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Optimizing Placing Speed of Concrete at Concrete Gravity Dams

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ABSTRACT:
The RCD method and ELCM (Extended Layer Construction Method) have great merits for improving the safety of construction work and thermal control.Naturally, the quality of the concrete is maintained at the same level as that obtained by conventional construction methods.
But in Japan, even in small size dams, there are so many structures in dam bodies, such as spillways, intake facilities, inspection galleries, etc.. that in the large size dams, it is difficult to achieve desirable placing speed during their execution.
This paper collects information about the recent executions of seven concrete gravity dams, and based on these cases, analyzes the quantity placed per hour and placing efficiency, considers the effects of structures inside dam bodies, and at the same time, discusses measures needed to optimize placing speed.

Keywords: Concrete dam, placing speed, RCD, RCC, ELCM

1. GENERAL FACTS CONCERNING CONCRETE PLACEMENT

Experience from past works has identified the following general facts concerning concrete placement.

(1) To speed up execution, the equipment capacity must be increased, but this causes divergence of efficiency values.

(2) At narrow locations such as vicinities of incidental structures, the heel and toe of the dam, parts in contact with rock, and near the dam top, almost all placement work is manually performed so the quantity of execution per hour is small.

(3) There are many specific issues causing inefficiency of concrete placement such as:

a. Transporting mortar
b. Spreading mortar on the lift joints
c. Switching the concrete composition
d. Any malfunction at a concrete mixing plant and transport equipments
e. Rainfall at the placing site

2. ANALYSIS AND CONSIDERATION

2.1. Analysis of Information Collected Concerning Seven Dams

Table 1 shows work contents of the dams examined in this study.

The analysis clarified the following related to actual efficiency:

(1) Amount of concrete placing per hour is greatly impacted by the concrete placement area at each elevation of the dam body (here, referred to as “shape properties (H-A curve)”). (Figs. 1 and 3)

(2) Amount of concrete placing per hour is greatly affected by concrete placement area of straight placing. (Figs. 2 and 4)

(3) Amount of concrete placing per hour is reduced by incidental structures such as spillways, intake facilities, and inspection galleries. (Figs. 1, 3 and 5)

Table 1. Specification of the Seven Dams

Dam Name		TAKIZAWA	KIDO	NAGAI	FUKUCHIYAMA	TOMISATO	KOTOKAWA	MIHARU
Dam Height	(m)	140.0	93.5	125.5	64.5	106.0	64.0	65.0
Crest Length	(m)	424	365	381	255	250	262	174
Top Width	(m)	10.0	8.0	11.5	8.0	7.0	5.0	6.5
Dam Volume	(m3)	1,660,000	501,000	1,170,000	205,000	510,000	206,000	195,000
Dam Body	(m3)	1,620,000	474,115	1,130,000	197,800	457,067	200,089	158,124
RCD	(m3)	910,000	422,151	980,000	81,800	322,342	-	-
ELCM	(m3)	710,000	51,964	150,000	116,000	134,725	200,089	158,124
Stilling Basin	(m3)	40,000	27,039	40,000	7,200	50,679	6,300	37,213
①		36	34	33	22	33	22	24
②		16	23	24	14	26	―	―
③		186	161	120	210	204	138	185
④	(m2)	17,800	6,790	12,730	3,790	7,500	3,640	3,770
⑤	(m2)	11,600	5,150	8,600	3,070	5,560	3,120	2,400
⑥	(cm)	100	75	100	75	75 and 100		
⑦	(cm)	150	100			150	75 and 100	75 and 100
⑧	(m3/h)	270	180	360	135	120	135	60
⑨	(m3/h)	220	120			95	100	48

①Number of concrete placing months
②Number of concrete placing months of RCD
③Number of concrete placeable days per year
④Maximum placement area/layer
⑤Mean placement area/layer
⑥Lift thickness of RCD
⑦Lift thickness of ELCM
⑧Batching plant capacity
⑨Capacity of concrete placing equipments

