30 Years' History of Roller-compacted Concrete Dams in Japan.

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ABSTRACT: Japan is the country where the world's first roller-compacted concrete dam was constructed in 1980. Since then, about 40 roller-compacted concrete dams have been constructed in Japan. Japanese roller-compacted concrete dams are called RCD dams and are distinguished from the other roller-compacted concrete dams because there are some differences in their design and construction philosophies. This paper describes the history of RCD dam construction in Japan. The paper also describes a new type of dams called the trapezoidal CSG dams that are being comprehensively studied and field-tested in Japan.

1. INTRODUCTION

Japan is the country where the world's first roller-compacted concrete dam was constructed. The 89 m high Shimajigawa dam with volume of 317,000 m^3 was completed in 1980. Since then, about 40 roller-compacted concrete dams have been constructed in Japan.

Japanese roller-compacted concrete dams are called RCD (RCD is the abbreviation of Roller-Compacted Dam concrete) dams in order to distinguish them from the other types of RCC (RCC is the abbreviation of Roller-Compacted Concrete) dams. The reason is that RCD dams are not considered to be a new type of dams (i.e., they are classified into concrete gravity dams.), but are considered to be dams constructed with a new construction method. The required performance of the RCD dams should be completely the same as that of conventional concrete gravity dams. For example, transverse contraction joints are installed every 15 m in order to prevent temperature cracks in the dams, 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 resistance to freeze-and-thaw action caused by climate change, and lift joints (lift surfaces) are treated in the same way as in the case of conventional concrete dams in order to assure good bond and water-tightness between the lifts, and so on.

On the other hand, Japan is now developing trapezoidal CSG (CSG is the abbreviation of Cemented Sand and Gravel) dams. The technology will first be applied at the Okukubi dam with height of 39 m and volume of 339,000 m^3. Trapezoidal CSG dams are classified as a new type of dams (not a new type of construction method) because their structural features differ from those of conventional triangular concrete gravity dams (described in detail in Chapter 6). Because they are such a new type of dams, they can use extremely low quality material such as riverbed materials or rock muck without washing, screening and grading processes.

This paper presents the history of RCD dams and an outline of trapezoidal CSG dams in Japan.

2. DEVELOPMENT OF RCD CONSTRUCTION METHOD – CONSTRUCTION OF THE SHIMAJIGAWA DAM–

2.1. Development of the RCD Construction Method

Construction of safe and economical dams is the objective of dam engineers.

In ancient times, earth dams were constructed by trial-and-error or empirical methods. The first earth dam referred to in Japanese historical sources was the Sayamaike Dam with height of 15 m built in the 6th century. This dam was modified and raised and is still in use.

The first dam constructed using modern technology was the 33 m high Nunobiki Gohonmatsu Masonry Dam built in 1900. And the 79 m high Komaki Dam constructed in 1929 was the first concrete gravity dam built using modern machinery construction technology. Concrete gravity dams were considered to be a safe and economical type of dams and many concrete gravity dams followed. Of course, earth dams were constructed at the same time, but they were limited to small pond construction.

The second stage of dam construction was the age of concrete arch dams. The concrete volume of dams could be drastically reduced utilizing the arch action. The first large arch dam in Japan was the 110 m high Kamishiiba Dam constructed in 1955. Many arch dams were constructed in the 1950s and 1960s. However, concrete gravity dams were still constructed at many sites because the sites with good foundation rock which were required for concrete arch dams were limited.

However, high economic growth in the 1960s and 1970s increased labor costs. Then, complicated construction techniques using a lot of labor, which were typical of concrete arch dam construction, obstructed economical dam construction. And dam construction using many machines was encouraged and rock fill dam construction was started. An example of rock fill dams in the early stage was the 131 m high Miboro dam. Rock fill dams were economical in wide valleys where spillways were easily constructed, but in Japan, valleys were generally so steep that rock fill dams could not be economically constructed in many places. So, efforts to find economical concrete dams construction methods began.

The Committee for the Economical Construction of Concrete Dams was established in 1974 by the Ministry of Construction (now reorganized as the Ministry of Land, Infrastructure and Transport.), and made a comprehensive study on the economical construction of concrete dams (Hirose, 1985, Kokubu et al., 1985). The basic philosophy of the committee was as follows:

(1) Reduction of the unit cost of concrete should be studied because of recent high labor costs. Reducing the concrete volume as in the case of concrete arch dams and concrete hollow gravity dams provided no benefit. Efforts should be made to reduce the unit cost of concrete.
(2) Reduction of the unit cost of concrete should be studied, because worsening foundation rock conditions had further increased the volumes of concrete gravity dams and raised their construction costs.

