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State of art of RCD dams in Japan

*Estado da Arte do RCD
barragens no Japão*

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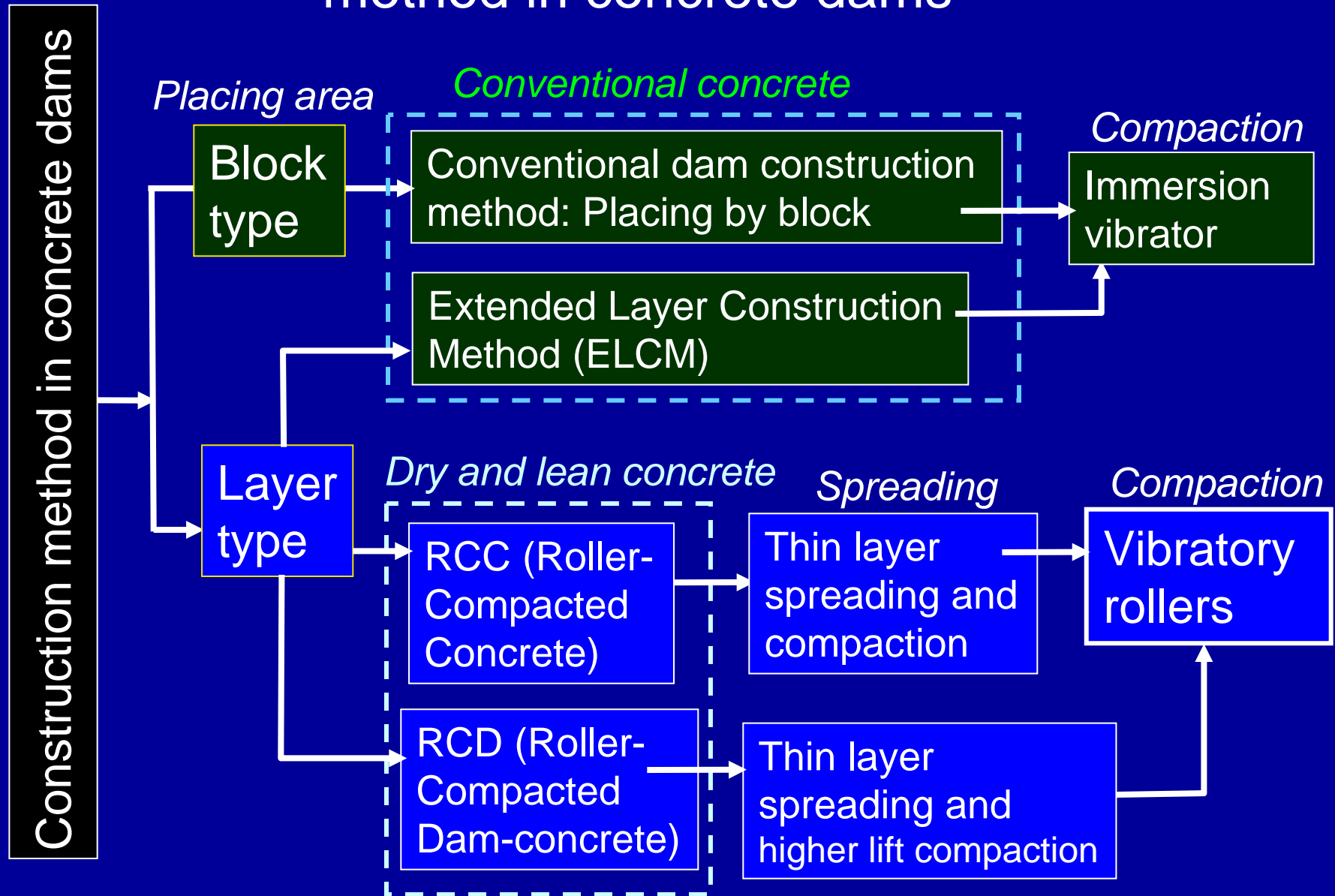
1. Introduction

RCD (Roller Compacted Dam concrete) construction method is a rationalized construction method for concrete dams which was developed by the Ministry of Construction, Japan in 1970's, as the first roller-compacted concrete construction method prior to RCC (Roller Compacted Concrete).

Through many RCD dam's experiences, RCD construction method has achieved reduction of the construction period, the labor cost, the environmental issue, and the hazard in safety for the constructor.

- 1.1 Features of RCD concrete and RCD construction method
- 1.2 Philosophy and background of RCD construction method
- 1.3 Comparison between RCD and RCC

Outline of the rationalized construction method in concrete dams



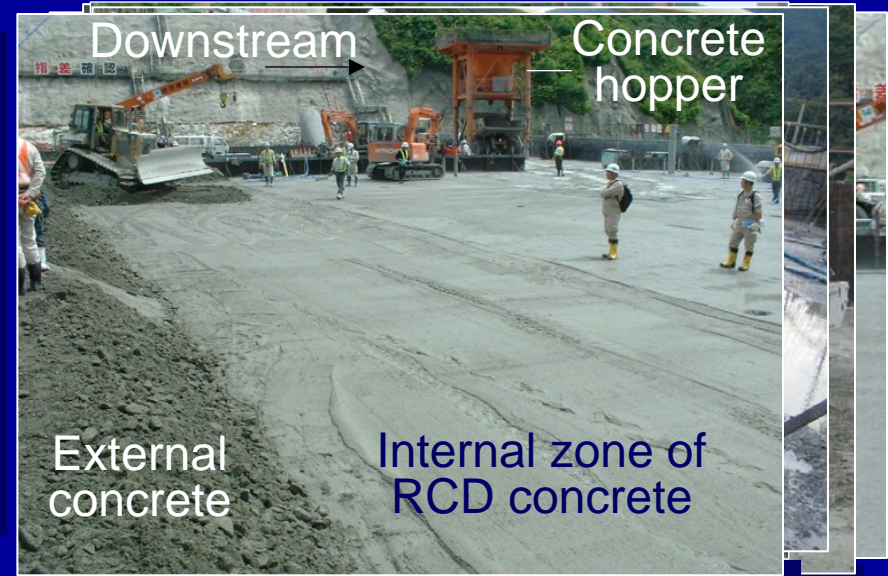
1.1 Features of RCD concrete and RCD

construction method

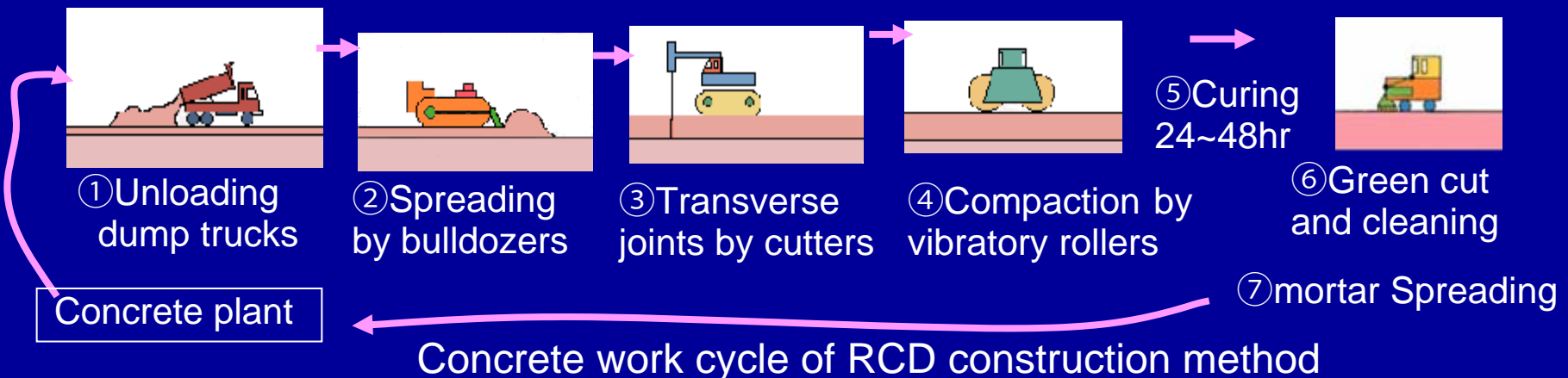
- a. RCD concrete is extremely dry and lean concrete in order to improve transportability and reduce hydrated heat. The Ministry of Construction made up RCD concrete under a new mixture concept to keep the same quality in strength and density as the conventional concrete has.
- b. Further, Japan established RCD construction method to manage this RCD concrete. In this method, the concrete is spread in several thin layers over the entire dam surface and is compacted by vibratory rollers

Procedures of RCD concrete works

7. The mortar is spread out before the next concrete is unloaded in the placing area.



Spreading mortar



1.2 Philosophy of RCD construction method

The philosophy of RCD is to keep the same performance as conventional concrete dams and to satisfy the same design criteria as conventional concrete dams , while to pursue the improvement of economy, safety, and environment.

Therefore, RCD is a construction method to rationalize the dam construction works and the required functions of RCD dams are the same as that of conventional concrete dams.

For example;

- a. Transverse contraction joints are installed every 15 m in order to prevent temperature cracks in the dams.
- b. Conventional concrete with high quality is placed at the upstream and the downstream surfaces of the dams in order to obtain water-tightness and high durability.
- c. Lift joints (horizontal surfaces) are treated in the same way as the conventional concrete dams in order to assure good bond and water-tightness between the lifts.

1.3 Comparison between RCD and RCC

RCD is compacted by a higher lift than RCC.
RCD is possible to place more concrete than ELCM.
However, They have many common concept and technical know-how.



