

## Impact assessment on water harvesting and valley dams

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ARTICLE INFO	ABSTRACT
<p><b>Original Research Article</b> Received on May 16, 2020 Revised on May 28, 2020 Accepted on June 11, 2020 Published on June 23, 2020</p> <p><b>Article Author</b> Attia El Gayar</p> <p><b>Corresponding Author Email</b> <a href="mailto:attiaelgayar@yahoo.com">attiaelgayar@yahoo.com</a></p>	<p>Gravity dam is one of the biggest structures built on the Earth. It is known as a life line structure, as it serves the purpose of irrigation, hydro-electric power generation, flood control, domestic and industrial water supply etc., which are important for human existence. This makes dam as a reliable structure. For this reason, dam should always be designed for highest safety. Dam is one of the hydraulic structures constructed to serve particular functions. It is a water control feature to impound water supply, to divert water from a water course, or to raise the elevation for water body. In supplying the water to the consumers, a dam holds it from flowing into the pipe, tunnel and conduit. Earth fill dams are a good alternative to dugouts where larger volumes of water must be stored at a reasonable cost and suitable site conditions exist. Proper design and construction is essential for dams; otherwise they will fail from washouts or seepage losses. If water quantity is your main priority, then a dam could be the best option. If better water quality is the important factor, a dugout is probably a better option. Take the time to properly plan, construct, inspect and maintain your dam, and it will be a valuable water resource for your farm for many years to come. However, poor management of dams can cause problems and disasters in terms of safety of dam and how it affects the people and the environment. This study focuses for conducts how the design, operator and maintenance of dam to be ensure it is safety.</p>
PUBLICATION INFO	KEYWORDS
<p>International Journal of Agricultural Invention (IJAI) RNI: UPENG/2016/70091 ISSN: 2456-1797 (P) Vol.: 5, Issue: 2, Pages: 266-282 Journal Homepage URL <a href="http://agriinventionjournal.com/">http://agriinventionjournal.com/</a> DOI: 10.46492/IJAI/2020.5.2.19</p>	<p>Gravity Dam, Hydraulic Structures, Water Control, Suitable Site, Design, Construction, Seepage Losses, Management, Dams, Environment, Operator, Maintenance, Safety</p>
HOW TO CITE THIS ARTICLE	
<p>Attia El Gayar (2020) Impact assessment on water harvesting and valley dams, <i>International Journal of Agricultural Invention</i>, 5(2): 266-282. DOI: 10.46492/IJAI/2020.5.2.19</p>	

Basically a gravity dam is defined as a structure which is designed in such a way that its own weight resists the external forces. It is primarily the weight of a gravity dam which prevents it from being overturned when subjected to the thrust of impounded water. This type of structure is durable, and requires very little maintenance. A dam is a structure or barrier constructed across a valley, river or stream to conserve, store or to control the flow of water. The water may be used for drinking water supplies, hydro-electric power generation, irrigation, or environmental conservation. There are many types of dams, based on their use, construction material, size and shape. Depending on construction material, dams can be made of concrete, rock-fill, masonry or earth.

Concrete dams may take various forms. These include gravity dams which are huge structures designed to use their own dead weight to resist the horizontal force of the water. An arch dam is built with its convex front facing the upstream side of the valley or reservoir, and derives its strength essentially to its shape. Thus an arch dam uses less concrete than a gravity dam. Concrete-butress dam is a gravity dam reinforced by structural supports, thereby reducing material needed to construct the wall itself by using support buttresses around the outside base (BDS, 2012). Earth dams utilize soil of good compaction quality to build up the embankment, and are variously known as earth-fill dams.

Earth dams rely on their weight to hold back the force of water, just like gravity dams. The cross-sectional profile of an earth-fill dam is a broad-based triangle. Thus, a small earth dam is one whose embankment is basically constructed using compacted earth. The dams can be of uniform material, or have clay core for better seepage control. They also have spillways to protect them from overtopping excess runoff flows. Small earth dams are usually constructed for rainwater harvesting or on small rivers to retain flood runoff during the rainy season, on a watercourse which may be a perennial river or a dry riverbed. The dam wall has a clay core, while the outlet has a stone apron and spillway to discharge excess runoff. Sediment traps and delivery wells may help to improve water quality but, as with water from earthen dams, it is usually not suitable for drinking without being subject to treatment. Small earth dams can provide adequate water for irrigation projects as well as for livestock watering (USFERC, 2012).

## **Design Considerations**

### **Local Conditions**

Collection of data on local conditions will eventually relate to the design, specifications and construction stages of a dam. Local conditions are not only needed to estimate construction costs, but may be of benefit when considering alternative designs and methods of construction. Some of these local conditions will also be used to determine the extent of the project designs, including such items as access roads, bridges and construction camps.

### **Maps and Photographs**

Maps and photographs are of prime importance in the planning and design of a concrete dam and its appurtenant works. From these data an evaluation of alternative layouts can be made preparatory to determining the final location of the dam, the type and location of its appurtenant works and the need for restoration and/or development of the area.

### **Hydrologic Data**

In order to determine the potential of a site for storing water, generating power or, other beneficial use, a thorough study of hydrologic conditions is required.

## **Reservoir Capacity and Operation**

Dam designs and reservoir operating criteria are related to reservoir capacity and anticipated reservoir operations. The loads and loading combinations to be applied to the dam are derived from the several standard reservoir water surface elevations. Reservoir capacity and reservoir operations are used to properly size spillway and outlet works.

### **Climate Effects**

Climate conditions at a site affect the design and construction of the dam. Measures to be employed during construction to prevent cracking of concrete are related to ambient temperatures at site.

### **Construction Materials**

Construction of a gravity dam requires availability of suitable aggregates in sufficient quantity. Aggregates are usually processed from natural deposits of sand, gravel and cobbles or, may be crushed from suitable rock.

### **Site Selection**

The two most important considerations in selecting a dam site are:

- (a) The site must be adequate to support the dam and appurtenant structures.
- (b) The area upstream of site must be suitable for a reservoir.

### **Configuration of Dam**

A gravity dam is a concrete structure designed so that its weight and thickness ensure stability against all the imposed forces.

### **Foundation Investigation**

The purpose of a foundation investigation is to provide data necessary to properly evaluate a foundation.

### **Construction Aspects**

Construction aspects that, should be considered in the design stage.

## **Various Uses of Dams (BDS, 2012)**

### **Irrigation**

Small earth dams are particularly useful for providing water for irrigation in dry areas, and from streams which have low or no flows during the dry season.

## **Water Supply**

Small earth dams are particularly useful for drinking water supplies to rural as well as urban communities. The multi-purpose nature of dams makes them ideal for community scale water supplies for irrigation, livestock watering and domestic water supplies.

## **Water Diversion**

Small dam can be used to divert water for irrigation, power generation, or other uses. Sometimes, they are used to divert water to another drainage or reservoir to increase flow there and improve water use in that particular area.

## **Stabilize Water Flow**

Dams are often used to control and stabilize water flow, often for agricultural purposes and irrigation.

## **Hydro Power Generation**

Small earth dams can be used for hydropower generation. This is particularly possible in dams having a steady flow and built across a gorge where there is a relatively good head drop. Many countries that have rivers with adequate water flow, that can be dammed for power generation purposes.

## **Land Reclamation**

Dams are used for land reclamation and to prevent inundation of water to an area that would otherwise be submerged. This facilitates reclamation of such areas for other use. Normally, dykes or levees are used for diverting the water

## **Flood Prevention**

Dams are sometimes constructed to impound excess flows during the rainy season and prevent flooding of downstream areas or infrastructure. They help to stabilize river flow especially of ephemeral streams.

## **Recreation and Aesthetics**

Earth dams provide a water body that can be used for recreational activities such as swimming, fishing, or tourism. Other than the water itself, a dam allows for creation of greenery and ecosystem restoration which are added benefits to agricultural use.

