５. Latest Technology for Concrete dam

(Dam Technology Trends and Challenges)

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1. Introduction

In recent years, organizations constructing dams have faced strong demands for the reduction of the cost of public works projects and the protection and conservation of the environment, compelling them to strengthen measures to lower costs and consider the environment. It is particularly important for dam technologists to respond to these demands as they both guarantee safety and reduce the cost of dam construction.

Simultaneously guaranteeing safety and lowering costs requires a wide range of technical knowledge extending from design to construction, Specifically, information concerning dam foundation and body materials obtained during the survey stage that precedes actual construction is extremely limited compared with information that is available after the start of construction, and after construction begins, changes must often be made in response to conditions very different from those originally predicted. It is frequently necessary to respond promptly to circumstances that appear during construction of a dam. In such cases, comprehensive judgments based on technical knowledge concerning design and execution must be made, and it is important to constantly collect and organize information throughout the construction phase so that the design can be revised without difficulty.

Recently, dam technology itself has been transformed into a comprehensive science, because in addition to design and construction, technologists must increase their understanding of methods of taking environmental measures to preserve water quality and protect plants and animals and of the customs and culture of the regions where dams are constructed.

This report deals with the latest technological trends in both the design and the construction phases, but introducing new technologies that go beyond design and construction is also important to improve the safety and functions of dams and to lower their cost. To introduce new technology, there are times when technical rationalization should extend to discussions of safety, and in this case, perfect safety is achieved by preparing fail-safe provisions to provide for unpredictable emergencies.

2. Dam Concrete

Concrete dam construction is performed as a series of works beginning with the production of concrete aggregate, and extending to mixing and placing. To place a massive volume of concrete at one time, it is executed with great care taken to prevent thermal cracking. These are characteristics that distinguish dams from other concrete structures.

The history of the improvement of dam concrete has primarily concerned minimizing the quantity of cement in order to restrict the heat produced during hydration and responding to a decline in execution properties resulting from the stiffening this causes, but recently, it has diversified to include improving the quality of cement or chemical admixtures.

2.1 Super-Stiff Concrete

The RCD (Roller-Compacted Dam-concrete) method developed in Japan in advance to the world brought the super-stiff concrete in middle of 1970s. Producing super-stiff (slump value = zero) concrete by reducing its unit water content to nearly half of that of conventional concrete with a certain degree of flow ability permits compaction by vibrating rollers and control of the heat of hydration, achieving large cost reductions by high speed concrete placing (See Fig.1, 2). The field has also been strongly impacted by the development of Roller Compacted Concrete for Pavement (RCCP) or Roller-Compacted Concrete (RCC) with U.S. specifications for dam use.

These super-stiff concrete are sensitive to changes of its water content because its unit water content has been reduced to the minimum possible level. Therefore, there are many compaction methods (vibrating roller, aggregate separation prevention, etc.), concrete mix designs (water content, chemical admixtures and admixture minerals, etc.), quality control methods (Vibrating Compaction testing, in-situ density testing, etc.), site control methods (responding to sunlight and rainfall, preventing drying, cooling, wet curing etc.) and other development know-how.

Fig.1 RCD concrete just after compaction

Fig.2 RCD concrete after green cut, wash

2.2 Dealing with Thermal Cracking

Concrete expands as its temperature rises under the effects of heat of hydration produced during hardening after placement, then after reaching its maximum temperature, contracts as the outside air temperature gradually cools it. Mass concrete such as that used for dams is at high risk of cracking by tensile stress inside the concrete produced in response to internal constraint on change of its volume caused by exterior constraint of the foundation rock and the surrounding concrete and by unequal decline of its temperature. (See Fig.3, 4, 5)

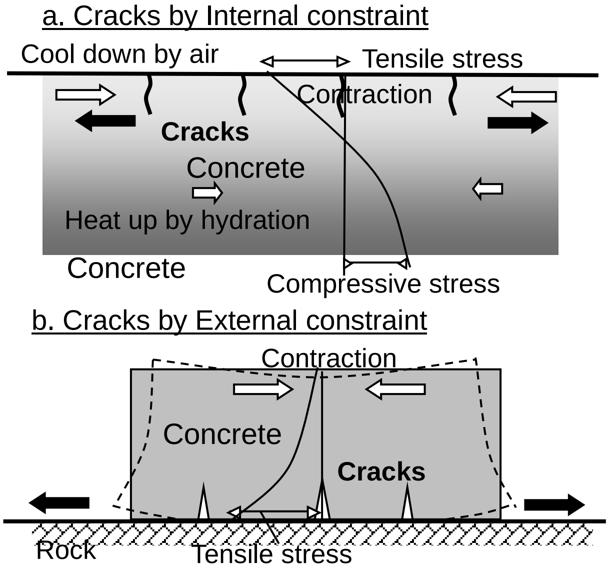


Fig.3 Internal and external constraint

⇨ : direction of concrete volume change

⬅ : direction of stress by constraint

To deal with the thermal cracking of dams, installing block joints (sometimes longitudinal joints), the use of moderate heat cement, pipe cooling, precooling the materials, and lift schedule adjustment, and other technologies have been developed in the past.

Recently, technology development has included the development of low heat cement with high long-term strength (low heat Portland cement etc.), increased substitution of cement with blast furnace slag and fly ash (reducing the unit quantity of cement by 30% to 50%), and precooling aggregate (various cooling methods include cold air, evaporation, vacuum, expansion, and liquid nitrogen).

In tropical or sub-tropical area such as Okinawa where the air temperature is high but differences in temperature between the night and day and between seasons are small, It is assumed that the risk of cracking etc. caused by the generation of thermal stress etc. is smaller than in the mainland. Here, placing has been done frequently at temperatures higher than the maximum placing temperature of 25°C stipulated by the temperature regulations in the JSCE Concrete Standard Specification; at 27°C at Aha Dam, 29°C at Kanna Dam, and 32°C at Kinjo Dam.