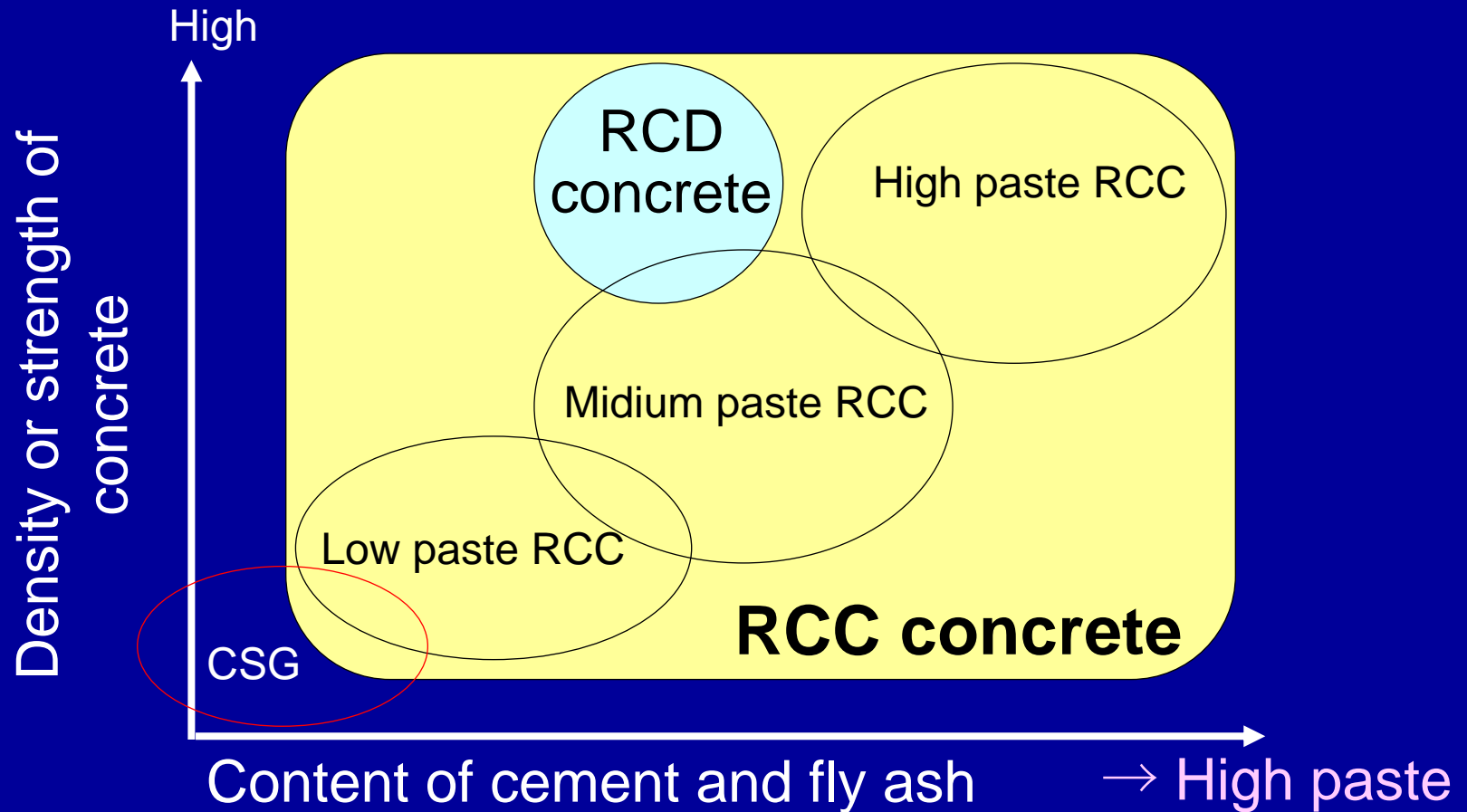
Comparison between RCD and the other types of concrete

(internal zone)

	Conventional dam concrete, ELCM*	RCD concrete	High paste RCC concrete	RCC in Kinta dam
Property of concrete	dry and lean concrete	extremely dry and lean	High paste concrete	High paste concrete
Unit content kg/m ³ W: water, C: cement	W=105~115 C+F=130~160	W=80~105 C+F=110~130	W=100~150 C+F=150~300	W=150 C+F=200
F/C+F, F: fly ash	20~40%	20~40%	≥50%	50%
Max size of aggregate	80~150mm	80~150mm	Mostly 40~65mm	63mm
s/a :sand/aggregate	25~30%	28~34%	Higher than RCD	41%
Consistency test	Slump value: 2~4cm	VC value: 10~25sec	VB value: 10~17sec	VB value: 12~17sec
Thickness of a lift	1.0m/1.5m	0.75m/1.0m	0.3m~0.4m	0.3m (slope layer)
Transverse Joint	Block formed by 15m span	Cut by 15m span using joint cutter	Cut by 15~60m span using joint cutter	Cut by 20m span using joint cutter
Lift Joint treatment	Green cut +cleaning + mortar spreading	Green cut + cleaning+ mortar spreading	Nothing to do until setting start	Nothing to do in 5hr after placing

Conceptual position of RCC & RCD concrete

The relationship between RCC and RCD concretes from the view of paste contents and density or strength of concrete.



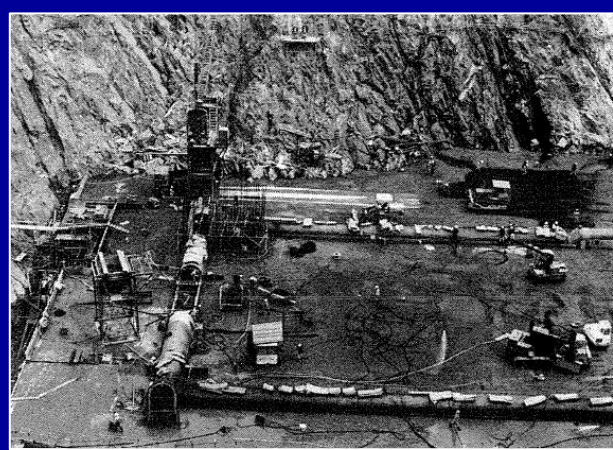
CSG: Cemented Sand and Gravel, new material for dams

2. History of RCD dams in Japan

The first applied RCD dams was Shimajigawa dam and Ohkawa dam. The both dams were completed in 1980. Then, RCD construction method was applied to Tamagawa Dam.

In the latter half of 1980's, RCD construction method was also adopted at many dams. In 1990's, RCD construction method raised technical completeness by the large-scale dam execution such as Ryumon dam, Miyagase dam, Urayama dam, and Gassan dam. At the same time, RCD construction method was adopted in many middle-scale dams. After 2000, Takizawa dam and Nagai dam achieved some improvements.

Today in Japan, Kasegawa dam and other several dams are challenging to progress to a new stage of dam technology for the sustainable future.



Shimajigawa dam



Miyagase dam



Origawa dam

Map of RCD dams by the transportation method

RCD dams grouped by the transportation method

1.Hokkaido

-  Damp track
-  Incline
-  Tower crane
-  Cable crane
-  Belt-conveyor
-  Under construction

