Brief note on the design construction and maintenance of large dams and the importance of the establishment of the international Congress on large dams

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Herein is described the historical development of Dam Design and Construction. The success and failures of various types of dams are enumerated to-gether with the inherent technical and organizational problems. Brief mention is made of the role of the ICOLD as a center of disseminating technical informations on design, construction, and maintenance of large dams. The present status of Water Resources Development in Ethiopia is described.

Introduction

Organic life cannot exist in our planet without water and it is due to this fact that water has been always of primary importance in human history. It is well known also that two-thirds of our planet is covered with water (rivers, lakes, and oceans).

The total average quantity of water which evaporates every year from the surface of the earth is estimated to be 514 x 10^3 cu.km. Since the atmosphere of the earth contains only 12,3 x 10^3 cu.km, all water in the atmosphere exchanges every 9 days or 42 times per year.

In the early stages of civilization water was used mainly for cleaning, drinking and irrigation purposes. Some of the early dams built for these purposes were in Egypt, India and Ceylon. The first dam which came to existence in Europe was the Segura Dam in Spain, constructed in the 12th century.

Although from the beginning of the 20th century the production of hydroelectric power has stimulated the construction of dams and creation of artificial lakes, the increasingly growing demand for water for domestic, industrial and recreation purposes is influencing the development and creation of reservoirs.

The dams constructed earlier were mostly of the embankment type. To-day though the technique for the design and construction of dams are well advanced, we are yet returning to the original idea of building embankment type of dams because of the lack of adequate sites for other types of structures. Out of about 10,000 dams registered in the world 52% are earth-fill, 26% concrete gravity dams 7% conorete arch dams, 4% rickfill, 3% concrete buttress dams and 8% of other types or a combination of the above.

As the demand for hydroenergy stimulated the construction of dams soon after the "First World War", the first idea to establish International Commission on Large Dams was discussed in the meeting of the World power Conference held in Switzerland in 1926. The decision to establish ICOLD was taken in the next meeting held in Paris in 1928 and the objectives of ICOLD were to promote and coordinate improvements in technical research, design, construction, maintenance and operation of large dams.

Since then in 1933 the first Congress was held in Stockholm, (with 21 member countries) followed by various meetings held in different countries of the world generally at intervals of three years. In the last (9th) congress held in 1967 in Istanbul 60 member countries were represented. The remarkable growth in the membership since the establishment of ICOLD in 1928 shows its importance as a media for promoting to engineers from all parts of the world the modern developments and achievements in the design and construction of large dams through discussion at International Congresses and through publications of technical papers.

Types of Dams

As regards the selection of a type of dam for any particular site many factors have to be taken into consideration: the two factors of decisive importance in this respect are the stability and cost of the structure. The different types of dams are described very briefly below.

Solid gravity concrete dams: are adaptable to most sites, require little maintenance and are more permanent than any other types of dams. But on the other hand their height is limited by the permissible bearing capacity of a foundation. For such type of dams for example, the maximum permissible dam height on soil foundation is about 20 m.

Hollow concrete dams: Produce less unit pressures on a foundation than solid concrete dams and require only 35-40% of concrete for solid dams. This type of dam is more attractive especially in places where the cost of construction material is expensive.

Arch Dams: Arch dams may be economically built in valleys with banks of good rock formation and height to chord length ratio not more than 1:3. This type of dam under favourable conditions may be the cheapest than any other type of concrete dam, but unfortunately good sites for such types are very scarce. As means of assessing the ultimate load capacity of arch dams, techniques have been developed for loading arch dam models to destruction and such tests normally reveal that arch dam model has a factor of safety of 5 to 10.

Embankment: In sites where the rock for foundation is at a considerable depth, embankment type of a dam may be cheaper than other type of structure provided sufficient material for the construction of such a dam is available locally or with an economically reasonable distance. Another important factor which should be considered when selecting this type of dam is the cost of a spillway.

