KURDISTAN ENGINEERS UNION

DEPARTMENT OF SULAIMANIYAH

Report on :

DAMS ISSUES AND GENERALITIES

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ABSTRACT

Nowadays, especially after the appearance of the global warming effects, water is becoming less and less available. Here appears the role of water resources engineering. That is; finding the mean through which we can collect water. One alternative for doing so is the storing of water behind dams. This is why this report will focus on dams' issues.
This report deals with the most common types of dams, the forces applied on them, the modes of failure of these structures, the environmental effects on the stream, the decommissioning and other technical matters .

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Introduction

A dam is a structure that is built across a river or stream for several purposes that are discussed in the following (see fig 1).

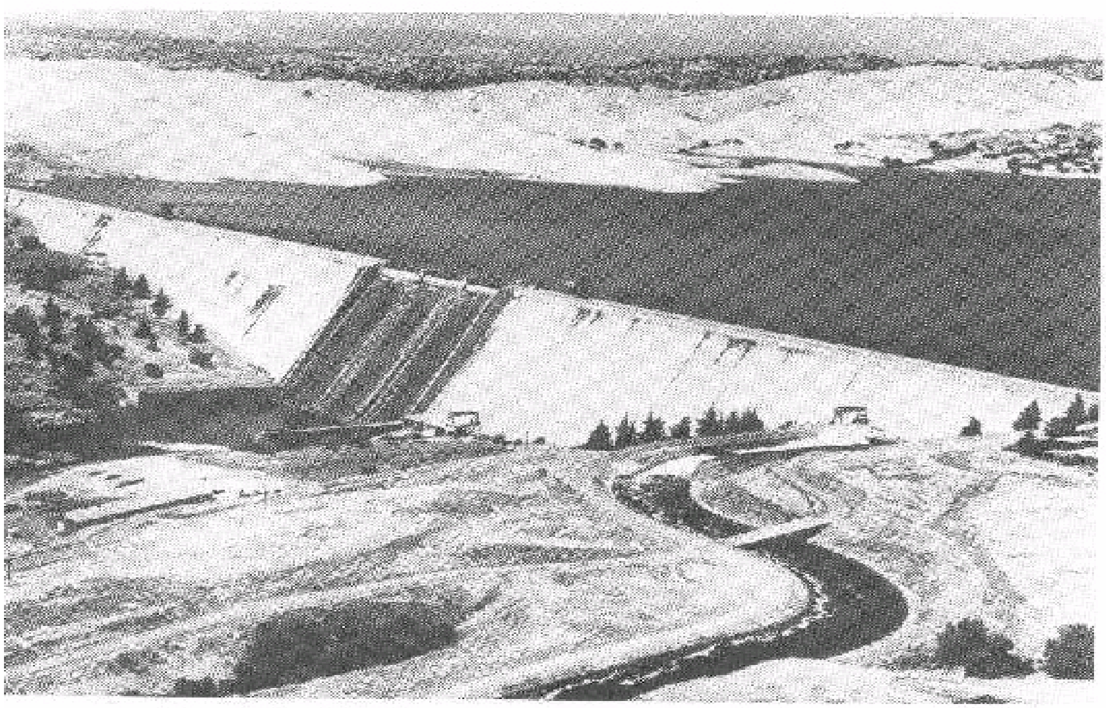


Figure 1. A dam ([1], p.283)

A dam is a structure that forms a “barrier” that obstructs the river and its flow. In order to distribute the water to the downstream side, there should be some outlet structures.

Dams have spillways (see fig 2) that are designed to pass water to the downstream side of the river safely (i.e. for dissipating huge floods, to maintain a certain quantity of water to reach the downstream side of the river for aquatic life or to protect the dam from being overtopped).

Figure 2. Comparison between a dam with spillway (top) and one without (bottom)

A dam is built to last for a very long time (50 to 150 years). Therefore it should be designed in such a way that it can sustain all possible problems it would face (i.e. different types of erosion, sustain against the biggest flood, sustain an earthquake and so on).

