Development of Cruising RCD Construction Method

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ABSTRACT:
The RCD construction method is a rationalized construction method for concrete dams which was originally developed in Japan in 1970's. The RCD construction method has been applied to about 50 concrete gravity dams in Japan, and has achieved reduction of the construction period, the labor cost, the environmental issue, and the hazard in safety for the constructor. However, under the current social and economic conditions, it is necessary to develop technologies to achieve further rationalization in order to cut costs.
The conventional RCD construction method has two major problems to be solved for the further rationalization, such as alternate placement of RCD and external concretes and setting of cross-forms along transverse joints at the stopping of RCD concrete placement in a lift. The "cruising RCD construction method" has been newly developed to solve these problems.
In this paper, we will introduce an outline of this technology including application cases based on "Engineering Manual for Cruising RCD Construction Method Technology" published by the Japan Dam Engineering Center.

Keywords: Cruising RCD Construction Method, Concrete Dams, Rationalization

1. INTRODUCTION

The RCD construction method, which is a rational construction method for concrete dams developed originally in Japan in the 1970's, is a roller compacted concrete construction method which preceded the RCC method. In Japan, about 50 dams have been constructed by the RCD method, contributing to the shortening of construction periods, reduction of labor costs, resolution of environmental problems, and ensuring safety during construction. But as a result of social and economic conditions which have appeared in Japan in recent years, there is a demand for the development of technologies to further speed up and lower the cost of dam construction, so technologies that permit faster and more efficient execution of the conventional RCD method have been developed.

But the conventional RCD method still has two major problems to be resolved for the further rationalization. One is an alternate placement of RCD concrete and external concrete in order to fully integrate the two types of concrete, and the other is the need to install cross-forms at placing ends of RCD concrete while aligning them with the transverse joint locations. To resolve these problems, the "***Cruising RCD Construction Method***" was developed as a new construction method. This method can speed up execution of construction by placing the RCD concrete prior to placing the external concrete and by stopping placing of RCD concrete without using cross-forms.

The cruising RCD construction method was established through a technology development study that began in 2006 at the Kasegawa Dam (Kyushu Regional Development Bureau, Ministry of Land, Infrastructure, Transport and Tourism (MLIT), dam height, H=97m, dam body volume, V=941,000m^3), where it was applied to the upper part of the dam body, confirming its effectiveness. And beginning in 2010, at the Yunishigawa Dam (Kanto Regional Development Bureau, MLIT, H=119m, V=1,060,000m^3), technology was studied and developed to permit continuous placing of an entire lift in order to further rationalize the cruising RCD construction method, confirming that this new technology further speeds up and improves the workability and safety of construction.

Based on these successes, the Japan Dam Engineering Center (JDEC), which has led the development of the cruising RCD construction method and the first application of it, published the "***Engineering Manual for Cruising RCD Construction Method***" in June 2010 [JDEC, 2010] and a revised edition in February 2012 [JDEC, 2012]. Since the publication of the revised edition, the application of the cruising RCD method has expanded as it has, for example, been applied to construct the Tsugaru Dam (Tohoku Regional Development Bureau, MLIT, H=97.2m, V=717,000m^3) and the Gokayama Dam (Fukuoka Prefectural Government, H=102.5m, V=935,000m^3).

This paper outlines this construction method and introduces the basic technologies which achieved this construction method and, based on actual applications, demonstrates its effectiveness.

2. CHRACTRISTCS OF THE CRUSING RCD CONSTRUCTION METHOD

The cruising RCD construction method has the three execution characteristics shown below which distinguish it from the conventional RCD construction method (see Fig. 1).

