UNMANNED MAINTENANCE WORK WITH UNDERWATER REMOTELY OPERATED VEHICLE (ROV) FOR DISCHARGE FACILITIES OF DAMS

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ABSTRACT

For maintenance work of discharge facilities of dams, manned diving operations have been usually implemented. And in some cases, they have been carried out in deep water over 40 meters. However, manned diving puts divers at the risk of fatal accidents. Therefore, the use of an unmanned underwater Remotely Operated Vehicle (ROV) will make the maintenance works safe, and also will contribute to cost reduction by avoiding the use of expensive diving support equipment.

As a first approach, we developed an underwater ROV to carry out the work for setting a water shut-off cover at the tap of water filling pipe facing reservoir water. We tested this work in a laboratory water tank and then at actual dam sites. The evaluation results of the test at actual dam sites suggest that this work is ready for practical application.

1. INTRODUCTION

In a dam, a lot of mechanical equipment is installed under water. A water filling system discussed in this paper is no exception (Fig. 1). The system, with its water filling pipe installed in deep water to take water, plays an important role in discharging water from a dam. Currently, such pipes are generally made of stainless steel. However, dams built before around 1980 used many piping-purpose carbon-steel pipes in Japan. The water filling pipes are generally buried in concrete, but exposed near the valve to conduct water filling operations (Fig. 2). The pipes require periodic repair to prevent leakage due to corrosion (Fig. 3). The valves sometimes also require complete replacement, if their function has deteriorated, even if they are made of anti-corrosive materials. As you see from the Figure 2, when we need to maintain the system at the upstream of the sub valve, we need to stop water at the inlet of the water filling pipe.

So far, we have employed diver operations to cap the inlet under water. This inlet is usually located in deep water, sometimes at a depth of more than 40 meters. To carry out such maintenance, we need to lower the dam water level and use mixed gases for diving (or saturation diving equipment, depending on the work). Just to install a cover on the inlet of the water filling pipe, we need to conduct very dangerous work in deep water at a depth of more than 40 meters. Moreover, the operation also creates a significant impact on reservoir management and incurs a lot of costs for equipment for diving and human supports. Diving operations in very deep water carry a high risk and the number of skilled divers who can deal with such risks is decreasing.

Under this situation, we developed an unmanned maintenance technique using an underwater ROV.