The construction method used at Alpe Gera dam in Italy where dump truck were used for concrete transportation on the dam, and the roller-compacted concrete construction that was studied at the Lost Creek Dam in the USA were referred to in order to accomplish rapid and economical construction.

After comprehensive research and discussions the following conclusions were reached.

(1) Concrete should be transported by simple machinery from a mixing plant to the construction area.
(2) The construction surface of dams should be so flat that dump trucks can transfer concrete from a ground hopper on the dam to concrete pouring areas.
(3) Concrete should be compacted by vibrating rollers in order to speed up its consolidation.
(4) Concrete should be stiff enough to be compacted by vibrating rollers.
(5) Concrete should be workable enough to be consolidated by vibrating rollers.
(6) Concrete lift should be thin enough to be compacted by vibrating rollers.
(7) Concrete should be spread uniformly (without segregation) by bulldozers.
(8) The upstream and downstream surfaces should be covered by high quality concrete to maintain water-tightness and to protect the concrete from freeze-and-thaw attack.
(9) The surface concrete and internal concrete should be cut by vibrating blades at 15 m intervals to prevent temperature cracks.
(10) Lift surfaces should be treated by green cutting and mortar spreading to obtain good bond for shear stress and water-tightness.

2.2. Mixture of RCD

The success of RCD construction depends on the mixture design of RCD. So the concepts of the coefficients α and β were introduced. The coefficient α is the volume ratio of cement slurry to the voids between sand particles (fine aggregate) and it must be designed as larger than 1. The coefficient β is the volume ratio of mortar to voids between gravel particles (coarse aggregate) and it must also be designed as larger than 1.

Compaction energy is also an important factor in determining the strength of RCD. So the consistency of RCD mixture was measured with the VC meter shown in Figure 1 and Table 1. Concrete specimens were made using the large specimen compaction device shown in Figure 2 and Table 2.

The RCD mixture is designed by the following process.

(1) Determination of the maximum size of aggregate. Usually 80 mm is adopted.
(2) Determination of cement content. Usually 120 kg/m^3 is adopted in consideration of the high quality of the RCD mixture.
(3) Determination of sand aggregate ratio that gives RCD the lowest VC value. Usually a ratio around 30 % to 35 % is adopted.
(4) Determination of water content. Water content that gives RCD 20 second of VC value is optimum. Usually 80 to 100 kg/m^3 of water is adopted.
(5) Strength and surface appearance of RCD (without honeycomb voids) were evaluated with the large specimen compaction device.

Typical features of RCD mixture from these tests are shown in Figure 3 to Figure 5.

