LARGE DAMS

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Contents

Summary

Large dams are hydraulic structures of cardinal importance to water resource development. Without dams it would not be possible to create artificial reservoirs for storing water over dry seasons, or longer drought periods. Recorded construction of dams goes back as far as 4800 years ago. The following are the main types of large dams (i.e., dams higher than fifteen meters): earth-fill dams, rock-fill dams, concrete dams and masonry dams. Concrete dams can again be subdivided into gravity, arch and buttress dams. The main phases of engineering of large dams are planning, design and construction. Planning is mainly concerned with the purpose and the selection of the optimum solution for the project. The design phase mainly involves structural analysis of the dam as a water retaining structure. Particular attention also has to be given to the design of hydraulic structures for the controlled release of stored water, the outlet works, and for the safe release of surplus floodwater, the spillway. The construction phase is engineered towards economical utilization of the site and available materials to ensure a cost-effective structure. The technique of dam building is continuously improved with innovations, such as roller compacted concrete, thin arch design and concrete-faced rock-fill dams. The design of large dams has also developed from the laborious early trial-load methods to present day computerized finite element techniques.

1. Introduction

Dams are arbitrarily divided at the height of fifteen meters into “small dams” and “large dams.” The height is measured from the general lowest foundation level to the level of the non-overspill crest. Basically the criteria which cover both small and large dams are the same, but the scope and depth of investigation and analysis increases progressively with the height. For very high dams, of the order of 300 meters and more, the ultimate strength of materials constituting the dam and the foundations becomes significant (see *Degradation of Concrete: Alkali Aggregate Reaction*).

2. Historical Background

Undoubtedly, the building of dams goes back as far as the history of civilized man and it is more than likely that prehistoric human beings engaged in some form of primitive dam building to satisfy the need for water. However, the oldest known major dam is the Sadd el-Kafata, built about 2800 BC near Helwan some thirty kilometers south of Cairo, Egypt. This had a maximum height of about twelve meters above the riverbed and would have just about qualified as a large dam. The dam had a sand and gravel core contained upstream and downstream by roughly constructed rubble masonry, and it would probably be classed today as a rock-fill dam. It does not appear to have had a spillway and failed by overtopping shortly after construction. The history of dams as significant features can, therefore, be said to go back about 4800 years.

3. Types of Dams

Dams are generally classified into three main types: embankment dams, concrete dams, and composite dams, which are a combination of the two previous types. Embankment dams, again, include earth-fill and rock-fill dams, and the combination of earth/rock-fill dams.

3.1 Large Earth-Fill Dams

The large earth-fill dams are divided across their section into zones of decreasing permeability from their outer slopes, to a central impervious core, typically of earth containing sufficient clay or silty material to ensure its relative impermeability. The zoning and the extent of the zoning will depend on what material is available close to the site and the outer upstream and downstream slopes will be regulated by the nature of the material, and the stability it affords against the loads to which the dam is subjected.

3.2 Rock-Fill Dams

Rock-fill dams, because of their inherent stability, can be built to much steeper slopes than earth-fill dams, depending on the nature of the rock-fill and the impervious element. The steepest slopes are found in the concrete faced rock-fill dam, where the impervious face created by the concrete slab is supported by the mass of rock-fill behind it. Other impervious elements for rock-fill dams are earth cores and asphalt cores and faces.

3.3 Concrete Dams

Concrete dams can be divided into gravity dams, where the resistance to loading is provided by the mass of the dam; arch dams, where the arch structure transfers the load to the foundation and the abutments; and arch/gravity dams which combine the action of gravity and arch resistance. In the past, buttress dams, where the water load on the upstream face is transferred to the buttresses either by slab or arch action, found a certain amount of usage. Buttress dams are seldom built nowadays, because present construction methods economically favor the rapid placement of thicker sections, rather than the more intricate construction of thinner sections (see *Concrete Dam Engineering*).

3.4 Masonry Dams

Masonry dams were used extensively by the Greeks and the Romans, and these relied on hydraulic lime and pozzolana to bind the mortar blocks together; the Roman structural use of the arch was extended to dam building. Masonry dams are finding a certain amount of modern use, especially where unskilled labor is cheap and plentiful.