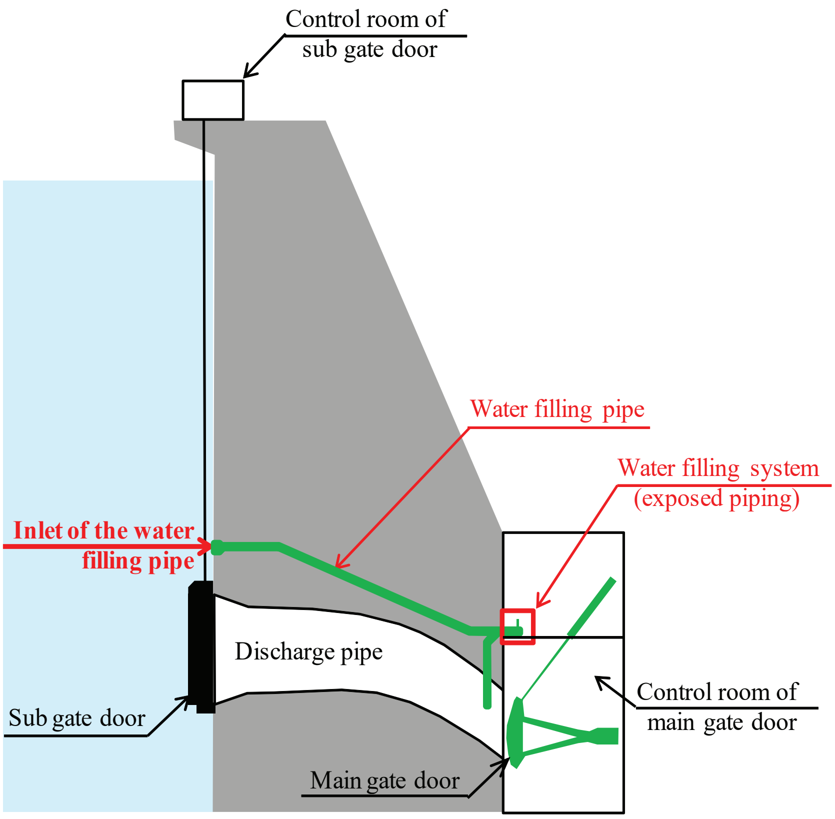

Figure 1 : General arrangement drawing of service spillway facilities

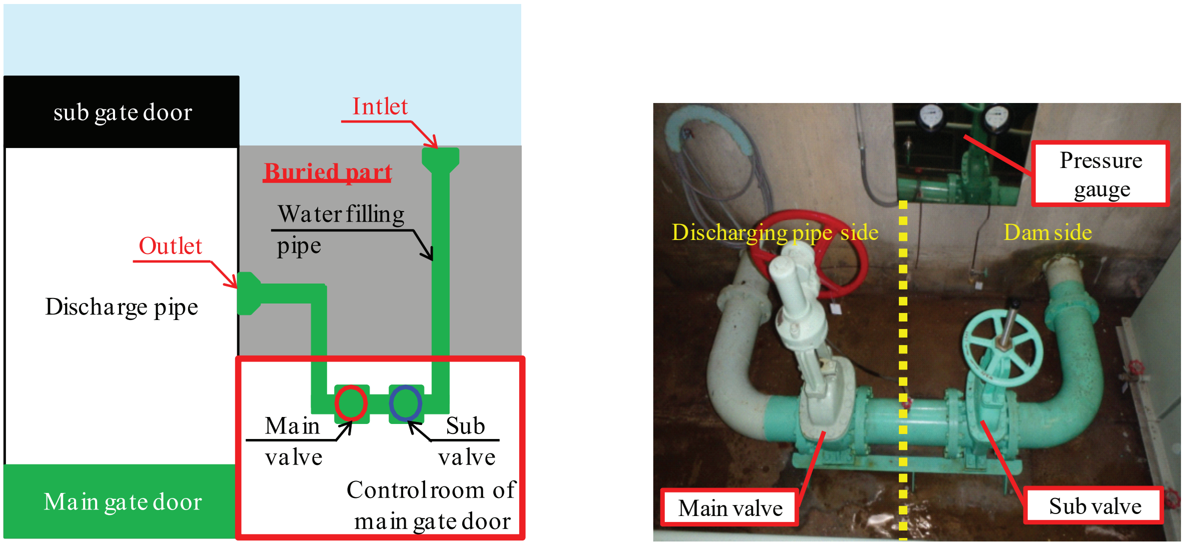

Figure 2 : Structure diagram of water filling system and water filling system (exposed piping)

Figure 3 : Damaged pipe (leakage) and its repair

2. STRUCTURE OF WATER FILLING SYSTEM

2.1 Inlet

The inlet of the water filling system is usually installed near the inlet of the discharge pipe at the reservoir side of the dam. However, its location may differ by each dam. In addition, each dam has its own shape of installation surface, shape of concrete, and conditions of concrete, such as uneven concrete surface or limited flat space where the water filling pipe is located.

2.2 Water filling valve

The water filling pipe after the inlet is buried in the dam body and its valves for water filling operation are generally exposed in the inspection gallery. The exposed section includes main and sub water filling valves. Water leakage due to corrosion after years tends to appear here. Even if without water leakage, the equipment constituting the exposed section needs to be periodically replaced or repaired.

3. TECHNICAL METHODS TO STOP WATER INTO THE WATER FILLING PIPE

Maintenance of the water filling pipe is needed and we should select the best technical method to eliminate any adverse impact on dam operation.

3.1 Method to install a water stop cover

A screen is provided at the inlet of the water filling pipe. This method requires installation of a water stop cover over the entire part of the inlet including the screen. The water stop cover needs to be manufactured according to the shape of the inlet of the water filling pipe at each dam, installed and removed by a diver.

Figure 4 shows an image of installation of a water stop cover by a diver.

3.2 Freezing method

This method freezes the exposed piping and water inside at the upstream of the sub valve with liquid nitrogen and stops water flow with ice in the pipe (Fig. 5). This method may not be applicable, depending on the material, coating, paint type, and/or pipe diameter.

