17

Dams in General and a few Dams in Particular

17.1. . General

17.1.1. Definition. A dam may be defined as an obstruction or a barrier built across a stream or a river. At the back of this barrier, water gets collected, forming a pool of water. The side on which water gets collected is called the upstream side, and the other side of the barrier is called the downstream side. The lake of water which is formed upstream is often called a *reservoir.*

17.1.2. Uses. The water collected in this lake can be used for recreation, or as a reservoir of drinking water, or it can be tapped off into surrounding farm land for irrigation. The energy of this collected water can be used to turn a mill to grind wheat or to turn the blades of a tubrine to generate electrical power. And in times of floods, the dams can serve as protections for the towns and cities farther down the river.

Apart from these numerous advantages and uses (such as navigation, irrigation, electricity, flood control, etc.) of a dam, it sometimes helps us in planning war strategy and helps us in controlling the advancement of enemies and their forces. Dams have been frequently opened in times of war. The Dutch breached their dikes during Second World War to bedevil the invading Germans. Chinese used to destroy their dikes to flood out the enemy. Russian army retreating from the Nazi marauders, partly destroyed the famous Dneprostroi Dam in the Ukraine to keep its power plant from falling into the hands of Hitler's men.

17.1.3. History of Dam Construction. It is very difficult to say as where and when the first man-made dam was built. Archaeological evidences help in estimating that the very first man made dam is at least 3000—5000 years old. Whenever it was built, that first dam was almost certainly an irrigation dam. Its designer might have observed beavers at work or he might have thought of it the some other way. Beavers are mammel creatures belonging to the family of rats, mice, squirrels. They live under water and are generally 1.2 m long including more than 0.3 m of tail, and weigh upto 25 to 30 kg. These rodents produce fur. These creatures create dam type barriers to create a place where their family can live. They provide themselves with comfortable ponds to live in, by building dam type barriers across the stream with the help of trees which they themselves cut.

These elegant structures, built out of logs, buttressed with twigs and branches and sealed with mud and stone help us many a times in controlling silt entry into the stream. A beaver dam accumulates silt brought down by its stream. When a beaver dam is breached, the silted water pours through, and the fertile silt is deposited over the wide area. This creates what farmers call a *beaver's meadow,* where crops grow particularly well.

Beavers are sometimes encouraged to build dams in areas where man can not reach easily to construct man-made dams.

17.1.4. Modern Dams. The first modern dam of the world was perhaps constructed on the Nile river, in Egypt at *Aswan.* It was completed in 1902 and was a major engineering project.

This famous **Aswan Dam** was designed primarily to control the flooding of the Nile river, to promote irrigation in the Nile Valley, and to further navigation along the river.

Aswan is 1200 km from the mouth of the Nile. The site was chosen because the river at Aswan is shallow and has a granite bed, on which a firm foundation could be erected.

The first step in damming any major river is to divert the flow of water so as to permit dam construction. This was accomplished at Aswan, by constructing a circular earthen barrier around the area chosen from the dam foundations. At low river, this enclosure was pumped out. All the work had to be completed before the river flooded again. The foundation was laid round the clock with a huge labour force. So much so that 3,600 tons of masonry were put in places in a single day.

This 120′ high dam, running for about $1\frac{1}{2}$ miles from shore to shore, 100 feet thick at its base and 24′ wide at top, costed about 1.5 crore dollars, when completed in 1902. A roadway ran along the upper rim. About 1 billion tons of water was its storage capacity, and 180 sluices were constructed into this barrier. Water could be collected during the rainy season and released through the sluice gates during the summer and drought.

Roosevelt Dam. The next famous dam of the world was completed in 1911 on the Salt River of Arizona (U.S.A.) and was called Roosevelt dam.

The Aswan dam was constructed with stone, while the Roosevelt dam was constructed with solid blocks of concrete : which was of the type known as 'Solid Masonry Gravity Dam' : which simply means that it was built with solid blocks of concrete, which hold back the flow of water by sheer weight. This type of dam is one of the most ancient.

The construction was started in 1905. Despite the numerous troubles in its construction, the dam was completed in 1911 with a reservoir capacity of $\frac{1}{2}$ billion gallons of water. The completed dam, 280 feet high, was *158 feet thick* and spanning for a length of 1,125 feet. Had the dam been built without the benefit of 19th century engineering advances in design and stress control, it would have had to be 700 to *1000 feet thick* at base ; a far more expensive and cumbersome thing to build.

This dam was a fascinating advancement, but was soon overshadowed by other vastly greater dams, such as Hoover Dam, (726′ high), Bhakra Dam (740′ high), etc. All of them are 'solid concrete gravity type' dams.

17.2. Various Kinds of Dams

Before we describe some of the famous dams of the world, it is worth while to classify the various types of dams.

Most engineers recognise seven general types of dams. Three of them are ancient in origin, and four have come into general use only in the last about 100 years or so.

The three older types of dams are :

(1) Earth Dams

(2) Rook-fill dams.

(3) Solid masonry gravity dams.

These types are discussed below :

(1) **Earth Dams**. Earth dams are made of soil that is pounded down solidly. They are built in areas where the foundation is not strong enough to bear the weight of a concrete dam, and where earth is more easily available as a building material compared to concrete or stone or rock.

Some important earth dams of the world are :

(*i*) Green mountain dam on Colorado river in U.S.A.

(*ii*) Swift dam in Washington in U.S.A.

(*iii*) Side flanks of Nagarjun Sagar dam in India.

(*iv*) Trinity Dam in California in U.S.A.

(*v*) Maithan Dam in India (which is partly Earthen and partly Rockfill).

(2) **Rockfill Dams.** Rockfill are formed of loose rocks and boulders piled in the river bed. A slab of reinforced concrete is often laid across the upstream face of a rockfill dam to make it water-tight.

Some important rock-fill dams of the world are ;

(*i*) The Salt Springs Dam in California (345′ high) in U.S.A.

(*ii*) The San Gabriel No. 1 Dam (321′ high) in U.S.A.

(*iii*) Cougar Dam on Mc-Knezie River in Oregon (445′ high) in U.S.A.

(3) **Solid-masonry Gravity dams.** These are familiar to us by now, after we have talked about Aswan, Roosevelt, Hoover, and above all Bhakra dam.

These big dams are expensive to be built but are more durable and solid than earth and rock dams. They can be constructed on any dam site, where there is a natural foundation strong enough to bear the great weight of the dam.

These three types of dams were all found in ancient days. In recent times, *four other types of dams have come into practice.* They are :

(4) Hollow masonry gravity dams ;

(5) Timber dams ;

(6) Steel dams ; and

(7) Arch dams.