Brief Review of the Dams Constructed Earlier

Although a number of engineering structures may be designed with a safety factor of more or less 100%, this is not true with the design of dams. From a large area normally covered by a dam only a limited portion is covered by tests and investigations and these results and characteristics are extrapolated over the total area occupied by a dam. The average of these results are considered for the design of the structures. Many assumptions employed in the design will depend on the extent and character of treatment which the foundation receives, and unfortunately the designer is not always the builder of the dam.

Half a century ago dams were designed without considering the effect of uplift and internal water pressures. It may be mentioned that several failures of the earlier dams were due to the lack of knowledge of this uplift force. In arch dams, the weight of the structure does not play an important role in the resistance of external loads and the uplift force at the base of such a dam was not considered to be an important design factor. A survey on the cross-sections of concrete gravity dams calculated with and without uplift forces could indicate the extent of the magnitude of the influence of such forces on the stability of a dam.

Scientific explanation of uplift forces was first given by Maurice Levy in 1895, but his criteria was accepted only by few engineers while others critisized him for being unduly severe. Today this criteria is accepted all over the world and no dam is designed without taking into account the uplift force.

Similarly the earthquake force has been introduced recently in the design of dams and engineers are paying more attention now-a-days to such a force in the design of structures.

Following the occurrence of spectacular accidents in the past few years, UNESCO established a commission, which after reviewing the suggestion of the National Committee on Large Dams sent to all Governments recommendations setting general procedure for efficient supervision of projects, construction and inspection of dams. This text is based essentially on the principle that such structure should at all stages of its life be closely supervised by competent persons nominated by the Government. Unfortunately in Ethiopia like in many other countries, the problem is not yet fully realized and very little supervision is done once the structure is constructed.

With the increasing number of dams coming to existance, the percentage of dam accidents has not been decreasing as much as it was hoped for. Some of the accidents have occurred, in the past, because of incomplete knowledge in statical analysis of structures. The accidents related to some earth dams can be attributed to the comparatively early stage of development of Soil Mechanics. However, such a cause of failure seems to have disappeared, thanks to the development of modern techniques and devices for testing and investigating the properties of construction materials. Yet, still technical difficulties exist which include the problem of predicting with precision the maximum floods and defining accurately the geological condition of a dam site.

As classical example of failures which occurred due to insufficient forecast of the maximum probable flood could be mentioned: Rio Negro (Uruguay), Molare (Italy) and El Habra (Algeria). In all of these cases the wide margin of assumed values of flood discharges were considerably smaller than what actually occurred after the completion of the construction of the structures. None of these floods could have reasonably been estimated on the basis of the limited existing records and the theories of probability alone and therefore no human negligence is to be attributed to these catastrophics.

Among the failure caused by geological conditions the case of Malpasset Dam could be remembered. The cause of the failure of Malpasset arch dam has been given different interpretations by various eminent authorities and the divergence in opinion resulted from the fact that everything was washed away and no remains were left for the investigation of the causes of the unfortunate incident. There exist comprehensive report on this matter prepared by the Inquiry Committee that was set up by the French Government. From the report it seems that the cause of the failure was the excessive deformation of the foundation followed by sudden rupture of the dam.

Another example of failure is the 33.50m high Vega de Terra Dam in Spain which was constructed as a masonary buttress dam with an upstream wall of concrete. On 9th January 1959, the left hand side of the dam burst when the reservoir was just reaching maximum level for overflow. At first it was thought that the failure was due to the foundation defect, but the technical analysis showed that the failure was confined to the dam itself. The upstream concrete wall, which was subjected to tension under load, fractured for a length of about 170m on a horizontal plane, about 20m below the crest. The shock created during sudden fracture was so intense that it was felt nearby as an earth-quake. The cause of the failure was due to the improper design of the dam since the cracks and fractures did not correspond with the predictions of the theoretical calculations. Considerably greater forces must have been exerted than those predicted, in order to bring about such a fracture in the concrete of the structure which was of good quality and certainly stronger than the masonary part of the rest of the structure.

The life span of a dam is limited either because of the gradual decay of building materials or because of the sudden "act of God" (flood, rock slide, earthquake, etc.) Should a dam collapse in a sudden failure the tremendous masses and stored energy when released is bound to result in a heavy loss of life and property.