Figure 1. VC Meter

Figure 2. Large Specimen Compaction Device

Table 1. Specification of VC Meter

(1) Vibrating Table

Item	Value
Full Amplitude	1 mm
Frequency	3000 cpm
Loading Mass	20 kg

(2) Specimen

Item	Value
Diameter	24 cm
Height	20 cm

Table 2. Specification of Large Specimen Compaction Device

(1) Vibrating Mass

Item	value
Full Amplitude	2.4 mm
Frequency	1900 cpm
Mass	648 kg

(2) Specimen

Item	Value
Diameter	48 cm
Height	40 cm

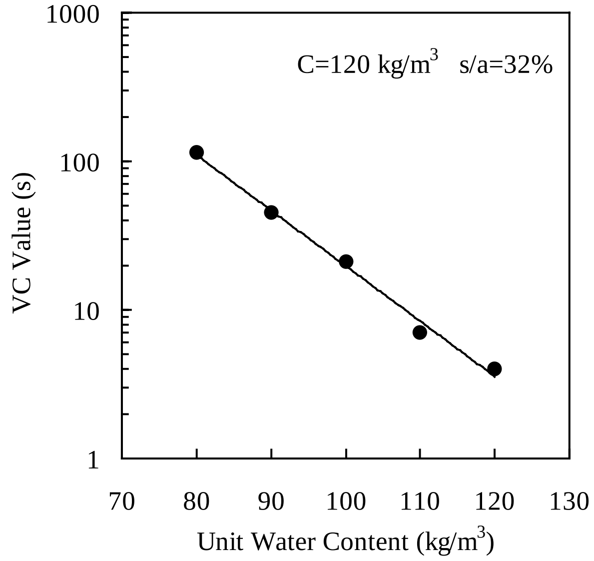

Figure 3. Unit Water Content vs. VC Value

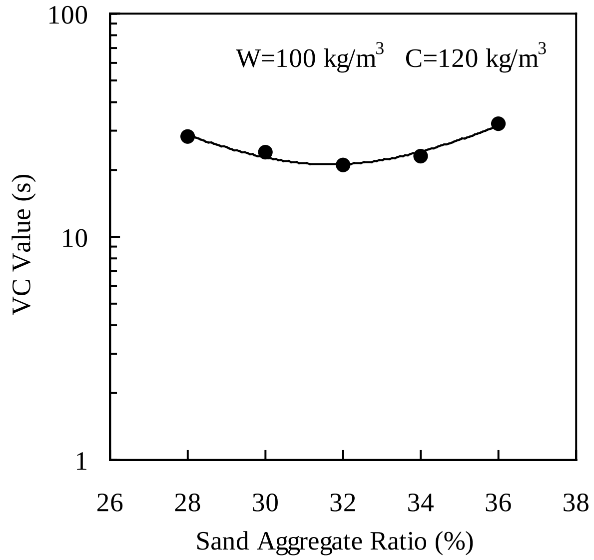

Figure 4 Sand Aggregate Ratio vs. VC Value

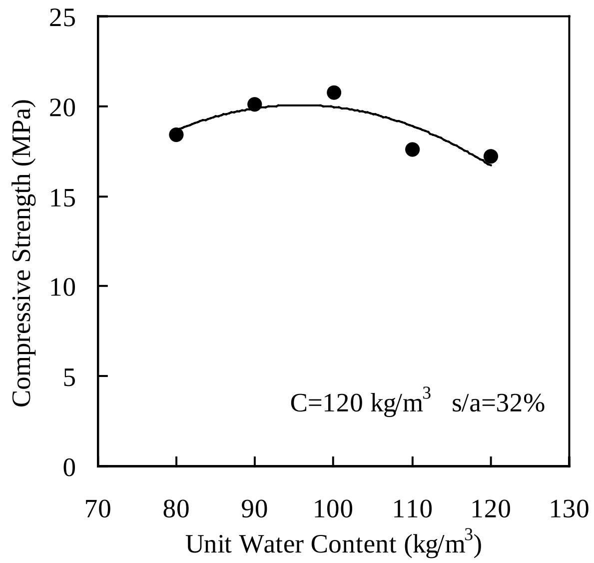

Figure 5 Unit Water Content vs. Compressive Strength

Table 3 RCD Mixture at Shimajigawa Dam

Item	Value
Maximum Size of Aggregate	80 mm
Water	105 kg/m^3
Cement	84 kg/m^3
Fly-ash	36 kg/m^3
Sand Aggregate Ratio	34 %
Fine Aggregate	752 kg/m^3
Coarse Aggregate	1482 kg/m^3
Air	1.5 %

2.3. Construction of the Shimajigawa Dam

The Shimajigawa Dam (height = 89 m, completed in 1980 by the Ministry of Construction) was selected as the first RCD dam, because its height was moderate and the installed structures in the dam body were very simple. The dam is located on the Saba River in the Chugoku Region. At the test yard, test filling was performed to study the lift thickness, the number of passes of a vibrating roller, and so on (Figure 6).

At the Shimajigawa Dam, a 75 cm lift (25 cm x 3 layer spreading) was planned at first. But, because it was noted that the upper layer was weaker than the lower layer after vibration, the lift thickness was lowered to 50 cm (17 cm x 3 layer spreading). However, good quality was revealed by the later test fill, and a 75 cm lift was adopted (25 cm x 3 layer spreading) in the upper part of the dam. The standard mixture proportion is shown in Table 3.

A typical feature of Japanese roller-compacted concrete dam construction is adoption of high lifts that can reduce the number of weak planes between

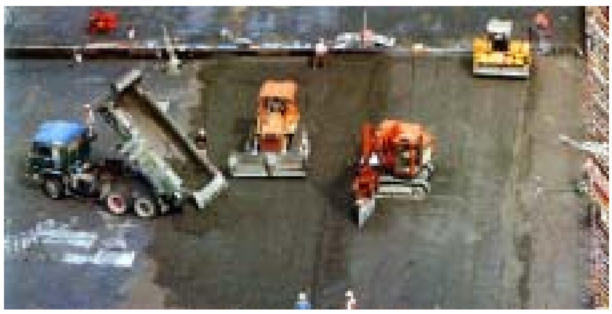

Figure 6. RCD Construction Method

successive lifts. Roller-compacted concrete is spread into thin layers by bulldozers, and then they are compacted by vibrating rollers. Thin layer spreading of roller-compacted concrete was the key factor that makes thick lift placement possible.

Roller-compacted concrete was consolidated by vibrating rollers. Vibrating rollers were passed over roller-compacted concrete twice without vibration and 9 times with vibration at the Shimajigawa Dam (nowadays, 5 to 6 passes are the norm).

Concrete was transported from the concrete batching and mixing plant to the dam by a fixed 13.5 t cableway-type crane. Concrete was received by a ground hopper and was transferred by dump trucks from the ground hopper to the placement area (Figure 7). Contraction joints were cut by a vibrating blade machine and galvanized steel plates were installed in the cutting plane to prevent closing (Figure 8). And at the upstream and downstream edges of the dam, galvanized steel plates were installed in advance. Then, water-stop plates and drainage holes were set in the upstream galvanized steel plate (Figure 9).