Purposes of Dams

Dams provide a life-sustaining resource for people. Dams represent a part of a nation's infrastructure. Dams are built for several reasons and purposes such as:

-Improvement of water supply for domestic and municipal uses

-Irrigation of agricultural areas

-Power generation (see fig 3)

-Water quality improvement

-Recreational improvement

-Fishery improvement.

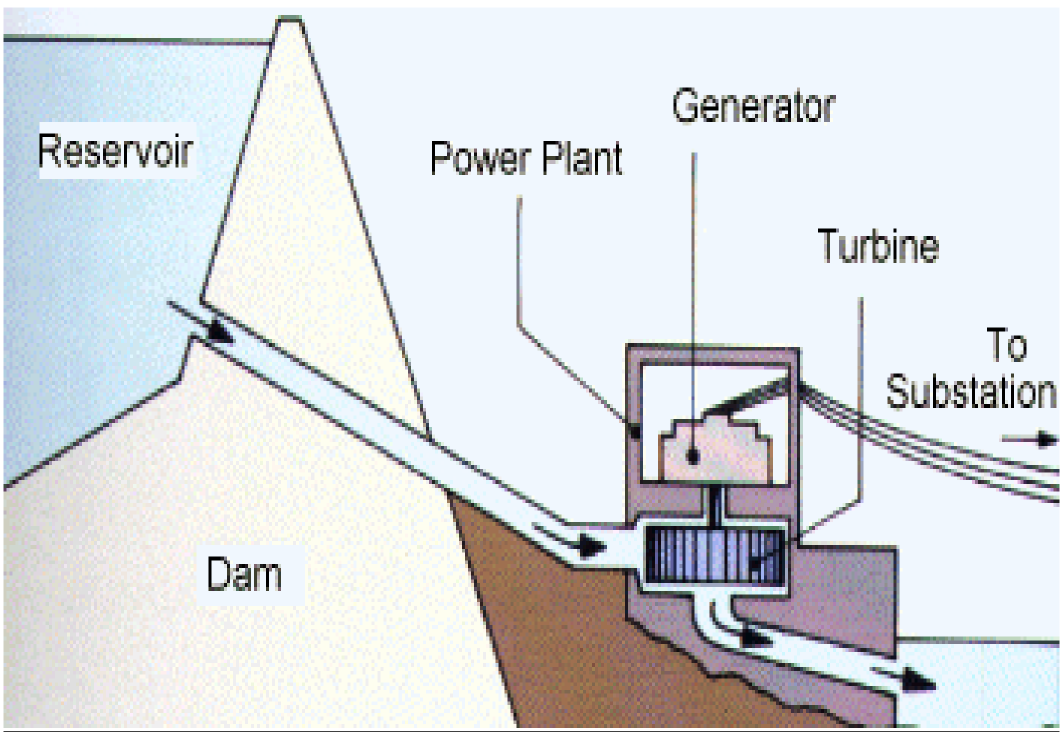


Figure 3. Example of dam used for power generation ([23])

The ranked uses of dams in the USA are listed below ([11]):

Recreation	31.3 %
Fire and Farm Ponds	17 %
Flood Control	14.6 %

Irrigation	13.7 %
Water Supply	9.8 %
Mine Waste Retention	8.2 %
Hydroelectric	2.9 %
Undetermined	2.3 %
Navigation	0.2 %

Many dams fulfill several purposes at the same time.

Design Flood Selection

In order to know the height of the dam and the peak discharge that can safely pass a design inflow hydrograph should be implemented and routed through the reservoir.

Criteria for Choosing the Inflow Design Flood

There are several methods to determine the inflow design flood ([6], p.11). The entire dam is assigned one IDF (intensity-duration-frequency), which is determined based on the consequences of failure of the section of the dam. This does not contradict with the design criteria for different sections of the dam that may be based on the effects of their failure on downstream areas ([6], p.11).

A flood less than the PMF (probable maximum flood) may be adopted as obtained from the design IDF in situations where the consequences of dam failure at flood flows larger than the selected IDF is acceptable.