## **Types of Earth Dams (DID/JPS, 2012)**

### **Earth-Fill Dams**

Earth fill dams also called earthen, rolled earth or simply earth dams, are constructed as a simple embankment of well compacted earth. Earth dams are trapezoidal in shape. They are constructed where the foundation or the underlying material or rocks are weak to support the masonry dam or where the suitable competent rocks are at greater depth. Earthen dams are relatively smaller in height and broad at the base. Earth dams are mainly built with clay, sand and gravel. The upstream face of an earth dam is usually protected from erosion by a surface layer of flat rock, called rip-rap.

There are three sub types of earth dams

- (i) Homogeneous type dams are constructed with a single type of soil throughout the cross section
- (ii) A zoned type dam has an impervious core zone surrounded by a relatively pervious zone.
- (iii) A diaphragm type dam, whereby a tall impervious wall of less than 10 m thickness replaces the impervious zone. Earthen dams can be constructed from materials found on-site or nearby they can be very cost effective in regions where the cost of producing or bringing in concrete would be prohibitive.

### **Rock-Fill Dams**

Rock fill dams are a variation of earth dams, whose embankments are constructed using loose rocks and boulders instead of soil. However, an impervious zone is created on the upstream face of the dam, made of masonry, concrete, plastic membrane, steel sheet piles, timber or other material. The impervious zone may also be constructed as a central cross-sectional pillar within embankment in which case it is referred to as a core. Rock-fill dams can be made with a steeper slope hence narrower than earth dams. When suitable rock material is available at site, transportation is minimized leading to cost savings during construction. In cases where clay is utilized as the impervious material, the dam is referred to as a composite dam. To prevent internal erosion of clay into the rock fill due to seepage forces, the core is separated using a filter. Filters are specifically graded soil designed to prevent the movement of fine grained soil particles into the rock fill.

Rock-fill dams are stable and more resistant to earthquakes due to the fact that the embankment structure contains loose particles which can vibrate independently. However, proper compaction and good quality control must be ensured during construction to prevent poor failure and seepage problems.

### **Regulating Dam**

A regulating dam is one that is designed with a capacity to store the flash floods from a single day's rainfall, and then release it slowly thus reducing the danger such a flood would have posed e.g. causing erosion downstream. The reservoir therefore has a permanent water outlet that releases the stored water at a flow rate of minimum risk. The stored water drains away continuously until the reservoir is dry in a day or two, ready to receive the next flash floods. An adequate spillway must be provided to guard against the collapse of the dam. The dam embankment can be earthen, concrete or packed stone gabions.

### **Dry Dam**

A dry dam also known as a flood retarding structure. It is a dam designed to control flooding. It normally does not hold back any water and allows the channel to flow freely, except during periods of intense flow that would otherwise cause flooding downstream, that time, it stores water temporarily. A dry dam is a kind of regulating dam, but without water storage during the dry season.

### **Silt Trap Dams**

Silt trap dams are made across water courses/streams to protect downstream structures from sedimentation. They are designed like ordinary earth dams, but the spillway is raised to enable sediments to sit in the dam. A simple technique, which can be adopted by smallholder farmers, involves using old gunny bags packed with soil packed on each other. The soil is scooped from adjacent areas. It is a very low cost technique. This type of structure is temporary and should not exceed 2 m high since it is not very strong. The embankment made of soil-packed bags can be re-built each season to improve its storage capacity. As the soil accumulates, the embankment is grassed to improve its stability.

### **Valley Dams**

Valley dams are the dams normally built across valleys and small seasonal water courses, which, may be on the boundaries between two or more landowners. Valley dams are normally made of earth, and are thus earth fill dams. However, they are shorter and thus have smaller reservoirs. Since valley dams can collapse during exceptionally heavy rainfall due to poor maintenance, incorrect design or poor construction work, this could endanger people and structures downstream.

### **Hillside Dam**

A hillside dam is an off-stream storage reservoir, constructed on sloping land or on a hillside. The system comprises a small dam, a collection area, a reservoir, a dyke, a spillway and a water draw-off device. It is constructed in hilly areas to capture runoff from catchments of area 100 to 2,000 ha. The water may enter the dam from surface runoff harvesting from the catchment above it, or it is brought by pipe or canal to the dam (pumped or by gravity). The main advantage of a hillside dam is that water may be taken down for use by gravity for irrigation or other purposes.

The dam embankment can be made of compacted earth, although concrete can also be used. The storage capacity of the reservoir can be about 10,000 to 400,000 m<sup>3</sup>. Since it lies on a hill, water is easily withdrawn by gravity through a pipe. Hill reservoirs tend to be more expensive than other conventional water harvesting systems because of their size and location, but they have many advantages as the water can reach larger downstream areas due to the height difference. The difference with ordinary pans and ponds is that a hill reservoir may not be located in a valley, thus making it possible to harvest large volumes of water from hills.

The storage to excavation ratio of hillside dams can be quite low (1.5 is common) and increasing the value is desirable. The site should be as flat as possible, and with good soil suitability and catchment yield. If necessary, the dam can be covered with concrete or clay grouting to prevent seepage. Although hillside dams are less prone to failure than gully dams, they still require sound design and construction to be successful.

## Hafir Dams

“Hafir” dams are usually small earthen reservoirs dug into the ground in gently sloping areas that receive runoff either from flood flow diverted from streams or from large catchment areas. Generally, they have a volume ranging from 500-10,000 m<sup>3</sup> and are used to store water for human and livestock consumption. Hafirs are located in natural depressions and the excavated soil is used to form an embankment around the reservoir to increase its capacity.

Wing walls and improvements to the catchment apron may help to increase runoff into the reservoir, but seepage and evaporation are often high in the dry season. Hafirs differ from water pans in that they are generally bigger in size, and also have good sedimentation basins. In hafirs, watering areas are well allocated, the site is securely fenced and the reservoir is de-silted every season. The major drawback with hafirs is the requirement of periodic cleaning to remove silt, which is not an easy task. Sediment traps and delivery wells may help to improve water quality but, as with water from earth dams, it is not usually suitable for drinking without some form of treatment.

## Gully dams

Gully dams are also off-stream dams since they tend to be located on an artificial watercourse which is on a hillside. Most gullies are formed from severe soil erosion due to uncontrolled surface runoff emanating from catchments above the gully or from road drains. Thus, a gully dam combines water harvesting with soil conservation. The method takes advantage of only those gullies or depressions which are stable enough and suitable for water storage.

A gully dam is designed just like any other small earth dam. However, care is taken to anchor the dam properly to the sides. Also, a large spillway is usually recommended at the center of the structure, to act as a weir and thus prevent excess water from undermining the structure. The banks of the dam are built from soil material dug from an excavation contained within the storage area. Gully dams are commonly used for storages ranging from 1,000 to 50,000 m<sup>3</sup>. They normally offer a low capital cost per unit of the stored water capacity.

