Module

4

Hydraulic Structures for Flow Diversion and Storage

Lesson

4

Structures for Water Storage – Investigation, Planning and Layout

Instructional objectives

On completion of this lesson, the student shall learn:

1. The different types of storage structures, that is, dams
2. The decisive factors for choosing suitable location for a dam
3. The criteria for selecting a particular dam type
4. The important appurtenant structures for a dam
5. Typical layouts of dams

4.4.0 Introduction

In Lesson 4.1, the two primary types of valley structures, ***storage*** and ***diversion*****,** were discussed. These are again displayed in Figure 1 for recapitulation.

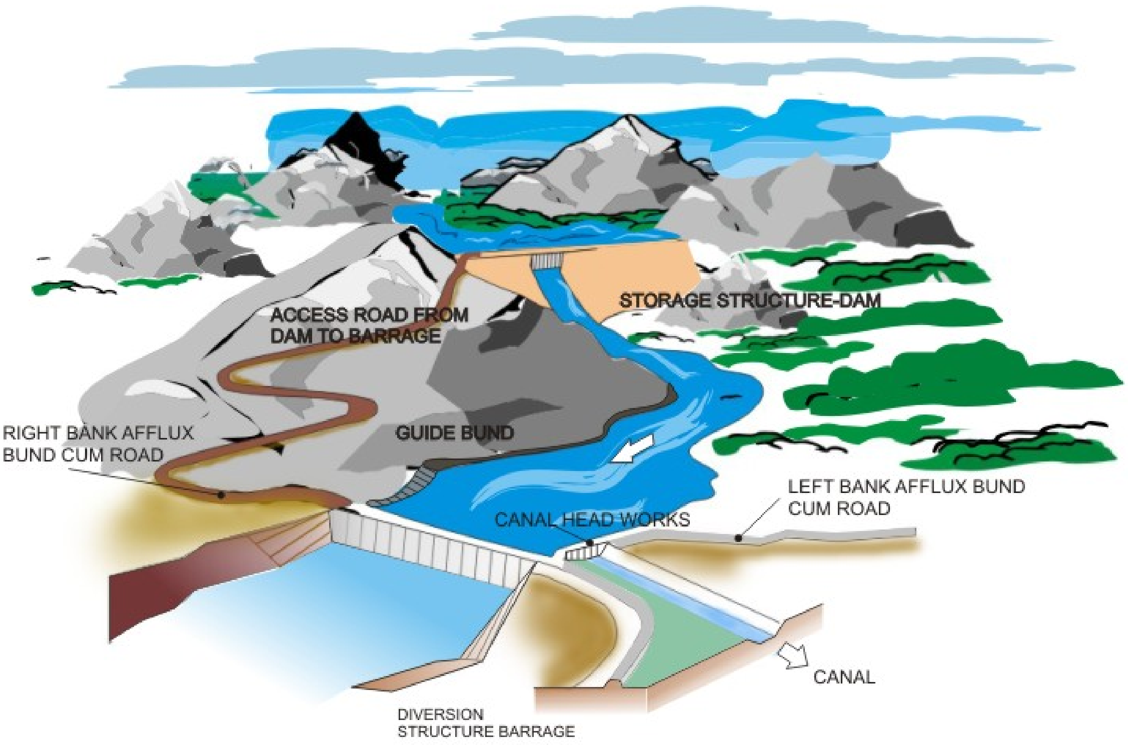


FIGURE 1. Structures for harnessing water resources potential of a river

Structures that are created as obstructions across rivers with an intention to store some of the water for future use are called storage dams. They are functionally slightly different from the structures used for flow diversion, called Barrages or weirs discussed in the Lessons 4.1 to 4.3. A diversion structure is primarily meant to create an elevation rise of the river water such that it may flow into a canal, perhaps through out the year or at least during the lean flow period of the river. During high flood in a river, the canal is kept closed in cases like irrigation canals for fear of high sediment entering and depositing on the canal bed. Even if some water is drawn into a canal during river flood season, the main bays of a diversion structures are usually kept wide open to let the flood water pass down the river with the minimum obstruction.

This is not so in case of storage dams, for which the storage of water especially a portion of the flood flow is primary concern. The storage of water is done with an intention to either reduce the impact of a flood down stream or to use the water beneficially in future. This is achieved by creating an obstruction of sufficient height which creates a reservation on the up stream of the structure. Naturally, since the reservoir would have a finite capacity which would vary with height of the dam and the shape of the river valley on the up stream, any excess flood water has to be discharged through a spillway. Hence, the principal components of a storage dam would be a storage a structure to obstruct river flow, a spillway for discharging excess flood water and outlets for allowing the storage water to be with drawn for the rest of the year for some useful purpose or even let it flow downstream at a regulated quantity. Some times sluice are provided in the body of the dam to lower the water level in the dam at the time of an emergency it is not necessary that all the principal components of a storage dam be located in the same structure. In fact, all three may be located separately. Of course, the spillway is usually made of reinforced concrete and sometimes combined with a concrete dam. But it may be economical or practically more feasible to construct an earthen or rock fill dam, in which case there has to be separate spill way made of concrete. In fact, it is also not essential for the spill way to be adjacent to the main dam, and can be located any convenient position at the periphery of the reservoir, if that helps in some way. Similarly, out let works may be located at any suitable place in the reservoir and possibly connected to a canal or a tunnel.

Sometimes dams are constructed to create a head difference for generating power but without using the storage. This may be done due to the requirements of the riparian rights, as in the case of the Salal Dam on Sutlej, which uses the head available to generate power put does not have an outlet or river sluice. Other types of dams include detention dams which are primarily created to retard flood runoff and control flood peaks.

In this lesson, we shall discuss about the types of dams in vogue, geotechnical and other site investigations that is required for planning the most suitable type of dam and the concept of general layout of an entire dam project including its various appurtenant structures.

4.4.1 Types of dams

Almost each dam that has been constructed all over the world is unique. This is so because a particular type is chosen because of the considerations of many factors, as discussed in subsequent sections. In fact, dam engineering brings together a range of disciplines, like structural, hydraulics and hydrology, geotechnical, environmental etc.

Never the less, primary purpose of a dam is to provide for the safe retention and storage of water. Structurally, a dam must be stable against overturning and sliding, either or within the foundations. The rock or soil on which it stands must be competent to withstand the superimposed loads without crushing or undue yielding. The reservoir basin is created must be watertight and seepage through the foundation of the dam should be minimal.

Though each situation demands a unique proposal for the type of dam, a broad classification based on the construction material can be made in dividing the types of dams that have been commonly constructed as:

1. Embankment dams, which are constructed of earth fill and/or rock fill, and

2. Concrete dams, which are constructed of mass concrete.

Of course, there are some dams that were constructed using rubble masonry, like the Nagarjuna Sagar dam on the river Krishna. But mostly embankment dams are more common for technical and economical reasons all over the world, they account for nearly 80 percent of all the large dams that have been built in modern times. The two main types of dams are further explained in the following paragraphs.

Embankment Dams

These can be defined as dams constructed of natural materials excavated or obtained from the vicinity of the dam site. The materials available are utilized to the best advantage in relation to their characteristics as an engineered bulk fill defined zones within the dam section. The natural fill materials are placed and compacted without the addition of any binding agent. Two main types of embankment dams that are commonly constructed include the following:

1. Earth-fill or earthen embankments –These may be classified as dams use compacted soil for constructing the bulk of the dam volume. An earth fill dam is constructed primarily of selected engineering soils compacted uniformly and intensively in the relatively thin layers and at a controlled moisture content. Some of the common sections designed for earth fill embankment dams are shown in Figure 2.

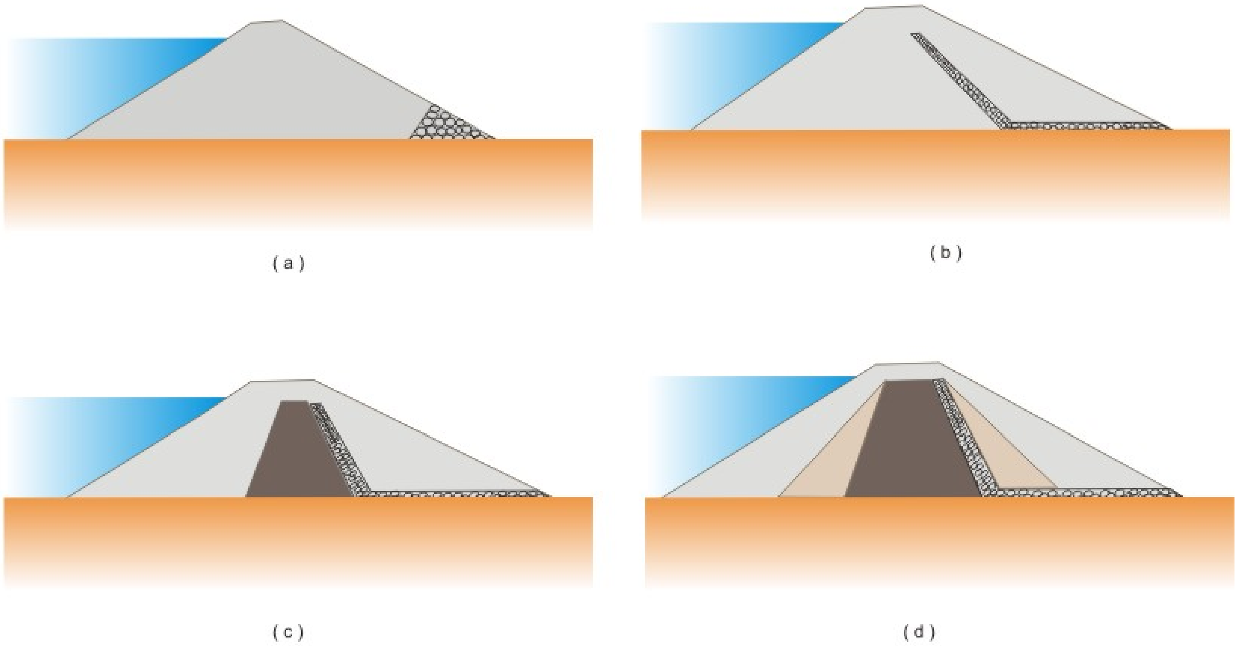
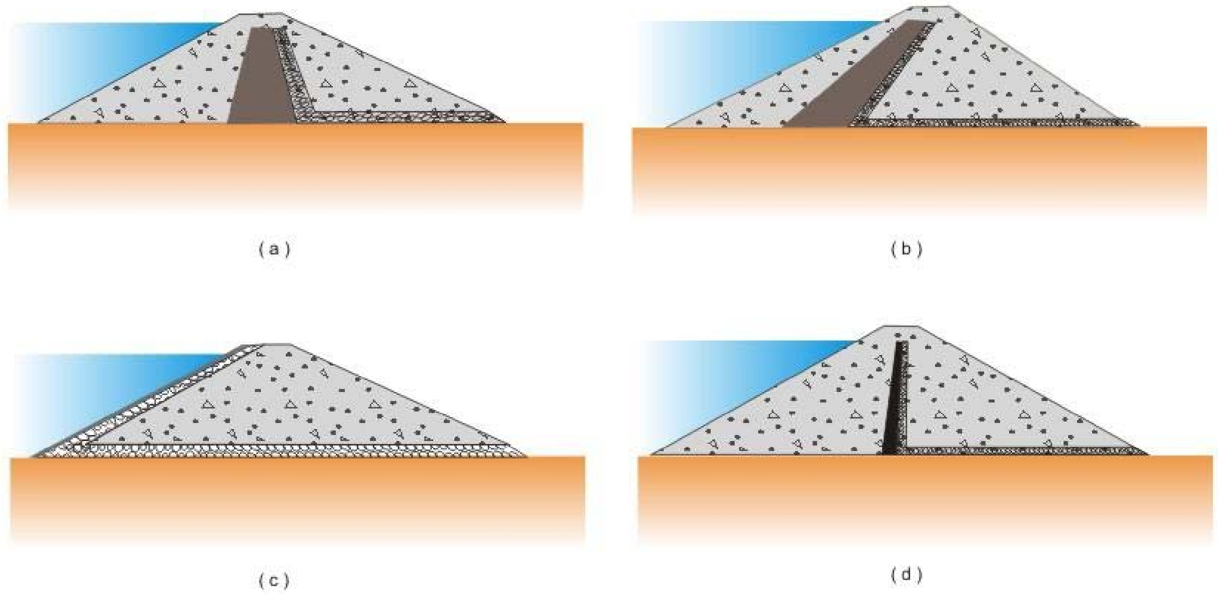

(a) (b) (c) (d)

FIGURE 2. Principal types of earthen embarkment dams
(a) Homogeneous with toe drain,
(b) Homogeneous with chimney drain & horizontal blanket ,
(c) Zoned with clay core chimney drain & horizontal blanket ,
(d) Zoned with earth & rockfill

2. Rock-fill embankments – In these types of dams, there is an impervious core of compacted earth fill or a slender concrete or bituminous membrane but the bulk of the dam volume is made of coarse grained gravels, crushed rocks or boulders. Typical sections of rock fill dams are shown in Figure 3. The stability of the outer shell of a rock fill dam relies on the frictional forces acting in between each rock gravel piece which ensures its safety against sliding kind of failure during earth quakes.



(a) (b) (c) (d)

Figure 3. Principal types of rockfill embankment dams, with the following features:
(a) Vertical clay core & drains, (b) Inclined clay core & drains,
(c) Upstream decked with asphaltic or concrete membrane & drains ;
(d) Central asphaltic membrane with drains.

It may be observed that shell of the rock fill dam is more permeable than that of an earth fill dam. Mostly, the water is prevented from flowing down by the impervious core of the rock fill dam.

Embankment dams are advantageous in the following major aspects:

1. These are suitable for river valleys of any type: steep gorges or wide valleys
2. Can adapt to a broad range of foundation conditions, ranging from good rock to even permeable soil type of foundation
3. Uses naturally available materials
4. Relatively less costly

Amongst the disadvantages, it may be raid that they have greater susceptibility to damage than concrete dams due to the possibility of getting washed away during an over tapping of the spill way which may occur if there is a flash flood in the river and the gates of the spill way are not operated in time or the spill way itself is of inadequate capacity.

A further disadvantage of the embankment dam when compared to a concrete dam is that the former requires to have a separate spill way in contrast to the latter, where the spill way may be integrated within the dam body itself. Also earthen embankments are prone to concealed leakage, perhaps due to faulty construction or internal erosion in the dam body or in a pervious foundation.

Concrete Dams

The use of mass concrete in dam construction started from about 1900 for reasons of ease of construction and to suit complex designs, like having spill way within the dam body. From about 1950 onwards, mass concrete came to be strengthened by the use of additives like slag or pulverized fuel ash, in order to reduce temperature induced problems or avoid undesirable cracking or to reduce the total cost of the project.

Amongst concrete dams, too, there are many varieties, the principal types of which described below.

1. Gravity dams (Figure 4a): A gravity dam is one which depends entirely on it's own mass for stability. The basic gravity profile is triangular in shape, but for practical purposes, is modified at the top. Some gravity dams are slightly curved in plan, with the curvature being towards the river upstream. It is mostly due to aesthetic and other reasons, rather than having an arch action for providing greater stability.

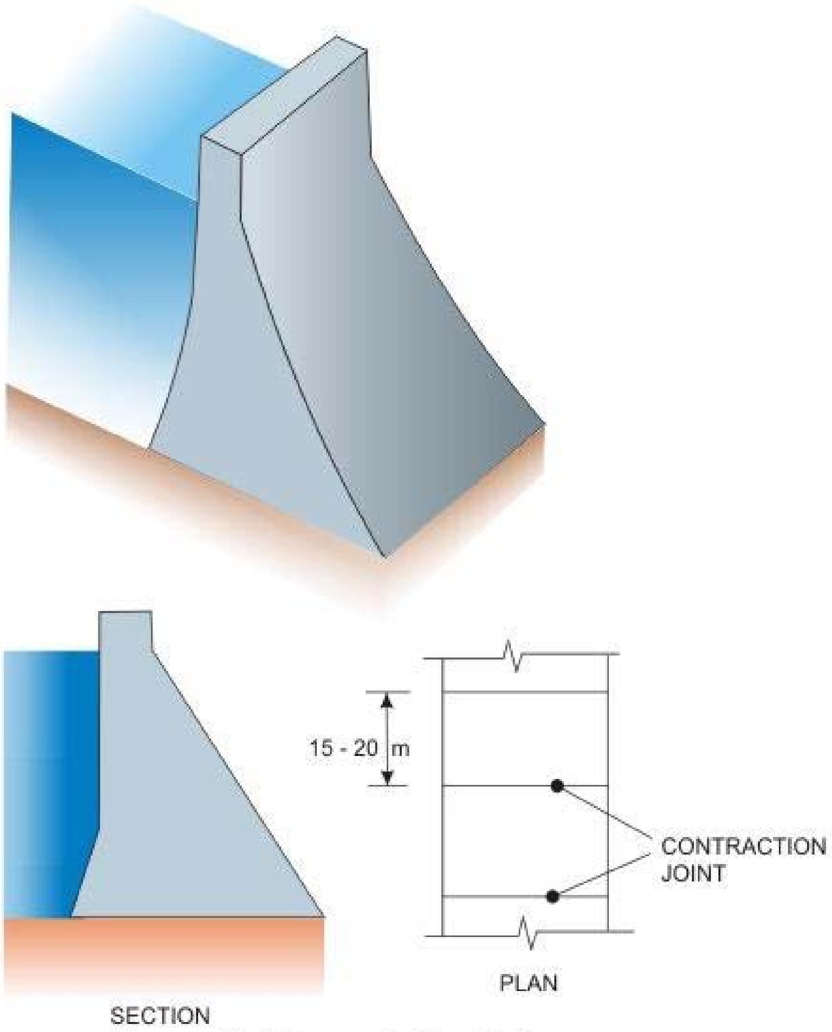


FIGURE 4(a) Concrete Gravity dam

2. **Buttress dams** (Figure 4b): This type of dams consist of a continuous upstream face supported at regular intervals by buttress walls on the down stream side. These dams are generally lighter than the solid type of dam but likely to induce slightly higher stresses at the foundation since most of the load now passes through the buttress walls and not spread uniformly over the foundation as in a solid gravity dam.

