DAMS AND STORAGE RESERVOIRS

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Contents

Summary

We have constructed many dams for the purpose of the generation of electricity, water storage for irrigation, industry, or human consumption, flood control, navigation and recreation. We are strongly required to construct dams in the future in many countries of the world, for some purposes of those mentioned above.

But, dams and their reservoirs naturally have a huge and direct impact on the environment and societies. Therefore, when we construct dams and create reservoirs, we

should much attention to this problem.

In this topic-level contribution, we provide a broad summary and evaluation of the subjects to be covered by seven article-level contributions concerning design and construction of dams, intake facilities, dam rehabilitation, environmental issues and so on. And, we also introduce some case histories related to the article-level contributions.

1. Introduction

As problems concerning the management of rivers and basins, we still have the need for enhancement against flooding, the need to ensure stability of water resources and the need to maintain the water environment. The important thing to solve such problems is the adjustment for management of flood damage reduction, water usage (water supply, agricultural and industrial uses as well as hydropower), environmental preservation, recreation, inland navigation and other issues.

We have until now considered dams as one solution to adjust these management issues among various dam users, and have promoted many dam projects in the world. On the other hand, there have been concerns regarding the negative impact of dam projects on the residents and the environment. What is now needed is an understanding of the dam as an alternative for the overall management of rivers. This can be accomplished by offering: (1) as many alternatives to deal with adjustment of the management issues; (2) an evaluation through combination of such alternatives; and (3) an effective management regimen, through inclusion of processes such as selection of alternatives that enables participation of the general public.

The role to be played by dam technology in the world is a great important one. Furthermore, dam projects are large-scale construction activities which takes a long period of time while exerting the huge impact on the project area and impact on the residents in the area nearby. Thus, for the construction and management of dams henceforth, the following must be targeted for the improved efficiency of the dam function.

(1) To maintain safety under difficult natural, social and labor conditions
(2) To ensure reliability and economic efficiency regardless of limited information, land, material and human resources
(3) To ensure environmental soundness that meets diversified requirements of different parties

In addition, technology development that reduces the impact of dams must also be promoted strongly.

In this topic-level contribution, we provide additional case histories as well as a broad summary and evaluation of the subjects to be covered by a group of articles listed below:

(1) Design and Construction of Dams, Reservoirs, and Balancing Lakes
(2) Multi-Dam Systems and Their Operations

(3) Selections of Types of Dams and Reservoirs
(4) Fish Protection Structures and Fish Passage Facilities
(5) Rehabilitation of Dams and Reservoirs
(6) Water Intakes Structures for Surface and Subsurface Structures
(7) Catchment Systems

2. Design and Construction of Dams

For thousands of years, dams have been used to store water and to create energy. However, 90 percent of global dam investments have been made after 1950, both in terms of small or medium sized dams and the thousands of dams higher than 50m.

Dams have various purposes, such as the generation of electricity, water storage for irrigation, industry, or human consumption, flood control (flood damage reduction), navigation and recreation. Over one-third of dams worldwide are multipurpose. The utilization of dams varies considerably from country to country. In addition, the great majority of dams built in the nineteenth century are still operating fully today. Therefore, redevelopment and rehabilitation of existing dams have become a key issue recently. But, the best utilization of many existing dams varies according to economic changes, and their operational targets may be usefully reviewed from time to time.

In 2000, irrigation water taken from dams produced food for about 15 percent of the world's population. It is estimated that during the first half of the twenty-first century, the population of Asia, Africa, and South Africa will increase by almost three billion people, and many further large dams may be built to provide for them. In most of these countries, rivers are fully dry for half of the year. Water storage for industry and drinkable water is thus a key target, one that is party reached by existing dams, often through multipurpose schemes.

As one billion people will live in area exposed to flood, the utilization of dams for flood control should increase. Past investment in this area has been about 10 percent of total dam investments, but the value of avoided damages is much higher, particularly in countries such as China, the United States, and Japan.

Main types of dams are concrete gravity dams, concrete arch dam and embankment dam, which is classified into earthfill and rockfill dams, as shown in Figure 1. Design and construction of these types of dams are briefly summarized below:

2.1 Concrete gravity dams

Gravity dams are rigid structures withstanding water pressure thanks to their own weight. The progress of gravity dams is clearly linked to improvements in cementitious material: lime or volcanic ash was used for 2000 years, until cement was introduced after 1900. This is a trigger of appearance of concrete gravity dams.

The cross section of this dam is in principle the minimum volume profile that gives no tensile strength to the dam body under normal conditions. The upstream face is vertical although seismic or sliding risks occasionally makes some inclination preferable; the latter has sometimes been used in Asia. The downstream face is usually inclined at 1:0.8 and a minimum width is kept in the upper part for practical reasons.