3.5 Composite Dams

Composite dams are often used where competent foundation rock exists in the riverbed, but does not rise with the abutments. This means that a concrete gravity section is an economic proposition in the central river section, but this needs to change to embankment sections on the flank to avoid excessive excavation. The concrete gravity section located in the river presents a suitable location for the spillway. These geological conditions are a feature of many of the major rivers in Brazil and the Itumbiara dam, a 106 meters high earth/gravity composite dam, is a typical example.

4. Statistics of Some of the Largest Dams and Reservoirs

The world's highest dam is the Rogun dam, an earth/rock-fill dam completed in 1990 in the former USSR, with a height of 335 m. This is followed closely by the Nurek dam, also in the former USSR, a rock-fill dam with a height of 300 m, completed in 1980. The world's highest concrete dam is the Grande Dixence dam, completed in Switzerland in 1961, with a height of 285 m. The highest concrete arch dam is the Inguri dam in the former USSR, completed in 1980 with a height of 272 m, and the highest multiple arch dam is the Daniel Johnson dam at 214 m, completed in 1968 in Canada. The highest composite dam is the Lower Kamskaya dam, with a height of 210 m, completed in 1987 in the former USSR.

The largest volume embankment dam is the Tarbela dam, a 143 meters high earth/rock-fill dam, completed in 1976, in Pakistan, with a volume of 148 million cubic meters. The largest volume concrete dam is the Grande Dixence dam, with a volume of 6 million cubic meters, in Switzerland.

The world's largest capacity reservoir is the Owen Falls reservoir in Uganda, completed in 1954, with a capacity of 2700 km^3, of which 270 km^3 was created by a gravity dam 31 meters high; the rest of the capacity is attributed to the natural capacity of Lake Victoria. This is followed by the Kakhovskava reservoir, completed in 1955, in the former USSR, a 37 meters high composite dam with a reservoir capacity of 182 km^3, and the Kariba reservoir, completed in 1959, a 128 meters high arch dam spanning the Zambesi River on the Zimbabwe/Zambia border with a reservoir capacity of 180 km^3.

5. The Purpose of a Dam

The purpose of a dam is to store water, in the reservoir created by it, for future controlled use. The principal uses are for irrigation, water supply for domestic and industrial use, stock watering, environmental needs, navigation, recreation and the generation of hydropower. By exercising control over a river system, dams also help to alleviate the disastrous effects of floods. Most major dams have a multipurpose function (see *Environmental Aspects of Dams*).

5.1 Dams and Water Resources Planning

Before the design of a dam is commenced, the water resources of the site must be studied to see if the site is the most suitable to satisfy the demands of the project, which may well be part of an international, national or regional development. This will involve many years of data acquisition and hydrological studies to determine yields and estimates of the floods to which the dam will be subjected. At this stage, the geology of the site and alternative sites will have to be generally assessed. Feasibility studies of the site and alternatives will be undertaken, and preliminary designs and cost estimates made in sufficient depth to make a reliable comparison for the determination of the optimum solution (see *Project Design: Dams*).

5.2 Preliminary Design

Once the site has been selected, more detailed hydrological studies and geotechnical investigations will be conducted for input into the engineering investigation, which at this stage, will be to determine what is the most suitable type of dam for the site. This will also involve further investigation of the materials, and of the availability, transportation and costs of imported materials, and comparative designs of competitive solutions, together with construction programs and costs. Out of this, the optimum type of dam for the site will be realized.

5.3 Design and Construction

The design and preparation of specifications and tender drawings then follow. The tender is advertised and let, detailed design plans are prepared, and the supervision of construction is implemented to bring the project to a satisfactory conclusion (see *The Construction of Small Earth-fill Dams*).

Dams have been constructed using a variety of materials, depending primarily on what was available at or near the site to be developed—thus earth, rock, alluvium, moraine, timber, steel, asphalt, masonry and concrete have found a place in dam construction (see *Testing of Materials and Soils*).