(4) **The hollow masonry gravity dams**. These are essentially designed on the same lines on which the solid masonry gravity dams are designed. But they contain less concrete or masonry ; about 35 to 40% or so. Generally, the weight of water is carried by a deck of R.C.C. or by arches that share the weight burden. They are difficult to build and are adopted only if very skilled labour is easily available, otherwise the labour cost is too high to build its complex structure.

(5) **Steel dams.** These are not used for major works. Today, steel dams are used as temporary coffer dams needed for the construction of permanent dams. Steel coffer dams are usually reinforced with timber or earthfill.

(6) **Timber dams.** These are short lived, since in a few years time, rotting sets in. Their life is not more than 30 to 40 years and must have regular maintenance during that time. However they are valuable in agricultural areas, where a cattle raiser may need a pool for his live stock to drink from, and for meeting other such low-level needs.

(7) **Arch dams.** Arch dams are very complex and complicated. They make use of the horizontal arch action in place of weight to hold back the water. They are best suited at sites where the *dam must be extremely high and narrow*. Some examples are :

(*i*) *Sautet dam* on the Drac River in France, 414′ high, but only 230′ long at top and 85′ long at bottom of the gorge, 56′ thick at bottom and 8′ thick at top.

(*ii*) *The Tignes dam* in France (592′ high).

(*iii*) *Mauvoisin dam* on the Drause River in Switzerland, (780′ high).

(*iv*) *Idduki* dam in Kerala State, across the Periyar river, which is the only arch dam in India. It is 366 m (1200′) long double curvature arch dam, made in concrete, and has a height of about 170 m (560′).

17.3. Problems in Dam Construction

Dams are extremely useful things. Anyone who lives in Punjab or at Asansol in West Bengal, knows how valuable dams are. The farmers of Punjab and people getting electricity from the Bhakra sing praises for it. The people of areas benefitted by various dams and other ancillary works on Damodar river are really thankful to those human beings who have miraculousy harnessed the Damodar river for them. The prosperity and welfare of millions and billions of people depend directly on these towering handsome dams with which the nation's rivers have been harnessed.

But dams can cause problems too. Dams have drawbacks and disadvantages also. Let us here discuss some of the negative features of dams and let us see what can be done to overcome them. There are four major problems, in general, which are posed by such huge constructions. They are:

(1) Fish Problem ;

(2) Submergence Problem ;

(3) Failure Problem; and

(4) Bomb Problem

They are described below:

(1) **Fish Problem.** On large rivers, in late summer season, fish move from downstream to upstream to lay their eggs. These eggs are fertilised by male fish. The old fish may get exhausted and the new born fish again move downstream. They, after two to three years, return to their ancestral spawning place and may die after getting exhausted, while the newborns move downstream. The cycle goes on for years.

The fish which move to their ancestral spawning place (upstream) are called *anadromous fish. Salmon and Hilsa* are typical examples of such a fish. These are commercially valuable fish, and important industries are dependent on them.

When a dam barrier is constructed on a river, these fish can not move upstream to lay their eggs; because it is impossible for these fish to overtop such a barrier. But surprisingly, even when they find a barrier in their path of advancement towards their ancestral spawning ground, these fish do not return to their downstream dwelling place (*i.e.* sea). However, they go on fighting against the barrier, trying furiously to overtop it, till they get exhausted and die down. This results in a serious large scale killing of fish, causing great damage to fish industry and economy of the nations.

In the beginning, much attention was not paid to this problem; but a little later, it was realised, and serious attempts were made to find out solution to the problem.

Sometimes, fish were trapped on one side of the dam and passed on to the other side by giant steel and plastic nets. An external arrangement called *Fish Ladder* was also devised.

Fish Ladder. Just as river-going vessels can bypass a dam by using a navigation lock, so a series of 'locks' enable the fish to get over the dam. A separate channel is created, consisting of a series of little dams that form a row of pools, rising up over the big dam to reservoir level. The salmon, entering the lowest rung of the ladder at the base of the dam, could leap from pool to pool until they had crested the dam. Then, they could continue on through the reservoir to the spawning grounds. The new born fish called *finger lings* could later return to the sea (downstream) in the same fashion via the ladder. A section, plan and photographic view of a fish ladder has already been shown in the chapter on Weirs.

In the beginning, the fish ladders worked better in theory than in practice. The fish seemed to prefer to mill ground in splashing water under spillway, instead of entering the ladder. This difficulty was overcome by careful design that put the fish ladder in the place where it was most likely to attract the fish. Another problem was that the slow moving water was stranger to fish and they tended to collect in the lower pools without going onward.

Millions and billions were spent into fish-ladder research. Improvements in design made the fish ladder more attractive to fish, more like the rapids they were accustomed to.

Fish ladders are not always practicable from engineering stand point. In such cases, other steps have to be taken to protect the fish.

Meanwhile, other experiments are going forward to see if fish can be successfully induced to spawn in waters other than their own ancestral spawning grounds. In the long run, it may save millions of currency to construct *fish hatcheries* instead of *fish-ladders*. There are many possible solutions to the problem of anadromous fish, and research is being undertaken in different regions of the world to find out a better solution to the problem.

(2) **Submergence Problem.** Whenever a dam is constructed across a river to store water on the upstream side, a large area gets submerged due to the rise in the water levels. The entire area which gets submerged, forming a reservoir, has to be calculated and acquired before a dam can be constructed. The owners of the land have to be persuaded, adequately compensated, and well settled somewhere else, before, the work can be taken up in hand. Hence it is necessary to investigate the probable damage caused by this submergence.

(3) **Failure Problem.** We try our best to build dams to last as long as possible. Every person whosoever has worked on a dam hopes that the dam will live as long as the pyramids of Egypt. But many a times, the dam give way under the continued insistent pressure of the water penned up behind them. This failure of the dam may be caused either due to bad workmanship or due to faulty design or due to the occurrence of unanticipated floods.

Luckily, these disasters have been comparatively rare in this century. Dams used to give way easily in olden times, but due to engineering advancement in modern times, their failure has been considerably reduced.

These huge structures are now properly designed, keeping in view the various forces which they are going to face. Proper and rational design, good supervision and constant vigil and watch during maintenance period ensures their safety and makes us fairly confident of it. Bhakra Dam on Satluj River in India and Boulder Dam on Colorado River in U.S.A. *cannot fail* in one attempt, how furiously these rivers may try to move their foundations. We are fairly confident of this, but sometimes the confidence is *rudely and cruelly repaid with tragedies.*

Dams may sometimes fail due to excessive and unanticipated earthquakes. The *Koyna Dam* in India was at the verge of failure in 1968 earthquake. Thanks to the efforts of the Indian engineers who saved that dam by toiling hard day and night. A very confident dam called *Vega de Tera Dam* is Spain failed in January 1959. The people were tucked in the town of Rivaldelago. The disaster caused was tremendous. Rivaldelago was flattened. Telephone poles were snapped like matchsticks. Within moments, 123 villages were drowned. Several hundred luckier ones were saved, but were rendered homeless. This was a case where a dam had simply not been built strong enough to bear the full weight of its intended reservoir. Heavy rains wrecked it. *Faulty design and bad engineering must be blamed.*

Another important dam called *The Malpasset Dam,* a 200 feet high arch dam on the Reyran River, was completed in 1954. This dam gave way in December 1956, causing 421 persons to die in floods. Investigations revealed that the dam had failed because the foundation rock has shifted along a thin clay seam in the left abutment, making the dam unstable and vulnerable to any serious stress.