Classical concrete dams have a great advantage over embankment dams in that they support overtopping by floods. However, they require a fair rock foundation, while embankment dams may be constructed upon soft materials.

From 1980 onwards, a practical change in construction method deeply modified the cost and design of many gravity dams. The use of earthmoving equipment to transport, spread in thin horizontal layers, and compact concrete allowed the retention of concrete's mechanical qualities while reducing cement content, cost, and construction time. This is an appearance of roller compacted concrete dams (RCC dams). These dams combine classical design and the roller compacted concrete construction method. In addition, internal obstacles such as galleries have been avoided.

Advanced technologies for dam construction are composed of three elements: design, execution, and materials. For example, the development of a concrete arch dam requires rationalization of the design, while the development of a RCC dam requires rationalization of the execution.

RCC dams have experienced a dramatic evolution since the inception of this technology. This evolution has been reported and described in various well-known documents. The highest completed RCC dam, La Miel, in Colombia, is 188-m high, Longtan, in China with 216.5 m is under construction, and Nan Ngum III, in Laos is being designed for a height of 220 m. All these are gravity-type dams. RCC arch and arch-gravity dams were also built particularly in China and South Africa.

Recently in Japan, the cost of producing aggregate accounts for 40% of the cost of the dam body construction. Therefore, the cost and environmental impact can be greatly decreased by reducing the cost of producing aggregate by rationalizing materials used.

The trapezoid-shaped cemented sand and gravel (CSG) dam is a new type of dam that combines the merits of a trapezoid shape of dam cross section and CSG, and simultaneously rationalizes the design, execution, and materials. Figure 2 shows a cross section of a trapezoid-shaped CSG dam. The raw material covers a wide range of materials such as riverbed gravel, excavation muck obtainable at the dam site, terrace sediment, or weathered rock. In CSG material, large stones have been removed from the raw material, and it is used without washing, grading or blending. CSG is a structural material, which is easier to produce by continuous mixing with the addition of cement and water to the CSG materials. Therefore, the CSG method does not require large facilities such as an aggregate production plant or a wastewater disposal plant.

Hardfill Dam is a general name for a dam built with a central core of cement enriched rockfill with outer thin shells of RCC complemented by an upstream element guarantying its imperviousness. The concept, originated in a paper by Londe and Lino (1991), is also known as FSHD (Face Symmetrical Hardfill Dam). It has been successfully applied in a score of dams built in different countries, with heights up to 100 m. Figure 3 shows the cross section Rio Grande Dam as an example of FSHD.

Lino and Derco (2006) presents a comprehensive review of the concept and of its main applications. Relevant economic aspects are the low cement content of the hardfill and RCC, its compatibility with using poor quality aggregates and the absence of contraction joints. On the other hand, the volume for a given height is of course larger than for a traditional RCC profile and economic considerations should weight appropriately these factors. Another very relevant characteristic is its compatibility with soft compressible foundations, which is essentially due to the low level of compressive stresses at the foundation level and its more even distribution.

2.2 Concrete arch dams

Water pressure upon their structure is transferred to the banks by a horizontal arching effect. Concrete arch dam requires a rather narrow valley and a sound rock foundation, thus the number of favorable sites is limited. In addition, it requires a specialized design.

2.3 Earthfill dams

For many centuries, earthfill was employed in the construction of hundreds of thousands of small dams used for irrigation or water mills, ones built with materials close to their sites. Little theory applied to all these dams but experience was obtained from the great number of structures and from many incidents and accidents.

Between 1920 and 1940 the United States had a key impact upon the development of earthfill dams through the analysis, testing, and treatment of soil, and through the development of heavy equipment for the transport and improvement of natural earth, such as trucks, motorscrapers, bulldozers, and heavy compactors. Heavy equipment has not only improved cost efficiency but also quality and safety.

A great advantage of earthfill dams is that they may be built upon soft soil foundations and may accept some settlement without serious drawbacks, whereas concrete dams usually require rock foundations.

Earthfill dam designs have to solve four problems of structure and foundation: mechanical stability, imperviousness, internal erosion, and external erosion.

Another potential problem of earthfill dams is external erosion, caused by floods overtopping the crest.

Earthfill dams will probably remain, in many cases, the preferred type of structure for both small and medium-sized dams, as well as for high dams built on soft foundations. However, the economic and technical progress of rockfill and concrete dams during the last thirty years will open to them a large part of future medium and high dams, which are by far the moist important dam investments.