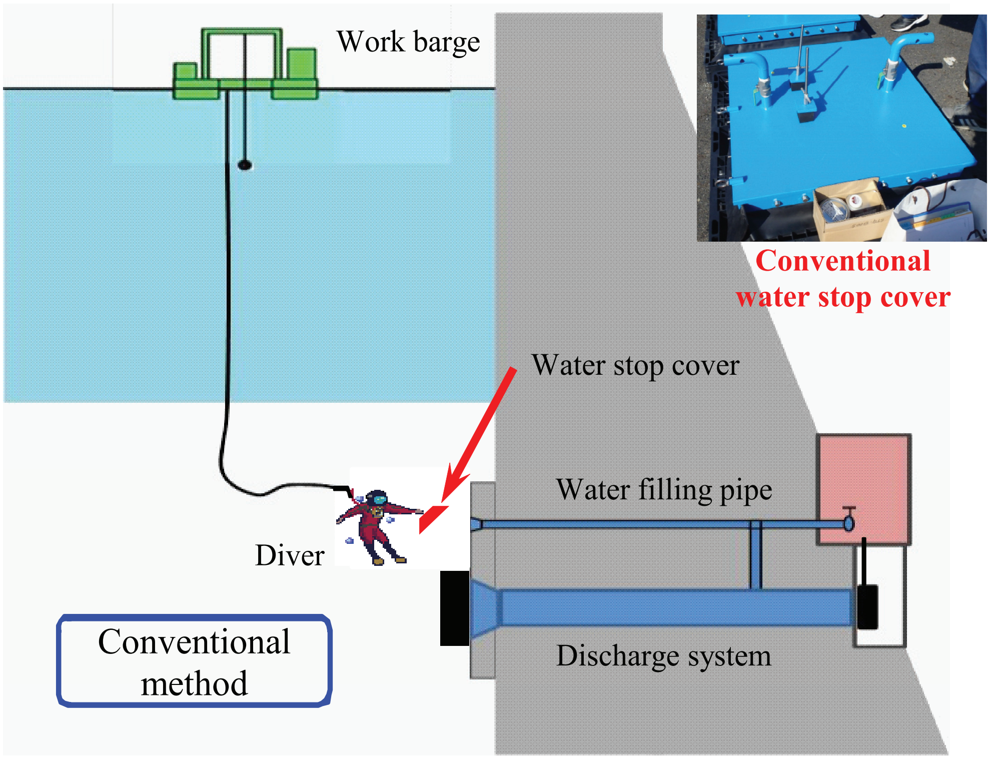

Figure 4 : Image of installation of a water stop cover by a diver

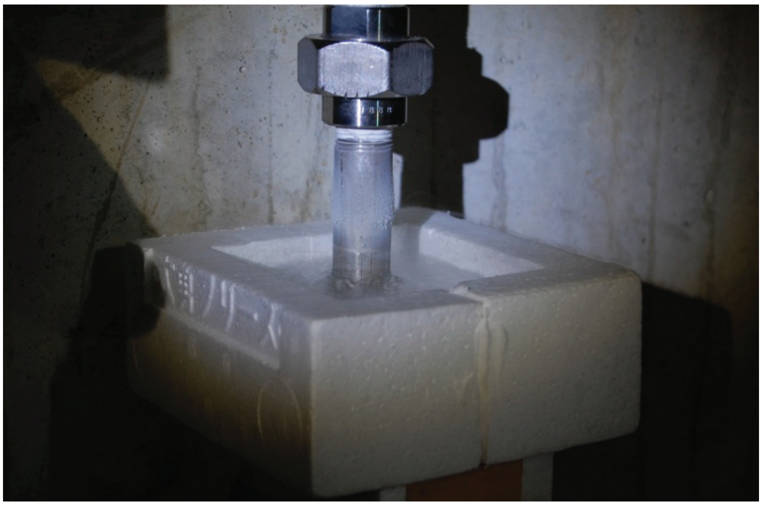

Figure 5 : Frozen piping

4. UNMANNED MAINTENANCE WORK WITH AN UNDERWATER ROV

We focused on the technical method of "Installation of a water stop cover" to stop water into the water filling system, which creates the least impact on dam operations, and accepts differences of pipe shapes or materials. And we aimed to develop a robot which requires no divers in consideration of their safety. To develop this technique, the following problems must be solved:

- Water stop mechanism for uneven concrete surface
- Attaching/detaching mechanism between the underwater ROV and the water stop cover
- Water injection mechanism to the water filling pipe
- Operability of the underwater ROV

4.1 System configuration (final version during the test at Hiyoshi Dam)

We adopted an underwater ROV, which had been developed for an inspection of waterways in power plants, as our main unit. It can go underwater up to a depth of about 100 meters. We adopted a bowl-type cover with an internal diameter of 800 mm and flexible watertight rubber located along its circumference, so that it can be applied to various types of water filling pipe inlets. After installing the water stop cover, we drain water from the water filling pipe. The cover is pressed to the concrete surface around the pipe by the surrounding water pressure of the dam reservoir, which lead to stop water into the pipe.

