INTRODUCTION

WATER RESOURCES DEVELOPMENT PROJECTS

Water-resources engineering is concerned with the utilisation of water, control of water, and water quality management. Water is *utilised* for various beneficial purposes such as irrigation, water supply, hydropower and navigation. Water is *controlled* and regulated for a variety of purposes such as flood control, land drainage, sewerage and bridges so that it does not cause damage to property, inconvenience to the public, or loss of life. *Water-quality management* or pollution control is also an important phase of water resources engineering to maintain the required quality of water for municipal and irrigation uses and to preserve the environment and ecological balance.

The *development* of water resources of a region requires the conception, planning, design, construction, and operation of various facilities to utilise and control water, and to maintain water quality. Because each water-development project is unique, it is not possible to give a standard solution. The special conditions of each project should be tackled through an integrated application of the fundamental knowledge of many disciplines.

The *Planning* of a water-resources development project involves systematic consideration of the original statement of purpose, evaluation of alternatives and the final decision. It forms the basis for the decision to accept or to reject a particular project. It involves a thorough study of various alternatives, selecting the best alternative and the methods for the implementing the same to achieve the optimum benefits. It is the most important aspect of the total engineering for the project. Planning is relatively easier if there is only one objective to be achieved. In multiple objectives, the planning becomes more difficult. The planning of the entire river-basin consisting of a number of projects is even more difficult because whatever is done at one site, it would affect other projects elsewhere in the basin. The planning of a water-resources development project generally consists of the following steps: (1) Statement of objectives, (2) Collection of data (eg, location, size, physiography, climate, history, ,population, Precipitation, evaporation, transpiration, stream flow, sediment, water quality, rock and soil type, ground water, minerals, erosion, topographic and other maps of the area, type of vegetation, fish and wild life, population statistics, data of people and various institutions, various industries, means of transportation, market, tourism, recreation, land, taxes, water rights, population control, land zoning, land ownership, administrative pattern, types and locations of various projects, opinions of different sections of society, land classification, crop water requirements, climatic data, types of crops, drinking water needs, industrial water needs, quality of water, need of power, variation of power demands, alternate energy sources, record of past floods, extent of damage caused, storm-water drainage requirements, existing water traffic patterns, alternate means of transport, existing recreational facilities, natural attractions, scenic data, existing waste discharge methods, location, time and character of waste, water pollution regulations, quality standards, type of fish and wild life, their migratory habits, protection requirements, etc), (3) Future projections, (4) Project formulation, (5) Project evaluation, and (6) Environmental considerations

Various Purposes

The water-resources development projects are planned to serve various purposes as follows:

(A) *Main Purposes*: The following are the main purposes.

1. **Irrigation:** The objective of irrigation is to increase the agricultural production. Various works required for irrigation are dams, reservoirs, wells, canals, distribution systems, drainage facilities, farmland grading, etc.

2. **Hydroelectric powers**: The objective of hydroelectric power development is generation of electric powers for economic development and improving living standards. The works include forebay, penstocks, turbines, generators, transformers, transmission lines, etc.

3. **Flood control**: Flood control works are required for prevention or reduction of flood damage, protection of areas, river regulation, recharging of water, etc. The various works and measures include dams, storage reservoirs, levees, flood walls, channel improvements, flood ways, flood-plain zoning, flood forecasting, etc.

4. **Domestic and industrial water supply**: The objective to be achieved is to provide safe and adequate water for domestic, industrial, commercial, municipal and other uses. The various works and measures adopted are dams, reservoirs, wells, conduits, pumping plants, treatment plants, distribution systems, etc.

5. **Navigation:** Inland navigation facilities are provided for transportation of goods and passengers. The various works and measures adopted are dams, reservoirs, canals, locks, channel improvement, harbour improvement, etc.

(B) *Secondary Purposes*: The following secondary purposes are also served by various projects.

1. **Recreational:** The objective is to provide recreational facilities for the health and welfare of the people. Various works and measures include reservoirs, swimming pools, facilities for boating and water sports, preservation of scenic beauty, etc.

2. **Fish and wild life**: The objectives in this case are improvement of habitat for fish and wild life, prevention of loss of fish and wild life, enhancement of sport facilities, expansion of commercial fishing, etc. The various works and measures are wild life refuges, fish hatcheries, fish ladders, reservoirs, regulation of stream flows, pollution control, land management, etc.

3. **Drainage control**: The objectives of drainage control are better agricultural production, urban development, protection of public health, prevention of waterlogging and salinity, etc. The various works and measures are ditches, tile drains, levees, pumping stations, etc.

4. **Watershed management**: The various objectives of the watershed management are conservation and improvement of soil, sediment reduction, runoff retardation, forest and grass land improvement, etc. The various works and measures include soil-conservation practices, forest and range management practices, debris detention dams, small reservoirs and farm ponds.

5. **Sediment control**: The objectives are reduction or control of silt load in streams, prevention of silting of reservoirs, preservation of fertility of soil, etc. The various works and measures adopted include soil conservation, afforestation, desilting works, revetment works, bank stabilisation, check dams, special reservoir operation, etc.

6. **Salinity control**: The objective is abatement or prevention of contamination of agricultural, industrial and municipal water supplies by different salts. The various works and measures include reservoirs for augmentation of low stream flows, barriers, ground water recharge, coastal jetties, etc.

7. **Pollution abatement**: The objectives is protection or improvement of quality of water

supplies for municipal, domestic, industrial and agriculture, aquatic life and recreation. The various works and measures include treatment facilities, reservoirs for augmenting low flows, sewage-collection systems, legal measures to control pollution, cleaning of polluted rivers, etc.

8. **Insect control**: The objective is protection of public health, recreational values, forests, crops, and land. The various works and measures include drainage, extermination measures, proper design and operation of reservoirs and associated works.

9. **Artificial precipitation**: The objective is to induce artificial precipitation within meteorological limits of the basin. The various works and measures include cloud-seeding equipment, meteorological instrumentation, etc.

(C) *Miscellaneous Purposes:* In addition to above main and secondary purposes, water resources development projects serve the following miscellaneous purposes:

1. **Employment**: The objective is to provide employment and other sources for increased income in backward areas having a lot of unemployment and underdevelopment.

2. **Acceleration of public works:** The objective is to accelerate the construction of various public works for the development of region. Sometimes, the projects are planned that they may be executed on cost-sharing basis among various agencies, such as central government, state government, local bodies and private organisation, to accelerate the development.

3. **Development of new water resources policies**: The objective is to initiate new policies for the development, composition, formulation and execution of the water-resources projects.

Classification

The water-resources development projects are usually classified on the basis of the number of purposes serves. (1) Single purpose projects: These projects are designed and operated to serve only one basic purpose. (2) Multipurpose projects: These projects are designed and operated to serve two or more purposes.

It may be noted that a project which is designed for single purpose but which incidentally also serves other purposes is not a multipurpose project. Most of the major water-resources development projects in India are multipurpose projects. These projects are designed to serve a number of purposes to make effective use of water resources of the country. Although water resources are quite abundant but because the population is also increasing at a fast rate, it is desirable that the maximum use shall be made of the available water resources by developing multipurpose projects. Moreover, multipurpose projects are generally more economically viable because the increase in costs is often not proportional to the increase in benefits. Additional benefits are, therefore, obtained with a small increase in cost.

Water Requirements of Multipurpose Projects

As discussed above, a multipurpose project is designed to serve a number of purposes. The purposes usually served are irrigation, hydropower, flood control, water supply, navigation, recreation, fish and wild life and sanitation. The water requirements for these functions are quite different. The successful use of stored water in a multipurpose project can be made for various purposes after studying the various requirements. If these requirements are compatible, the stored water is used more effectively because it would simultaneously serve more than one purpose. Water requirements for various functions are briefly reviewed below:

1. **Irrigation**: Water requirements for irrigation in India are mostly seasonal. The maximum demand of water for irrigation is during the winter months for *Rabi crops.* However, there is usually a small demand of water for *Kharif crops* during the summer months just prior to the onset of the monsoon. Water requirements for irrigation are generally higher in a year of low rainfall. But the average demand does not vary greatly from year to year if the irrigated area remains the same. Because irrigation is a sort of insurance against drought, it is desirable to reserve as much storage as possible for irrigation use.

2. **Hydropower:** Water requirements for hydropower depend upon the type of area served. The power demand generally has a marked seasonal variation. However, most of the hydropower plants are connected to a power grid and, therefore, there is considerable flexibility in their operation. The water requirements for hydropower can generally be coordinated with other uses of water. During the period when hydropower production is low, thermal and nuclear plants can be run to full capacity. Moreover, hydropower production does not make consumptive use of water as the water released for hydropower can serve other purposes. Thus hydropower production is quite *compatible* with other uses. Water released for irrigation and water supply may be used to produce hydropower. However, when irrigation demands are low in the rainy season, water has to be released only for hydropower. If the power production is limited only during the period when irrigation demand exists, the load factors for the plant will go down and there will be a loss in overall efficiency.

3. **Flood control**: The basic requirement for flood control is that there should be a lot of empty space in the reservoir so that the flood water can be stored. The flood control use is, therefore, not compatible with other uses which require that adequate water should be stored in the reservoir. However, the flood control requirement is seasonal as it is only during the rainy season.

4. **Water supply**: Requirements for domestic water supply are more or less constant throughout the year. However, the demand is somewhat more during the summer months. With an increase in population, the water demand increases from year to year, and this factor should be considered while planning a water supply project. Adequate reserve should be maintained to avoid water shortage during the periods of drought.

5. **Navigation**: Requirements for inland navigation are that there should be adequate flow in the river to maintain the required water depth. Water is released from a storage reservoir to sustain downstream flow for navigation. There is a marked seasonal variation in the demand. Generally, peak releases are required during the summer months when the natural flow is low.

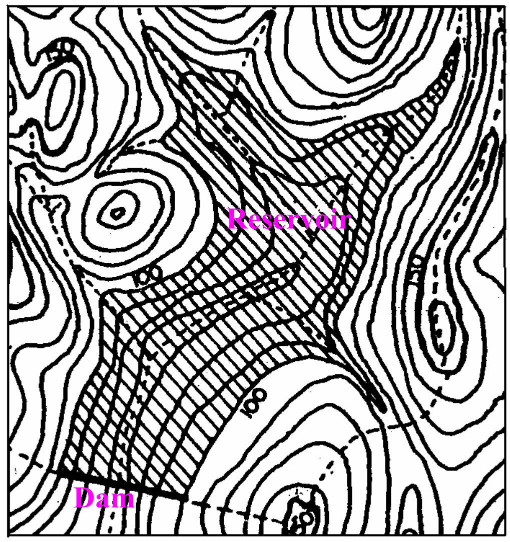
6. **Recreation**: The basic requirements for recreation is that the reservoir should remain nearly full during the recreation season to permit boating, fishing, swimming and other water sports. Moreover, there should not be sudden large drawdowns which may create several problems. However, reservoirs are seldom designed to serve recreation alone. The reservoirs designed for other purposes may have recreation as an incidental purpose.

