LECTURE NOTES ON
WATER RESOURCES ENGINEERING-II
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CIVIL ENGINEERING

UNIT-III
RESERVOIRS-DAMS

Water storage reservoirs may be created by constructing a dam across a river, along with suitable appurtenant structures. However, in that lesson not much was discussed about fixing the size of reservoir based on the demand for which it is being constructed. Further, reservoirs are also meant to absorb a part of flood water and the excess is discharged through a spillway. It is also essential to study the relation between flood discharge, reservoirs capacity and spillway size in order to propose an economic solution to the whole project. These and topics on reservoir sedimentation have been discussed in this lesson which shall give an idea as to how a reservoir should be built and optimally operated. Fundamentally, a reservoir serves to store water and the size of the reservoir is governed by the volume of the water that must be stored, which in turn is affected by the variability of the inflow available for the reservoir. Reservoirs are of two main categories: (a) Impounding reservoirs intowhich a river flows naturally, and (b) Service or balancing reservoirs receiving supplies that arepumped or channeled into them artificially. In general, service or balancing reservoirs are required to balance supply with demand. Reservoirs of the second type are relatively small in volume because the storage required by them is to balance flows for a few hours or a few days at the most. Impounding or storage reservoirs are intended to accumulate a part of the flood flow ofthe river for use during the non-flood months.

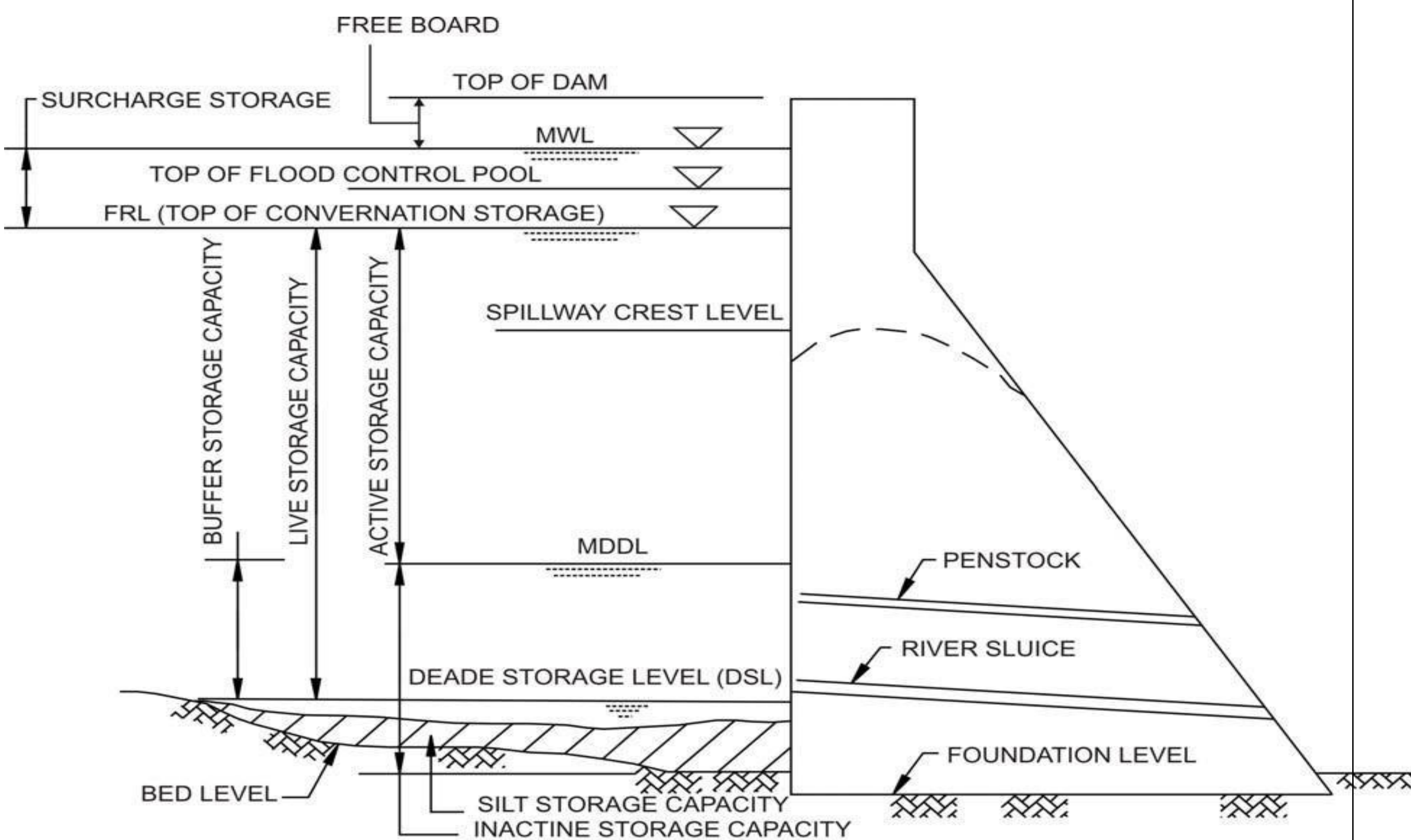


FIGURE 1. SCHEMATIC DIAGRAM SHOWING STORAGE ZONES (OF CAPACITY) NOMENCLATURE

These specific levels and parts are generally defined as follows:

Full Reservoir Level (FRL)**:** It is the level corresponding to the storage which includes both inactive and active storages and also the flood storage, if provided for. In fact, this is the highest reservoir level that can be maintained without spillway discharge or without passing water downstream through sluice ways.

Minimum Drawdown Level (MDDL)**:** It is the level below which the reservoir will not be drawn down so as to maintain a minimum head required in power projects.

Dead Storage Level (DSL)**:** Below the level, there are no outlets to drain the water in the reservoir by gravity.

Maximum Water Level (MWL)**:** This id the water level that is ever likely to be attained during the passage of the design flood. It depends upon the specified initial reservoir level and the spillway gate operation rule. This level is also called sometimes as the ***Highest Reservoir Level*** or the ***Highest Flood Level***.

Live storage**:** This is the storage available for the intended purpose between Full Supply Level and the Invert Level of the lowest discharge outlet. The Full Supply Level is normally that level above which over spill to waste would take place. The minimum operating level must be sufficiently above the lowest discharge outlet to avoid vortex formation and air entrainment. This may also be termed as the volume of water actually available at any time between the Dead Storage Level and the lower of the actual water level and Full Reservoir Level.

Dead storage**:** It is the total storage below the invert level of the lowest discharge outlet from the reservoir. It may be available to contain sedimentation, provided the sediment does not adversely affect the lowest discharge.

Outlet Surcharge or Flood storage**:** This is required as a reserve between Full Reservoir Level and the Maximum Water level to contain the peaks of floods that might occur when there is insufficient storage capacity for them below Full Reservoir Level.