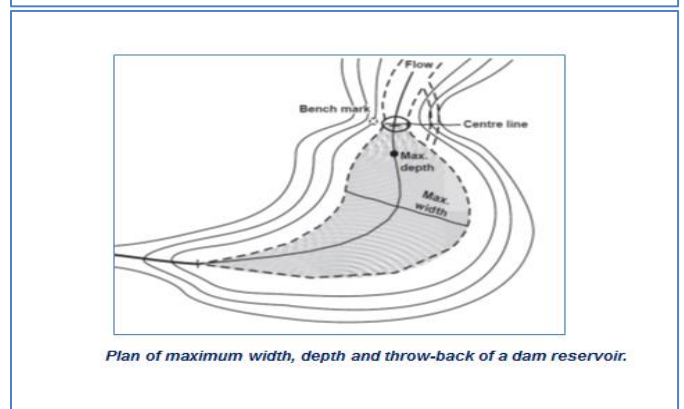
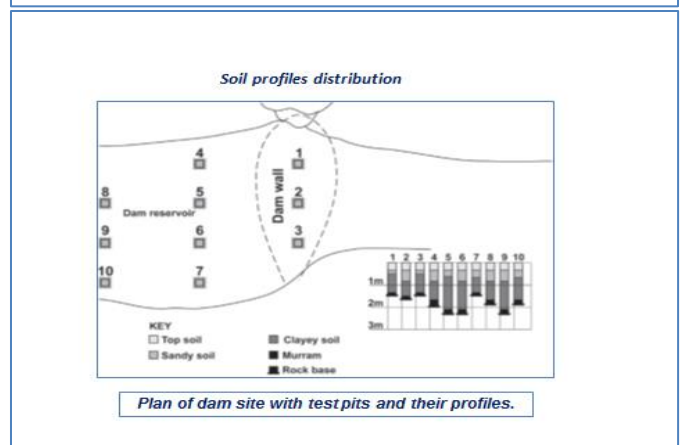
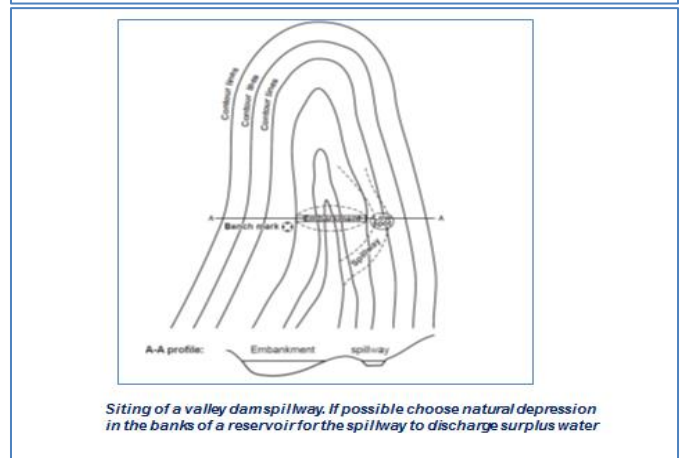
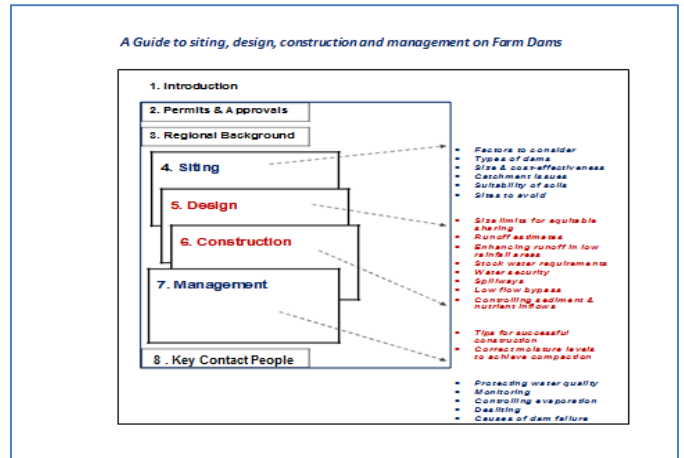


Fig 1. Designs of small earth dams

## Components of Dam

A small earth dam comprises a water impoundment zone or reservoir, the dam embankment itself, water outlet and delivery works, spillway and control facilities. The inflow of water into the reservoir must be monitored continuously and the outflow should be controlled to achieve optimum benefits. Under normal operating conditions, the reservoir is controlled by the outlet works, consisting of a channel or conduit at stream level with control gates (Yang *et al.*, 1999). The main parts of a dam include:

**(a) Heel**

Contact with the ground on the upstream side.

**(b) Toe**

Contact on the downstream side.

**(c) Abutment**

Sides of the valley on which, the structure of the dam rest.

**(d) Galleries**

Small rooms like structure left within the dam for checking operations.

**(e) Diversion Tunnel**

Tunnels are constructed for diverting water before the construction of dam. This helps in keeping the river bed dry.

**(f) Spillways**

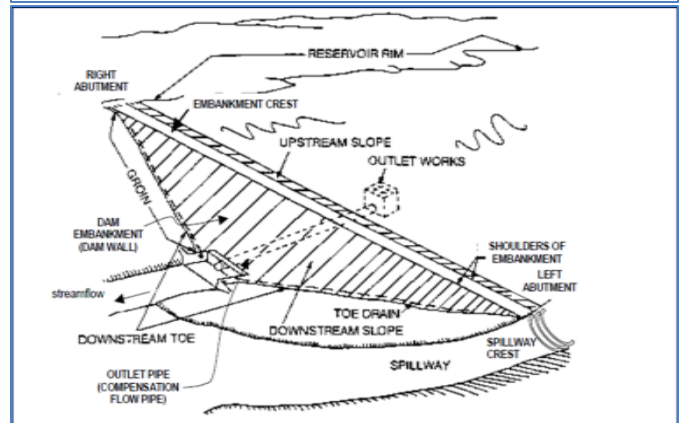
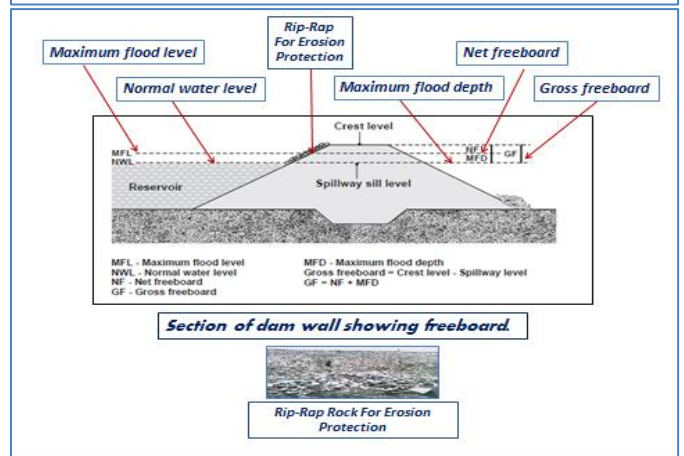
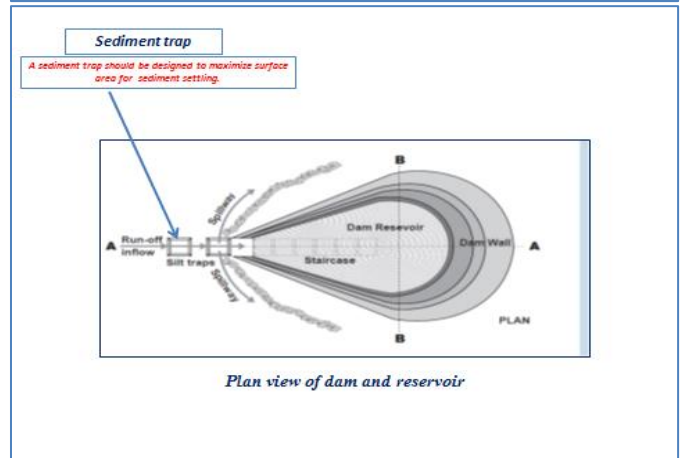
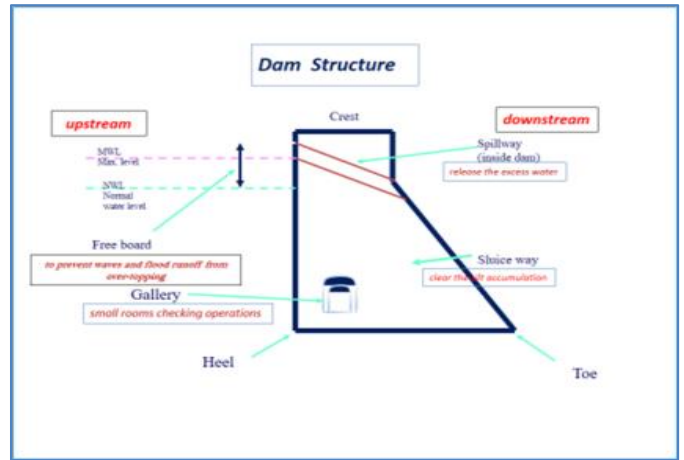
It is the arrangement near the top to release the excess water of the reservoir to downstream side

**(g) Sluice Way**

An opening in the dam near the ground level which is used to clear the silt accumulation in the reservoir side.

**(h) Dead Storage**

The amount of water that remains in the dam at the lowest level. It also comprises the part of the reservoir that cannot be drained by an outlet or by pumping. The latter depends largely on the suction arrangements of the pumping set up. Note should be taken that it is not always wise to drain a dam completely, most especially if ‘cracking clays’ have been used in the embankment, core or reservoir floor.