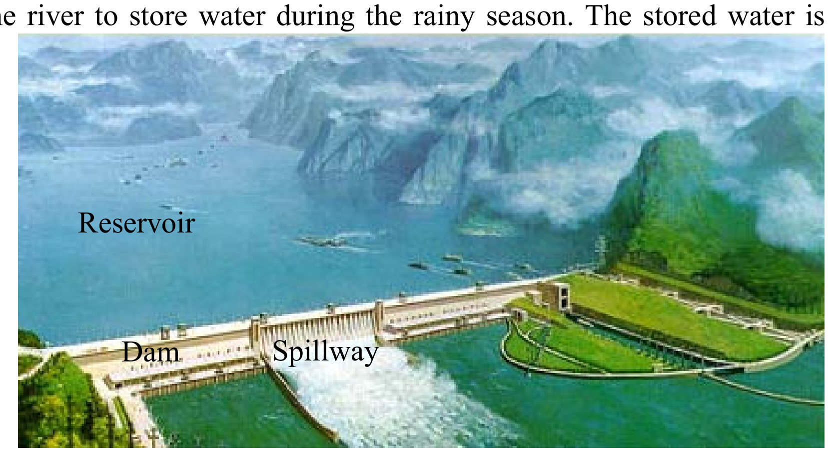
7. **Fish and wild life**: For protection of fish, there should not be large and rapid fluctuations in water level of the reservoir, particularly during the spawning period. Moreover, the flow of water of downstream of the dam should not be completely stopped, as it would lead to the destruction of fish and wild life. Fish ladders or other suitable arrangements are required at the dams to permit migratory fish to travel upstream as well as downstream. However, the construction of a reservoir causes a major change in habitat for existing fish and wild life, and there may be a decrease or an increase in species of fish and wild life.

8. **Sanitation**: The requirement for proper sanitation is that there should be adequate flow downstream of the dam. Sanitation requirements are compatible with other uses as these can be easily combined with the release of water for other uses. Sometimes there is another requirement in some areas that the reservoir should be operated such that there is less mosquito growth. This is usually achieved by causing rapid fluctuations of water level.

RESERVOIRS

A reservoir is a large, artificial lake created by constructing a dam across a river (Figs). Broadly speaking, any water pool or a lake may be termed a reservoir. However, the term reservoir in water resources engineering is used in a restricted sense for a comparatively large body of water stored on the upstream of a dam constructed for this purpose. Thus a dam and a reservoir exist together. The discharge in a river generally varies considerably during different periods of a year. This is especially so for a country like India in which about 75% of the total precipitation occurs during the monsoon season from June to September. Most of the rivers carry very little or no water during non-monsoon period, except the Himalayan rivers, which also carry a substantial discharge in the non-monsoon period due to melting of snow. During the period of low flow, it is not possible to meet the water demands for various purposes such as irrigation, water supply and hydroelectric power. To regulate the water supplies, a reservoir is created on the river to store water during the rainy season. The stored water is later released during the period of low flows to meet the demand. In the monsoon season, the reservoir store excess water when the discharge in the river is high. Thus besides releasing the water during the period of low flows, the reservoirs also help in flood control.





Types of Reservoirs

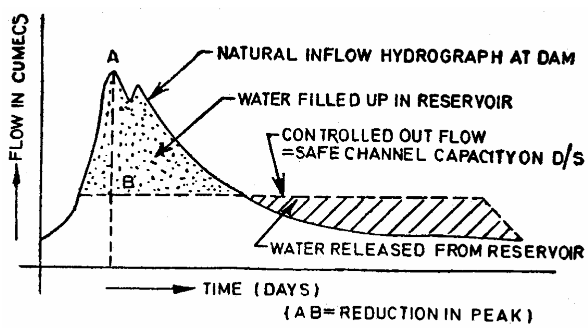
If a reservoir serves only one purpose, it is called a *single-purpose reservoir.* On the other hand, if it serves more than one purpose, it is termed a *multipurpose reservoir.* Because in most of the cases, a single purpose reservoir is not economically feasible, it is the general practice in India to develop multipurpose reservoirs. The various purposes served by a multipurpose reservoir include (i) irrigation *(ii)* municipal and industrial water supply, *(iii)* flood control *(iv)* hydropower, *(v)* navigation, *(vi)* recreation, *(vii)* development of fish and wild life, *(viii)* soil conservation *(ix)* pollution control and *(x)* mosquito control.

Depending upon the purpose served, the reservoirs may be broadly classified into four types: (1) Storage (or conservation) reservoirs, (2) Flood control reservoirs, (3) Multipurpose reservoirs, (4) Distribution reservoirs, and (5) Balancing reservoirs.

1. **Storage reservoirs**: Storage reservoirs are also called conservation reservoirs because they are used to conserve water. Storage reservoirs are constructed to store the water in the rainy season and to release it later when the river flow is low. Storage reservoirs in India are usually constructed for irrigation, the municipal water supply and hydropower. Although the storage reservoirs are constructed for storing water for various purposes, incidentally they also help in moderating the floods and reducing the flood damage to some extent on the downstream. However, they are not designed as flood control reservoir.

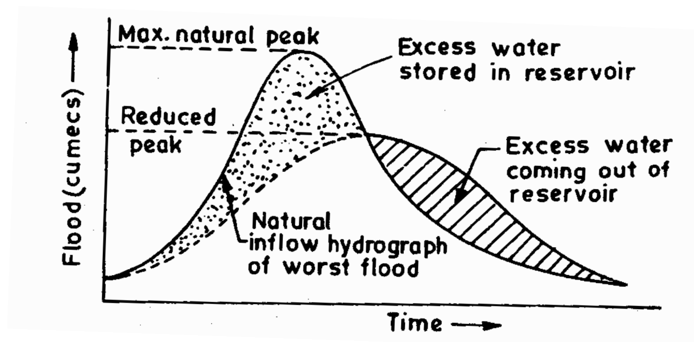
2**. Flood control reservoirs**: A flood control reservoir is constructed for the purpose of flood control. It protects the areas lying on its downstream side from the damages due to flood. However, absolute protection from extreme floods is not economically feasible. A flood control reservoir reduces the flood damage, and it is also known as the flood-mitigation reservoir. Sometimes, it is called flood protection reservoir. In a flood control reservoir, the flood water is discharged downstream till the outflow reaches the safe capacity of the channel downstream. When the discharge exceeds the safe capacity, the excess water is stored in the reservoir. The stored water is subsequently released when the inflow to reservoir decreases. Care is, however, taken that the discharge in the channel downstream, including local inflow, does not exceed its safe capacity: A flood control reservoir is designed to moderate the flood and not to conserve water. However, incidentally some storage is also done during the period of floods. Flood control reservoirs have relatively large sluice-way capacity to permit rapid drawdown before or after the occurrence of a flood. The flood control reservoirs are of two types: (i) Detention reservoirs and (ii) Retarding reservoirs.

i. **Detention reservoirs:** A detention reservoir stores excess water during floods and releases it after the flood. It is similar to a storage reservoir but is provided with large gated spillways and sluiceways to permit flexibility of operation. *The discharge from a detention reservoir to the downstream channel is regulated by gates.* In the earlier stages of a flood, the gates are left open and the water is released subjected to the safe carrying capacity B of the channel downstream. In the later stages of the flood when the discharge downstream exceeds the maximum capacity of the downstream channel, the gates are kept partially closed. There is basically no difference between the detention reservoir and a storage reservoir except that the former has a larger spillway capacity and sluiceway capacity to permit rapid drawdown just before or after a flood. The reservoir is quickly emptied and thus the full reservoir capacity is made available again for moderating a subsequent flood after a short interval. In this manner, the available capacity is more effectively used. When the natural inflow is greater than controlled outflow rate (B), the excess water is stored in the reservoir. The volume of stored water is indicated by dotted area. When the discharge is less than B the stored water is released. The volume of released water is shown by hatched area. Because of detention reservoir, the flood peak is reduced from A to B. Thus the effect of reservoir on a flood is to reduce the peak discharge by absorbing a volume of flood water when the flood is rising, and releasing the same later gradually when the flood is receding. *Advantages* (1) The detention reservoirs provide more flexibility of operation and better control of outflow than retarding reservoirs. Large



reservoirs are usually detention reservoirs. (2) The discharge from various detention reservoirs on different tributaries of a river can be adjusted according to the carrying capacity of the d/s channel. *Disadvantages* (1) The detention reservoirs are more expensive than the retarding reservoirs because of high initial cost and maintenance cost of gates and the lifting machinery. (2) Due to the possibility of human error or negligence, a disaster can occur.

ii. **Retarding Reservoirs**: A retarding reservoir is provided with spillways and sluiceways which are *ungated.* The maximum combined discharging capacity of all spillways and sluiceways is limited to the safe-carrying capacity of the channel downstream. The retarding reservoir stores a portion of the flood when the flood is rising and releases it later when the flood is receding. However, in this case, the discharge downstream cannot be controlled because there are no gates. There is an automatic release of water, depending upon the level of water in the reservoir. As the flood occurs, the reservoir gets filled and at the same time, the discharge from the spillways and sluiceways occurs. When the elevation of water in the reservoir increases, the discharge through spillways and sluiceways also increases. The water level in the reservoir goes on rising until the flood starts receding when the inflow is reduced and it becomes equal to or less than the outflow. After that stage has reached, the water level in the reservoir starts falling and it continues till the stored water has been completely discharged and the water level has reached the lowest sluiceway level. Fig. shows the peak reduction mechanism of a retarding reservoir. The stored water in the reservoir (dotted), which is later released, is shown hatched. A favourable location for a retarding reservoir is just above the area or the city to be protected against floods. A retarding reservoir is also usually located on a tributary of a river just upstream of its confluence to protect the area downstream of it. *Advantages* (1) The retarding reservoirs are relatively less expensive than detention reservoirs. (2) As the outflow is automatic, there is no possibility of a disaster due to human error or negligence. *Disadvantages* (1) The retarding reservoirs do not provide any flexibility of operation as the outflow is automatic. (2) The discharge from retarding reservoirs on different tributaries of a river may coincide and cause heavy flood in the river downstream.



3. **Multipurpose Reservoirs**: A multipurpose reservoir is designed and constructed to serve two or more purposes. In India, most of the reservoirs are designed as multipurpose reservoirs to store water for irrigation and hydropower, and also to effect flood control.

4. **Distribution Reservoir**: A distribution reservoir is a small storage reservoir to tide over the peak demand of water for municipal water supply or irrigation. The distribution reservoir is helpful in permitting the pumps to work at a uniform rate. It stores water during the period of lean demand and supplies the same during the period of high demand. As the storage is limited, it merely helps in distribution of water as per demand for a day or so and not for storing it for a long period. Water is pumped from a water source at a uniform rate throughout the day for 24 hours but the demand varies from time to time. During the period when the demand of water is less than the pumping rate, the water is stored in the distribution reservoir. On the other hand, when the demand of water is more than the pumping rate, the distribution reservoir is used for supplying water at rates greater than the pumping rate. Distribution reservoirs are rarely used for the supply of water for irrigation. These are mainly

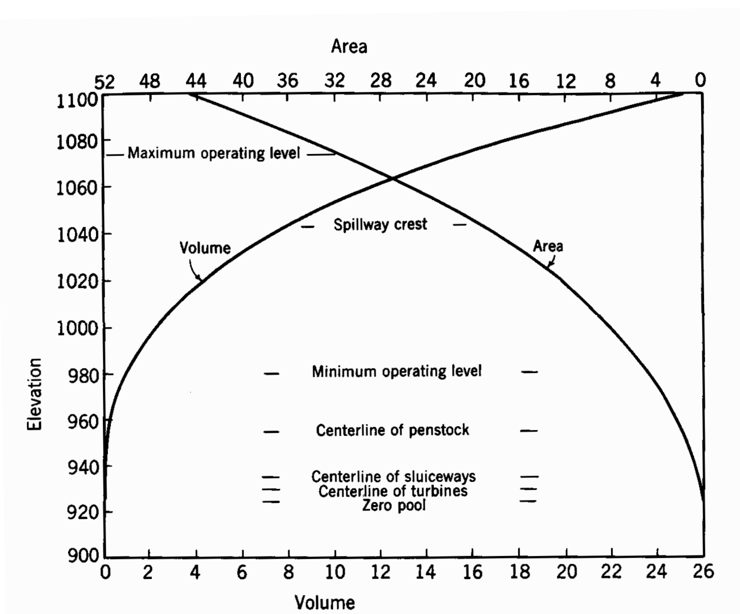
used for municipal water supply.