Lift joints were cleaned (green-cut) 24 to 48 hours after concrete placement (depending on the season). A motor sweeper or water jet was used for green cutting. Mortar with thickness of 1.5 mm was then spread before the above lift was placed.

Figure 10 is a perspective view of the completed Shimajigawa dam. Its features were the completely the same as those of conventional concrete gravity dams.

Figure 7　Concrete Transportation

Figure 9.　Installation of Water-stop and Drainage

Figure 8.　Installation of Transverse Joint

Figure 10.　Shimajigawa Dam

3. ESTABLISHMENT OF RCD CONSTRUCTION METHOD – CONSTRUCTION OF THE TAMAGAWA DAM –

3.1. *General*

The Tamagawa Dam is a 100 m high concrete gravity dam with volume of 1.15 x 10^6 m^3. The dam was constructed on the Omono River in the Tohoku Region in 1987 by the Ministry of Construction. Figure 11 shows a view during construction, and Figure 12 is a perspective view of the completed dam. The RCD construction method developed at the Shimajigawa Dam was really established through the experience of the Tamagawa Dam.

The Tamagawa Dam was located in a cold region where snowfall accumulates to 2 m and the air temperature falls as low as –15°C. Construction work of the dam had to be suspended for five months in the winter. To economically construct a high dam under such climate conditions, the RCD construction method was adopted.

Figure 11. RCD Construction Method

Figure 12. Tamagawa Dam

3.2. *Characteristics of RCD Construction Method at the Tamagawa Dam*

The principal features of the RCD construction method at the Tamagawa Dam were the challenge to high construction speed and thick lift of concrete (Yamauchi,et al., 1985, Yamaguchi, et al., 1988).

At the Tamagawa Dam, the concrete batching and mixing plant was built at the crest level of the dam. Mixed concrete was loaded on the transfer-car. Then it was loaded on the bucket-cars that ran on the inclined railways. Then, concrete was dumped into the hopper station at the construction level and was transported to the pouring area by 20 t dump trucks.

The incline system consisted of two bucket-cars and two rows of railways. The maximum height difference of the railway was 94.5 m and maximum speed of the bucket-cars was 150 m/min (Figure 13). This incline system recorded 270 m^3/h of concrete transportation at the peak time. It revealed that the incline system was superior to the conventional cableway-type crane system in terms of its transport capacity, easiness of operation, safety of operation and so on. For these reasons, the incline system has been adopted at many

Figure 13. Incline System

dams since the Tamagawa Dam.

In order to speed up construction and to reduce the number of lift surface treatments, lift thickness had to be increased. But it was accompanied by a risk of inadequate compaction of RCD. At the Tamagawa Dam, 1 m of lift thickness was made possible by thin layer placement. A 1 m thick lift was divided into four thin layers that were spread by bulldozers. After spreading, the entire lift was compacted by vibrating rollers. Furthermore, in order to control the quality of RCD after compaction, density control was executed with an insert-type radioisotope density meter. These measures permitted thick lift placement without inadequate compaction.

The thin layer spreading method used in the RCD construction completely differs from compaction in RCC construction which adopted compacting concrete in a single layer. Thick lift placement, as used in conventional concrete dam construction, prevents the formation of a possible weak plane on the lift surface.

After experience of constructing 1 m thick lifts at the Tamagawa Dam, new vibrating rollers with high vibrating force have been developed and used for all RCD construction.

Because the Tamagawa Dam was the first high dam built by the RCD construction method, a wide-ranging surveys and research on temperature control were carried out. In order to reduce the cement content, 150 mm of maximum size of aggregate was used and the cementitious material content was limited to 130 kg/m^3. Moderate heat Portland cement was used and 30 % of it was replaced by fly-ash. Table 4 shows the design mixture of RCD at the Tamagawa Dam.

Table 4 RCD Mixture at Tamagawa Dam

Item	Value
Maximum Size of Aggregate	150 mm
Water	95 kg/m^3
Cement	91 kg/m^3
Fly-ash	39 kg/m^3
Sand Aggregate Ratio	30 %
Fine Aggregate	657kg/m^3
Coarse Aggregate	1444 kg/m^3
Air	1.5 %

Thanks to the use of the RCD construction method in this way, 1.15 x 10^6 m^3 of concrete were placed in 26 months excluding a break period during the winter, and a calculation has showed that using RCD construction method at the Tamagawa Dam shortened the concrete placing period 5 to 7 months compared with the conventional block construction method.