Between the period of 1799 and 1944, 308 cases of total or partial failures of dams are recorded. In this list are included also dams fo 7,5 m height. If these small dams are excluded the total number of failures come to 165 (or about 1.5% of the constructed dams). If the minimum "dangerous" height of a dam were fixed at 15, 22.5, and 30m., the number of cases of failures from 1799 to 1944 would be reduced to 85, 45 and 32 respectively. According to the above mentioned data, earth dams would appear to be those involved in the greatest absolute number of failures, followed by masonary gravity type, rockfill, multiple and single arch, and others. On the other hand, upon estimating the relative number of failures (with respect to the total number of dams built for each type) of dam higher than 30m, the mulitple-arch type shows the worst record, followed by the rock fill, the earth type, the masonary-gravity, the single-arch and other types.

Of all the causes for failures of dams the most frequent ones are the inadequacy of spillways and pore pressure. Earth-quake appears to be but a minor cause of danger, accounting only for about 1% of the failures. The number of failures have been increasing with the increase in the number of dams built. Among the most important failures of dams that occurred recently could be listed:

1959—Vega De Terra (Spain, 140 dead)
1959—Malpasset (France, 421 dead)
1960—Oros (Brasil, 50 dead)
1961—Baby-Jar (Ukraina, USSR, 175 dead)
1962—Panshet (India)
1961—Hyokiri (South Korea, 250 dead)
1961—Kuala Lumpur (Malaysia, 600 dead)
1963—Baldwin Hills (California, USA, 5 dead)

More than 1600 lives have been lost as a result of the foregoing failures. Towards the end of 1963 the town of Longarone (Northern Italy) was washed away by the flood of water that a monstrous rockslide on the left bank of the valley has projected over the crest of the Vaiont Dam (Concrete arch Dam of 262 m height). As a result of this accident about 2300 lives were lost and considerable properties were destroyed.

During the night between 9th, and 10th, October 1963 a tremendous rockslide (about 300,000,000 cu.m.) fell from Mount Toc into the reservoir upstream of the dam. The impact of such a mass falling with remarkable speed raised gigantic waves, one or more of which overflowed the crest of the dam. This caused 25 to 30 x 10^6 cu.m. of water to spill down the narrow gorge and to strike a deadly blow across the larger part of the little town of Longarone lying in its path.

The arch dam remained practically intact and without a single crack in the body of the structure, despite the tremendous shock produced by the overflowing wave and the cascading earth and rock. It is very doubtful whether any other type of dam could have supported such an excessive load. The dynamic load was such that stresses produced in the concrete could probably have been close to its ultimate strength. Also the foundation in the upper part of the valley (which was carefully grouted and prestressed) subjected to such very abnormal forces showed no visible sign of rupture. Italian designers and contractors of Vaiont dam can be proud of their work.

After Vaiont disaster no one designer will pay less attention to the stability of reservoir banks than to the stability of the dam itself. The catastrophies occurred to Malpasset and Vaiont Dams inspired the discussion for the 9th International Congress under the topic "The safety of dams from the point of view of the foundation and reservoir banks."

The causes of Malpasset and Vaiont Dams provide more valuable experience than can be obtained from any model test. The experience gained from these two dams indicate that arch dams have the highest safety factors of all the dams if natural properties of the foundation is found to be the same as those considered in the statical computation. However such structure is very sensitive to slight displacement in the abutments.

Conditions of Dam design and Construction in Ethiopia

Climatological, geological and geographical peculiarities of Ethiopia are suitable for the creation of large reservoirs. Distribution of preoipitation in the country is uneven and of short duration. This is normally sufficient only for one crop. Reservoirs created on high plateaus would provide possibilities for the development of agriculture in the lowlands which generally receive very low rain fall. The difference in natural elevation between the reservoir site and the lowlands could be employed for the production of hydro eletric power.

There are many good sites on the highlands for the creation of huge reservoirs with small and cheap dams. For example Finchaa reservoir of 650 x 10^6 cu.m. will be obtained by a dam of 20 m height only and Koka reservoir with 1500 x 10^6 m3 capacity is the result of a 42 m high Dam. In Europe, inorder to create such a big reservoir, a very high dam would be required.