5. **Balancing reservoir**: A balancing reservoir is a small reservoir constructed d/s of the main reservoir for holding water released from the main reservoir.

Storage Capacity of a Reservoir

Whatever may be the use of a reservoir, its most important function is to store water during floods and to release it later. The storage capacity of a reservoir is, therefore, its most important characteristics. The available storage capacity of a reservoir depends upon the topography of the site and the height of dam. To determine the available storage capacity of a reservoir upto a certain level of water, engineering surveys are usually conducted. For preliminary estimates of the capacity, the Survey of India maps can be used. These maps are available to a scale of 1 cm = 500 m *(RF* = 1/50000) and 1 cm = 2500 m *(R.F* = 1/250000), with contours marked on it. For accurate de-termination of the capacity, a topographic survey of the reservoir area is usually conducted, and a contour map of the area is prepared. A contour plan of the area is prepared to a scale of 1 cm = 100 m or 150 m *(RF* = 1/10,000 or 1/50000) with a contour interval of 1 to 3 m, depending upon the size of the reservoir. The storage capacity and the water spread area at different elevations can be determined from the contour map, as explained below. In addition to finding out the capacity of a reservoir, the contour map of the reservoir can also be used to determine the land and property which would be submerged when the reservoir is filled upto various elevations. It would enable one to estimate the compensation to be paid to the owners of the submerged property and land. The time schedule, according to which the areas should be evacuated, as the reservoir is gradually filled, can also be drawn.

(a) Area-Elevation Curve: From the contour plan, the water spread area of the reservoir at any elevation is determined by measuring the area enclosed by the corresponding contour. Generally, a planimeter is used for measuring the area. An *elevation-area curve* is then drawn between the surface area as abscissa and the elevation as ordinate.



(b) Elevation-Capacity Curve: The storage capacity of the reservoir at any elevation is determined from the water spread area at various elevations. An elevation-storage volume is plotted between the storage volume as abscissa and the elevation as ordinate. Generally, the volume is calculated in Mm^3 or M ha-m. The following formulae are commonly used to determine the storage capacity *(i.e.* storage volumes).

1. **Trapezoidal formula**: According to the trapezoidal formula, the storage volume between two successive contours of areas A_1 and A_2 is given by

$$\Delta V = \frac{h}{2}\left(A_1 + A_2\right)$$

where *h* is the contour interval. Therefore the total storage volume V is

$$V = \frac{h}{2}\left(A_1 + 2A_2 + 2A_3 + 2A_4 + \ldots + 2A_{n-1} + A_n\right)$$

where *n* is the total number of areas.

2. **Cone formula:** According to the cone formula, the storage volume between two successive contours of areas A_1 and A_2 is given by

$$\Delta V = \frac{h}{3}\left(A_1 + A_2 + \sqrt{A_1 A_2}\right)$$

3. **Prismoidal formula:** According to the prismoidal formula, the storage volume between three successive contours is given by

$$\Delta V = \frac{h}{6}\left(A_1 + 4A_2 + A_3\right)$$

The total storage volume is

$$V = \frac{h}{3}\left(\left(A_1 + A_n\right) + 4\left(A_2 + A_4 + A_6 + \ldots + A_{n-1}\right) + 2\left(A_3 + A_5 + A_7 + \ldots + A_{n-2}\right)\right)$$

The prismoidal formula is applicable only when there are odd numbers of areas (i.e. n should be an odd number). In the case of even number of areas, the volume upto the last but one area is determined by the prismoidal formula, and that of the last segment is determined by the trapezoidal formula.

4. **Storage Volume from cross-sectional areas**: In the absence of adequate contour maps, the storage volume can be computed from the cross-sectional areas of the river. Cross-sectional areas (a_1, a_2 ... etc) are obtained from the cross-sections of the river taken upstream of the dam upto the u/s end of the reservoir at regular interval *d*. The volume is determined from the prismoidal formula. The formula is applicable for odd number of sections

$$V = \frac{d}{3}\left(\left(a_1 + a_n\right) + 4\left(a_2 + a_4 + a_6 + \ldots + a_{n-1}\right) + 2\left(a_3 + a_5 + a_7 + \ldots + a_{n-2}\right)\right)$$

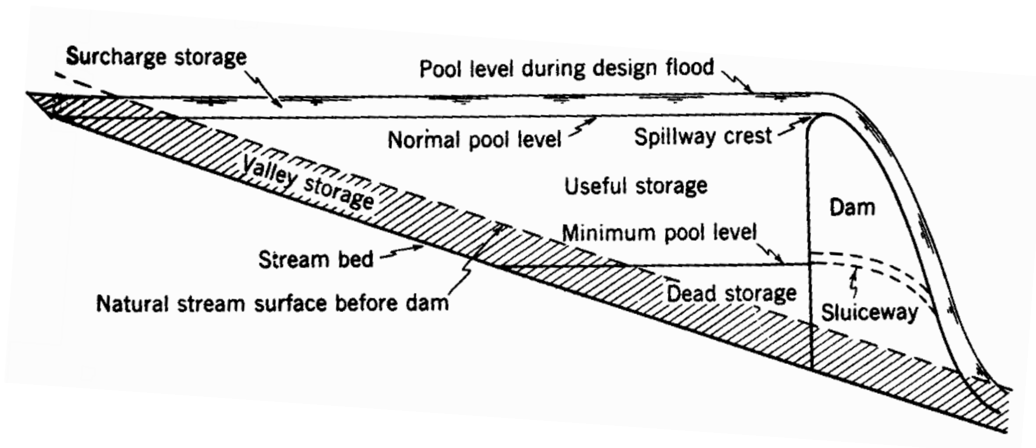
(c) Combined Diagram: It is the usual practice to plot both the elevation-area curve and the elevation- storage curve on the same paper. It is important to note the abscissa markings as the areas and volumes increase in the opposite directions.

Basic Terms and Definitions

A large number of terms are commonly used for reservoir planning. These terms are defined below. It may be noted that various terms are sometimes used to indicate the same quantity.
1. **Full reservoir level (FRL):** The full reservoir level (FRL) is the highest water level to which the water surface will rise during *normal* operating conditions. The effective storage of the reservoir is computed upto the full reservoir level. The FRL is the highest level at which water is intended to be held for various uses without any passage of water through the spillway. In case of dams without spillway gates, the FRL is equal to the crest level of the spillway. However, if the spillway is gated, the FRL is equal to the level of the top of the gates. The full reservoir level is also called the *full tank level* (FTL) or the *normal pool level* (NPL). Normal conservation level (NCL) It is the highest level of the reservoir at which

water is intended to be stored for various uses other than flood. The normal conservation level is different from the FRL as the latter may include a part of the flood. However, if there is no storage for flood upto FRL, the normal conservation level and the FRL become identical.

2. **Maximum water level (MWL):** The maximum water level is the maximum level to which the water surface will rise when the design flood passes over the spillway. The



maximum water level is higher than the full reservoir level so that some surcharge storage is available between the two levels to absorb flood. The maximum water level is also called the *maximum pool level* (MPL) or *maximum flood level* (MFL).

3. **Minimum pool level:** The minimum pool level is the lowest level up to which the water is withdrawn from the reservoir under ordinary conditions. The minimum pool level generally corresponds to the elevation of the lowest outlet (or sluiceway) of the dam. However, in the case of a reservoir for hydroelectric power; the minimum pool level is fixed after considering the minimum working head required for the efficient working of turbines. The storage below the minimum pool level is not useful and is called the dead storage.

4. **Useful storage:** The volume of water stored between the full reservoir level (FRL) and the minimum pool level is called the useful storage. The ·useful storage is available for various purposes of the reservoir. In most of the reservoirs, the useful storage is the conservation storage of the reservoir. However, in the case of multipurpose reservoirs in which the flood control is also a designed function, the useful storage is subdivided into *(a)* the conservation storage for other purposes and *(b)* the flood control storage for the flood control, in accordance with the adopted plan of operation of the reservoir. The useful storage is also known as the *live storage.*

5. **Surcharge storage:** The surcharge storage is the volume of water stored above the full reservoir level upto the maximum water level. The surcharge storage is an uncontrolled storage which exists only when the river is in flood and the flood water is passing over the spillway. This storage is available only for the absorption of flood and it cannot be used for other purposes.

6. **Dead storage:** The volume of water held below the minimum pool level is called the *dead storage.* The dead storage is not useful, as it cannot be used for any purpose under ordinary operating conditions.

7. **Bank storage:** If the banks of the reservoir are porous, some water is temporarily stored by them when the reservoir is full. The stored water in banks later drains into the

reservoir when the water level in the reservoir falls. Thus the banks of the reservoir act like mini reservoirs. The bank storage increases the effective capacity of the reservoir above that indicated by the elevation-storage curve. However, in most of the reservoirs, the bank storage is small because the banks are usually impervious.

8. **Valley storage:** The volume of water held by the natural river channel in its valley upto the top of its banks before the construction of a reservoir is called the valley storage. The valley storage depends upon the cross section of the river, the length of the river and its water level. The net increase in the storage capacity after the construction of a reservoir is equal to the total capacity of the reservoir upto FRL minus the valley storage. However, this distinction between the net storage capacity and the total storage capacity is not of much significance in a conservation or storage reservoir where the main concern is the total water available for different purposes. But in the case of a flood control reservoir, the difference between the net storage capacity and the total storage capacity is quite important because the effective storage for flood control is reduced due to the valley storage. The effective storage is equal to the sum of the useful storage and the surcharge storage minus the valley storage in the case of a flood control reservoir.

9. **Yield from a reservoir**: Yield is the volume of water which can be withdrawn from a reservoir in a specified period of time. The time period for the estimation of yield is selected according to the size of the reservoir. It may be a day for a small reservoir and a month or a year for a large reservoir. The yield is usually expressed as Mha-m/year or Mm^3/year for large reservoirs. As discussed later, the yield is determined from the storage capacity of the reservoir and the mass inflow curve.

10 **Safe yield (Firm yield):** Safe yield is the maximum quantity of water which can be supplied from a reservoir in a specified period of time during a critical dry year. Generally, the lowest recorded natural flow of the river for a number of years is taken as the critical dry period for determining the safe yield. However, there is a possibility that a still drier period may occur in future and the yield available may be even less than that determined on the basis of past records. This factor should be kept in mind while fixing the safe yield. There is generally a firm commitment by the organisation to the consumers that the safe yield will be available to them. It is therefore also called the *firm yield* or the *guaranteed yield.*

11. **Secondary yield**: Secondary yield is the quantity of water which is available during the period of high flow in the rivers when the yield is more than the safe yield. There is no firm commitment (or guarantee) to supply the secondary yield. It is supplied on *as and when basis* at the lower rates. The hydropower developed from secondary yield is sold to industries at cheaper rates. However, the power commitment for domestic supply should be based on the firm yield.

12. **Average yield:** The average yield is the arithmetic average of the firm yield and the secondary yield over a long period of time.

13. **Design yield:** The design yield is the yield adopted in the design of a reservoir. The design yield is usually fixed after considering the urgency of the water needs and the amount of risk involved. The design yield should be such that the demands of the consumers are reasonably met with, and at the same time, the storage required is not unduly large. Generally, a reservoir for the domestic water supply is planned on the basis of firm yield. On the other hand, a reservoir for irrigation may be planned with a value of design yield equal to 1.2 times the firm yield because more risk can be taken for the irrigation water supply than for domestic water supply.