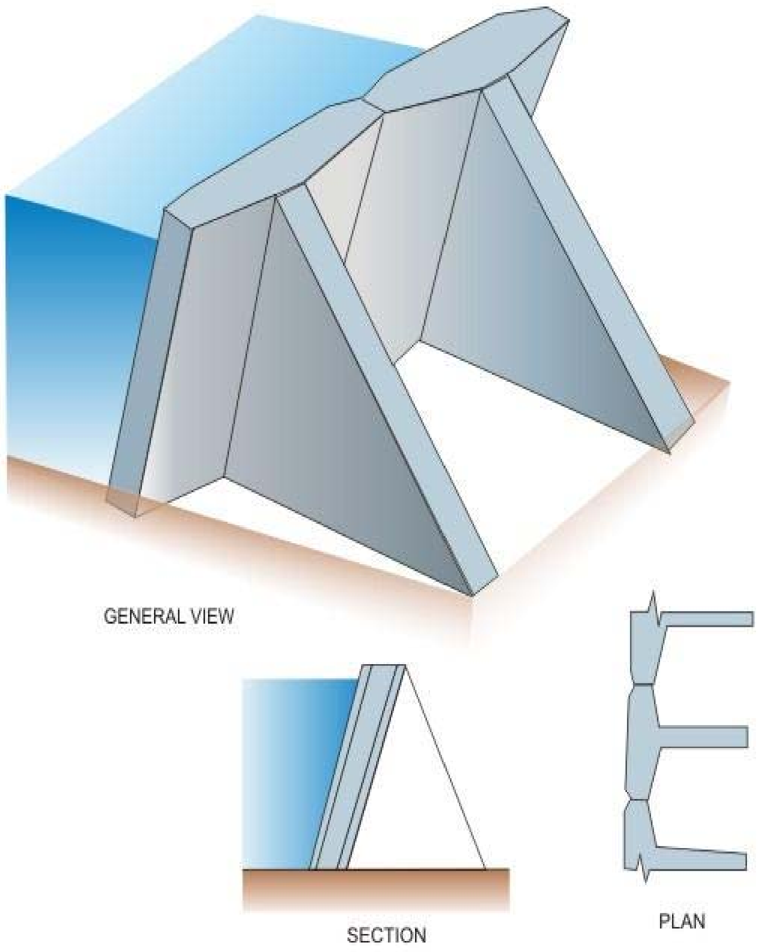


FIGURE 4b Buttress Dam

3. Arch dams (Figures 4c and d): These types of dams have considerable upstream curvature in plan and rely on an arching action on the abutments through which it passes most of the water load on to the walls of the river valley. This type of dam is structurally more efficient gravity dams and greatly reduces the volume of concrete required. Of course, a prime necessity in constructing an arch dam is to have sound foundation and abutments.

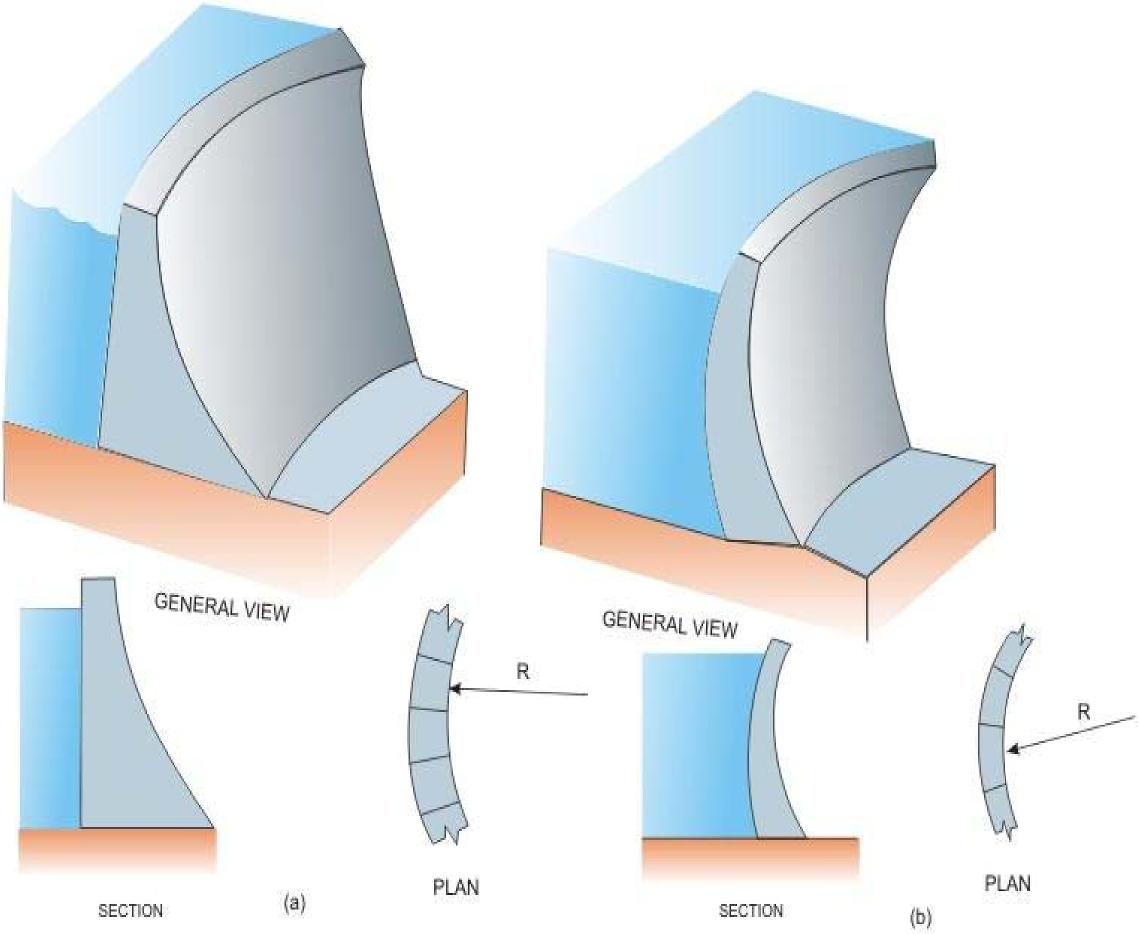


FIGURE 4. Principal types of concrete dams(continued) ; (c) Arch gravity dam ; (d) Cupola or double curvature - arch dam.

These are a few other types of concerted dams that have been constructed, a couple of which have been illustrated in Figures 5a and b.

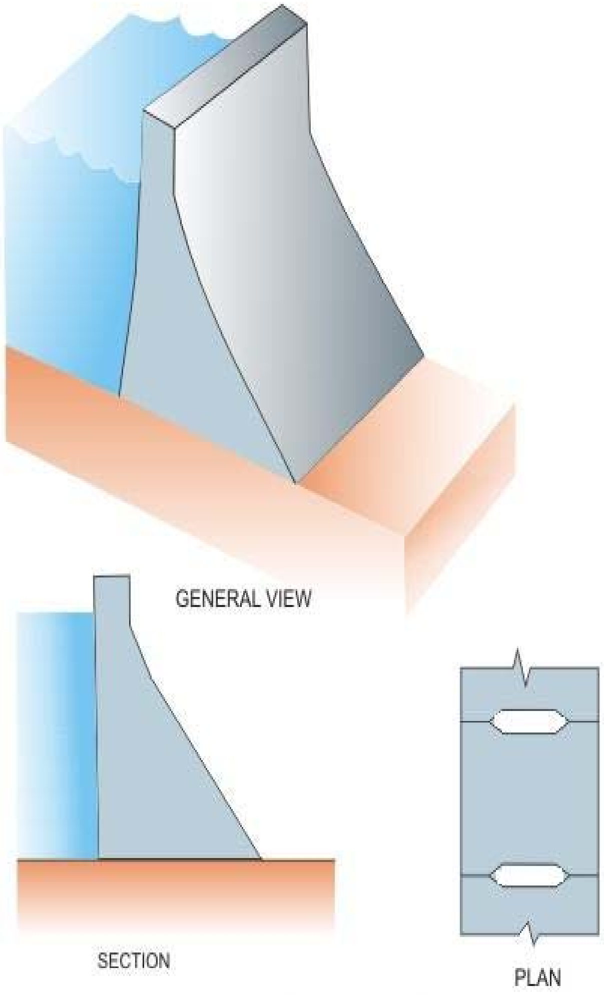


FIGURE 5a. Hollow gravity dam

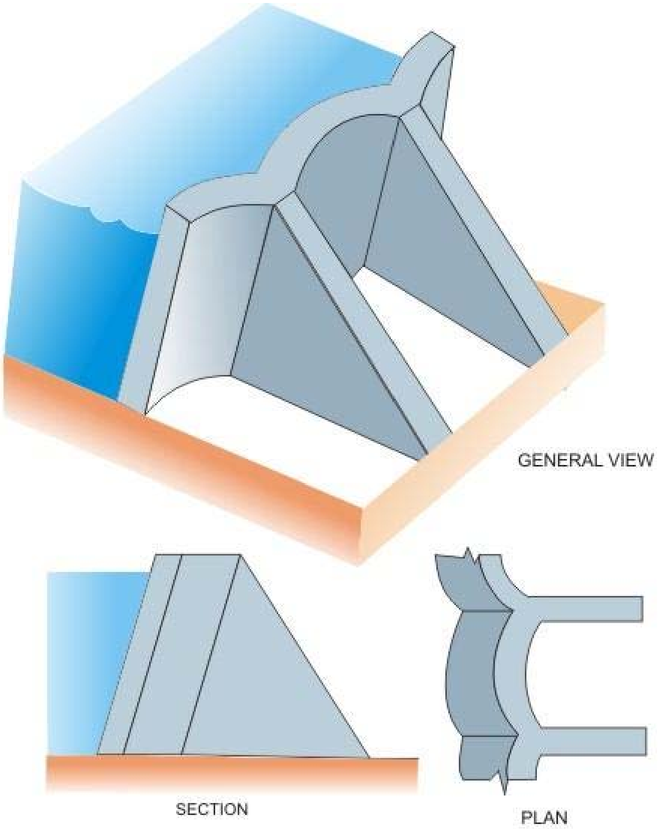


FIGURE 5b. Multiple Arch dam

Some of these, it may be noted, are made of reinforced concrete, and not mass concrete for gravity dam. Some of major advantages of having a concrete dam are listed below:

1. Concrete gravity, hollow gravity or buttress dams are suitable to all kinds of river valleys- narrow or wide, provided that good rocky foundation is available at moderate depths below the river bed.

2. Concrete dams are not sensitive to over topping, unlike the embankment dams. However, the water over topping the concrete dam may destroy the foundation down stream due to the impact of the falling water.

3. Concrete dams may accommodate a crest spill way, or sluice ways through the body of the dam, which is not possible for embankment dams. The cost of having a separate spill way channel is thus avoided.

4. Concrete dams are more resistant to withstand seismic disturbance.

5. Cupola or Double curvature arch dam is an extremely strong and efficient structure, provided a narrow valley exists with good rock in abutments and foundation.

4.4.2 Choosing a suitable location of dam

With a decision made about the necessity of having the dam across a river near about a broad area, attention is focused on narrowing down into one, or preferably two or three alternate sites that may be apparently suitable from visual inspection. Detailed investigations are carried next to examine the option that satisfies as being most economical, technically more suitable, convenient for construction etc. The various investigations that are carried out for finalizing a particular dam, specifying its type, height, method of construction, etc. are mentioned below.

Topographic Requirement

From a preliminary observation of the elevation contour maps of a region, one has to decide on an option that seeks a gorge which is most narrow, which would require minimum quantities of dam construction material. At the same time, an ideal location may also be decided from the volume of the water that may be able to store in the reservoir behind the dam. This may be observed from Figure 6 which shows two possible alternate sites that may be considered suitable from the available narrow gorge sites, A-A and B-B. Though the heights of the dams are nearly the same as may be observed from the corresponding elevation contours, the length of the dam for the latter is clearly more with an expected corresponding higher volume of construction material that would be required. Nevertheless, a further inspection of the elevation contours on the upstream indicates that a dam A-A would have a much smaller reservoir as compared to that at B-B.

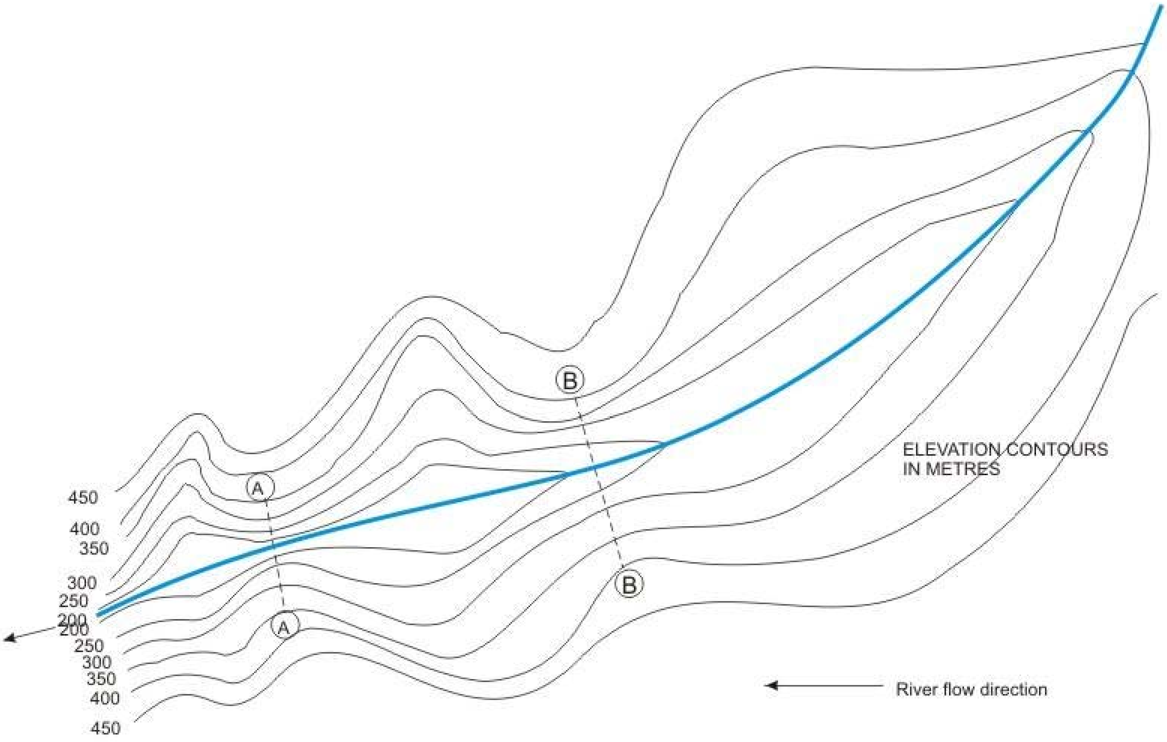


FIGURE 6. Topography of a typical damsite area showing possible alternate location

Submergence possibilities

Though a preliminary investigation indicates one location to be more preferred than others, it may have to be seen what losses have to be sustained if each of these alternatives are selected. There could be a valuable forest area which might get submerged. Of course, it is possible to replenish the loss by planting more saplings at other places not subjected to submergence. However, there could be some industry located upstream, or some mines, whose relocation may not be economically possible.