2.Tohoku

4.Hokuriku

6.Kinki

7.Chugoku

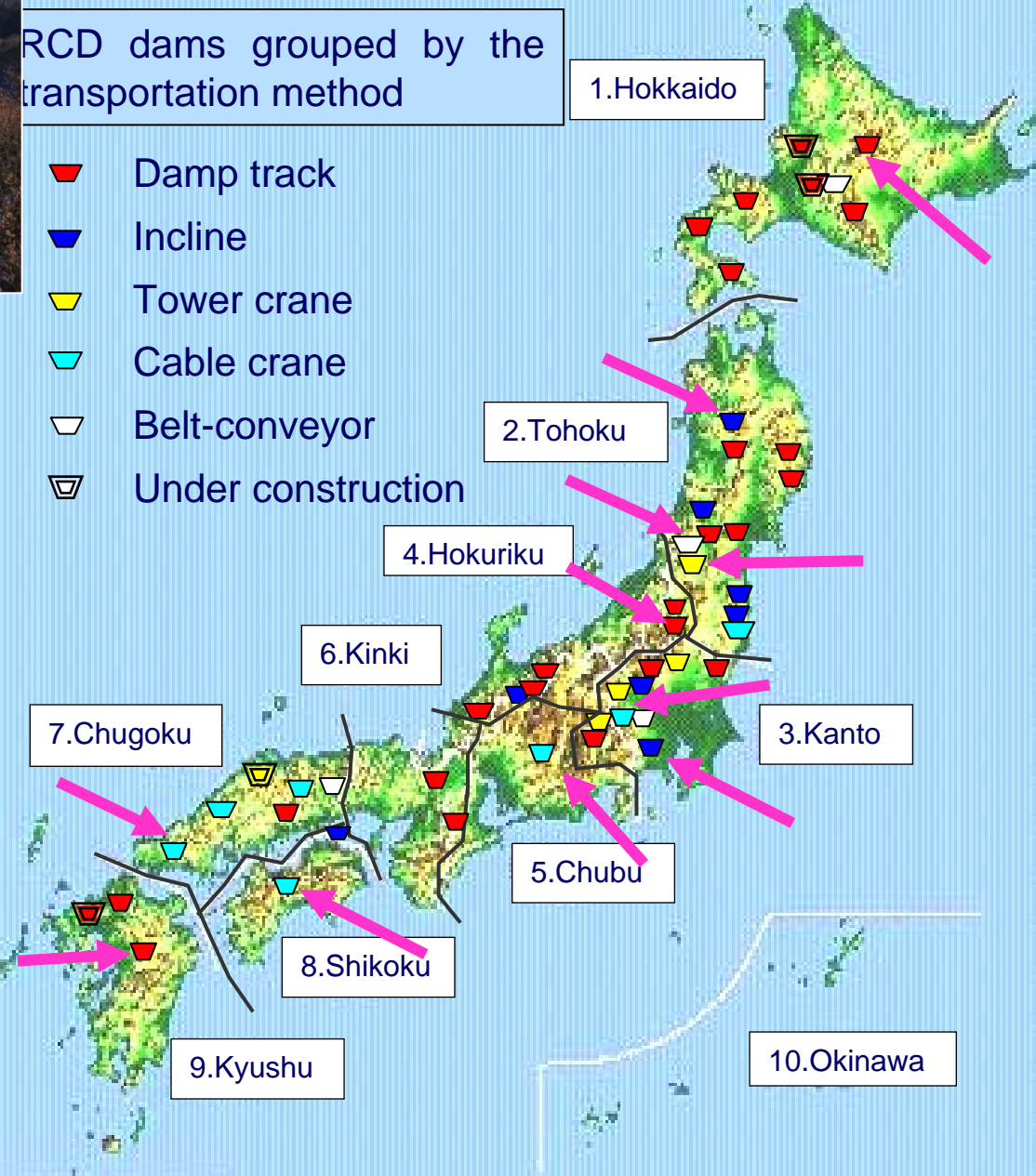
3.Kanto

5.Chubu

8.Shikoku

9.Kyushu

10.Okinawa



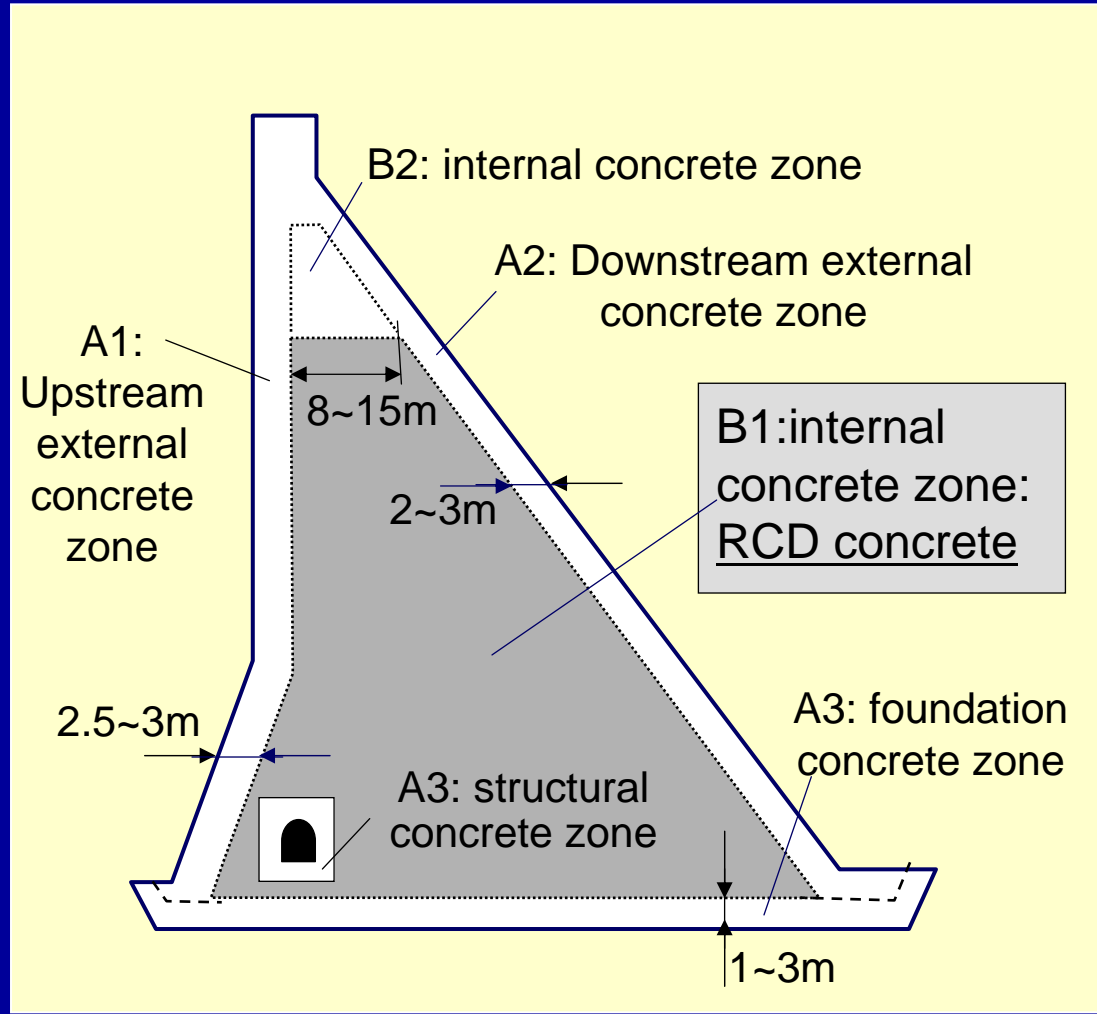
3. Planning of RCD construction method

The basic plan of RCD construction method is decided by considering the schedule, temperature control, compacting thickness, construction facility capacity, geography, geology, climate and environment.

- 3.1 Zoning of dam concrete
- 3.2 Lift schedule
- 3.3 Temperature control
- 3.4 Choice of concrete plant capacity and mixer type
- 3.5 Choice of transportation system
- 3.6 Simplification of inside structures of dam body

3.1 Zoning of dam concrete

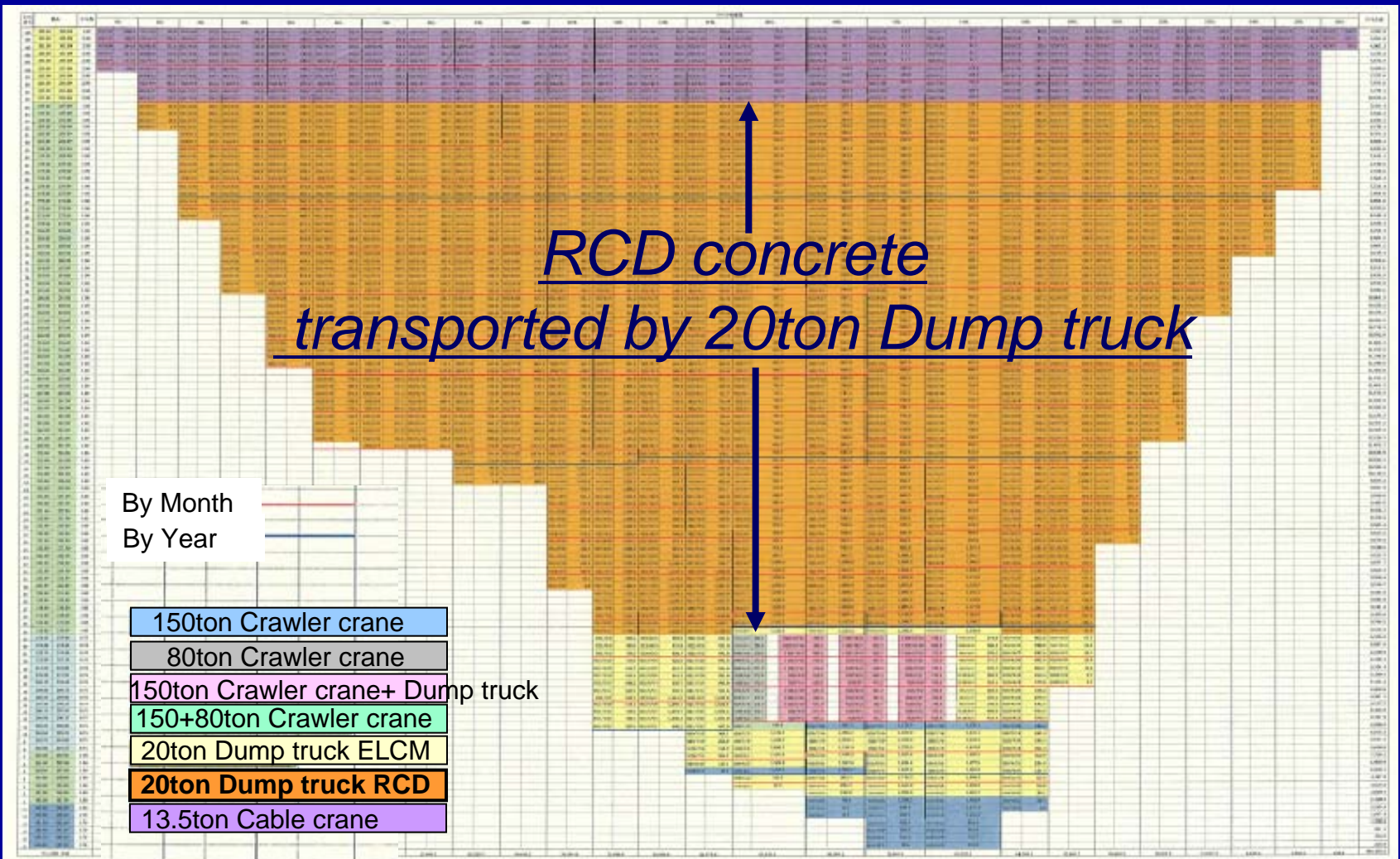
The upstream and downstream of dam surfaces should be covered by high quality concrete to maintain water-tightness and durability to protect the concrete from freeze-and-thaw attack or other aging. RCD concrete is placed in internal zone



Cross section of RCD dams classified by concrete mixture

3.2 Lift schedule

In RCD construction method, much more concrete can be placed. Therefore it is extremely important to plan an appropriate lift schedule to obtain construction efficiency and to prevent temperature cracks.



Lift thickness 1m

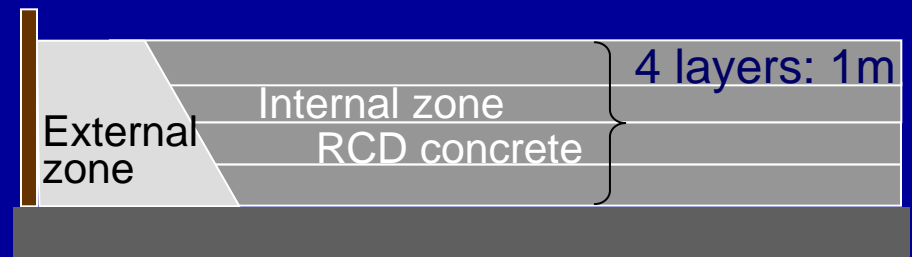
06.2008, Kasegawa dam

In order to speed up construction and to reduce the number of lift surface treatments, lift thickness had to be increased.

Thick lift placement prevents the formation of a possible weak plane on the lift surface.

At Tamagawa Dam, 1 m of lift thickness was made possible by thin layer placement.

The thin layer spreading method used in RCD construction method completely differs from compaction in RCC construction which adopted compacting concrete in a single layer.



1 m of lift thickness was divided into four thin layers that were spread by bulldozers.