Fig.4 Curing in Nagai dam

Fig.-5 penetrated cracks at the dam toe

Fig.-6 Micro cracks at the upper surface

2.3 Hot Weather Concrete

Hot weather concrete used in high temperature in the summer faces a special problem: compared with cases in normal condition (20°C), its faster hydration reaction accelerates its solidification, sharply lowering its workability over time, and its initial strength is high but its long-term strength does not increase.

The deterioration of its workability is an important problem with rational dam construction methods used for high volume concrete placing like as RCD and ELCM (See Fig.7), so the performance of AE (air entrained) water reducing type retarder and super retarder that delay solidification time has been improved. But during high volume placing, it is economical to substitute fly ash that provides cement reduction effects and workability improvement effects by rounding shapes in micro size for a high content of the cement.


Fig.7 Segregation of large size aggregate, because of deterioration of workability under the hot weather

The cooling methods such as precooling are effective ways to lower the placing temperature to delay solidification. Blocking sunlight and performing wet curing have also improved these methods.

2.4 Self-compacting Concrete

Self-compacting concrete has the properties of fresh concrete that include high flowability, high filling properties, and high material separation resistance: properties that are the result of increasing its fine grain fraction by using more fine-admixture minerals than normal concrete and by adding rock powder, and also the result of adding chemicals to increase its viscosity (See Fig.8).

Fig.8 Placement by self compacting concrete（around the conduit）

During placing, it can completely fill every space in the form as it flows naturally to create uniform concrete. Because it does not require compaction, it has been widely used in recent years to form parts with complex reinforcing bars where the concrete cannot be easily compacted by vibrators. Examples are the concrete around the standard spillway of Okumiomote dam (Niigata Pref., See Fig.8, 9) and around the outlet and bottom of the precast gallery of Otaki Dam (Kinki MLIT). Further, efforts are being made to lower its labor requirements and improve its quality.

Fig.9 Placement by self compacting concrete (under precast gallery base)

3. Rational Construction Method in Concrete Dams

3.1 RCD (Roller Compacted Dam-concrete) method

The RCD method was developed by Ministry Of Construction in the mid nineteen-seventies, and now it is one of standard dam construction methods in Japan. RCD’s features are executed by leveling super-stiff interior concrete with bulldozers than compacting it with a vibrating roller (See Fig.10). Because a wide flat area can be executed at one time, its execution properties are superior, and because its cement content is lower than that of conventional concrete, it produces less heat so that there is low risk that it will be cracked by thermal stress, even when large quantities are placed at one time.

Consequently, it provides good cost reduction effects by contributing to more efficient work and, by allowing high volume placing, shortens work periods. It is reported that it can shorten work periods from 30% to 40% and lower overall costs by 20% compared with conventional column block concrete placement.

As large-scale mechanization of fill dam earth work appeared, Ministry of Construction (the present MLIT) began to study the RCD method in 1974. Since it was applied to construct Shimajigawa Dam (1978.10 to 1980.4, Chugoku MLIT) and the mat of Okawa Dam (1979.7 to 1980.7, Hokuriku MLIT), it has been used at approximately 60 dams including Tamagawa Dam (Tohoku MLIT) and Miyagase Dam (Kanto MLIT), and is now the principal execution method used at medium to large-scale gravity concrete dams.

In particular, in recent years, Takizawa Dam (JWA, See Fig.11), Nagai Dam (Tohoku MLIT, See Fig.12) and other large dams constructed by the RCD method have been completed one after another, and the RCD quality control and execution methods have been almost improved through the construction of these dams. The concrete is transported using dump trucks that is the principal method or using belt conveyors, inclines, cable cranes, tower cranes, and other methods according to topographical and dam body conditions.

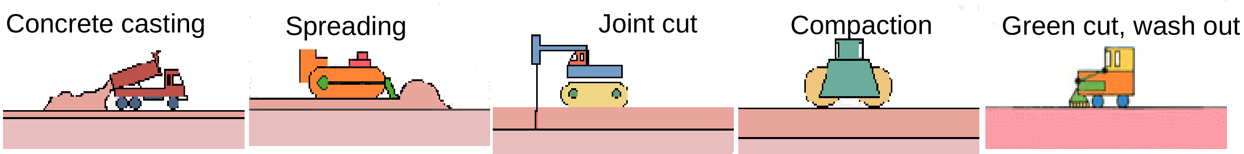


Fig.10 Procedure of RCD method: the above cycle is repeated on concrete work of the RCD dam

Fig.11 Takizawa dam RCD 021125

New trial was executed by spreading then compacting thin layers.

Fig.12 Nagai dam, continuous RCD test

3.2 ELCM (Extended Layer Construction Method)

This method is abbreviated as ELCM (Extended Layer Construction Method). Like the RCD method, it is a wide and flat area execution method that does not form level differences on the placed surface, and like the conventional block column execution method, it requires vibrator compaction and uses slump concrete that is softer than RCD concrete. It is similar to the RCD method in many ways, but it is superior to it in that the interior and exterior concrete are compacted by the same method, few machines are used, and its unit water content is high, which means that it is more resistant to water content fluctuation during light rain or under sunlight. But it is inferior to the RCD method in that it is not a suitable for large quantity placing, its cement content is high, and the concrete produces a large quantity of heat, etc.

The ELCM construction method was first used for the trial execution (November 1979) of an auxiliary energy dissipater at Hitokura Dam (November 1979, JWA), since then it has been established as a construction method through its use for the main bodies of Nunome Dam (1988, JWA), Kuriyama Dam (1989, Hokkaido Pref.), Miharu Dam (1990, Tohoku MLIT), and Nakasujigawa Dam (1991, Shikoku MLIT). It is now the principal method used to construct small to medium scale gravity concrete dams. It is also often used to construct the narrow part of the crest of large dams (See Fig.13, 14, 15).

Further, after some trial executions under harsh sunlight conditions at Taiho Dam (OGB), it was confirmed that ELCM was adaptable to a subtropical area in quality by high-ration fly ash (30%~50% substituting for cement), and this concrete dam completed in 2008.


