Construction of Gokayama Dam by the Cruising RCD Construction Method

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ABSTRACT:
RCD (Roller Compacted Dam-Concrete) construction method was developed as a rationalizing dam concrete placing method and has been used to speed up the construction works of concrete gravity dams. The cruising RCD construction method adopted to construct Gokayama Dam has been developed to aim for even more rationalizing dam concrete placing, and which improves construction work efficiency by advancing the placing procedure of the internal RCD, so it enables the continuous placement of dam concrete and enables placement of concrete more speedily.
In Gokayama Dam, the slumping concrete is placed in the outer concrete and RCD is place in the inner concrete. Originally, the RCD is not placed unless the placement of slumping concrete is finished in one lift. The cruising RCD construction method is that the placement of RCD starts from one side of the dam site, while the slumping concrete is placed at the other side of the dam site. In that case, the RCD is placed at the next lift. Simultaneously, the RCD and slumping concrete are placed at different two lifts. The placement of RCD antecedent to that of the slumping concrete enables this execution, unlike the conventional RCD construction method in which the slumping concrete is placed antecedent to that of RCD.

Keywords: Concrete gravity dam, Gokayama Dam, Cruising RCD construction method

1. INTRODUCTION

Gokayama Dam is a 102.5m-high concrete gravity type and is now under construction on the Naka River by Fukuoka Prefecture, Japan.

The purposes of the dam are flood control, maintenance of normal function of the river flow, water supply for public use and emergency supply during droughts.

Figure 1. View of dam body placement
(View of placement work on July 31, 2015, EL401.5m, 88 lifts)

Table 1. The main features of dam and reservoir

Type	Concrete gravity
Height	102.5m
Crest lenght	556.0m
Volume	935,000m^3
Catchment area	18.9km^2
Reservoir area	1.3km^3
Total reservoir capacity	40,200,000m^3
Effective reservoir capacity	39,700,000m^3
Flood control capacity	8,000,000m^3
Water use capacity	15,100,000m^3

The originally adopted conventional RCD construction method was placed by the so called cruising RCD construction method due to shortening the construction period. This construction method was technically proposed by the contracted construction company and was the fourth time in Japan. Fig. 1 is a construction view of Gokayama Dam, and Table 1 shows the main features of dam and reservoir.

Table 2 shows the construction equipment used for Gokayama dam, and the layout of the construction equipment, respectively. At Gokayama Dam, an

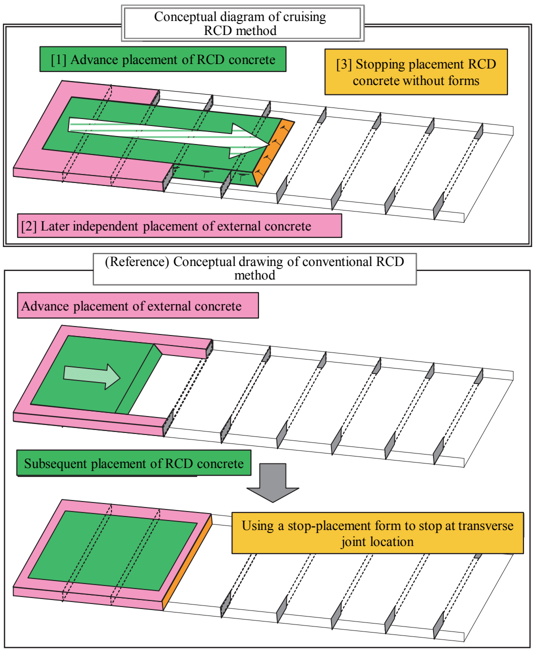


Figure 2. Conceptual drawing of the cruising RCD construction method

Table 2. Execution Equipment

Equipment		Equipment specifications
Placing equipment	Concrete production plant	2-shaft forced circulating mixer 3.0m^3×2×1 (Batcher top improved type)
	Cement storage equipment	1,000t (Fly-ash replacement rate of 20%)×1 600t (Fly-ash replacement rate of 30%)×1
	Concrete transport equipment	18t fixed cable crane×1 (5.5m^3) 6.5t fixed cable crane×1 (2.5m^3) SP-TOM×1 (diameter 700)
	On-site concrete transport equipment	40t dump truck (to transport RCD) ×3 10t crawler dump (to transport slumping concrete) ×4 9.0m^3 ground hopper×1
Aggregate handling equipment	Production equipment	Production capacity: 500t/h (wet production)
	Storage equipment	Coarse: 9 bins, Fine: 4 bins (4-day supply at average daily use during maximum placement month
	Transport equipment	W1,050mm belt conveyor
	Adjustment bins	Coarse: 3 bins, Fine: 1 bin (5-day supply)
	Others	Heating and cooling equipment

SP-TOM (Spiral Pipe Transportation Method) is installed on the left bank abutment in order to transport large quantities of concrete. Fig. 3 is a view of the installation of the SP-TOM.