Some other terms related to reservoirs are defined as follows:

Buffer Storage**:** This is the space located just above the Dead Storage Level up to Minimum Drawdown Level. As the name implies, this zone is a buffer between the active and dead storage zones and releases from this zone are made in dry situations to cater for essential requirements only. Dead Storage and Buffer Storage together is called Interactive Storage.

Within-the-Year Storage**:** This term is used to denote the storage of a reservoir meant for meeting the demands of a specific hydrologic year used for planning the project.

Carry-Over Storage**:** When the entire water stored in a reservoir is not used up in a year, the unused water is stored as carry-over storage for use in subsequent years.

Silt / Sedimentation zones**:** The space occupied by the sediment in the reservoir can be divided into separate zones. A schematic diagram showing these zones is illustrated in Figure (as defined in IS: 5477).

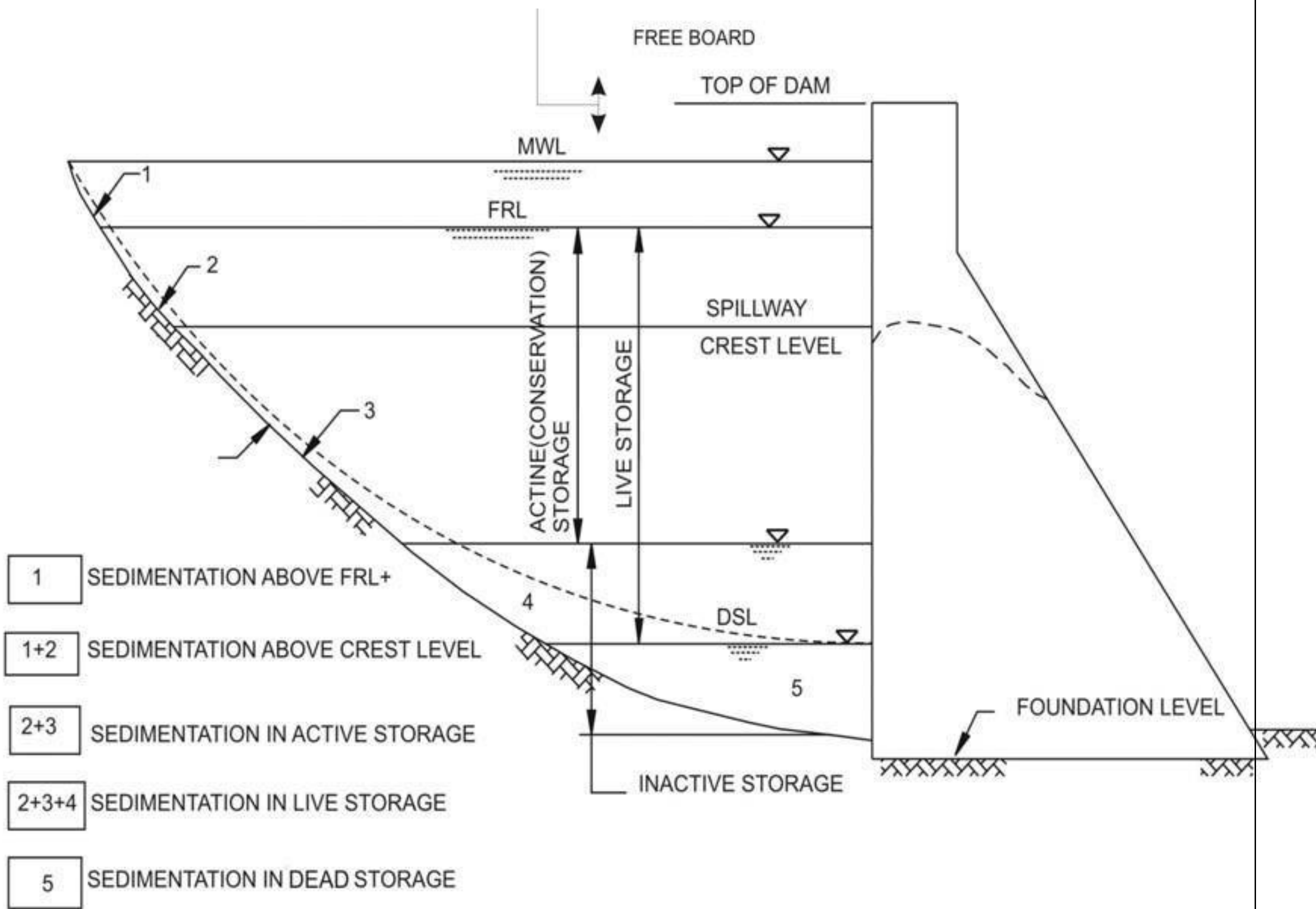


FIGURE 2. SCHEMATIC DIAGRAM SHOWING ZONES OF RESEERVOIR SEDIMENTION

***Freeboard*:** It is the margin kept for safety between the level at which the dam would be overtopped and the maximum still water level. This is required to allow for settlement of the dam, for wave run up above still water level and for unforeseen rises in water level, because of surges resulting from landslides into the reservoir from the peripheral hills, earthquakes or unforeseen floods or operational deficiencies.

The functions of reservoirs are to provide water for one or more of the following purposes. Reservoirs that provide water for a combination of these purpose, are termed as ‘Multi Purpose’ reservoirs.

FUNCTIONS OF THE RESERVOIRS:

1. **Human consumption** and/or **industrial use:**
2. **Irrigation:** usually to supplement insufficient rainfall.
3. **Hydropower:** to generate power and energy whenever water is available or to provide reliable supplies of power and energy at all times when needed to meet demand.

4.Pumped storage hydropower schemes: in which the water flows from an upper to a lower reservoir, generating power and energy at times of high demand through turbines, which may be reversible, and the water is pumped back to the upper reservoir when surplus energy is available. The cycle is usually daily or twice daily to meet peak demands. Inflow to such a reservoir is not essential, provided it is required to replace water losses through leakage and evaporation or to generate additional electricity. In such facilities, the power stations, conduits and either or both of the reservoirs could be constructed underground if it was found to do so.

4. ***Flood control:*** storage capacity is required to be maintained to absorb foreseeable flood inflows to the reservoirs, so far as they would cause excess of acceptable discharge spillway opening. Storage allows future use of the flood water retained.
5. ***Amenity use:*** this may include provision for boating, water sports, fishing, sight seeing. Formally, the Bureau of Indian Standards code IS: 4410 (part 6)1983 "

Reservoirs" defines the following types of reservoirs:

1. ***Auxiliary or Compensatory Reservoir:*** A reservoir which supplements and absorbed the spill of a main reservoir.

2. ***Balancing Reservoirs:*** A reservoir downstream of the main reservoir for holding water let down from the main reservoir in excess of that required for irrigation, power generation or other purposes.

3. ***Conservation Reservoir:*** A reservoir impounding water for useful purposes, such as irrigation, power generation, recreation, domestic, industrial and municipal supply etc.