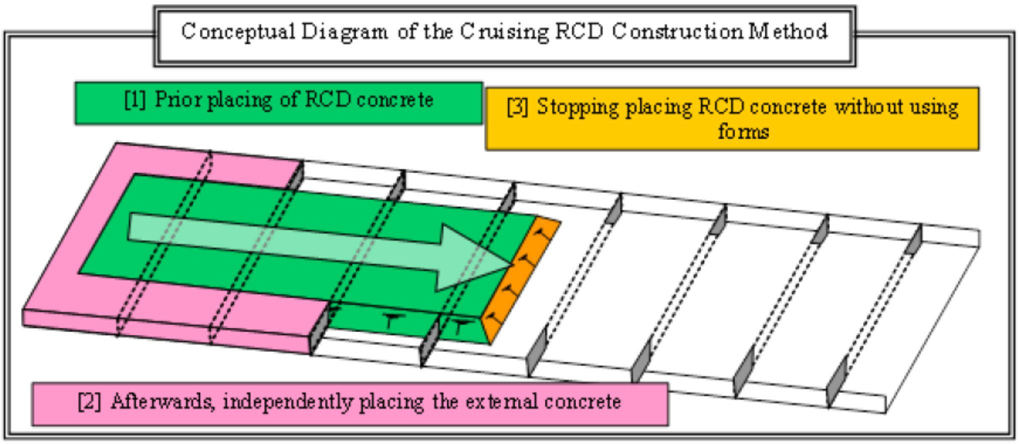


Figure 1. Concept of cruising RCD construction method

[1] Advance placing of the RCD concrete

When applying the conventional RCD method, placing is performed while ensuring mutual integration of the external concrete and RCD concrete by complying with placing time regulations, so external concrete and RCD concrete are repeatedly placed alternately. This is a major factor causing a decline of the placing efficiency.

When applying the cruising RCD method on the other hand, prior placing of the RCD concrete permits the external concrete and RCD concrete to be executed separately and independently. This means it is not necessary to alternately place external concrete and RCD concrete, maintaining high placing speed that takes full advantage of the equipment capacity beginning immediately after the start of placing, and at the same time, improving placing efficiency.

Photo 1 is a view of the cruising RCD method being executed by prior placing of the RCD concrete.

Photo 1. View of cruising RCD construction method

[2] Later independent placing of external concrete

The external concrete is placed independently of the RCD concrete after it has been placed, in small block units enclosed by upstream- or downstream-surface form, RCD concrete and transverse joints (see Photo 2). And the placing joints between the external concrete and RCD concrete do not, in practice, require placing time restrictions. For the above reasons, the execution plan is extremely unrestricted, improving the efficiency of placing, and at the same time sharply improving the safety of the execution.

[3] Omitting the cross-forms at placing ends of RCD concrete

When using the cruising RCD construction method, instead of using the placing method performed by installing cross-forms at the transverse joint locations and placing slump concrete at the edges of these forms, which is done using the conventional RCD method, a placing stop execution method at any optional location is executed by generally forming an end slope with gradient of 1:0.8 at the RCD concrete placing. This eliminates the need to temporarily stop placing RCD concrete by installing cross-forms, and the complexity of the execution accompanying the installation of cross-forms.

The RCD concrete, whose placing was stopped at an optional location, is jointed to the RCD concrete by carefully applying mortar to its placing joint surface.

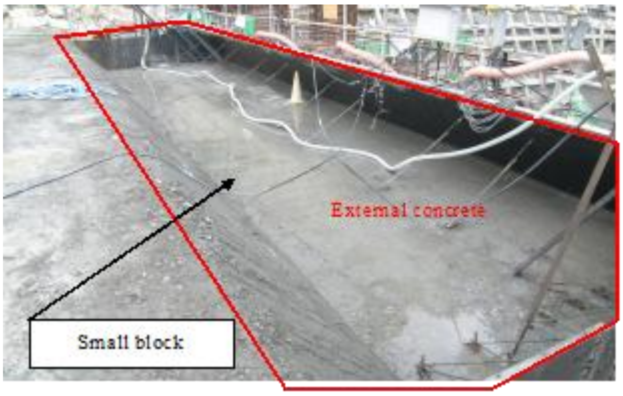


Photo 2. View of Placing of External Concrete using the Cruising RCD Construction Method

3. BASIC TECHNOLOGIES FOR CRUSING RCD CONSTRUCTION METHOD

[1] Technology for advance placing of RCD (internal) concrete

End slope compaction technology

With the cruising RCD construction method, the RCD concrete is placed prior to the external concrete, so that end slopes are formed at the outside edges of the RCD concrete. These end slopes are formed with a slope gradient of 1:0.8, and compacted firmly by a specialized machine so that its density is equal to that of the general part of RCD concrete (see Photo 3).