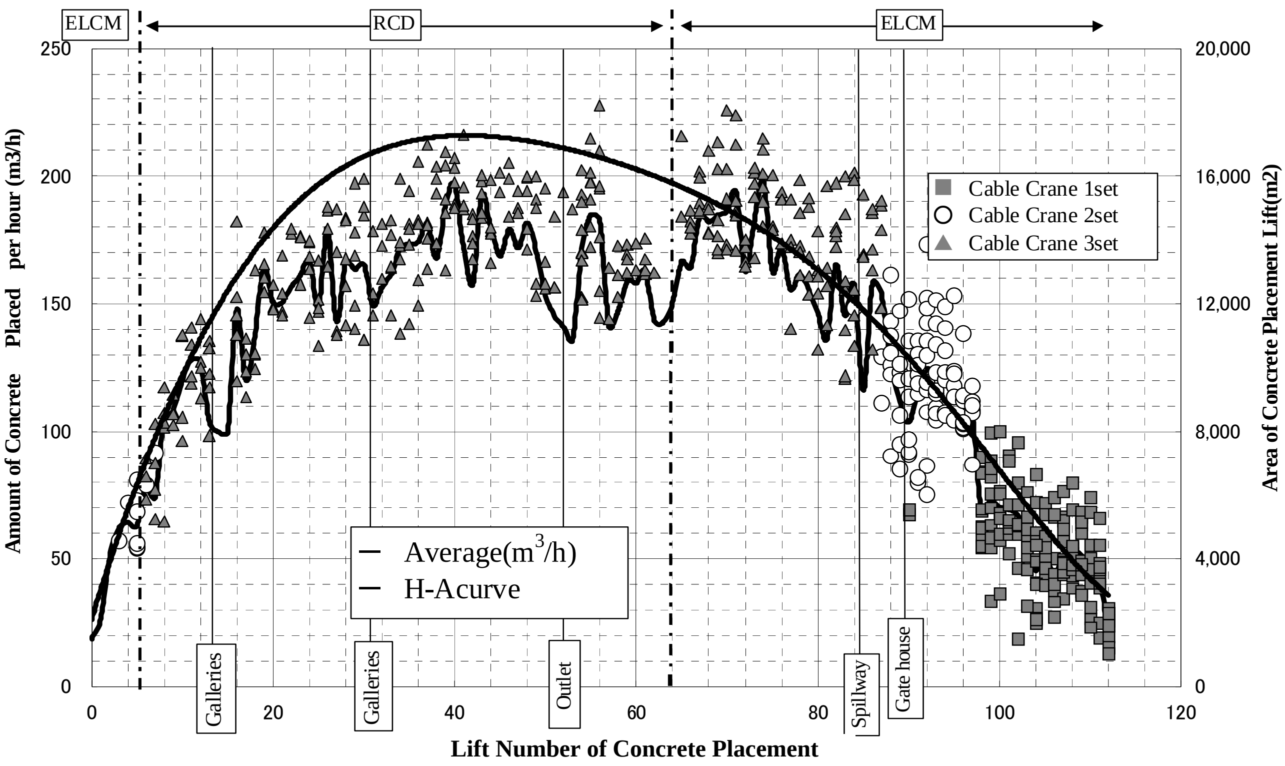

Figure 1. Lift Number of Concrete Placement, Amount of Concrete Placed per hour, and Area of Concrete Placement Lift (Takizawa Dam)