4. ***Detention Reservoir:*** A reservoir where in water is stored for a relatively brief period of time, past of it being retained until the stream can safely carry the ordinary flow plus the released water. Such reservoirs usually have outlets without control gates and are used for flood regulation. These reservoirs are also called as the ***Flood Control Reservoir*** or ***Retarding Reservoir***.

5. ***Distribution Reservoir:*** A reservoir connected with distribution system a water supply project, used primarily to care for fluctuations in demand which occur over short periods and as local storage in case of emergency such as a break in a main supply line failure of a pumping plant.

6. ***Impounding or Storage Reservoir:*** A reservoir with gate-controlled outlets wherein surface water may be retained for a considerable period of time and released for use at a time when the normal flow of the stream is in sufficient to satisfy requirements.

7. ***Multipurpose Reservoir:*** A reservoir constructed and equipped to provide storage and release of water for two or more purposes such as irrigation, flood control,power generation, navigation, pollution abatement, domestic and industrial water supply,fish culture, recreation, etc.

PLANNING OF RESERVOIRS

The first step in planning the construction of a reservoir with the help of a dam is for the decision makers to be sure of the needs and purposes for which the reservoir is going to be built together with the known constraints (including financial), desired benefits. There may be social constraints, for examples people's activism may not allow a reservoir to be built up to the desired level or even the submergence of good agricultural level may be a constraint. Some times, the construction of a dam may be done that is labour intensive and using local materials, which helps the community for whom the dam is being built. This sort of work is quite common in the minor irrigation departments of various steps, especially in the drought prone areas. The Food-for-Work schemes can be utilised in creating small reservoirs that helps to serve the community. In a larger scale, similar strategy was adopted for the construction of the Nagarjuna Sagar Dam on the River Krishna, which was built entirely of coursed rubble masonry and using manual labour in thousands.

The second step is the assembly of all relevant existing information, which includes the following:

1. Reports of any previous investigations and studies, if any.
2. Reports on projects similar to that proposed which have already been constructed in the region.
3. A geographical information system (GIS) for the area of interest may be created using a base survey map of the region.
4. Topographical data in the form of maps and satellite pictures, which may be integrated within the GIS.
5. Geological data in the form of maps and borehole logs, along with the values of relevant parameters.
6. Seismic activity data of the region that includes recorded peak accelerations or ground motion record.
7. Meteorological and hydrological data - of available parameters like rainfall, atmospheric and water temperatures, evaporation, humidity, wind speed, hours of sunshine, river flows, river levels, sediment concentration in rivers, etc.
8. For water supply projects, data on population and future population growth based on some acceptable forecast method, industrial water requirement and probable future industrial development.
9. For irrigation projects, data on soils in the project area and on the crops already grown, including water requirement for the crops.
10. For hydropower projects, data on past demand and forecasts of future public and industrial demand for power and energy; data on existing transmission systems, including transmission voltage and capacity.
11. Data on flora and fauna in the project and on the fish in the rivers and lakes, including data on their migratory and breeding habits.
12. Data on tourism and recreational use of rivers and lakes and how this may be encouraged on completion of the proposed reservoir.
13. As may be noted, some of the data mentioned above would be needed to design and construct the dam and its appurtenant structures which would help to store water behind the reservoir.
14. Size of the reservoir and, consequently, height of the dam
15. Size of the spillway and elevation of the Spillway crest level
16. Sizes of the sluices
17. Two important aspects of reservoirs planning: Sedimentation Studies and Geological Explorations

RESERVOIR SEDIMENTATION:

It is important to note that storage reservoirs built across rivers and streams loose their capacity on account of deposition of sediment. This deposition which takes place progressively in time reduces the active capacity of the reservoir to provide the outputs of water through passage of time. Accumulation of sediment at or near the dam may interfere with the future functioning of water intakes and hence affects decisions regarding location and height of various outlets. It may also result in greater inflow of into canals / water conveyance systems drawing water from the reservoir. Problems of rise in flood levels in the head reaches and unsightly deposition of sediment from recreation point of may also crop up in course of time.In this regard, the Bureau of Indian Standard code IS: 12182 - 1987 “Guidelines for determination of effects of sedimentation in planning and performance of reservoir” is an important document which discusses some of the aspects of sedimentation that have to be considered while planning reservoirs. Some of the important points from the code are as follows: While planning a reservoir, the degree of seriousness and the effect of sedimentation at the proposed location has to be judged from studies, which normally combination consists of:

In special cases, where the effects of sedimentation on backwater levels are likely to be significant, backwater studies would be useful to understand the size of river water levels. Similarly, special studies to bring out delta formation region changes may be of interest. The steps to be followed for performance assessment studies with varying rates of sedimentation are as follows:

a. Estimation of annual sediment yields into the reservoir or the average annual sediment yield and of trap efficiency expected.

b. Distribution of sediment within reservoir to obtain a sediment elevation and capacity curve at any appropriate time.

c. Simulation studies with varying rates of sedimentation.

d. Assessment of effect of sedimentation.

In general, the performance assessment of reservoir projects has to be done for varying hydrologic inputs to meet varying demands. Although analytical probability based methods are available to some extent, simulation of the reservoir system is the standard method. The method is also known as the working tables or sequential routing. In this method, the water balance of the reservoir s and of other specific locations of water use and constraints in the systems are considered. All inflows to and outflows from the reservoirs are worked out to decide the changed storage during the period. In simulation studies, the inflows to be used may be either historical inflow series, adjusted for future up stream water use changes or an adjusted synthetically generated series.

Procedure for planning a new reservoir

The standard procedure that needs to be carried out for planned storages requires an assessment of the importance of the problem to classify the reservoir sedimentation problem as insignificant, significant, or serious. Assessment of reservoir sedimentation problem, in a particular case may be made by comparing the expected average annual volume of sediment deposition with the gross capacity of the reservoir planned. If the ratio is more than 0.5 percent per year, the problem is usually said to be serious and special care is required in estimating the sediment yields from the catchment. If it is less than 0.1 percent per year, the problem of siltation may be insignificant and changes in reservoir performance. For cases falling between these two limits, the sedimentation problem is considered significant and requires further studies.

The following studies are required if the problem is insignificant:

1. No simulation studies with sediment correlation are necessary.
2. The feasible service time for the project may be decided. Sediment distribution studies to ensure that the new zero-elevation does not exceed the dead storage level may be made.

In the above, the following terms have been used, which are explained below:

Feasible Service Time: For a special purpose, the period or notional period for which a reservoir is expected to provide a part of the planned benefit in respect of storage in the reservoirs being impaired by sedimentation. Customarily, it is estimated as the time after which the new zero elevation of the reservoir would equal the sill of the outlet relevant for the purpose.

New Zero Elevation: The level up to which all the available capacity of the reservoir is expected to be lost due to progressive sedimentation of the reservoir up to the specified time. The specified time should be any length of time such as Full Service Time, Feasible Service time, etc.