The maximum quantity of transported concrete is 220m^3/h due to the concrete production capacity of the batcher plant.

2. EXECUTION OF THE DAM BODY BY THE CRUISING RCD CONSTRUCTION METHOD

2.1 Characteristics of the Cruising RCD Construction Method

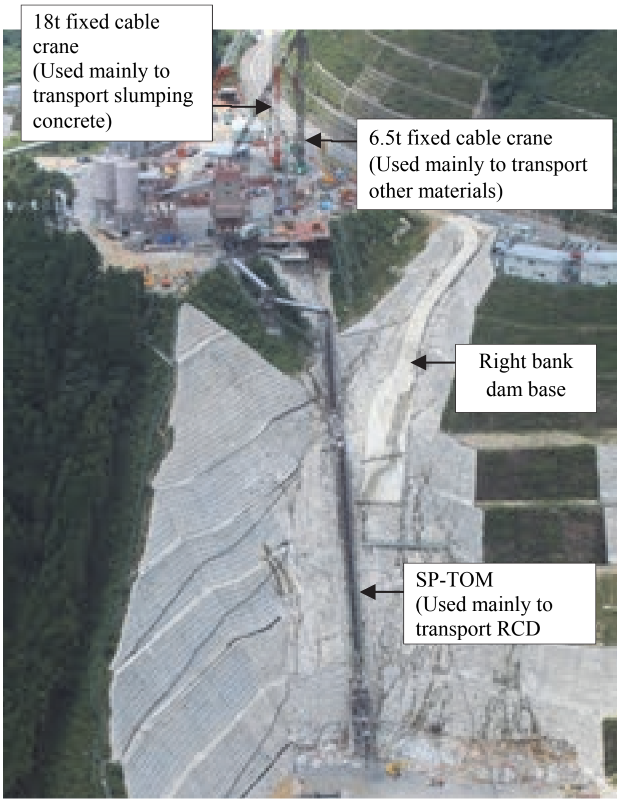


Figure 3. View of layout of concrete placement equipment

The cruising RCD construction method is developed in Japan to achieve greater rationalization of execution. It has the following three characteristics.

1) The preceding placement of the inner RCD.

2) The outer slumping concrete is independently placed afterwards.

3) Placing of RCD can be stopped at any time without using a metal form.

Fig. 2 shows the concept of this execution method (JDEC 2012). The various execution specifications of the basic technologies for the execution method implemented at Gokayama Dam are shown in Table 3 (Kamouchi et al. 2015a).

2.2 Development of new technologies and innovations to maintain high speed execution

The execution technologies of the cruising RCD construction method newly implemented at Gokayama Dam are described below along with their effectiveness.

1) Adoption of a flat plate compactor (FPC) to compact the slope edges of RCD.

