The Underwater Excavation By The Shaft-Style Underwater Excavator T-iROBO UW

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ABSTRACT:
In order to solve the problems caused by deterioration and the inefficiency of the conventional method in redevelopment of existing dams, a shaft-style underwater construction machine (T-iROBO UW) was developed and utilized in the Amagase Dam Redevelopment Project in Uji City, Kyoto Prefecture. The machine is operated remotely to ascend, descend, rotate, to crash and gather the rock using a power shovel that is fixed to a shaft that goes down from the barge to the lake bottom, for underwater works. The underwater excavation is carried out while observing several monitors at the same time. One of the monitors shows landform of the lake bottom in 3D graphics, using the data obtained by investigation of sonar device. On the 3D graphics of landform, the movement of the power shovel is featured in animation, by measuring the angles of the arm of the power shovel. The ultrasonic camera is used to provide the operator a real-time image on the other monitor. It is also possible to replace attachments of the power shovel, and currently the underwater breaker, bucket, and pump are being used. This is a report of the development of T-iROBO UW and its performance.

Keywords: underwater excavation, remote operation, visualization of blurred underwater image, diver unnecessary, deep water

1. INTRODUCTION

In recent years, existing dams in Japan are deteriorating, and dams that were built more than 50 years ago are increasing. However, there are few sites suitable for dam construction, and it has become difficult to secure land for the construction of new dams. As a result, there is a growing need to redevelop existing dams and to use them efficiently for long periods of time. In the redevelopment of existing dams, it is preferred that work be carried out while maintaining the function of the dam, so underwater work performed while maintaining the level of water in the reservoir is increasing. In this case, a large-scale temporary pier and diver work at great depths is often necessary, which causes issues such as longer construction time, an increase in cost, and more hazardous work.

In order to solve the problems that arise in underwater construction and to execute the work safely and accurately, a shaft-style remote-controlled underwater construction machine, the T-iROBO UW (patent No.4792123), was developed and utilized in a dam redevelopment project. This paper is a case study of the utilization of the shaft-style remote-controlled underwater construction machine T-iROBO UW in the excavation of reservoir bedrock.

2. UNDERWATER EXCAVATION ISSUES IN DAM REDEVELOPMENT

In the redevelopment construction of existing dams, it is preferred that work be carried out while maintaining the function of the dam. Therefore, it is necessary to carry out the work while retaining the level of the water in the reservoir. Excavation at great depths, such as bedrock excavation, is particularly challenging.

In underwater construction, securing the construction yard is the most immediate challenge. In the past, the construction yard was secured by installing a coffering structure. (Fig.1.) However, when working at great depths the pier needs to be very high, requires time to install, and increases construction costs.

Furthermore, in underwater bedrock excavation, usually the methods such as casing rotation excavation method and percussion method that are using heavy machinery is used, the efficiency of the construction is low. Because this conventional construction method precludes observation of the excavation site, excavation must be carried out while constantly checking vertical accuracy on the pier, which also makes precision work in close proximity to underwater structures impossible. Furthermore, the placement large amounts of heavy machinery results in many blind spots on the pier, so this method has a constant risk of accidents, such as caught-between accidents. In this method, divers are used to check excavation conditions and progress and for precision work in close proximity to underwater structures. However, diver work has a high level of potential danger, and in projects like this case study, which required work at a depth of close to 40m, air diving allows only a short period of time for work, and equipment for saturation diving incurs an enormous expense.

Figure 1. The conventional way of securing construction yard by installing a coffering structure (casing rotation excavation method)

3. DEVELOPMENT OF T-IROBO UW

3.1 Development Focal Points

To solve the problems mentioned above, the development of an excavator that could be controlled remotely to excavate bedrock was undertaken.

First of all, in order to implement excavation accurately underwater, it was important to determine how to obtain the location information (coordinates) of the construction machine, which would be underwater and invisible to the naked eye. Therefore, a method was adopted in which a construction machine is attached to a shaft and lowered beneath the water and location information for the underwater construction machine is obtained by giving location information to the top end of the shaft and measuring the inclination of the shaft and the position of the machine upon it.

In addition, a visualization apparatus to give information to the operator and a machine guidance system was developed in order to enable the remote control of the underwater construction machine.

A hydraulic excavator that can be fitted with a variety of attachments was selected to serve as the base machine in order to handle the various requirements of the underwater work, which is not limited to excavation. Moreover, the hydraulic excavator consists of 3 joints which enable smooth movements, making it optimal for displaying the functions of a variety of attachments.

3.2 Composition

A shaft-style remote-controlled underwater construction machine (T-iROBO UW) was manufactured based on the development focal points mentioned above. T-iROBO UW (Fig.2.) is fixed to a shaft that goes down from a barge to the lakebed, and an underwater auger is equipped to the end of the shaft to fix it on the lake bedrock. Since the underwater construction machine is a hydraulic excavator that attaches to the shaft, it can be operated to ascend, descend, and rotate on the shaft.

Figure 2. The key map of T-iROBO UW

A control room for the remote operation of the construction machine, an electric power generator, and a crawler crane were installed on the barge.