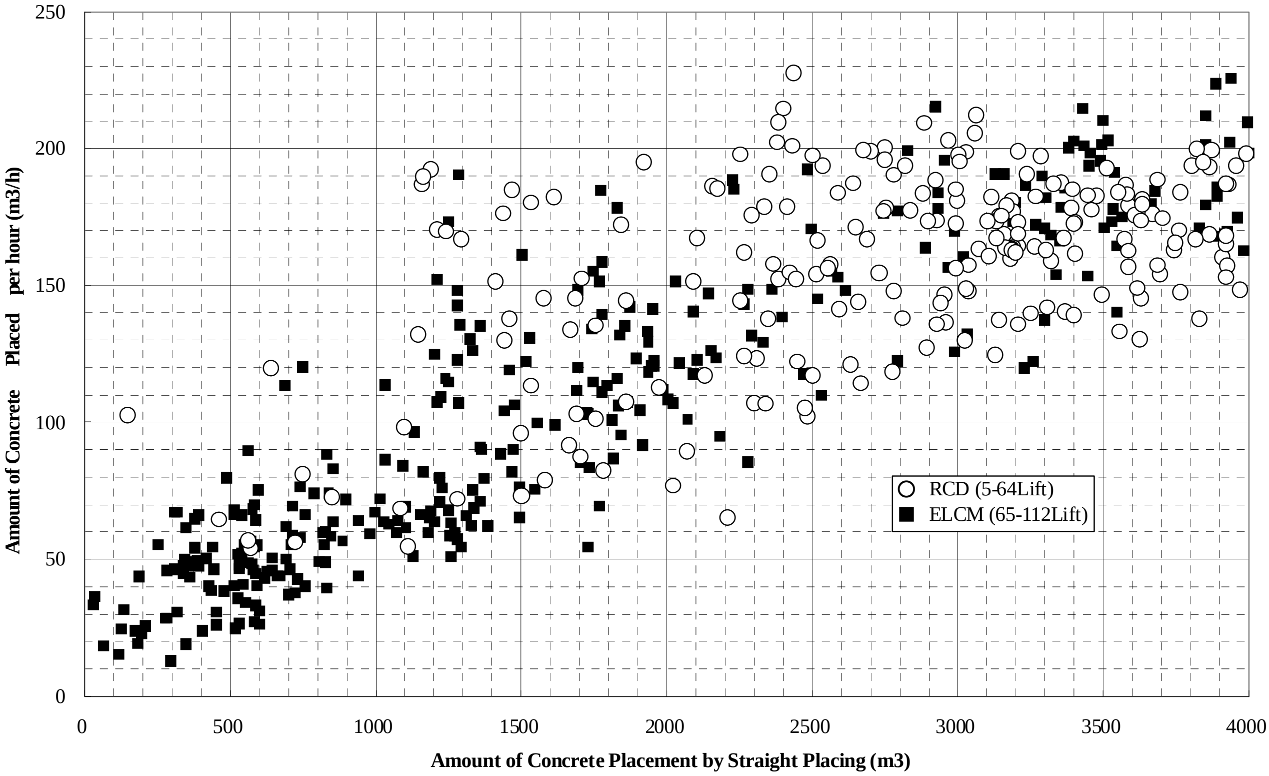

Figure 2. Amount of Concrete Placement by Straight Placing and Amount of Concrete Placed per hour (Takizawa Dam)