Full Service Time: For a specified purpose, the period or notional period for which the reservoir provided is expected to provide, a part of the full planned benefit inspite of sedimentation.

The following studies are required if the problem of sedimentation in the reservoir is assessed to be significant, but not serious.

1. Both the full service time and feasible service time for the reservoir may be decided.
2. Simulation studies for conditions expected at the end of full service time may be made to ensure that firm outputs with required depend ability are obtained. The studies used also assess non-dependable secondary outputs, if relevant, available at the end of this period. Studies without sedimentation, with the same firm outputs should bring out the additional potential secondary outputs which may be used, if required in economic analysis, using a linear decrease of these additional benefits over the full service time.
3. No simulation studies beyond full service time, is required.
4. Sediment distribution studies required for feasible service time are essential.

The following studies are required if the problem of sedimentation is serious.

1. All studies described for the 'Significant' case have to be made.
2. The secondary benefits available in the initial years should be more in such cases. If they are being utilized, for a proper assessment of the change of these, a simulation at half of full service time should be required.
3. In these cases, the drop of benefits after the full service time may be sharper. To bring out these effects, a simulation of the project at the end of the feasible service time is required to be done.

Life of reservoir and design criteria

A reservoir exists for a long time and the period of its operation should normally check large technological and socio-economic changes. The planning assumptions about the exact socio-economic outputs are, therefore, likely to be changed during operation, and similarly, the implication of socio-economic differences in the output due to sedimentation are difficult to access**.** The ever increasing demands due to both increase of population and increases in per capita needs are of a larger magnitude than the reductions in outputs, if any, of existing reservoirs. Thus effects of sedimentation, obsolescence, structural deterioration, etc. of reservoirs may require adjustments in future developmental plans and not simply replacement projects to bring back the lost potential. On a regional or national scale, it is the sufficiency of the total economic outputs, and not outputs of a particular project which is relevant. However, from local considerations, the reduction of outputs of reservoir like irrigation and flood control may cause a much greater degree of distress to the population which has got used to better socio-economic conditions because of the reservoir. 'Life' strictly is a term which may be used for system having two functional states 'ON' and 'OFF'. Systems showing gradual degradation of performance and not showing any sudden non-functional stage have no specific life period. Reservoirs fall in the later category. The term 'life of reservoir' as loosely used denotes the period during which whole or a specified fraction of its total or active capacity is lost. In calculating this life, the progressive changes in trap efficiency towards the end of the period are commonly not considered. In some of the earlier projects, it has been assumed that all the sedimentation would occur only in the dead storage pocket and the number of years in which the pocket should be filled under this assumption was also sometimes termed as the life of reservoir. This concept was in fact used to decide the minimum size of the pocket. Under this concept, no effect of sedimentation should be felt within the live storage of the reservoir. It has subsequently been established that the silt occupies the space in the live storage of reservoir as well as the dead storage.

If the operation of the reservoir becomes impossible due to any structural defects, foundation defects, accidental damages, etc., this situation should also signify the end of the feasible service time. Before the expiry of this feasible service time, it may be possible to make large changes in the reservoir (for example, new higher level outlets,structural strengthening, etc.) or other measures, if it is economically feasible to do so. If these studies are done, the feasible service time may be extended.

FACTORS GOVERNING THE SELECTION OF SITE FOR THE RESERVOIR

Though a dam is constructed to build a reservoir, a reservoir has a large area of spread and contained in a big chunk of the river valley upstream of the dam. Hence, while identifying a suitable site for a proposed dam, it is of paramount importance that the proposed reservoir site is also thoroughly investigated and explored. The basis of planning for such explorations is to have a rapid economical and dependable pre-investment evaluation of subsurface conditions. It is also necessary that a degree of uniformity be followed while carrying out subsurface explorations so that the frame of reference of the investigation covers all requisite aspects. In view of above, the Bureau of Indian Standards has brought out a code IS: 13216 - 1991 "Code of practice for geological exploration for reservoir sites", that discusses the relevant aspects. According to the code since reservoir projects in river valleys are meant to hold water; therefore, the following aspects of the reservoirs have to be properly investigated

(a) Water tightness of the basins
(b) Stability of the reservoir rim
(c) Availability of construction material in the reservoir area
(d) Silting
(e) Direct and indirect submergence of economic mineral wealth
(f) Seismo-techtonics

These aspects are determined through investigations carried out by surface and sub- surface exploration of proposed basin during the reconnaissance, preliminary investigation, detailed investigation, construction and post-construction stages of the project. The two basic stages of investigation: reconnaissance and preliminary investigations are explained below:

Reconnaissance

In the reconnaissance stage, the objective of investigation is to bring out the overall geological features of the reservoir and the adjacent area to enable the designers, construction engineers and geologists to pinpoint the geotechnical and ecological problems which have to be tackled. The scale of geological mapping for this stage of work need not be very large and the available geological maps on 1:50,000 or 1: 250,000 scales may be made use of. It is advantageous to carry out photo geological interpretation of aerial photographs of the area, if available. If a geological map of the area is not available, a traverse geological map should be prepared at this stage preferably using the aerial photos as base maps on which the engineering evaluation of the various geotechnical features exposed in the area should be depicted.

A topographical index map on 1: 50 000 scales should be used at this stage to delineate the areas which would require detailed study, subsequently. To prevent an undesirable amount of leakage from the reservoir, the likely zones of such leakage, such as major dislocations and pervious or cavernous formations running across the divide of the reservoir should be identified at this stage of investigation for further detailed investigations.Major unstable zones, particularly in the vicinity of the dam in tight gorges, should be identified at this stage for carrying out detailed investigations for the stability of the reservoir rim. The locations for suitable construction material available in the reservoir area should be pin pointed at this stage so that after detailed surveys such materials can be exploited for proper utilisation during the construction stage prior to impounding of reservoir.The rate of silting of the reservoir is vital for planning the height of the dam and working out the economic life of the project. Since the rate of silting, in addition to other factors, is dependent on the type of terrain in the catchment area of the reservoir, the major geological formations and the ecological set up should be recognized at this stage to enable a more accurate estimation of the rate of silting of the reservoir. For example, it should be possible to estimate at this stage that forty percent of the catchment of a storage dam project is covered by Quaternary sediment and that this is a condition which is likely to a yield a high silt rate or that ninety percent of the catchment of another storage dam project is composed of igneous and metamorphic rocks and is likely to yield a relatively low sediment rate. This information will also be useful in examining whether or not tributaries flowing for long distances through soft or unconsolidated formations, prior to forming the proposed reservoir, can be avoided and if not, what remedial measures can be taken to control the silt load brought by these tributaries.