Flood frequency and risk based analyses may be used to hold operation and maintenance costs to a reasonable level, to maintain public confidence in owners and agencies responsible for dam safety and to be in compliance with local, state or other regulations applicable to the facility ([6], p.11). Generally, it would not be an appropriate risk to design a dam having a potential for failure of a return period less than 100 years (T=100 years) ([6], p.11).

Design Flood Computations

There are two distinct ways by which the design flood is computed:

1-By using a rainfall–runoff model (or a deterministic model) .In this case, the whole analysis is based on the probable maximum precipitation (PMP).

2-By using a statistical analysis (or an extreme value analysis). This method is based on either floods or rainfalls having specified probabilities or return periods.

The procedure of each method is discussed in the following:

Rainfall Runoff Model

The steps to be followed in this procedure are ([2], p.45):

1-Divide the drainage area into sub areas

2-Implement a runoff model

3-Determine the PMP (probable maximum precipitation)

4-Order PMP increments into acceptable storm rainfall patterns

5-Estimate, for each time interval, the losses from rainfall due to detention and infiltration within the watershed

6-Subtract losses from rainfall in order to have rainfall excess

7-Apply rainfall excess values to a runoff model for each sub area of the basin

8-Obtain the flood hydrograph of each area

9-Route the flood of each area

10-Route the inflow through the outlets and spillways to obtain estimates of storage elevations, discharges of the dam and tail water elevations.

If the routing reveals that there is chance for overtopping failure of the dam, the resulting flood wave may be routed through the downstream valley to give a basis for assessment of damages.

Statistical Method

This method is mainly based on the analysis of an extreme value of peak annual floods. By fitting a distribution (i.e. Pearson's method) to these peaks, you can get the design flood that corresponds to a chosen probability of exceedence or T-year flood.

Classification of Dams

Dams are classified according to two criteria ([2], p.16):

1- Size: based on the height of the dam and storage capacity. There are 4 sizes of dams: small, medium, large and major (see table 1)([3], p.50).

Table1.Classification of dams according to their size ([3], p.50)

Size	**Capacity (10^6 m^3)**	**Height (m)**
Small	Below 1	Below 8
Medium	1-3	8-15
Large	3-20	15-30
Major	Above 20	Above 30

2- Hazard potential:the hazard potential is the possible adverse incremental consequences caused by the release of water or stored contents due to failure or misoperation of the dam or appurtenances ([6], p.5). It describes the consequences or effects of the dam's failure. It is assigned based on the effects of a failure during both normal and flood flow conditions ([6], p.5).

There are 4 categories of hazard potential, but no exact dollar amounts are taken as a scale by which one can choose the category ([6], p.5). These categories are: very low, low, significant, high (see table 2):

a) Very low: where loss of life is impossible and economical consequences are sustainable

b) Low: where failure or misoperation results in a zero probability loss of human life and low economic and environmental losses at the downstream side of the dam.

c) Moderate: where there is zero probability loss of human life but appreciable economic and environmental damages occurred at the downstream of the dam.

d) High: may cause loss of human life that may be sometimes catastrophic.

Table 2.Hazard potential classification ([3], p.50)

Hazard potential	Loss of life	Economic loss
Very low	Impossible	Minimal
Low	Impossible	Marginal
Moderate	Possible	Appreciable
High	Probable	Excessive

The combination of both hazard and size for dam is given in table 3.

Table 3.Classification of dams according to both size and hazard ([3], p.50)

Hazard /size	Small	Medium	Large	Major
Very low	4	3	2	1
Low	3	2	1	1
Moderate	2	1	1	1
High	1	1	1	1

Table 4 classifies dams according to the flood for which they are designed keeping in mind the conditions of (i) the peak flow without overtopping of the dam (no freeboard) and (ii) accommodating the design flood with normal dry freeboard allowance.

Table 4.Classification of dams according to their design flood and peak flood ([3], p.51)

Class	Peak Flood yr (i)	Design Flood yr (ii)
1	10000	2000
2	2000	500
3	750	250
4	250	100

Table 5 summarizes the classification of size and hazard potential in VIRGINIA.