5.4 Structural Analysis

The stability of an embankment dam is analyzed by studying the sliding potential along slip surfaces of the dam section. These are generally circles or other appropriate curves; sliding wedges are particularly applicable to rock-fill dams. The downstream slope is

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Bibliography

American Society of Civil Engineers (1988). *Second Conference on Roller Compacted Concrete*, San Diego, California, USA, February. USA: American Society of Civil Engineers. [A review of progress in this field of dam engineering.]

American Society of Civil Engineers (1992). *Third Conference on Roller Compacted Concrete*, San Diego, California, USA, February. USA: American Society of Civil Engineers. [A later review of progress.]

Chinese National Committee on Large Dams (1999). *Proceedings of the International Symposium on Roller Compacted Concrete Dams*, Dujiangyan, China, April 1999. Department of Structures and Materials, China Institute of Water Resources and Hydropower Research (IWHR). China: Chinese National Committee on Large Dams. [The most recent survey of progress in this technique of large dam construction.]

Guthrie Brown J. (1975). Dams. In *Encyclopaedia Britannica*,15th Edition, Vol. 5. Chicago: W. and H. H. Benton Publishers. pp. 440–447. [A comprehensive exposition of the history, technology and achievements in dam engineering, worldwide.]

International Commission on Large Dams (ICOLD) (1988). *World Register of Dams (first updating)*, Paris: ICOLD. [An authoritative source of information on various particulars relating to large dams.]

International Commission on Large Dams. *ICOLD Bulletins*. Paris: ICOLD. [Detailed treatment of design aspects in the engineering of large dams.]

International Commission on Large Dams. *Transactions of the Congresses*. Paris: ICOLD. [A wide range of questions relating to engineering aspects of dams are addressed at each congress.]

International Water Power and Dam Construction (1991). *Year Book*. UK: International Water Power and Dam Construction. [An updated survey of the details and statistics of large dams and hydropower projects of the world.]

Olivier H. (1977). *Great Dams in Southern Africa*, South Africa: Purnell. [A distinguished engineer's review of the achievements and romance around great dam-building projects on the Southern African subcontinent.]

Spanish National Committee on Large Dams (1995). *Proceedings of the International Symposium on Roller Compacted Concrete Dams*, Santander, Spain, October, 1995. Spain: Spanish National Committee on Large Dams. [An updated review of progress in this field.]

United States Department of the Interior. *Treatise on Dams*, Denver, Colorado: Bureau of Reclamation. [A basic engineering handbook for the designers of dams.]

US Army Corps of Engineers, Department of the Army. *Engineering Manuals*. Vicksburg, Mississippi: US Army Corps of Engineers. [These deal with most engineering design concepts, including those of dams.]

Biographical Sketch

Frank Hollingworth was born in Manchester, England, in 1925. He graduated from the Victoria University of Manchester in 1951 with a B.Sc. (Hons.) in Civil Engineering. He is a Professional Engineer in South Africa, and a Fellow of the South African Institution of Civil Engineers. He is an ex Professional Engineer in Canada and Member of the Engineering Institute of Canada. He has been involved in dam and irrigation engineering in many parts of the world, including the Bow River Project, and Columbia River studies in Canada; construction of the Darweshan Diversion Dam, and the Marja, Darweshan irrigation projects, on the Helmand River Project in Afghanistan; and the rehabilitation of the Artibonite Valley in Haiti. In 1963 he joined the Department of Water Affairs in South Africa where he has been responsible for the design of some thirty-five dams, associated works and tunnels. In 1990 he retired as Chief Engineer Specialist: Concrete Dams. He presently acts as s Specialist Consultant advisor on concrete dams and roller-compacted concrete (RCC) dams. He has consulted on designs, and feasibility studies, for RCC straight and arched dams up to 220 meters in height. In 1983 he received a Commendation for Excellence in the Use of Concrete from the Concrete Society of South Africa, and in 1988 he was named "Concrete Man of the Year" by that body. In 1989 he received the A.D. Lewis Medallion—an award for outstanding achievement (for his pioneering work in the application of RCC techniques to dam engineering in South Africa). He is author and coauthor of a number of technical papers for Congresses of the International Commission on Large Dams, and in the international technical press.