3.3 Temperature control

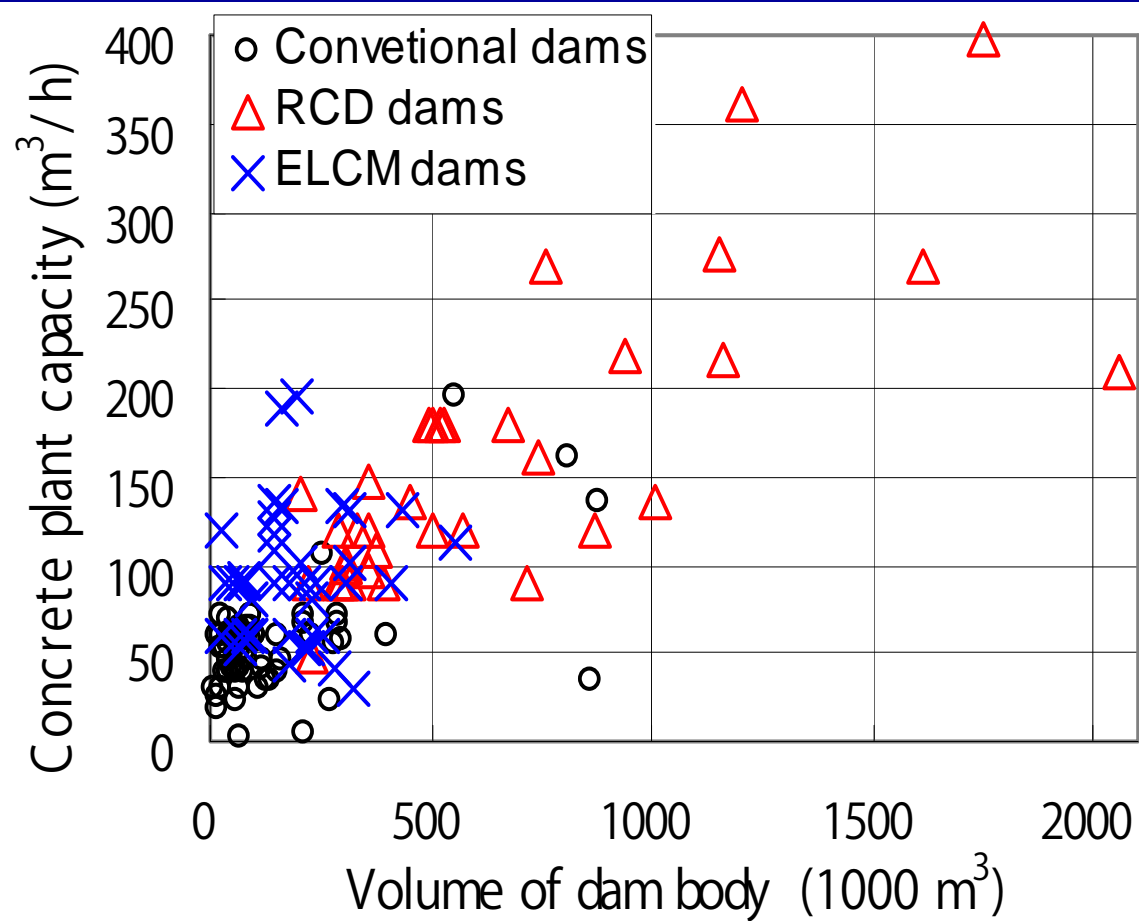
Temperature control plan should be prepared to prevent temperature cracks.

1. To suppress the heat of hydration: Moderate-heat Portland cement with fly ash is used and the unit cement content is reduced in RCD concrete.
2. Cutting of transverse joints: Experiences have shown that temperature cracks can be prevented mostly when the transverse joints are placed about 15 meters apart.
3. Curing RCD concrete: Through the term of concrete placing in most of RCD dams, the concrete is cured by ponding and water sprinkler. Further, in cold winter, the surfaces of concrete dams should be covered by heat insulators like as urethane materials.
4. Pre-cooling of materials: In the summer season, most of RCD dams have executed pre-cooling of concrete materials (mainly, water and coarse aggregates).
5. Another important step is to start the concrete placing from the more advantageous month. Miyagase dam started the concrete placing from September from this idea.

3.4 Choice of concrete plant capacity

As RCD construction method enables to place much more concrete, RCD concrete plants should have enough capacity to speed up the concrete placement.

Figure shows that concrete plant capacities in RCD dams tend to be bigger and more in accordance with the dam volumes than the others, because RCD dams are more free from the restrictions of temperature control, concrete transportation and concrete placing.



Concrete plants to dam volumes

3.6 Simplification of inside structures

of dam body

Inside structures such as inspection galleries, temporary diversion channels, conduits and gates might affect the smooth concrete placing of RCD construction method. So, various simplifications of inside structures have been implemented to speed up the RCD concrete works in Japan. For example, they are adoption of precast members, rearrangement or shortcut of galleries to avoid duplication with concrete works, reposition or bridging of temporary diversion channels, course and elevation change of conduits, and improvement of complicated structural works which is a bottleneck of the rationalization.

Photo shows the precast setting for inspection galleries to simplify formworks.



4. RCD Concrete

The requirements of RCD concrete mixes are the same as those of conventional concrete. The mixture design of RCD has been improved throughout the history of RCD construction method.

- 4.1 Requirement to RCD concrete
- 4.2 Material properties used in RCD concrete
- 4.3 VC (Vibrating Consistency) test
- 4.4 Mixture design of RCD concrete
- 4.5 Ratio of volume to void in concrete and mortar

4.1 Requirement to RCD concrete

The unit cement content and unit water content in RCD concrete are much less than those in the conventional concrete for dams.

It is because RCD concrete should be extremely dry and lean concrete. Extremely dry concrete is required to allow the construction equipment to travel on fresh concrete. Lean concrete is required to minimize temperature rises which may cause temperature cracks.

Hardened RCD concrete should have the same properties as conventional concrete, which is required to construct the safe and watertight concrete dams.

Like conventional concrete, RCD concrete must have strength, unit weight, water tightness and durability to satisfy the requested performance.³

4.2 Material properties used in RCD concrete

Prior to mix design, materials should be selected like as below.

1. Cement: moderate-heat Portland cement, and low hydration heat type cements. The unit cementitious material (cement and fly ash) content was reduced to 110kg/m³.
2. Aggregates: Aggregates used in RCD concrete must have the same quality as those of conventional concrete. The maximum size of aggregate in RCD concrete is mostly 80 mm and sometimes 150 mm.
3. Finer particles: Reducing the cement paste content or mortar content may cause the segregation of the aggregates. It is improved by adding finer particles (50 % grain size of about 50 μ m) to the fine aggregate.
4. Admixture: Fly ash is generally used as mineral admixture and 20 % to 40 % of cement is replaced by fly ash. The use of fly ash contributes to lowering the heat of hydration, improving consistency, and increasing long term strength.

4.3 VC (Vibrating Consistency) test

Since RCD concrete is dry and lean, the slump test cannot be used to measure its consistency. So, the VC test method was developed to measure the consistency of RCD concrete.

There are two kinds of container used in the VC test: the standard-size (diameter 24cm) and the large-size (diameter 48cm) container.

In the VC test using a standard-size shown in Photo 1, concrete wet screened up to 40mm or less is used. In the VC test using a large-size container shown in Photo 2, a full-size mix of concrete is applied.



Photo 1 :
VC test with a
standard size
container



Photo 2 :
VC test with a large-
size container

4.4 Mixture design of RCD concrete

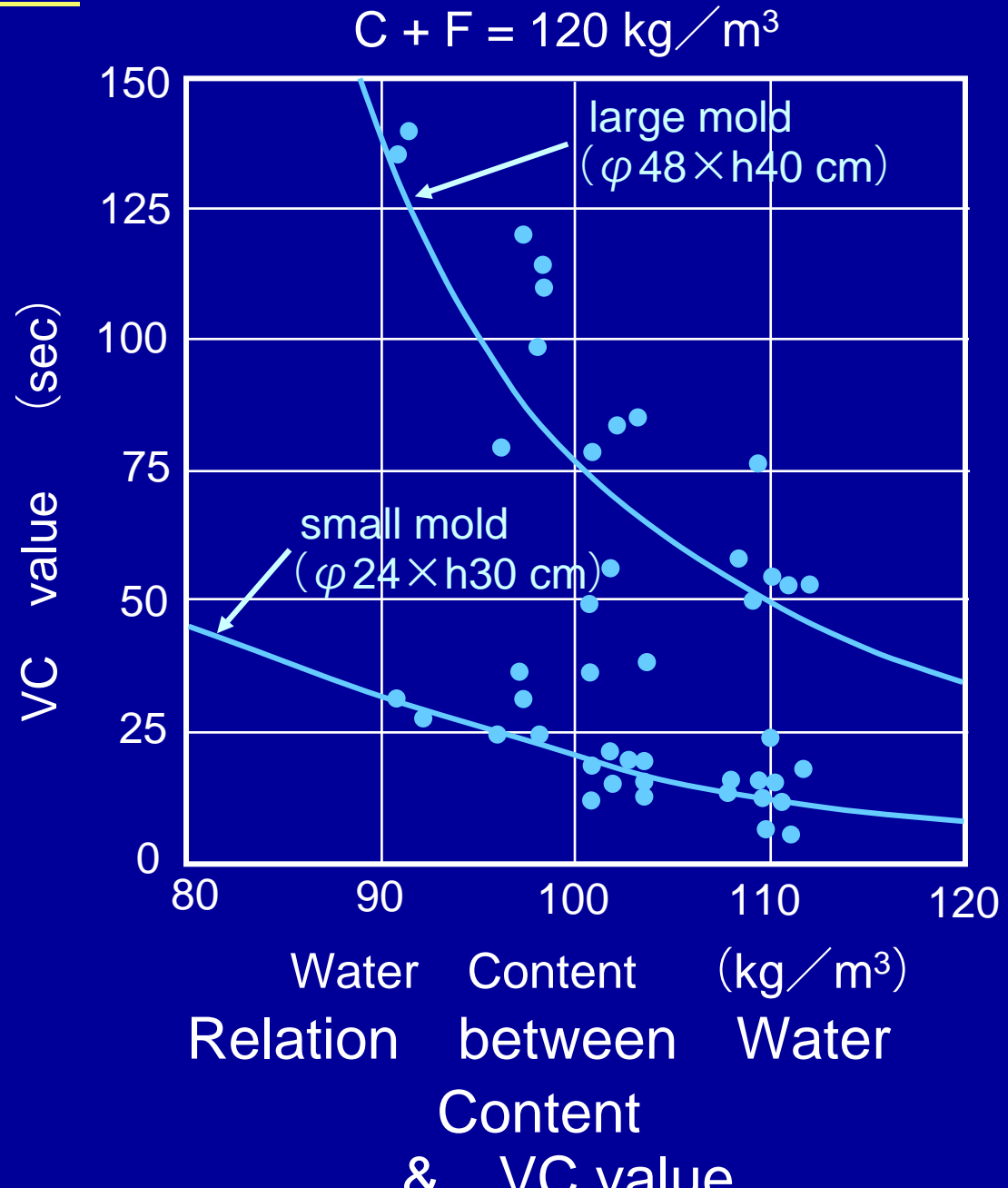
The success of RCD construction depends on the mixture design of RCD. In the development of RCD concrete, some new concepts are adopted. The mix design of RCD concrete is carried out as shown below.