Compaction by a vibrator backhoe

Fig.-13 ELCM (Extended Layer Construction Method), Mimurogawa dam

Fig.-14 ELCM, Takoh dam

Fig.-15 ELCM, Kotogawa dam

3.3 Precast Structures; gallery, elevator shaft, etc.

Dams consist mostly of cast-in-place concrete, but a type of technology whose development will provide an extremely effective way to rationalize execution and shorten construction periods is the use of precast members that are concrete members manufactured in advance and installed at the stipulated locations, eliminating the need for complex form work (installation and removal) performed before and after concrete placing. It is essential to guarantee adequate strength and water blocking capacity of connections between segments, and adhesion strength between the precast members and the cast-in-place concrete.

Precast execution has been advanced through its use at gravity concrete dams: constructing precast galleries at Unazuki Dam (Hokuriku MLIT), Kubusu Dam (Toyama Pref.), Fukuchiyama Dam (Fukuoka Pref.), Nagashima Dam (Chubu MLIT, and Otaki Dam (Kinki MLIT). Progress in the application of the precast method to elevators and other long blockouts has also been achieved (See Fig.16, 17, 18, 19).

At fill dams on the other hand, it is difficult to construct the entire section using precast members because the body would become large if designed to bear the entire overburden load, but making only the forms or part of the members by the precast method is a valuable method. Precast form work has been done at Tsunakigawa Dam (Yamagata Pref.) and Masutani Dam (Fukui Pref.).

Fig.16 Precast gallery, Fukuchiyama dam

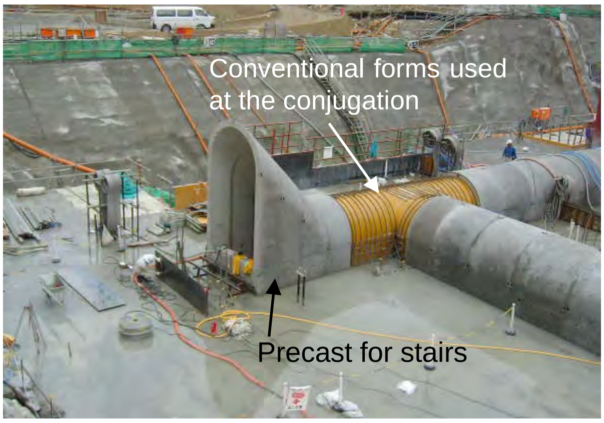


Fig.17 Precast gallery, Kido dam

Fig.18 Precast gallery, Hirokami dam

Fig.19 Precast elevator, Nagai dam

3.4 Concrete Conveyance Machines and Equipments

In concrete works, various machine models are adopted from a viewpoint of laborsaving or speeding up of construction.

Currently, the movable types with crawlers or wheels are adopted in small-scale dams, and have contributed also to cost reduction by less facility expense or improvement in operating time (See Fig.20, 21, 22).

Further, various machineries such as the continuous mixing system, the gravity fall mixer, the automated circulation bucket, the spiral mixing pipe, and other equipments by IT are developed with some computer controlled system (See Fig.23, 24, 25).

Fig.20 Belt conveyor concrete casting machine with crawler, Toppu dam

Fig.21 Crushing machine with crawler, Kido dam

Fig.22 Crushing machine with crawler, Ohtagawa dam

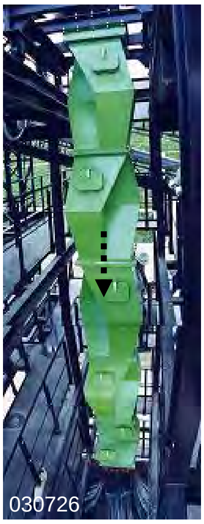


Fig.23 gravuty fall mixer, Kido dam

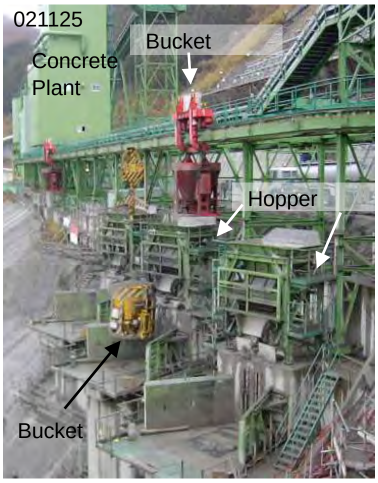
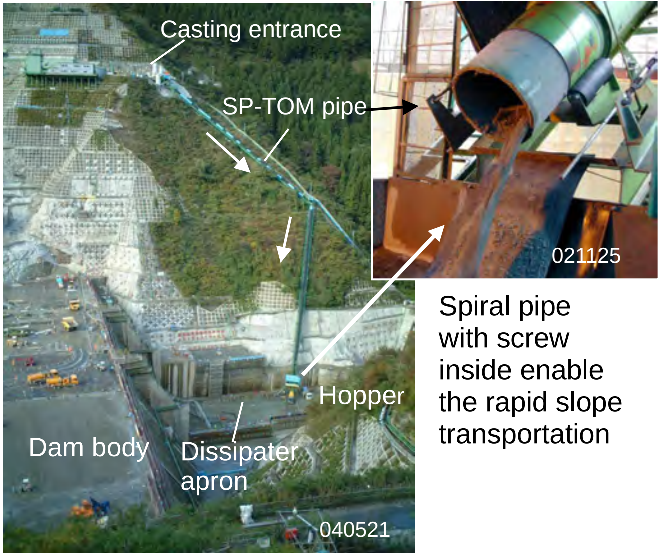


Fig.24 Circulation bucket, Takizawa dam



Spiral pipe with screw inside enable the rapid slope transportation

Fig.25 Continuous Spiral pipe, SP-TOM, Takizawa dam

4. Foundations Improvement

According to diverse hydro-geological condition at each dam, the most efficient measures must be considered and performed, such as the grouting, the diaphragm wall, and the concrete abutment.

4.1 Grouting; rationalizing

If the groutability around the abutment is sufficient, curtain grouting to form the water-tightness zone along the dam axis should be the most effective method in the performance and cost.