Table 5.Size and hazard classification in VIRGINIA ([2], p.155)

Class of Dam	Hazard potential if impounding structure fails	Size Classification	Maximum Capacity (ac-ft)	Height (ft)	Spillway Design Flood (SDF)
I	Probable loss of life; excessive economic loss	Large Medium Small	>50000 >1000 and <50000 >50 and <1000	>100 >40 and <100 >25 and <40	PMF PMF 1/2PMF to PMF
II	Probable loss of life; appreciable economic loss	Large Medium Small	>50000 >1000 and <50000 >50 and <1000	>100 >40 and <100 >25 and <40	PMF 1/2PMF to PMF 100 yr to ½ PMF
III	No loss of life; minimal economic loss	Large Medium Small	>50000 >1000 and <50000 >50 and <1000	>100 >40 and <100 >25 and <40	PMF 1/2PMF to PMF 50 yr to 100 yr

In classifying the hazard potential of a dam, this classification should be based on the worst –case failure condition ([2], p.17). This classification can be assessed by field investigations and review of available data such as the topographic maps, performing a dam break modeling and running a gradually varied flow analysis ([6], p.6).

In simulating the dam breach if there is no loss of life downstream, the chosen design flood need not be very conservative ([3], p.51).

For dams where failure may cause loss of life downstream, the recommended guidelines suggest ([3], p.52):

1) Design for a 1000 to 10000 year flood and check the safety of the dam by routing a PMF through the reservoir.

2) Design for the PMF (probable maximum flood).

These criteria differ from one country to another. Here is a comparison between the flood selection criteria in the USA and that in UK.

A) In the United States, the recommended design floods range from 100years for a small dam with a small reservoir and no expected downstream losses, to the PMF for large dams with estimated significant human and economical losses.

B)-In the UK, if failure threatens the downstream life, the PMF is required, no matter how small the dam is. In addition to those requirements, dams are classified into 4 categories:

-A: Where lives in a community would be endangered by failure

-B: Where lives are possibly endangered by failure but not in community

-C: Where there is negligible risk to life and little damage

-D: Where there is clearly no loss of life and very little damage.

Moreover three levels of standard are recommended ([3], p.52):

1-A general standard (overtopping unacceptable)

2-An alternate standard (rare overtopping tolerable)

3-A minimum standard (economic analysis acceptable)

The acceptable design flood depends on both the category and standard of the dam.

How to Evaluate the Effects of a Dam Failure?

It is directly related to the extent of existing and future downstream development, size and type of dam. Careful considerations should be given to the following factors ([6], p.7):

- Quantities of stored water in the dam
- Reservoir inflow
- Size and shape of the expected breach
- Hydraulic head
- Time of breach formation

The extent of an affected downstream area by a flood wave resulting from a theoretical dam breach is a function of both the height of the flood wave and the downstream distance and width of the river at a particular location ([6], p.8). An associated and important factor is the flood wave travel time. These elements are not only a function of the rate and extent of dam failure, but also are functions of channel and floodplain geometry and roughness and channel slope ([6], p.8).

The flood wave should be routed downstream to the point where the effect of the failure will no longer have negative consequences.

There are several methods used for analyzing the dam break. These models will be discussed in the literature review section

Types and Forces on Different Dams

In this section, we will deal with all aspects of dams and the forces applied on them.

Selection Criteria for Dams

The dam's choice at a certain location depends mainly on experience, judgment, topography and geology of the site. But, the existing conditions are the most critical in the dam's selection, these conditions are ([9], p.40-43):

-Safety: not all types of dams are safe at any location: in other words, they are location sensitive.

- Cost of the hydraulic structure: this cost is mainly affected by the availability and cost of the needed construction materials. Additional funds vary enormously between one type of dam to another.

Types of Dams and Their Characteristics

The types of dams are ([9], p.40):

-Earth and rock embankments

-Solid gravity concrete dams.

-Buttress concrete dams

-Arched concrete dams

-Steel dams

-Timber dams

-Other types

In what follows, a review concerning each type of dam and the forces affecting it is presented ([9], p.40-43; [10]; [12]; [13]; [14]; [18]).