2.4 Rockfill dams

There are about 2000 large rockfill dams today. Ninety-five percent of them have been built since 1950. Most are higher than 30m.

In the mid-twentieth century there was great improvement in both the quality and cost of rockfill. New solutions and equipment for drilling and blasting in quarries considerably reduced costs.

A large part of rockfill dams use designs similar to the high earthfill dams. Imperviousness is also insured by a rather thin clay core, but the upstream and downstream parts are of rockfill, not earthfill.

After 1970, the improved quality of rockfill has favored the development of a very cost effective type of medium and high dam, the Concrete Faced Rockfill Dam (CFRD), which also apply to dams well over 100m.

Bench marks in this evolution were the Cethana dam, 110-m high in Australia (1970), Foz do Areia dam, 160-m high in Brazil (1980), Aguamilpa dam, 187-m high in Mexico (1998) and now Shuibuya dam, 230-m high in China. Besides evolution in dam height, innumerous other features have been introduced in design concepts and construction processes aiming at reducing construction time and cost.

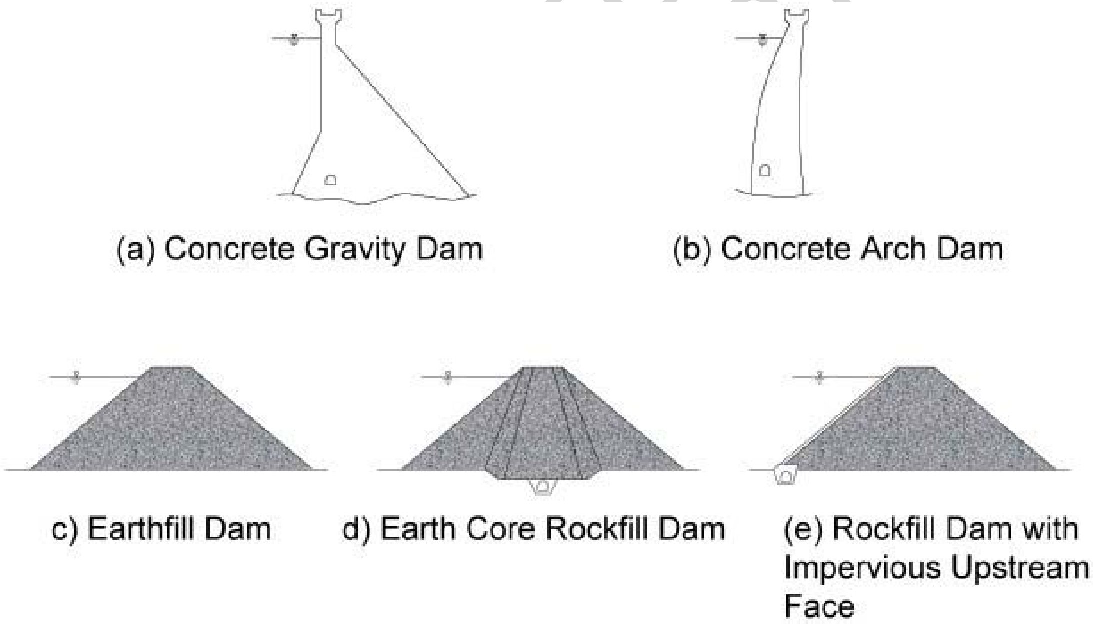

Figure 1. Types of dams

The design of CFRDs has been fundamentally based on experience rather than on theoretical modeling. Nevertheless an impressive effort is being employed by research organizations and specialized engineering companies to develop mathematical models capable of simulate the embankment performance taking into consideration the rockfill deformation under load, the foundation reaction, the valley shape, the construction sequence, and the concrete slab interface. However, since models are dependent on mathematical relationships representing these parameters, so far, results have been good to indicate trends and should be used with care to support design decisions.