On the other hand, progress in geological surveying methods has increased the precision of assessments of ground permeability properties, and at the same time, computer control systems that accurately and rapidly process and analyze data have achieved rapid progress, encouraging rationalization by suitably controlling the injection pressure, mix proportion, and quantity injected in real time.

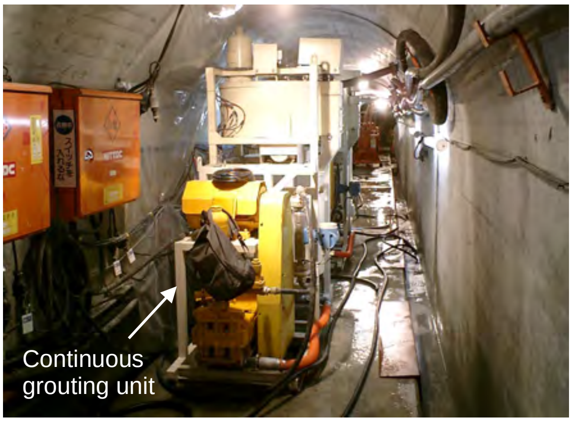


Fig.26 Curtain grouting by a new system

The application range of hard technology for grouting will expand to foundation ground in response to the development of grout materials and improvement of grout injection methods. For example, by the continuous grouting unit (See Fig.26) which changes the grout density automatically and performs continuous grouting, shortening of injection time and increase of the amount of cement milk are achieved, and the amount of abandoned cement can be reduced now to about 1 / 3 ~1 / 2.

The Grouting Technical Guideline revised in 2002 is a rationalization achieved in response to these demands and to technical progress, and its purpose is to "clarify conventional goals of execution and the range of executions, and verify and review grouting suitable for foundation ground during executions" on the premise the safety will not be reduced. In particular, this revision that reflected the swing from specification regulations to performance regulations means future judgments made in the field will be increasingly important, and grouting optimized for each dam site should be done according to the geological and other properties of dam sites.

4.2 Diaphragm Wall; as a water blocking or ground strengthening method

If the groutability around the abutment is insufficient, the diaphragm concrete wall is an attractive water blocking method in the performance and cost. Recent progress of this method is outstanding with the development of diaphragm technology.

Diaphragm walls have been constructed by first forming a long narrow excavation with the walls of the excavation controlled by a stabilizing fluid such as bentonite slurry, performing slime processing, then inserting H-shaped steel and cages into the groove, and finally pouring concrete or mortar to form a continuous structure underground.

Recently the economic benefits of this method have been boosted by lowering the size of the machinery used, resulting in remarkable progress.

The large-scale diaphragm walls to block water at dams have been constructed such as Kawanabe Dam (Kagoshima Pref.), Miyagase Dam (Kanto MLIT), and Chubetsu Dam (Hokkaido MLIT), Koyama Dam (Ibaraki Pref., See Fig.27) and others

Furthermore, for the foundation which runs short of strength and stiffness, the box type wall was developed through basic construction of a Pirika Dam (Hokkaido MLIT) and Kinjo Dam (Okinawa Pref.), and it was adopted as the artficial dam abutment at Yochi Dam (Nagano Pref.) and Iwaikawa Dam (Nara Pref., See Fig.28).

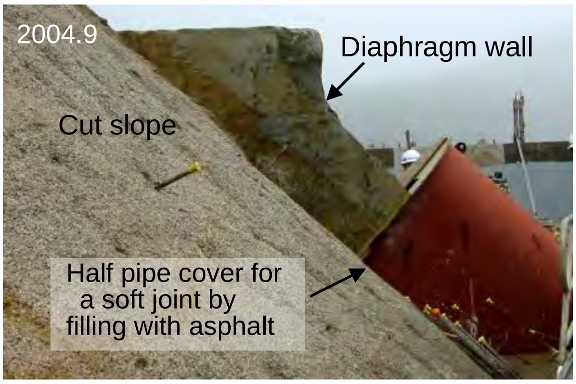


Fig.27 Diaphragm wall, Koyama dam

Fig.28 Box type diaphragm, Iwaigawa dam

4.3 Fillet, Concrete Mat and Massive Concrete Replacement

Recent years have brought a rise in the number of cases where the inadequate shear resistance of foundation ground at a gravity concrete dam with a normal triangular section has been overcome by lengthening the dam base in the upstream and downstream directions, guaranteeing stability against sliding at the same time as it distributes the stress to increase the safety of the ground.

This method includes the fillet method (triangular part of a thick layer installed on the upstream slope of the dam body) and the mat method (extension primarily towards the downstream side using a bottom plate as the dam base). The fillet method has been used often at dams with inferior foundation bedrock since it was first used at Sameura Dam (JWA), Odo Dam (Shikoku MLIT), and Shozenjigawa Dam (Niigata Pref.) that were constructed in the late nineteen-seventies.

The mat method has been used with increasing frequency in recent years including its use on terraces since it was first used in 1980 on riverbeds at Okawa Dam (Hokuriku MLIT), and others.

A massive concrete replacement is performed on top of the large-scale fragile layer exposed on the gentle slope to transmit stress to the bedrock (an expanded version of the conventional fault processing). This lowers the quantity of dam body excavation and the quantity concrete placed to construct the dam body.

4.5 Vertical Type Concrete Abutment

A variety of measures have been taken to minimize the transformation of natural features at dam sites in recent years, but minimizing the cut slopes at dam sites is growing in importance. So recently, replacing the ends of the dam body and the slopes of terraces with a special structural body artificial abutment to limit the size of the quantity of dam body excavation and the area of the cut slopes is a new method whose use is growing.

Vertical type concrete abutment is also described as a method that uses natural ground to minimize excavation. The abutment ends are excavated with an enough long base and replaced with standing concrete bodies (Fig.29, 30). Thus, the vertical concrete abutment sharply reduces the cut slopes.

Additionally, the top flat face of the concrete abutment can serve as an effective flat space such as work yards and maintenance/ management space.