4. POPULARIZATION OF THE RCD CONSTRUCTION METHOD

4.1. General

The completion of the Tamagawa Dam confirmed that the RCD construction method is a rapid and economical concrete dam construction method. Since then, it has been widely applied to many concrete gravity dams throughout Japan, not only those constructed by the Ministry of Construction and the Water Resource Development Public Corporation, but also those constructed by local governments (Toyoda, et al., 1991). With about 40 completed RCD dams and about 20 RCD dams at the design stage, this technology has now matured.

Technology development of the RCD construction method started with the introduction of vibrating roller compaction, and it extended to the improvement of concrete transportation systems. Other related studies such as temperature control, quality control, and peripheral technologies such as installed structures and contraction joint cutting have also been improved. In these improvements, the improvement of RCD mixture and improvement of transportation machinery are described below.

4.2. Improvement of RCD Mixture

The mixture design of RCD has been improved throughout the history of RCD dam construction. In particular, the filling properties of concrete, i.e., the appropriate values of the parameter α (the volume ratio of cement slurry to the voids between sand particles) and the parameter β (the volume ratio of mortar to voids between gravel particles) have been studied in detail. The results have shown that compared with the α = 1.5 to 1.8, β = 1.2 to 1.5 of conventional dam concrete, and α = 2.1 to 2.4, β = 2.0 to 2.3 of structural concrete, α = 1.1 to 1.3, β = 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 (cement and fly-ash) content is in the range of 110 to 130 kg/m^3 and unit water content is in the range of 80 to 100 kg/m^3 for RCD.

However, 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 μm) to the fine aggregate. At the Hiyoshi Dam (height = 67 m, completed in 1997 by the Water Resource Development Public Corporation), a dry-process-type sand production facility was adopted in order to increase the content of finer particles. Then, workability was improved and the unit cementitious material content was reduced to 110 kg/m^3. And at the Urayama Dam (height = 156 m, completed in 1999, by the Water Resource Development Public Corporation), a dry-process-type coarse aggregate production facility was adopted. The finer particles produced during production of coarse aggregates that were formerly discarded as industrial waste material, were effectively used to improve the workability of the RCD mixture.

Technological progress has been achieved in the areas of admixture mineral, chemical admixture, and cement. Fly-ash is generally used as admixture mineral 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. At the Tomisato Dam (height = 111 m, completed in 2000 by the Water Resource Development Public Corporation), cement and fly-ash were mixed at the dam site according to the season and concrete mixture. Namely, 40 % of the cement in RCD was replaced by fly-ash in the summer season and 30 % in the other seasons, and 35 % of the cement in conventional concrete (external concrete) was replaced by fly-ash in the summer season.

Special chemical admixtures for RCD and low hydration heat type cements were also developed.

4.3. *Improvement of Transportation Machinery*

Noteworthy achievements in the RCD construction method were the improvement of transportation machinery and the diversification of transportation system.

Because the construction surface of a dam built by the RCD construction method is flat, dump trucks can transport RCD 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. These transportation systems include direct transportation by dump trucks, belt conveyors, inclines, tower cranes, cableway-type cranes and so on.

The Pirika Dam (height = 40 m, completed in 1991, by the Hokkaido Development Bureau) is a combined dam consisting of a concrete gravity dam and a rock fill dam with crest length of 1,480 m and with height of 40 m. Because of it topographical feature of the site, the RCD construction method using the direct transportation system by dump trucks was adopted for the concrete gravity sections (the crest length is 755 m of the left side). The road to the dam body was designed as an embankment-type road. The direct transportation system by dump trucks was applied at the Shiramizugawa Dam (height = 54.5 m, completed in 1991, by Yamagata Prefecture). The road to the dam body was connected by a temporary bridge that was 30 m long and 4 m wide. The bridge raised itself every 50 cm. The use of the direct transportation system by dump trucks is often applied to lower dams or the lower part of the dams (Figure 14).

At the Tsugawa Dam (height = 76 m, completed in 1996 by Okayama Prefecture), a belt conveyor system was used to transport concrete. 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 pouring area (Figure 15). Transportation of RCD by a belt conveyer system was performed at the high dams such as the Gassan Dam (height = 123m, completed in 2001 by the Ministry of Construction).

An incline system is a transportation method that is often used at relatively large scale RCD dams because it has large transportation capacity and is not dependent on the dam site topography. Dams constructed by the incline transportation system include the Tamagawa Dam (height = 100 m, completed in 1987 by the Ministry of Construction), the Sakaigawa Dam (height = 115m, completed in 1993 by Toyama Prefecture), and the Miyagase Dam (height = 156 m, completed in 1998 by the Ministry of Construction).