**Fig 2. Structure and Components of Dams**

## Requirements of Good Dam Design (Armstrong, 1977)

The design of an earth dam considers the technical, social, economic and environmental data. Preliminary designs and cost estimates are prepared and reviewed by hydrologic, hydraulic, geotechnical, and structural engineers, as well as geologists. Environmental quality of the water, ecological systems, and cultural data are also considered in the site-selection process. Factors that affect the type and size of structure include the topography, geology, foundation conditions, hydrology, possibility of earth movements, and availability of construction materials. The foundation of the dam should be as sound and free of faults as possible. All dams are designed and constructed to meet certain basic requirements, (USACE, 2000), which include:

- It should consider peak flood flows, and the design of spillways and other protective structures,
- The dam should remain stable under all conditions, *i.e.* during construction, while in operation, both at the normal reservoir operating level and under all flood and drought conditions.
- The dam wall and its foundation must be watertight to control seepage and maintain the desired reservoir level.
- The dam should have sufficient spillway and outlet capacity
- A freeboard is usually included in the design to prevent floodwater overtopping.
- Impacts of the dam on the water table of affected areas, and whether this is desirable or not.
- Reservoir silting, which should be minimized or accounted for in the dam design,
- Environmental impacts on river aquatic life e.g. riparian vegetation, fish and fisher-folk,
- Impacts on human habitation and resettlement there are costs associated with the compensation for land being flooded as well as population resettlement. This may also include the removal of toxic materials and buildings from the proposed reservoir area.

## Site Selection Criteria

The most suitable site for a small earth dam is where the valley will enable the construction of a straight embankment dam. Such sites are normally found at valley cross sections where a natural deep

gorge exists. Sometimes, a natural depression on sloping ground can provide a good site for a curved hillside dam. It is essential to select a site where the dam foundation will be watertight and without seepage, while it accords ease of construction and a stable structure can be assured (BDS, 2012). Thus, small earth dams should be sited in areas which bear the following characteristics:

- The site should be located where surface runoff from rains on the catchment area, or other runoff flows, can fill the dam reservoirs at least once a year. The dam must have the potential to fill with runoff (most years) or store sufficient water between runoff events that fill the reservoir. It is essential that the dam and reservoir have sufficient depth and volume to last through extended periods of drought.
- A topographical survey of the proposed dam site is normally done to determine features such as slope, width and height of dam, reservoir capacity, as well as to estimate costs, prepare necessary information for licensing and provide construction details.
- The dam site should be selected on a natural valley which will provide a relatively high depth to surface area ratio (for a given design volume), to minimize evaporation losses. A simple way of identifying such a site is where the valley is bounded by steep hillsides.
- The dam can also be sited just below the confluence of two tributaries to gain more volume. One of the best sites for construction of a dam is a narrow part of a deep river valley; the valley sides then act as natural walls. The primary function of the dam's structure is to fill the gap in the natural reservoir line left by the stream channel. The sites are usually those where the gap becomes a minimum for the required storage capacity. The current use of the land to be flooded should be dispensable.
- Thorough site investigations are needed especially for the dam foundation to avoid cracked, loose soil or other weaknesses that may cause seepage or failure. The dam foundation must be solid impermeable rock with no soil pockets or fracture lines, while rock surfaces should not be fractured or cracked, to avoid causing leakage losses. In some cases, field pumping tests are performed to evaluate seepage potential. Soil conditions must be suitable for both compaction and the prevention

of seepage losses through the dam. Pre-construction soil testing should be done at the proposed site. This testing can be accomplished by digging several test pits where the dam and reservoir is to be located. Soils should be checked to depths at least a meter below that of any proposed excavation for the dam or reservoir.

- There should be no soil erosion in the catchment area, no anthills, pits, sewage outlets, saline or calcareous soils. An assessment of the hazard potential downstream should be done. Watershed activities that could affect the water quality or quantity of runoff are also assessed.
- Location must be convenient for the user group. This could be where peoples and livestock are in need for water and where the community has implemented soil conservation measures on any cleared land in the catchment area of the dam.
- Land tenure and ownership also affect site location. The dam should, wherever possible, be located on public land with access road for the community members and users of the dam.
- Location of dam also considers the cultural and socio-economic conditions so as to serve a large population, without infringing on laws, customs and social structures of beneficiary communities. Whenever possible, local communities should be supportive of the dam.

### Dam Capacity and Side Slopes

For stability, the upstream slope must be a minimum of 3:1. Erosion protection is required to protect the dam from wave action. This protection can be achieved with a combination of smaller and larger rocks (or other suitable material) and, with smaller projects, a floating log boom. The downstream slope requires a minimum 2:1 slope, seeded with native grasses to prevent surface erosion. The top or crest of the dam should be a minimum of 3 m wide (preferably 5 m) to accommodate road traffic and minimize the potential for erosion. The crest elevation should be a minimum of 1 m above the full supply level (FSL) of the reservoir (BDS, 2012). The dam should be fenced to prevent livestock traffic, as this traffic can be a major cause of slope and crest degradation. The water storage capacity of a dam and reservoir can be estimated as follows:

$$\text{Dam Capacity} = [\text{Reservoir Length} \times \text{Width (at the dam)} \times (\text{Max. depth of the Water})] / 3$$

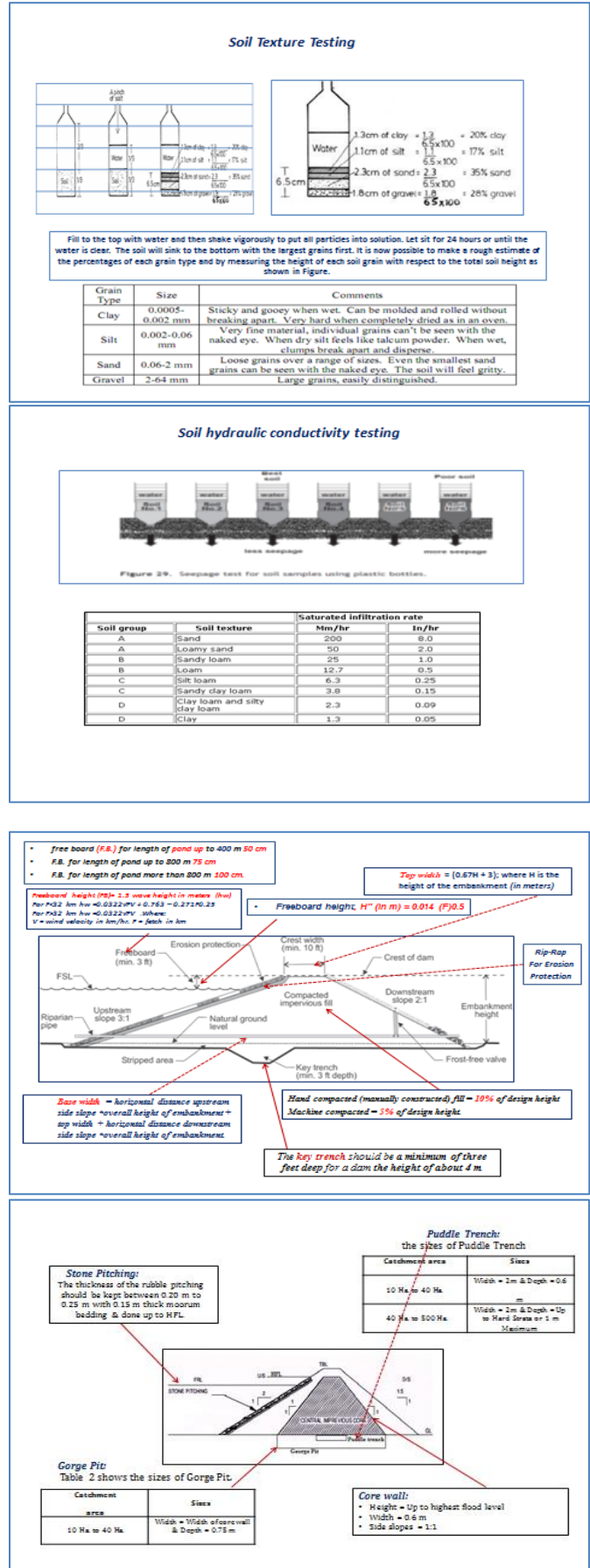


Fig 3. Soil testing and construction of dam

## Design of Earthen Bund

The various components of an earthen bund include:

- Foundation including key trench or cut-off
- Height of bund
- Side slopes
- Top width
- Free board
- Settlement allowance

It is possible to construct a stable and economical earthen bund on any foundation. Sites with foundation conditions requiring relatively expansive construction measures should be avoided. The most satisfactory foundation is one that consists of, or is underlain at a shallow depth by a thick layer of relatively impervious consolidated material. Such foundations cause no stability problems. Where a suitable layer occurs at the surface no special measures are required. It is sufficient to remove the top soil (with vegetation and roots) and plough the area to provide a good bond with the new fill material of the bund. Where the impervious layer is overlain by pervious material (sand), a compacted clay cut-off extending from the surface of the ground into the impervious is required to prevent excessive seepage and to prevent possible failure by piping.