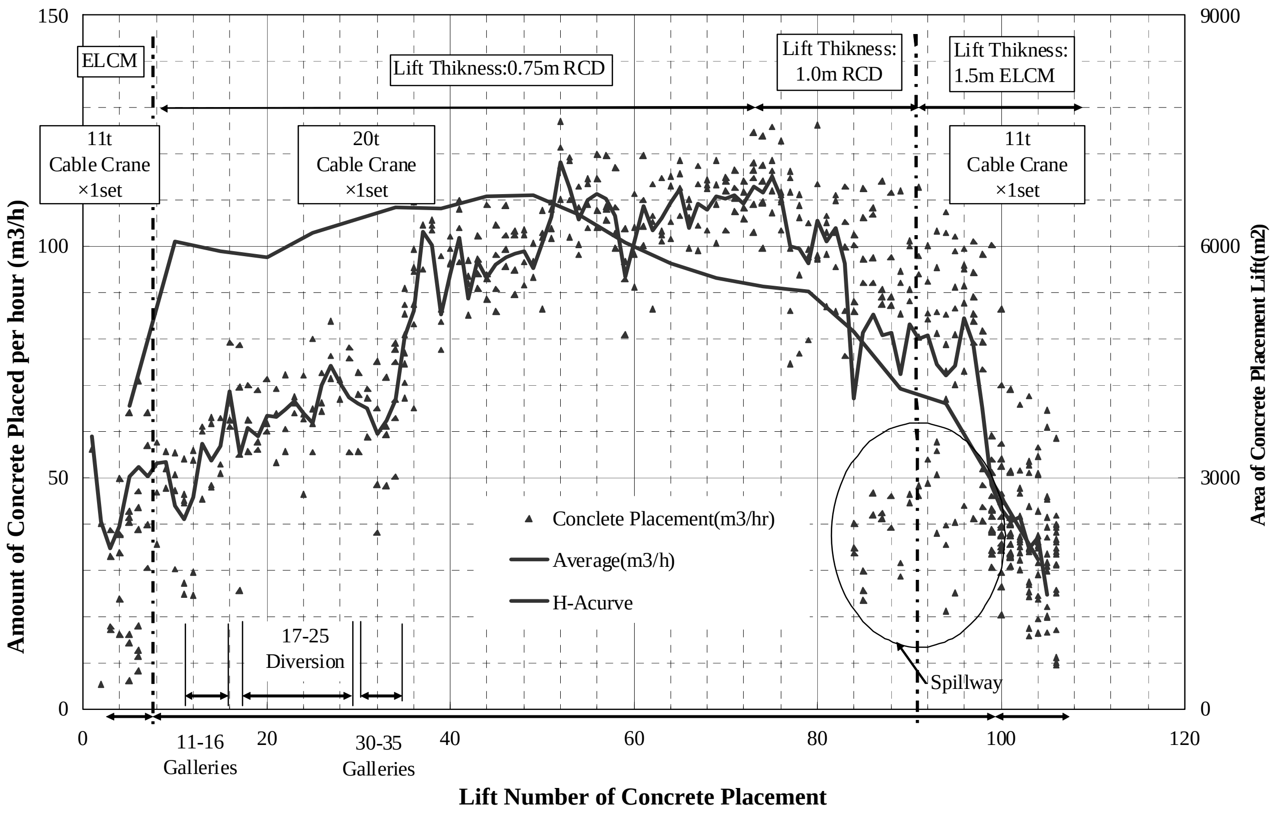

Figure 3. Lift Number of Concrete Placement, Amount of Concrete Placed per hour, and Area of Concrete Placement Lift (Kido Dam)