Concrete transportation by buckets such as the tower crane and cableway-type crane methods are also used, because they permit three-dimensional transportation. At the Sabigawa Dam (height = 104 m, completed in 1994 by Tokyo Electric Power Corporation), change of the environment at the dam site was minimized by installing two 13.7 ton tower cranes on the left and right banks. Two 9 m^3 ground hoppers were installed on the construction surface of the dam and concrete was transported from the ground hoppers to the pouring area by dump trucks (Yamamoto et al., 1994).

Figure 14. Temporary Bridge

Figure 15. Belt Conveyor

Figure 16. Both-side-running Cableway –type Crane

At the Tomisato Dam, 20 ton both-side-running cableway-type cranes were installed as RCD transportation system (Figure 16). This cableway-type crane permitted transportation not only in the dam axis direction but also in the river flow direction by 22 m. This crane was fully used for installation of water discharge facilities and pouring of the concrete around the conduit pipe, and for pouring concrete of the upper parts of the dam where working area was so narrow.

In addition, the automated transportation system and automated concrete batching and mixing plant were introduced.

5. APPLICATION OF RCD CONSTRUCTION METHOD TO EXTREMELY HIGH DAMS

5.1. The Miyagase Dam

The Miyagase Dam (completed in 1998 by the Ministry of construction) is an extremely high RCD dam with height of 156 m and with volume of 2.06 x 10^6 m^3. The dam was located on the Sagami River in the Kanto Region. Figure 17 shows a perspective view of the completed Miyagase Dam.

At the Miyagase Dam, the major challenge to be overcome was the problem of thermal stress in the large RCD dams. To resolve this problem, thermal stress analysis based on the restraint matrix method was performed and a comprehensive study of the starting time of concrete placement and the placement schedule was performed (Hirose et al., 1988). When a dam is raised uniformly as it is using the RCD construction method, the concrete temperature at each elevation of the dam is governed not only by the heat of hydration but also by the seasonal temperature fluctuation. At the Miyagase Dam, various studies of the placement starting time and concrete placement schedule were performed by restraint matrix analysis, obtaining the conclusion that beginning concrete placement in October would be most beneficial for temperature control. In practice, inclined contraction joints were installed in order to make concrete placement efficient at the lower part of dam and in order to reliably protect RCD from temperature cracks (Figure 18).

At the Miyagase Dam, the concrete was transported by inclines where dump trucks were directly loaded (Figure 19). Concrete mixed at the batching and mixing plant was dumped into 20 t dump trucks, then dump trucks with 9 m^3 of concrete were transported to the construction surface through two rows of inclines. Dump trucks were carried on the incline at a speed of 180 m/min. Since this transportation method eliminates the transfer of concrete from bucket to bucket, it effectively shortened the transportation cycle time, reduced the segregation of materials that occurs during reloading, and restricted quality fluctuations such as the temperature or consistency of concrete.

Figure 17.　Miyagase Dam

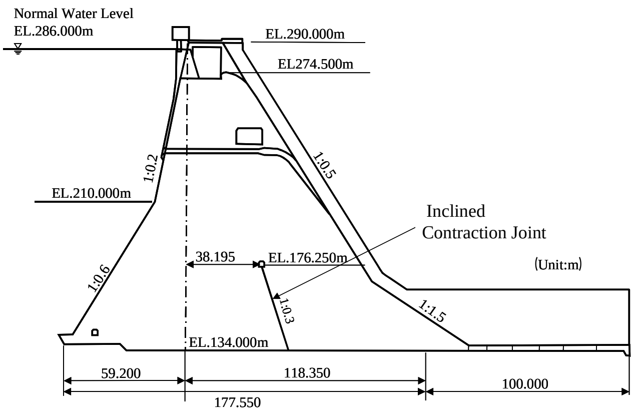

Figure 18.　Inclined Contraction Joint

In addition, pre-cast products were efficiently used at the Miyagase Dam. Pre-cast products were used for the inspection galleries and the elevator shaft.

5.2.　The Urayama Dam

The Urayama Dam is an extremely high RCD dam with the height of 156 m and volume of 175 x 10^6 m^3 constructed on the Ara River in the Kanto Region by the Water Resource Development Public Corporation. It was completed in 1999. Figure 20 is a view of the completed the Urayama Dam.

From the results of a detailed study of the thermal stress problem that was carried out based on experience at the Miyagase Dam, it was concluded that the thermal stress was under the regulated value even at the maximum layer length of 170 m at the bottom of the dam, as long as the concrete was raised rapidly and constantly (Yamazumi. et al., 1994).