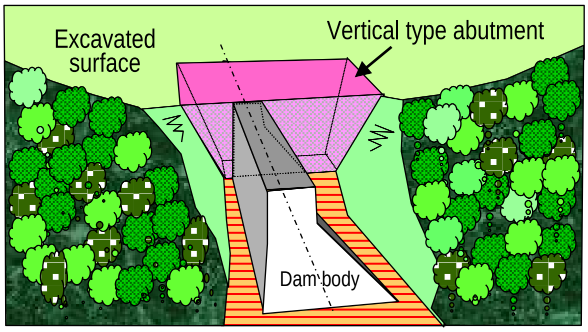


Fig.29 Example of the setting of a vertical type abutment and a dam body

Fig.30 Vertical type concrete abutment ,Yamato dam

4.6 Slope Type Concrete Abutment

As for the slope type concrete abutment, a concrete body shaped like a long gently sloping mat is installed on the slope in the upstream-downstream direction. This greatly reduces the quantity of dam body excavation and the quantity of dam body concrete placing.

The design concept of the slope type concrete abutment is visualized in Fig.31. The dam body can be set on the rock zone above the weak zone, if the rock zone has enough thickness and hardness. Therefore, the area surrounded by a broken line is replaced with

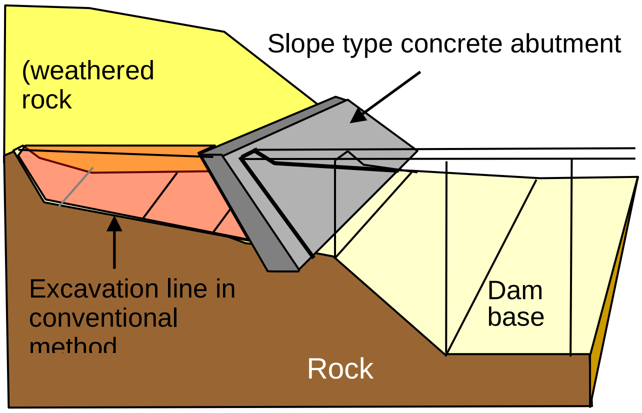


Fig.31 Concept of slope type concrete abutment

Fig.32 Concrete abutment, Inaba dam

the concrete abutment to provide artificial thick hard rock.

Table 1 Inaba dam specification

Items		Value
Dam height（m）		56.0
Length on Dam top（m）		233.5
Elevation of Dam top (EL.m)		462.0
Concrete Volume of Dam (×10^3 m^3)		210
Concrete Abutment Height	Left: 37.5m	Right: 38.0m

Fig.32 shows the shape of the sloped concrete abutment, which is constructed at the sides of a dam. The shape that is long and rigid in the flow direction is to provide greater shear resistance to the base and backside. The ground is excavated so that the high terrace mostly remains unremoved, and the cut slope area is reduced greatly. Eventually, it is easy to realize a remarkable reduction in the volume of excavation and dam concrete volume, and provides an excellent cost reduction advantage.

4.3 PS Rock Anchor and Ground Anchor

PS anchor works, grating crib works, and other materials and installation methods used to control large slopes and landslides have progressed remarkably in recent years. This progress has been supported by dam construction.

PS anchor works are executed by installing anchors modified so they will provide powerful resistance deep in the ground, then fixing them to walls or structured by tension steel. Grating crib works is an extremely low-cost and efficient method whose application range is expanded by combining rock bolts with PS anchors.

The PS rock anchor is a large scale bedrock reinforcing method first used at Kawamata Dam (Kanto MLIT) in 1960s, Okumiomote Dam (Niigata pref. completed in2001), etc. and is also used as an underground opening work method for electric power plants.

Recent public demand that the area of excavated slopes be minimized and that they be reforested in order to lower their impact on the environment has triggered a need for further improvement of slope treatment works such as the ground anchor (See Fig.33).