The underwater excavator is controlled remotely with a joystick and pedals, the same as a normal excavator used on land. The visualization apparatus and machine guidance are deployed from the monitor. Underwater sound waves are picked up using a hydrophone.

3.3 Features

T-iROBO UW has numerous features, including the ability to carry out the excavation with a high level of accuracy, versatility, and enhanced safety. The following is a detailed description of the features of the T-iROBO UW.

3.3.1 Shaft-style Excavator

Adopting a shaft-style system made it possible to obtain accurate location information for the underwater construction machine. Real-time location information can be gathered by setting the target on the top end of the shaft and tracking it automatically. As the distance between the shaft and the underwater construction machine is measured beforehand, and the real-time position of the underwater construction machine is obtained from a protractor and encoder attached to the boom, it is possible to easily obtain location information for the main body of the machine and the extremities of the attachments based on the location information of the top end of the shaft. With a conventional underwater construction machine, it was difficult to get location information on a centimeter-scale basis, and diver work was necessary, resulting in there being a limit to the depth at which construction work could be carried out. In regard to this matter, with the specifications of the T-iROBO used in this project operation at a depth of 50m was possible. If some parts are changed, the design allows for underwater operation at a depth of up to 100m.

The adoption of the shaft-style system allows for the machine to be easily fixed on steep slopes and for a counterweight to be secured. The stability of the underwater construction machine is ensured by inserting a separately-developed underwater auger, which is equipped to the end of the shaft, approximately 1m into the bedrock fixing the shaft securely between the barge and the bedrock.

3.3.2. Remote Control via Computerized Construction Apparatus

The computerized construction apparatus (the underwater construction visualization apparatus and sound receiver) is one of the most important functions performed during underwater construction.

Figure 3. The remote control room

The topography data sounded by the multi-fan beam is projected in 3D on the monitor in the remote control room. (Fig.3.) Simultaneously, an animation of the main body of the underwater construction machine based on the data obtained by each measuring instrument is projected on the same monitor. (Fig.4.) It is possible to display the real-time position of the main body of the construction machine, so the operator can control the machine while looking at its position.
If there is any existing structure under the water, by inputting the information in advance, the operator can see the structure as though they were actually looking at it in real time.

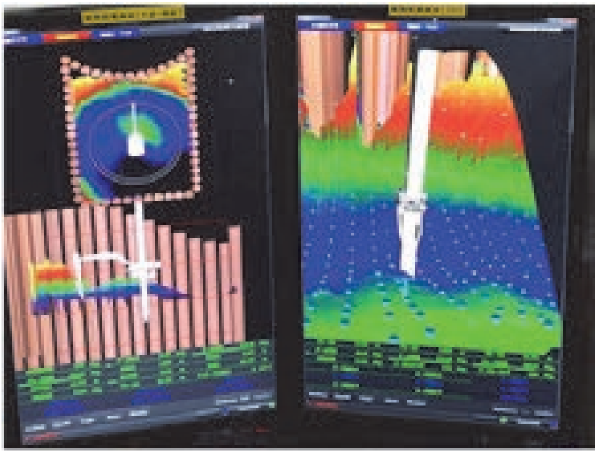

Figure 4. The animation of the main body of the underwater construction machine projected on the monitor

The topography data is updated when sounding is carried out, so it does not change in real-time during excavation. However, the coordinates of extremities of the attachments, such as the breaker and bucket, can be attained in real time, so the operator can check them and decide when to finish crushing and excavating the bedrock.

To support these functions, an underwater camera and hydrophone were installed. It is difficult to display the lakebed with an optical camera due to the great depth and turbidity of the water, so an ultrasound camera was chosen. The video taken by the ultrasound camera enabled the operator to see the location and distance of existing structures and obstacles with their own eyes, allowing them to carry out excavation without accidental collision.

Speakers were installed in the remote control room so that the operator could listen to the sound from the hydrophone while working. The hydrophone clearly picks up the sound of the rocks being broken and the bucket collecting sand and earth as well as the sound of the hydraulics. By obtaining aural information in addition to visual information, it was possible to convincingly replicate the feeling of sitting in the operator’s chair that you would have when operating machinery on land in the control room.

3.3.3 Versatility at Various Types of Construction

As the base machine is a highly versatile hydraulic excavator, it is possible to mount it with most of the attachments that you would use in onshore construction. In this project it was used for excavation, but it is also suitable for a variety of other construction work, such as concrete demolition and removal of obstructions and extraneous matter.

3.3.4 Machine Operator

No special training is required for the operation of this machine. It can be operated by anyone with qualifications to operate an onshore machine. In the operation of an onshore backhoe, ground vibrations are felt directly by the operator during excavation, which places a burden on their body. However, the operator’s seat for this machine is on the barge, meaning no vibrations are felt, reducing the burden on the operator’s body. It is also easy to take breaks, and the operator’s work environment is vastly improved.

For these reasons, it is also helpful as a countermeasure against the increased age of workers and the lack of skilled workers, which have become societal issues in recent years.