1) Unit cement content

The unit cement content must be kept lowest in order to prevent a high temperature rise, as long as the required workability, strength, and other properties are satisfied. Mostly, the unit cement content of RCD concrete is 110 to 130 kg/m³.

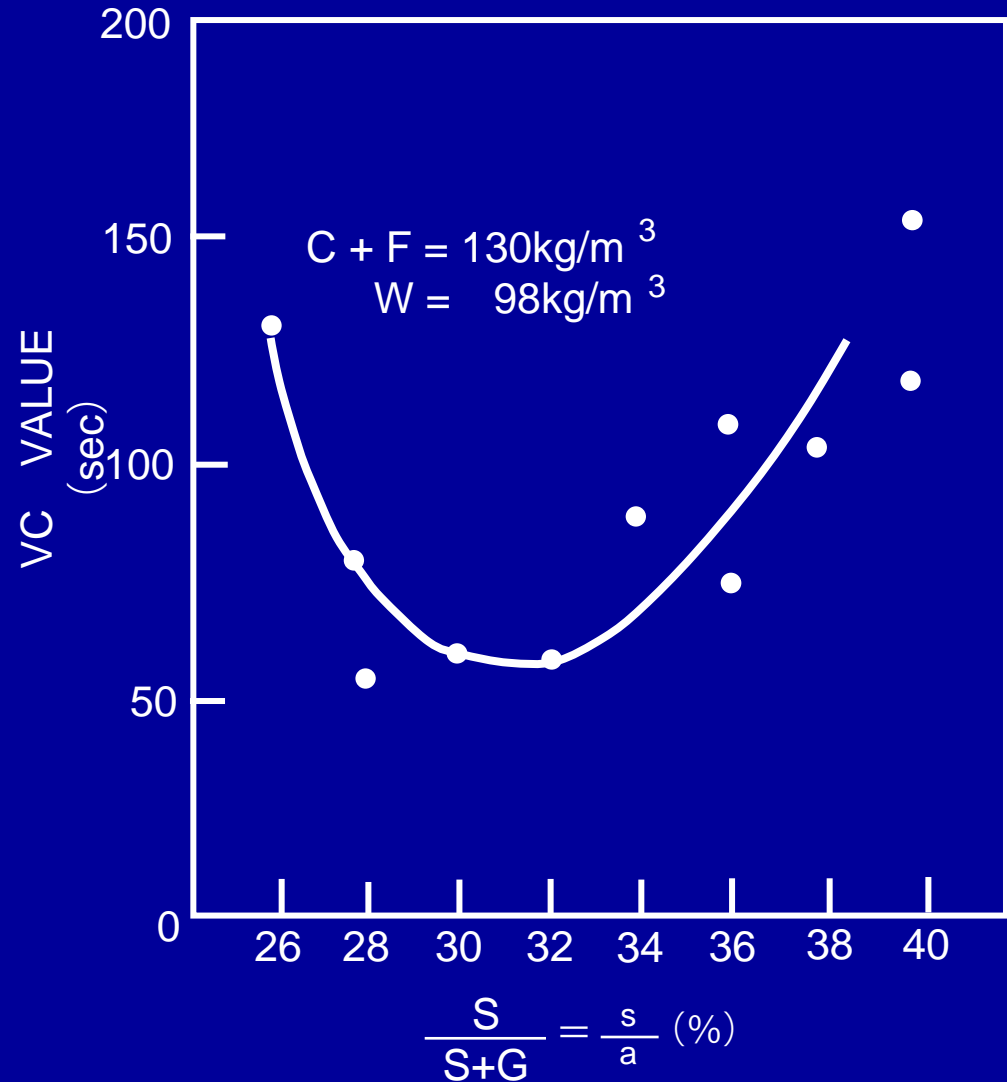
2) Unit water content

The unit water content is determined so that adequate compacting can be achieved. In the VC test, the optimum water content is determined when the prescribed VC value is obtained. Normally, the optimum VC value is 20 seconds and the unit water content is 80 to 105 kg/m³.



3) Sand aggregate ratio

The optimum sand aggregate ratio is the ratio where the VC value is at its smallest. The sand aggregate ratio of RCD concrete is about 30% in general. In comparison to conventional concrete, the sand aggregate ratio in RCD concrete is higher. Full size mix of concrete is used in the VC test with a large-size container. In this VC test, the unit cement content and unit water content are held constant, but the sand aggregate ratio is varied.



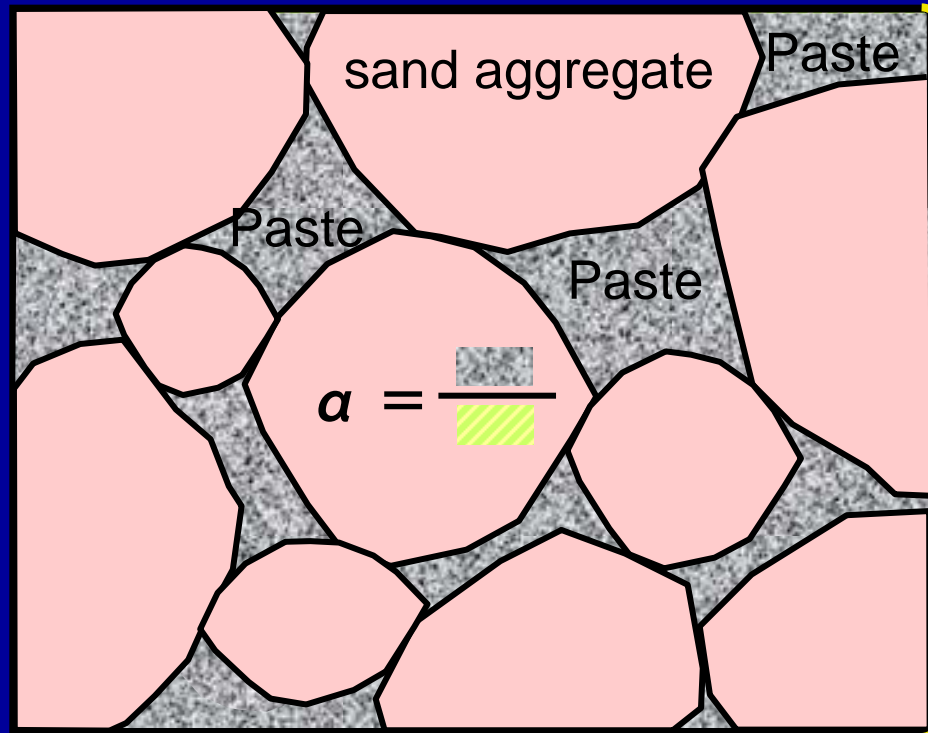
4.5 Ratio of volume to void in concrete

and mortar

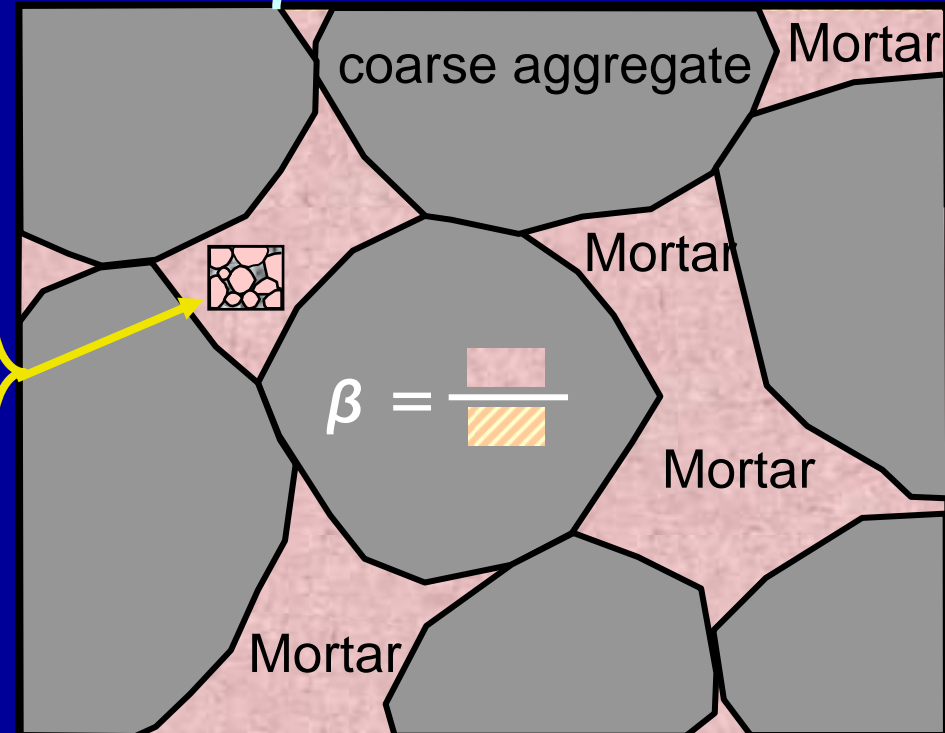
To find the optimum mixture ratio, the concepts of the coefficients α and β are introduced. The ratio of paste volume to the voids in the sand aggregate is defined as α and the ratio of mortar volume to the voids in the coarse aggregate is defined as β .

In order to fill the voids in coarse aggregate and sand with mortar or cement paste sufficiently, both α and β should be more than 1.

α in Mortar



β in Concrete



α and β values in RCD concrete

According to this α and β concept, compared with $\alpha = 1.5$ to 1.8 , $\beta = 1.2$ to 1.5 of conventional dam concrete, and $\alpha = 2.1$ to 2.4 , $\beta = 2.0$ to 2.3 of structural concrete, $\alpha = 1.1$ to 1.3 , $\beta = 1.2$ to 1.5 are suitable values for RCD.

It is noted in particular that the volume of cement slurry is close to the volume of voids between fine aggregates.

