood control and water supply functions, requiring the construction of a cofferdam in the reservoir before drilling the dam body. It is usually necessary to place pedestal concrete as the foundation on the reservoir side and to construct the cofferdam on top of the pedestal. But at Tsuruda Dam, because underwater construction work in deep water was necessary, we developed a new type of floating cofferdam. Cofferdam assembled in advance on the reservoir surface was towed to the dam body and installed there, eliminating the need for a pedestal concrete, reducing the quantity of deep underwater work and speeding up the work.

The redevelopment project of Tsuruda Dam includes, in addition to these works, improvement of the existing energy dissipation works, and the relocation of two penstocks on the left side of the dam body.

This report introduces an outline of the design and execution of large-scale dam body drilling at Tsuruda Dam redevelopment project.

2. DEVELOPMENT OF THE FLOATING COFFERDAM

2.1. Outline

Dam redevelopment projects in Japan are often executed while maintaining the dam’s flood control and water supply functions. To drill a dam body while it stores water, it is necessary to install a cofferdam upstream the dam body in advance, then drain the water from inside it to create a dry space on the reservoir side. At Tsuruda Dam, we developed a new type of floating cofferdam and used along with a conventional pedestal concrete type cofferdam, verifying the effectiveness of the new floating cofferdam.

2.2. Background to the technology development

In Japan, cofferdams installed inside reservoirs are usually either the bearing frame type or pedestal concrete type. A bearing frame type cofferdam is constructed by first installing a brace and the cofferdam’s bottom shutter in the water, then constructing the cofferdam on top of it by assembling shutters one level at a time. A pedestal concrete type is built by excavating the concrete footing and bedrock at the upstream side of the dam body, then installing the pedestal concrete. The cofferdam is constructed by assembling shutters one at a time above the pedestal concrete. In case of Tsuruda Dam, according to the initial plan, in order to ensure safety of the cofferdam from the large buoyancy acting on it, the pedestal concrete type was to be adopted for the cofferdams at all three outlets.

A pedestal concrete type cofferdam requires diving work to excavate the foundation bedrock in the reservoir, to remove the existing concrete footing, and to place the pedestal concrete. At Tsuruda Dam, the diving work must be done at a depth of more than 30m.To insure the safety of the divers, it is necessary to use special diving technology called saturation diving. And the existing concrete crushing work in deep underwater was very difficult. This presented problems related to the cost of the work, difficulty of execution, and work period. So as the cofferdam used for the No. 3 outlet which was installed furthest to the right of the three outlets, we adopted the newly developed floating cofferdam (Fig. 2).