### Determining Top Width

The minimum allowable top width (W) of the embankment shall be the greater dimension of 3 m or W, as calculated by the following formula:

$$W = (0.67H + 3), \text{ where } H \text{ is the height of the embankment (in meters)}$$

The sides of the dam embankment should slope at an angle that will provide a stable structure depending on the type of fill materials. The upstream slope of earth dams should be no steeper than 1 vertical on 3 horizontal. The downstream slope of earth dams without seepage control measures should be no steeper than 1 vertical on 3 horizontal. If seepage control measures are provided, the downstream slope should be no steeper than 1 vertical on 2 horizontal. The upstream side should be covered with stone pitching (rip-rap) and filter with recommended depth of 20 to 30 cm.

## Height of Bund

The height of bund will depend upon the volume of runoff to be stored and topography of the reservoir area. The high of the bund should also be selected in such a way that its cost per unit of storage (cum volume) is minimum, while calculating the cost corresponding to any height some allowance for settlement and free board, and temporary flood storage may be added to give the actual bund height or in other words the actual quantity of earth work.

### Top Width of Embankment

Adequate top width is provided to the bund so that it can be used as road way and communication routes adjoining villages or watersheds. Simple formulae for top width (T.W.) as a function of height (H) may be used.

$$\text{Up to 10 m height, T.W.} = H/5+2$$

$$10 \text{ to 15 m height, T.W.} = H/5+3$$

Where,

H = Maximum height in m

T. W. = Top width in m

### Side Slope of Bund

Adequate upstream and downstream side slopes of the embankment must be provided to satisfy the stability requirements of reservoir filled with water, sudden drawdown to minimize the erosion, and to facilitate establishment of good sod forming grass.

### Foundation Cutoffs

Usually a cut-off joining the impervious stratum in the foundation with the base of the dam is needed. The most common type of cutoff is one constructed of compacted or puddle clay material. A trench, also called key-trench, is cut parallel to the central line of the bund to a depth that extends well into the impervious layer. The trench should have a bottom width of not less than 1.5 meters but adequate to allow the use of mechanical equipment if necessary, to obtain proper compaction. The sides of the trench should be filled with puddle clay or with successive thin layers of relatively impervious material each layer being properly compacted (Frost and Sullivan, 2010).

- Side slopes of earth dams according to fill materials used

Side slopes (horizontal to vertical)	Side slopes (horizontal to vertical)	
	Upstream	Downstream
clay, clayey sand, sandy clay, silty sand	3:1 - 3.5:1	2.5:1 - 3:1
silt, clay, clayey gravel, silty gravel	3:1 - 3.5:1	2.5:1 - 3:1
silt or clayey silt	3.5:1 - 4:1	3:1 - 3.5:1

- Minimum Crest Widths

Height of Dam (H) (m)	Crest Width (B) (m)
Up to 2.0	2.5
2.1 to 3.0	2.8
3.1 to 4.0	3.0
4.1 to 5.0	3.3
5.1 to 6.0	3.5
6.1 to 7.0	3.7
7.1 to 8.0	3.9
8.1 to 9.0	4.0
9.1 to 10.0	4.2

Typical Facing Thickness

Height of Dam (H) (m)	Facing Thickness (m)
Up to 5	0.60
6	0.75
7	0.90
8	1.05

Typical Values for Optimum Moisture Content for Compaction

Soil Type	Typical Value of Optimum Moisture
Sand	6-10%
Sand-Silt Mixture	8-12%
Silt	11-15%
Clay	13-21%

Typical Facing Thickness

Height of Dam (H) (m)	Facing Thickness (m)
Up to 5	0.60
6	0.75
7	0.90
8	1.05

ESTIMATED ANNUAL RUNOFF FORMULA

- Catchment runoff = 100 x A x R x Y litres

where:

- A is the catchment area in hectares (ha)
- R is the average annual rainfall in millimetres (mm)
- Y is the runoff as a percentage of annual rainfall

- Table of Safe limit of flow velocity under different soil texture channel

Soil Texture	Safe limit (m/s)
Sandy soil	0.4
Sandy loam and silty loam	0.5
Clay loam	0.65
Clay	0.70
Gravelly soil	1.0

Recommended slopes for various soil conditions and dam dimensions

Dam Height (m)	Dam Face	Soil Conditions		
		>50% Gravel >15% Clay	>50% Sand >15% Clay	>55% Clay
3	Upstream	2.5:1	2.5:1	3:1
	Downstream	2:1	2:1	2.5:1
3.1-6	Upstream	2.5:1	2.5:1	3:1
	Downstream	2.5:1	2.5:1	3:1
6.1-10	Upstream	3:1	3:1	3.5:1
	Downstream	2.5:1	3:1	3:1

- Measuring Seepage

$$q = k(\sqrt{L^2 + D^2} - L)$$

- Where:
- q = Flow through dam per unit width.
- k = Hydraulic conductivity of soil.
- D = Depth of reservoir.
- L = Horizontal distance from where the top of the reservoir intersects the dam to the centre of the filter.

Runoff as a % of average annual rainfall (Y)

Average annual rainfall (R) (mm)	Total annual evapo-rainfall (mm)	Reliability (years out of 10)	Runoff as a % of average annual rainfall (Y)			
			In flow sand or less m silt (%)	Sandy clay (%)	Clayey clay (%)	Clay pans, (metastatic clay or shale) (%)
> 1100		8	10 to 15	10 to 15	15 to 20	15 to 25
		9	6.5 to 10	6.5 to 10	10 to 13	10 to 16.5
800 to 1100		8	10 to 12.5	10 to 15	12.5 to 20	15 to 20
		9	6.5 to 8	6.5 to 10	8 to 12	10 to 12
500 to 800	1800	8	7.5 to 10	7.5 to 10	7.5 to 15	10 to 15
		9	5 to 6.5	5 to 10	5 to 10	6.5 to 10
1200 to 1800		8	5 to 7.5	5 to 12.5	5 to 10	10 to 15
		9	2 to 5	2 to 8	2 to 6.5	6.5 to 10
400 to 500	2300 to 2800	8	2.5 to 5	5 to 10	2.5 to 7	7.5 to 12.5
		9	1.5 to 2	2 to 6.5	1.5 to 2	5 to 8
200 to 400	>1800	8	0 to 2.5	0 to 5	0 to 2.5	2.5 to 7.5
		9	0 to 1.5	0 to 2	0 to 1.5	1.5 to 5
	>1800	8	0	0 to 2.5	0	2.5 to 5
		9	0	0 to 1.5	0	1.5 to 2

General Guidelines for Embankment Section (Homogeneous Section)

Sl. No	Description	Height up to 5m		Height between 5 and 10 m	
		U/S	D/S	U/S	D/S
1.	Slopes	U/S	D/S	U/S	D/S
2.	Soil				
	Well graded gravel and sand	Not suitable	Not suitable	Not suitable	Not suitable
	Gravel and sand with silt and clay	2:1	2:1	2:1	2:1
	Silt and clay with low compressibility	2:1	2:1	2.5:1	2.5:1
	Silt and clay with high compressibility	2:1	2:1	3.75:1	2.5:1
3.	Rock toe height	Not necessary, up to 2 m above 2 m, 1 m rock toe should be provided		(Necessary), height should be 1/5 where H is the height of embankment	
4.	Top width	Minimum 2 m		Minimum 2.5 m	
5.	Free board	Min 2 m and max 3 m over maximum flood level			

Fig 4. Side Slope of Bund

## Free Board

It is the added height of the bund provided as a safety factor to prevent waves and flood runoff from over-topping the embankment.