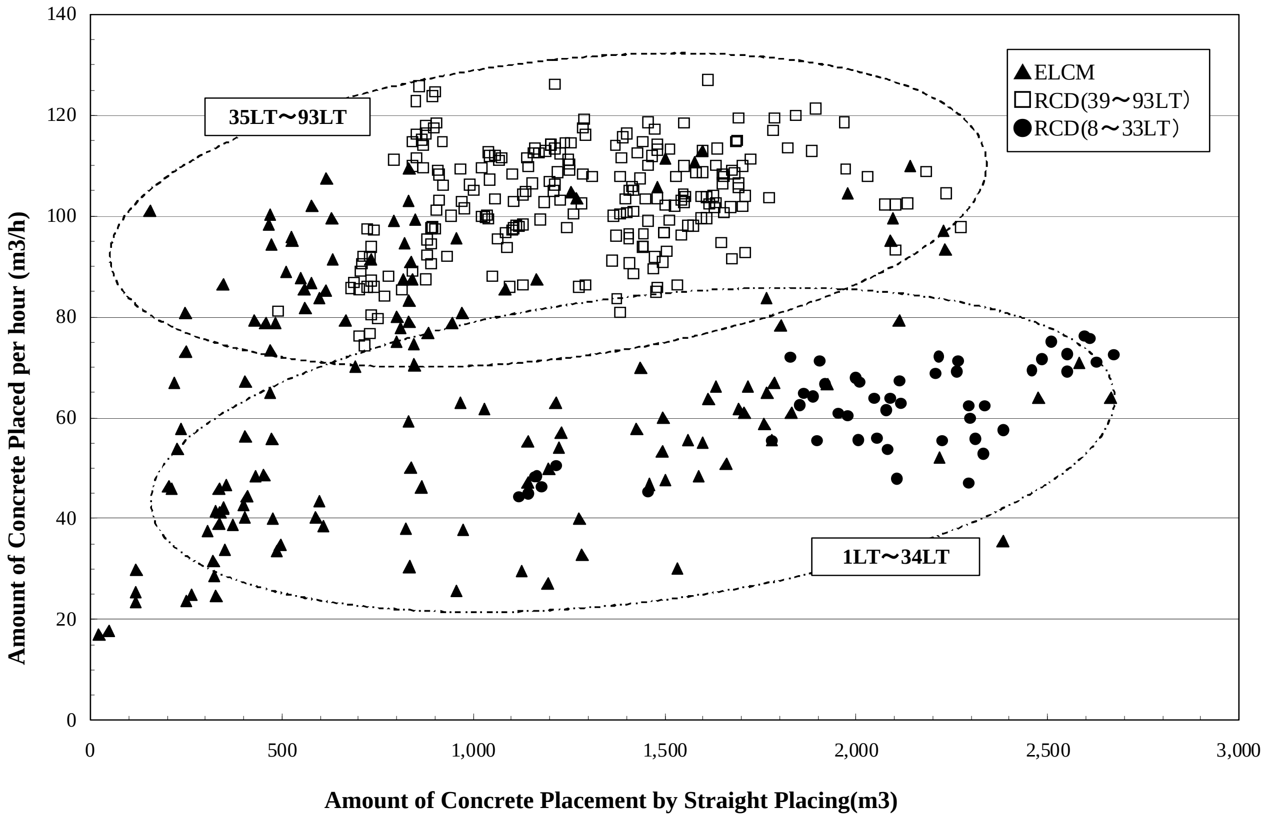

Figure 4. Amount of Concrete Placement by Straight Placing and Amount of Concrete Placed per hour (Kido Dam)

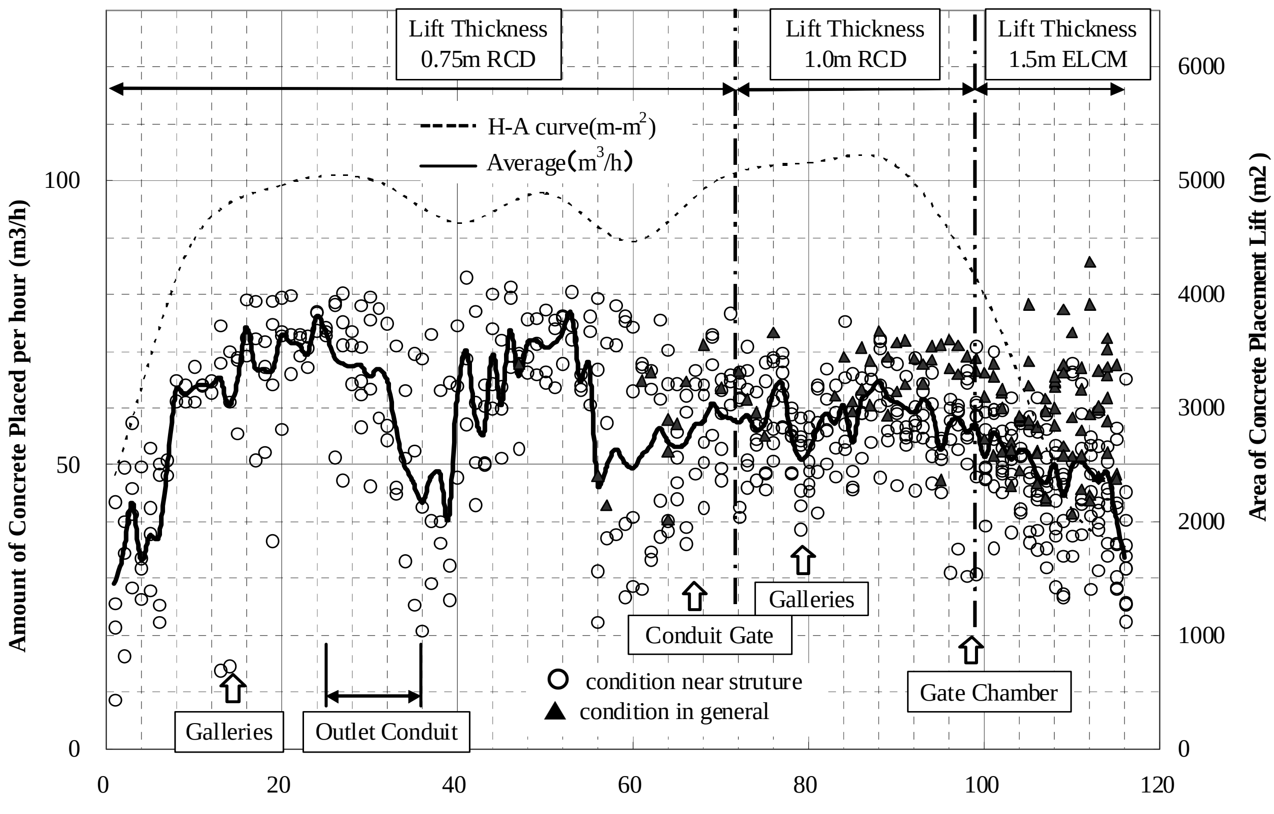

Figure 5. Lift Number of Concrete Placement, Amount of Concrete Placed per hour, and Area of Concrete Placement Lift (Tomisato Dam)