We learnt from our mistakes;and several other dams of the same type, then under construction in Europe, were quickly resurveyed to find the possibility of such a geological formation. This was very very small comfort to the relatives of those who died when Malpasset failed; but at least, we should learn from our mistakes and there should be no such repetitions.

(4) **The Bomb Problem.** The dams create dangers in wars, especially in modern atomic age. One single atom bomb may cause the failure of Hoover Dam (Boulder Dam) or Bhakra Dam. The resultant failure of such a dam will create catastrophes, but also, it will get contaminated by radioactivity from which there could be no escape.

This is an important point which is generally stressed by opponents of big dams. But the only answer to this argument is that it would not be advisable to deprive ourselves of the benefits of big dams simply because they are hazards in war time. After all, an atom bomb dropped in Calcutta, Delhi, or New York would also cause tremendous damage and catastrophe, but this *does not mean* that we should not *develop big cities.*

Atomic war is dangerous to every aspect of living and not only to the construction of dams. We don't refuse riding in automobiles or aeroplanes because of the fear of accidents. *Certain risk has to be accepted if there is to be progress.*

So, without denying the very great damage that could be caused by atomic explosions at our dams, we must go on building dams. We need them and we must devote our energies to the cause of continued peace, so that bombs will never be able to fall. We may also take more precautions, and anticraft guns and radars can be established at and in the vicinity of such important works. The use of atomic energy for peaceful purposes and a general feeling of brotherhood is the only possible way to reduce such threats.

17.4. Selection of the Type of Dam and Their Classifications

(1) *Classification.* Dams can be classified in various ways depending upon the purpose of the classification.

(1) *Classification According to the Material used for Dam Construction :*

The dams classified according *to the material used* for construction are: Solid masonry gravity dams, Earthen dams, Rockfill dams, Hollow masonry gravity dams, Timber dams, Steel dams, and R.C.C. Arch dams. They have already been explained in a previous article.

(2) *Classification According to Use*

(*i*) **Storage Dams.** They are constructed in order to store water during the periods of surplus water supply, to be used later during the periods of deficient supply. The stored water may be used in different seasons and for different uses. They may be further classified depending upon the specific use of this water, such as navigation, recreation, water supply, fish, electricity, etc.

(*ii*) **Diversion Dams.** These small dams are used to raise the river water level, in order to feed an off-taking canal and or some other conveyance systems. They are very useful as irrigation development works. A diversion dam is generally called a **weir** or a **barrage.**

(*iii*) **The Detention Dams.** They detain food-waters temporarily so as to retard flood runoff and thus minimise the bad effects of sudden flood.

Detention dams are sometimes constructed to trap sediment. They are often called debris dams.

(3) *Classification According to Hydraulic Designs*

(*i*) **Overflow Dams.** They are designed to pass the surplus water over their crest. They are often called Spillways. They should be made of materials which will not be eroded by such discharges.

(*ii*) **Non-overflow Dams.** They are those which are not designed to be overtopped. This type of design gives us wider choice of materials including earthfill and rockfill dams.

Many a times, the overflow dam and the non-overflow dam are combined together to form a composite single structure.

(*iii*) **Rigid Dams and Non-rigid Dams.** Rigid dams are those which are constructed of rigid materials like masonry, concrete, steel, timber, etc.; while non-rigid dams are constructed of earth and rock-fill. They have already been explained.

17.5. Factors Governing the Selection of a Particular Type of Dam

Whenever we decide to construct a dam at a particular place, the first baffling problem which faces us, is to choose the kind of the dam. *Which type will be the most suitable and most economical?* Two, three kinds of dams may be technically feasible, but only one of them will be the most economical. Various designs and their estimates have to be prepared before signalling one particular type. The various factors which must be thoroughly considered before selecting one particular type are described below:

(1) **Topography.** Topography dictates the first choice of the type of dam. For example:

(*i*) A narrow U-shaped valley, *i.e.* a narrow stream flowing between high rocky walls, would suggest a concrete overflow dam.

(*ii*) A low, rolling plain country, would naturally suggest an earth fill dam with a separate spillway.

(*iii*) The availability of a 'Spillway Site' is very important while selecting a particular kind of a dam.

(*iv*) A narrow V-shaped valley indicates the choice of an arch dam. It is preferable to have the top width of the valley less than one-fourth of its height. But a separate site for the spillway must also be available.

(2) **Geology and Foundation Conditions.** The foundations have to carry weight of the dam. The dam site must be thoroughly surveyed by geologists, so as to detect the thickness of the foundation strata, presence of faults, fissured materials, and their permeability, slope, and slip, etc.

The various kinds of foundations generally encountered are discussed below:

(*i*) *Solid Rock Foundations.* Solid rock foundations such as granite, gneiss, etc. have a strong bearing power. They offer high resistance to erosion and percolation. Almost every kind of dam can be built on such foundations. Sometimes, seams and fractures are present in these rocks. They must be grouted and sealed properly.

(*ii*) *Gravel Foundations.* Coarse sands and gravels are unable to bear the weight of high concrete gravity dams and are suitable for earthen and rock-fill dams. Low concrete gravity dams up to a height of 15 m may also be suggested on such foundations.

These foundations have high permeability and, therefore, subjected to water percolation at high rates. Suitable cut-offs must be provided to avoid danger of undermining.

(*iii*) *Silt and Fine Sand Foundations.* They suggest the adoption of earth dams or very low gravity dams (upto height of 8 m). A rockfill dam on such a foundation is not suitable. Seepage through such a foundation may be excessive. Settlement may also be a problem. They must be properly designed to avoid such dangers. The protection of foundations at the downstream toe from erosion must also be ensured.

(*iv*) *Clay Foundations.* Unconsolidated and high moisture clays are likely to cause enormous settlement of the dam. They are not fit for concrete gravity dams or for rock-fill dams. They may be accepted for earthen dams, but that too, after special treatment. (*v*) *Non-uniform Foundations.* At certain places, a uniform foundation of the types described above may not be available. In such a case, a non-uniform foundation of rock and soft material may have to be used if the dam is to be built. Such unsatisfactory conditions have to be dealt with by special designs. However, every problem is an individual problem and a solution has to be found by experienced engineers. For example—

The Jawahar Sagar Dam in Rajasthan offered such a problem. A bed of clay was encountered, between the base of the dam and solid rock foundation. It was not economically feasible to remove this clay bed. The solution adopted was to anchor the base of the dam to the foundations below, by means of prestressed cables.