The impounding of a reservoir may submerge economic/strategic mineral deposits occurring within the reservoir area or the resultant rise in the water table around the reservoir may cause flooding, increased seepage in quarries and mines located in the area and water logging in other areas. It is, therefore, necessary that the economic mineral deposits, which are likely to be adversely affected by the reservoir area, are identified at this stage of the investigation. For example, if an underground working is located close to a proposed storage reservoir area, it should be identified for regular systematic geo-hydrological studies subsequently. These studies would establish whether the impoundment of the water in the reservoir had adversely affected the underground working or not. References should also be made to various agencies dealing with the economic minerals likely to be affected by the impoundment in the reservoir for proper evaluation of the problem and suitable necessary action. A dam and its reservoir are affected by the environment in which they are located and in turn they also change the environment. Impoundment of a reservoir sometimes results in an increase of seismic activity at, or near the reservoir. The seismic activity may lead to microtremors and in some cases lead to earthquakes of high magnitude. It is, therefore, necessary to undertake the regional seismotechtonic study of the project area. The faults having active seismic status

should be delineated at this stage.

Simultaneous action to plan and install a network of seismological observatories encompassing the reservoir area should also be taken.

Preliminary Investigation

The object of preliminary investigation of the reservoir area is to collect further details of the surface and subsurface geological conditions, with reference to the likely problems identified during the reconnaissance stage of investigation by means of surface mapping supplemented by photo geological interpretation of aerial photographs, hydro geological investigations, geophysical investigations, preliminary subsurface exploration and by conducting geo-seismological studies of the area. On the basis of studies carried out during the reconnaissance stage it should be possible to estimate the extent of exploration that may be required during the preliminary stage of investigation including the total number of holes required to be drilled and the total number and depth of pits, trenches and drifts as also the extent of geophysical surveys which may be necessary. For exploration by pits, trenches, drifts and shafts guidelines laid down in IS 4453: 1980 Name of IS code should be followed. The potential zones of leakage from the reservoir and the lateral extent of various features, such as extent of aeolian sand deposits, glacial till, land slides, major dislocations or pervious and cavernous formations running across the divide, should be delineated on a scale of 1: 50000. The geo-hydrological conditions of the reservoir rim should be established by surface and sub-surface investigation as well as inventory, as a free ground water divide rising above the proposed level of the reservoir is a favourable condition against leakage from the reservoir. The level of water in a bore hole should be determined as given in IS 6935: 1973. The extension of various features at depth, wherever necessary, is investigated by geophysical exploration and by means of pits, trenches, drifts and drill holes. For example, the resistivity survey should be able to identify water saturated zones.

Trap Efficiency

Trap efficiency of reservoir, over a period, is the ratio of total deposited sediment to the total sediment inflow. Figures 1 and 2 given in Annex A of IS 12182 cover relationship between sedimentation index of the reservoir and percentage of incoming sediment and these curves may be used for calculation of trap efficiency.

Losses in Reservoir

Water losses mainly of evaporation and seepage occur under pre-project conditions and are reflected in the stream flow records used for estimating water yield. The construction of new reservoirs and canals is often accompanied by additional evaporation and infiltration. Estimation of these losses may be based on measurements at existing reservoirs and canals. The measured flows and outflows and the rate of change of storage are balanced by computed total loss rate. The depth of water evaporated per year from the reservoir surface may vary from about 400 mm in cool and humid climate to more than 2500 mm in hot and arid regions. Therefore, evaporation is an important consideration in many projects and deserves careful attention. Various methods like water budget method, energy budget method, etc may be applied for estimating the evaporation from reservoir. However, to be more accurate, evaporation from reservoir is estimated by using data from pan-evaporimeters or pans exposed to atmosphere with or without meshing in or near the reservoir site and suitably adjusted. Seepage losses from reservoirs and irrigation canals may be significant if these facilities are located in an area underlain by permeable strata. Avoidance in full or in part of seepage losses may be very expensive and technical difficulties involved may render a project unfeasible. These are generally covered under the conveyance losses in canals projected on the demand side of simulation studies.

Measurement of sediment yields

The sediment yield in a reservoir may be estimated by any one of the following two methods:

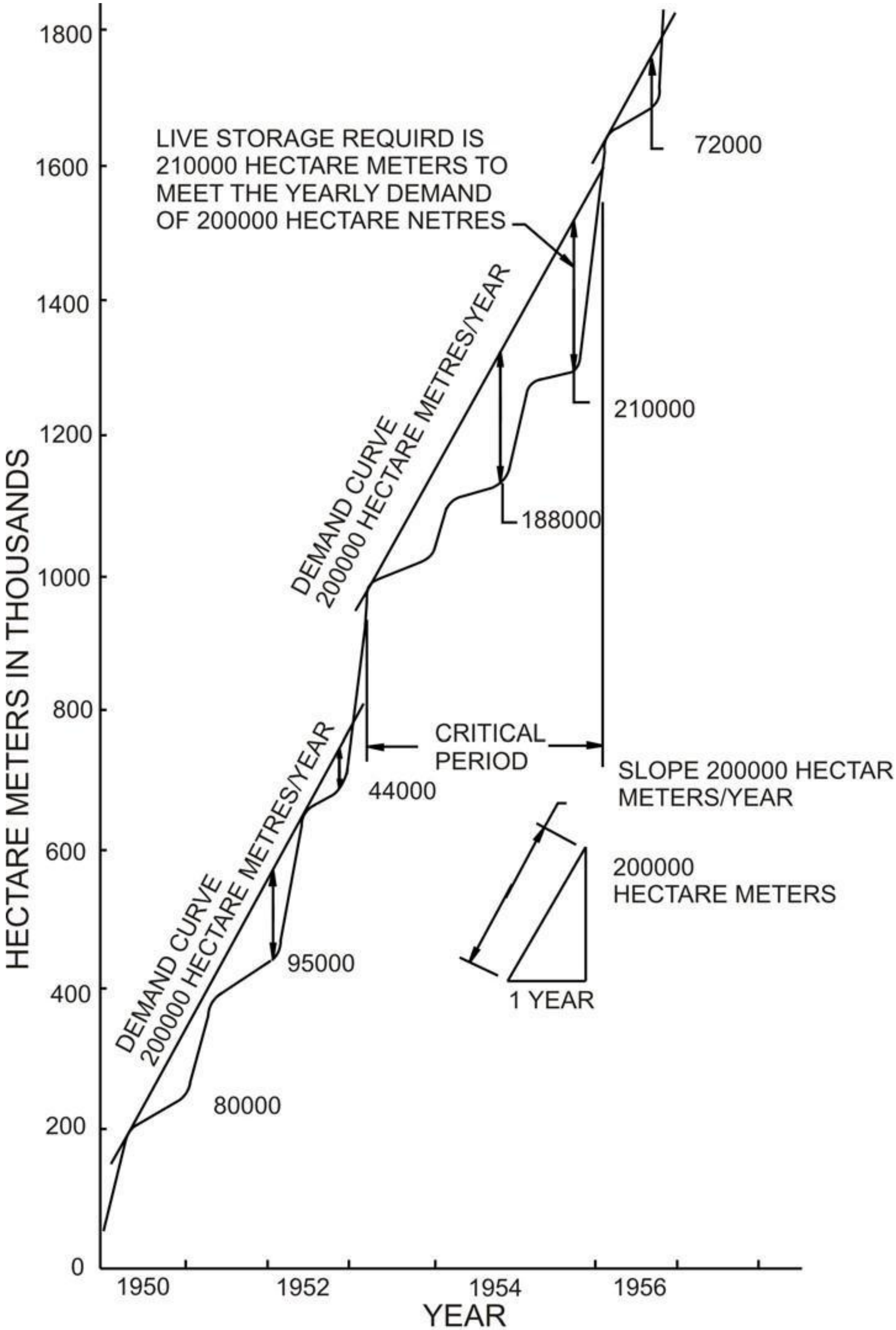
a) Sedimentation surveys of reservoirs with similar catchment characteristics, or

b) Sediment load measurements of the stream.