DAMS

A dam is a hydraulic structure of fairly impervious material built across a river to create a reservoir on its upstream side for impounding water for various purposes. A dam and a reservoir are complements of each other. A distinction should be made between a weir and a dam. A weir is also a structure built across a river; however, its purpose is not to store water but to divert it. Thus there is no reservoir on the upstream of a weir. If there is a small storage reservoir on its upstream, the weir is called a *storage weir*. Dams are generally constructed in the mountainous reach of the river where the valley is narrow and the foundation is good. Generally, a hydropower station is also constructed at or near the dam site to develop hydropower.

Sometimes, a *pickup weir* is constructed on the downstream of a dam quite away from it in the boulder reach or the alluvial reach of the river to divert the water released from the dam into canals for irrigation and other purposes. Dams are probably the most important hydraulic structure built on the rivers. These are very huge structure. Thousands of workers and engineers work for a number of years in the construction of a dam.

Classification of Dams

Dams can be classified according to different criteria, as given below:

(a) ***Based on Function Served****:* Depending upon the function served, the dams are of the following types -

1. **Storage dams**: Storage (or conservation) dams are constructed to store water during the rainy season when there is a large flow in the river. The stored water is utilized later during the period when the flow in the river is reduced and is less than the demand. The water stored in the reservoir is used for a number of purposes, such as irrigation, water supply and hydropower. Storage dams are the most common type of dams and in general the dam means a storage dam unless qualified otherwise.

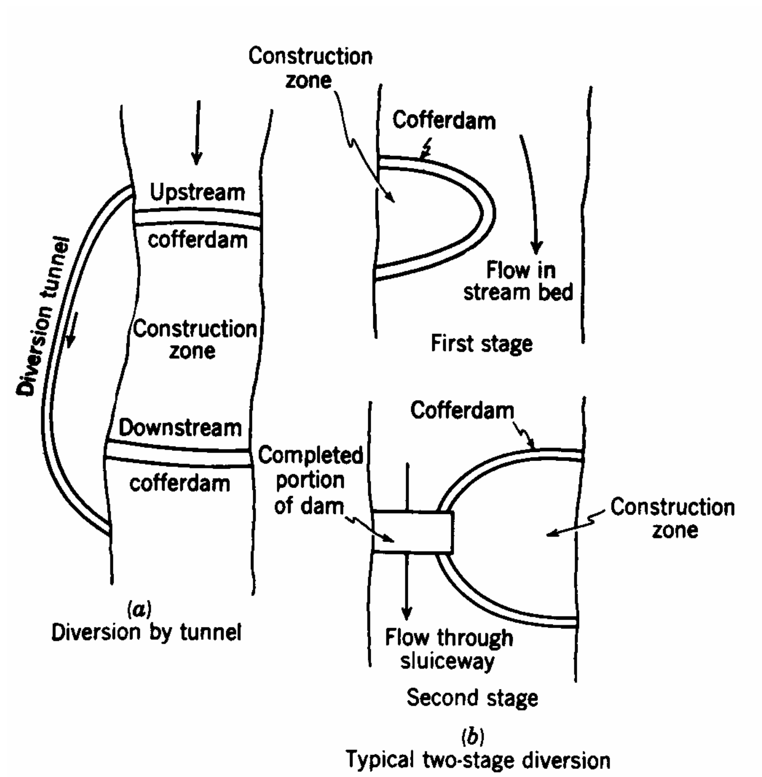
2. **Detention dams:** Detention dams are constructed for flood control. A detention dam retards the flow in the river on its downstream during floods by storing some flood water. Thus the effect of sudden floods is reduced to some extent. The water retained in the reservoir is later released gradually at a controlled rate according to the carrying capacity of the channel downstream of the detention dam. Thus the area downstream of the dam is protected against flood.

3. **Diversion dams**: A diversion dam is constructed for the purpose of diverting water of the river into an off-taking canal (or a conduit). A diversion dam is usually of low height and has a small storage reservoir on its upstream. The diversion dam is a sort of storage weir which also diverts water and has a small storage. Sometimes, the terms weirs and diversion dams are used synonymously.

4. **Debris dams**: A debris dam is constructed to retain debris such as sand, gravel, and

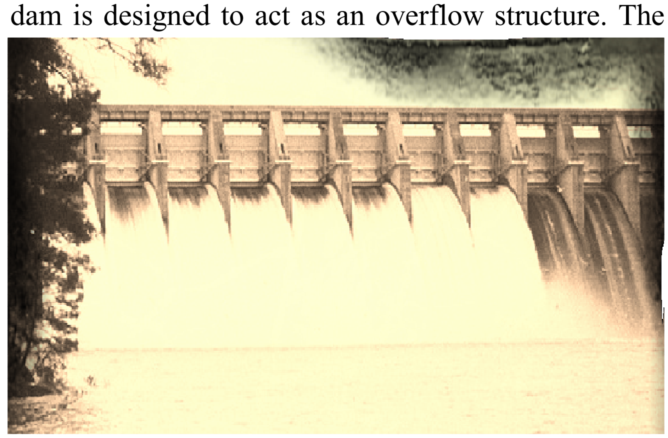
drift wood flowing in the river with water. The water after passing over a debris dam is relatively clear.

5. **Coffer dams**: A coffer dams is not actually a dam. It is rather an enclosure constructed around the construction site to exclude water so that the construction can be done in dry. A coffer dam is thus a temporary dam constructed for facilitating construction. A coffer dam is usually constructed on the upstream of the main dam to divert water into a diversion tunnel (or channel) during the construction of the dam. When the flow in the river during construction of the dam is not much, the site is usually enclosed by the coffer dam and pumped dry. Sometimes a coffer dam on the downstream of the dam is also required.



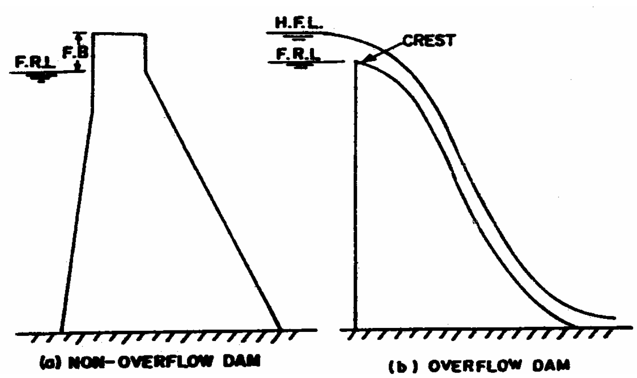
(b) ***Based on Hydraulic Design***: On the basis of hydraulic design, dams may be classified as

1. **Overflow dams:** An overflow dam is designed to act as an overflow structure. The surplus water which cannot be retained in the reservoir is permitted to pass over the crest of the overflow dam which acts as a spillway. The overflow dam is made of a material which does not erode by the action of overflowing water. Generally, cement concrete is used in overflow dams and spillways. Most of the gravity dams have overflow sections for some length and the rest of the length as a non-overflow dam. However, sometimes the entire length of the dam of low height is designed as an overflow dam. The overflow dam is also called the *spillway section.*



2. **Non-overflow dams:** A non-overflow dam is designed such that there is no flow over it. Because

there is no overflow, a non-overflow dam can be built of any material, such as concrete, masonry, earth, rockfill and timber. As already mentioned, the non-overflow dam is usually provided in a part of the total length of the dam. However, sometimes the non-overflow dam is provided for the entire length and a separate spillway is provided in the flanks or in a saddle away from the dam. Fig shows a non overflow earth dam.



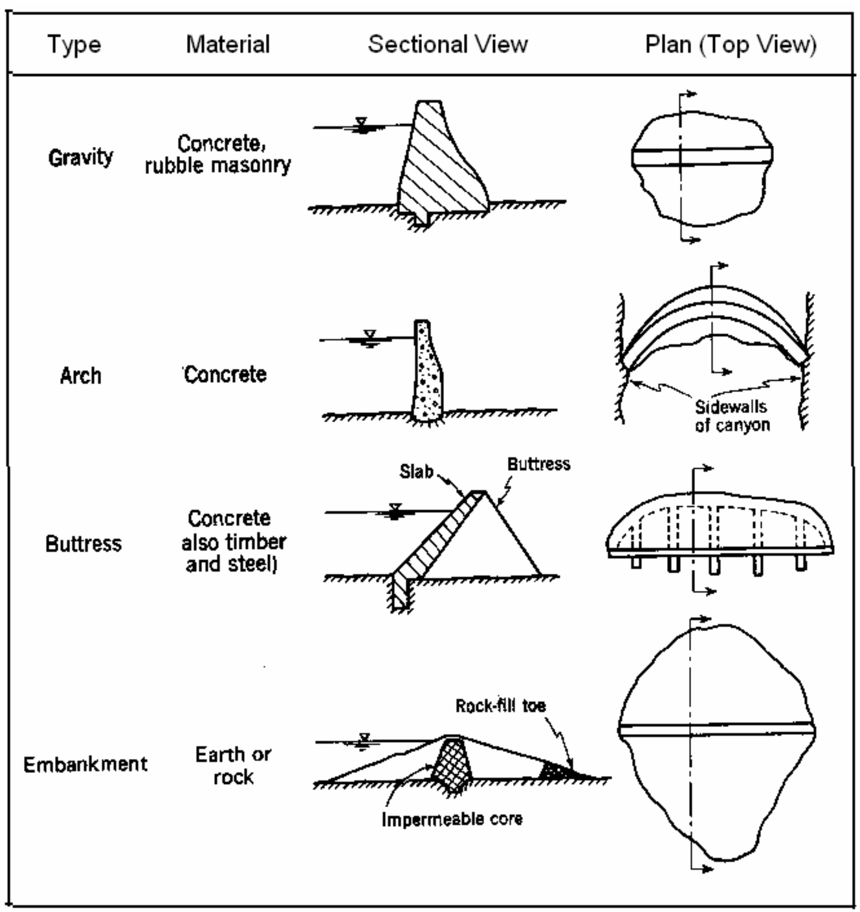
(c) ***Based on Materials of Construction****:* Based on the materials used in construction, the dams are classified as follows: (1) Masonry dam, (2) Concrete dam, (3) Earth dam, (4) Rockfill dam, (5) Timber dam, (6) Steel dam, (7) Combined concrete-cum-earth dam, and (8) Composite dam.

(d) ***Based on Rigidity***: On the basis of the rigidity, the dams are classified into 2 types:

1. **Rigid dams**: A rigid dam is quite stiff. It is constructed of stiff materials such as concrete, masonry, steel and timber. These dams deflect and deform very little when subjected to water pressure and other forces.

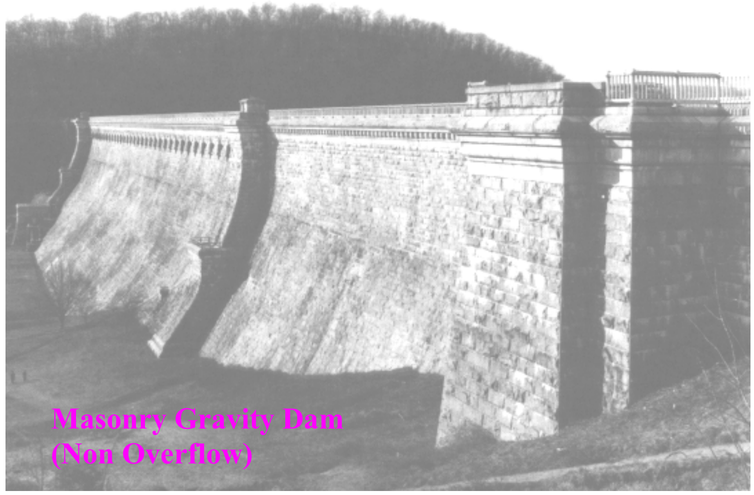
2. **Non-rigid dams:** A non-rigid dam is relatively less stiff compared to a rigid dam. The dams constructed of earth and rockfill are non-rigid dams. There are relatively large settlements and deformations in a non-rigid dam. Rockfill dams are actually neither fully rigid nor fully non-rigid. These are sometimes classified as semi-rigid dams.