Electromagnets are used to attach/detach the water stop cover to/from the underwater ROV at three points.

The water injection mechanism is operated by a needle valve, maneuvering a power cylinder to enable reliable water injection under high water pressure.

The underwater ROV is equipped with thrusters moving to the traverse, propulsion, and vertical directions. The underwater position can be sufficiently controlled with three-direction thrusters and the attitude control system mounted on the main unit (weight drive method). However, to help its movement with a water stop cover mounted on its top, an adjuster using a float is also provided. With increasing depth and water pressure, the water stop rubber of the water stop cover receives compression deformation and changes its buoyancy.

The underwater ROV is equipped with an optical camera to secure the view required for operation. In addition, to help its movement in deep water with diminishing light, additional lights, ultrasonic sonar for position recognition and an acoustic camera for geometry recognition are provided to assist the function of the optical camera.

Figure 6 shows the system configuration of the underwater ROV and Figure 7 shows the structure of the new water stop cover.

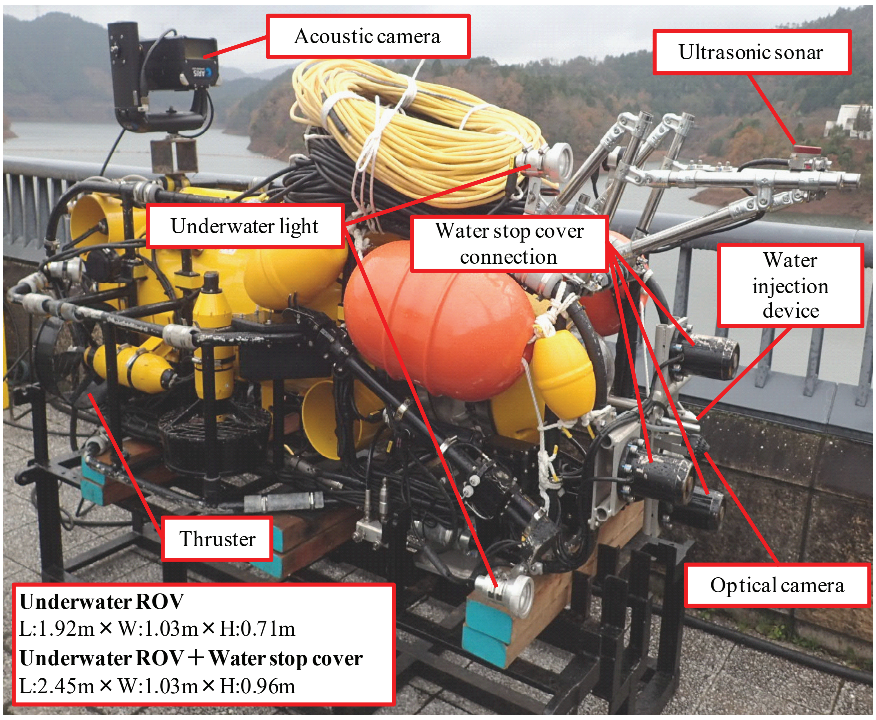

Figure 6 : System configuration of the underwater ROV

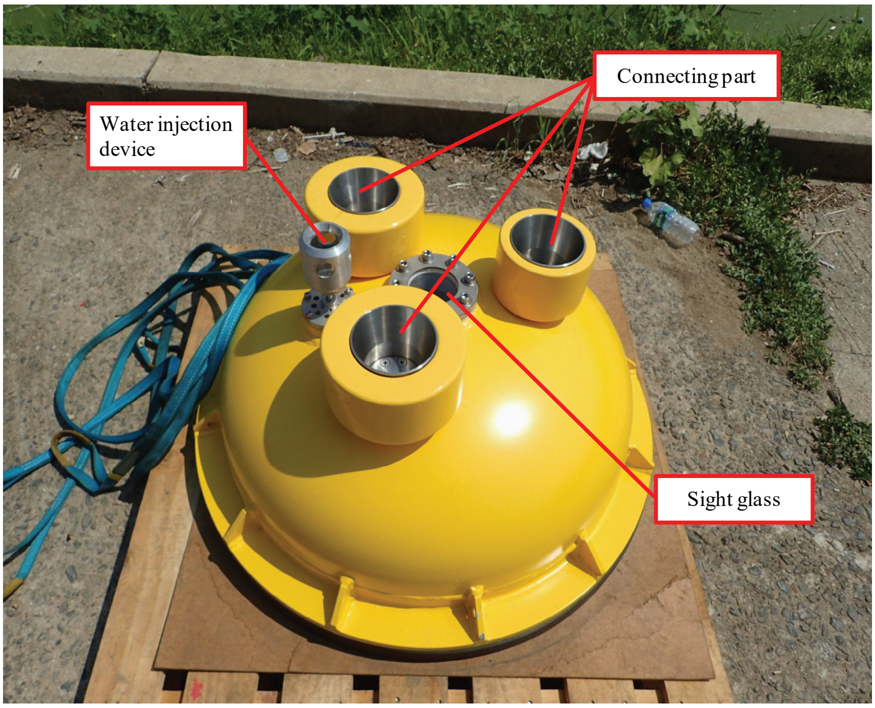

Figure 7 : New water stop cover

5. DEMONSTRATION TESTS TOWARD PRACTICAL APPLICATION

5.1 Test at Takayama Dam (Fig. 8)

5.1.1 *Test conditions and status*

Test period: August 8-10, 2016 (clear weather for three days)

Test water depth: 9.5 meters

Turbidity: 3.7-4.0 (at a depth of around 9.5 meters at the inlet of the water filling pipe)

5.1.2 *Takayama Dam is an arch gravity dam with 67m of dam height.*

We employed a diver to monitor the ROV used in the first field test. On the first day, we only submerged and surfaced the ROV. On the next day, we approached to the inlet of the water filling pipe and attached the water stop cover over the concrete surrounding the inlet. On the final day, we installed the cover, drained water from the water filling pipe, detached the cover from the ROV, examined the water tightness, and withdrew from the site.

During the submergence on the first day, we found that a lot of aquatic organisms had attached themselves to the inlet screen. The concrete structure around the inlet of the water filling pipe at Takayama Dam was complex and we needed to install the water stop cover by offsetting its center by 30 mm from the center of the inlet. However, due to the aquatic organisms there, we had difficulty in finding the inlet center (Fig. 9). In addition, due to the turbidity on the day and waterweeds on the water surface, we lost our view at a depth of 6 meters. We turned on an underwater light to secure visibility of 1 meter. From the next day, we increased the number of underwater lights to secure visibility during the test. To examine the aquatic organism's disturbance to the water tightness of the water stop cover, we also sent a diver. We confirmed that the installation of the water stop cover was completed by the ROV alone, without any assistance from the diver.