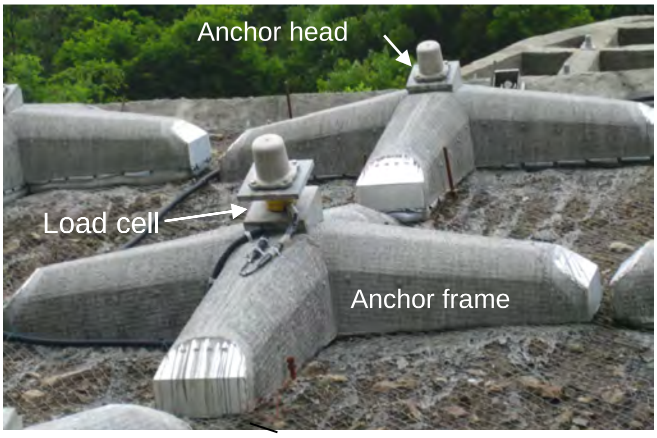


Fig.33　Ground anchor, Okutainai dam

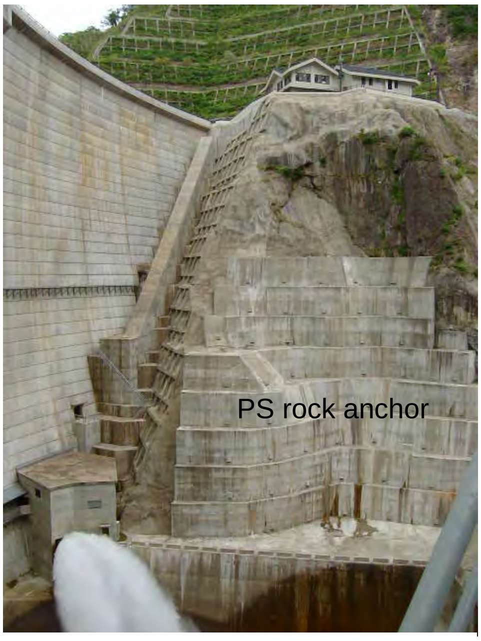


Fig.34 PS Rock Anchor, Okumiomote dam

5. Trapezoidal CSG Dams - New Dam Type

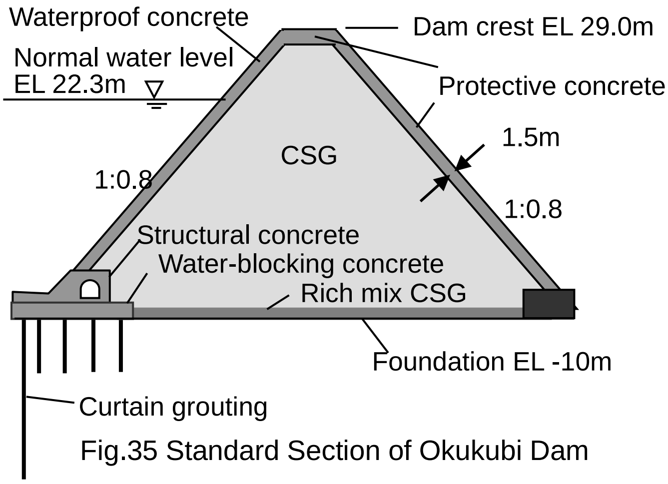


Fig.35 Standard Section of Okukubi Dam

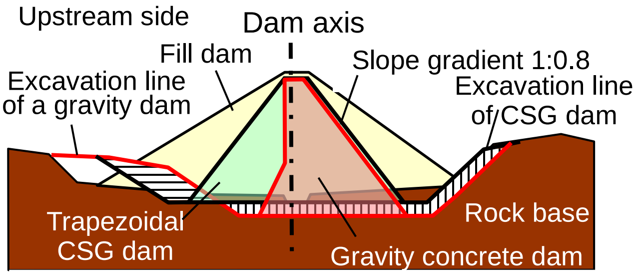


Fig.36 Differences between
the excavation lines of three types of dam

CSG (Cemented Sand and Gravel) is a cement hardened material made by adding cement and water to riverbed gravel, excavation muck, or other rocky material easily obtained near dam sites, and mixing these constituents by a simple mixing process.

Because CSG material is weaker than concrete, it is used as a new structural type (trapezoidal CSG dam) that reduces stress generated inside the dam body. The basic shape of the section is a trapezoid with an upstream surface and downstream surface with identical gradients. This form can greatly lower costs, because it permits the sharp scale reduction of the quarry, aggregate production plant, mixing plant, and turbid water treatment plant.

A trapezoidal CSG dam not only reduces costs, it also protects the environment by reducing the scale of quarries and effectively using waste material, and also guarantees greater safety by improving stability during earthquakes. For these reasons its use is expected to spread in the future as it is executed at a number of dam sites (See Fig.37) in Japan, and it is counted on to attract great interest internationally.

Okukubi Dam which is the first trapezoidal CSG dam will be completed in 2011, and Tobetsu dam as the second CSG dam will be completed in 2012.

Fig.37 CSG works in the Inaba dam, left: Spiral mixer, right: Spreading of CSG by bulldozers

6. Intake and Outlet Facilities

The gates and airlocks that are not lift-up type have the potential to be more compact and more maintenance-free intake and outlet systems by combining main and auxiliary high pressure use valves that are becoming increasingly durable. And because the size of the gate chamber can be by greatly reduced by omitting lift space, their use is counted on to improve the scenery and lower costs.

6.1 Conduit Gates

Fig.38 Tension Radial Gate, Haneji dam

Conventional outlet gates were designed as gates made of steel and subject to compression load, and to prevent buckling of members, had to be made of thick members and reinforcing steel to increase their compressive strength. This increased the weight and the cost of the gates. But recently, based on a 180° change in design methods, a new type for gates subject to tensile loads has been developed taking advantage of the properties of steel. In Japan, this type gate is called a “tension radial gate”.

At Haneji Dam (OGB), tension radial gates with their watertight properties greatly improved and their operation simplified were installed in 2000 for the first time in Japan at two locations on the dam: for emergency outlet use (size: 1150mm x 1150mm, Fig.38). Compared with the jet flow gate (ϕ1,400mm) in the original design, its benefits include, “lowering the quantity of steel by using thinner members, reducing the inlet diameter by increasing the coefficient of discharge, and lowering the roof by eliminating the spindle rod (reducing civil engineering costs),” achieving 30% lower manufacturing and installation cost and 40% lower civil engineering costs.

The large-scale tension radial (Normal discharge gate, size: 2 gate x 2,200mm × 2,050mm) with more improvements was installed at Tomata Dam (Chugoku MLIT, Fig.39) in 2002 and Haizuka Dam (Chugoku MLIT, Fig.40) in 2004.