This result shows that unit cementitious material content is in the range of $C+F=110$ to 130 kg/m^3 and unit water content is in the range of $W=80$ to 105 kg/m^3 for RCD.

$$\alpha = \frac{\text{Paste volume}}{\text{Voids in the sand aggregate}}$$

$$\beta = \frac{\text{Mortar volume}}{\text{Voids in the coarse aggregate}}$$

5. Transportation system

of RCD construction

Spectacular achievements in RCD construction method has been the improvement and diversification of transportation system. Because the construction surface of a dam built by RCD construction method is flat, dump trucks can transport RCD concrete to every pouring area on the dam. It provides greater freedom of choice of the transportation system from concrete batching and mixing plant to the dam. Accordingly, by selecting the most suitable transportation systems, there is less damage to the natural environment.

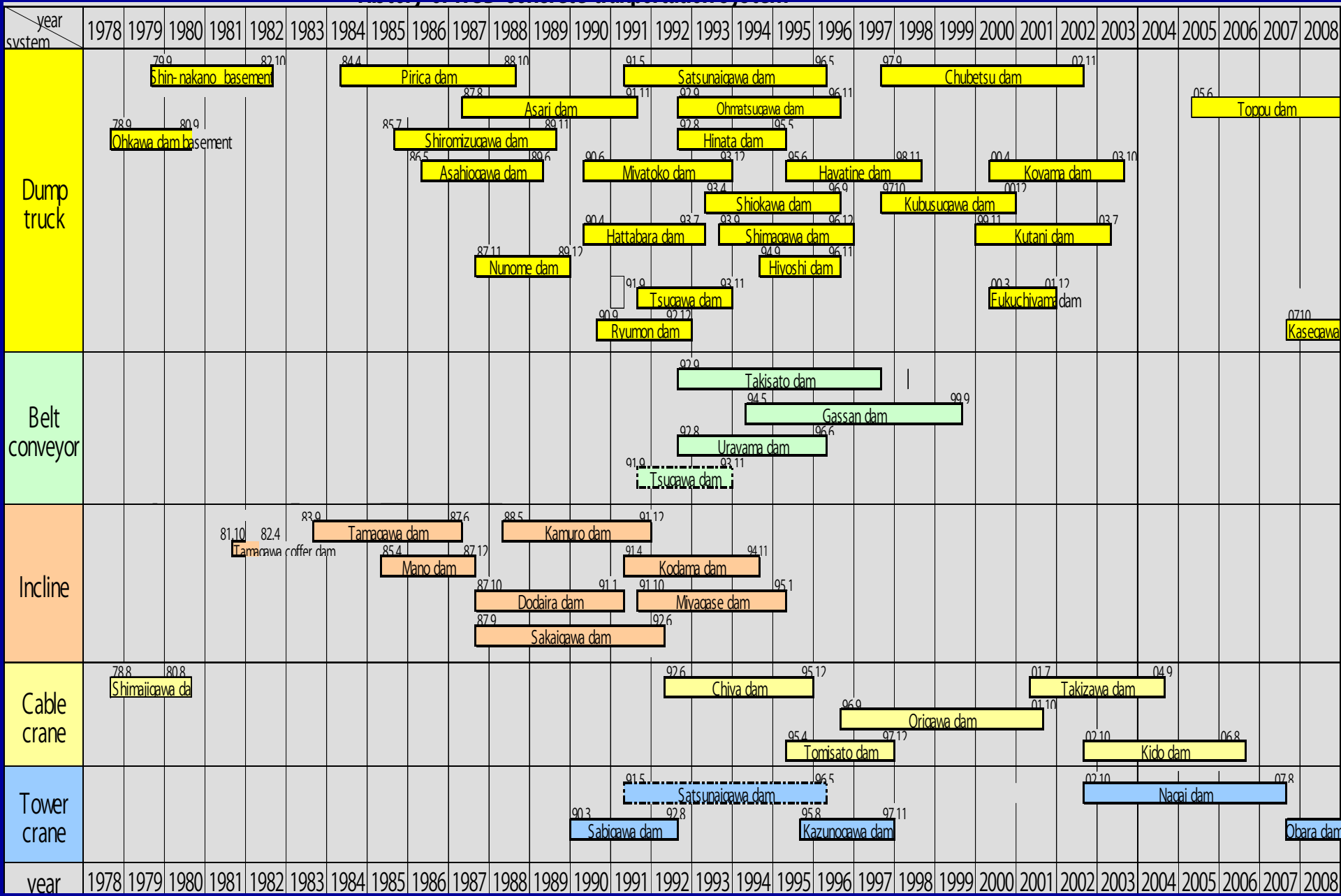
5.1 Dump truck (direct transportation system)

5.2 Incline

5.3 Cableway and tower crane

5.4 Belt-conveyor

History of RCD concrete transportation system in Japan



5.1 Dump truck (direct transportation system)

The direct transportation from the mixing plant to the lift surface by dump trucks is most advantageous when the topographical conditions are suitable, because there are no other special transportation facilities and no reloading during transportation. The use of the direct transportation by dump trucks is also often applied to the lower part of the dams.



Dump truck, Kutani dam, 2002



Dump truck, Toppu dam, 7.2005

5.2 Incline system

Inclines can be adopted at the steep slopes and transport large amounts of concrete per hour. So, inclines have been often used at relatively large scale RCD dams without depending on the dam site topography.

Dams constructed by the incline transportation system include Tamagawa dam, Miyagase dam and other dams.



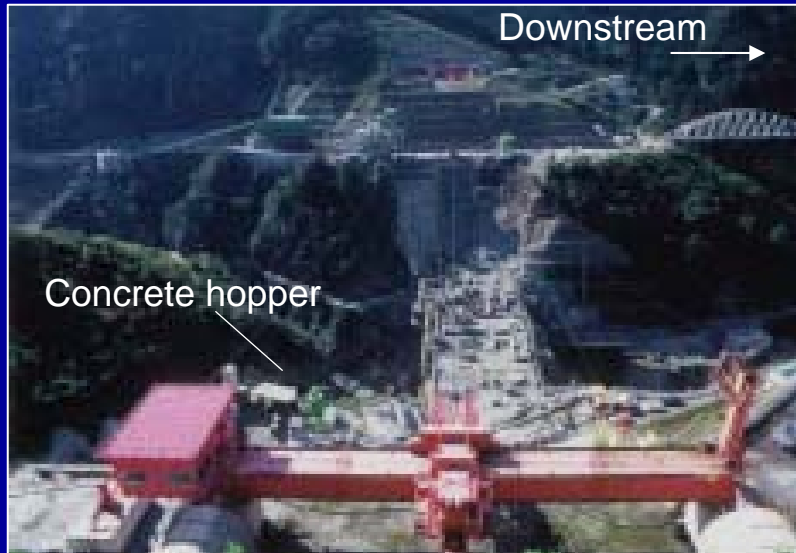
Miyagase dam, 1992



Tamagawa dam, 1984

5.3 Cableway and tower crane

Concrete transportations by buckets such as the tower crane and cableway-type crane methods are also useful, because they permit three-dimensional transportation. This method is not affected by the topography of the river bed, and it's easy to operate.



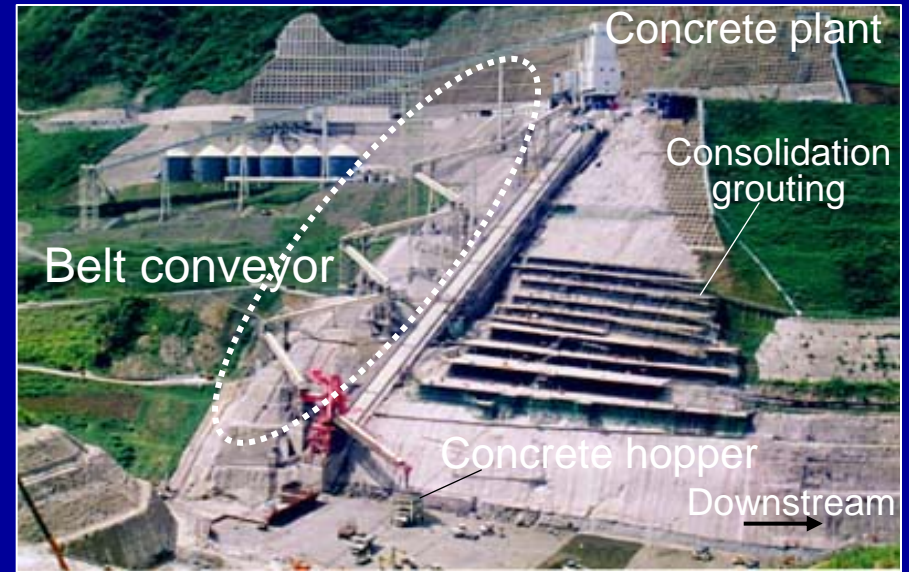
Cable crane, Tomisato dam



Tower crane, Nagai dam, 5.2005

5.4 Belt-conveyor

Belt conveyers are another important transporting system performed in high dams. Concrete transported from the concrete batching and mixing plant by belt conveyers was temporarily stocked in a ground hopper installed on the dam, then was transported by dump trucks to the placing area.



Belt conveyor, Gassan dam, 1995



Belt conveyers in Urayama dam

6. Concrete works in RCD

construction

method

The concrete works in RCD construction method has been improved through many RCD dam experiences in Japan, because the compaction of RCD dry lean concrete by vibratory rollers need much more experiences and technologies.

- 6.1 Test filling of RCD concrete works
- 6.2 Lift joint treatment by green cut and mortar spreading
- 6.3 Unloading of concrete by dump trucks
- 6.4 Spreading of RCD concrete
- 6.5 Roller compaction of RCD concrete
- 6.6 Contraction joint (transverse joints)
- 6.7 Compaction between different concretes
- 6.8 Curing
- 6.9 Quality control

6.1 Test filling of RCD concrete works

Test filling of RCD concrete works is conducted in order to reconfirm the mix design and to determine a compaction method appropriate to the specific site condition. Test filling must be carried out in accordance with actual construction conditions. Upstream coffer dams and basement of downstream apron are used in the test filling. Another important effect of test filling is to master the RCD skill on spreading by bulldozers, compaction by vibrating rollers and so on.