Geotechnical suitability

Since a dam is a massive structure, the foundation should be geo technically sound to sustain the high stresses that is expected to be developed due to the self weight of the structure, water pressure of the reservoir and earth quake vibration induced forces at the dam body and the water in the reservoir.

The geological and geotechnical investigation of a dam site for detailed evaluation is to be directed towards determining the geological structure, stratigraphy, faulting, foliation and jointing, and to establish ground water conditions adjacent to the dam site, including the abutments. The objective of these investigations is to:

- Determine the engineering parameters which can be reliably used to evaluate the stability the dam foundation.

- To determine the seepage patterns and the parameters for enabling the assessment of the probable seepage pressures.
- To make sure that there are no bad patches within the would–be reservoir area, like lime stone caves, through which reservoir water may leak out.

It needs also to be established by geotechnical investigations about available construction materials in the economical vicinity of the dam site. The tasks that need to be performed for geotechnical testing include the following:

- Logging of all natural and excavated rock exposures and borehole records.
- Correlation between the exposures and borehole data and inferring out a spatial pattern of subsurface rock jointing patterns, layers or seams of weak materials, etc.
- Excavation of additional trial pits, boreholes, shafts and exploratory adits wherever considered necessary.

For carrying out testing in rock, rotary drilling and coring techniques have to be used. The Bureau of Indian Standard code IS: 6926-1996 “Diamond core drilling – site investigation for river valley projects- code of practice” may be referred for subsurface exploration for valley projects using core drilling with diamond drill bit. The following two codes may also be referred for recommendations about the ways of storing the geo logical data and preparation of drilling information which might be useful to the designer of the dam:

- IS: 4078-1967 “Code of practice for indexing and storage of drill cores”
- IS: 4464-1967 “Code of practice presentation of drilling information and core description in foundation investigation”

For exploring the continuity or character of subsurface formation and depth, explorations have to be carried out through drifts or tunnels. They are most frequently used for investigation of fault shear zone, buried channels and suspected places of weakness in dam foundation, abutments and beneath steep slopes or back of cliff like faces.

For investigating open fissures or the explore zones of weak rock which could break up in the core barrel and are incapable of being recovered intact, deep trial pits may have to be used. For continuous exposure of the ground along a line or section, trenches may be used, which are best suited for shallow explorations on moderately steep slopes, as for abutment of dams. Exploration may also be done through borings, which are perhaps the simplest methods for subsurface investigation and sampling.

The details of various methods followed for subsurface exploration for dams may be found in the following Bureau of Indian Standards codes:

- IS: 6955-1973 “Code of practice for subsurface exploration for earth and rock fill dams”

- IS: 4453-1967 “Code of practice for exploration by pits, trenches, drifts and shafts”
- IS: 1892-1962 “Code of practice for site investigation for foundations”

Sometimes, geophysical methods can be appropriate to obtain in relatively very short time; information regarding the nature of the various strata and their position and depth of change. These are not direct measurements and methods include a) Seismic refraction technique and b) Electrical resistivity technique. In the former, earth vibration are set up artificially by explorations which causes waves to travel to the subsurface layers which get refracted due to the changes in waves speeds and are finally picked up by geophones placed on the surface at certain intervals. In the latter, four electrodes at equal distances are laid along a line and an electric current is passed between outer electrodes. The potential difference between the inner electrodes is measured to obtain the resistivity.

All the above investigation techniques are used in one way or other to evaluate the following engineering parameters that are necessary inputs to dam designs:

1. Depth of overburden.
2. Permeability and porosity parameters with reference to seepage control.
3. Compressibility characteristics of sandy strata and their relative density.
4. Shear strength and consolidation properties of cohesive strata.

Depending on the above parameters, the most suitable type of dams can be selected based on designer’s judgement. If one site is geologically not suitable (for example, having very weak foundation) then a different location may have to be considered.

Hydrologic adequacy

At any site, the construction of a dam for creating a reservoir for water storage would require the following points to be adequately satisfied:

1. The average quantity of water available in the river through out year.
2. The minimum flow of the river, both as the absolute minimum and the minimum average over a period of a month or a year.
3. The maximum flow that has been recorded and estimates of what might occur in future.

When records of sufficient time are not available or are of doubtful accuracy, correlation is attempted with rainfalls and flows that have been recorded in the surrounding catchments. Hydrometeorology studies can give estimates of future predications. Some times visual inspections may also lead to signs of high flood marks.

Apart from the flow parameters mentioned above, which are required for designing the size of the reservoir (and consequently the dam height) and that of the spill way for passing the largest flood flow, local rain fall records are also essential to prepare reasonable construction schedule of dam. Continuous heavy rains during most of the year could deter the possibility of constructing an earth dam.

Sedimentation possibilities

The average quantity of sediment carried by the river has to be known, as precisely as possible, which would give an idea of the rate at which a proposed reservoir way get filled up. If the rate of sedimentation is too excessive on a certain river, then the project may have to be dropped or suitable engineering design, like provision of large sluices using the a concrete dam at lower levels of the dam, have to be incorporated by the design engineer.

Availability of a suitable spillway site

All dam should have an adequate spillway for passing flood flows. If a river gorge is narrow, then there may not be sufficient spillway width available and a suitable location on the periphery of the reservoir has to be found to locate a spillway. If that is not possible, then the proposed dam site has to be abandoned and other alternatives are selected. A good judgment is also required to decide the suitable type of dam based on spillway consideration.

Possibility of river diversion during construction

The way, river can be diverted at a particular site for making way for construction of the dam may affect the design of the dam and also the construction schedule.

4.4.3 Selection of the type of dam

The following major factors may have to be considered while selecting a suitable type of dam.

1. **Environment and public opinion-** a dam must be constructed without disturbing the surrounding environment, at least to the minimum extent as is possible. If constructing a dam at a certain location entails quarrying up large areas of beautiful greenery, for example, then another alternative may have to be thought of or a suitable remedial measure chalked up.

2. **Availability of construction material-** If the cost of transportation of construction material is excessively high, then an alternate design with locally available materials, have to be considered. For any type of dam, the source of construction material has to be critically evaluated. For earth fill dams, borrow source are prone to over estimation of the available yield of suitable material owing to undetected variations in soil type or quality. It is therefore essential to prone quantities of individual fill materials substantially before proposing a dam section at a site using those materials. The proving of sources for rock fill is superficially more, straight forward than earth fill. The essential requirement is a source of sound durable rock, the location of which sis generally apparent from the initial geological appraisal. Investigation of the suitability of the rock fill will normally require trial fill and in the case of excavated or quarried rock, it will also

be necessary to conduct blasting or ripping trials to determine rock fragment size, grading, shape, etc. Aggregate sources for concrete dams include borrow areas and the use of crust aggregate derived from quarries or excavations.

3. **Unavailability of skilled workers-** In case of sophisticated dam section, skilled workers are an absolute necessity. Unavailability of such workers at proposed dam construction site may have to force the designer to adopt a more easy to construct a type of dam.

4. **Seismicity-** With available dynamic structural analysis computer program for dams using techniques like the Finite Element Method, it is possible to analyse the behavior of the dam under earth quake vibrations thereby making it possible for the designer to check if a particular section is suitable or not. It has been observed that rock fill dams provided with filters, materials from which could move into and seal crakes in the core material appears to be one of the subject type of section that may be provided in earth quake prone regions. One of the foremost dynamic structural analysis computer program developed was that by G L Fenves and A K Chopra of Earthquake Engineering Research Center of University of California at Berkeley. A description of the program is available at the following web-site: http://nisee.berkeley.edu/elibrary/getdoc?id=141382.

5. **Geology and foundation strength-** The existence of joint patterns in the abutments (their orientation, inclination and infilling) may indicate the possibility of instability under loading from an arch dam and reservoir water. Such a site would be more satisfactory for an embankment dam or an adequately dimensioned gravity dam. Where the possibility exists of differential deformation of the foundation along the axis of a dam, a gravity or arch dam would not be a suitable choice because of their inherent rigidity due to their construction in concrete. Instead, an embankment dam may be proposed, which is more flexible. Further, it may be noted that the stresses expected at the base of a dam may have to be checked with the bearing capacity of the foundation material to propose the suitability of a particular section. Embankment dams produce the least formation stress, Followed by gravity, buttress and arch, in that order.

6. **Hydrology-** If, during the construction season, there are possibilities of the partially constructed dam being overtopped by the floods of the river water, then a concrete dam section would be preferred then an embankment dam section. If an embankment dam section is still proposed to be built, then adequate diversion works have to be provided for diverting the river flood water. It may be noted that if a concrete dam is inuded and overtopped, not much loss would occur, where as if such a thing happens over an embankment dam, then the downstream face of the dam would be eroded away, gradually reducing the section and finally causing it to collapse.

7. **Valley shape and overburden-** the shape of the river valley and the overburden, that is, the loose bouldery, gravelly, or sandy material overlying the river floor also influences the type of dam that may be proposed to be constructed. In case of a wide valley with deep deposits of fine-grained soil overburden, say more than 5 meters, favours earth fill embankment dams (Figure 7a) A river valley that has much less over-burden (Figure 7b), would be suitable for embankment, gravity or buttress dams. A narrow valley with steep sides (Figure 7c) and with sound rock in the valley floor and sides may be suited to an arch or cupola dams. If not, then the economics of proposing an alternative in the form of, say, rock fill embankment dam has to be studied. In case of a wide valley separated in two parts (Figure 6d) may suggest a combination of two types of dams. An earth fill embankment may be constructed where the overburden depth is considerable and a concrete gravity dam on the site where the overburden is less. The spillway portion can then be located on the concrete gravity section. Of course, in all the four cases mentioned, the availability of alternative construction materials and their relative costs would have to be considered as well, to choose the final section.

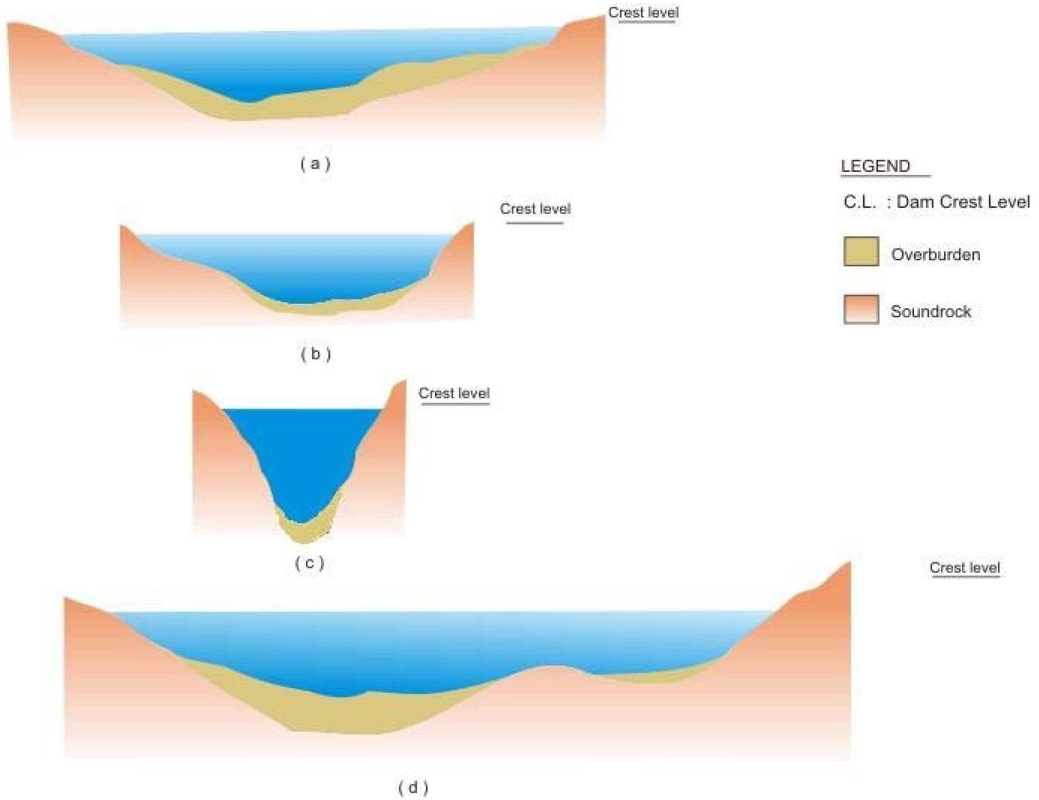


FIGURE 7. Typical valley shapes (a) Wide valley with deep overburden ; (b) Valley with little overburden ; (c) Narrow valley with little overburden ;(d) Valley with irregular depth of overburden

It may be concluded that all the possible alternative designs of dams for a particular dam site must be weighed very carefully. However, some times sufficient time is not available for comparison of acceptable alternatives. At certain sites, it may be expedient to select a simple type of dam – either simple to design or simple to construct. Of course, this may not be safest or most economical dam for a particular site.

Further, the time and money spent on investigation also has an impact on the decision of having a particular dam section. An illustration of a particular case would prove that investigation, especially for geotechnical and foundation suitability cannot be under estimated. The case in point is that of the Salal dam on river Sutlej where an embankment dam was proposed to block river and a chute spillway was found attractive over a mountain ***saddle***. A typical location of such a proposal, but with hypothetical elevation contours is shown in Figure 8a. The designs were made considering a suitable foundation of the spillway and construction commenced. However, during the course of foundation and excavation for the spillway it was that the rock quality of the saddle is quite poor due to the presence of phyllites. In order to get to the sound rock strata, further excavation was carried out, till the spillway foundation level was lowered up to the riverbed. A comparison between the original section proposed (Figure 8b) and the final section constructed (Figure 8c) shows the increase in cost that resulted due to an economization at the time of original investigation. Had a more careful (and consequently slightly more costly) investigation been carried out, then perhaps a better alternative might had been proposed with a concrete gravity dam at axis A-A with an integrated over flow spillway.

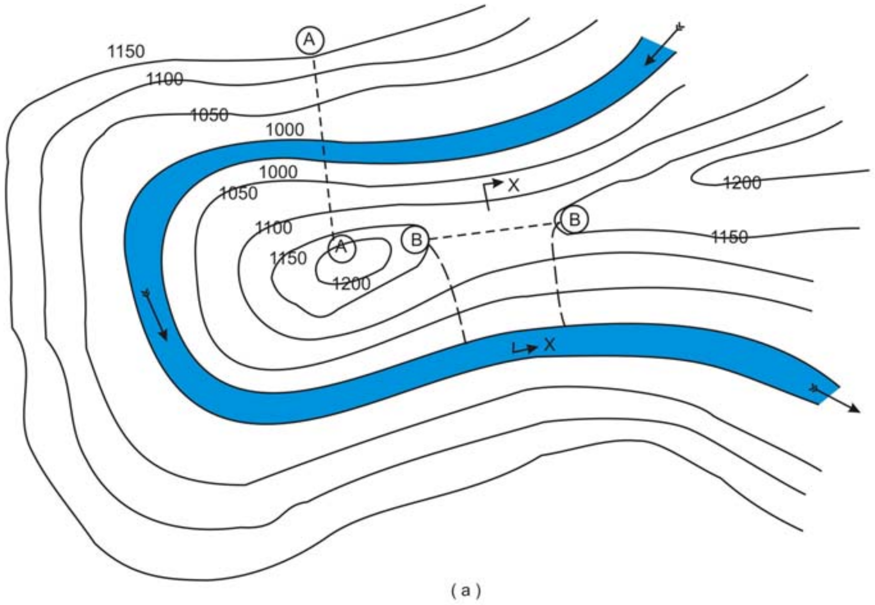


FIGURE 8(a). Schematic layout of a dam and spillway proosed at a river bend
Axis A - A proposed for embankment dam & B - B for chute spillway.