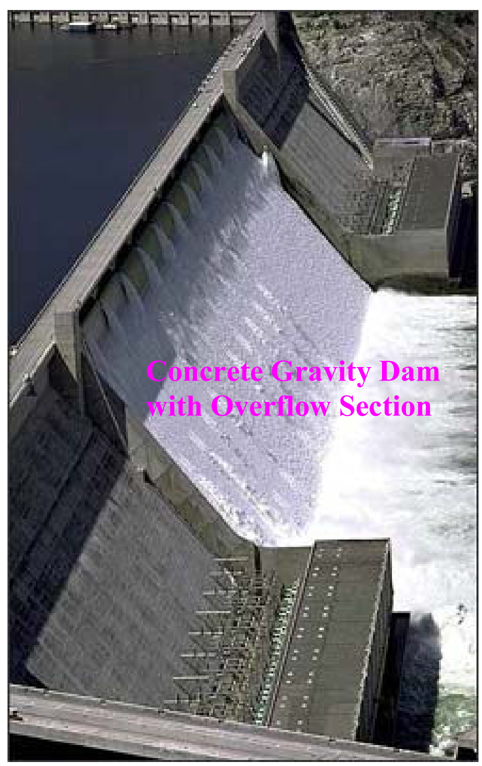
(e) *Based on the structural action*: This is the most commonly used classification of dams. Based on the structural action, the dams are classified as (1) Gravity dams, (2) Earth dams, (3) Rockfill dams, (4) Arch dams, (5) Buttress dams, (6) Steel dams, and



(7) Timber dams.

1. **Gravity dams:** A gravity dam resists the water pressure and other forces due to its weight (or gravitational forces). Thus the stability of a gravity dam depends upon its weight. The gravity dams are usually made of cement concrete. In the past, the gravity dams were made of stone masonry, (Nagarjuna Sagar Dam (AP), Krishnaraja Sagar Dam (KN), Gandhi Sagar Dam (MP), d, Jawai Dam(RJ)) but now the masonry dams are rarely constructed, except for very small heights. The gravity dams are generally straight in plan (i.e. axis is straight from one abutment to the other) and are called straight gravity dams. However, sometimes they are slightly curved in plan, with convexity towards the upstream and are called curved-gravity dams (Hoover dam). The gravity dams are approximately triangular in cross-section, with apex at the top. The gravity dams are generally more expensive than earth dams but are more durable. They are quite suitable for the gorges with very steep slopes. They require strong rock foundation. However, if the foundation consists of soil, the height of the gravity dams is usually limited to 20 m or so. A gravity dam is called *solid* gravity dam when it is a solid mass of concrete (or masonry) with no hollow spaces inside the dam, except for small drainage galleries or shafts. On the other hand, a *hollow* gravity dam has large hollow spaces left within the body of the dam for the purpose of reducing the weight and for more effective use of concrete for resisting the stresses. Hollow gravity dams are similar to buttress dams. Hollow gravity dams are rarely constructed these days. Hence, the gravity dam, in general, means a solid gravity dam. Most of the gravity dams constructed in India are straight solid gravity dams. Bhakra dam (structural height of 226 m) was the highest concrete gravity dam of the world when built (surpassing then existing 221 m high Hoover dam in USA). At present, it is second highest after Grand Dixence Dam in Switzerland (284 m high). Koyna Dam (MR), Rihand Dam (UP), Sardar Sarovar Dam, etc are few examples of concrete gravity dams. Nagarjuna Sagar Dam (structural height of 125 m) is the highest masonry dam of the world. It is also the largest (storage capacity) dam of India.





Advantages

(i) Gravity dams are quite strong, stable and durable.

(ii) Gravity dams are quite suitable across moderately wide valleys and gorges having steep slopes where earth dams, if constructed, might slip.

(iii) Gravity dams can be constructed to very great heights, provided good rock foundations are available.

(iv) Gravity dams are well adapted for use as an overflow spillway section. Earth dams cannot be used as an overflow section. Even in earth dams, the overflow section is usually a gravity dam.

(v) Gravity dams are specially suited to such areas where there is very heavy downpour. The slopes of the earth dams might be washed away in such an area.

(vi) The maintenance cost of a gravity dam is very low.

(vii) The gravity dam does not fail suddenly. There is enough warning of the imminent failure and the valuable property and human life can be saved to some extent.

(viii) Gravity dam can be constructed during all types of climatic conditions.

(ix) The sedimentation in the reservoir on the upstream of a gravity dam can be somewhat reduced by operation of deep-set sluices.

Disadvantages

(i) Gravity dams of great height can be constructed only on sound rock foundations. These cannot be constructed on weak or permeable foundations on which earth dams can be constructed. However, gravity dams upto 20 m height can be constructed even when the foundation is weak.

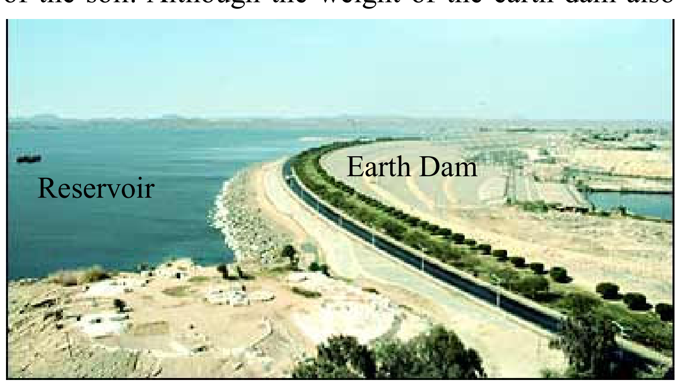
(ii) The initial cost of a gravity dam is usually more than that of an earth dam. At the sites where good earth is available for construction and funds are limited, earth dams are better.

(iii) Gravity dams usually take a longer time in construction than earth dams, especially when mechanised plants for batching, mixing and transporting concrete are not available.

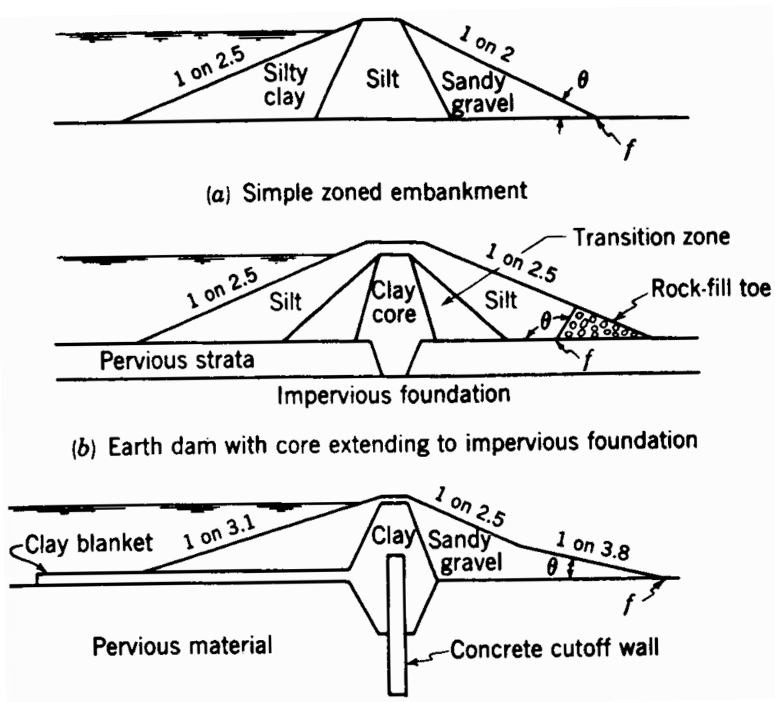
(iv) Gravity dams require more skilled labour than that in earth dams.

(v) Subsequent raising is not possible in a gravity dam.

(2) **Earth dams**: An earth dam is made of earth (or soil). It resists the forces exerted upon it mainly due to shear strength of the soil. Although the weight of the earth dam also helps in resisting the forces, the structural behaviour of an earth dam is entirely different from that of a gravity dam. The earth dams are usually built in wide valleys having flat slopes at flanks (abutments). The foundation requirements are less stringent than those of gravity dams, and hence they can be built at the sites where the foundations are less strong. They can be built on all types of foundations. However, the height of the dam will depend upon the strength of the



foundation material. The section of an earth dam can be homogeneous when the height of the dam is not great. Generally, the earth dams are of zoned sections, with an impervious zone (called core) in the middle and relatively pervious zones (called shells or shoulders) enclosing the impervious zone on both sides. If the earth dam is built on a pervious foundation, a concrete cutoff wall or a steel sheet pile line is also provided in the continuation of the core section. Moreover, a drainage filter or a rock toe is provided on the downstream to carry away the water that seeps through the dam and its foundation. Earth dams are usually cheaper than the gravity dams if suitable earth in abundant quantity is easily available near the site. Nowadays majority of dams constructed are of this type. The highest dams of the world are earth dams (Rongunsky dam Rusia, 325 m and Nurek dam, Rusia, 317 m) as well as the largest capacity dams (New Cornelia dam, USA and Tarbela dam, Pakistan). The highest dam of India is Tehri dam (261 m), which is earth and rockfill type. Hirakund dam (Orissa) is the longest earthen dam of the world (25.3 km).



Advantages

(i) Earth dams are usually cheaper than gravity dams if suitable earth for construction is available near the site.

(ii) Earth dams can be constructed on almost all types of foundations, provided suitable measures of foundation treatment and seepage control are taken.

(iii) Earth dams can be constructed in a relatively short period.

(iv) The skilled labour is not required in construction of an earth dam. Earth dams can be raised subsequently.

(vi) Earth dams are aesthetically more pleasing than gravity dams.

(vii) Earth dams are more earthquake-resistant than gravity dams.

Disadvantages

(i) Earth dams are not suitable for narrow gorges with steep slopes.

(ii) An earth dam cannot be designed as an overflow section. A spillway has to be located away from the dam.

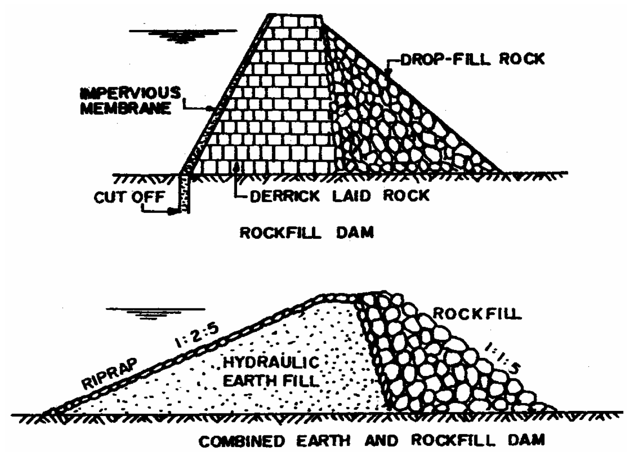
(iii) Earth dams cannot be constructed in regions with heavy downpour, as the slopes might be washed away.