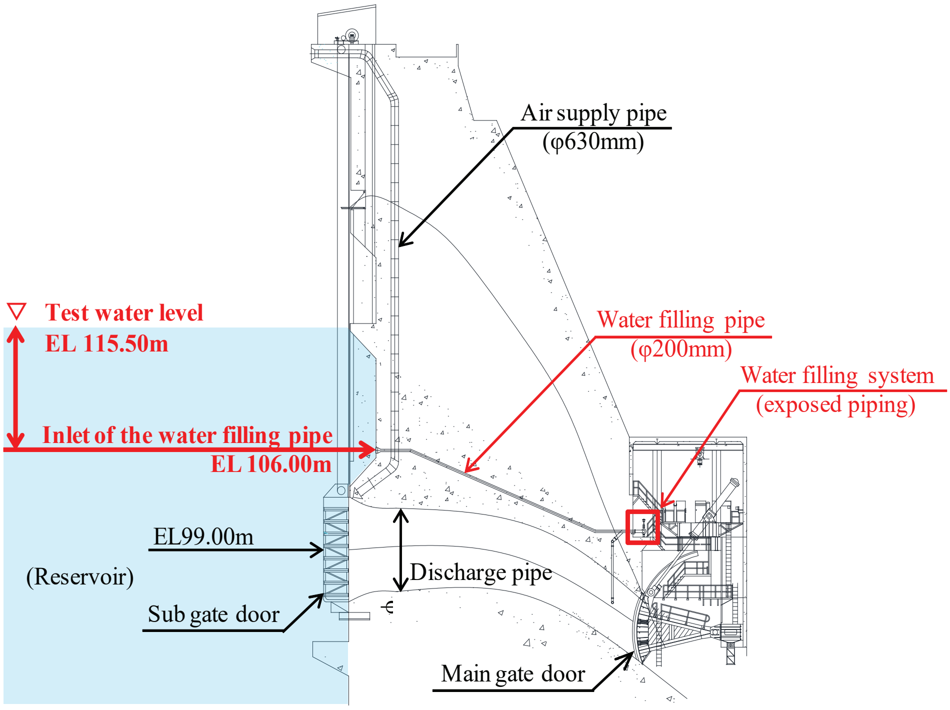

Figure 8 : Vertical sectional view of Takayama Dam

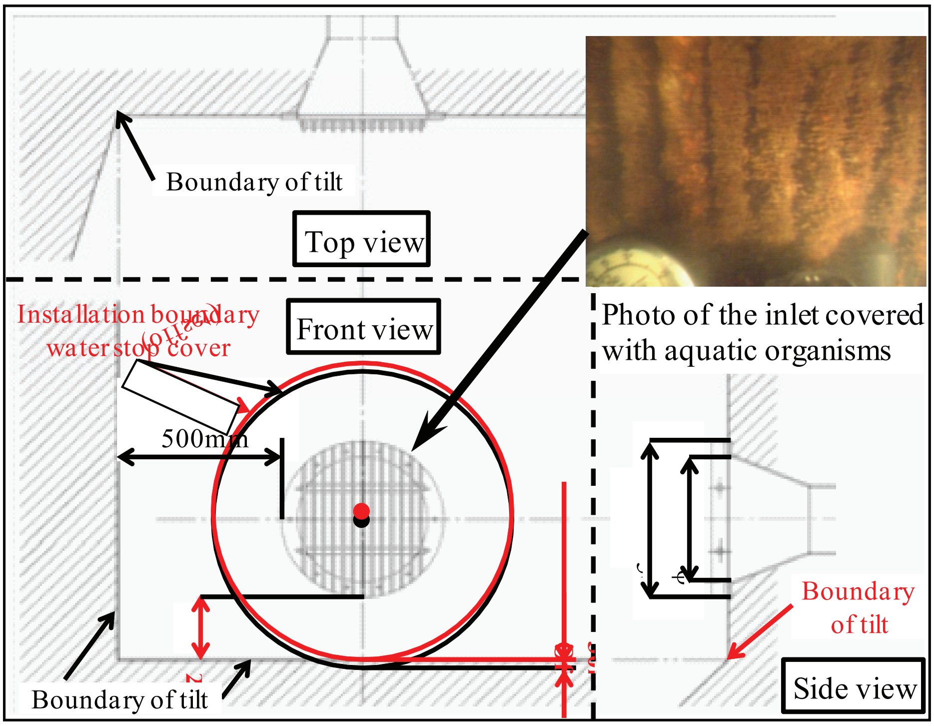

Figure 9 : Inlet of the water filling pipe of Takayama Dam

5.1.3 *Test results and consideration*

A standard light mounted on the ROV was not sufficient to secure the necessary visibility for operation, because the water stop cover mounted on the front of the ROV blocked the front view and the light was too near to the installation position, which reduced the range illuminated by the lights. Therefore, we need to increase the number of underwater lights.

The water tightness of the water stop cover was sufficient even on an inclined surface. At Takayama Dam, even at a relatively shallow water depth of 9.5 meters, and with attachment of aquatic organisms, we confirmed excellent water tightness and the leakage of only 0.3 ml/min, much better than the construction management standard at the installation of a jet flow gate.

The function to attach/detach the water stop cover to/from the ROV worked without any problems. However, due to contact with something during submergence, the cover detached from the ROV. This can be avoided by strengthening the electromagnetic force.

The specific gravity of the water stop cover shifts to the sinking direction deeper than the depth of 5 meters.

Accordingly, the attitude control of the ROV body will be increasingly difficult with depth, requiring the adjustment of buoyancy to expected depth.

A single optical camera can capture a target. However, to avoid interference during submergence and reduce time before reaching the target, as well as to have better understanding of the surroundings, mounting multiple cameras will be helpful.

Understanding these problems, we went for another demonstration test at Hiyoshi Dam.