Reservoir Sedimentation Survey

The sediment yield from the catchment is determined by measuring the accumulated sediment in a reservoir for a known period, by means of echo sounders and other electronic devices since the normal sounding operations give erroneous results in large depths. The volume of sediment accumulated in a reservoir is computed as the difference between the present reservoir capacity and the original capacity after the completion of the dam. The unit weight of deposit is determined in the laboratory front the representative undisturbed samples or by field determination using a calibrated density probe developed for this purpose. The total sediment volume is then converted to dry- weight of sediment on the basis of average unit weight of deposits. The total sediment yield for the period of record covered by the survey will then be equal to the total weight of the sediment deposited in the reservoir plus that which has passed out of the reservoir based on the trap efficiency. In this way, reliable records may be readily and economically obtained on long-term basis.

The density of deposited sediment varies with the composition of the deposits, location of the deposit within the reservoir, the flocculation characteristics of clay content and water, the age of deposit, etc. For coarse material (0.0625 mm and above) variation of density with location and age may be unimportant. Normally a time and space average density of deposited materials applicable for the period under study is required for finding the overall volume of deposits. For this purpose the trapped sediment for the period under study would have to be classified in different fractions. Most of the sediment escape front getting deposited into the reservoir should be front the silt and clay fractions. In some special cases local estimates of densities at points in the reservoir may be required instead of average density over the whole reservoir. The trap efficiency mainly depends upon the capacity-in-flow ratio but may vary with location f outlets and reservoir operating procedure. Computation of reservoir trap



(Inflow adjuasted for evaporation and required release for downstream uses,if any)

FIGURE 4. A TYPICAL MASS CURVE

Estimation of a Demand from a Given Live Storage Capacity

The net inflow mass curve is plotted from the available records. The demand lines arc, drawn at peak points of the mass curve in such a way that the maximum ordinate between the demand line and the mass curve is equal to the specified live storage. The demand lines shall intersect the mass curve when extended forward. The slop of the flattest line indicates the film demand that could he met by the given live storage Capacity. Before fixing the reservoir capacity, it would be desirable to plot a curve between the net annual drafts and the required live storage capacities for these drafts. This curve will give an indication of the required live storage capacity. However, the economics of the capacity will have to be considered before deciding final capacity.

Fixing of flood and surcharge storage

In case of reservoirs having flood control as one of the purposes, separate flood control storage is to be set apart above the storage meant for power, irrigation and water supply. Flood control storage is meant for storing flood waters above a particular return period temporarily and to attenuate discharges up to that flood magnitude to minimize effects on downstream areas from flooding. Flood and surcharge storage between the full reservoir level (FRL), and maximum water level (MWL) attainable even with full surplus by the spillway takes care of high floods and moderates them.

Flood Control Storage

Storage space is provided in the reservoir for storing flood water temporarily in order to reduce peak discharge of a specified return period flood and to minimize flooding of downstream areas for all floods IS: 5477 (Part 1) : 1999 equal to or lower than the return period flood considered. In the case of reservoirs envisaging flood moderation as a purpose and having separate flood control storage, the flood storage is provided above the top of conservation pool.

Surcharge Storage

Surcharge storage is the storage between the full reservoir level (FRL) and the maximum water level (MWL) of a reservoir which may be attained with capacity exceeding the reservoir at FRL to start with. The spillway capacity has to be adequate to pass the inflow design flood making moderation possible with surcharge storage. The methods that are generally used for estimate of the Design Flood for computing the Flood Storage are broadly classified as under:

1. Application of a suitable factor of safety to maximum observed flood or maximum historical flood.
2. Empirical flood formulae.
3. Envelope curves.
4. Frequency analysis.
5. Rating method of derivation of design flood from storm studies and application of the