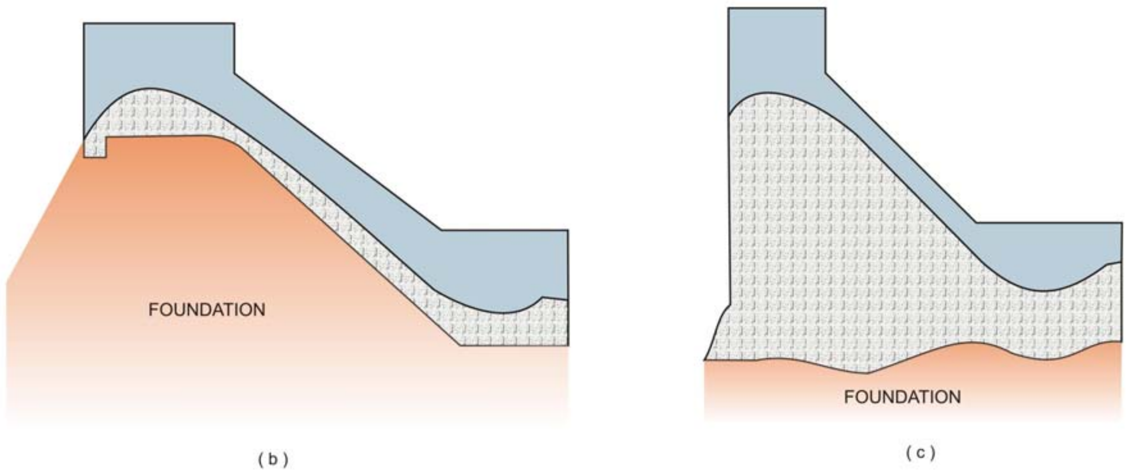


FIGURE 8 (b) Section X-X through originally proposed chute spillway for damsite shown in Figure 7(a)
(c) Final section of spillway adopted due to poor foundation geology

4.4.4 Appurtenant structure and ancillary works

It is not just sufficient to have dam constructed across a river to store water in a reservoir. Each dam has to have certain appurtenant structures to enable them to discharge their operational functions safely and effectively. One important aspect is the passage that has to be constructed to allow the flood waters to flow down the river without affecting the safety of the dam. Then there are the outlet works which provide a means for controlled and regulated discharges for meeting certain demands. These and other structures discussed briefly here, but would be dealt in detail in subsequent lessons.

Spillway

Spillways or passages for letting out flood waters when the reservoir, is over flowing has three major components:

- Entry to the spillway, which may or may not be controlled using gates.
- A channel for conveying the water from the reservoir side to the down stream of the dam.
- And energy dissipating arrangement for the water flowing down the spillway channel as it reaches a lower elevation near the outlet of the channel.

The capacity of the water conveyance of the spillway should be such that it must safely pass the maximum design flood. More than one type of spillway may be provided in a particular dam. For example in the Indira Sagar Dam on river Narmada, two sets of spillways have been provided, one called the main spillway and the other auxiliary spillway. All the spillways are gated, but the crest level of the auxiliary spillways, are slightly higher than that of the main spillways. Under normal flood situations, the main spillways may be operated but if the flood is excessive, auxiliary spillways can be brought into operation. Spillways can be integrated into any type of concrete dam, if so desired but for embankment dams, separated passage has to be designed.

Outlets

These include outlets for irrigation canals, power channels or tunnels, water conditions for domestic and industrial use etc. The provision for such works can be readily accommodated within a concrete dam. However, for embankment dams, it is normal practice to provide an external control structure or value tower, which may be quite separate from the dam. A bottom discharge facility operating under high pressure of the water in the reservoir, through provided in many concrete dams, may be quite expensive, since it is necessary to ensure long life and reliable operation. The following types of sluices are used for following purposes:

- For used during river diversion, at the time of construction of the concrete dam. If these sluices are left out in the body of the dam at a lower level, the construction of the dam can safely go on at higher levels.
- To control the rate of filling of the reservoir. This would be necessary during the first time reservoir filling.
- As part or the whole of the permanent spillway discharge, as it has been done for some arch dams.
- To release the bottom water from a stratified lake. This action may be desirable to remove foul water from the bottom of the reservoir after initial filling.

Cut off

The seepage under and round the flank of a dam must be controlled, or else the foundation of the dam may be weakened. This is achieved by the construction of a cut off or a barrier below the dam penetrating the foundation. This should be continued further towards the abutments on either flank also in order to ensure the complete safety. Different types of cutoffs are in vogue for dams resting on pervious foundation (like river overburden) or drilled and grouted holes in fissured rocks.

Internal drainage arrangement

Any dam, embankment or concrete, is bound to have seepage of water from the reservoir side to the downstream. Of course, the rate of seepage through a concrete dam would be much less than that through an embankment dam. Hence, internal drainage system is almost invariably provided in most of the dams. In embankment dam, a thin vertical wall of very pervious material acts like a drain, collecting the seepage water and passes it downstream with the help of a connected horizontal layer of pervious material that extends up to the down stream face of the embankment dam. In concrete dams, vertical drains are formed near the upstream face of the dam which collects the seeping water and pass it on to a gallery near the base of the dam that extends from one abutment to the other. From this gallery, the collected water is drained off to the downstream by drains located at suitable points.

4.4.5 Layout of dams

As pointed out earlier, each dam project is designed uniquely based on the local conditions and other factors. Hence, there may not be any generalized solution for the layout but has to be decided individually for each case. In this section, some particular projects have been illustrated demonstrating typical layouts for embankments and concrete dams. A brief description of the projects accompanies the figures.

Bhakra Dam

This is the so far tallest dam in India constructed under the Bhakra-Nangal project on the river Sutlej meant to serve irrigation and power generation. The dam is 225.6m high concrete gravity type with two power houses having an aggregate installed capacity of 1050 MW. Some kilometers downstream of the Bhakra Dam is the 27.4m high Nangal Dam for regulation and flow diversion (as done in a barrage) through a 64km long power channel supplying to two power houses of aggregate of installed capacity of 154MW and a network of irrigation canals which command an area of 2.63 million hectors in the State of Punjab, Haryana and Rajasthan.

The general layout of the Bhakra Dam and its appurtenant structures is shown in Figure 9. A section through the spillway of the dam is shown in Figure 10. Two views of the dam, one from upstream and another from downstream are shown in Figure 11.

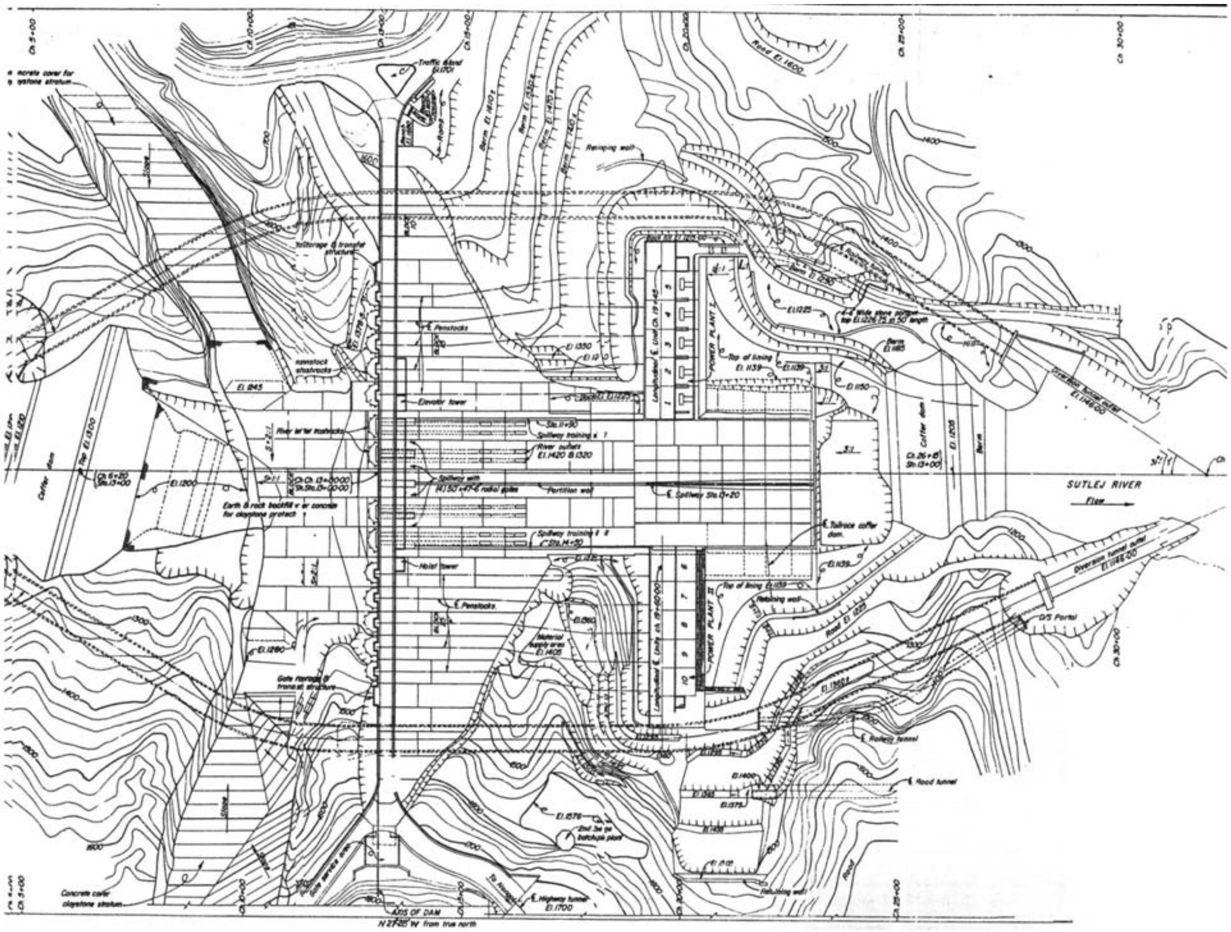


FIGURE 9. GENERAL LAYOUT OF BHAKRA DAM ON RIVER SUTLEJ

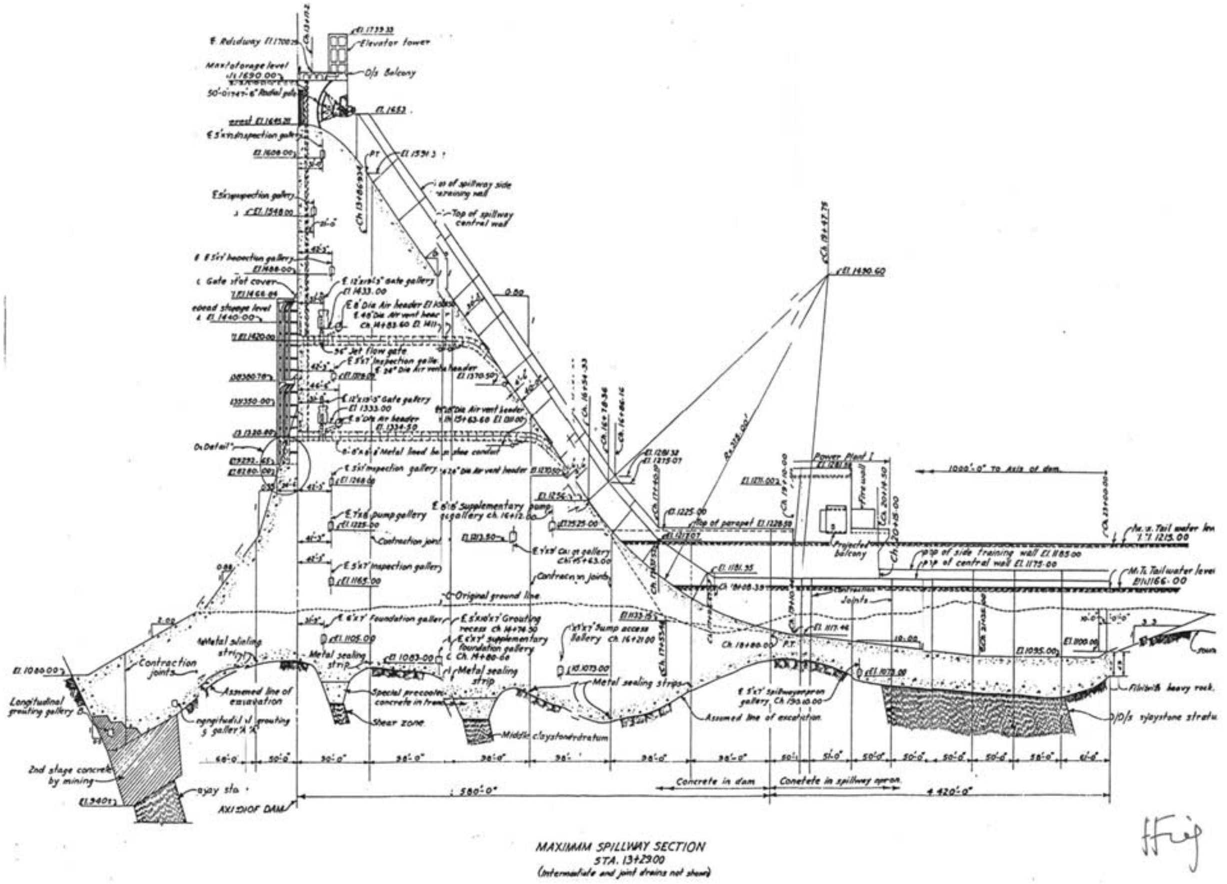


FIGURE 10. SECTION THROUGH BHAKRA DAM

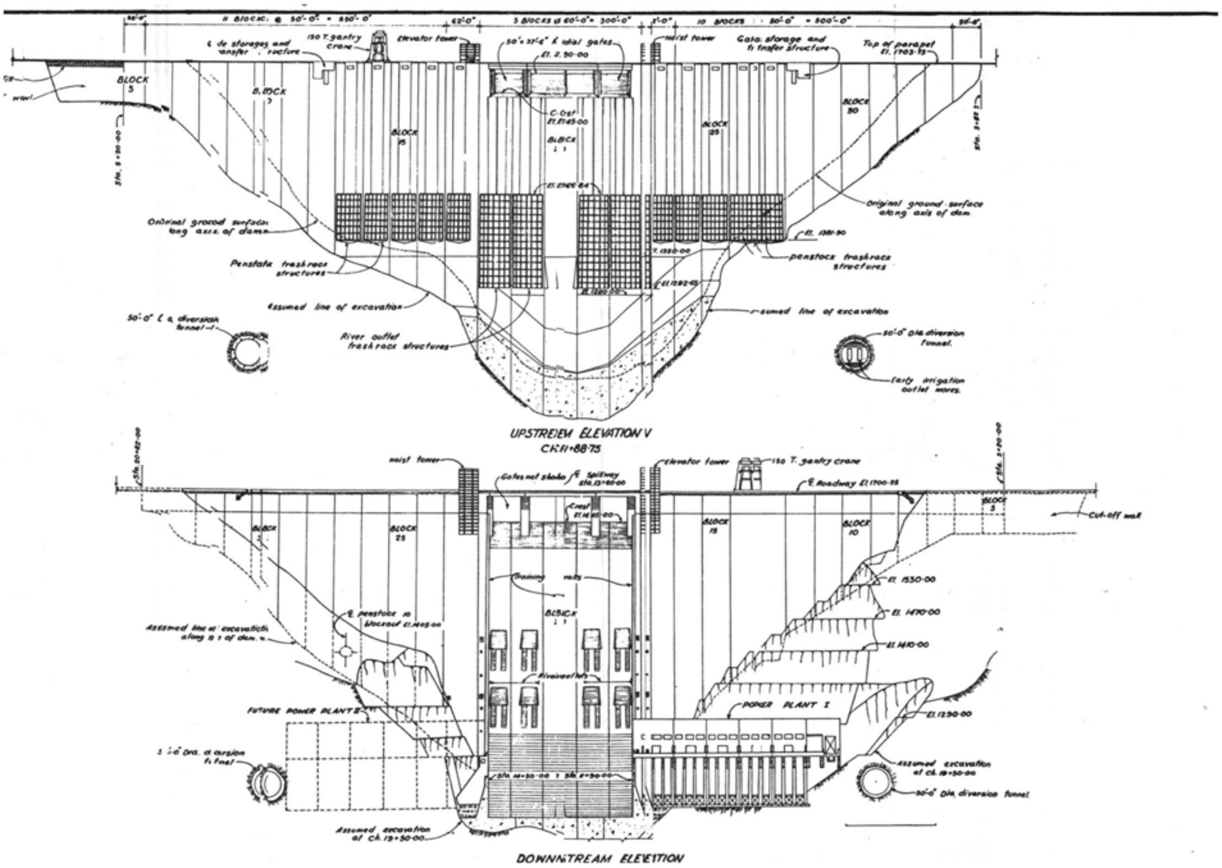


FIGURE 17. Upstream and downstream views of Bhakra dam

Nagarjuna Sagar Dam

This dam, on the river Krishna, is the tallest masonry dam not only in India but in entire world, with a maximum height (at the deepest portion of the river valley) of 124.7 m. Another unique aspect of the dam is that it was built entirely of human labour, employing about 60,000 workers almost throughout its period of construction. The dam is part of an irrigation project and has a reservoir with a gross storage capacity of $11.56 \bullet 10^6$ m^3. With two canals taking off from the reservoir at either flank to irrigate lands to the extent of $7.60 \bullet 10^5$ hectare and $4.45 \bullet 10^5$ hectare respectively, catering to about eight districts in the state of Andhra Pradesh.

A general layout of Nagarjuna Sagar Dam is shown in Figure 12 and section through the spillway and non-overflow blocks are shown in Figure 13. Though the main dam is built in masonry, it is connected to the higher banks of the river valley on either side by earthen embankment dams of length 2.56km on the left flank and 0.85km on the right flank. A section through the embankments is shown in Figure 14.