2) Realization of 2-lift continuous execution

Table 3. Execution Specifications of Basic Technologies at Gokayama Dam

Item	Results of confirmation trial execution	Execution specifications decided
Compacting edge slopes of RCD	The RI method and core sample confirmed that the densities of the edge slope and normal parts are equal.	(1) Compacted using FPC. (2) Crest 15sec+slope 15sec of compaction time
Treatment of RCD joint surfaces (soft treatment)	Good quality treatment was achieved by doing it about 2 hours after completing 0.7MPa (50 to 100l/min.) roller compaction (cumulative temperature of 70°C・h according to outside air temperature).	(1) Done about 2 hours after completion of roller compaction (cumulative temperature of 70°C・h according to outside air temperature) (2) Treatment water pressure is 0.7MPa (water quantity 50 to 100l/min.)
Integrating RCD with outer concrete	Good reliable integration was confirmed by a sampled core even at a joint 720 hours after edge slope compaction. Even compressive testing did not break the joint surface.	Outer concrete joints possible until 720 hours after slope compaction. But, mortar is spread on edge slope surface before placement external concrete.
Jointing to 1:0.8 edge slope of RCD	The joint surface of a core sampled from a joint is firmly integrated, and even the compressive test results show no breakage of the joint surface and strength equal to normal parts.	(1) Spreading mortar on edge slope (2) Not concentrating large pebbles near edge slope (3) Manually cutting and trimming thin edge at crest. (4) Reliably compacting to edge with a vibrating roller
Driving dump trucks on fresh concrete	Plastic planking was placed immediately after roller compaction was completed, and a 10t dump truck drove over it 20 round trips, but the concrete surface was undamaged, confirming there are no problems.	(1) Six hours after completing roller compaction (cumulative temperature of 130°C・h according to outside air temperature), protecting it with plastic planking. (2) After six hours, it is unprotected, but curb sections are protected by plastic planking etc.
Edge treatment of sloped placement stops	Treatment height of 15cm, 4.0 hours after completion of roller compaction (cumulative temperature of 83.3°C・h of exterior air temperature) obtained good result.	After roller compaction, edges are treated to height of 15cm with the target set as cumulative outside air temperature between 80 and 100°C・h.

3) Development of other new technologies

2.2.1. Adoption of the flat plate compactor (FPC) to compact slope edges of RCD

Slope edge compaction, which is an important aspect of preceding placement of RCD, was carried outusing a 2-surface constraining type compactor at existing 3 dams.

Before the use of this type of compactor, the slope edge must be formed carefully by using a slope bucket after spreading RCD with a bulldozer, in order that the gradient of the slope edge fit the fixed compaction plate shape. So, this compactor could simultaneously vibrate both crest and slope surfaces. However, this careful forming (scraping) increases the execution work, and makes it necessary to ensure adequate distance between the downstream surface form and the backhoe arm, which tended to expand the width of the outer slumping concrete.

So at Gokayama Dam, the FPC (see Fig. 4) was developed to eliminate the preliminary slope trimming and simplify the compaction work of the slope edge. The single plate of FPC compacted each surface －the crest and slopes, respectively. This compactor saved labor required for slope edge compaction, improving workability (Kamouchi et al. 2015b).

Furthermore, the FPC enables compaction according to the natural state of the slope after spreading of RCD, and is capable of dealing with the change of the lift thickness. As a result, finishing sloped joint necessary to move heavy machines could be formed unrestrictedly and efficiently. The FPC also allows partial compaction of RCD according to conditions.

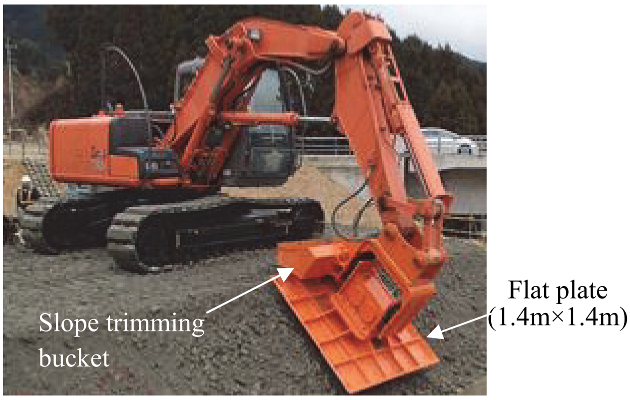
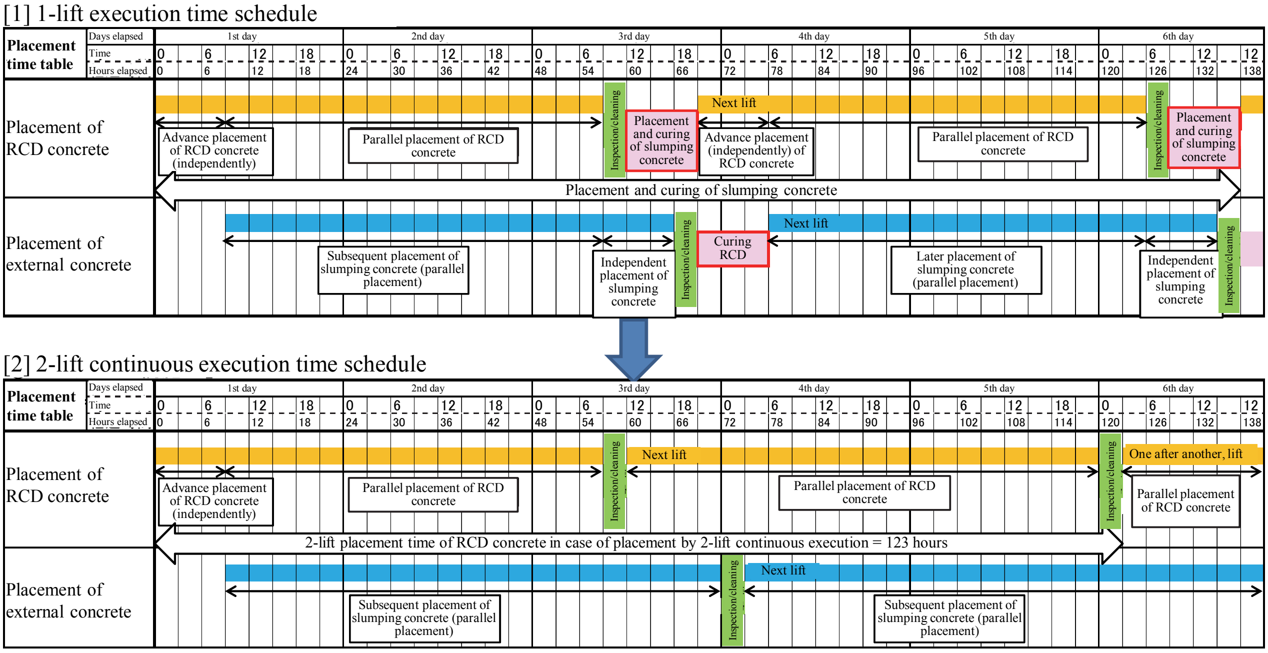