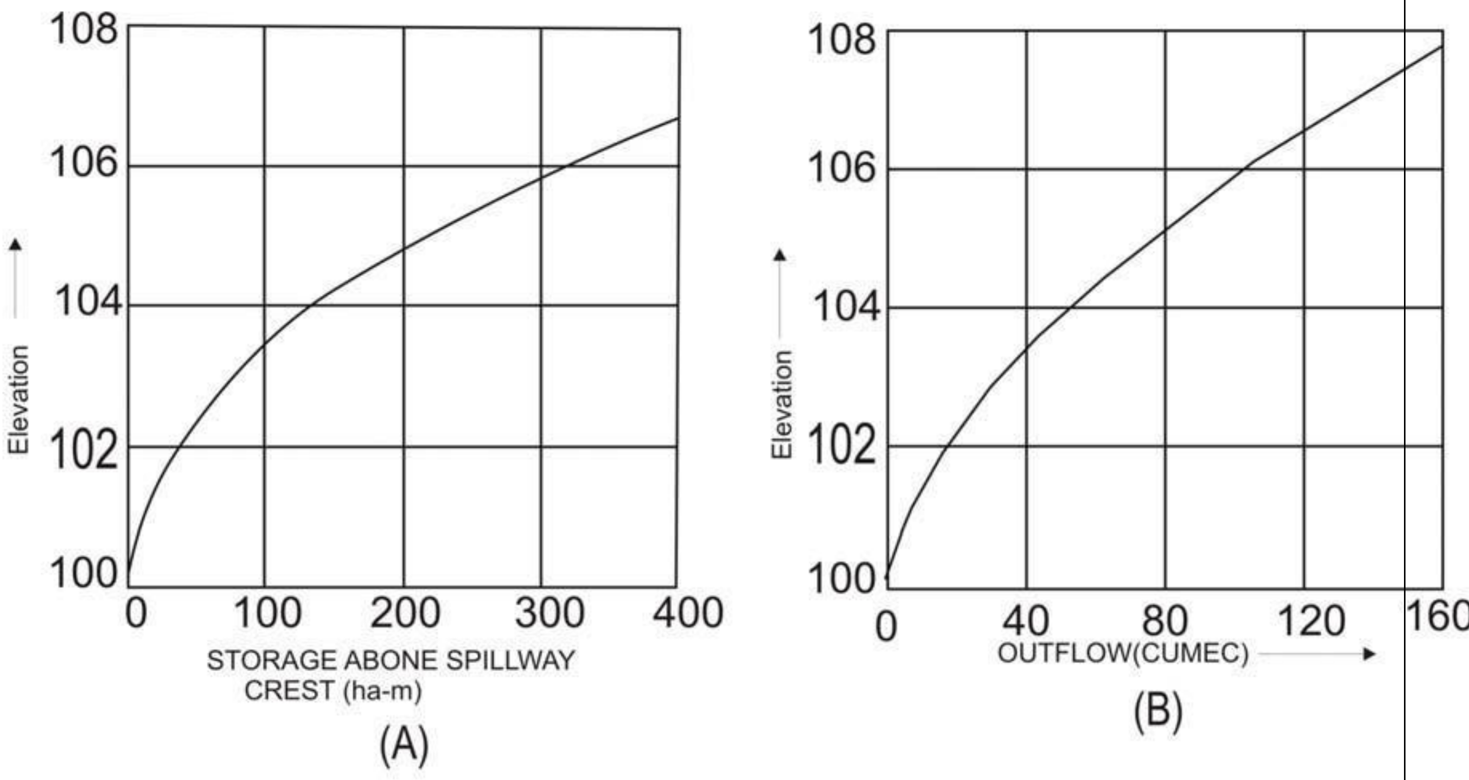


FIGURE 5. TYPICAL CURVES FOR (A) STORAGE Vs ELEVATION
(B) OUTFLOW Vs ELEVATION

1. Initial reservoir stage
2. The design flood hydrograph
3. Rate of outflow including the flow over the crest, through sluices or outlets and through power units, and
4. Incremental storage capacity of the reservoir.

Control of sediment deposition

The deposition of sediment in a reservoir may be controlled to a certain extent by designing and operating gates or other outlets in the dam in such a manner as to permit selective withdrawals of water having a higher than average sediment content. The suspended sediment content of the water in reservoirs is higher during and just after flood flow. Thus, more the water wasted at such times, the smaller will be the percentage of the total sediment load to settle into permanent deposits. There are generally two methods: (a) density currents, and (b) waste-water release, for controlling the deposition and both will necessarily result in loss of water

DAMS

A **dam** is a barrier that stops or restricts the flow of water or underground streams. Reservoirs created by dams not only suppress floods but also provide water for activities such as irrigation, human consumption, industrial use, aquaculture, and navigability. Hydropower is often used in conjunction with dams to generate electricity. A dam can also be used to collect water or for storage of water which can be evenly distributed between locations. Dams generally serve the primary purpose of retaining water, while other structures such as floodgates or levees (also known as dikes) are used to manage or prevent water flow into specific land regions.

The purpose of a dam is to impound (store) water for any of several reasons, e.g., flood control, water supply for humans or livestock, irrigation, energy generation, recreation, or pollution control.

Types of Dams

Dams may either be human-built or result from natural phenomena, such as landslides or glacial deposition. The majority of dams are human structures normally constructed of earthfill or concrete. Naturally occurring lakes may also be modified by adding a spillway to allow for safe, efficient release of excess water from the resulting reservoir.

- the different types of dams
- essential components of a dam
- how the components function, and
- important physical conditions likely to affect a dam.

Human-built dams may be classified according to the type of construction materials used, the methods used in construc-tion, their slope or cross-section, the way they resist the forces of the water pressure behind them, the means of controlling seepage, and occasionally, their purpose.

Construction Materials— The materials used for construction of dams include earth, rock, tailings from mining or milling, concrete, masonry, steel, and any combination of tho se materials.

Embankment Dams—Embankment dams, the most common type in use today, have the general shape shown in Their side slopes typically have a grade of two to one (horizontal to vertical) or flatter.Their capacity for water retention is due to the low permeability of the entire mass (in the case of a homoge- neous embankment) or of a zone of low-permeability material (in the case of a zoned embankment dam).Materials used for embankment dams include natural soil or rock obtained from borrow areas or nearby quarries, or waste materials obtained from mining or milling. If the natural material has a high permeability, then a zone of very-low-permeability material must be included in the dam to retain water. An embankment dam is termed an “earthfill” or “rockfill” dam depending on whether it is com-posed mostly of compacted earth or mostly of compacted or dumped pervious rock. The ability of an embankment dam to resist the hydrostatic pressure caused by reservoir water is primarily the result of the mass, weight, and strength of its materials.

Concrete Dams—Concrete dams may be categorized into gravity and arch dams according to the designs used to resist the stress due to reservoir water pressure. A concrete gravity dam (shown in Figure 2.2) is the most common form of concrete dam. In it, the mass weight of the concrete and friction resist the reservoir water pressure. A buttress dam is a specific type of gravity dam in which the large mass of concrete is reduced, and the forces are diverted to the dam foundation through vertical or sloping buttresses. Gravity dams are constructed of non-reinforced vertical blocks of concrete with flexible seals in the joints between the blocks.Concrete arch dams are typically rather thin in cross-section (Figure 2.3). The reservoir water forces acting on an arch dam are carried laterally into the abutments. The shape of the arch may resemble a segment of a circle or an ellipse, and the arch may be curved in the vertical plane as well. Such dams are usually built from a series of thin vertical blocks that are keyed together, with water stops between the blocks. Variations of arch dams include multi-arch dams, in which more than one curved section is used, and arch gravity dams, which combine some features of the two types.A recently developed method for constructing concrete gravity dams involves the use of a relatively weak concrete mix which is placed and compacted in a manner similar to that used for earthfill dams. Roller-compacted concrete has the advan-tages of decreased cost and time. In addition, there are no joints where seepage could occur.

Arch dams

In the arch dam, stability is obtained by a combination of arch and gravity action. If the upstream face is vertical the entire weight of the dam must be carried to the foundation by gravity, while the distribution of the normal hydrostatic pressure between vertical cantilever and arch action will depend upon the stiffness of the dam in a vertical and horizontal direction. When the upstream face is sloped the distribution is more complicated. The normal component of the weight of the arch ring may be taken by the arch action, while the normal hydrostatic pressure will be distributed as described above. For this type of dam, firm reliable supports at the abutments (either buttress or canyon side wall) are more important. The most desirable place for an arch dam is a narrow canyon with steep side walls composed of sound rock.[39] The safety of an arch dam is dependent on the strength of the side wall abutments, hence not only should the arch be well seated on the side walls but also the character of the rock should be carefully inspected. Two types of single-arch dams are in use, namely the constant-angle and the constant-radius dam. The constant-radius type employs the same face radius at all elevations of the dam, which means that as the channel grows narrower towards the bottom of the dam the central angle subtended by the face of the dam becomes smaller. The multiple-arch dam does not require as many buttresses as the hollow gravity type, but requires good rock foundation because the buttress loads are heavy.