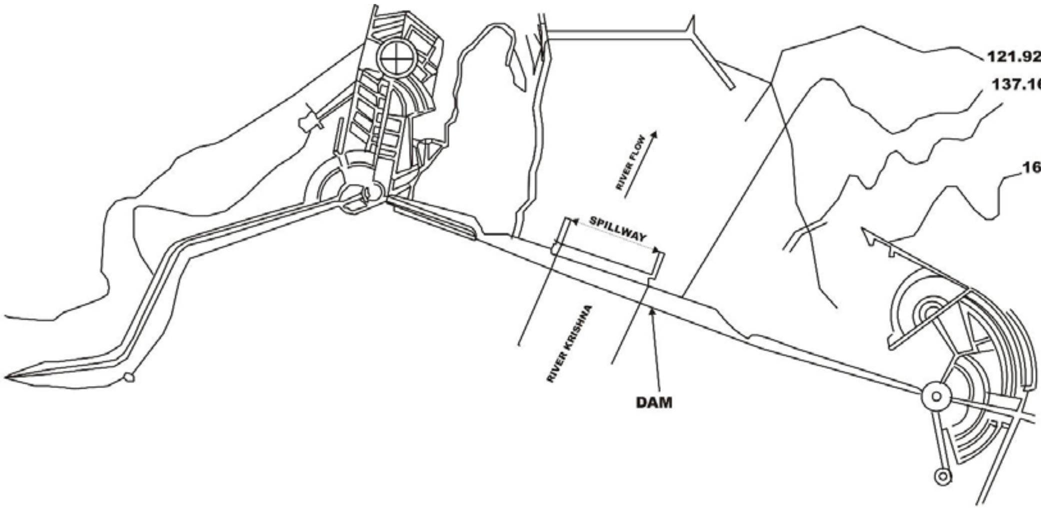
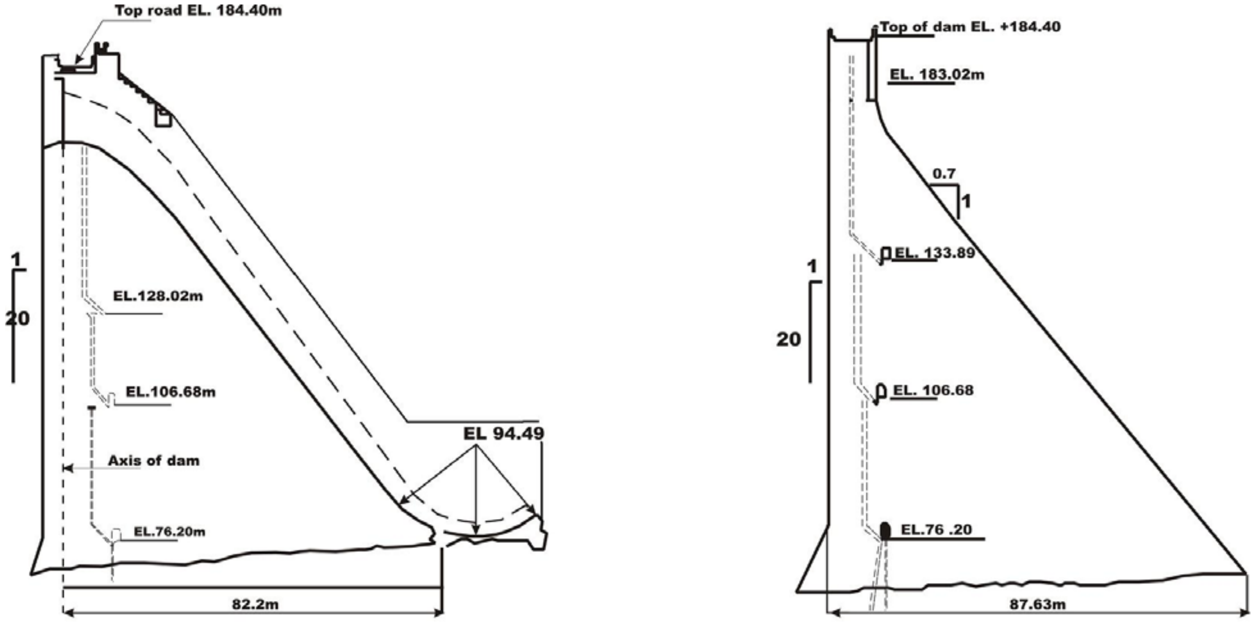


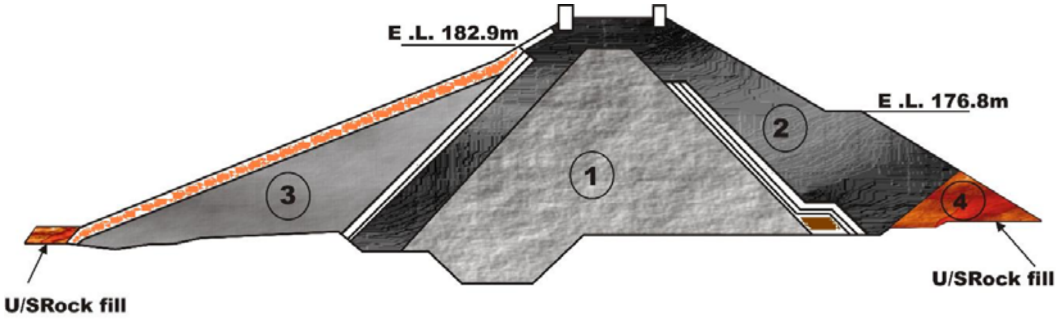
FIGURE 12. GENERAL LAYOUT OF NAGARJUNA SAGAR DAM ON RIVER KRISHNA



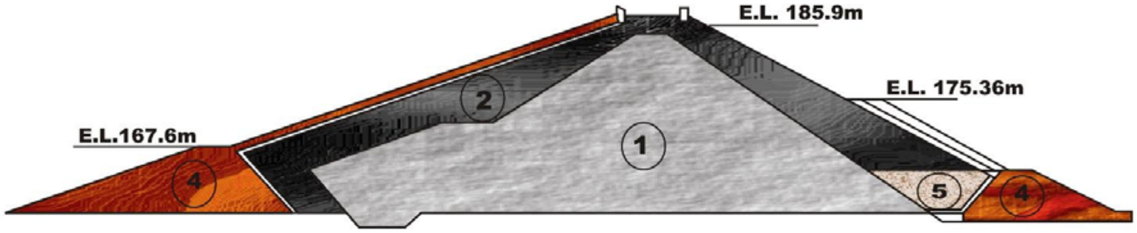
Maximum spillway section

Maximum non-overflow section

FIGURE 13 MAXIMUM SECTIONS THROUGH SPILLWAY AND NON-OVERFLOW BLOCKS OF NAGARJUNA SAGAR DAM



Right earth dam



LEGEND
1 . Impervious
2 . Semiperviuous
3 . Pervious
4 . Rock fill

Left earth dam

FIGURE 14. Maximum section of embankment dams of Nagarjuna Sagar project

Pong Dam

The Pong Dam is located in the Himalayan foot-hills in the district Kangra in Himachal Pradesh, on the river Beas. It is of the rock fill type with a central earthen core and sand and gravel shell zones on the upstream and downstream sides. The dam stands 132.6m from the deepest foundation level in the river valley. The length at the crest level is 1950.7m and width at the top is 13.7m except at special section where it is more. The overall base width at the deepest bed level is 610m. The dam serves the purposes of storing water for irrigation, power generation and flood control. A general layout of the dam is shown in Figure 15 and a view of the maximum section in Figure 16. The dam has an overflow type of gated chute spillway, whose plan and elevation are shown in Figure 17.

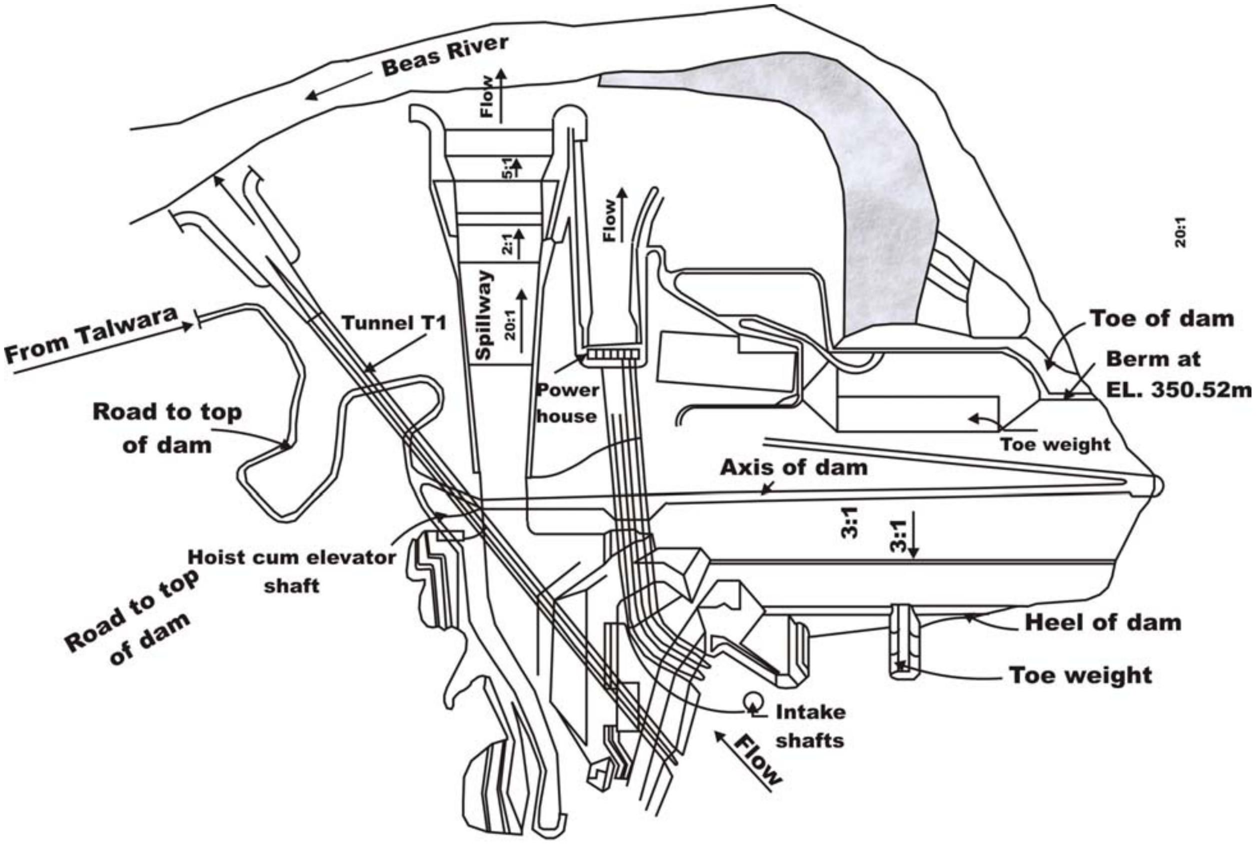


FIGURE 15. GENERAL LAYOUT OF PONG DAM ON RIVER BEAS

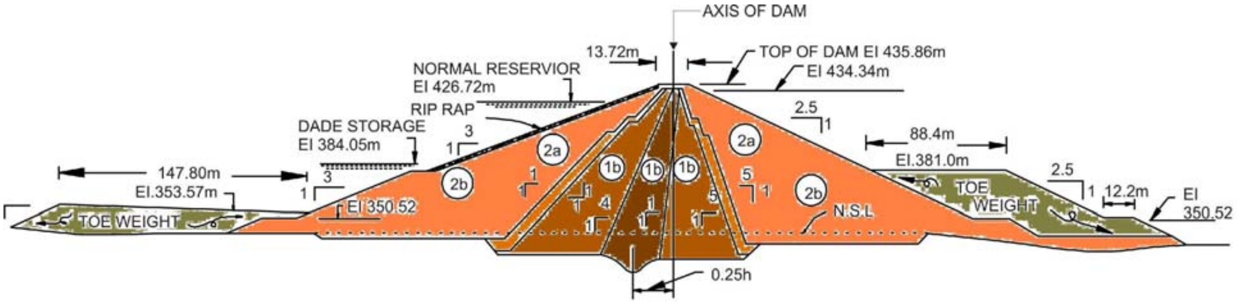
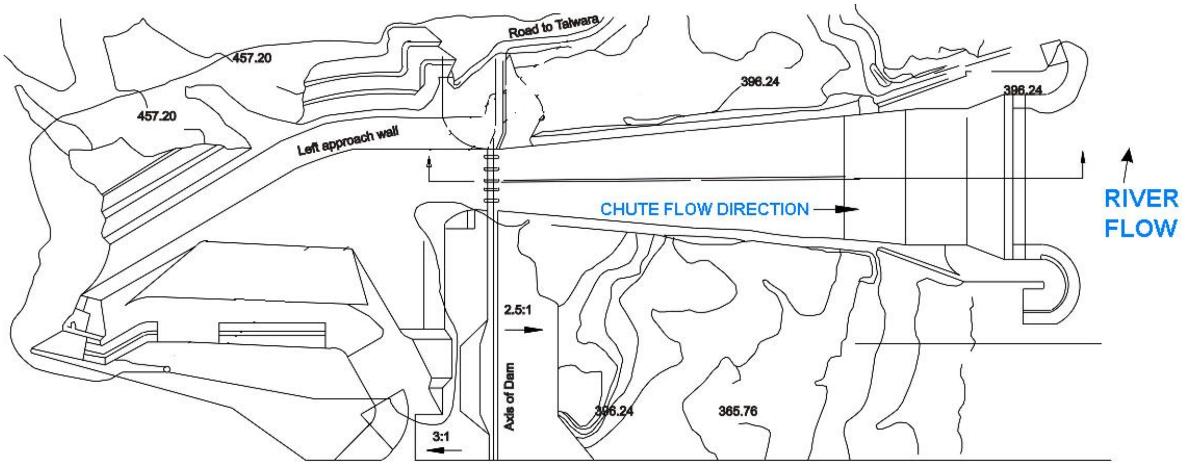
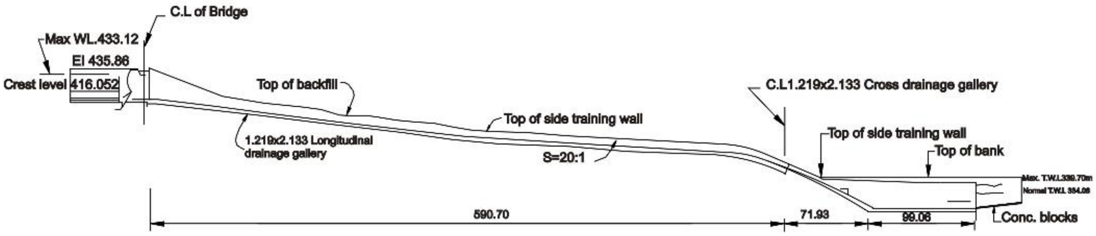


FIGURE 16.MAXIMUM NON-OVERFLOW EMBANKMENT DAM SECTION OF PONG PROJECT



PLAN



section A-A

FIGURE 17. PLAN AND SECTIONAL ELEVATION OF CHUTE SPILLWAY OF PONG PROJECT

Ukai Dam

This dam on the river Tapi is meant for irrigation to a total commended area of about 427110 ha and power generation of 193 MW. As may be seen from the general layout of the dam (Figure 18), there are two main parts of the dam- the masonry dam, as in the spillway portion (Figure 19) and power dam portion (Figure 20) and the earthen embankment dam (Figure 21).