Figure 4. FPC (Flat Plate Compactor)

2.2.2. Achievement of 2-lift continuous execution
At existing three dams constructed by the cruising RCD construction method, “1-lift placement” execution was adopted: starting placement of the following one lift after completing previous one lift. This 1-lift placement is restricted from the layout of concrete transport equipment and transport conditions (see Fig. 2).

Table 4. Comparison of 1-lift execution with 2-lift continuous execution

[1] 1-lift execution time schedule



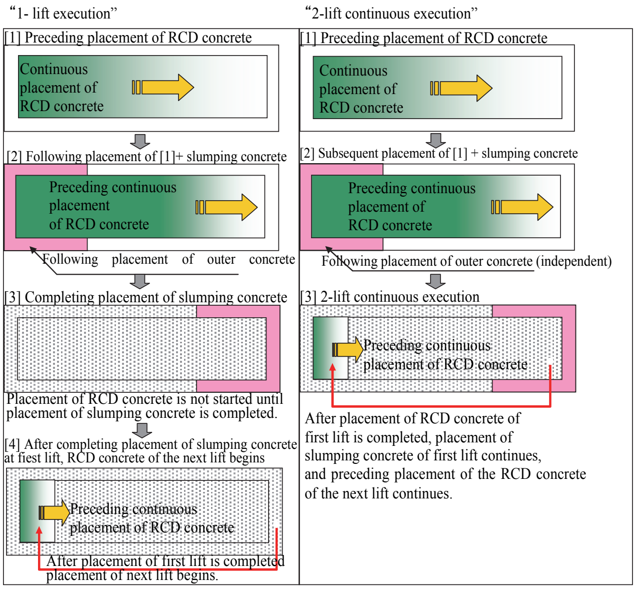


Figure 5. Differences between 1-lift execution and 2-lift continuous execution

In response to such previous cases, at Gokayama Dam, the layout of construction facilities was planned from the beginning considering 2-lift continuous execution. For the first time in Japan, 2-lift continuous execution was performed at 61 lifts of dam body during about 10 months.

Differences between 1-lift execution and 2-lift continuous execution are shown in Table 4 and Fig. 5 (Nishiyama, et al. 2015a). 2-lift continuous execution enables placement of slumping concrete for a concerned lift and the preceding placement of the RCD for the next lift simultaneously. The shortening of waiting time comes to the large speed-up of the execution.

It is necessary for the 2-lift continuous execution to plan in the early stage the layout of the construction facilities capable of transporting concrete of different mixtures to the different placement locations simultaneously.

At Gokayama Dam, this 2-lift execution was made possible by combining the immovable supply equipment, SP-TOM (Spiral Pipe Transportation System) with an 18t fixed cable crane.

It was necessary for the installation of the cable crane of slumping concrete transportation to consider its relationship with the layout of the inspection gallery as is needed the placement of slumping concrete.