(3) **Availability of Materials.** In order to achieve economy in the dam, the materials required for its construction must be available locally or at short distances from the construction site.

Sometimes, good soil is easily available, which naturally calls for an earthen dam. If sand, cement and stone, etc., are easily available, one should naturally think of a concrete gravity dam. If the material has to be transported from far off distances, then a hollow concrete dam (Buttress) is a better choice.

(4) **Spillway Size and Location.** Spillway, as defined earlier, diposes of the surplus river discharge. The capacity of the spillway will depend on the magnitudes of the floods to be by- passed. The spillway will, therefore, become much more important on streams with large flood potential. On such rivers, the spillway may become dominant structure, and the type of dam may become the secondary consideration.

The cost of constructing a separate spillway may be enormous or sometimes a suitable separate site for a spillway may not be available. In such cases, combining the spillway and the dam into one structure may be desirable, indicating the adoption of a concrete overflow dam.

At certain places, where excavated material from a separate spillway channel may be utilised in dam embankment, an earthfill dam may prove to be advantageous. Small spillway requirement often favours the selections of earth fill or rockfill dams even in narrow dam sites.

The practice of building a concrete spillway on earth and rock embankments is being discouraged these days, because of their conservative design assumptions and the vigil and watch that has to be kept during their operations.

(5) **Earthquake Zone.** If the dam is to be situated in an earthquake zone, its design must include the earthquake forces. Its safety should be ensured against the increased stress induced by an earthquake of worst intensity. The type of structures best suited to resist earthquake shocks without danger are earthen dams and concrete gravity dams.

(6) **Height of the Dam.** Earthen dams are usually not provided for heights more than 30 m or so. Hence, for greater heights, gravity dams are generally preferred.

(7) **Other Considerations.** Various other factors such as, the life of the dam, the width of the roadway to be provided over the dam, problem of skilled labour, legal and aesthetic point must also be considered before a final decision is taken. Overall cost of construction and maintenance and the funds available will finally decide the choice of a particular kind of a *dam at a particular place.*

17.6. Selection of Dam Site

The selection of a site for constructing a dam should be governed by the following factors:

(1) Suitable foundations (as determined in the previous article) must be available.

(2) For economy, the length of the dam should be as small as possible, and for a given height, it should store the maximum volume of water. It, therefore, follows, that the river valley at the dam site should be narrow but should open out upstream to provide a large basin for a reservoir. A general configuration of contours for a suitable site is shown in Fig. 17.1.

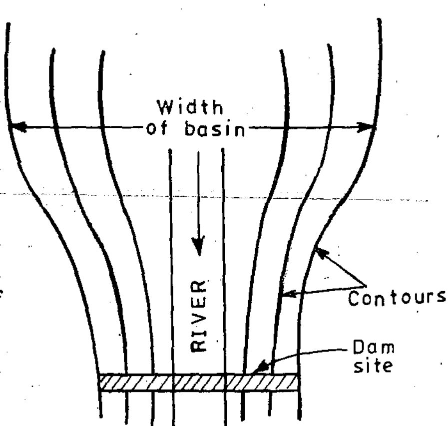

Fig. 17.1

(3) The general bed level at dam site should preferably be higher than that of the river basin. This will reduce the height of the dam and will facilitate the drainage problem.

(4) A suitable site for the spillway should be available in the near vicinity. If the spillway is to be combined with the dam, the width of the gorge should be such as to accommodate both.

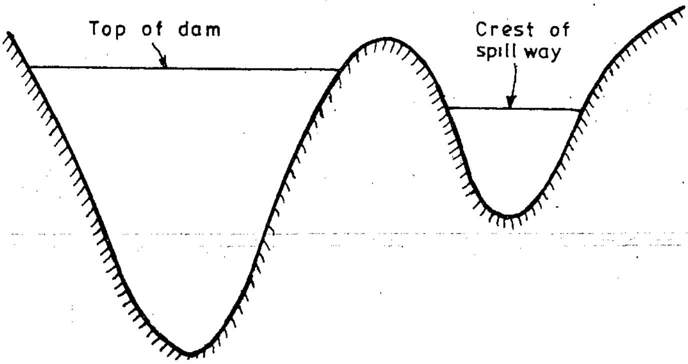

Fig. 17.2

The best dam site is one, in which a narrow deep gorge is separated from the flank by a hillock with its surface above the dam, as shown in Fig. 17.2.

If such a site is available, the spillway can be located separately in the flank, and the main valley spanned by an earthen or similar dam. Sometimes, the spillway and concrete masonry dam may be compositely spanned in the main gorge, while the flanks are in earth at low cost.

(5) Materials required for the construction should be easily available, either locally or in the near vicinity, so that the cost of transporting them is as low as possible.

(6) The reservoir basin should be reasonably water-tight. The stored water should not escape out through its side walls and bed.

(7) the value of land and property submerged by the proposed dam should be as low as possible.

(8) The dam site should be easily accessible, so that it can be economically connected to important towns and cities by rails, roads, etc.

(9) Site for establishing labour colonies and a healthy environment should be available in the near vicinity.

STORIES OF A FEW IMPORTANT DAMS

Before we take up the actual planning and design of concrete gravity dams and earthen dams in subsequent chapters, let us narrate the stories of certain such important dams. This will give us an idea as to what actually happens in the field and to what kind of difficulties are encountered and how they are overcome.

17.7. Hoover Dam

Hoover dam (Fig. 17.3) is a concrete gravity dam, constructed on the Colorado river in California (U.S.A.). The construction of this dam was taken off the drawing boards on January 26, 1892 when the Colorado River Commission presided by Mr. Harbert Hoover discussed its construction in their first meeting. But the actual construction of this dam could start only in late 1930. The construction took about 2 years of non-stop work, every minute of the hour, 24 hours a day, and 365 days a year. On the day of Christmas, the pouring of concrete was tremendous even under searing desert sun by day and under floodlights at night.