- Minimum free board (F. B.) for length of pond up to 400 m 50 cm.
- F. B. for length of pond up to 800 m 75 cm.
- F. B. for length of pond more than 800 m 100 cm.

## Settlement Allowance

This includes the consolidation of the fill materials and the foundation materials due to the weight of the bund and increased moisture caused by the storage of water.

- Hand compacted (manually constructed) fill = 10% of design height
- Machine compacted = 5% of design height.

## Spillways

A spillway is a conduit or channel made on a dam and designed to pass water from the upstream to the downstream side of a dam. Many spillways have floodgates so as to control the flow through the spillway. The spillway should be designed with a wide base and a gentle slope, which will reduce water velocity and spillway soil erosion. The spillway base and sides should also be seeded to grass. To prevent spillway erosion, riprap (a collection of loose stones) alone or in combination with geo textile material may be required if the base slope of the spillway is steep. Side slopes of the cut spillway should be no less than 2:1 (4:1 slopes are preferred).

The spillway should be located away from the dam fill, not through or directly adjacent to the fill. This placement will reduce the risk of the dam washing out. Culverts are often used in spillway design, and if undersized, they can restrict spillway flow and result in project failure.

## Types of spillways

There are several designed of spillways depending on operation (BDS, 2012). They include:

- A fixed weir spillway which is usually at the center of the structure and allows the over-spilling for the common floods.
- A service spillway or primary spillway is one which allows the passage of normal flow.

- An emergency spillway is designed for extreme conditions, such as a serious malfunction of the service spillway.
- An auxiliary spillway releases flow in excess of the capacity of the service spillway.
- A fuse plug spillway is a low embankment designed to be over topped and washed away in the event of a large flood.
- Fuse gate elements are independent free-standing block set side by side on the spillway so as to allow an increase in the normal pool of the dam without compromising the security of the dam because they are designed to be gradually evacuated for exceptional events.

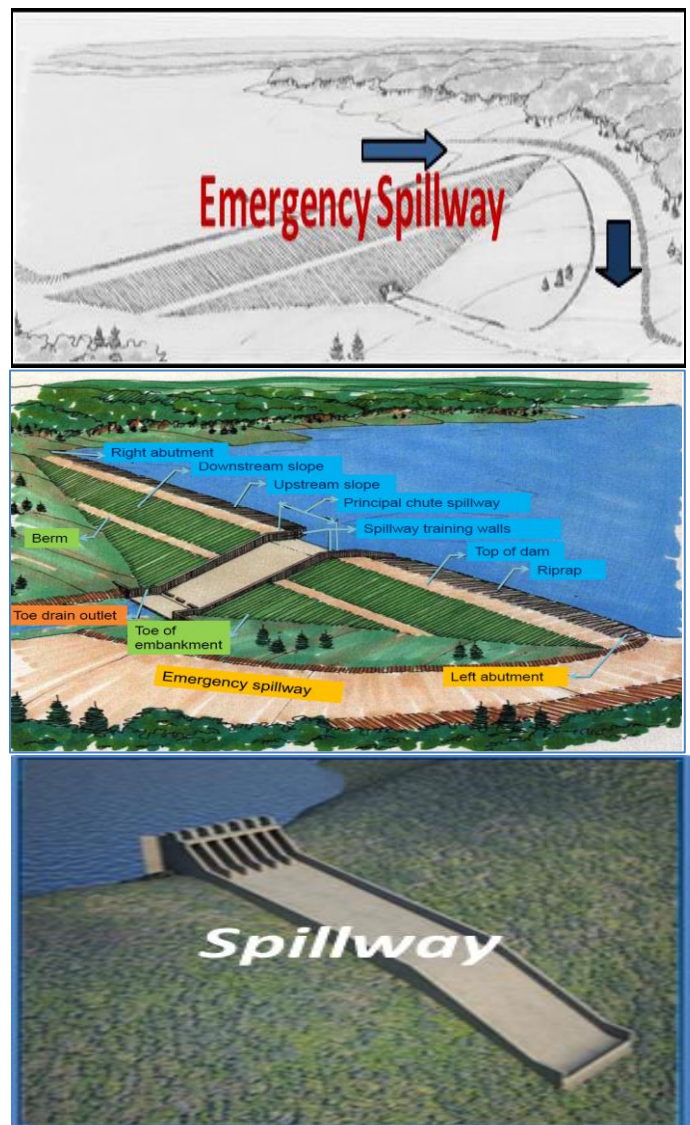
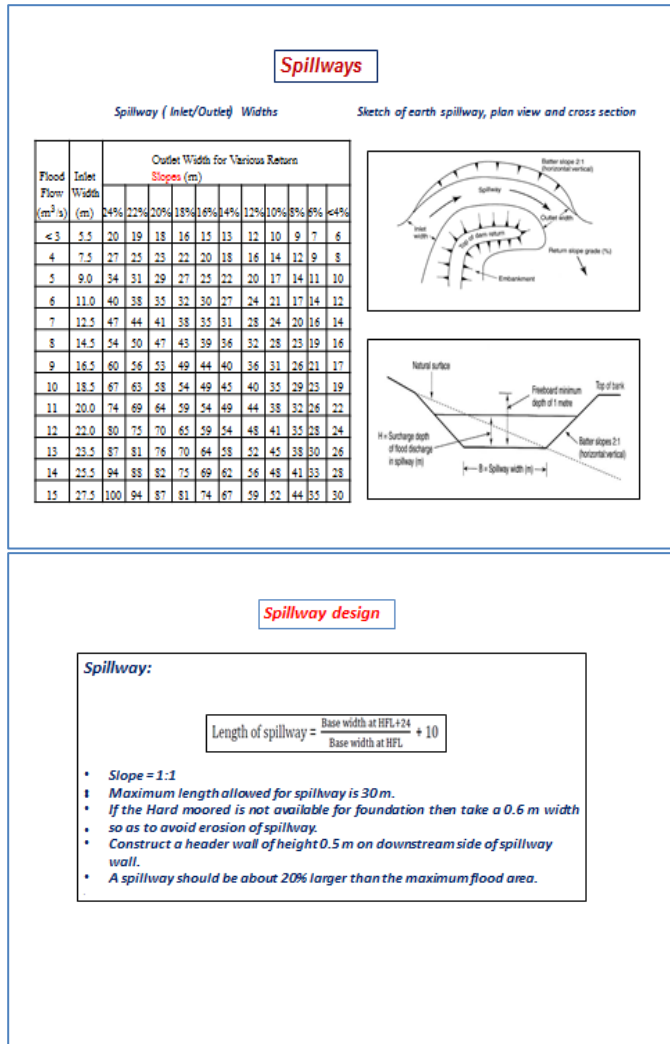


Fig 5. Types of Spillway

Spillway and embankment designers should coordinate their efforts closely so that a spillway scheme is compatible to both their needs.



**Fig 6. Design of Spillway**

**Construction**

**Environmental Impact Assessment**

Before the construction of any dam, an environmental impact assessment (EIA) is usually done to ensure that there will be no adverse effects on the human livelihoods as well as ecosystems affected by the dam. Reservoirs hold large quantities of water which could affect many ecological aspects of a river, particularly flow to downstream water users. An EIA can take several scenarios, such as the benefits to human society arising from the dam (agriculture, water, damage prevention and power), the harm or benefit to nature and wildlife, impact on the geology of an area. It also considers whether the change to water flow and levels will increase or decrease stability, and the disruption to human lives. Water releases from a reservoir including that exiting a turbine usually contains very little

suspended sediment, and this in turn can lead to scouring of river beds and loss of riverbanks; causing erosion. Reservoir may also host pests and other disease causing organisms which were not endemic to the area. Positive environmental attributes of a dam should also be factored such as improved tree cover, and recharge of ground water resources (Lane, 2008).