To increase the amount of concrete product per hour, an integrated belt conveyor system was installed from the quarry to the dam. This belt conveyer system

Figure 19 Dump Truck Mounted Incline

Figure 20.　Urayama Dam

consisted of three kinds of conveyors, one for crushed rock, one for aggregate, and one for concrete. The quarry was located 4.5 km upstream from the dam site, the aggregate production plant 2.5 km upstream from the dam site, and the concrete batching and mixing plant directly upstream from the dam site. The belt conveyor for crushed rock was 1,050 mm wide, 1,500 mm long, and operated at a speed of 120 m/min. It transported crushed rock with maximum size of 300 mm from the quarry to the aggregate production plant. The belt conveyer for aggregate was 1,050 mm wide, 2,300 m long, and operated at a speed of 110 m/min. It transported four grades of coarse aggregate and one grade of fine aggregate produced at the aggregate production plant to the concrete batching and mixing plant (Figure 21, Figure 22). The belt conveyor for concrete consisted of two parts: the main conveyor that was 900 mm wide, moved at 120 m/min, and had a trough angle of 30°, and the access conveyor that was attached to the dam body. The access conveyors were 4-level conveyors with a trough angle of 18° and a lift head of 40 m so that it could cover a dam height of 156 m . The RCD was transported at approximately 140 m/min. During these processes, hoods were placed on the belt conveyors to prevent infrared rays and the belt surface was moistened before material was loaded.

Figure 21. Belt Conveyor from Aggregate Production Plant to Dam Site

Figure 22. Belt Conveyor and Ground Hopper

6. DEVELOPMENT OF CSG AND TRAPEZOIDAL CSG DAMS

6.1. Development of CSG at the Nagashima Dam Site.

The 113m high Nagashima dam was a conventional concrete gravity dam, because the many conduit gates installed in the dam body prevented flat layer construction such as the RCD construction method. However, because the riverbed deposit was very thick at the site, the RCD construction method was used to replace the original riverbed and a conventional concrete dam was constructed on it.

At first, the upstream cofferdam was to be made of earth and rock because it was constructed on deformable riverbed deposits. However, after a large flood washed away the cofferdam, the dam constructor decided to construct a new cofferdam with

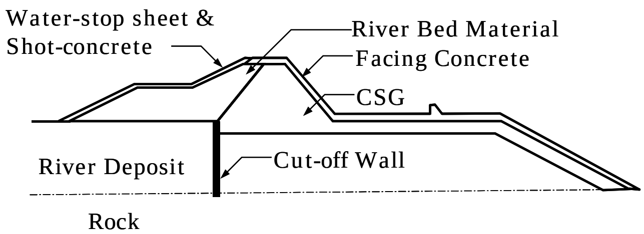

Figure 23. Cross Section of Nagashima Coffer Dam

Figure 24 Nagashima Coffer Dam

soil-cement-like material. First riverbed material was dumped at the site then cement was dusted on it. Then a skeleton-type backhoe mixed the materials and a vibrating roller compacted the materials. When the water content was judged to be low, additional water was sprinkled on it. This material is called CSG that is the abbreviation of Cemented Sand and Gravel. The cross section of the CSG cofferdam at the Nagashima Dam is shown in Figure 23 and a perspective view in Figure 24. The CSG cofferdam had properties similar to soil-cement. It was confirmed that the structure could resist overflow by flood water during the flood season. CSG cofferdams have been constructed at many dam sites since then.

CSG had the optimum water content from 6 to 8 %, as the soil had. The water content was kept on the wet side in the consolidating CSG to prevent honeycomb voids and to keep the strength deviation relatively low. Cement content was about 60 kg per unit volume (1 m^3) of CSG.

This CSG was designed to allow for a wide range of deviation of mechanical properties (unit weight, strength, modulus of elasticity) and the existence of entrapped voids, because it was used as the material for temporary structures. For example, the strength range of CSG was sometimes 2 to 10 N/mm^2 on the 28th day.

6.2. the Nagashima Sand-Trap Dam

The Nagashima dam was constructed on the Oi River by the Ministry of Construction. Because the river flow of the Oi River includes much silt and sand during flooding, a 34 m high sand-trap dam with volume 50,000 m^3 was constructed in the upper part of the reservoir (Figure 25).

Because the Nagashima Sand-trap Dam was constructed in the reservoir of the Nagashima Dam, its safety requirements were relatively low. Economical construction methods were, therefore, studied in advance of construction (Yokotsuka et al., 2000).

As a result of the study, CSG was used to make the dam body. Using skeleton backhoes to mix the CSG was not effective because of the large volume of the dam. Then, the continuously mixing drum-type mixer was adopted. CSG materials were provided from the river bed. Originally no grading process was planned, but the variation of the grading of the materials proved very high. So, a 20 mm sieve feeder was adopted and CSG materials were classified into materials larger then 20 mm (larger aggregate) and materials not larger than 20 mm (smaller aggregate). They were stocked separately. Furthermore, it was found that grain size under 5 mm is very small, so fine sand was excavated from a pool in the river and mixed into the smaller aggregate (Figure 26).