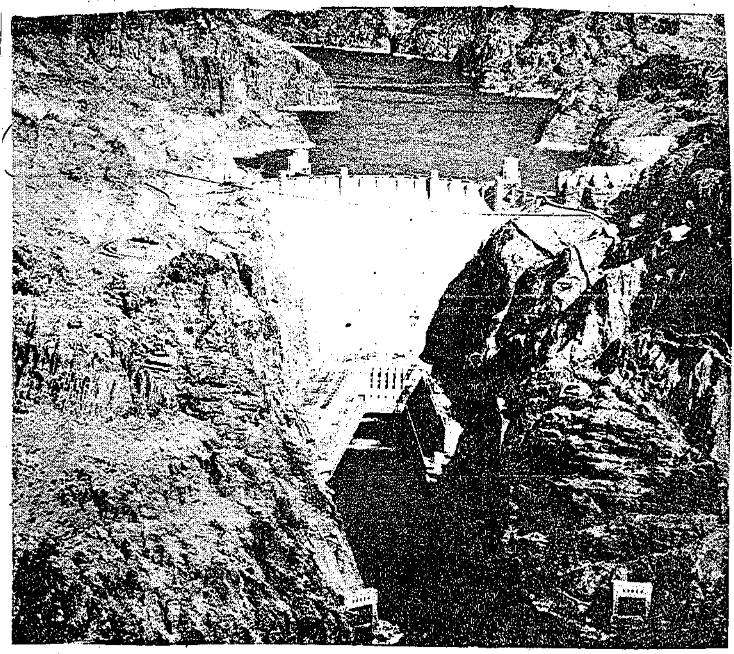

Fig. 17.3. Photo view of Hoover Dam..

Name Problem. The name of the Hoover Dam became a political issue. It was first of all named as *Boulder Dam.* Later when Herbert Hoover became the President of America, its name was changed to *Hoover Dam.* In 1933, when the Democrats replaced the Republicans, President Roosevelt changed this name again to *Boulder Dam.* It was known as *Boulder Dam* for 14 years. When again in 1946, Republicans came to power, the name was once again changed to *Hoover Dam,* which still exists today.

Dimensions of the Dam. The original dimensions of the dam are given below in F.P.S. units:

Height	= 726 ft
Span	= 1300 ft from rim to rim of the Canyon
Thickness at the base	= 660 ft
Thickness at the top	= 45 ft
Name of the reservoir formed at the back of the dam	= Lake Mead
Length of the reservoir	= 115 miles.

Something about the river. This big dam straddles the Colorado river. The Colorado river rises in the State of Colorado, runs down through Utah and into Arizona, then California, emptying finally into the Gulf of California in Mexico.

The Colorado is a river with muscles. It is a very strong river - containing huge amounts of silt and mud in it. It cuts numerous deep narrow canyons while it flows. The mile deep walls of the Grand canyon proves the power of this river.

It is a young river and all such rivers have strong powers for forming deep narrow gorges (*i.e.* canyons). They are the most turbulent, and the deepest digging. They are the best sources of hydroelectric power. Irrigation or navigation is not possible on this kind of rivers, unless, they are tamed.

Attempts were made to tame this river by constructing dikes or levees, but failed.

Spring floods of 1904 brought havoc. Another catastrophe occurred in 1916. Gila River, a tributary of Colorado, flooded at a rate of about 5, 560 cubic metres/sec. The town of Yuma in Arizona, where the Gila empties into the Colorado, was submerged to a depth of 1.2 metres.

It was extremely desirable to tame this river. But how? A solution was dreamt of. The idea of constructing a big dam was visualised by Arthur Davis. It was an ambitious plan.

Planning for the Dam. A scheme was planned. A concrete gravity dam, of about 700 to750 feet height was thought. A reservoir at the back of the dam could hold every drop of water, the Colorado could send in any 2 years of steady flow. It was to be the biggest man-made lake in the world. It was going to be a multi- purpose dam, generating about 6 billion Kilo watt-hours of electrical energy each year for the growing cities of southern California. The reservoir would hold the flood waters, and the spillways would release the required amounts of water to the downstream farmers.

Flood control, irrigation and electricity were the three main purposes of this project. Supply of drinking water to 13 cities of California and creation of a recreational and navigable lake reservoir were the additional advantages.

Selection of a suitable site. A thorough search was made for the spectacular gorges of the Colorado, seeking the best possible site. They studied 70 such sites before choosing 'Black canyon' on the border between Arizona and Nevada, 48 km from the city of Las Vegas (Nevada).

The preliminary survey of *Black canyon* took about 3 years. Here, the river flows through cliffs 1000-2000 feet (300 m to 600 m) high. At the water line, the rock walls were 350 feet (105 m) apart.

Engineers roamed in heat and sun, testing the rocks, drilling into it, to make sure that it could stand the burden of enormous weight of the concrete that would be laid upon it. *Their conclusion was that it could. They recommended that the giant dam be built.*

After the technical green-signal was obtained, some political issues such as to who will be benefitted and up to what extent, were settled with a great difficulty. The rift between the different States always persists in such huge projects.

Construction of the Dam. The real work began in late 1930. Herbert Hoover was the President of America at that time. He himself was an engineer. The work started under his vigilance, Arthur Powell Davis, 70 years old and about to retire, saw his life long dream fulfilled as he stood high above the Colorado and watched thousands of workers working hard with picks and dynamite far below.

The dam site was very hot. It was not a congenial surroundings to work. But a *dam had to be built.*

First of all, a town was built to house the workers. A permanent city, now called Boulder-city, was settled at an expenditure of about $70 million. This was spread in an area of about 300 acres and could accommodate 5, 000 workers.

Whenever a dam is constructed, the water of the river is first of all to be diverted so that the construction could start. This is called by engineers as 'to turn the river off.' 4 tunnels, each 56 feet wide and 4000 feet long were dug into the solid rock of the canyon walls. These *bypass tunnels* received the flow of the river and carried it down to the downstream, to a point beyond the construction site. About 1 $\frac{1}{2}$ million cubic feet of rock had to be removed for building these four tunnels.

Then, the Coffer dam was built. A coffer dam is a temporary retaining embankment upstream of the site. Huge amounts of rock and earth was heaped up, forcing the river into four bypass tunnels. The bed of the river was thus laid bare.

Workers then descended into this river bed to lay the foundations for the dam. Seven million tons of concrete had to be laid. It was 660 feet thick at the base.

The dam curves upstream, so that the water load is held back in part by the walls of the canyon. The completion of the dam took about 2 years of non-stop work.

After completion, the bypass tunnels were blocked up and the water started coming and collecting against the dam. The lake formed on the upstream side was called *Lake mead.* Electrical power houses, which are of the size of 20-storey sky-scrapers were constructed. The lake, the power houses, the dam galleries etc. are open for visitors and for inspection. It was a great achievement indeed.

17.8. Bhakra Dam

Bhakra Dam is a concrete gravity dam. It is 740 feet **(226 m)** high, spanning the V-shaped gorge in the lower Shivalik hills. The dam is 1700 ft long at the top and only 325 ft at the bottom. The thickness of the dam at foundations is 1320 ft and it tapers to 30 ft at the top where a road runs. *Bhakra dam was the highest concrete gravity dam of the world when built, thus surpassing the existing* 726 ft (221 m) high Hoover dam. But the highest concrete gravity dam of the world, at present, is **Grand Dixence dam** in Switzerland **(284 m high)**. Bhakra dam is situated in Himachal Pradesh State of India near a village used to be called Bhakra. It has been constructed on Satluj river. Satluj is a river coming from Himalayas. It is a perennial river but carries enormous water during floods and rains.