Gravity Dam :In a gravity dam, the force that holds the dam in place against the push from the water is Earth's gravity pulling down on the mass of the dam.[40] The water presses laterally (downstream) on the dam, tending to overturn the dam by rotating about its toe (a point at the bottom downstream side of the dam). The dam's weight counteracts that force, tending to rotate the dam the other way about its toe. The designer ensures that the dam is heavy enough that the dam's weight wins that contest. In engineering terms, that is true whenever the resultant of the forces of gravity acting on the dam and water pressure on the dam acts in a line that passes upstream of the toe of the dam.

Furthermore, the designer tries to shape the dam so if one were to consider the part of dam above any particular height to be a whole dam itself, that dam also would be held in place by gravity. i.e. there is no tension in the upstream face of the dam holding the top of the dam down. The designer does this because it is usually more practical to make a dam of material essentially just piled up than to make the material stick together against vertical tension.

Note that the shape that prevents tension in the upstream face also eliminates a balancing compression stress in the downstream face, providing additional economy.For this type of dam, it is essential to have an impervious foundation with high bearing strength.When situated on a suitable site, a gravity dam can prove to be a better alternative to other types of dams. When built on a carefully studied foundation, the gravity dam probably represents the best developed example of dam building. Since the fear of flood is a strong motivator in many regions, gravity dams are being built in some instances where an arch dam would have been more economical. Gravity dams are classified as "solid" or "hollow" and are generally made of either concrete or masonry.

Arch-gravity dams

A gravity dam can be combined with an arch dam into an arch-gravity dam for areas with massive amounts of water flow but less material available for a purely gravity dam. The inward compression of the dam by the water reduces the lateral (horizontal) force acting on the dam. Thus, the gravitation force required by the dam is lessened, i.e. the dam does not need to be so massive. This enables thinner dams and saves resources.

Other Types—Various construction techniques could be used in a single dam. For example, a dam could include an earthen or rockfill embank-ment as well as a portion made of concrete. In such a case, the concrete section would normally contain the spillway or other outlet works.A recent design for low-head dams (with a minimal height of water behind the dam) uses inflatable rubber or plastic materials anchored at the bottom by a concrete slab.Some dams are constructed for special purposes, such as diversion of water, or permit construction of other facilities in river valleys. These dams are called diversion dams and cofferdams, respectively.

Water-Retention Ability

Because the purpose of a dam is to retain water effectively and safely, its water-retention ability is of prime impor-tance. Water may pass from the reservoir to the downstream side of a dam by:

(1)Seeping through the dam.

(2)Seeping through the abutments.

(3)Seeping under the dam.

(4)Overtopping the dam.

(5)Passing through the outlet works.

(6)Passing through or over a service (primary) spillway.

(7)Passing over an emergency spillway.

Seepage through a Dam—All embankment dams and most concrete dams allow some seepage. The earth or other material used to construct embankment dams has some perme-ability, and water under pressure from the reservoir will eventually seep through. However, it is important to control the quantity of seepage by using low-permeability materials in construction and by channeling and restricting the flow so that embankment materials do not erode.

Seepage through a concrete dam is usually minimal and is almost always through joints between blocks, or through cracks or deteriorated concrete which may have developed. Maintenance of these joints and cracks is therefore essential. The seepage water should be collected and channelized, so that its quantity can be measured and erosion minimized.

Seepage Around a Dam—Seepage under a dam, through the dam foundation material, or around the ends of a dam through the abutment materials may become a serious problem if the flow is large or of sufficient velocity to cause erosion. Seepage under a dam also creates high hydrostatic uplift (pore-water) pressure,which has the effect of diminishing the weight of the dam, making it less stable.Seepage through abutments or foundations can dissolve the constitu-ents of certain rocks such as limestone, dolomite, or gypsum so that any cracks or joints in the rock become progres-sively larger and in turn allow more seepage. Abutment or foundation seepage may also result in “piping” internal erosion, in which the flow of water is fast enough to erode away small particles of soil. This erosion progresses from the water exit point backward to the entrance point. When that point is reached, water may then flow without restriction, resulting in even greater erosion and probable dam failure.

Obviously, large, unrestricted seepage is undesirable. To minimize this possibility, dams are constructed with internal impermeable barriers and internal drainage facilities such as drainpipes or filter systems, or other drainage systems such as toe, blanket, or chimney drains.Flow through a dam foundation may be diminished by grouting known or suspected highly permeable material, constructing a cutoff wall or trench below a dam, or constructing an upstream impermeable blanket.

Selection of Dam Site

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

1. Suitable foundation must be available.
2. For economy, the length of the dam should be as small as possible, and for a given height, it should store the maximum volume of water.
3. The general bed level at dam site should preferably be higher than that of the river basin. This will reduce the height of the dam.
4. A suitable site for the spillway should be available in the near vicinity.
5. Materials required for the construction of dam should be easily available, either locally or in the near vicinity.
6. The value of land and property submerged by the proposed dam should be as low as possible.
7. The dam site should be easily accessible, so that it can be economically connected to important towns and cities.
8. Site for establishing labor colonies and a healthy environment should be available near the site.

Factors Affecting Selection of Dam

These factors are discussed one by one.

Topography

Topography dictates the first choice of the type of dam.

1. A narrow U-shaped valley, i.e. a narrow stream flowing between high rocky walls, would suggest a concrete overflow dam.
2. A low plain country, would suggest an earth fill dam with separate spillways.
3. A narrow V-shaped valley indicates the choice of an Arch dam

Geological and Foundation Conditions

Geological and Foundation conditions should be thoroughly surveyed because the foundations have to carry the weight of the dam. Various kind of foundations generally encountered are

1. Solid rock foundations such as granite have strong bearing power and almost every kind of dam can be built on such foundations.
2. Gravel foundations are suitable for earthen and rock fill dams.
3. Silt and fine sand foundations suggest construction of earth dams or very low gravity dams.
4. Clay foundations are likely to cause enormous settlement of the dam. Constructions of gravity dams or rock fill dams are not suitable on such foundations. Earthen dams after special treatments can be built.

Availability of Materials

Availability of materials is another important factor in selecting the type of dam. In order to achieve economy in dam construction, the materials required must be available locally or at short distances from the construction site.

Spillway Size and Location

spillway disposes the surplus river discharge. The capacity of the spillway will depend on the magnitude of the floods to be by-passed. The spillway is therefore much more important on rivers and streams with large flood potential.

Earthquake Zone

If dam is situated in an earthquake zone, its design must include earthquake forces. The type of structure best suited to resist earthquake shocks without danger are earthen dams and concrete gravity dams.

Height of Dam

Earthen dams are usually not provided for heights more than 30 m or so. For greater heights, gravity dams are generally preferred.

Hint: The availability of spillway site is very important in selection of a particular type of dam