At the energy dissipater, Kido dam, 12.2002



0.2 Lift joint

treatment

On the surface of each lift, green cutting is performed by motorized sweepers so that the lift joints don't become weak layers in the structure.

The time to implement green cut of RCD concrete is determined by the hardening time of RCD concrete. In the summer, it is usually about 24 to 36 hours after compaction. In the winter, it is about 36 to 48 hours after compaction.

Before the placement of the next lift of RCD concrete, the water is removed and the mortar is spread immediately so that a good bond is secured at the horizontal lift joints. The standard thickness of the mortar is 15 mm.



green cut machine



Motorized green cut sweeper



mortar spreading



Lift surface for next placement of RCD concrete

6.3 Unloading of concrete by dump trucks

RCD concrete of uniform quality is transported by dump trucks to the placement area. However, when RCD concrete is unloaded from a dump truck, coarse aggregate of a large diameter is easy to segregate.

So, various techniques have been adopted to prevent this phenomenon, such as providing a hatch on the discharge gate of dump trucks or unloading RCD concrete in two piles.



From bucket to dump truck



transported on dump truck



Unloading concrete



Segregation of large size Aggregate

6.4 Spreading of RCD concrete

In RCD construction method, the concrete is spread out thinly and evenly by bulldozers. Each layer is spread about 20~30 cm thick and 3 or 4 layers make one lift.

Thin layer spreading by bulldozers is effective to prevent the segregation of RCD concrete. If the spread layer is too thick, RCD concrete will segregate easily, and it will be impossible to compact it sufficiently. Further, spreading by bulldozer is quite effective to compact the concrete prior to the compaction by vibratory rollers.

Reduction of segregation by bulldozer works



spreading works by scattering aggregates



Uniformed aggregates by spreading works

Nagai dam,
9.2005

6.5 Roller compaction of RCD concrete

Vibratory roller, 11.2002, Takizawa dam



Vibratory roller

RCD concrete is compacted by vibratory rollers. Compacting should be carried out as soon as possible because if a long period elapses after mixing, adequate compacting is difficult to perform.



Finishing compaction by tire roller



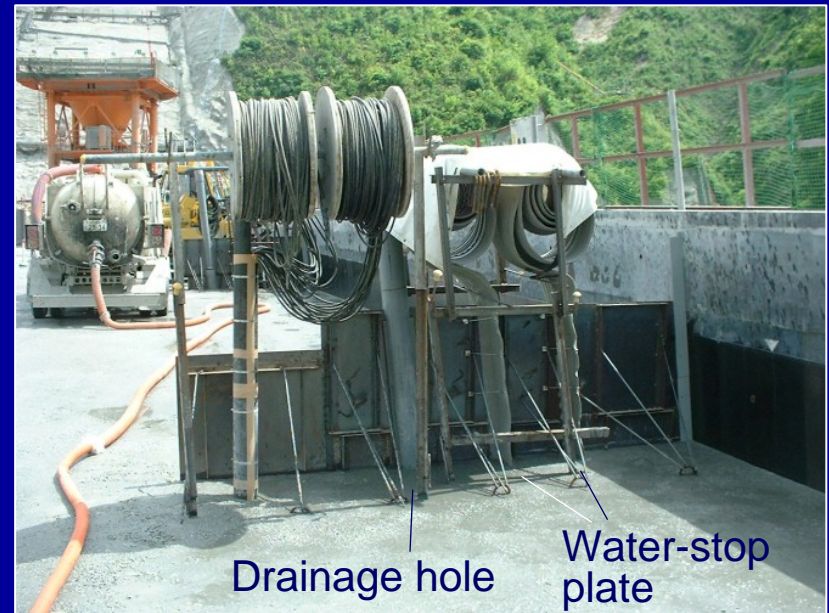
RCD concrete after compaction

6.6 Contraction joint 1

At the upstream and downstream edges of the dam, galvanized steel plates were installed in advance as a contraction joint at interval of 15m. Then, water-stop plates and drainage holes were set in the upstream galvanized steel plate



Koyama dam, 10.2002

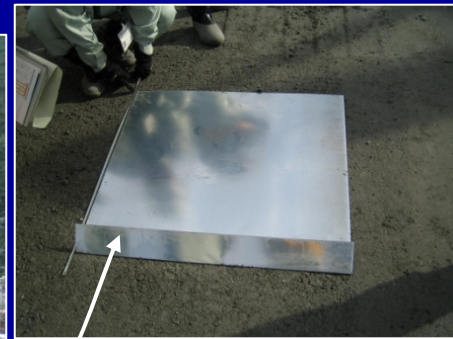


Kido dam, 6.2004

Contraction Joint in upstream side

Contraction joint 2

After RCD concrete is spread, transverse joints are installed to prevent temperature cracks in the concrete. Contraction joints were cut by a vibratory blade machine and galvanized thin plates were installed in the cutting plane to prevent closing.



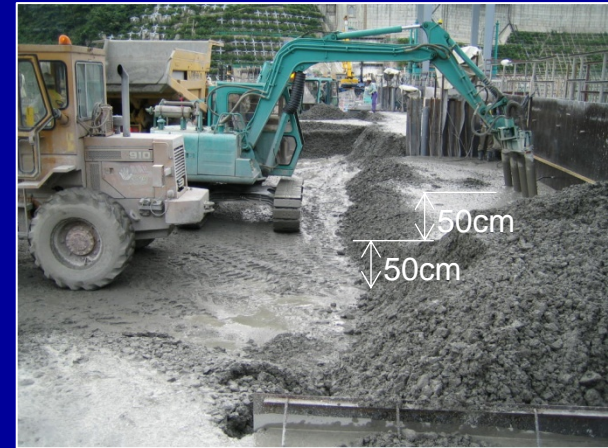
Contraction joints are cut by a vibratory blade machine



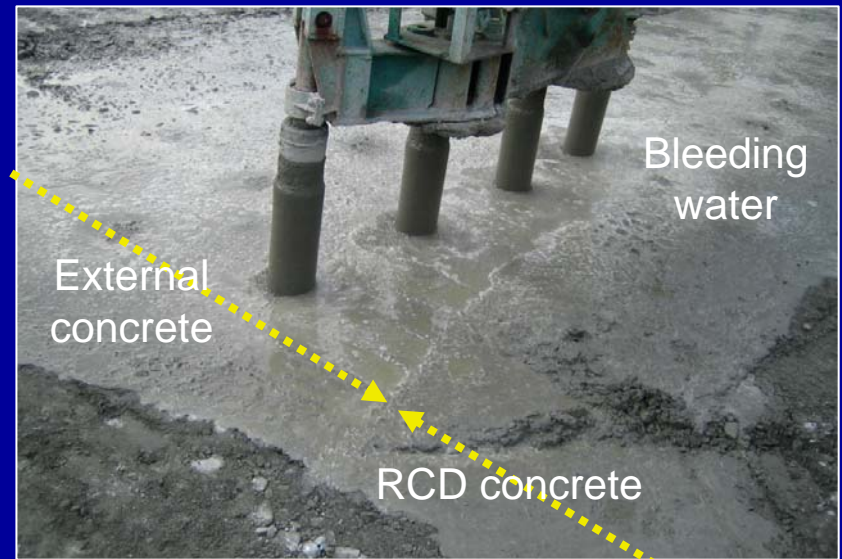
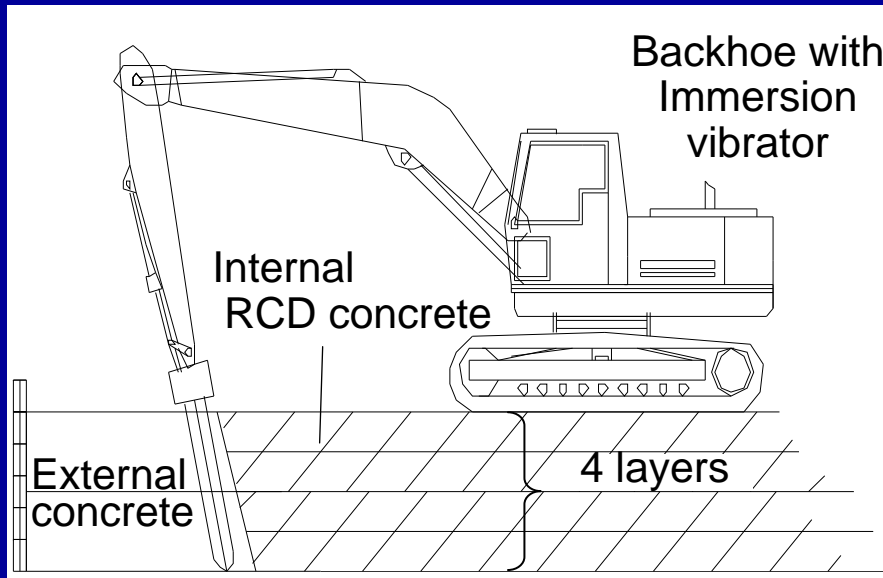
6.7 Compaction between different concretes

RCD concrete in the internal zone is placed after conventional wet concrete in the external zone.

So, the connection zone between RCD concrete and the conventional concrete should be compacted thoroughly by the method like as Figure.



Compaction of external concrete



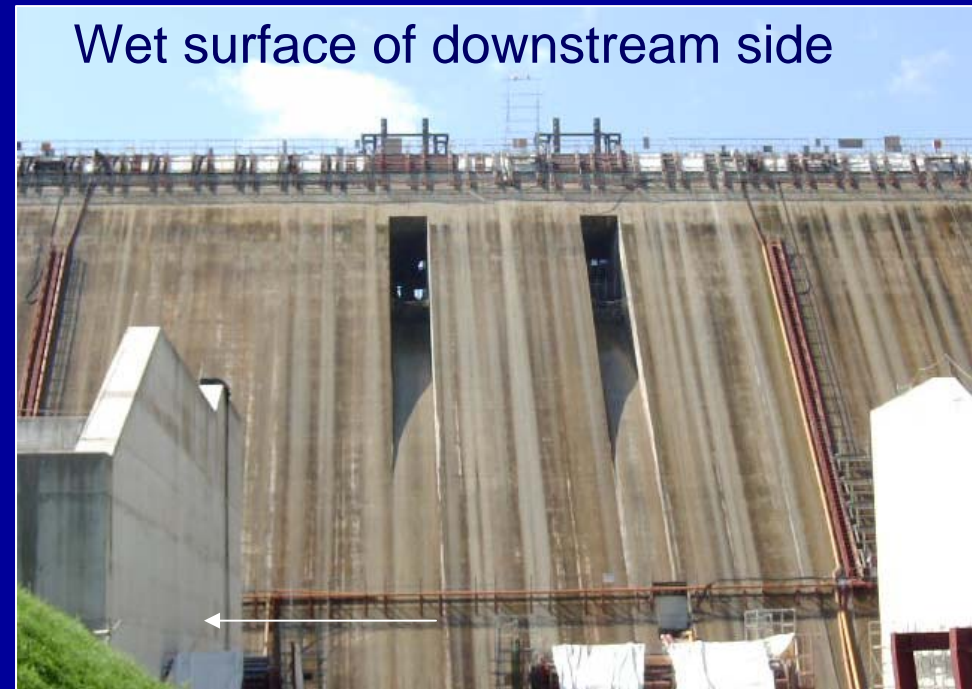
Compaction between different concretes

6.8 Curing

After RCD concrete has been placed, it is cured thoroughly in the specified temperature and wetness conditions.