**Handling existing flows**

An important consideration in dam construction is how to handle the stream flow around or through the dam site during construction works. Stream flow records provide the information for use in determining the largest flood to divert during the selected construction period. One common practice for diversion involves constructing the permanent outlet works, which may be a conduit or a tunnel in the abutment, along with portions of the dam adjacent to the abutments, in the first construction period. The stream is diverted into the outlet works by a cofferdam high enough to prevent overtopping during construction. A downstream cofferdam is also required to keep the dam site dry. A cofferdam is a temporary barrier, dam or embankment constructed to divert water from its normal course during the construction of a dam, bridge or such other structures. It can be made using concrete, steel sheet piling, or wood. When the construction is completed, the cofferdam may be demolished or removed. Sometimes, a coffer dam may be made as a closed or open channel, which is converted into a pipe shaft on completion of the project.

**Steps in Construction**

**Stripping**

This really means land clearing. The area covered by the base of the dam must be stripped of all vegetation and organic soil. The organic soil can be stockpiled and used on the downstream slope of the fill. All slopes steeper than 1.5:1 on sides of draw should be flattened to minimum of 2:1.

**Key Trench**

A key trench (cutoff trench) is excavated below the base of the fill upstream of the centerline of the fill. The key trench is incorporated in the design for two reasons: to anchor the dam to the

base material and to prevent piping (seepage under the fill). The key trench should be a minimum of three feet deep for a dam the height of about 4 m. It should extend the full length of the dam and reach one third to one half of the way up the side slope of the draw.

### Fill Construction

The earth dam is normally constructed using impervious clay or clay-based material. A simple field test is used to determine the suitability of the material for compaction requires adding a small amount of moisture to a handful of soil then rolling it between the palms and hands. The material having good compaction characteristics is the one which can be rolled to the diameter of a pencil, approximately six inches long, then bent into a loop without breaking.



**Fig 7. Earth dam construction**

Construction material taken from the surrounding hillsides or an excavation in the reservoir area must be placed close to horizontal in the fill in six inch layers and compacted. If the material is dry, moisture will have to be added, and suitable compaction equipment such as a sheep's foot packer used to obtain the proper compaction. A simple test to evaluate proper compaction is to place the edge of the heel of a hard-soled boot on the fill

and push down hard with all your weight. If only a mark is left, compaction is satisfactory. If the heel sinks in, compaction is poor. No rocks over 15 cm in diameter should be placed in the fill (BDS, 2012).

### Dam Failure

Dam design criteria require the dam to withstand different loads, namely construction and reservoir water loads. Dams are designed to have a low probability of failure during their construction and operation life span. Dam failure may occur due to a variety of causes. Earthen dams may fail due to faulty design, improper construction and poor maintenance practices, etc. The various causes of failure may be classified as:

- a) Hydraulic failure (40%)
- b) Seepage failure (35%)
- c) Structural failure (25%)

The most common causes of dam failure are leakage and piping (35%), overturning (25%), spillway erosion (14%), excessive deformation (11%), sliding (10%), gate failure (2%), faulty construction (2%) and earthquake instability (1%). Clearly, dam failure events pose a significant threat not only to human life but also to the environment and in general to economic development. Thus, it is essential to investigate properly these failures and to find out technical solutions to reduce their risk of occurrence. Recently, dam safety draws increasing attention from the public authorities. This is because floods resulting from dam failure can lead to terrible disasters with tremendous loss of life and properties, especially in densely populated areas (Rahimah, 2009). The failures of dams are following:

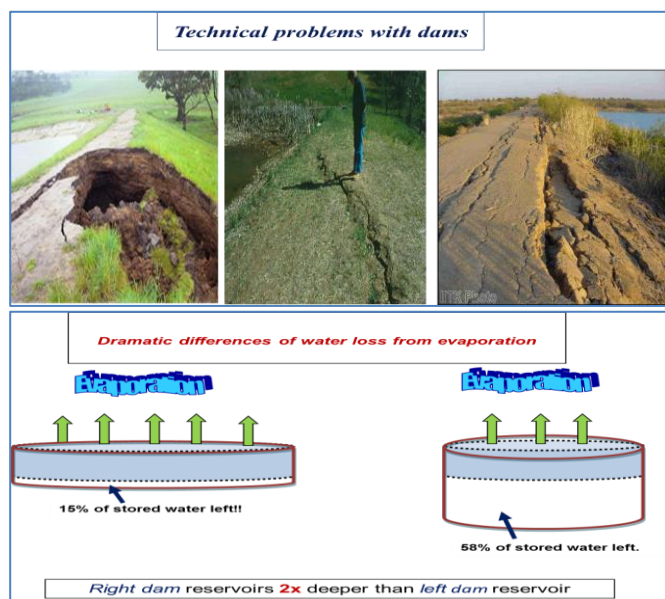
- The most common causes of earth dam failures are overtopping and piping in the dam body or foundation.
- A good understanding of failure causes leads to prevent similar failures from occurring in the future and this is required for disasters prevention.
- Conveying dam failure information to the broad of dam safety and the community so that similar deficiencies can be corrected at existing dams and avoided at new dams.
- Proper geotechnical and hydrological investigations are essential prior to design or rehabilitation of dam.
- For homogeneous earth-fill dams, spillways, foundations, and downstream slopes are believed to be potential locations at risk for overtopping

failure; while any part of the dam body/foundation can be a potential location at risk for piping failure.

- Any dam that fails has a detrimental impact on the environment. This will vary depending on the size of the failure. Small dams will probably only impact a very small portion of the environment downstream.

### Safety Features (Murphy, 1977)

Dams can fail if the structure is breached or suffers significantly damage. Dams may also fail slowly through siltation of the reservoir or loss of water through seepage. If a dam fails due to structural weakness, it can cause extensive damage including fatalities and this should be avoided at all costs. It is therefore necessary to monitor signs of weakness such as cracks, submergence or seepage around the structure. Most dams are designed with mechanisms to permit the reservoir to be lowered or even drained in the event of such problem. Cracks and other fissures can be remedied through rock grouting – which involves pressure pumping of concrete mix into weak fractured rock. Small earth dams should be fenced and the catchment area protected from damage so as to reduce siltation damage. Animals and people should not access water directly from the dam, but the design should incorporate water off-take structures to minimize human traffic and trampling. Communities must be trained on the acre, utilization and management of the dam.



**Fig 8. Technical dam construction problems**

### Vegetation Control

Trees and bushes are not permitted on earth dams because:

- (i) Extensive root systems can provide seepage paths for water
- (ii) Trees that blow down or fall over can leave large holes in the embankment surface that will weaken the embankment and can lead to increased erosion
- (iii) Trees and bushes obscure the surface limiting visual inspection; provide a habitat for burrowing animals and retards growth for grass vegetation.

The stumps of cut trees should be removed so grass vegetation can be established and the surface mowed. Stumps should be removed either by pulling or with machines that grind them down. All woody material should be removed to about 15 cm below the ground surface. The cavity should be filled with well compacted soil and grass vegetation established. Grass vegetation is usually planted on dam embankments as it is an effective and inexpensive way to prevent erosion and stabilize the surface. Grass also enhances the appearance of the dam and provides a surface that can be easily inspected.

### Maintenance of Earth Dams

Earth fill dams require regular inspection and maintenance. An inspection before spring runoff is critical to ensure the spillway is not blocked with snow or other material. All blockages must be removed to prevent overtopping and the dam washing out. During runoff, additional inspections should be carried out to watch for signs of erosion, spillway blockages or overtopping of the dam. After the dam is free, a visual inspection can be completed to assess the slopes for erosion, rodent damage, seepage or slumping. Burrowing rodents such as beavers, muskrats and gophers should be removed from the dam immediately. All potential problems must be repaired as soon as possible to safeguard the dam. Side slopes should be cleared of tree growth on a regular basis (DID/JPS, 2009).

Maintenance of the structure and the storage following as:

- If required extra dumping of soil with manual ramming where ever there are any settlement cracks.