Downstream and upstream views of Bhakra dam are shown in Photo Fig. 17.4.

This dam has given tremendous prosperity to India and has given her a high name in the world. The various functions served by this dam are:

(*i*) Flood control (*ii*) Irrigation
(*iii*) Electricity (*iv*) Fish development.

Bhakra Project is not a single Bhakra Dam but consists of the following:

(*i*) 740 ft high Bhakra Dam (*ii*) 95 ft high Nangal Dam

(*iii*) Nangal Hydel Channel (*iv*) Ganguwal and Kotta Power houses

(*v*) Bhakra Canal System.

Planning and Construction. The survey works for the construction of this multi-purpose project started in 1919. From 1919 to 1930, the survey continued and various sites were considered for various purposes. From 1932 to 1946, the work was interrupted, and finally in 1946, a railway line was spread in this area, and then the actual construction started.

After selecting a suitable narrow canyon for the construction of Bhakra Dam, the dam site was dewatered after the river was 'turned off'. Two diversion tunnels, one in either abutment were constructed in order to carry the river water. Two coffer dams enclosing the foundation area, were also constructed. Both the tunnels are 50 ft, in finished diameter, half a mile long and are lined with 3.6 ft thick heavily reinforced concrete. The work on these two tunnels was started in 1948 and was completed in 1953. The total expenditure incurred on them was approximately Rs. 3.6 crores.

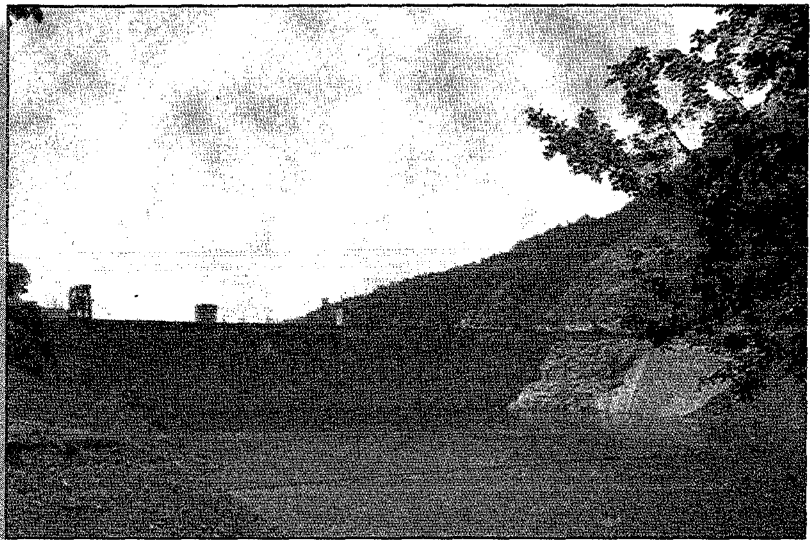

Fig. 17.4 (*a*) Upstream view of Bhakra Dam.

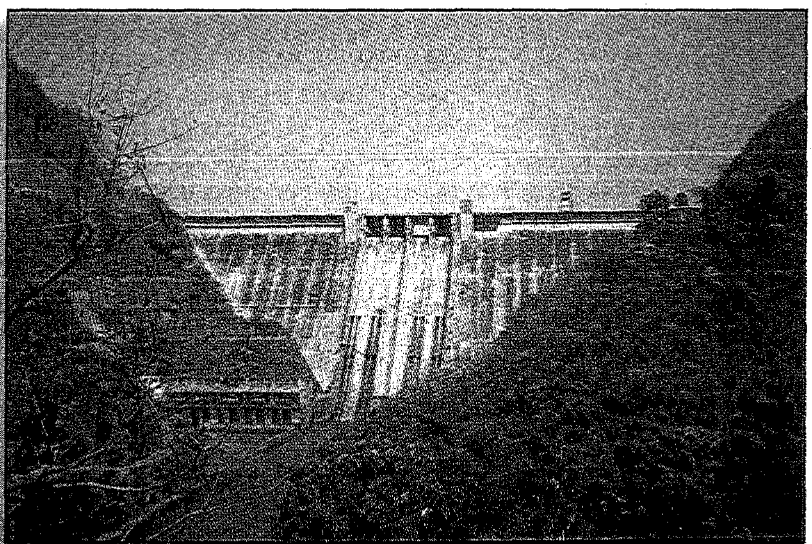

Fig. 17.4 (*b*) Downstream view of Bhakra Dam.

Fig. 17.4. Photoviews of Bhakra Dam.

After the construction of these tunnels, two earth (rolled) and rock coffer dams were constructed to enclose the operation area of the dam site. The construction of 215 ft high coffer dam began in 1956. The water was forced into the tunnels and taken downstream beyond the construction point. The 15 ft high downstream coffer dam did not let the water come back in the pit.

The foundations of these rolled fill earthen dams or dikes were carried down to 60ft and 70 ft below the river bed level. After the construction of coffer dams, the dewatering of the area was expeditiously completed and the excavation of the river bed started. The rock was blasted by an explosive. Desert-shovels were employed for loading the material in special trucks having capacity of 914 cubic yards. The material was carried and dumped at the dumping site. The total excavation was of the order of 700 million cubic yards. About one million cubic yard was excavated per day.

While the excavation was going on, a large constructional plant, capable of producing high quality concrete economically and efficiently was also installed. This required a $4\frac{1}{2}''$ long belt conveyor system, aggregate processing plant, cement handling plant, cooling plant, batching and mixing plants, high steel tristles, revolving cranes and other electricity operated cranes, etc. etc. It was an expensive, completely automised concrete plant. It was capable of handling about *600 tons* of concrete per hour.

Then, the actual concreting work of the dam started in November 1956. Huge electric cranes including 6 cantilever-cranes and 2 stiff-legged-cranes were employed for concreting of dam.

A very low heat cement was used in the construction of this dam. Because, when cement sets, it produces a large amount of heat which is liable to cause cracks in the structure. So in order to avoid this cracking, steel pipes were embedded in the structure and ice-cold water was circulated through them.

The first stage of the dam (390 ft.) was completed by 1959. Work in the 2nd stage was interrupted by a flood in the diversion tunnel that drowned ten workers and damaged the power house. The tunnel and plugging of the dam was completed in 1962.