5.2 Test at Hiyoshi Dam (Fig.10)

5.2.1 *Test conditions and status*

Test period: November 29 to December 2, 2016
(Cloudy with occasional rain and sometimes sunny)

Test water depth: 23.7 meters

Turbidity: 3.8-4.6 (at a depth of around 23.7 meters at the inlet of the water filling pipe)

5.2.2 *Hiyoshi Dam is a concrete gravity dam with 67.4m of dam height.*

In the Hiyoshi Dam test, we added an acoustic camera and ultrasonic sonar.

The inlet of the water filling pipe at Hiyoshi Dam is installed just beside the place which is a little protruded from the upstream dam surface because of the structure of the guide frame for the guard gate of the service spillway facilities. The inlet is installed at the concrete wall which had a plane perpendicular position to the upstream face of the dam (Fig.11). Due to the deeper location of the inlet compared to that of Takayama Dam, access to the inlet of the water filling pipe was more difficult. By installing an acoustic camera, we were able to visualize the surrounding environment without being affected by the turbidity and darkness in the water. Consequently, we were able to smoothly guide the ROV to the target inlet.

Regarding the change in specific gravity of the water stop cover, we were able to control the attitude of the ROV through its original trim adjustment by adjusting the number and the size of floats. As a result, at the work space which was limited to only 4 meters in front of the inlet, the entire ROV body with 2.48 meters in length smoothly entered into the required position without losing balance to install the water stop equipment. The water leakage immediately after drainage of water was 220 ml/min, which was larger than 0.3 ml/min at Takayama Dam. However, after two hours, the leakage became practically undetectable.