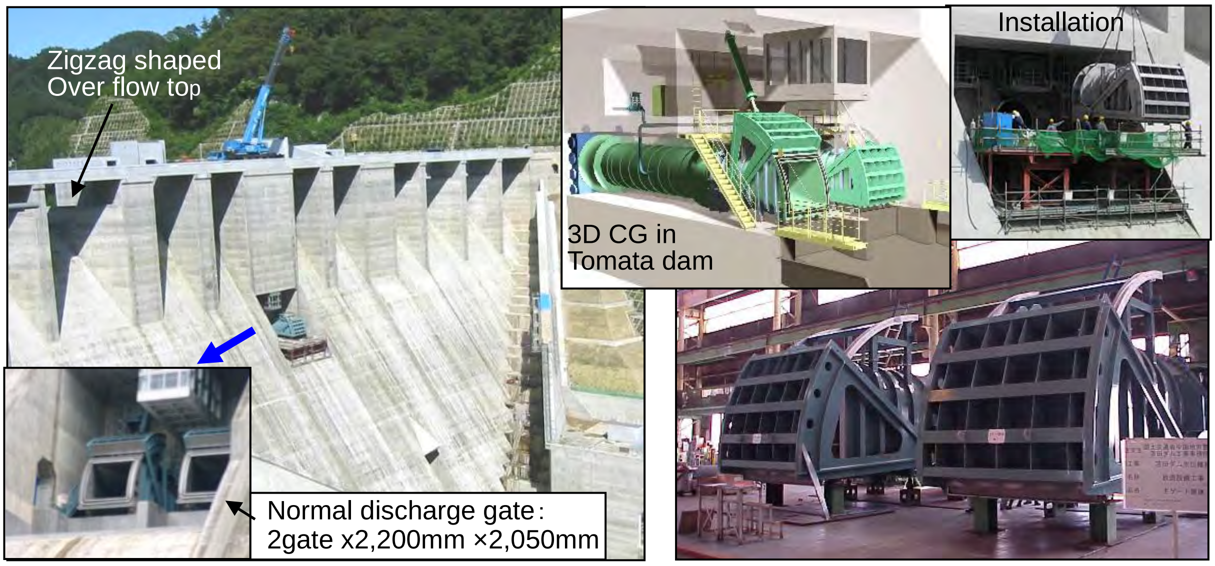


Fig.39 Tension Radial Gate, Tomata dam

Fig.40 Tension Radial Gate, Haizuka dam

6.2 Selective Intake Systems

In response to the diversification of the need to take in water and water quality problems, beginning with the construction of the Sameura Dam (JWA), the Kyuragi Dam (Kyushu MLIT) and others in the late nineteen-seventies, many dams have been equipped with selective water intake systems that efficiently take in water from the layer with the stipulated quality. Selective intake systems that have been developed include multi-level type (rectangular, semi-circular, circular openings) and multiple type (series of rectangular openings), and others distinguished by the shape of the inlets, and the more recently each type has been developed, the more advanced its functions. But because conventional selective intake systems require many gates, winches, and other heavy equipment, they tend to be more expensive to install and maintain.

In contrast, at Haneji Dam, an air-lock type gateless selective water intake system that holds back the water with compressed air has been developed. The basic principle of the air-lock is storing air in a reverse U-shaped pipe to cut-off the water (See Fig.41).

This system was extensively improved by eliminating unnecessary equipment and, where necessary, strengthening the equipment. The result is a design that is functional, lower cost, and safer by simplifying the machinery and structures, superior water-tightness, superior durability and easier maintenance, because it has no gate and winch, simplified automation system, superior safety because the air lock is automatically unlocked when there is a water level difference, and almost no waste oil or exhaust gasses.

Fig..41 is continuous selective intake tower by air lock in Shitumi Dam (See Fig.42) as extensive model of the above air lock system. Recently, this new model is spreading to many other dams such as Obara Dam (Chugoku MLIT), Yubari shuparo Dam, Tono Dam (Chugoku MLIT), Kurokuigawa Dam (Yamaguchi pref.). Further, it has future potential as a structure without a shed and as a sediment flushing system.

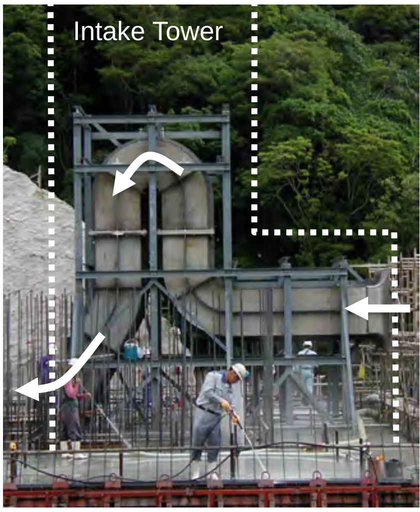


Fig.41 Setting of intake pipe, Haneji dam

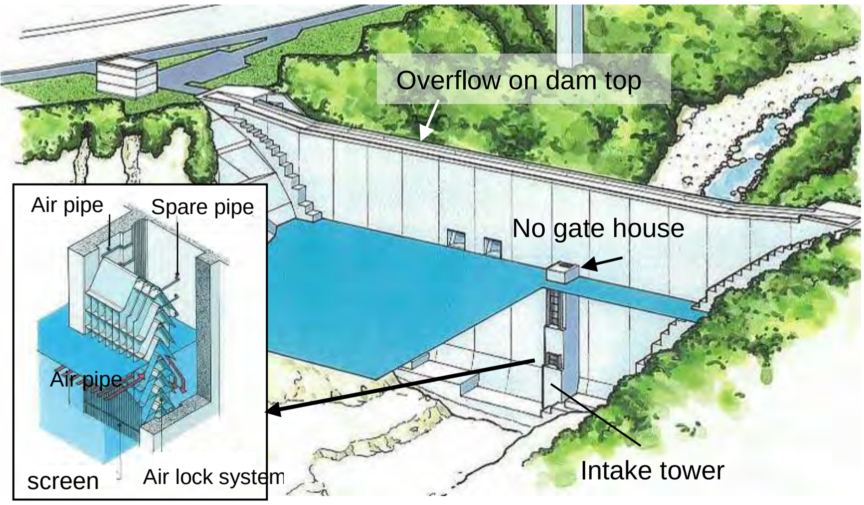


Fig.42 Continuous selective intake tower by air lock, Shitumi dam

7. Development of Sediment Management Technology.

7.1 Flushing and Sediment Sluicing

Flushing systems (flushing pipes, flushing gates, etc.) are installed inside dam bodies to flush sediment. Sediment sluicing means discharging influent water containing sediment before the sediment particles have settled, and in many cases, it is done by maintaining the stored water at a low level during the flood runoff period when sediment traction capacity is high. Flushing lowers the water level in the reservoir, increasing the tractive force so that the flowing water moves, flushing the deposited sediment.

The first full-scale flushing channel inside a dam body at an MLIT dam was installed in Unazuki Dam (Hokuriku MLIT). It began flushing sediment jointly with upstream Dashihira Dam (Kansai Electric Power Co.) in June 2001.

7.2 Sediment Bypass Tunnel

To reduce the quantity of sediment flowing into the reservoir, a separation weir etc. is constructed in the upstream reservoir, to cause all or part of the flood runoff containing sediment to bypass the reservoir through a bypass to flush it downstream. In order to separate large diameter gravel, generally a sediment check dam is also used.

Sediment flushing by a sediment flushing bypass began at Asahi Dam (Kansai Electric Power) in 1999 and a long-distance sediment bypass tunnel was constructed at Miwa Dam (Chubu MLIT, See Fig.43) in 2004.