In the design, the unit mass of CSG was assumed to be 2,200 kg/m^3, and 100 kg of cement and 100 kg of

Figure 25. Nagashima Sand-trap Dam

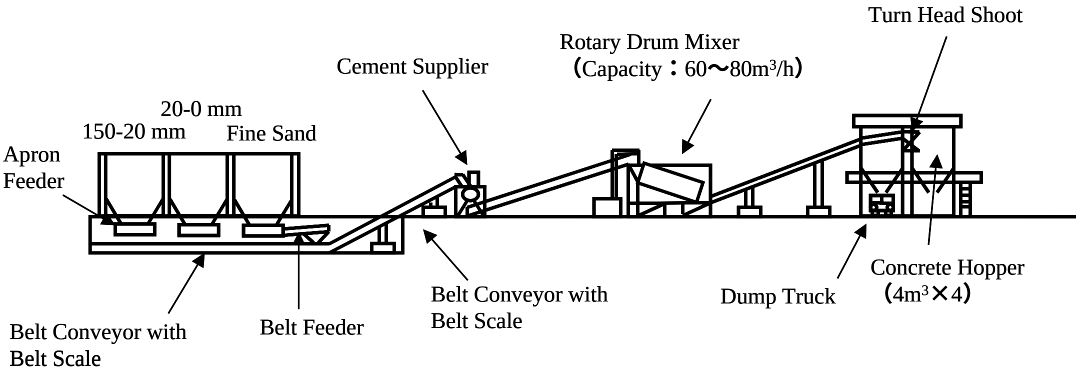

Figure 26 Bathing and Mixing Plant (Continuously Mixing Type)

sand were added. These materials were weighed on the belt scale. Also, the water contents of sand and smaller aggregate were measured on a belt scale and adequate water was added to obtain VC value of 20 seconds. The result of the test fill was excellent and cement content was reduced to 90 kg/m^3.

CSG manufactured by the continuously mixing drum type mixer was stocked in the hopper and a dump truck transported it from the hopper station to the dam. The compaction method and other processes were almost the same as those of RCD except that surface concrete (conventional concrete with 220 kg/m^3 of cement) and bedding mortar were manufactured at a local private concrete plant. Delay of concrete supply was not observed.

6.3. Concept of a trapezoidal CSG dam

A trapezoidal CSG dam is a new type of a dam that combines a trapezoidal dam and CSG materials.

Conventional concrete gravity dams were usually designed to satisfy three requirements: resistance against overturning, resistance against sliding and allowable compressive strength. In the seismic coefficient method, middle third condition guarantees the no tensile stress in the concrete gravity dam. But under real earthquake conditions, the large tensile stress is induced in the dam body. So, the compressive strength of concrete should have much larger than the allowable stress. However, if the shape of the dam is trapezoidal with a slope of 0.8 : 1.0, no tensile stress is induced even by the design earthquake. This means a large safety factor is unnecessary.

At the same time, the maximum compressive stress in a concrete gravity dam is relatively low compared with other concrete structures. This means that a trapezoidal concrete dam can utilize even CSG as its dam body material (Hirose et al., 2001).

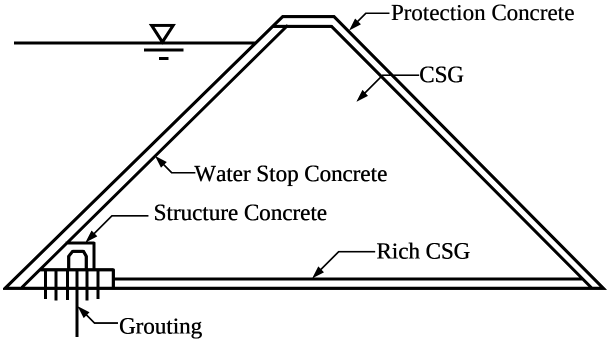

Figure 27. Trapezoidal CSG dam

On the other hand CSG does have low resistance to freeze-and-thaw attack and high permeability. Then conventional concrete should be placed in order to prevent water leakage at the upstream surface, and in order to prevent freeze-and-thaw attack at the downstream surface.

Furthermore, leakage of water from the foundation rock to the CSG should be prevented. Therefore, the bottom of the dam along the foundation rock from the heel of the dam to the drainage holes is covered with conventional concrete and foundation grouting is executed.

At the crest level of a CSG dam, 8 to 10m width is adopted because the transportation of CSG by dump trucks and the compaction of CSG by vibrating rollers can be easily done.

Therefore, the typical cross section of a trapezoidal CSG dam is as shown in Figure 27. Trapezoidal CSG dams are now at the design stage of the Okukubi Dam (height = 39 m), Sanru Dam (height = 50 m) and Hommyogawa Dam (height = 64 m).

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