As stated above, at dams which have a plan to adopt the cruising RCD construction method in the future, it is important to plan in early planning stage a concrete transport system that enables 2-lift continuous execution.

2.2.3. Developing other new technologies

At Gokayama Dam, the efforts to develop other new technologies such as the following were made to further rationalize the execution.

1) RCD in rock contact part

Slumping concrete has been conventionally placed in rock contact part in order to ensure reliable filling of concrete and water tightness in uneven surfaces of the foundation bedrock. This procedure has practically reduced the efficiency of the construction work.

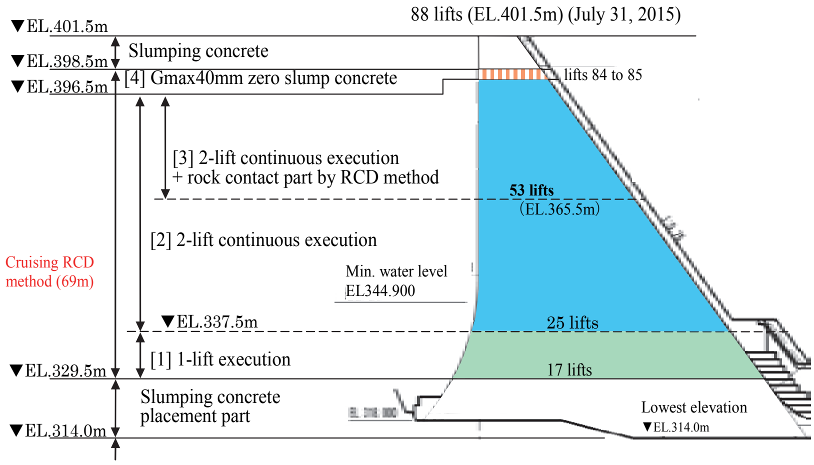


Figure 6. Placement sections by cruising RCD construction method (placement section [1] - [4]) at Gokayama Dam

Table 5. Placement sections by cruising RCD construction method at Gokayama Dam

Category	Lifts	Execution range	Outline of execution	Average placement rate (m/Month)
Placement section [1]	17 to 24	EL.329.5m to EL.337.5m	1 lift execution	4.7 m/Month (1.5 Months)
Placement section [2]	25 to 52	EL.337.5m to EL.365.5m	2-lift continuous execution	6.0 m/Month (10 Months)
Placement section [3]	53 to 83	EL.365.5m to EL.390.5m	2-lift continuous execution + rock contact part by RCD method	
Placement section [4]	84 to 85	EL.396.5m to EL.398.5m	Execution by RCD method using Gmax40mm zero slump concrete	4.0 m/Month

So, at Gokayama Dam, the rich blend RCD mix with 40mm of G_{max} (the maximum grain size of aggregates used) and an execution method using this mix were developed. This method improved work efficiency significantly and increased construction speed on rock contact parts.

The rich blend RCD mix with 40mm of G_{max} shows no segregation of aggregates and good construction property as the conventional slumping concrete does.

2) Execution of the RCD construction method in narrow parts near the dam crest

Originally, in the narrow range of construction width less than about 15m near the dam crest, the execution was switched to ELCM (Extended Layer Construction Method) due to complication from the passing each other of dump trucks, bulldozers, and backhoes etc. at conventional RCD construction method .

As the cancelation of complication of the construction work and the maintenance of placing speed, the cruising RCD construction method using the inner zero-slump concrete with 40mm of G_{max} was also executed instead of ELCM at the narrow area near the dam crest. This was confirmed to provide both good workability and quality.

3. EXECUTION RESULTS OF THE DAM BODY

At Gokayama Dam, placement of the dam body began on February 17, 2014, and full-scale placement by the cruising RCD construction method started on June 16 (17 lifts, EL329.5m). By July 30, 2015, placement had advanced to 88 lifts at EL.401.5m. This was about 91% volume of the dam body.

The cruising RCD construction method at Gokayama Dam was, as explained in Chapter 3, divided into 4 sections—[1] [2] [3] [4]—shown in Table 5 and Fig. 6 (Nishiyama, et al. 2015b).

Fig. 7 shows the placement rates of the conventional RCD construction method at comparatively large-scale dams, and performance of the cruising RCD construction method at Gokayama Dam and other two existing dams (Nishiyama, et al. 2015b).