Dimensions and other data about Bhakra Dam are given below:

Height of the dam	= 740′
Length at the bottom	= 325′
Length at the top	= 1200′
Breadth or thickness at the bottom	= 1320′
Breadth or thickness at the top	= 30′
Concrete required for the dam	= 55 lakh cubic yard
Electricity generated	= 12 lakh Kilowatt
Name of the reservoir formed	= Govind Sagar
Length of the reservoir	= 90 miles
Maximum depth	= 740′
Minimum depth	= 300′
Total irrigation	= 1 crore acre of area
Population of these villages	= 30, 000
Total storage capacity	= 8 million acre ft.
Catchment area	= 22, 000 sq. miles
Live storage	= 6.35 million acre ft.
No. of Inspection galleries	= 46

Power Houses. There are two power houses called (*i*) The Left Power House; and (ii) The Right Power House. The left power house is more important and was first constructed.

The left power house is a reinforced concrete structure. It is standing on a stone consisting partly of clay stone and partly of sand stone. The foundation chosen were adverse to the geological conditions required for a good dam site. The permeability of sand stone is high, and thus there was a possibility of leakage and danger of undermining of the foundations. It necessitated a heavily reinforced raft foundation. The left power house building is seven storeyed and its construction took about two to three years. It required about 635, 000 cubic yards of concrete, about one million sq.ft. of finishing work and 6, 000 tons of reinforced steel.

The machinery used in this power house is of cosmopolitan in nature. The turbines were supplied by Japan, the generators and transformers by U.K., and over-head cranes by Yogoslavia.

The local manufacture of 10 ft diameter penstocks, made out of 1.75″ thick steel plate was considered as a big engineering feat of the country in such a short period of independence. The left power house had costed nearly Rs. 10 crores. The work on right power house was also completed afterwards..

Problem of Wood Transport. Like all other perennial rivers of India, the River Satluj has been the cheapest means of transporting wood from the Himalayan forests down to the plains. But since the dam is very high above the river water level, it has become impossible to use this river for this purpose.

The problem is overcome by bringing logs of woods from Govind Sagar to Nangal railway station by means of an aerial rope-way. This is about $5\frac{1}{2}$ miles long. A wooden log loom has been put across Govind Sagar to obstruct timber. From there, the timber is taken by the inclined carriage way to the loading station on the upstream of the right side.

17.8.1. Nangal Dam. Nangal Dam is 95 ft high subsidiary dam, 8 miles downstream of Bhakra on Satluj. It falls within the jurisdiction of Punjab State in India. The length of the dam is 1, 000 ft. The object of this dam is to head up water of the river Satluj and then divert it into the canal off-taking from the left bank of the river. The canal is called Nangal Hydel Canal, and is a 40 miles long concrete lined canal.

This dam has 29 strong gates of span 30 ft each. An enormous tunnel called the Inspection gallery has been made in the river Satluj in the lower portion of this dam. This was the first tunnel constructed by the Government under Bhakra Project Scheme. In order to enter into this tunnel, one has to go 70 ft down. The tunnel goes across Satluj River.

Bhakra Nangal Project is something tremendous, stupendous, something which shakes up and thrills us when we see it. It marks the India's progress after her Independence. It is something which cannot be forgotten easily, if we see it once.

17.9. Nagarjuna Sagar Dam

The multipurpose Nagarjuna Sagar dam is located across Krishna River, near Nandikonda village in Nalgonda District (Andhra Pradesh). It is named after Buddhist Savant, Acharya Nagarjuna, who lived at the spot about 2,000 years ago to fulfil a mission.

This Dam irrigates in Guntur, Kurnool, Nellore, Nalgonda, Khamman and Krishna Districts. Its irrigation Potential is about 35 lakh acres of land and electrical potential is 1 lakh kilowatt hours of firm power (guaranteed-power generation) and 4.6 lakh kilowatt hours of seasonal power.

A photoview of this dam is shown in Fig. 17.5.

Salient Features of the Dam. The river gorge is blocked by a masonry dam 409 ft (124.6 m) high above the deepest foundation level and 4756 ft long. The full reservoir level is +590.0 ft above the mean sea level (M.S.L.). The most unique feature of this dam is the adoption of Stone masonry for its construction, deviating from the traditional concrete. The use of stone had resulted in a large saving and had created huge employment potential for a large labour force. Hence, Nagarjuna Sagar Project ranks first in the man-power utilisation among the modern gigantic projects of its own kind in the world. It was designed and executed entirely by Indian engineers. On either side of the masonry dam, earth dams have been constructed for a length of about two miles, the maximum height being 85 ft. The spillway crest has been installed with 26 Radial gates each of size 45′×44′. Other component-works of this mighty dam include 8 penstock pipes on the left side, three Power sluices and 9 irrigation sluices on the right side, two chute sluices and a diversion-cum-irrigation tunnel. Two canals-off-take on either side of the dam for irrigation. The expenditure on the project was of the order of Rs. 80 crores. The crest level of the dam is +605 ft and the crest level of spillway is +546 ft. Various details of the dam are given below:

(1) **Location.** Lat. = 16°34′ North, Long. = 71°19′ East, $1\frac{1}{2}$ mile downstream of Nandikonda village Miryalaguda Taluk, Nalgonda District, 90 miles from Hyderabad.

(2) **States Covered.** ANDHRA PRADESH

(3) **Hydrology**

(*a*) Water-shed area at dam site	... 83,087 sq. miles
(*b*) Maximuml flood discharge (observed)	... 11.7 lakh cumecs.

(4) **Reservoir**

(*a*) Full Reservoir level	... + 590′.0
(*b*) Maximum water level	... + 594′.0
(*c*) Gross storage capacity	... 9.37 M.a.ft
(*d*) Net (live) storage capacity	... 5.51 M.a.ft
(*e*) No. of villages submerged	... 57
(*f*) Population displaced	... 4,824 families

(5) **Masonry dam**

(*a*) Total length	... 4,756 ft
(*b*) Spillway length	... 1545 ft
(*c*) Non-overflow length including power dam	... 3,211 ft
(*d*) Height of dam (maximum)	... 409 ft
(*e*) Base width (maximum)	... 320 ft
(*f*) Top width	... 28 ft

(*g*)	Top level	... + 605′.0
(*h*)	Top of crest in spillway	... + 546′.0
(*i*)	Chute sluices 2 No. 10′ × 25′ provided in blocks 25 and 51 with sill level elevation	... + 450′.0
(*j*)	8 No. of 16′ diameter penstocks provided one in each in blocks 16 to 23 with central line in elevation	... + 405′.0
(*k*)	3 No. power sluices 15′ × 38′ provided (two in block 71 and one in block 72) with sill level at elevation	... + 479′.0
(*l*)	Radial Crest Gates 26 No. 45′ × 44′, with crest elevation	... + 546′.0
(*m*)	Thickness of spillway pipes	... + 15′
(*n*)	Nine No. sluices 10′ × 15′ are provided for right canal head regulator with sill at elevation	... + 489′.0