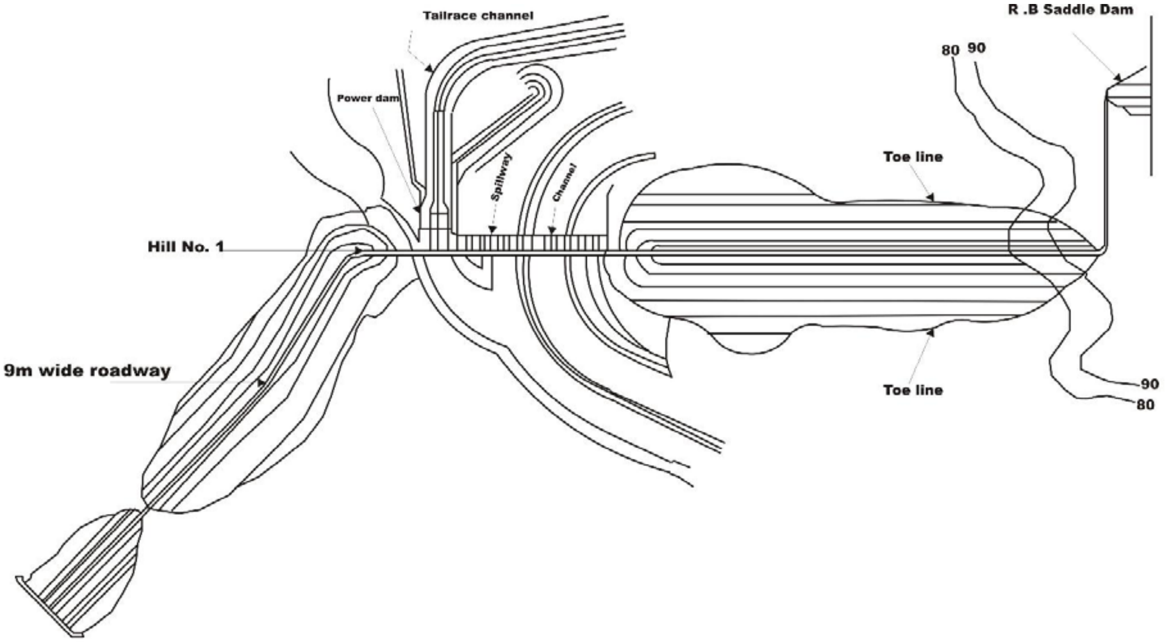


Figure 18 General layout of Ukai Dam on river Tapi

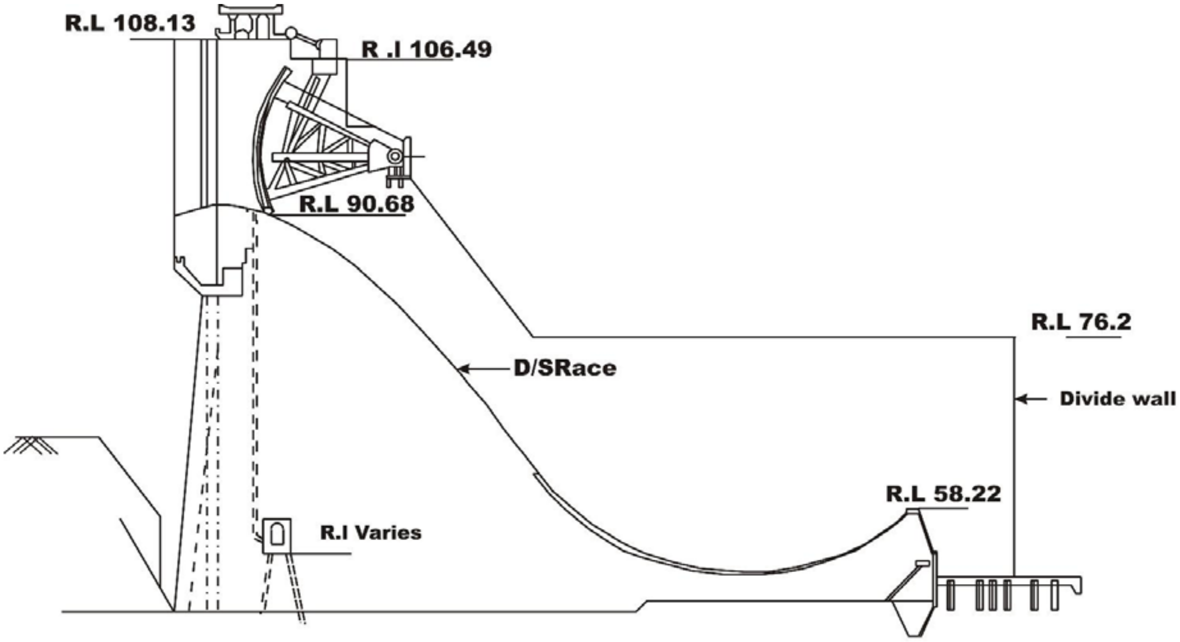


FIGURE 19. Spillway section of Ukai Dam

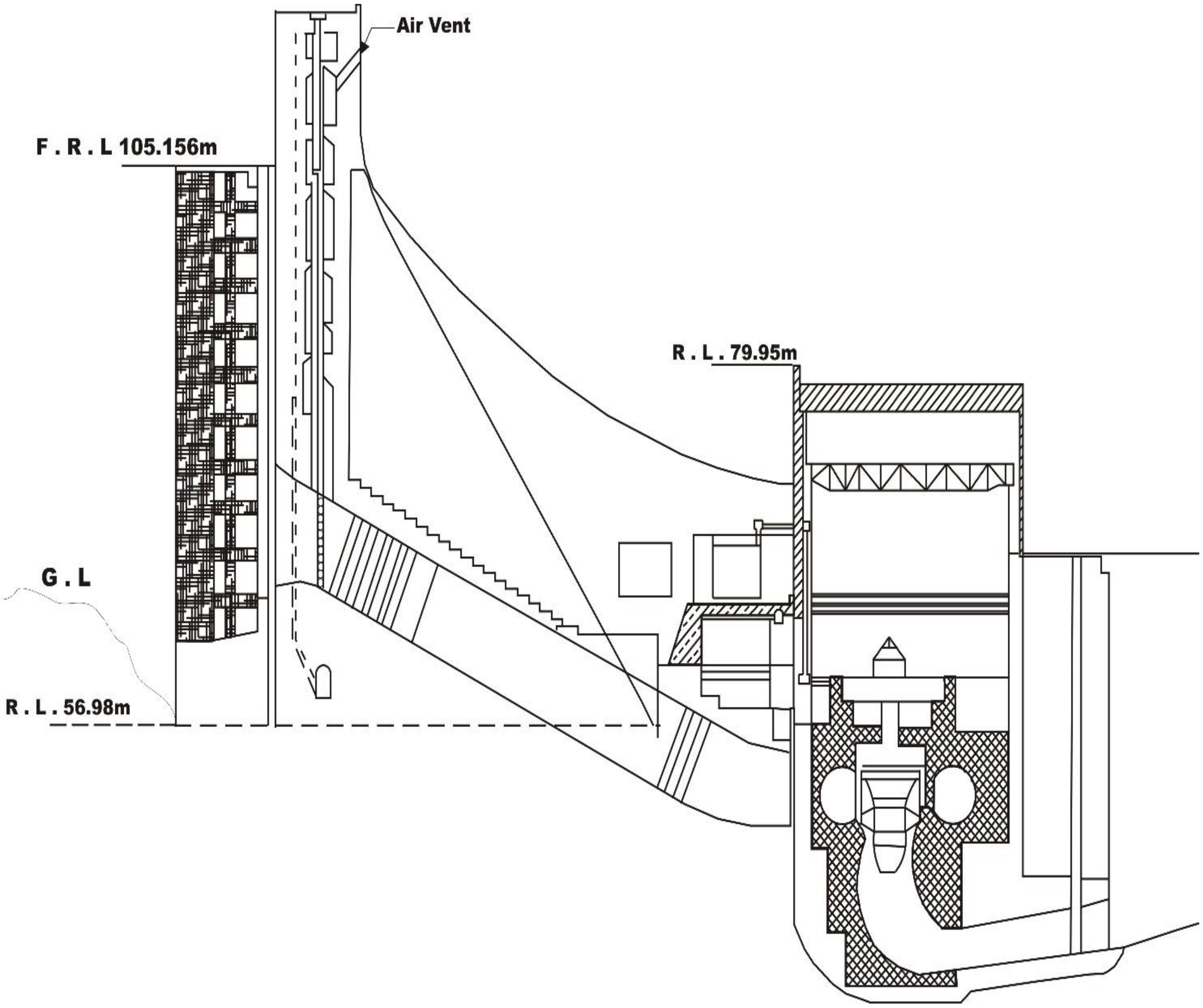


FIGURE 20. Power dam section of Ukai project

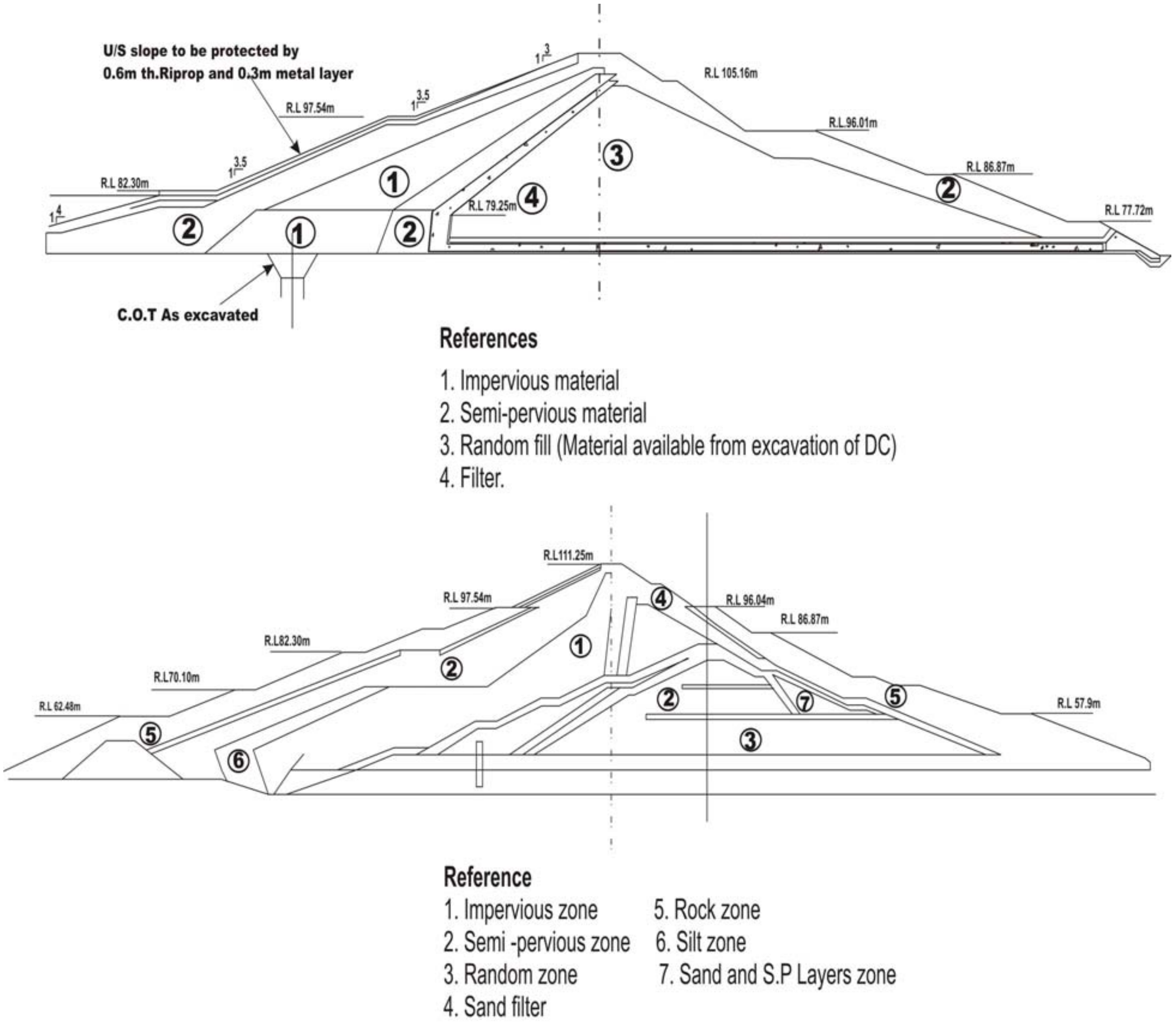
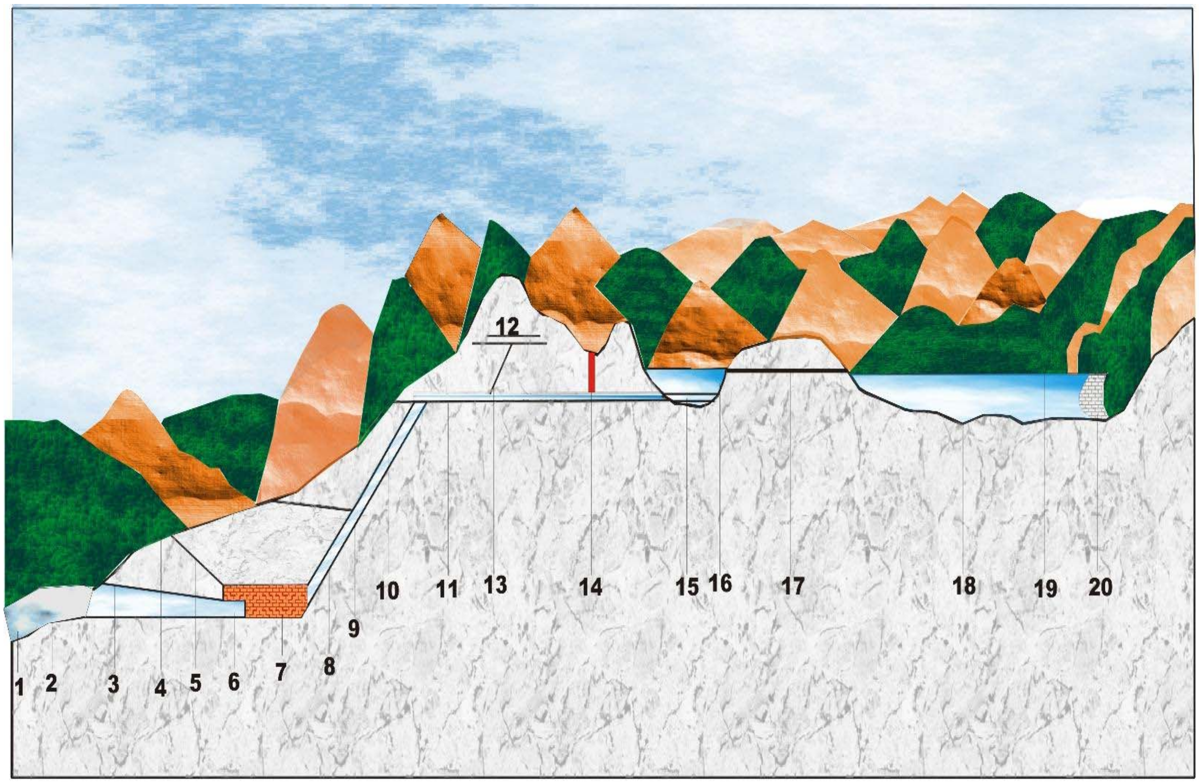


FIGURE 21. TYPICAL EMBANKMENT DAM SECTIONS OF UKAI PROJECT

Idukki Dam

This dam is a part of a hydro electric project and is the only arch dam so far built in this country. The total project consists of this dam (182.9m high) across the river Periyar and another on the river Cheruthoni (152.4m high), which is a tributary of Periyar, to create a common reservoir of about $2 \bullet 10^9$ m^3 of storage. A tunnel diverts the water from this reservoir to an underground power house as shown in schematic profile (Figure 22). The Idukki Dam is defined as a thin double curvature, parabolic, asymetrical high arch dam, the plan and section which being shown in Figure 23.