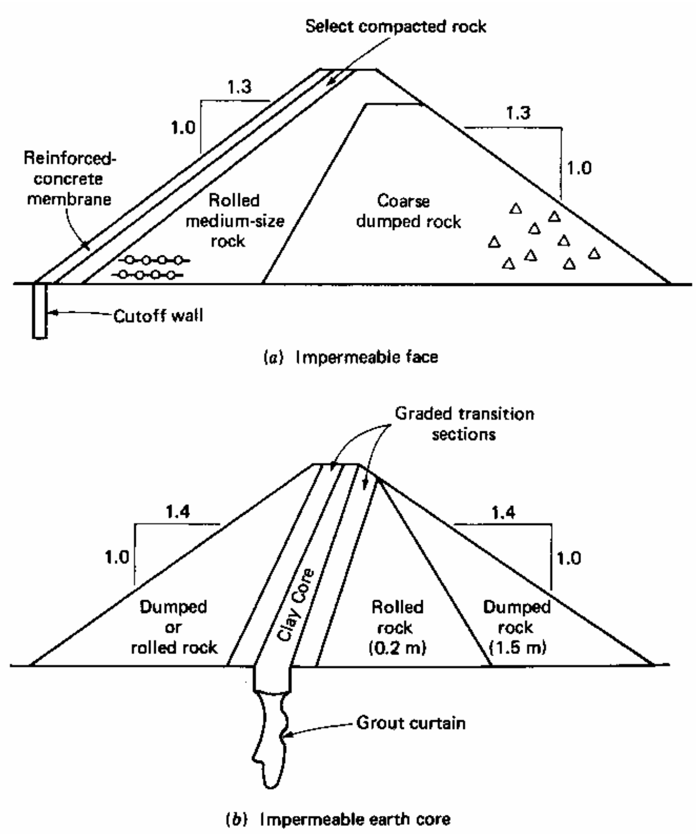
(iv) The maintenance cost of an earth dam is quite high. It requires constant supervision.

(v) Sluices cannot be provided in a high earth dam to remove slit.

(vi) An earth dam fails suddenly without any sign of imminent failure. A sudden failure causes havoc and untold miseries.

(3) **Rockfill dams**: A rockfill dam is built of rock fragments and boulders of large size. An impervious membrane is placed on the rockfill on the upstream side to reduce the seepage through the dam. The membrane is usually made of cement concrete or asphaltic concrete. In early rockfill dams, steel and timber membrane were also used, but now they are obsolete. A dry rubble cushion is placed between the rockfill and the membrane for the distribution of water load and for providing a support to the membrane. Sometimes, the rockfill dams have an impervious earth core in the middle to check the seepage instead of an impervious upstream membrane. The earth core is placed against a dumped rockfill. It is necessary to provide adequate filters between the earth core and the rockfill on the upstream and downstream sides of the core so that the soil particles are not carried by water and piping does not occur. The side slopes of rockfill are usually kept equal to the angle of repose of rock, which is usually taken as 1.4:1 (or 1.3:1). Rockfill dams require foundation stronger than those for earth dams. However, the foundation requirements are usually less stringent than those for gravity dams. Rockfill dams are quite economical when a large quantity of rock is easily available near the site. Thiem dam (PJ), Ramganga dam (UP), etc. are rockfill dams in India, while Mica dam (242 m, Canada), and Chicoasen dam (240 m, Maxico) are highest rockfill dams. Rockfill dams have almost the same advantages and disadvantages over gravity dams as discussed for earth dams. However, they have the following particular advantages and disadvantages over earth dams.





(a) **Advantages**

(i) Rockfill dams are

quite inexpensive if rock fragments are easily available.

(ii) Rockfill dams can be constructed quite rapidly.

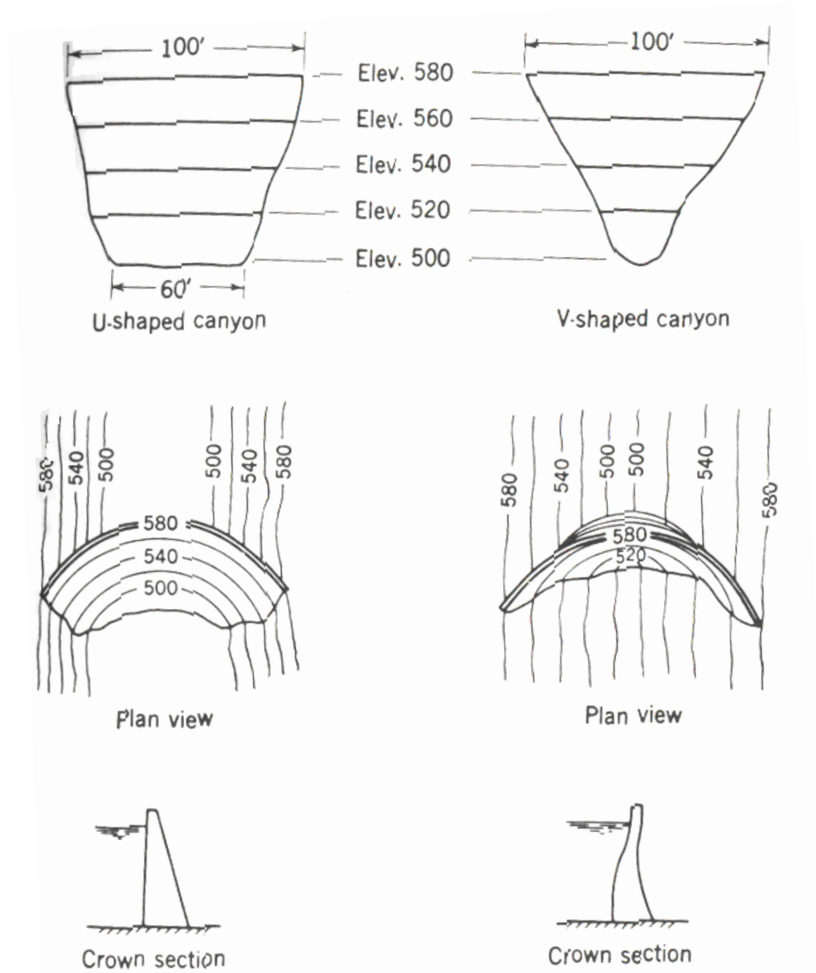
(iii) Rockfill dams can better withstand the shocks due to earthquake than earth dams.

(iv) Rockfill dams can be constructed even in adverse climates.

(b) **Disadvantages**

(i) Rockfill dams require more strong foundations than earth dams.

(ii) Rockfill dams require heavy machines for transporting, dumping and compacting rocks.



(4) **Arch Dams**: An arch dam is curved in plan, with its convexity towards the upstream side. An arch dam transfers the water pressure and other forces mainly to the abutments by arch action. An arch dam is quite suitable for narrow canyons with strong flanks which are capable of resisting the thrust produced by the arch action. The section of an arch dam is approximately triangular like a gravity dam but the section is comparatively thinner. The arch dam may have a single curvature or double curvature in the vertical plane. Generally, the arch dams of double curvature are more economical and are used in practice. The arch dams are not common in India. Only one arch dam has been constructed in India at Iddukki in Kerala so far. Its height is 169 m. Outside of India, there are many arch dams over 200 m (Juguri dam (272 m), Russia, Vaiont dam (262 m), Italy, Manvoisin dam (237 m) Switzerland). The arch dam requires good quality concrete for resisting the stresses. The quantity of

concrete required in an arch dam is less than that for a gravity dam, but it is not necessarily less expensive because of high cost of concrete and form work. The arch dams are subjected to large stresses because of changes in temperature shrinkage of concrete and yielding of abutments.

Advantages

(i) An arch dam requires less concrete as compared to a gravity dam as the section is thinner.

(ii) Arch dams are more suited to narrow, V-shaped valley, having very steep slopes.

(iii) Uplift pressure is not an important factor in the design of an arch dam because the arch dam has less width and the reduction in weight due to uplift does not affect the stability.

(iv) An arch dam can be constructed on a relatively less strong foundation because a small part of load is transferred to base, whereas in a gravity dam full load is transferred to base.

Disadvantages

(i) An arch dam requires good rock in the flanks (abutments) to resist the thrust. If the abutments yield, extra stresses develop which may cause failure.

(ii) The arch dam requires sophisticated formwork, more skilled labour and richer concrete.

Buttress Dam (d/s side)

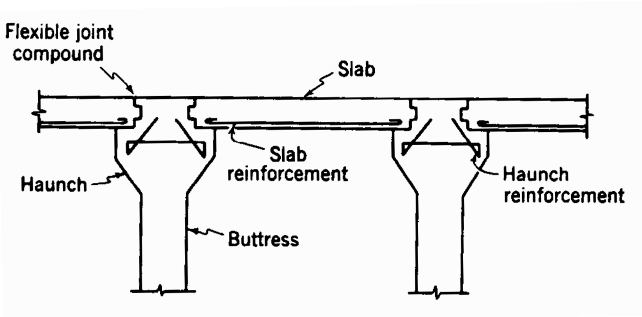
Multiple Arch Buttress Dam (u/s side)

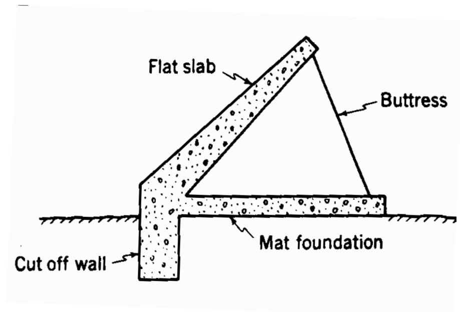
(iii) The arch dam cannot be constructed in very cold climates because spalling of concrete occurs due to alternate freezing and thawing.

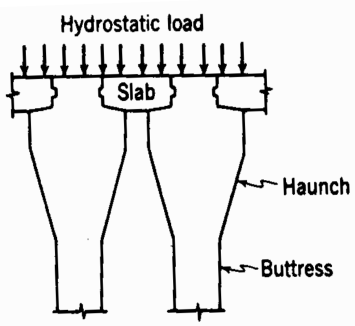
(iv) The arch dams are more prone to sabotage.

(v) The speed of construction is relatively slow.

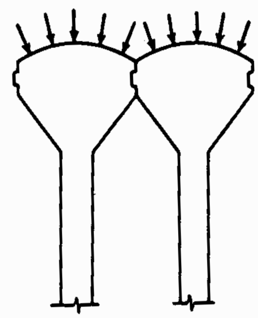
(5) **Buttress Dams**: Buttress dams are of three types: (i) Deck type, (ii) Multiple arch-type, and (iii) Massive-head type. A deck type buttress dam consists of a sloping deck supported by buttresses. Buttresses are triangular concrete walls which transmit the water pressure from the deck slab to the foundation. Buttresses are compression members. The deck is usually a reinforced concrete slab supported between



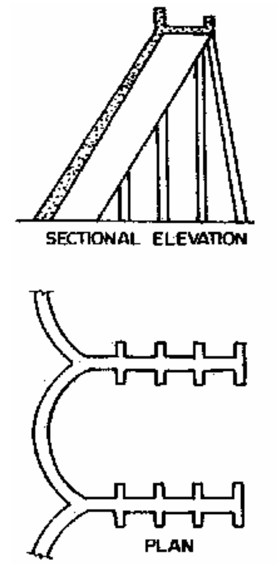




Section through massive buttress



Mushroomed head buttress



MULTIPLE ARCH TYPE

the buttresses, which are usually equally spaced. In a multiple-arch type buttress dam the deck slab is replaced by horizontal arches supported by buttresses. The arches are usually of small span and made of concrete. In a massive-head type buttress dam, there is no deck slab. Instead of the deck, the upstream edges of the buttresses are flared to form massive heads which span the distance between the buttresses. The buttress dams require less concrete than gravity dams. But they are not necessarily cheaper than the gravity dams because of extra cost of form work, reinforcement and more skilled labour. The foundation requirements of a buttress dam are usually less stringent than those in a gravity dam.