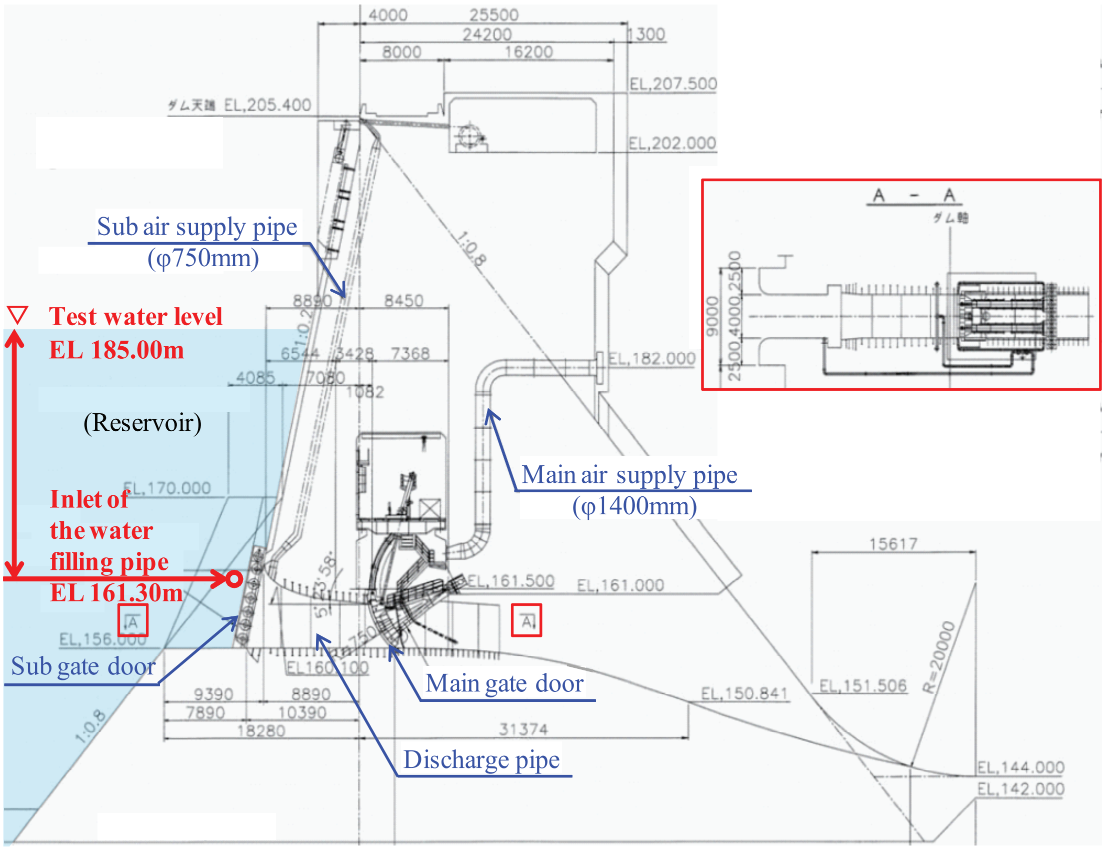

Figure 10 : Vertical sectional view of Hiyoshi Dam

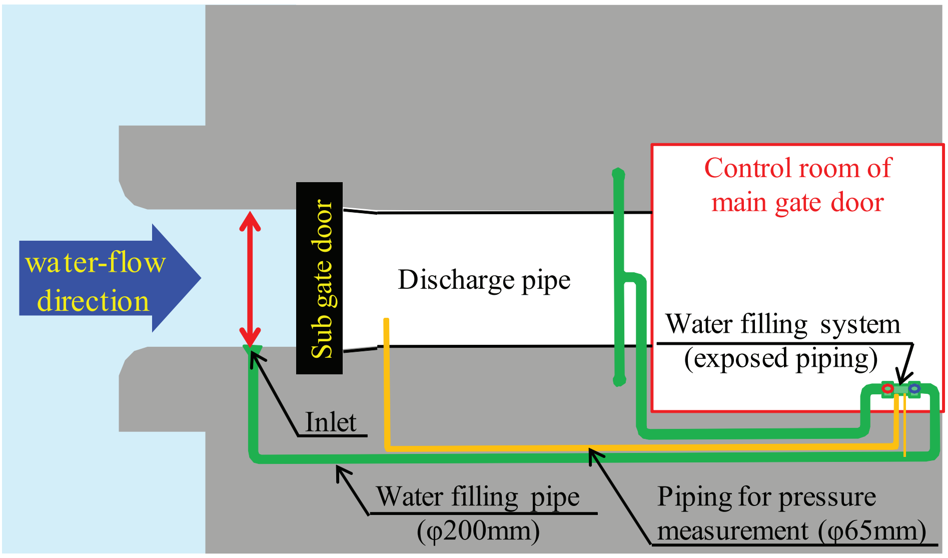

Figure 11 : Water filling system layout drawing of Hiyoshi Dam (Top view of A-A section in Figure 10)

5.2.2 *Test results and consideration*

A combination of an acoustic camera and an optical camera provided good ROV operability even under poor visibility in the water. We also installed ultrasonic sonar to detect the distance from surrounding structures. However, its reflection of sound wave generated the time rag from the acoustic camera and the optical camera, which affected the ROV operation. Because the acoustic camera's image was capable of expressing a sense of distance, we found out that the combination of the acoustic camera and the optical camera was sufficient for the operation. In the meantime, we discovered that the acoustic camera was capable of recognizing surrounding structures, even in conditions of no visibility by an optical camera, where air bubbles were created during the removal of the water stop cover. We believe that the acoustic camera is very useful.

We also discovered that by adjusting the floats' volume for the attitude control of the ROV body, the trim adjustment function worked to address the changes in the buoyancy of the water stop cover.

There is an angle at which the camera and the light are obstructed by the equipment attached to the ROV body. Therefore, we need to reconsider their mounting positions. In addition, we need to reinforce some parts with additional covers to mitigate the problems caused by physical contact.

6. CONCLUSIONS