LEGEND

1. Nachar
2. R.C.C. Conduit
3. Access tunnel
5. Switchyard
6. Tail -race tunnel
7. Underground power house
8. Pressure shafts
9. Intermediate adit
10. Penstock
11. Butterfly valve chamber
12. Expansion chamber
13. Surge shaft
14. Control gate -head race tunnel
15. Power tunnel Intake- tower
16. Kulamvu Dam
17. Open cut channel
18. Indukki Reservoir
19. Cheruthoni Dam
20. Indukki Arch Dam across Periyar

FIGURE 22. Schematic profile through Intake project water conductor system, reservoir and dam

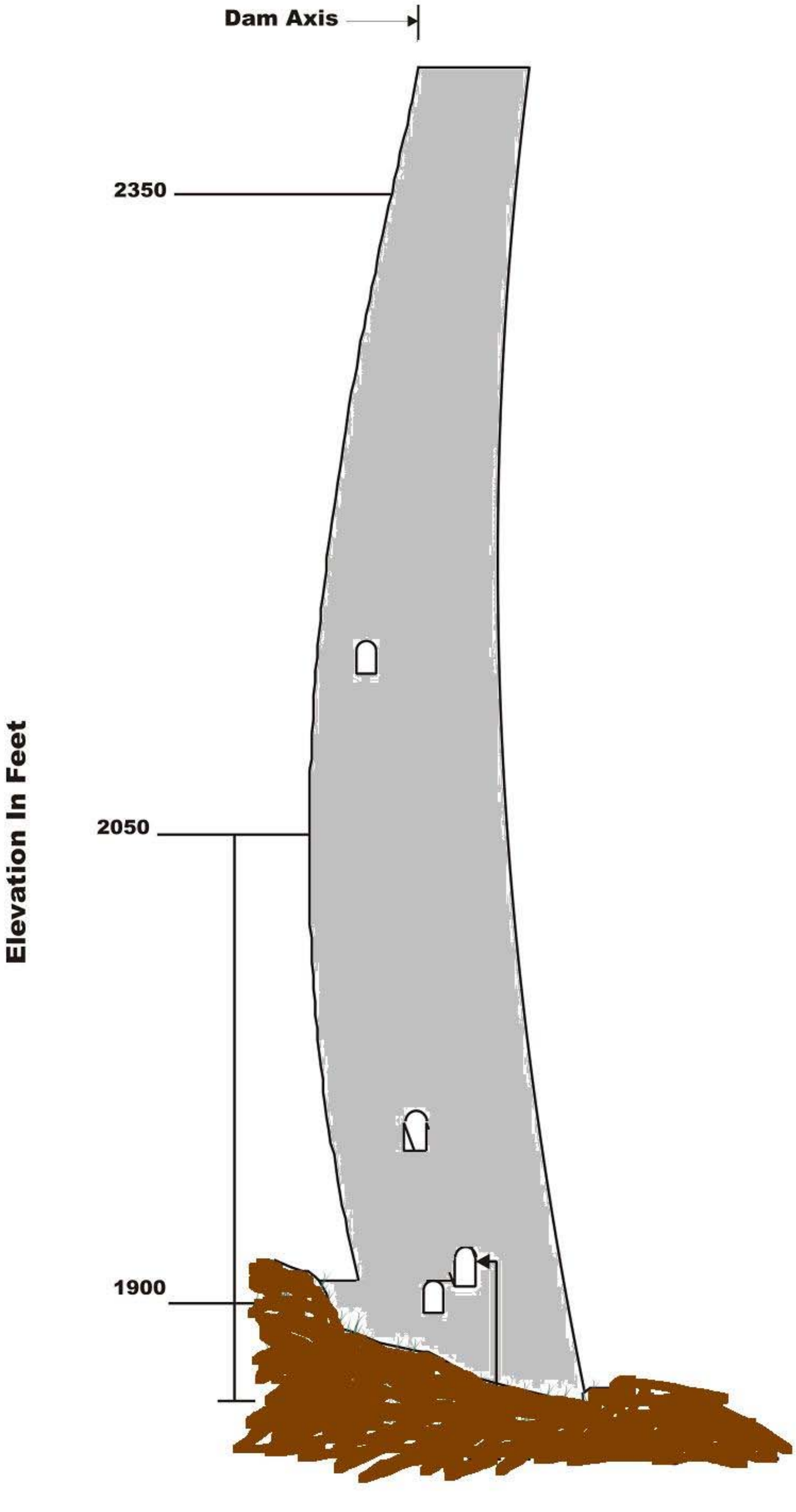
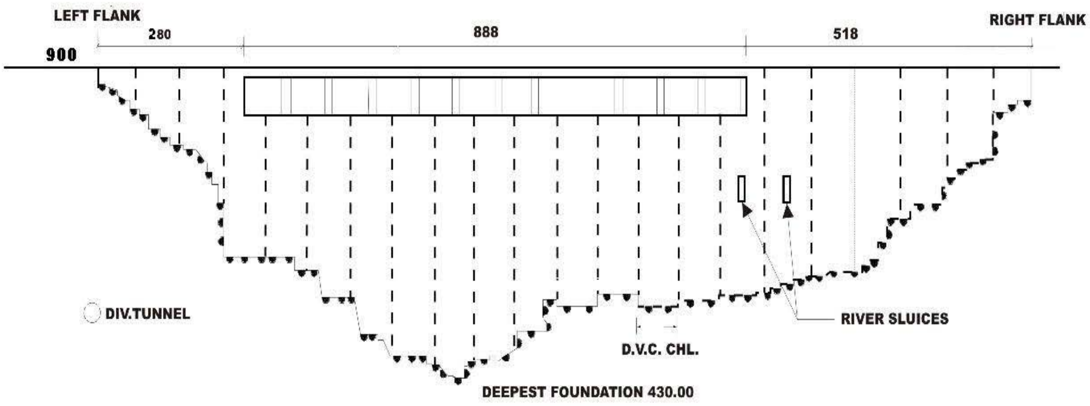


FIGURE 23. SECTION OF IDUKKI ARCH DAM SHOWING GALLERIES,SHAFTS AND ADITS

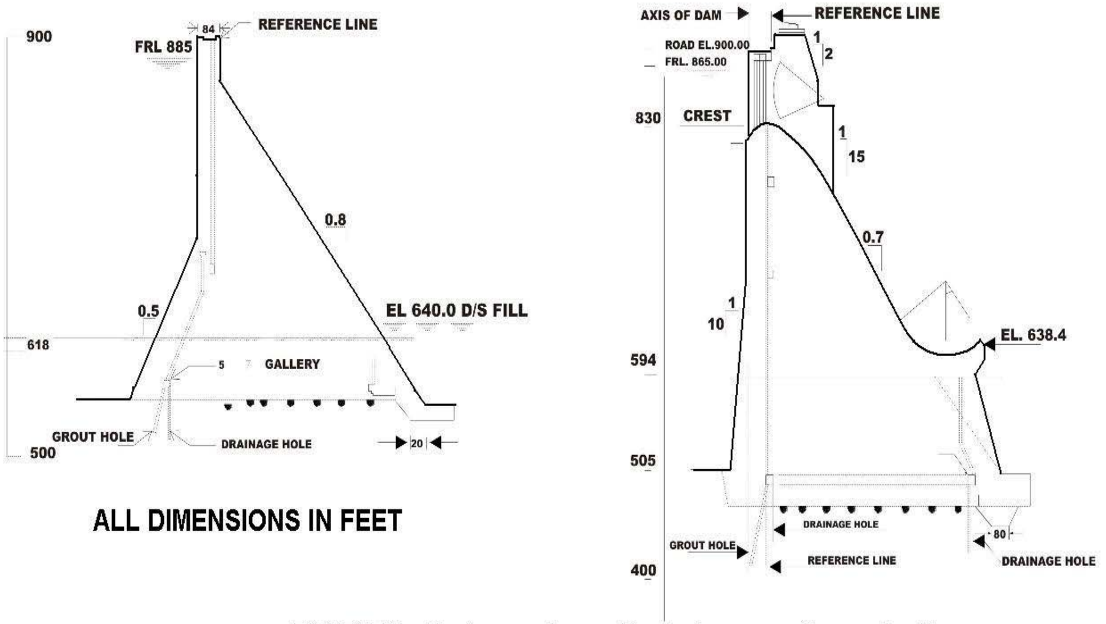
Srisailam Dam

This dam, built on the river Krishna in Andhra Pradesh, is primarily meant for hydro power generation. Apart from a total generating capacity of 770 MW, the dam also caters to the storage of water for irrigation to about $1.6 \cdot 10^5$ hectares. Though the narrowness of the gorge at the dam suggests the adoption of an arch dam, this idea was ruled out as the abutment rocks were not considered competent enough to take the arch thrusts. The dam was finalized to be of concrete- gravity type. A general layout of the project is shown in Figure 24. An upstream view of the dam along with typical sections, are shown in Figure 25.

FIGURE 24. GENERAL LAYOUT OF SRISAILAM DAM ON RIVER KRISHNA



Logitudinal section of the Srisailam Dam along reference line



ALL DIMENSIONS IN FEET

FIGURE 25. Upstream view and typical non- overflow and spillway sections of Srisailam Dam

Kangsabati and Kumari Dams

These are the part of one common project which utilizes the waters of the river Kangsabati and its tributary Kumari by providing an 11km long earthen embankment dam across the two rivers, as shown in Figure 26. The height above the deepest foundation of the Kumari Dam is 41m and the Kangsabati Dam is 88m, a typical section of which is shown in Figure 27. The spillway of the Kangsabati Dam is located on a high level saddle between two hills, the section through is shown in Figure 28. The project releases water through two canals, one each on either bank, and supplies water to about 340890 hectares.

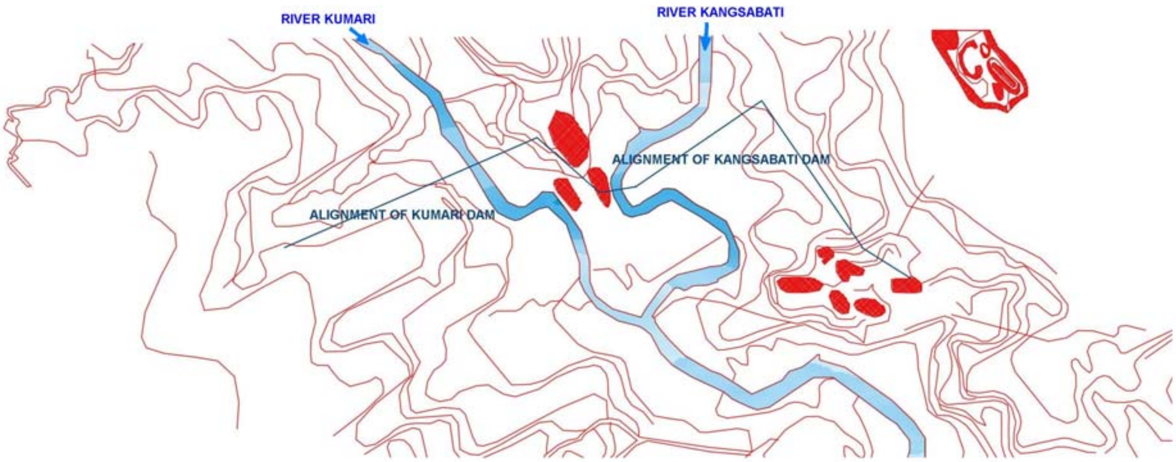


FIGURE 26. General layout of Kumari and Kangsabati dams

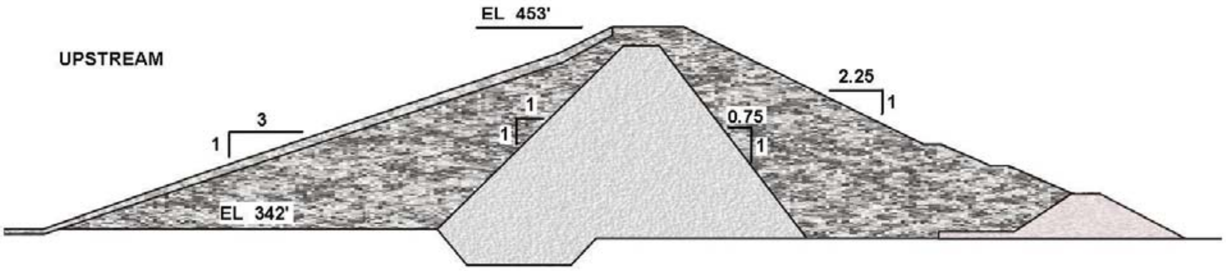


FIGURE 27. Section through Kangsabati embankment dam

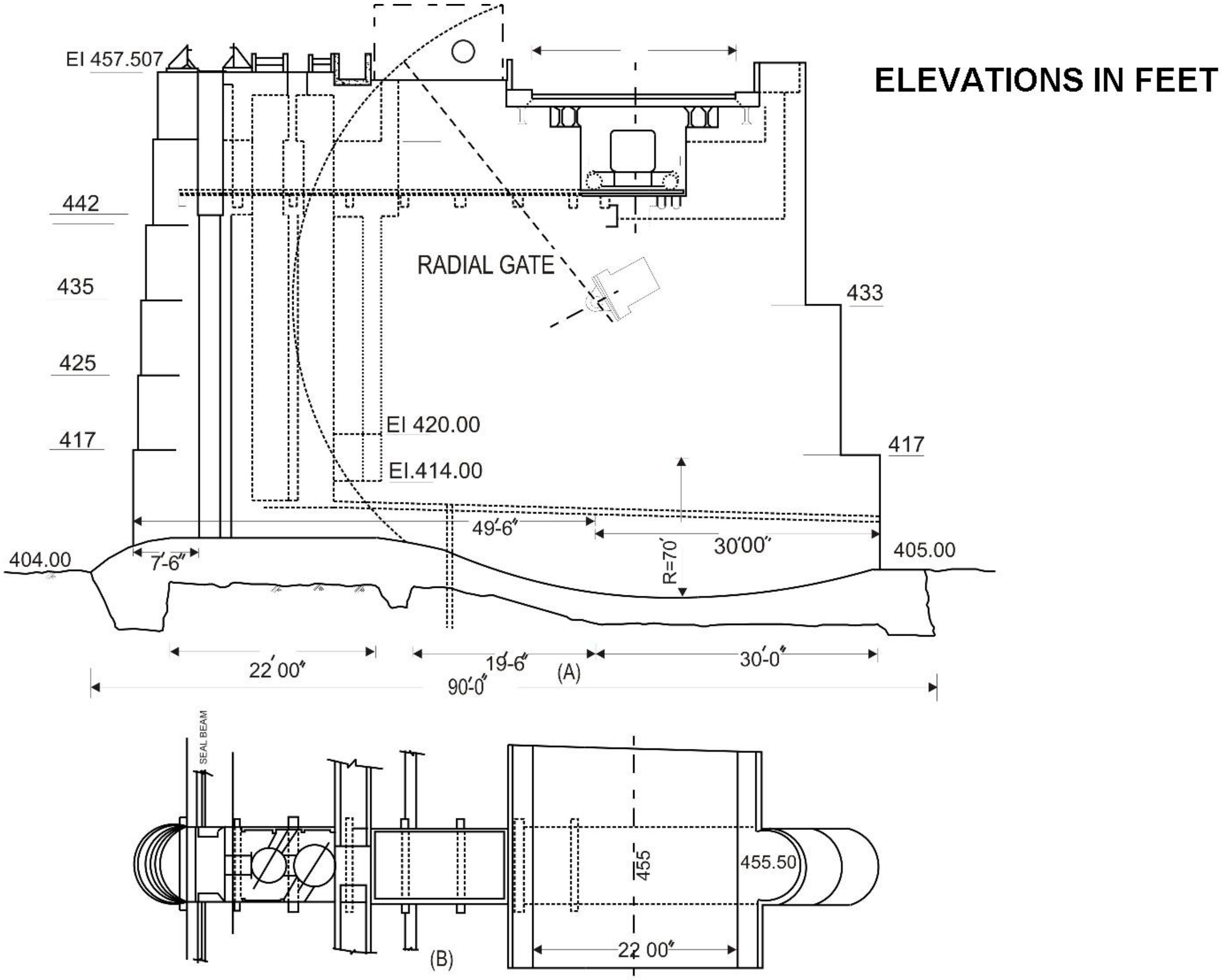


FIGURE 28. (A) SECTION THROUGH THE SPILLWAY OF KANGSABATI PROJECT
(B) PLAN OF PIER

Indira Sagar Dam

This dam on the river Narmada is primarily being built for irrigating around 1230 sq. km. through a canal about 250 km long in the state of Madhya Pradesh. The dam is of concrete gravity type of length 653 m and maximum height above the deepest foundation level is 92m. It is meant to generate power to the tune of 1000 MW. The general layout (Figure 29) shows the dam to be slightly curved towards the upstream in plan, though it is not an arch-type dam. The layout of the dam is shown enlarged in Figure 30. A typical spillway section is shown in Figure 31. It may be interesting to note that the design flood discharge being quite high (83500 cubic meters per sec.) almost all the blocks of the dam are spillway blocks and span continuously from the left to the right flanks of the dam.