According to Gokayama Dam in Fig. 7, in contrast to a placement rate of 4.7m/month by 1-lift execution in placement section [1], the placement rate of 2-lift continuous execution (placement sections [2] – [3]) was improved to an average of 6.0m/month. This was a result of shortened waiting time until the start of placement of next lift. During 10 months (sections [2] - [3]), a monthly average volume of about 60,000m^3 was maintained.

The numbers [1] to [4] shown in balloons of Fig. 7 correspond to those enclosed in boxes in Table 5 and in the drawing in Fig. 6.

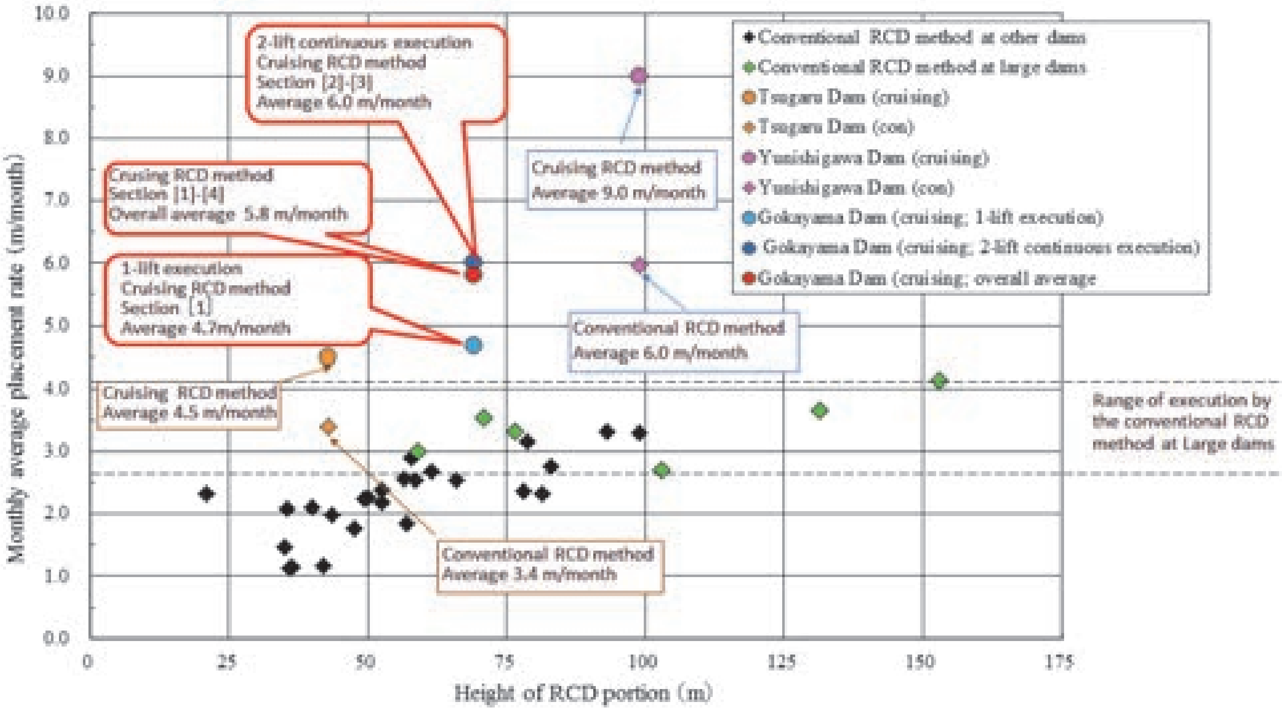


Figure 7. Placement rate at Gokayama Dam

4. CONCLUSIONS

As explained above, at Gokayama Dam, continuous placement by the cruising RCD construction method and applying other newly developed technologies were executed at totally 69 lifts. Its placement rate was an average of 5.8m/month for the 12.5 month placement period by the cruising RCD construction method, and for 10 month among this period, it was 6.0m/month (raising height of placed concrete per month) at sections [2] and [3]. As a result, 1.3 m/mon. of concreting speed is improved comparing with that at section [1].

At dams where the cruising RCD construction method will be adopted in the future, it will be important to plan a layout of the construction facilities that will allow the efficient and continuous transports of different concrete mix without any mutual interference.

In conclusion, the execution of Gokayama Dam by the cruising RCD construction method was finished on July 12, 2015, and the whole completion of dam will be at the end of 2017.

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