With the use of an underwater ROV for the inspection of waterways in power plants, we tested the adoptability of the ROV to install/remove the water stop cover without assistance from divers and confirmed that a comprehensive operation can be performed with it. However, discovering some modifications are needed, we are trying to produce a product that satisfies the following requirements.

- Downsizing an ROV
- Strengthening thrusters
- Additional cameras to check electromagnetic connection
- Additional lights for the water stop cover with an individual power cord that also serves as a drop-off prevention
- An acoustic camera as standard equipment
- Stronger electromagnet (from 1,000 N to 2,000 N)
- Expansion of attitude control function

The underwater ROV cost is relatively high compared to the cost of diver's manual work in shallow water, but unmanned maintenance using it is originated from a human safety concern. Most of its costs are related to the rental fee of the underwater ROV, which depends on the operating rate of the ROV and may be improved in the future.

The results of our demonstration test presented two advantages: smaller temporary facilities requirement and shorter work hours. The applications can be expanded to worksites with limited space for temporary facilities and works, and limited application period for temporary transportation.

At the moment, we have no track record of unmanned maintenance using an underwater ROV. Therefore, we will try to expand the application in many sites and reduce costs by improving the operating rate of this equipment. We will continue to demonstrate the operation with an underwater ROV to highlight its advantages.

This time we reported our test results only, but in the near future, we would like to spread our specific business applications with this system.