Advantages

(i) Buttress dams require less concrete than gravity dams.

(ii) The uplift pressure is generally not a major factor in the design of buttress dams.

(iii) Buttress dams can be constructed on relatively weaker foundations.

(iv) Power house and water treatment plants, etc. can be housed between buttresses.

(v) The ice pressure is relatively less important because ice tends to slide over the inclined deck.

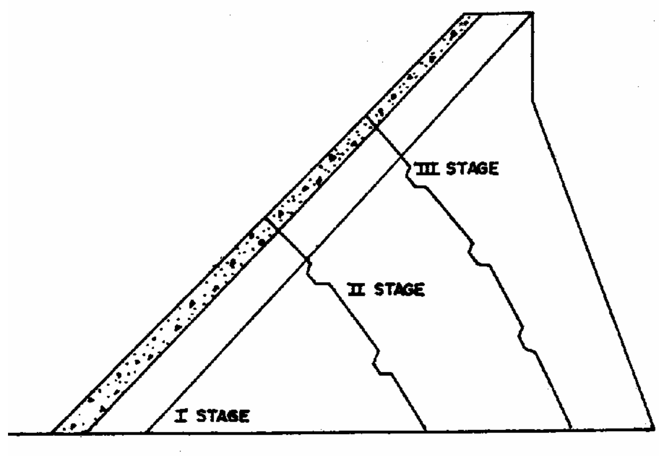
(vi) The vertical component of the water pressure on deck prevents the dam against overturning and sliding failures.

(vii) Buttress dams can be designed to accommodate moderate movements of foundations without serious damages.

(viii) Heat dissipation is better in buttress dams. Therefore, the speed of construction is more.

(ix) The back of the deck and the foundation between buttresses are accessible for inspection.

(x) Buttress dams can be easily raised subsequently by extending buttresses and deck slabs.



RAISING HEIGHT OF BUTTRESS DAM

Disadvantages

(i) Buttress dams require costlier formwork, reinforcement and more skilled labour. Consequently, the overall cost of construction may be more than that of a gravity dam.

(ii) Buttress dams are more susceptible to damage and sabotage.

(iii) Buttress dams cannot be constructed in very cold climates because of spalling of concrete.

(iv) Because the upstream deck slab is thin, its deterioration may have very serious effect on the stability.

(6) **Steel Dams**: A steel dam consists of a steel framework, with a steel skin plate on its upstream face. Steel dams are generally of two types: (i) Direct-strutted steel dams, and (ii) Cantilever type steel dams. In a direct strutted steel dam, the water pressure is transmitted directly to the foundation through inclined struts. In a cantilever type steel dam, there is a bent supporting the upper part of the deck, which is formed into a cantilever truss. This arrangement introduces a tensile force in the deck girder which can be taken care of by anchoring it into the foundation at the upstream toe. Hovey suggested that tension at the upstream toe may be reduced by flattening the slopes of the lower struts in the bent. However, it would require heavier sections for struts. Another alternative to reduce tension is to frame together the entire bent rigidly so that the moment due to the weight of the water on the lower part of the deck is utilised to offset the moment induced in the cantilever. This arrangement would, however, require bracing and this will increase the cost. No steel dam has been constructed in India. These are quite costly and are subjected to corrosion. These dams are almost obsolete. Steel dams are sometimes used as temporary coffer dams during the construction of the permanent dams. Steel coffer dams are supplemented with timber or earthfill on the inner side to make them water tight. The area between the coffer dams is dewatered so that the construction may be done in dry for the permanent dam.

(a) DIRECT STRUTTED TYPE (b) CANTILEVER TYPE

Advantages

(i) Steel dams can be constructed with great speeds with the modern methods of fabrication.

(ii) The steel dams are usually statically determinate. Hence the section can be designed with more confidence and more economically.

(iii) Steel dams are usually cheaper than gravity dams.

(iv) If properly fabricated, there is very little leakage through a steel dam.

(v) Steel dam can easily withstand stresses due to unequal settlements.

Disadvantages

(i) Steel dam cannot be designed as overflow dams because they are unable to withstand stresses due to vibrations and shocks of spilling water on thin steel section.

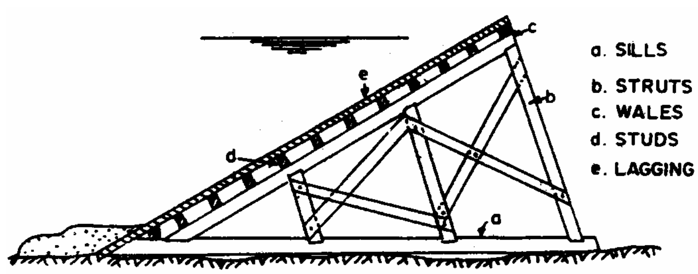
(ii) Steel dams require strong and deep anchorages in foundation.

(iii) Steel dams require careful regular maintenance.

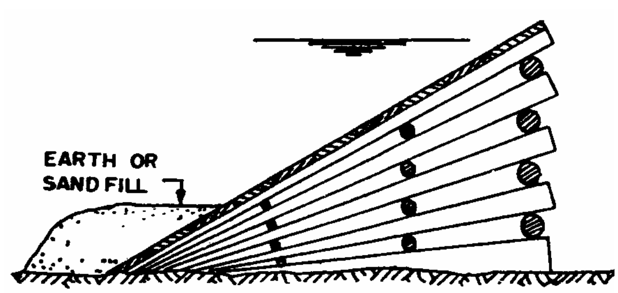
(iv) The life of steel dam is short.

(v) There is concentration of bearing stresses at the points of contact of the members.

(7) **Timber Dams**: A timber dam consists of a framework made of timber with a facing of timber planks. The framework is comprised of struts and beams. It transfers the water pressure on the upstream planks to the foundation. The timber dams are mainly of three types: (i) A-frame type, (ii) Rock-filled crib type, and (iii) Beaver type. The *A-frame type* timber dam is built of timbers and planks making the shape of English letter A. The stability depends upon the weight of the water on the deck and upon anchorage of sills. The sill is fixed to a ledge rock by wedge bolts or anchor bolts for proper anchorage. The struts are fixed to the sill and are held in position by cross-bracing and batten blocks. The wales are then fixed on the struts and the whole structure is thoroughly drift-pinned to form a bent. These bents are usually spaced 2 to 4 m apart, depending upon the height of the timber dam and the size of the timber members used. Transverse members, called studs, are then placed across the bents, and a suitable lagging is nailed to them to form the upstream deck to retain water. In *rock-filled crib rock type* of timber dam, cribs of timber members are drift-bolted together. The timber members are generally of round or square section and are placed at 2.5 m centres in both directions. The bottom members of the cribs are generally pinned to the rock foundation. The space between various members is filled with rock fragments or boulders to give stability. A top plank is then placed on the cribs. *A beaver type* timber dam consists of timber members of round section forming a bent. The butts of all the timber members point downstream. Spacer logs are placed between the butts and driftpinned to the other logs. The tips of the timber members pointing upstream



A-FRAME TYPE TIMBER DAM



BEAVER TYPE TIMBER DAM

are also driftpinned together. The bottom members are fixed to the foundation with anchor bolts. A plank is placed on the bent to form a deck. Sometimes, a mat made of brushwood or the branches of the trees is used as a deck. The upstream slopes are not steeper than 2: 1. This type of timber dam is used for low heights. Timber dams are generally used as temporary dams. These are short lived, but if well-designed, constructed and maintained, they may last even 30 - 40 years. The timber dams are used at places where timber is available in plenty and the height of the dam is low. However, because of shortage of timber, these dams are becoming obsolete.

Advantages

(i) The initial cost of timber dams is low when timber is available in plenty.

(ii) Timber dams can be constructed on any type of foundation.

(iii) Timber dams are suitable when construction is for a short period.

(v) The design and construction of timber dams is easy.

(v) Timber dams can be constructed at a great speed.

Disadvantages

(i) The life of timber dams is short.

(ii) The leakage through a timber dam is quite high.

(iii) The maintenance cost of a timber dam is high.

(iv) Timber dams cannot be constructed for great height.

Selection of Site for a Dam

A dam is a huge structure requiring a lot of funds. Extreme care shall be taken while selecting the site of a dam. A wrong decision may lead to excessive cost and difficulties in construction and maintenance. The following factors shall be considered when selecting the site of a dam.

1. **Topography**: As far as possible, the dam should be located where the river has a narrow gorge which opens out upstream to create a large reservoir. In that case, the length of the dam would be small and the capacity of the reservoir on its upstream would be large. In case there is a confluence of two rivers in the selected reach, the dam should be located downstream of the confluence to take advantage of the flow of both rivers. The dam should be preferably located where the river bed is high, to reduce the height and cost of the dam.

2. **Suitable Foundation**: Suitable foundation should exist at the site for the particular type of dam. If suitable foundation is not available but it can be improved by adopting various measures, the site may be considered for selection. However, in that case, the cost of such measures should not be excessive. For gravity dams of great height, sound rock is essential. However, earth dams can be constructed on almost any type of foundation provided suitable measures are adopted.

3. **Good Site for reservoir**: As the dam is constructed to store water in the reservoir, so the site should have the following characteristics to make a good site for a reservoir: (i) *Large storage capacity:* The topography of the site should be such that the reservoir has a large capacity to store water. (ii) *Shape of reservoir basin*: The reservoir basin on the upstream of the dam should preferably be cup-shaped, with a flat bottom but steep slopes. (iii) *Watertightness of the reservoir*: The geological conditions of

the reservoir site should be such that the reservoir basin is watertight. The reservoir sites having pervious rocks are not suitable. The reservoir basins having shales, slates, schists, gneiss, granite, etc. are generally suitable. (iv) *Good hydrological conditions*: The hydrological conditions of the river at the reservoir site should be such that adequate runoff is available for storage. The catchment area of the river should give high yield. There should not be heavy losses in the catchment due to evaporation, transpiration and percolation. (v) *Deep reservoir:* The site should be such that a deep reservoir is formed after the construction of the dam. A deep reservoir is preferred to a shallow reservoir because in the former the evaporation losses are small, the cost of land acquisition is low and the weed growth is less. (vi) *Small submerged area*: The site should be such that the submerged area is a minimum. It should not submerge costly land and property. It should not affect the ecology of the region. Monuments of historical and architectural importance should not be submerged. (vii) *Low silt inflow*: The dam site should be such that the reservoir would not silt up quickly. The life of the reservoir depends upon the rate of silting. The site should be selected such that it avoids or excludes the water from those tributaries which carry a high percentage of silt, i.e. if any tributary carries relatively large quantity of sediments, the dam should be constructed upstream of the confluence of that tributary with the river. (viii) *No objectionable minerals*: The soil and rock mass at the reservoir site should not contain any objectionable soluble minerals which may contaminate the water. The stored water should be suitable for the purpose for which the water is required.

4. **Spillway site**: A good site for a spillway should exist at or near the darn site. The valley should be sufficiently wide to locate the spillway if it is an integral part of the dam. If the spillway is to be located separately, the best site of spillway is that in which there is a saddle near the dam site which is separated from it by a hillock. In that case, the main dam can be located in the gorge and the spillway can be constructed in the saddle.

5. **Availability of materials**: The dam requires a large quantity of material for its construction. Suitable type of material in sufficient quantity should be available at or near the dam site to reduce the cost.

6. **Accessibility**: The site should be easily accessible. It should be preferably well-connected by a road or a railway line. This would facilitate transportation of labour, materials and machinery.

7. **Healthy surroundings**: The surroundings of the site should be healthy and free from mosquitos so that the labourers can comfortably live in colonies constructed near the dam site.