Photo 3. Compacting end slope of RCD concrete

[2] Technology for independent and later placing of external concrete

Confirming integration of RCD concrete and external concrete

With the conventional RCD method, after advance placing of the external concrete, RCD concrete is subsequently placed within 4 hours, and they are integrated by concrete vibrators.

In contrast, when executing the cruising RCD method, the external concrete is placed later in small blocks enclosed by its end slopes, upstream- or downstream-form and transverse joint panels with the end slopes of the previously placed RCD concrete already compacted to firmly integrate the two kinds of concrete (see Photo 2).

[3] Technology for placing stop of RCD concrete without using cross-forms

Confirming integration with placing joints of RCD concrete by end slope compaction

With the cruising RCD construction method that does not use cross-forms, in some cases, two blocks of RCD concrete are jointed with each other, but generally end slope formed at a gradient of 1:0.8 (see Photo 4). When jointing RCD concrete placing at the end slope, the careful application of mortar to the end surface of RCD concrete formed at a gradient of 1:0.8, is required.

Photo 4. Stopping placing with 1:08 end-slope in cruising RCD construction method

[4] Technology for continuous execution

Horizontal placing joint surface treatment technology for external concrete and RCD concrete

To apply the cruising RCD construction method, it is necessary to start horizontal placing joint surface treatment as soon as RCD concrete placement is finished, and at the same time, improve treatment speed to keep pace with the rise of placing speed.

Because bleeding of the external concrete occurs after it is compacted, it is necessary to perform placing joint surface treatment by a method that can effectively remove laitance. When doing this while applying the cruising RCD construction method, it is necessary to have a technology that permits good reliability and workability with curing time shorter than that of past placing surface treatment and reliable treatment of the narrow spaces at form edges and transverse joints. In past cases, treatment was done by pressurized water.

But bleeding of RCD concrete does not occur, so placing joint surface treatment is done by a method that can reliably removing the concrete sludge leakage formed on the surface by roller compaction done using a vibrating roller. It has been confirmed that before setting, it is possible to perform appropriate placing joint surface treatment using the so-called “soft treatment”, which is removal using water washing with an appropriate pressure (see Photo 5).

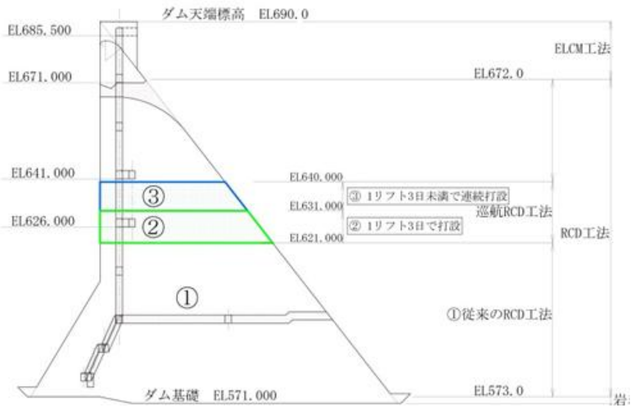
Photo 5. Soft treatment for RCD concrete placing joint surface

Next, regarding the placing joint surface of the RCD concrete end compacted slope, unlike horizontal placing joint surface compacted with a vibrating roller, this slope need not be treated by water washing that is done on horizontal placing joint surfaces to prevent the occurrence of concrete sludge leakage.

4. EFFECTS BY THE CRUSING RCD CONSTRUCTION METHOD

4.1 Faster placing speed

So the placing speed improvement effectiveness is analyzed based on the past application of the cruising RCD construction method at the Yunishigawa Dam. At the Yunishigawa Dam, the cruising RCD construction method was applied to build approximately 180,000m^3 from EL.621m to EL.640m, and of this part, from EL.621m to EL.631m (Range [2] in Fig. 2) was placed at 3 days per lift, and from EL.631m to EL.640m (Range [3] in Fig. 2) was placed continuously at a rate faster than 3 days per lift.