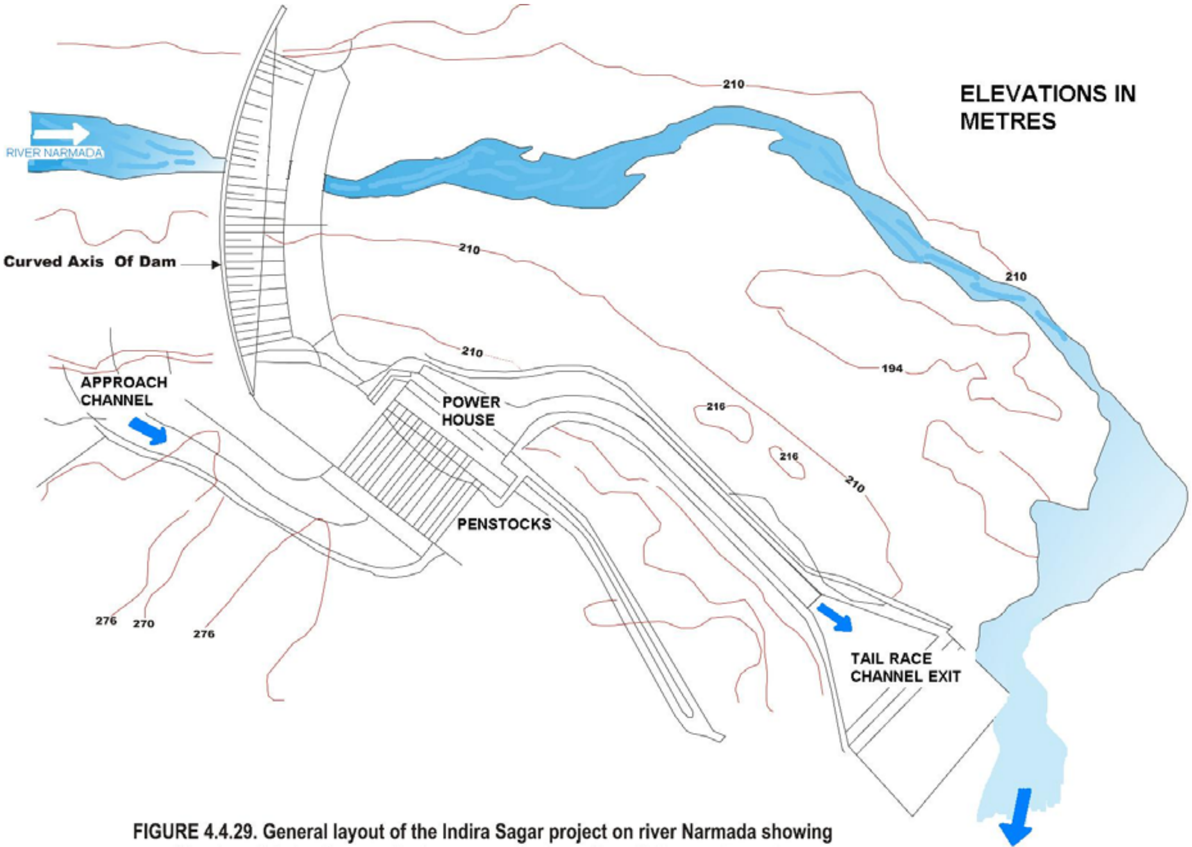


FIGURE 4.4.29. General layout of the Indira Sagar project on river Narmada showing the dam , intakes for penstocks, approach channel and tail race channels

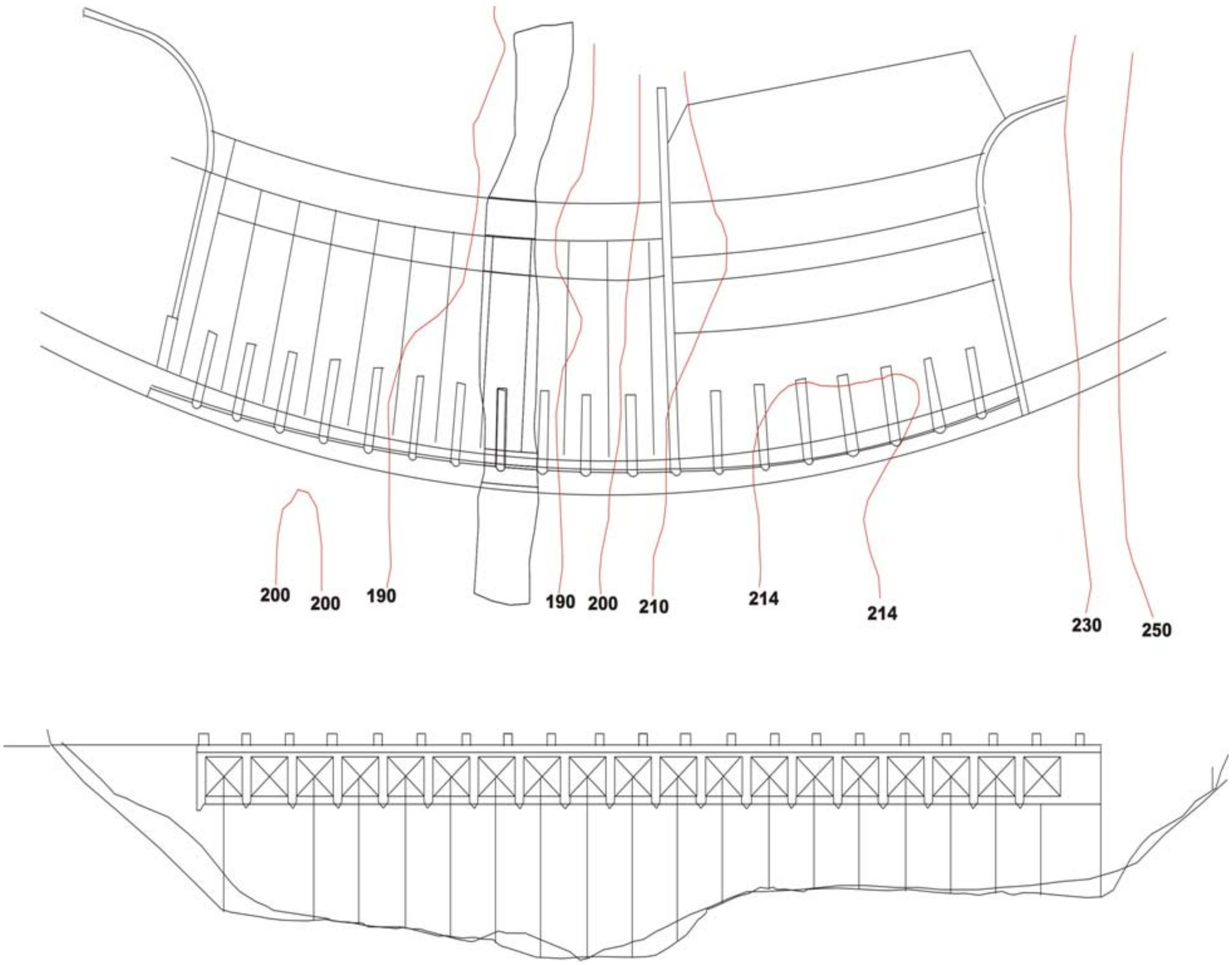


Figure 30. Detailed plan of the Indira Sagar dam and upstream ealevation

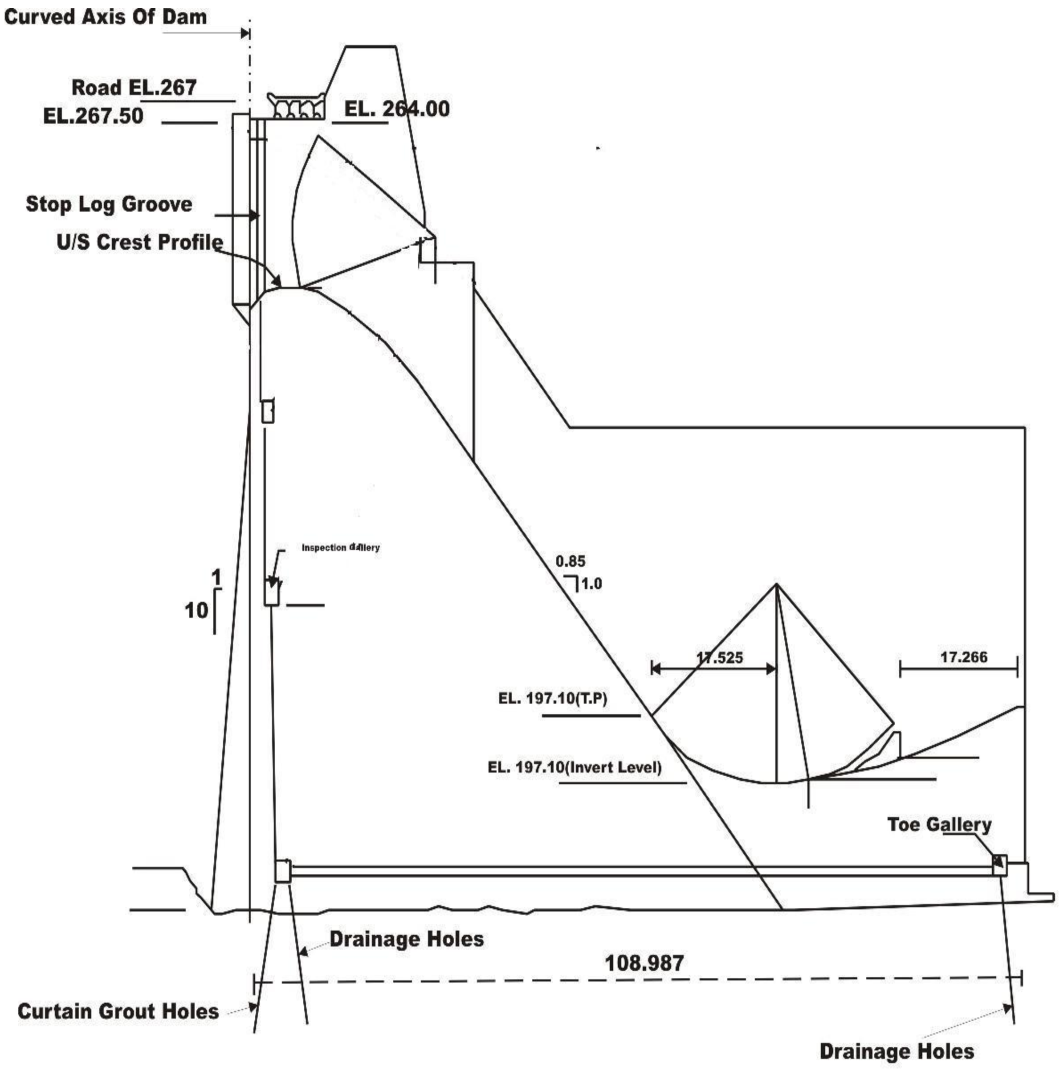


FIGURE 31. Section view through Indira Sagar dam spilway

Sardar Sarovar Dam

This dam, also on river Narmada, is meant to convey water through 458 km long canal in Gujarat and 74 km long canal in Rajasthan for drinking and irrigation. The area proposed to be irrigated is around 17920 sq. km. in Gujarat and 730 sq. km. in Rajasthan. The dam is of concrete gravity type, and its general layout and a typical cross section are shown in Figure 32 and Figure 33 respectively. The dam also proposes to develop 1200MW of power using direct flow in the river, and 250 MW through a power house located at the head of the canal. The turbines of the main power house are actually, reversible type that is they generate power when water flows through them but may also be used as if power is fed to them. These reversible pump turbines have been installed to lift water during night by utilizing the excess power in the national grid from a lower reservoir proposed to be made later by constructing a weir downstream.

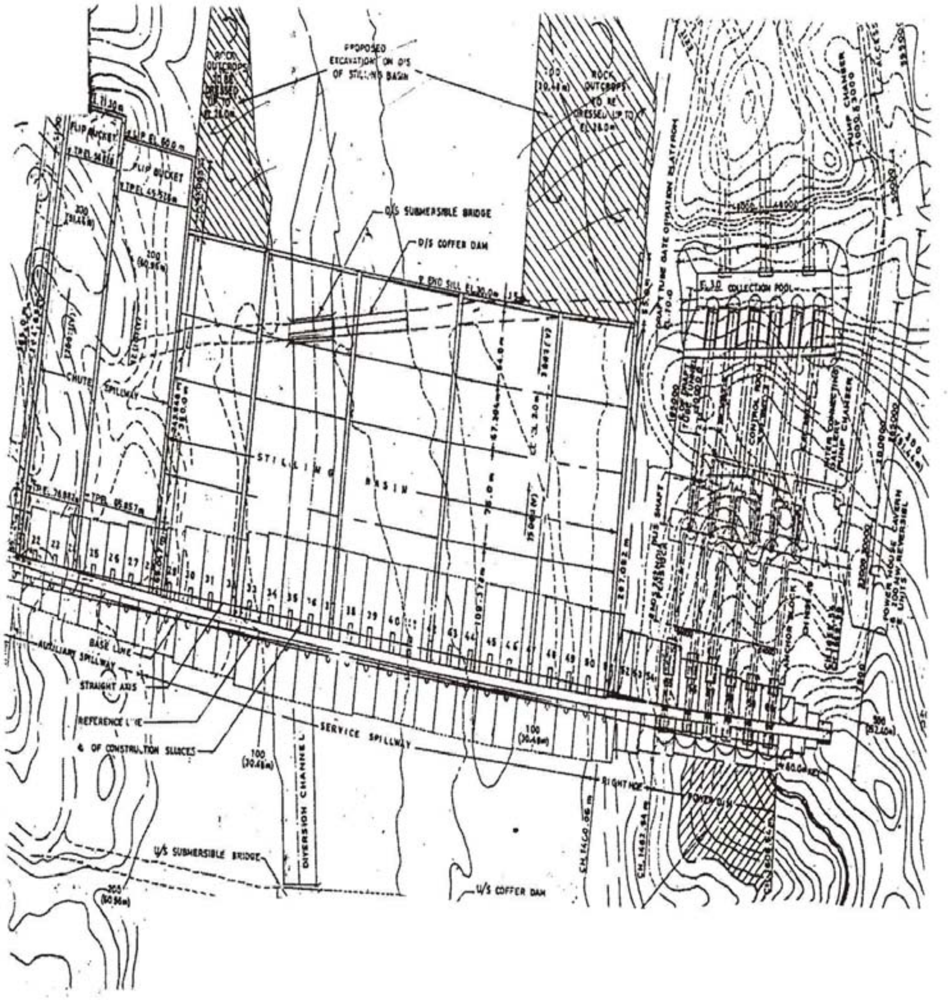


FIGURE 32. LAYOUT OF SARDAR SAROVAR DAM ON RIVER NARMADA AND ITS UNDERGROUND POWER HOUSES WITH CORRESPONDING INTAKES AND TAIL RACE TUNNELS / CHANNELS

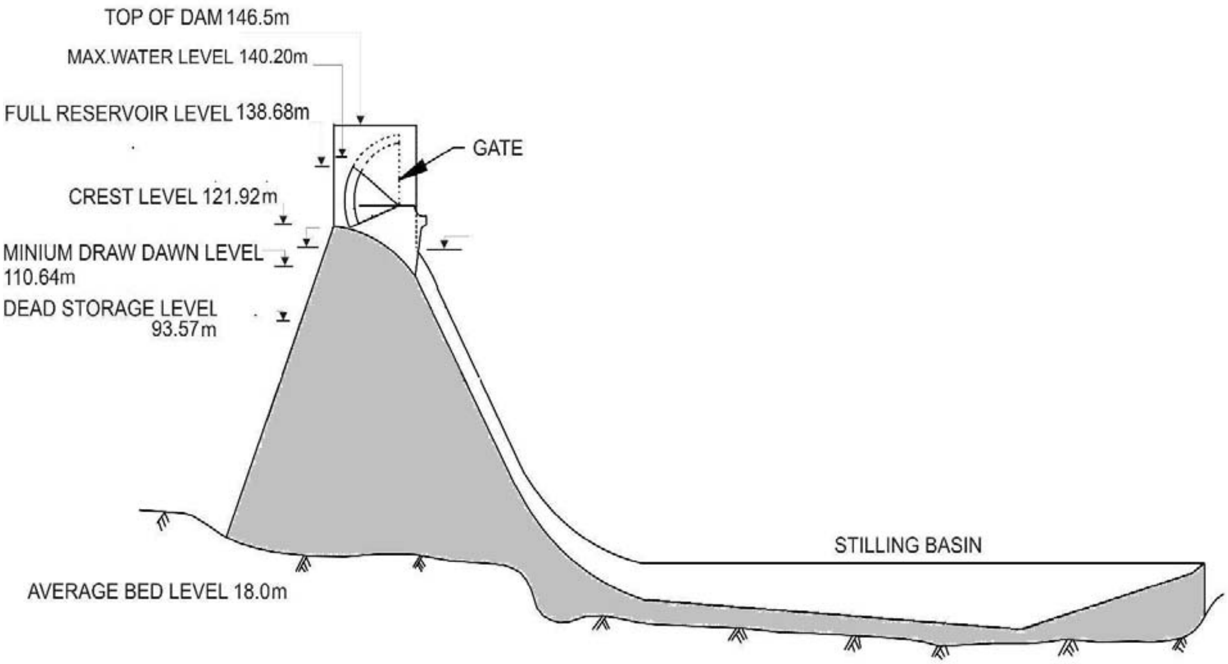


FIGURE 33.SECTIONAL VIEW THROUGH SARDAR SAROVAR DAM SPILLWAY

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- IS: 4078-1967 “Code of practice for indexing and storage of drill cores”
- IS: 4464-1967 “Code of practice presentation of drilling information and core description in foundation investigation”
- IS: 6955-1973 “Code of practice for subsurface exploration for earth and rock fill dams”
- IS: 4453-1967 “Code of practice for exploration by pits, trenches, drifts and shafts”
- IS: 1892-1962 “Code of practice for site investigation for foundations”