Even though the execution yard for the ELCM is much smaller, the concrete placing efficiency is not reduced, while, the RCD method is vulnerable to the impact of switching the concrete composition and placing at narrow yards or around structures. Hence, the overall concrete placing efficiency is increased by using the ELCM for concrete placing at low and at high elevation parts where the concrete placing area is small, and using the RCD method at medium elevation parts where the area is broad.

2.2. Construction Equipment Used for Small-scale Dams or for Dams Containing Many Structures

A smaller dam has a higher ratio of narrow construction field to incidental structures, the heel and toe of dam, and portions in contact with the rock bed, so the study must be conducted from a different perspective than large dams.

At the Miharu Dam, built using a cable crane, an almost identical amount of concrete placing per hour was achieved from low to high elevation parts, and the average speed of placement for the entire dam body was 49.4 m^3/hour, which is higher than the planned value (48.5 m^3/h).

The Kotokawa Dam, built using a tower crane, achieved between 80% and 90% of the planned value at the middle elevations.

At the Tomisato Dam, constructed by a double-end movable cable crane, ELCM was adopted and concrete was directly placed in the high elevation portion, but the difference in concrete placing capacity of the cable crane with and without internal structures was only about 10%

The results of direct placing by a crane show that the work efficiency is hardly reduced due to the effect of structures inside the dam body, expect that the placement is done manually. For this reason, at dams with many internal structures, direct concrete placing by crane could be effective.

2.3. Increasing Placing Capacity by Combining with Rational Material Transportation System

In dam construction, only one kind of transportation equipment is generally used to transport the concrete from the riverbed to the crest, regardless of the dam body shape (H-A curve).

However, considering the overall construction process, concrete placing speed varies according to the progress of concrete placement. At the riverbed, placement speed is low due to the bumpy bedrock condition. When the foundation bedrock at the riverbed has been covered with concrete, the placing speed can be increased. Later, as the work approaches the crest, the workable area becomes smaller, and the concrete placing speed is reduced.

Thus, in the period when the highest speed is required, it is rational to introduce supplementary transport equipment. At the Kasegawa Dam and the Yunishigawa Dam, in addition to the cable crane as the principal transport equipment, SP-TOM (the Spiral Pipe Transportation Method) was adopted for locations with a large concrete placing area at the middle elevations, sharply reducing the concrete placing period.

2.4. Selection of Equipment Capacity and Maintenance of Equipment

For smooth construction of dams, the production, transport, and placement of concrete must be performed continuously without delays, but to achieve this, it is essential to balance the capacities of the concrete production equipment and transport equipment with the concrete placement time.

The capacity of aggregate production equipment must also be sufficient to smoothly supply the required material. In a case with no surplus capacity, the quantity of concrete to be placed will be limited by the quantity of aggregate produced. In actual fact, it is rarely revealed since it is estimated according to the aggregate stock.(Table 2)

Furthermore, sufficient time for inspecting and maintaining the equipment must be ensured. Otherwise, equipment may malfunction and cause the suspension of concrete placing, and reduction of the overall efficiency.

2.5. Increasing Transport Capacity by Automating the Crane Operation

At the Miharu Dam, high transport capacity was achieved thanks to the superior skills of experienced operators, but it may be difficult to ensure such experienced operators in the future.

On the other hand, the automatic dam construction control system has been extensively researched since 1990, and automated cranes have been developed and used at many dams.

At the Takizawa Dam, integrated automation of the transportation system from the concrete mixing plant to the construction field ensured efficient construction work.

Automation ensures safe and stable transport speed, and effectively overcomes problems related to the use of multiple cranes and complex topographical conditions.