[1] Conventional RCD construction method (placing in 3 blocks per lift)
[2] Cruising RCD construction method (placing at 3 days per lift)
[3] Cruising RCD construction method (continuous placing faster than 3 days per lift)

Figure 2. Execution locations and categorization of construction method at Yunishigawa Dam

At the construction of the Yunishigawa Dam, the placing equipment with higher capacity than that for previous RCD construction cases was prepared. Therefore, even conventional RCD construction method achieved a high average placing speed of 142.7m^3/h. But, the average placing speed by the cruising RCD construction method executed at 3 days per lift was 153.8m^3/h, and was improved by about 7% over the average placing speed by the conventional RCD construction method. In addition, by the application of the cruising

RCD construction method executed continuously faster than 3 days per lift, the average placing speed was 155.7m^3/h, and was improved by about 9% above the average placing speed of the conventional RCD construction method.

In addition to increasing placing speed, the cruising RCD construction method shortens interval periods. When using the conventional RCD construction method, when placing is done with 1 lift divided into 3 sections, the period from completion of one section to the start of placing of the next section is, based on past works, an interval of between 2 and 3 hours needed to move the materials and machinery, and three of these intervals occur for each lift. At Yunishigawa Dam, there were 3 interval periods per lift, taking an average total of about 6 hours.

But when using the cruising RCD construction method to perform continuous placing at a rate faster than 3 days per lift, the execution was continuous without any division of the lifts and placing continued as the machinery was moved, so no intervals were needed while placing each lift. Only one interval was needed: that when the placing advanced to the next lift. The interval period per lift was an average of 2.2 hours at the Yunishigawa Dam. This means that the work period could be shortened by about 4 hours for each lift.

4.2 Raising speed improvement and work period shortening effect

Figure 3 shows monthly average raising speed of the RCD part of the Yunishigawa Dam compared with those at other dams.

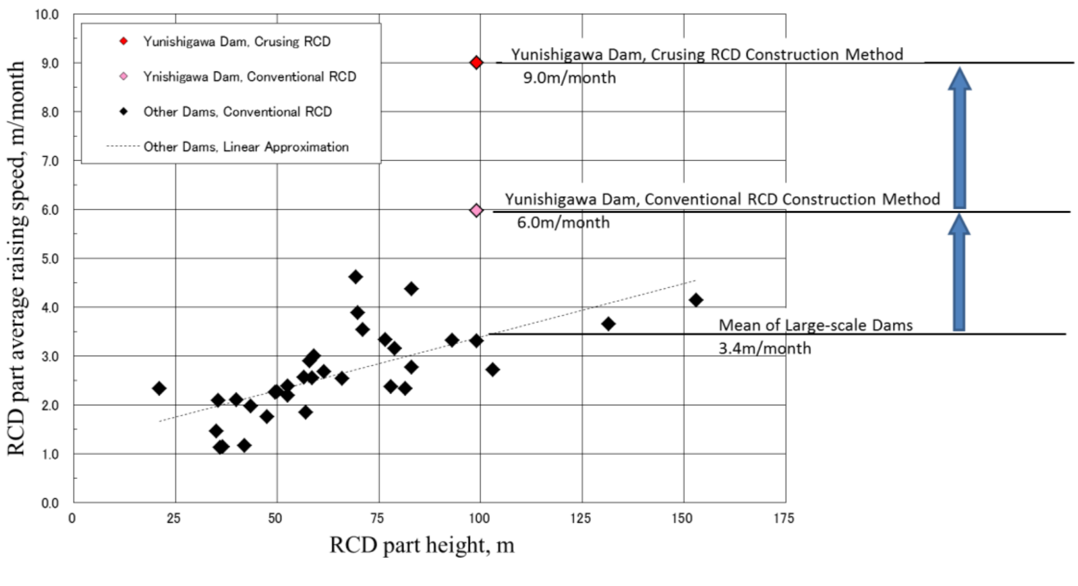


Figure 3. Relationship of RCD part height with RCD part average raising completion speed

This figure shows that the monthly average raising speed of the RCD part of the Yunishigawa Dam constructed by the conventional RCD construction method was 6.0m/month due to the higher capacity of placing equipment, and was higher than that of previous large-scale dams of 3.4m/month. Besides, when using the cruising RCD construction method at the Yunishigawa Dam, the execution efficiency was improved largely, and construction monthly average raising speed of the RCD part of the Yunishigawa Dam increased to 9.0m/month.