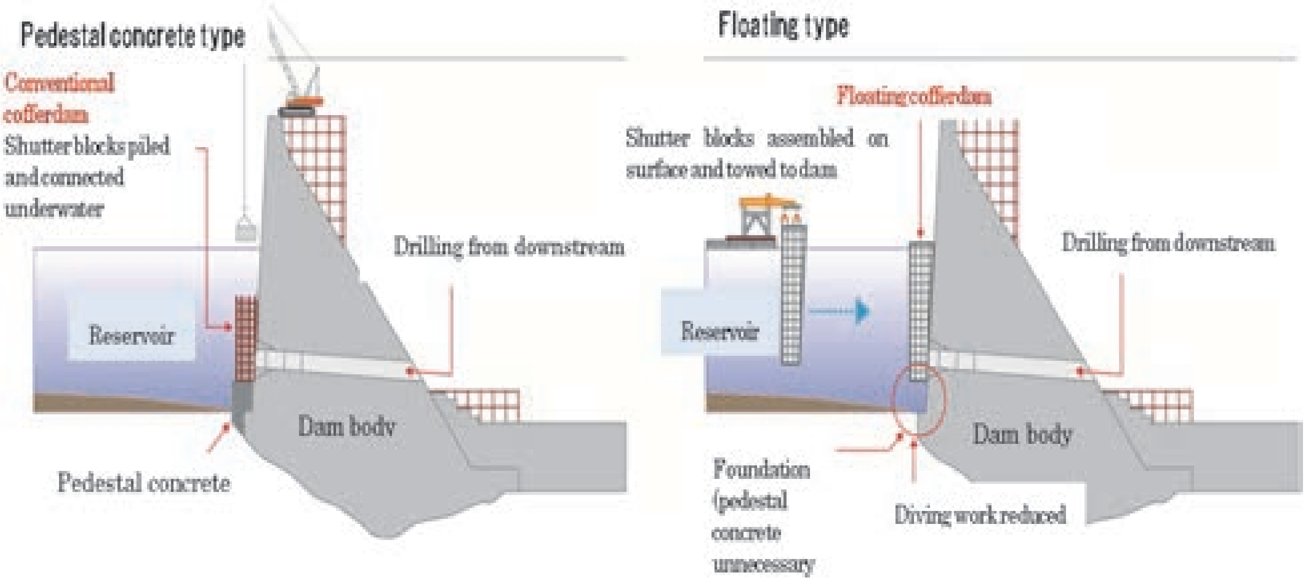

Figure 2. Comparison of pedestal concrete type and floating type

2.3. Structure of the floating cofferdam

A floating cofferdam applies the ballast water technology of oil tankers. On the shutter blocks of a floating cofferdam, air-tight buoyancy chambers are formed by attaching steel plates (skin plates) on the inside and outside (Fig. 3). The quantity of water in the buoyancy chambers installed on each shutter block is adjusted, permitting control of buoyancy acting on the shutters and their attitude. The cofferdams are shaped asymmetrically, and if buoyancy is simply applied to the shutters, only one side is buoyant and it rotates, so its attitude cannot be maintained. Thus, when a shutter is installed, it is necessary to maintain a balance between self-weight and buoyancy by filling and draining the buoyancy chambers inside the shutter in a correct sequence. When water has been drained from inside the cofferdam, water pressure presses the watertight rubber installed on the shutters against the gate sheets installed in advance on the dam body, maintaining water-tightness. It is designed so that the friction resistance produced by water pressure and the floating prevention hardware installed above the shutters resists the buoyancy that acts on the cofferdam.

2.4. Execution

Shutter blocks manufactured at an on-site plant are assembled on the surface of the reservoir (Fig. 4).
The assembled cofferdam is towed to the installation location at the dam body where it is pulled against and installed on the dam body with a winch (Fig. 5).
After it is installed, water is drained from the cofferdam by pumps (Fig. 6).
Leakage from the cofferdam after draining was extremely small, at about 1 liter/minute (Fig. 7).

2.5. Effects of the floating cofferdam

The floating cofferdam reduced deep water work, because large scale equipment such as pedestal concrete or bearing frame of a conventional cofferdam were unnecessary. This resulted in safer execution, a shorter work period, and lower cost. When drilling multiple holes in a dam body, such as was done at Tsuruda Dam, it is necessary to dissemble and reassemble cofferdams just as it is with the conventional method. But in the case of a floating cofferdam, it is possible to tow it to the next execution location and easily install without disassembling the shutters. This method is, therefore, counted on to be applied to other dams in the future.