Table 2. Operating records of Aggregate plant

Dam name		URAYAMA			TAKIZAWA			KIDO		
Dam Volume (m3)		1,750,000			1,660,000			501,000		
		Throughtout the whole turm of Dam construction								
		①	②	③	①	②	③	①	②	③
④	(hs)	5,752.0	6,395.0	6,592.0	5,081.1	8,624.8	9,522.4	5,739.3	4,103.5	2,151.1
⑤	(days)	734	823	836	728	780	782	745	662	564
⑥	(hs/day)	7.8	7.8	7.9	7.0	11.1	12.2	7.7	6.2	3.8
⑦	(hs)	810.5	1,383.0	384.5	1,551.1	1,189.0	1,444.1	951.0	2,505.0	870.5
⑧	(hs)	1,540.5	3,007.5	3,223.5	2,301.6	2,433.4	4,111.4	608.0	1,601.0	1,128.5
⑨	(hs)	2,351.0	4,390.5	3,608.0	3,852.7	3,622.4	5,555.5	1,559.0	4,106.0	1,999.0
⑩		0.409	0.687	0.547	0.758	0.420	0.583	0.272	1.001	0.929
		Greatest term (month) of Concrete placement								
		①	②	③	①	②	③	①	②	③
④	(hs)	224.0	268.5	245.5	210.5	390.6	434.4	264.5	181.0	116.0
⑤	(days)	24	26	26	24	24	24	27	27	25
⑥	(hs/day)	9.3	10.3	9.4	8.8	16.3	18.1	9.8	6.7	4.6
⑦	(hs)	10.0	66.5	9.5	26.0	61.4	9.8	21.5	62.5	13.0
⑧	(hs)	31.0	79.5	105.0	71.3	103.1	159.0	15.5	45.0	36.0
⑨	(hs)	41.0	146.0	114.5	97.3	164.5	168.8	37.0	107.5	49.0
⑩		0.183	0.544	0.466	0.462	0.421	0.389	0.140	0.594	0.422
		Planned value								
		①	②	③	①	②	③	①	②	③
⑪	(t/h)	1,050	880	285	840	530	180	340	274	89
⑫	(m3/h)	340	340	340	270	270	270	120	120	120
⑬		3.088	2.588	0.838	3.111	1.963	0.667	2.833	2.281	0.743
⑭	(kg/m3)	674+1572	674+1572	674	710+1520	710+1520	710	676+1587	676+1587	676
⑮	(kg/m3)	569+1625	569+1625	569	597+1547	597+1547	597	585+1597	585+1597	585
⑯	(kg/m3)	2,246	2,246	674	2,230	2,230	710	2,263	2,263	676
⑰	(t/h)	763.6	763.6	229.2	602.1	602.1	191.7	271.6	271.6	81.1
⑱		1.375	1.152	1.244	1.395	0.880	0.939	1.252	1.008	1.100

①Primary crushing plant
②Screening plant
③Fine aggregate production plant
④Amount of operation hours
⑤Amount of operation days
⑥Daily mean of operation hours (=④/⑤)
⑦Amount of repair hours
⑧Amount of service hours
⑨Amount of maintenance hours (=⑦＋⑧)
⑩Ratio of maintenance to operation hours (=⑨/④)
⑪Aggregate plant capacity
⑫Concrete placement capacity
⑬Ratio of aggregate plant to concrete placement (=⑪/⑫)
⑭Quantity of aggregate per unit volume of concrete (RCD)
⑮Quantity of aggregate per unit volume of concrete (ELCM)
⑯Large quantity of aggregate RCD or ELCM
⑰Amount of necessary aggregate per hours
⑱Ratio of aggregate plant capacity to aggregate usage(=⑪/⑰)

3. CONCLUSIONS

The following have important roles in optimizing the concrete placing speed in a concrete gravity dam:

(1) Selecting equipment suited to dam body conditions
Whether the RCD method or ELCM is superior is mainly determined by such factors as the concrete placing area, shape properties (H-A curve) and layout of structures inside the dam body, but it is important to study appropriate combinations of these methods. The transport equipment should also be studied carefully, including the usefulness of direct placing of concrete with a crane.

(2) Reducing time other than concrete placing time
Although not discussed in this paper, the investigation results also revealed that the inspection of execution equipment, preparation and inspection before the start of concrete placing, and time preparing before and after holidays and other times when concrete placing is not possible, accounts for a high percentage of the total work time.

To shorten the total concrete placing period, it is necessary to investigate ways to minimize these particular periods.

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