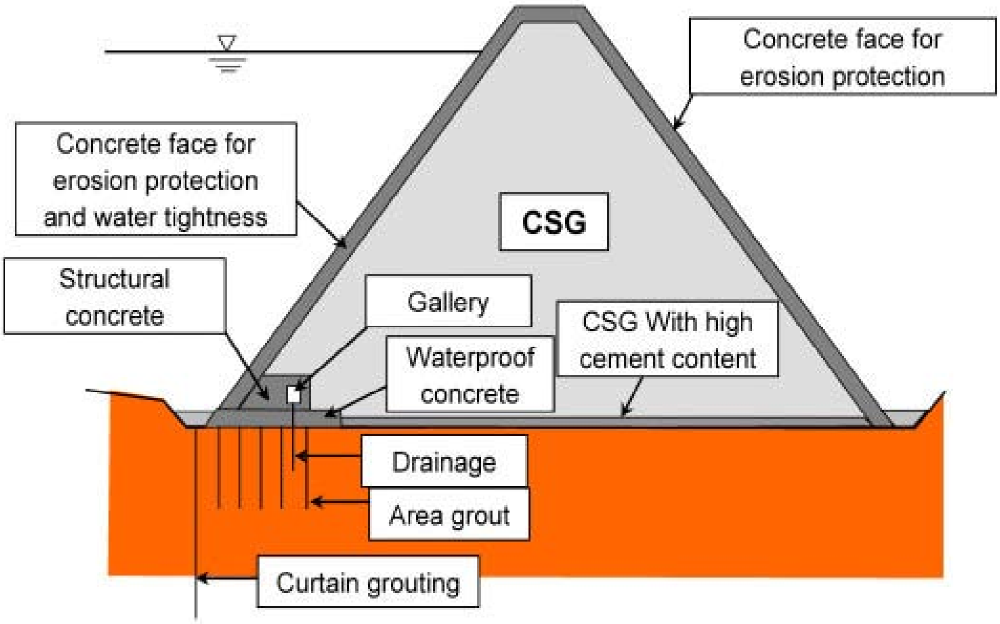

Figure 2. Cross section of trapezoid-shaped CSG dam

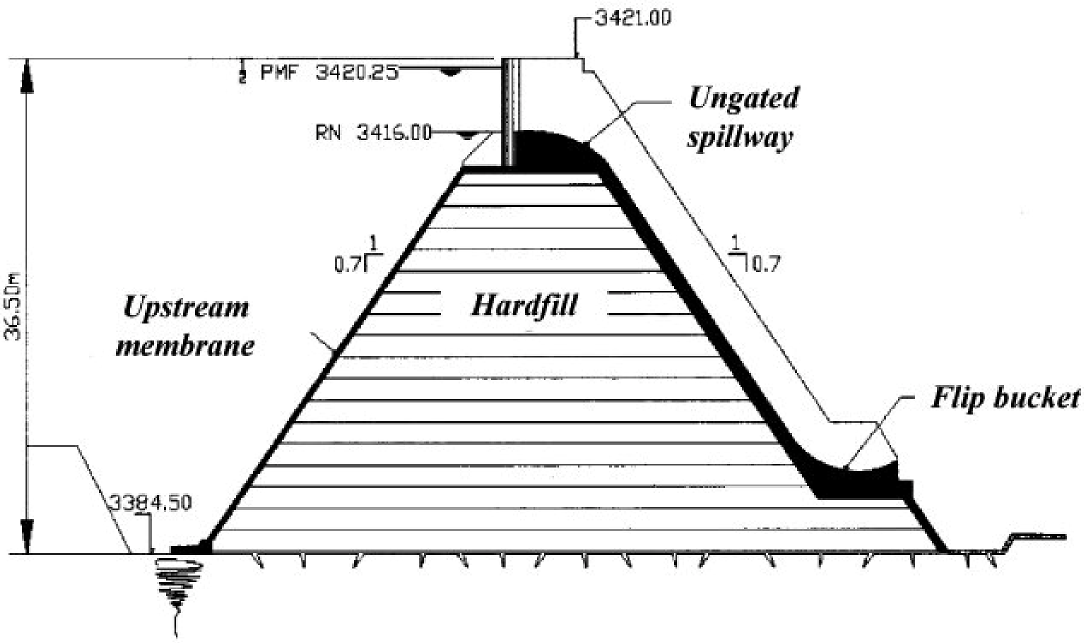

Figure 3. Rio Grande Dam cross section

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Biographical Sketches

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He exercises strong leadership in promoting many advanced research works and development in the civil engineering field, as chief executive of Public Works Research Institute, Japan. He held important positions, such as Director-General of Tohoku Regional Construction Bureau, Ministry of Construction (present Ministry of Land, Infrastructure and Transport) and Chief Executive of Japan Dam Engineering Center, in his carrier. He is also eminent researcher in dam engineering field. He received the Japan Society of Dam Engineering Award in 1999.

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He exercises strong leadership in promoting many advanced researches and development in the dam engineering field, as leader of Dam Structure Research Team, Public Works Research Institute, Japan, and give technical advices to many dam under design/construction and existing dams. He is also eminent researcher in the field of dam and geotechnical engineering. He has prepared numerous technical reports, and authored and presented many papers at technical conferences. He received several awards from the Japan Society of Civil Engineering, the Japan Society of Dam Engineering, the Japanese Association of Groundwater Hydrology and the Japan Society of Engineering Geology.