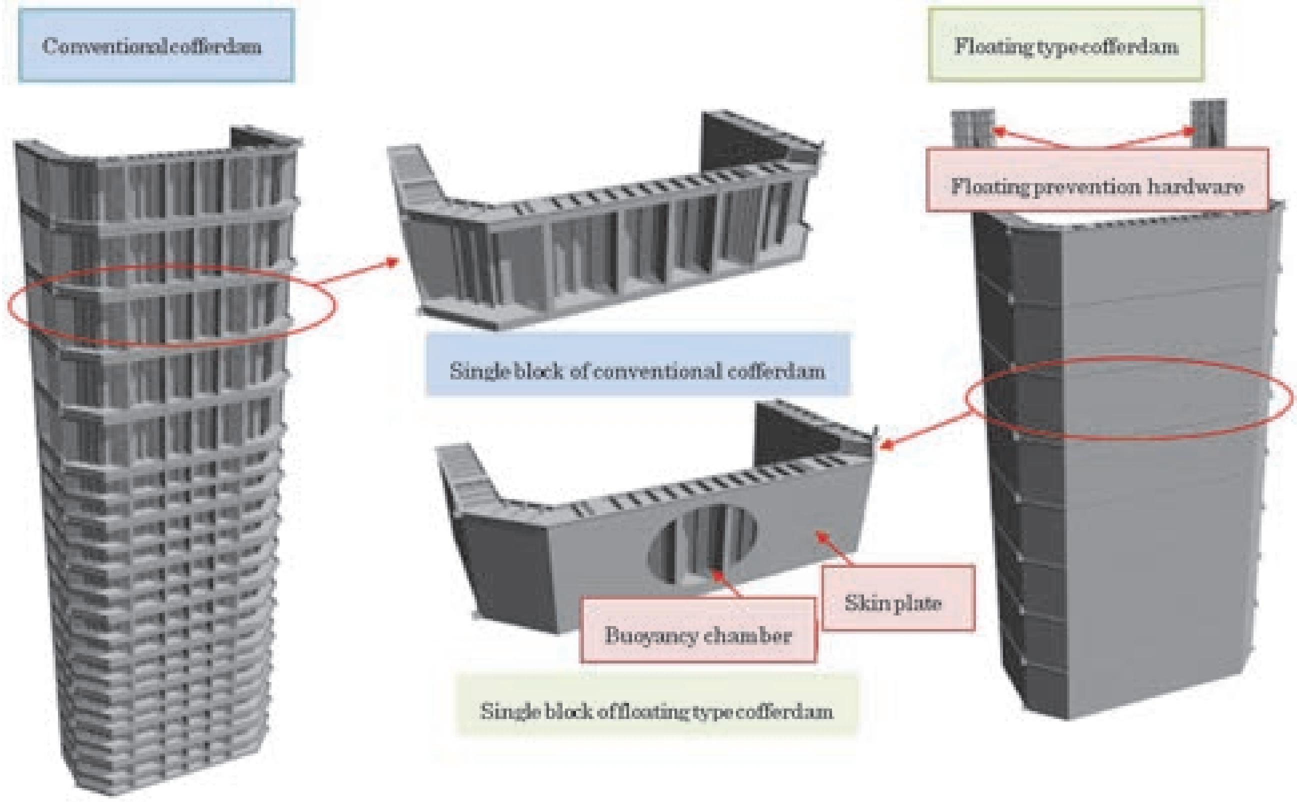

Figure 3. Comparison of conventional type and floating type cofferdams

Figure 4. Assembly on the reservoir

Figure 5. Towing to the dam body

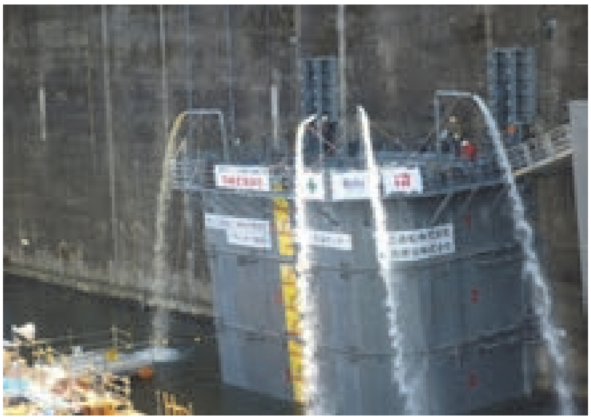

Figure 6. Drainage by pumps

Figure 7. Inside the cofferdam after drainage

3. DRILLING THE DAM BODY

3.1. Outline of the drilling work

At Tsuruda Dam, 3 holes are drilled in the right side of the dam body. In Japan, there have been several cases of dam body drilling, but remarkable features of the Tsuruda Dam projects are its large scale: 6m diameter holes and 4.8m diameter outlet, and the more than 60m level difference between the bore holes and the dam crest.