Total water power potential on the earth could be estimated to be 750,000,000 HP of which 36.7% is in Africa. Very rough estimation indicates that hydroelectric potential of Ethiopia is about 10-15 x10^6 KW and irrigable land of several million hectares exist. Ethiopia has yet to do a lot in the development of both hydroenergy and irrigation. General studies exist only for two river basins-the Blue Nile and and the Awash. As it can be seen from the following review, the work which awaits Ethiopian hydraulic engineers will engage them for several generations to come.

In the preliminary report of the Blue Nile Basin about 70 dams have been foreseen, of which 21 are higher than 50m, 9 are higher than 100m, 3 are higher than 150m and one is higher than 250m. For the complete development of the entire catchment many more dams would be required than listed in the report, since particularly many parts of the sub-basins have not been included in the report.

The Preliminary Report on the Awash River has foreseen 30 dams within the catchment area. Here again final number of dams are expected to be higher. It can be estimated that the total number of possible dam sites in Ethiopia are not less than 2000. To date, only eleven dams that can be classified as large dams have been constructed.

Due to the peculiar geological conditions prevailing in Ethiopia one does not expect that many concrete high dams could be built, and in particular not arch dams. Most adoptable type of dams will be rock and earth fill dams. The present practice of adopting 0.1 as coefficient of gravitational acceleration for design purposes have to be modified, at least for some parts of the Empire. This problem will have to be solved in collaboration with the Geophysical Observatory of the University. The ultimate goal should be to prepare earthquake intensity map of the Empire.

Flood design for determination of spillway capacity is another problem which is very difficult to solve under existing circumstances in Ethiopia. In most of the developed countries flow data exist for as much as 100 years or more. But even with records for such long periods it is not possible to predict future floods accurately. Due to the uncertainty of maximum flood forecasting, to-day's trend in the design of dams in some countries such as in U.S.A. and Spain is to provide oversized reservoirs to store more than one year's flow. Few years ago this criteria was considered unacceptable from the economic point of view, but to-day this criteria is widely accepted.

In Ethiopia the longest period of flow observation barely exceeds 10 years. Due to this fact, when designing dams one is obliged to select the type of dam which permits itself for overflow and resort to oversizing the spillway for safety purposes. Thus the cost of the structures would be high. If meteorological and hydrological records would be available for longer periods this unnecessary high cost could be reduced substantially.

Problems of Siltation: In ancient times Ethiopia's high plateau was almost completely covered with dense forests, while today a major part of it is destroyed. That is why in Ethiopia it is very rare to find clear streams. The absence of covers promotes erosion and the loss of good fertile soil. In addition the huge quantity of sediment load reduces the useful life of the reservoirs. Due to the foregoing reasons a legislation for soil conservation should be issued as early as possible.

On the basis of several years measurement in the Zula Reservoir the silt load was found to be 5.5-8.5% of the water flow. This means, after 15 - 20 years the reservoir will be completely silted. It is unfortunate that sedimentation measurement is not being continued in order to follow up the problem.

On the basis of few measurements carried out during the construction period the useful life of Koka Reservoir was estimated to be about 80 to 100 years. However due to the above discussed problem the life of the reservoir might be reduced unless soil conservation programme is undertaken in the Koka catchment.

In order to secure a better understanding of the behaviour of the structure and other phoenomena, various testing devices should be installed in the dams. The testing programme should include the analyses of the data observed during the construction period, and the close observation of the behaviour of the structure as it ages in service. As far as it is known, except for the measurement devices incorporated in the Zula Dam, in no other dam testing devices of any kind has been installed during the construction or after completion.

Conclusion:

From this short review in regard to the design and construction of dams in Ethiopia, it can be concluded that the following important issue should receive careful attention. There is no centralized body at present in charge of reviewing of designs supervision of constructions, operations and maintenance of dams. The establishment of a National Committee on dams could assist in providing the required advice to the Government regarding this very important issue. At present, however, the problem is not receiving sufficient attention since the Government Departments have not been made to realize the magnitude of such problems.

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