3.3.5 Improvement of Safety

The T-iROBO UW is operated via remote control, meaning that it requires no workers aside from one operator and no divers, allowing for the guarantee of a high level of safety. Just by virtue of being operated underwater, the burden of safety management against caught-in and caught-between accidents is dramatically reduced.

4. CONSTRUCTION RESULTS

4.1 Construction Outline

The T-iROBO UW was introduced for the inflow section (Fig.5.) construction work on the Amagase Dam redevelopment project in Uji, Kyoto. There was approximately 5000m³ of underwater excavation, and of that the T-iROBO UW was used for approximately 1300m³ of bedrock excavation. The horizontal area excavated was approximately 21 x 8m, with the circumference surrounded by steel pipe sheet piles and a maximum depth of 38m. This underwater construction machine has an operating radius of 10m, however as excavation close the shaft is not possible, it was shifted 3 - 4 times in order to cover the entire horizontal area.

Figure 5. Amagase Dam Redevelopment Project (The inflow section)

4.2 Construction Method

The barge is moved to the designated position according to the location survey. When the position of the barge is decided, the shaft is assembled using a crawler crane. A single standard shaft is 9m, with 4m and 2m shafts for adjustment. The numbers of adjustment shafts necessary for the shaft to reach the lakebed are added to the standard shaft. When the lakebed is reached, the auger is turned on, sunk soundly into the bedrock, and fixed.

Next, the underwater construction machine is suspended and attached to the top of the shaft. The underwater construction machine is first fitted with a 3m shaft, so it can carry out construction work while being attached to the shaft. After attachment, the underwater excavation machine is launched and sunk via remote control.

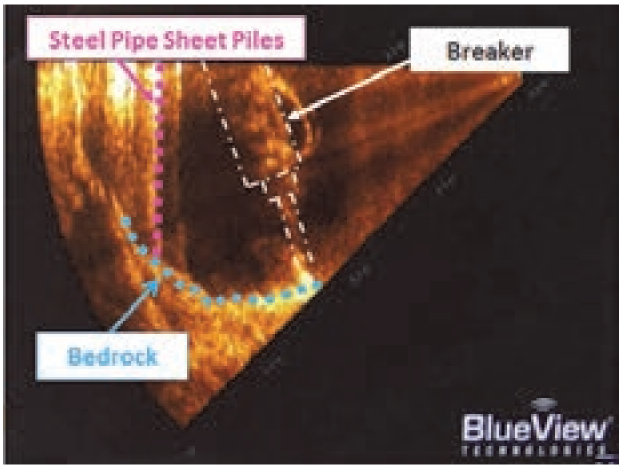

Figure 6. The real time video taken by ultrasonic camera

The operator checks the elevation of the underwater excavation machine on the monitor and stops it at the designated depth, then uses a multi-fan beam to sound the topography of the lake bed and project it in 3D. The operator carries out excavation work while looking at this 3D topography data and real-time video taken by an ultrasonic camera.

Fig.6 shows the monitor equipped at the remote control room which provides the operator real time information obtained by an ultrasonic camera. On the screen, the breaker, bedrock, steel pipe sheet pile is projected, and the operator carries out the excavation by steering the point of the breaker towards the bedrock.

Excavation begins by using a breaker to crush the rock, then switching the attachment to a bucket to collect the rock. This switching operation can be carried out with the ease of an onshore operation by lifting the underwater construction machine to the surface of the water and placing the boom on the barge. When excavation is complete, the underwater construction machine is lifted and placed temporarily on the barge. The numbers of shafts are detached to not touch the lakebed, the barge is moved to the next position, and the excavation recommences. The surplus rock crushed and collected by the underwater construction machine is dredged using a bucket attached to a crawler crane.

Figure 7. The whole view of T-iROBO

4.3 Construction Results

This construction work took 6.5 months from assembly to excavation and disassembly. The average area excavated per day was 25m³ (including movement of the shaft and dredging work by the floating crane) with a total of 10 shaft shifts requiring 3-4 hours and 5 shaft shifts to switch to dredging requiring 6-8 hours. All construction works were implemented more or less to schedule.

Using conventional methods this project would require approximately 10.1 months. It was possible to reduce the necessary construction time by 40% to 6.5 months. Furthermore, conventional methods would require the installation and removal of temporary piers, requiring approximately 10 additional months. It was also possible to reduce construction costs by 40% when compared with the cost of conventional methods, ascertaining this method's validity.

4.4 Precision of Construction

When placing the underwater construction machine at the site of construction, calibration was carried out onshore, and underwater excavation commenced after ascertaining that the margin of error between the coordinates of the underwater construction machine displayed on the monitor in the remote control room and the coordinates measured by the actual machine was less than 5cm. The final result of the excavation was able to sufficiently satisfy standards.

5. CONCLUSION

The T-iROBO UW (Fig.7. and 8.) was introduced for the first time in the Amagase Dam redevelopment project, and operation was carried out according to plan with no complications. In the future, the T-iROBO UW can contribute to the improvement of functions and the prolonging of the life of existing infrastructure with a reduction in the length of construction time, construction costs, and the amount of dangerous work involved in projects such as dam renewal that require construction work at great depths.

Figure 8. The whole view of T-iROBO