8. **Low cost of real estate:** The cost of real estate for the reservoir site, dam, dwellings, roads, railways, etc. should be low.

9. **Minimum overall cost**: The site should be such that it entails the minimum overall cost of the project, including subsequent maintenance. Generally, two or three probable sites are selected and rough estimates are made. The site which entails the minimum overall cost can be tentatively selected.

10. **Other considerations**: For the development of a particular backward area, the dam may be constructed in that region. Sometimes political considerations and public opinion may affect the site of a dam.

Selection of Type of Dam

Selection of the most suitable type of dam for a particular site requires a lot of judgment and experience. It is only in exceptional cases that the most suitable type is obvious. Preliminary designs and estimates are usually required for several types of dams before making the final selection on economic basis. The salient features of different types of dams discussed in the preceding sections should be kept in mind while selecting the type of dam. Various factors which govern the selection of type of dam are discussed below:

1. **Topography and valley shape**. The choice or the type of dam for a particular site depends to a large extent on the topography and the valley shape. The following are the general guidelines. (a) If the valley is narrow, V-shaped and has sound rock in bed and abutments, an arch dam is generally the most suitable type. (b) If the valley is moderately wide, V-shaped and has sound rock in bed, a gravity dam or a buttress dam may be quite suitable. (c) For a low rolling plain country, with a fairly wide valley and alluvial soil or boulders in the bed. an earth dam or a rockfill dam may be quite suitable.

2. **Geology and foundation conditions**. A dam is a very huge structure. All the loads acting on the dam, including its own weight, are ultimately transferred to the foundations. While selecting the type of dam for a particular site, geologic character and thickness of rock, inclination of the bedding planes, existing faults and fissures, permeability of strata, etc. affect the selection. Most suitable type of dam for different types of foundation is usually determined as follows: (a) *Rock foundation*: Any type of dam can be constructed on good rock foundation. Such foundations have high bearing capacity and resistance to erosion and percolation and are ideal for all types of dams. The most suitable type of dam for a particular site will depend upon other factors such as availability of construction material and spillway site, etc. If seams and fractures exist in the rock, these should be sealed by consolidation grouting. If the rock is disintegrated at surface, it should be removed and further disintegration should be stopped by taking suitable measures. (b) *Gravel and coarse sand foundation*: The bearing capacity of foundation consisting of gravel and coarse sand is low. For such foundations, earth dams and rockfill dams are usually selected. However, gravity dams of low height can also be selected. There is considerable seepage through these foundations. Cutoff walls or sheet piles are generally provided in the foundation to reduce seepage and to prevent piping. (c) *Fine sand and silt foundations*: These foundations are generally suitable only for earth dams and low concrete dams. In such foundations, there are a number of problems such as excessive settlement, piping, seepage erosion at the d/s toe and liquefaction failures. Suitable measures are adopted before the construction of dams. (d) *Clay foundation*: In general, clay foundations are not suitable for the construction of a dam. These foundations have very low bearing capacity. Moreover, the settlements are quite large, especially if the clay is nominally-consolidated or under-consolidated. In over-consolidated clays, the settlements are relatively small. In some special cases, low earth dams can be constructed on such foundations after properly treating and consolidating the foundations. The maximum height of dam that can be permitted at a site would depend upon the shearing strength and consolidation characteristics of clay. Undisturbed samples are usually taken to determine the properties of clay. (e) *Non-uniform foundations*: Non-uniform foundations may consists of soils of different types of a combination of soils and rocks. Such foundations are not good for the construction of dams and should be avoided as far as possible. If unavoidable, special designs are adopted and appropriate foundation treatments are required.

3. **Availability of construction materials**. The construction of a dam requires a huge quantity of construction material. While selecting the type of dam, the availability of the required construction materials should be considered. If a particular material is available in abundance at or near the dam site, the maximum use of that material should be made to reduce the cost. The materials which are not available near the site should be either avoided or the minimum use shall be made of such materials. For example, if suitable aggregates such as crushed stone, gravel and sand are available, a gravity dam may be suitable. On the other hand, if suitable soil is available in large quantity, an earth dam may be cheaper.

4. **Overall cost**. The overall cost is perhaps the most important factor which affects the selection of the suitable type of dam for a particular site. The initial cost of the dam depends upon the availability of material, the quantity of material required, labour and the construction methods. The cost of subsequent maintenance depends upon the durability of the materials used and the type of construction. The dam with a minimum overall cost is usually the best. All the factors affecting the overall cost should be considered. For example, the quantity of concrete required for buttress dams and arch dams is much less than that in a gravity dam, but when the cost of form work and reinforcement is also considered, a gravity dam may have lower overall cost. Similarly, the initial cost of an earth dam may be less than that of a gravity dam, but when the maintenance cost is also considered, a gravity dam may be cheaper in the long run,

5. **Spillway size and location**. A spillway is an overflow structure provided at or near the dam site to discharge excess flood water to downstream. The size of the spillway mainly depends on the maximum discharge. The selection of the most suitable type of dam for a particular site is sometimes governed by the size and location of spillway. In a gravity dam, the spillway section and non--overflow section can easily be provided side by side. Therefore, if a large spillway is required and there is no separate location to keep the spillway away from the dam, a gravity dam will be more suitable than an earth dam. In special cases, overflow spillways are also provided along with earth dams and rockfill dams, but a long divide wall between the main dam and the spillway is required to keep the flow away from the dam.

6. **Earthquake hazards**: If the dam site is located in a seismic zone, the most suitable type of the dam is one which can resist the earthquake shock without much damage. Earth dams and rockfill dams are generally more suitable for such sites, provided suitable modifications are made in the design. However, by adopting suitable measures and considering various forces and factors affecting the seismic design, other types of dams can also be provided.

7. **Climatic conditions**: Climatic conditions should also be considered while selecting the type of dam. In extremely cold climates, buttress and arch dams should be avoided. These dams have thin concrete sections and are easily damaged due to spalling of concrete which occurs due to alternate freezing and thawing. Similarly, if there are frequent rains and the climate is extremely wet, it will be difficult to control water content of the soil and compaction in an earth dam. Therefore, earth dams should be avoided.

8. **Diversion problems**: During the construction of the dam, the river water has to be diverted so that construction can be done in dry. If the river water cannot be diverted through a suitable tunnel (or channel) located in one of the flanks

(abutments), it has to be passed over the partly constructed dam when the construction is done in the other part. In such a case, an earth dam cannot be provided, and the choice will be more in favour of a gravity dam or any other type of concrete dams.

9. **Environmental considerations**: The dam and its appurtenant works should be aesthetically acceptable and they should not have any adverse effect on ecology and environment. Generally, earth dams are more suitable than concrete dams for aesthetical consideration. They merge easily with the natural environment in the valley. Sometimes, a particular reach of the river has good scenic beauty for recreational facility which is likely to be spoiled by construction of a high dam and creation of a large reservoir. In such a case, the dam site maybe shifted. Alternatively, a low diversion dam may be constructed to divert the water to an off-stream reservoir developed at a suitable site away from the dam to preserve the site for recreation.

10. **Roadway**: If a wide, straight roadway is to be provided over the top of dam, an earth dam or a gravity dam is more suitable than an arch dam or a buttress dam.

11. **Length and height of dam**: If the length of the dam is great and the height is low, an earth dam is generally better than a gravity dam. On the other hand, if the length is small and the height is great, a gravity dam is better.

12. **Life of dam**: If the expected life of the project is long, a concrete dam is usually preferred. Earth and rockfill dams have moderate life, whereas timber dams have short life.

13. **Miscellaneous considerations**: Sometimes the selection of the type of dam is made due to other miscellaneous considerations. For example, if earth-moving machines are cheaply available at the site, an earth dam may be preferred. Similarly, if mixing plants, batching plants, etc. are already available near the site, a gravity dam or a buttress dam may be selected. Likewise, if cheap labour is locally available, a masonry dam may be preferred to a concrete dam.

Investigations of Dam and Reservoir Site

The following investigations are usually conducted locate the most suitable site for a dam

1. **Engineering surveys**: Engineering surveys are conducted for the dam, the reservoir and other associated works. Generally, the topographic survey of the area is carried out and the contour plan is prepared. The horizontal control is usually provided by triangulation survey and the vertical control by precise levelling. For the area in the vicinity of the dam site, a very accurate triangulation survey is conducted. A contour plan to a scale of 1/250 or 1/500 is usually prepared. The contour interval is usually 1 m or 2 m. The contour plan should cover an area at least upto 200 m upstream and 400 m downstream and for adequate width beyond the two abutments. For the reservoir, the scale of the contour plan is usually 1/15,000 with a contour interval of 2 m to 3 m, depending upon the size of the reservoir. The area-elevation and storage-elevation curves are prepared for different elevations upto an elevation 3 to 5 m higher than the anticipated maximum water level (MWL).

2. **Geological Investigations**: Geological Investigations of the dam and reservoir site are done for (a) Suitability of foundation for the dam, (b) Watertightness of the reservoir basin, and (c) Location of the quarry sites for the construction materials. Subsurface explorations are carried out to determine the depth of overburden to be removed for laying the foundation of the dam, the type of rock, the nature and extent of the fault zones, if any, present in the

rock. The information obtained from the geological investigations is used for devising a suitable programme of foundation treatment and grouting if necessary. Geological investigations are conducted to detect the presence of faults, fissures, and cavernous rock formations which have cavities and are porous. If such formations exist in small areas, they may be treated and made watertight. However if they are wide spread, the site may have to be abandoned. Geological investigations are also conducted for location of suitable quarries for stones and borrow areas for soils. The quality and the quantity of the available construction materials are also ascertained.

3. **Hydrological Investigations**: Hydrological Investigations are conducted (a) to study the runoff pattern and to estimate yield and (b) to determine the maximum discharge at the site. The most important aspect of the reservoir planning is to estimate the quantity of water likely to be available in the river from year to year and seasons to season. For the determination of the storage capacity of a reservoir, the runoff pattern of the river at the dam site is required. The spillway capacity of the dam is determined from the inflow hydrograph for the worst flood when the discharge in the river is the maximum. Flood routing is done to estimate the maximum outflow and the maximum water level reached during the worst flood. The methods for the fixation of reservoir capacity, for the estimation of the maximum flood discharge, and for flood routing are already learnt in Hydrology course.

4. **Sub-surface exploration**: Sub-surface exploration programme usually includes one or more of the following methods. (i) Geophysical method, (ii) Sounding and penetration methods, (iii) Open excavations, (iv) Exploratory boring, and (v) Rock drilling. Foundations of a dam are usually of the following two types: (a) Rock foundation, and (b) Alluvial foundation. High dams are usually constructed on rock foundations. Moreover, the spillways and outlets are normally built on sound rock. Thorough subsurface explorations of rocks are carried out to determine the depth of overburden, location of fault zones, extent of jointing, existence of solution cavities, presence of soluble materials, disintegration of rock, etc. The presence and nature of clay or any other material in the seams of the jointed or fractured zones of the rock should be specially investigated. Such materials create problems and may even lead to failure when the reservoir is filled and very high hydrostatic pressure develops. The depth of exploratory investigations should be taken upto the bed rock. If the bed rock is at great depth, there should be at least one boring upto the bed rock. Investigations must be done through all soft, unstable and permeable strata of the overburden. For large dams, the foundations should be thoroughly investigated to great depths. Alluvial foundations consist of sand, gravel, silt and clay. Generally, earth dams and low gravity dams are constructed on such foundations. For all other types of dams, rock foundations are required. Geophysical methods and sub-surface soundings are used to determine the depth of bed rock. The properties of soils such as permeability, density, consolidations characteristics and shear strength are determined.