Embankment Dam

This type of dam is the most commonly built in the United States (see fig 5). If sufficient quantities of materials are present near the site, embankment can be constructed at a much lower cost than a concrete gravity dam. Usually, an earthen dam has a high ratio of length to height. It can be built at sites where the foundation is pervious. There are two categories of embankment: 1-earthfill dam that is made of fine materials, and 2-rockfill dam where the shells are made form rock.

An earthfill dam is feasible if:

(1) Suitable construction materials are available.

(2) An adequate amount of clay (for the impermeable core) is nearby.

(3) Usually built in a flat area.

A rockfill dam is feasible under the following conditions:

(1) The foundation is unreliable for sustaining the pressure on concrete dams.

(2) Suitable rock is nearby.

(3) An adequate amount of clay (for the impermeable core) is nearby.

(4) The dam’s site is wide enough for the manipulation of heavy earth moving machinery.

The problem of embankment dams is that they require large spillway for handling floods. Some spillways would require most of the length of the dam, leading to the infeasibility of the embankment.

If well maintained, an embankment dam should last for a long time.

This type of dams is also used in a region where it is required to preserve the natural look of the site because of its main components (earthen materials: clay, sand and rocks).

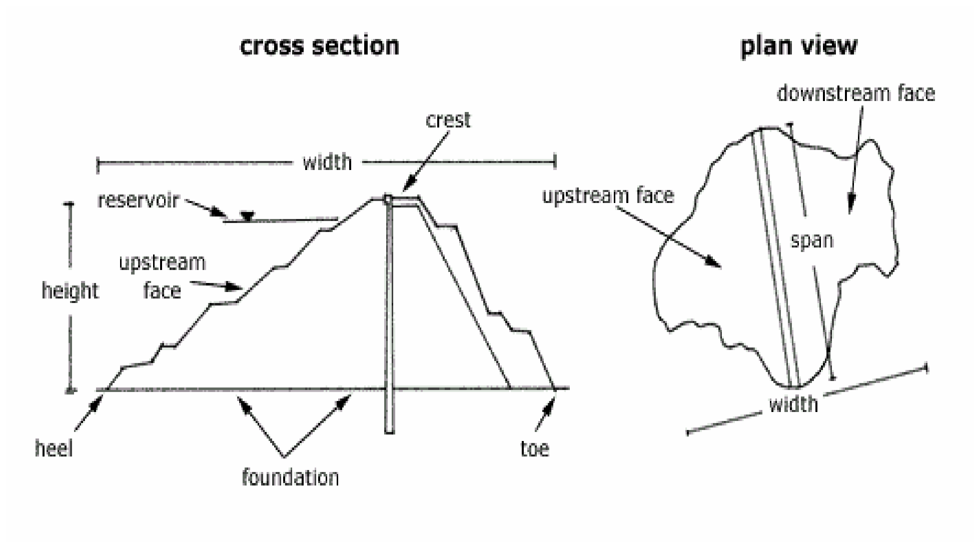


Figure 4.Embankment dam cross section ([11])

Embankment dams rely on their heavy weight to resist the force of the water (see fig 6). Inside embankment dams, there is an impervious region called core. This region has the role to stop the water from seeping through the dam.

The uplift force is directed upward, or in the opposite direction of the dam's weight. The problems facing this kind of dam (piping, overtopping, and erosion) will be discussed later.

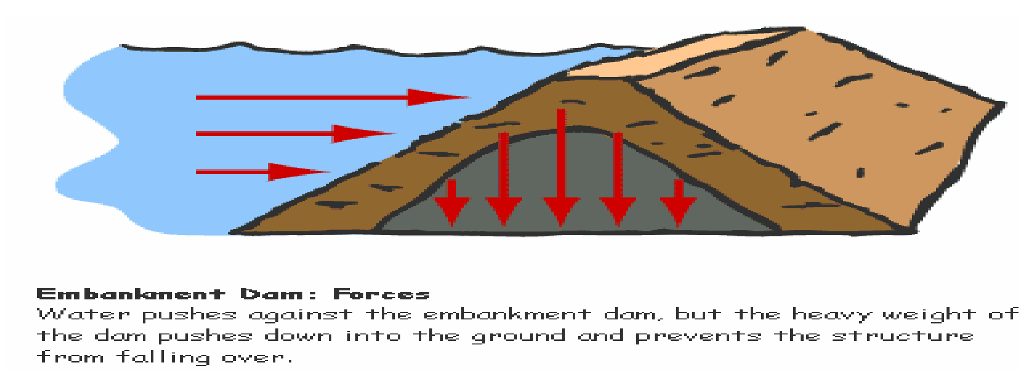


Figure 5.Forces applied on an embankment dam ([13])