Fig.43 Outlet of bypass tunnel, Miwa dam

7.3 River Bed Perforated dam (Dry Dam or Gateless Conduit Dam)

This is a so-called exclusive flood control dam, a type that has recently increased. A spillway is installed near the riverbed, and by also operating it as a sediment spillway, it flushes sediment as the water is reduced (as the water level falls) after the flood runoff has been stored, minimizing the sedimentation inside the reservoir. It is a method whose benefits include not causing water quality problems such as prolonged turbidity or eutrophication.

Masudagawa Dam (Shimane Pref., See Fig.44) and Nishinotani Dam (Kagoshima Pref., work to begin soon) will be dams that are 100% flood control dams that normally store no water. This type dam is called as a “Dry dam”, and they have a gateless opening type flushing channel inside the dam body.

Fig.44 Dry dam, Masudagawa dam

7. Redevelopment and Improvement

7.1 Raising

It is expected that the raising of existing dams will be quite more advantageous than construction of new dams economically in respect of storage capacity and in environmental influence, and the cases of the raising will increase if it is possible in geographical condition.

As the raising of a concrete dam, there were Kawakami Dam (completed in 1980), a new Nakano Dam (completed in 1985), Magaribuchi Dam (completed in 1993), Kayase Dam (completed in 2000), Shimonohara Dam (completed in 2006, Fig.45), etc. in the past. There are Hikawa Dam (Kumamoto pref.), New Katurazawa Dam (Hokkaido MLIT), etc. as a dam under construction.

As the technical subjects of the raising of existing dams, there are unification of new and old concrete, flood disposal and water-stop in the works, etc..

Fig.45 Raising height 5.9m, Shimonohara dam

7.2 Outlet openings in Dam bodies

It is now possible to form large openings in dam body concrete while the dam continues to operate, thanks to progress in tunnel excavators and water-blocking technologies. Openings have been formed in dam bodies to install outlet pipes without lowering the reservoir water level at Yoroihata Dam (Tohoku MLIT) and Ikari Dam (Kanto MLIT).

Forming an opening in a dam body or the foundation bedrock generates large tensile stress around the opening. It is, therefore, important to guarantee the structural stability of the dam body or the foundation bedrock, and stress analysis must be performed in advance to confirm this structural stability. It is also necessary to perform studies to deal with hydraulic problems; detailed study of the way water flows through the outlet pipe for example.

Even though the openings were formed several decades after the dams were constructed, the concrete in the bodies of both dams had not deteriorated, confirming the high quality of the dam concrete placed at that time (See Fig.46).

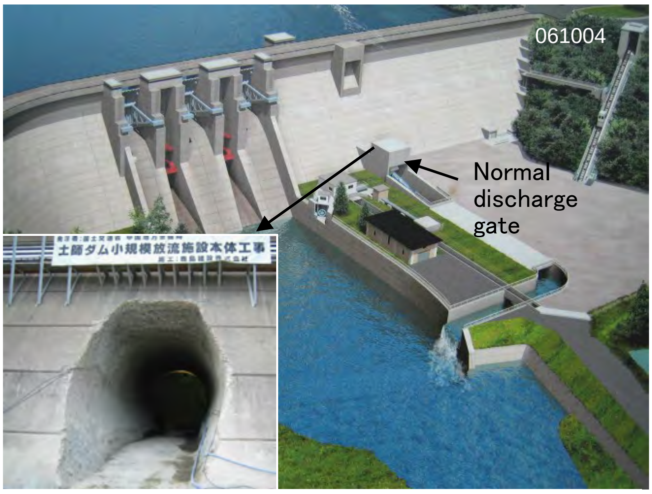


Fig.46 Opening by drilling machine, Haji dam

9. Future Trends in Dam Technology

It is predicted that future dam technology will be developed mainly to lower costs and conserve the environment. It is assumed that technology will make particularly big contributions to the use of low quality materials, rationalization of execution and saving labor, developing more efficient intake and outlet systems, conserving the environment and restoring vegetation, and simplifying maintenance. These are described separately below.

9.1 Rationalizing of Design

Concrete dam and fill dam design methods have not basically changed since the nineteen-sixties, but in recent years, progress in the computer field has provided the means to perform precise design based on advanced analysis. Computers are particularly useful in seismic design, because they can perform localized stress analysis. And in CSG design, they are used to verify a dam section by studying stress inside the dam body. For these reasons, the principal approach is to combine dam design methods to first perform waste-free rationalized section followed by the use of detailed analysis to verify the design.

9.2 Rationalizing of Construction

Construction of dam bodies has been rationalized remarkably during the past twenty years: particularly through the mechanization of both fill dam and concrete dam construction. Rationalized construction methods such as the RCD method are reflected in easily executed dam body designs. Using precast members and automatically operating equipment needs have reduced Labor. The progress of society will reduce the percentage of skilled laborers at dam sites, resulting in a growing need to automate and mechanize site work.

9.3 Introduction of Borderless Dam Technologies

In addition to dam body technologies, this report has described the state of progress of the latest peripheral technologies such as grouting, foundation treatment, sediment flushing, water intake systems, gates, slope treatment, energy use etc., but various new technologies that utilize new materials, new machinery, and so on are being developed. Dam engineers and experts in other fields are developing many of these dam technologies cooperatively, and it is predicted that technology will diversify beyond borders between fields. This diversification is itself a good reason to call dam technology total engineering.

9.4 Priority on Maintenance in Long-life Management

In the past, thorough design and construction of dams with more durability and safety than was required were recommended in order to lower the burden after each dam began operating. But in recent years, there has been a tendency to try to lower costs by avoiding striving to provide excess performance, even when it is considered necessary for safety and management reasons. And a new approach has appeared: the view that in order to extend the service life of structures, if the structure can be easily maintained, the burden of dam management may be increased to some degree by lowering the initial investment.

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Abbreviation

MLIT: Ministry of Land, Infrastructure, Transport and Tourism (former Ministry Of Construction, its name changed in 2001.1)
JWA: Japan Water Agency (former Water Resources Development Corporation)
OGB: Okinawa General Bureau, Cabinet Office