- In the summer season if the dam gets empty, removal of sedimentation in the submergence would provide more storage.
- Water level records in the check dam and the flood level records in the spill way would help hydrological analysis in the future.
- In the spill way region, the approach of water in the spill way should not be obstructed. Villagers will have to look for this.
- Down stream field bund protection, if any.
- For future studies and analysis at least a rain gauge should be installed near the check dam. It would provide more reliable, accurate and the authentic data.
- Cleanliness of the stored water should be maintained for drinking water purpose. Animals should not be taken to the storage water for drinking or washing purpose.

### Seepage Control

Seepage failure or foundation failure occurs due to the saturation of the foundation material leading to either washout of the material or a weakening of the rock towards a sliding failure. The flow of water through a pervious foundation produces seepage forces as a result of the friction between the percolating water and the walls of the pores of the soil through which it flows (BDS, 2012).

The design should consider seepage control measures such as:

- Foundation cutoffs
- A core of appropriate width of no brittle impervious materials
- Upstream impervious blankets
- Transition zones and filters; internal drainage such as inclined or vertical drains, drainage blankets or pervious zones
- Toe drains
- Relief wells
- Defensive measures against seepage and piping at all embankment/structure interfaces

In addition, close construction control is required to ensure proper foundation treatment, use of fill materials, gradation control, water content control, compaction control, and installation of cutoffs and/or drainage facilities.

### Erosion Protection

Finished embankment surfaces should be properly graded and protected from wave and surface erosion to prevent beaching or serious maintenance problems. This protection is provided by riprap and bedding, soil cement, turf, vegetation, etc. Erosion control is required at embankment-abutment contacts because surface flows concentrate there. The final lines and grades of the embankment and surface protection should control erosion and be aesthetically pleasing.

### Environmental Protection

Environmental protection considerations have become very important in the design of dams and can influence the type and dimensions of a dam and the location of the spillway and appurtenant facilities. The goal is to achieve clean and healthy watersheds that support aquatic life, economic development, and human needs.

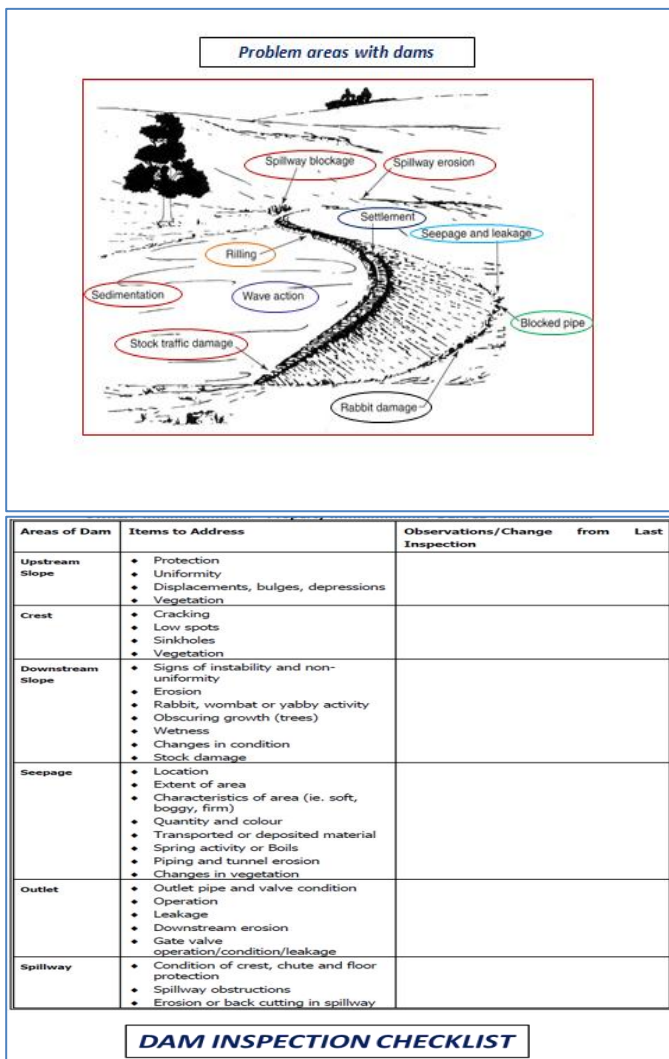


Fig 9. Problem areas with dams and inspection checklist

Managing water resources in a river basin, including the design and construction of an embankment dam, has an impact on a river basin's natural water cycle. The scale of the impact depends on the actual size and natural condition of the area to be developed and the extent of development (Bergkamp, *et al.*, 2000).

Mitigation measures are essential elements in the planning, design, construction, and operation of an embankment dam, including clearing of vegetation in the area to be flooded, multilevel outlet structures to optimize downstream water temperature and quality, provisions for the migration of fish and other aquatic organisms, and operational rules for regulating downstream flows at critical times to protect habitat for reproduction or migratory routes. Appropriate site selection, along with the implementation of these techniques, will result in both new and rehabilitated projects that minimize unacceptable environmental impacts. The following environmental considerations should be incorporated into the design, construction, and operation phases of embankment dams:

- Minimal or no construction outside of the footprint of the dam and spillway.
- Minimal or no disturbance to ground cover during and after construction.
- Minimizing erosion during and after construction.
- Provision of adequate control of sedimentation.
- Minimizing impact on water quality during construction.
- Minimal or no impact during future operation.

### **Economics**

The designers should continually strive to strike an equitable balance between economy, purpose, safety, and environmental concerns. The dam must fulfill project purposes and dam safety requirements, but at the same time be economically feasible. Infrastructure investments shall be based on systematic analysis of expected benefits and costs, including both quantitative and qualitative measures. Good engineering incorporates a good balance between adequate design and economy.

### **Challenges Faced**

#### **Sourcing of Materials and Machinery**

The serious challenge of monopoly of material and machine supplier, for materials like

rubble, metal etc. and for earth moving machines because of supplier's social and political strength.

#### **Work Environment**

Due to the social tensions in the region, engineers were under substantial psychological pressures especially from the life safety point of view.

#### **Labor Problem**

Villages initially were very hesitant to work and were very much irregular. This caused a severe labor shortage and in turn time overruns in the schedules. Later, with the interactions with the water committee, the situation was quite improved and the time overruns were minimized.

#### **Water Scarcity**

This increased the lead time of water tanker and cost of the watering. Also the cycle time of machines *i.e.* working efficiency got hampered.

#### **Unavailability of Hearting Soil near the Dam Site**

Hearting soil was not available in near proximity of the dam. Leads were considerable for the soil transport. This also caused the delay in the work.

#### **Feasibility Analysis (WSDOE, 2011)**

#### **Legal, Social and Environmental Feasibility**

- **Availability of Water:** The dam once operational would enable modifications to existing communal water access and management practices.
- **Raising Government Taxes:** The dam, once operational, will catalyse activities such as domestic/household water supply, irrigation, fishing, boating among others which will also be a source of taxes.
- **Skills Development:** Local people employed in the Project will obtain technical in-service training.
- **Infrastructure:** The road leading to the dam site will be improved.
- **Flood Control:** Creation of reservoir will provide means of holding excess flow during rainy season.

#### **Economic Feasibility**

- **Irrigation Boost:** This will improve food security in the region and the country at large.

- **Employment Opportunities:** This will mainly come from the local area and in turn their participation will generate income leading to improved standards of living.
- **Enhanced Local Economy:** Positive impacts on the local economy.

### **Conclusion and Recommendations**

It is found from this study, plays a crucial role in ensuring the safety of dam. The finding and results show that the stability of reservoir embankment slope is the most important component that determines the safety of dam. Meanwhile, the inspection, monitoring and maintenance are divided into five major components. The components are dam embankment, civil structure, mechanical installation, electrical installation and finally the concrete culvert, stilling basin and outlet channel section. Besides the two factors, the safe access, environment and working condition also play an important role to ensure that dam is safe and secure. Also there are some recommendations for who wants to study about the dam and this aspect:

- It is better to design of the dam using rock fill material to show the different between earth dam and rock fill dam.
- Checking the stability and seepage analysis using other hand calculation to check the results of this dam.
- For future dam it is better to design the dam and its appurtenant structures such as (spillway and bottom outlet).
- Estimating the life of the reservoir according to the sediment inflow from the river.

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