Gravity Dam

The gravity concrete dam is the most common of all concrete dams and is considered the safest (see fig 7). The gravity dam resists the water entirely by its own weight. It should be well maintained in order to be effective and safe. Most gravity dams are expensive to build because they require huge amount of concrete.

A gravity dam can be built at any location, but its height is limited by the strength of the foundation. Therefore, if built on an earthen foundation, its height cannot be more than 30 m. A gravity dam is feasible if the length of the crest is at least five times the height of the dam .It has a concrete core mainly concentrated on its upstream face in order to reduce tensile stress due to bending and to obtain favorable gravity load. If the foundation is rock, and if the required materials are available, building an earthfill dam is more economical than a gravity concrete one.

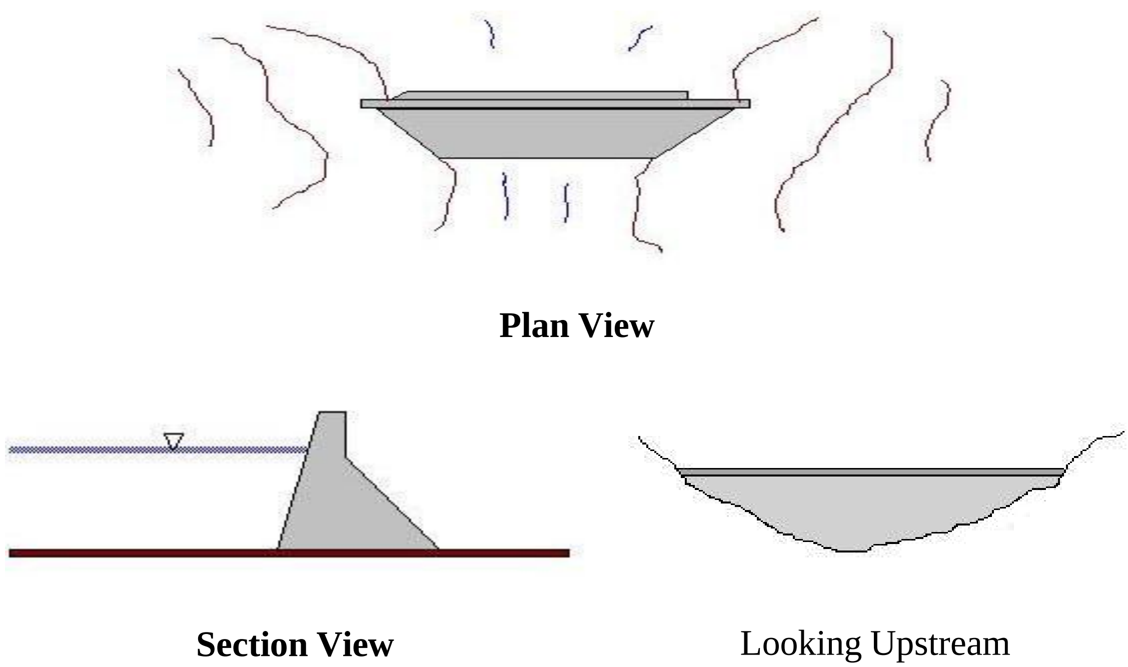
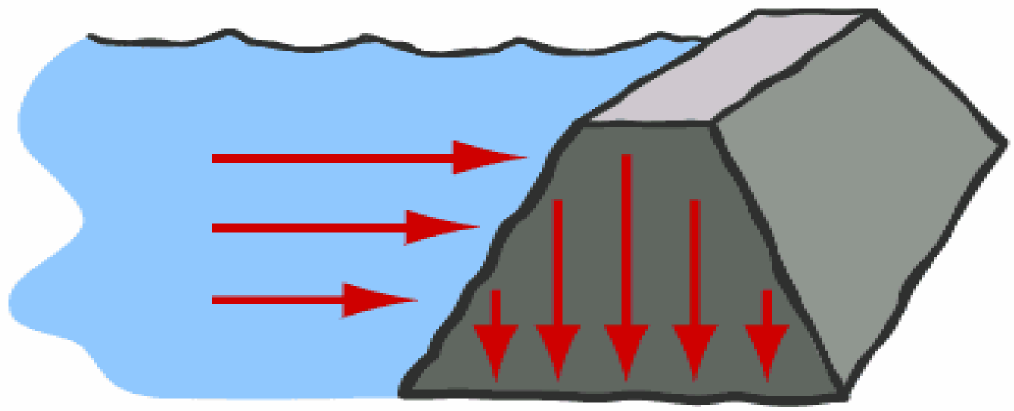