4.3 Improving workability

(1) Improving workability when temporarily stopping and resuming placing

[1] Improving workability in response to rainfall

Using the cruising RCD construction method, even when rainfall is predicted, it is possible to stop placing RCD concrete at an end slope of 1:0.8 at an optional place at a location which avoids the surrounding of transverse joints, permitting placing to continue until the just before rain begins and leaving time needed for placing stop treatment. And after the rain has fallen, execution can begin by applying mortar to the end slope, permitting quick resumption of concrete placing. For this reason, it is possible to make on-site decisions to temporarily stop and restart placing in hour units, permitting the minimization of stopping placing work during a period when no rain will fall.

When using the conventional RCD method on the other hand, it is necessary to stop placing by installing a transverse joint in response to a prediction of rainfall, so it is impossible to continue placing until immediately before the rain starts, and even after the rain has stopped, it takes time to revise the lane demarcation plan, so it is difficult to quickly restart placing.

[2] Improving workability the day before a holiday

When executing work the day before a holiday, it is necessary that the placing plan should also consider extending the work period in response to unpredictable events. In this case, when using the cruising RCD construction method, it is possible to continue placing almost up to the predicted time of completion, by considering the placing stop work time.

When using the conventional RCD construction method, the quantity executed tends to shrink for the similar reason mentioned in [1].

[3] Response when execution is only possible for a short period

There are days during placing of the body of a dam when the number of hours placing can be executed is shortened because of various circumstances. Using the conventional RCD construction method, even when it is necessary to suspend placing on a specific day, for the same reason cited in [1] and [2] above, using the cruising RCD construction method, it is possible to place according to the time, so it is possible effectively use times when placing is possible.

(2) Improving freedom of placing external concrete

When using the cruising RCD construction method, the external concrete is independently placed in small block units enclosed by the RCD concrete which was placed earlier, upstream- or downstream-surface form, and transverse joint panels installed at transverse joints (see Photo 2).

(3) Improving freedom of lane dividing for concrete placing

When using the conventional RCD construction method, there is a placing time restriction stipulating less than 4 hours between placing adjoining slump concrete and RCD concrete.

In contrast, using the cruising RCD construction method, there are no placing time restrictions between different kinds of concrete, so it is possible to relatively reduce the quantity of slump concrete, which is executed slowly, boosting the overall execution speed.

(4) Improving workability of placing concrete in contact with rock foundation

Using the cruising RCD construction method, slump concrete including that in contact with rock foundation is independently placed after other concrete, so after prior placing of the RCD concrete, there are no restrictions on placing time period.

4.4 Improving execution safety

The work of placing RCD concrete and slump concrete is done by two teams: an RCD concrete placing team and a slump concrete placing team.

Using the conventional RCD construction method, because RCD concrete and slump concrete are executed at adjoining places, there are time periods when the two teams are working at the same place. This means the ensuring safety of workers from the other team's heavy execution machinery is an important challenge.

In contrast, using the cruising RCD construction method, the RCD concrete and the slump concrete placing locations are completely separated, eliminating working at the same place as another team, greatly improving execution safety.

5. CONCLUSIONS AND FUTURE PLANS

Japan has developed the cruising RCD construction method, as a concrete dam construction method that can speed up execution by placing RCD concrete prior to the external concrete and at the same time, stopping placing of the RCD concrete without using cross-forms. This construction method is a technology established by verifying its applicability while executing it at actual dams, that is, the Kasegawa Dam (Kyushu Regional Development Bureau, MLIT) and the Yunishigawa Dam (Kanto Regional Development Bureau, MLIT), and it has already been summarized in the "***Engineering Manual for Cruising RCD Construction Method***" (published in June 2010 and revised in February 2012) [JDEC, 2010 & JDEC, 2012]. Its application is expanding, as it is now adopted as the dam body construction method for two new dams.

This paper outlines this construction method and introduces the basic technologies which achieved this construction method and, based on actual applications, demonstrates its effectiveness.

In the future, we must introduce new innovations to further rationalize the construction method. Examples of challenges that must now be faced include improving workability of end slopes, further speeding up placing and placing completion by continuous execution of two lifts as an advance of the 1 lift continuous execution method, and applying the cruising

RCD construction method from river beds through upper elevations, including the lifts installed to build a structure.

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