If the hole diameter is smaller than 5m, which is 1/3 of the 15m width of 1 block, stress generated in the dam body concrete during drilling is not so large. But the hole diameter of Tsuruda Dam is 6m. And the height of the dam crest above the holes is more than 60m. In Japan, there has never been a case where holes were drilled with such large diameter so far below the dam crest. So the design work included a detailed analytical study of the tensile stress that will be generated in the concrete during drilling of the dam body. And a preliminary drilling test conducted in advance of the work confirmed that the drilling does not cause cracking. A control value was set for vibration velocity and during execution the vibration velocity was constantly monitored in order to prevent any harmful impacts on the dam body concrete.

3.2. Measures taken at the design stage

3.2.1 3D stress analysis

In order to confirm the tensile stress that will be generated in the concrete during drilling of the dam body, 3D finite element method based stress analysis was performed. The results confirmed that tensile stress produced in the crest of the hole during drilling will be below the concrete tensile strength. And stress analysis was also performed of the tensile stress that will be generated by fluctuation of the reservoir water level when the reservoir is in operation after completion of the redevelopment project. The results confirmed that it will be below the tensile strength of the concrete. These analyses were done using a model that abstracted only one block of the dam body. In fact, tooth-shaped keys were formed at the transverse joints between the blocks of the dam body, and to control the behaviour of both blocks, the actual tensile force produced was reduced to a level lower than the analysis value. It is estimated that the analysis value will be higher than the stress actually produced and on the safe side.

3.2.2 Shapes of the excavation sections

The shapes of the excavation section selected were rectangular. This selection was made because it will lower the maximum value of tensile stress by 25% than in the case of a circular section.

3.2.3 Preliminary drilling test

Among dam redevelopment projects already undertaken in Japan, the tensile stress generated during drilling of the dam body of Tsuruda Dam is the largest value. So before starting drilling, a trial drilling was done on the downstream slope of Tsuruda Dam at almost the same location as tensile stress is generated during drilling. The results of the trial drilling confirmed that tensile cracking will not occur, so final full-scale drilling work was started.

3.3. Measures taken during execution (measuring the vibration velocity)

In order to prevent harmful effects on dam body concrete by drilling work, 2 to 5 kine (1kine = 1cm/s) is normally set as the vibration velocity control value, during execution to perform the execution under the control value. For Tsuruda Dam, the control value of the vibration velocity was set at 2 kine. Before and during the work, the vibration velocity was measured at three stages from Phase 1 to Phase 3 shown below.

3.3.1 Phase1 : Measurement on the downstream surface of the dam body

Before drilling No. 3 outlet, which was the first drilled, a vibration velocity gauge was installed on the downstream slope of the dam body and used to measure the vibration velocity. The drill machine is a free cross-section excavator.

3.3.2 Phase 2: Measurement in the inspection gallery

On the left side of Tsuruda Dam, work to relocate 2 penstock is in progress. The No. 1 penstock will cross the inspection gallery inside the dam body. So when the hole for the No. 1 penstock was drilled, a vibration velocity gauge was installed on the side wall of the inspection gallery and used to measure the vibration velocity before pass through. This was done in order to confirm the suitability of concluding drilling at a location where the thickness of the concrete from the upstream surface of the dam body was 80cm.

3.3.3 *Phase3: Measurement on the upstream surface of the dam body*

When the bell mouth that will be installed on the upstream side of the dam body was drilled, a compact vibration velocity gauge was installed on the upstream surface of the dam body to measure the vibration velocity.
The measurements were done at all drilling locations.