(6) **Quantities of Work**

(*a*)	Excavation for foundations	... + 42.07 M. cft
(*b*)	Volume of masonry and concrete	... 198 M. cft
(*c*)	Quantity of cement	... About 11 lakh tons
(*d*)	Quantity of steel	... About 60,000 tons

(7) **Earth Dams**

(*a*)	Length of Left Earth Dam	... 8,400 ft
(*b*)	Length of Right Earth Dam	... 2,800 ft
		11,200 ft
(*c*)	Maximum height above foundation level	... 85 ft
(*d*)	Top width	... 30 ft
(*e*)	Top level	... 610′
(*f*)	Excavation of foundation	... 9.2 M. cft
(*g*)	Earthwork for embankment	... 88 M. cft

(8) **Irrigation-cum-Diversion Tunnel (horse-shoe in Section)**

(*a*)	Length	... 2,590 ft
(*b*)	Diameter	... 27 ft

(9) **Power Plant**

(*a*)	Left side 8 No. of penstocks 16 ft. diameter to develop	... 3 lakh kW
(*b*)	Right side 3 power sluices of size 15′ × 38′ to develop	... 0.6 lakh kW

(10) **Man-Power** ... 50,000

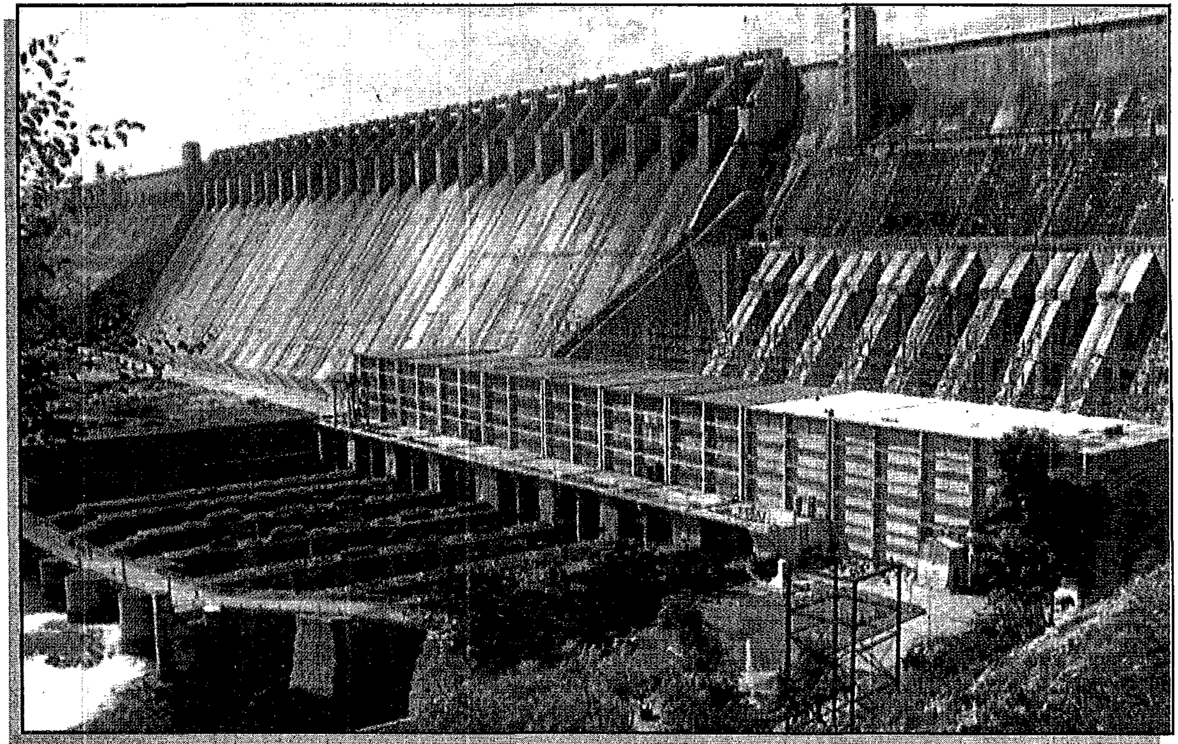

Fig. 17.5. Photoview of Nagarjuna Sagar Dam.

Organisation. In the earlier years of construction, a Control Board was the orverall incharge of the Nagarjun Sagar Project including technical, financial and administration aspects. The project was then located in the Andhra Pradesh and the Hyderabad States. After the reorganisation of States, the project came entirely in Andhra Pradesh State. The State Government assumed its full responsibility w.e.f. 1.8.1959. The Control Board became an advisory Body to the State Government, whose advice is accepted as a matter of convention.

The programme of construction of dam and canals was so adjusted that partial benefits started accruing even from 1967. The reservoir was able to deliver water to first crop of Krishna delta in time for raising substantial acreage in 2nd crop. Letting out waters in the two canals was inaugurated, by Smt. Indira Gandhi, the then Prime Minister of India, on 4.8.1967.

Rehabilitation. The man-made lake of Nagarjuna Sagar fully submerged lands of 52 villages and partially submerged that of 5 villages.

About 4,900 families were displaced and rehabilitated in 24 Rehabilitation centres. Good facilities, liberal compensation and other amenities were provided to those who had to be uprouted.

Nagarjunakonda Excavations. As the Nagarjuna Sagar reservoir was to completely submerge the famous relics of Nagarjuna Konda, which was the seat of Ikshwaku Kings and one of the principal centres of Mahayana System of Buddhism, the whole area was excavated by the Archeological Department of the Governmernt of India. The more important of the relics were located in a museum constructed for the purpose, on the top of an adjoining hill. Practically, all the relics had been unearthed and shifted to the museum. Expenditure to the extent of 12 lakh rupees was debited to the Project and the balance was met by the Archeological department.

PROBLEMS

1. (*a*) What is meant by a "dam and a reservoir" ? What are the different meterials that are commonly used for dam construction and what are their comparative advantages and disadvantages ?

(*b*) Discuss the geological and tropological features which affect the selection of the type of dam.

2. (*a*) What are 'arch' and 'buttress' dams ? Illustrate with sketches and mention site conditions favourable for construction of such dams.

(*b*) Discuss the factors which are considered in the selection of the site for a proposed dam. It is assumed that the type of the dam has already been selected for the project.

3. (*a*) What useful purpose is served by a dam ? What are the illeffects of dam construction ?

(*b*) How do you classify dams according to :

(*i*) their use ;

(*ii*) their hydraulic designs ;

(*iii*) their materials of construction.

(*c*) Discuss the various factors which govern the selection of a particular type of dam for a particular project.

4. "Dams are the sources of sorrow and grief". Debate the above statement giving points in favour as well as against it.

5. Narrate briefly the story of construction of any major dam of India.