Wet curing by ponding or sprinklers is generally applied.

Water is sprayed on RCD concrete by sprinklers.



6.9 Quality control

Various quality control measures are executed at RCD dams so that the quality of materials is monitored carefully.

1. **Concrete strength**: Once or twice a day, a compressive strength test is conducted to confirm the strength of RCD concrete.
2. **Density**: There are several methods to check the rate of compacting of RCD concrete: the number of passes of the vibratory rollers, the RI (Radio Isotope) density meter, or the settlement of the lift during compaction.
3. **Water content**: The surface water content and grading of aggregates must be monitored with special care since they affect the consistency of RCD concrete.
4. **Consistency**: The VC test with the standard container is conducted to monitor the consistency of RCD concrete. The test is conducted once every one to two hours.
5. **Temperature**: The temperature of the mixed concrete is measured periodically to confirm that the concrete is placed according to the temperature restrictions. Thermometers are also embedded in the dam when necessary.

7. New approaches in RCD

construction

method

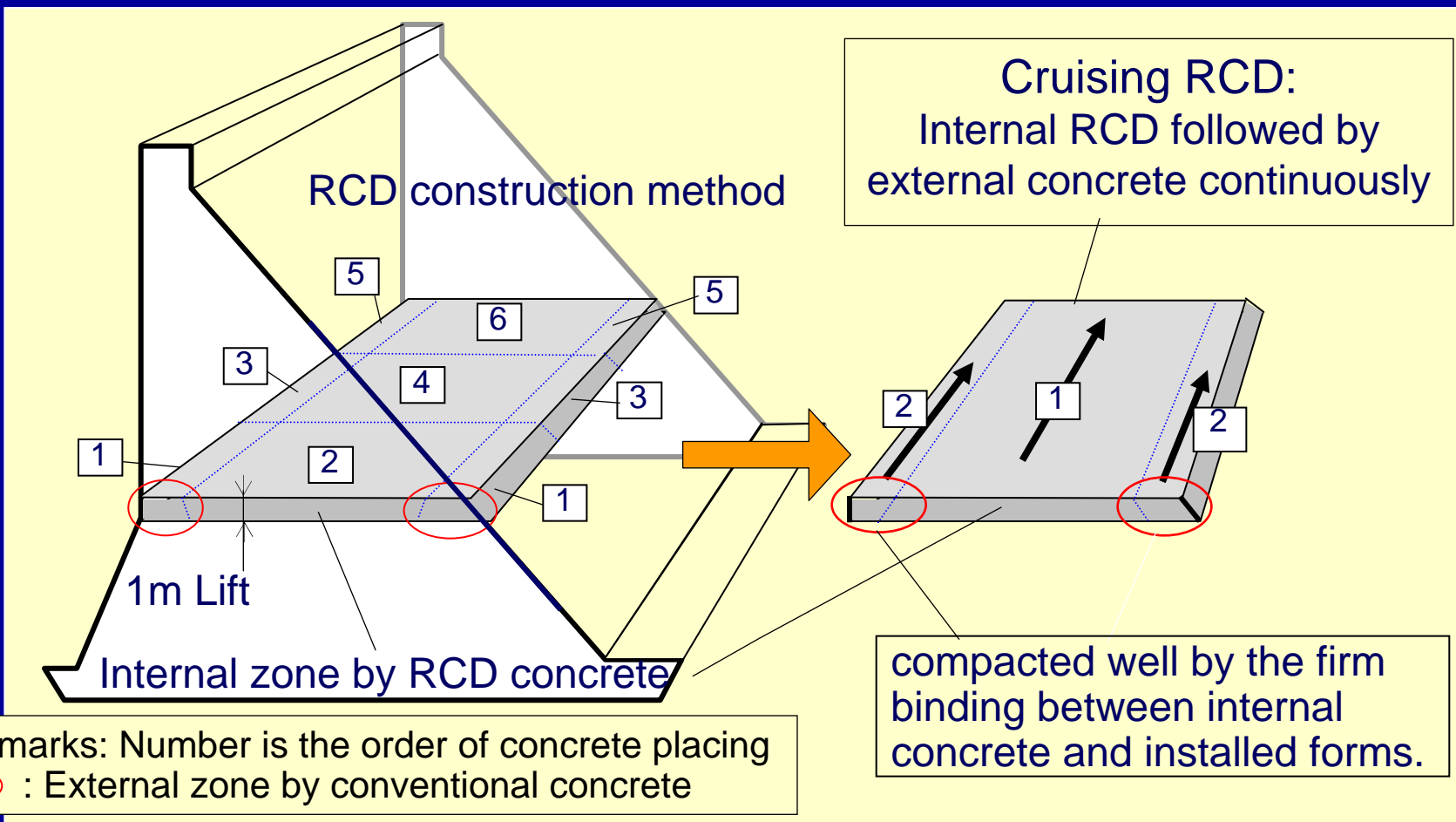
RCD construction method is still progressing with new technologies for the further rationalization.

- 7.1 Rationalization of external concrete in Kasegawa dam
- 7.2 Facilitation by precast concrete form
- 7.3 Construction management by IT (Information Technology)

Kasegawa dam

in Kasegawa dam, Cruising RCD is progressing :

- 1) Internal RCD and the external conventional concrete can be placed independently, and the efficiency of concrete works is greatly increased.
- 2) External concrete will be compacted efficiently because of the firm binding between internal RCD concrete and installed external forms.



Compaction works at the end of internal concrete for cruising RCD, Kasegawa dam, 6.2008



Well compacted internal end using a special machine



Internal RCD concrete



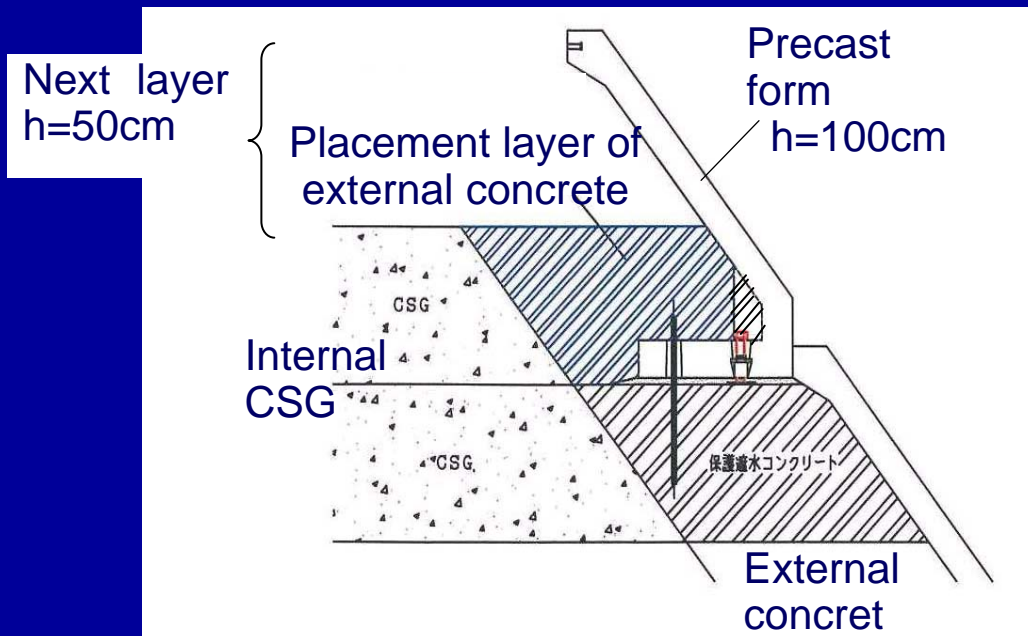
External concrete zone

Conventional concrete in the external zone will be compacted efficiently

7.2 Facilitation by precast concrete form

In Japan, the precast concrete (the concrete structure of pre-fabricated members) have been developed to increase the safety and efficiency in construction works. So far, it has been improved in light-weighting of members, holding of strength and water-tightness at each segment junction, adhesion to the around concrete and concrete placing under precast floors.

Recently, external precast forms for the upstream side and downstream side have been developed, and it was confirmed to be efficient in facilitating the concrete works.



Cross section of precast form



Set up of precast form

7.3 Construction management by IT

In recent years, IT (Information Technology) for the quality management by use of GPS information, latest measuring equipments, and integrated information on design and construction is rapidly progressing. Currently, a full-scale real-time IT system is adopted in Kasegawa dam for quality and quantity management, concrete volume surveying, internal concrete temperature observation, three-dimensional drawings, and labor-saving measures. Photo shows RCD compaction works controlled by IT with GPS positioning and observation of compacted situation by counting.

Now, construction managements by IT for concrete dams are scheduled to be adopted in other RCD dams to increase quality and efficiency in Japan.

GPS receiver



Vibratory roller SD451 with IT,
Kasegawa dam

Environmental merits of RCD

1. RCD can reduce the CO₂ emission.

Reduction of unit cement content

Cement : 1.0ton → CO₂ : 0.73ton

Unit cement content of RCD is less than conventional dam concrete by 20~50kg/m³.

2. RCD provides greater freedom of the concrete transportation by dump trucks on the placed concrete. Accordingly, by selecting the most suitable systems, there is less damage to the natural environment.

Thank you for your attentions

Muito obrigado pela sua atenção