3.4. Evaluating vibration velocity

The relationship of the distance from the drilling location and the measured maximum value of vibration velocity is shown in Fig. 8. This figure shows results of all measurements from Phase 1 to Phase 3 at Tsuruda Dam including the results of measurements made earlier at Yoroihata Dam. The measured vibration velocities are smaller than the control value of 2 kine, and it can be concluded that the vibration of dam body drilling by a free section excavator will not impact the existing dam concrete.

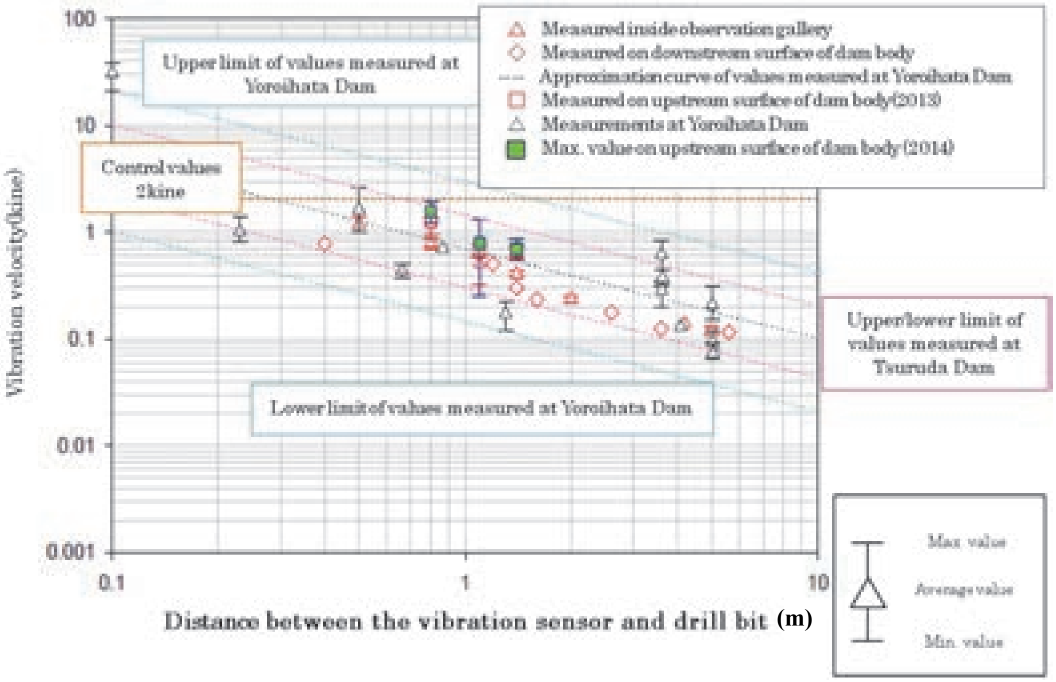

Figure 8. Distance from drilling location and vibration velocity

The following conclusions have been reached based on these results.

- When a free section excavator is used to drill a dam body, it generates low vibration velocity and actually has no harmful impact on the dam body concrete.
- When vibration velocity is measured, the distance between the blades and measuring location at vibration velocity of 0.1 kine or higher is good after it is smaller than 2m.

4. CONCLUSIONS

At Tsuruda Dam redevelopment project, we developed a new type of floating cofferdam. Leakage from the cofferdam after draining was extremely small. The floating cofferdam reduced deep water work. This resulted in safer execution, a shorter work period, and lower cost. When drilling multiple holes in a dam body, it is possible to tow it to the next execution location and easily install without disassembling the shutters. We hope the floating cofferdam will be applied to other dam redeveloping projects in the future.

We used a free section excavator to drill the dam body.

It generated low vibration velocity and actually had no harmful impact on the dam body concrete.

Large-scale dam body drilling of Tsuruda Dam started in 2011, and the three outlets and new energy dissipation works on the downstream side were completed in March 2016.