Figure 6.Gravity dam cross section ([19])

The forces applied on the gravity dam are (see fig 8):

- The thrust of water upstream
- The weight of the dam acting downward
- Sometimes the uplift force that is directed vertically upward.



Gravity Dam: Forces
Water pushes against the gravity dam, but the heavy weight of the dam pushes down into the ground and prevents the structure from falling over.

Figure 7.Forces on a gravity dam ([13])

Arched Concrete Dam

This type is mainly used in narrow and deep valleys where the height is much larger than the dam’s length, and when the sides of the valley are made of hard rocks, which had to handle a large amount of stress (see fig 9).

Arched dams are not expensive because they require less material than a gravity dam but require good skills in order to place the formwork. The main difference between this type and the gravity dam is that the first one relies on the strength of the dam’s material as opposed to the latter that relies on the materials’ weight.

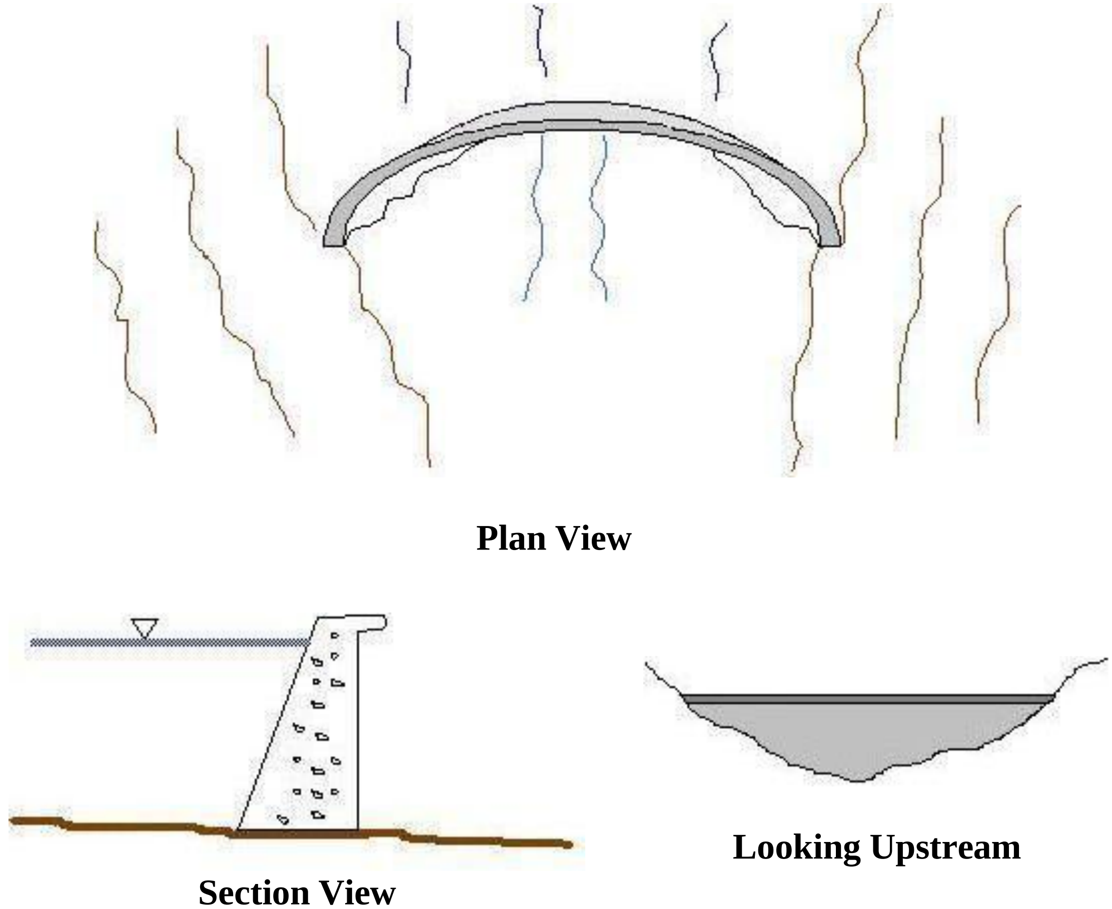


Figure 8.Arch dam cross section ([19])

This type uses the arch effect in order to resist loads placed on it. Therefore, its weight will not contribute enormously to the external loads resistance. That is why the uplift force on its base is not an important design factor (see fig 10).

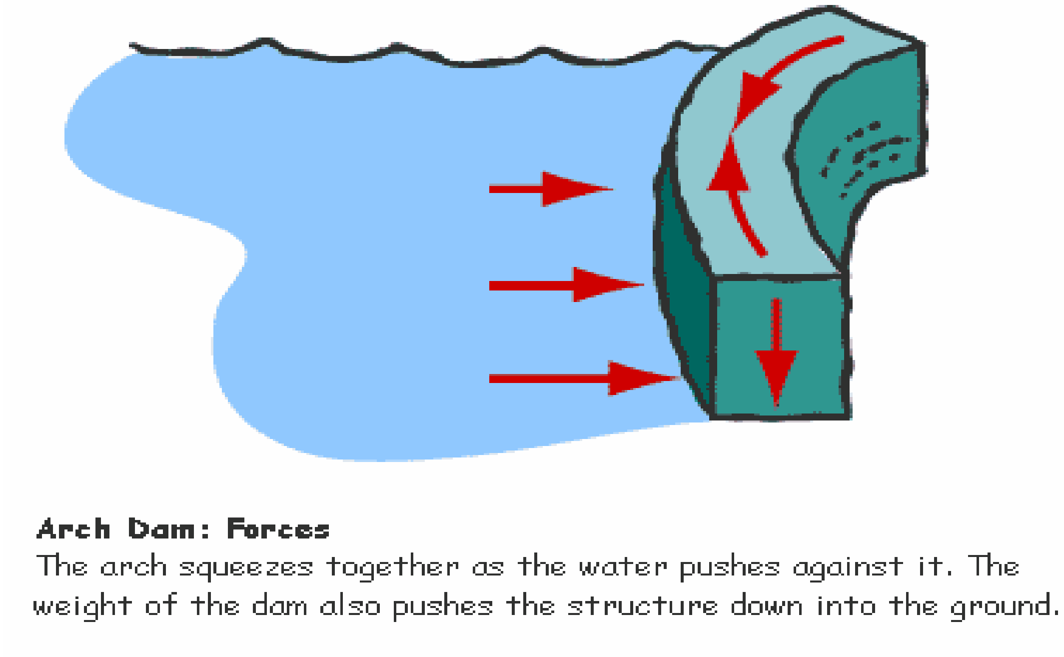


Figure 9.Forces applied on an arch dam ([13])

Buttress Dam

The buttress dam is often a combination of both the gravity and arch dams (see fig 11). It requires less concrete than a gravity concrete dam having the same volume; but needs more labor force. Buttress dams are much lighter than gravity ones, thus they exert less pressure on the foundations. Compared to an arched dam, a buttress dam does not require strong sides.

Its main disadvantage is the deterioration of concrete due to the stored water. This is not very frequent in a thick gravity dam.

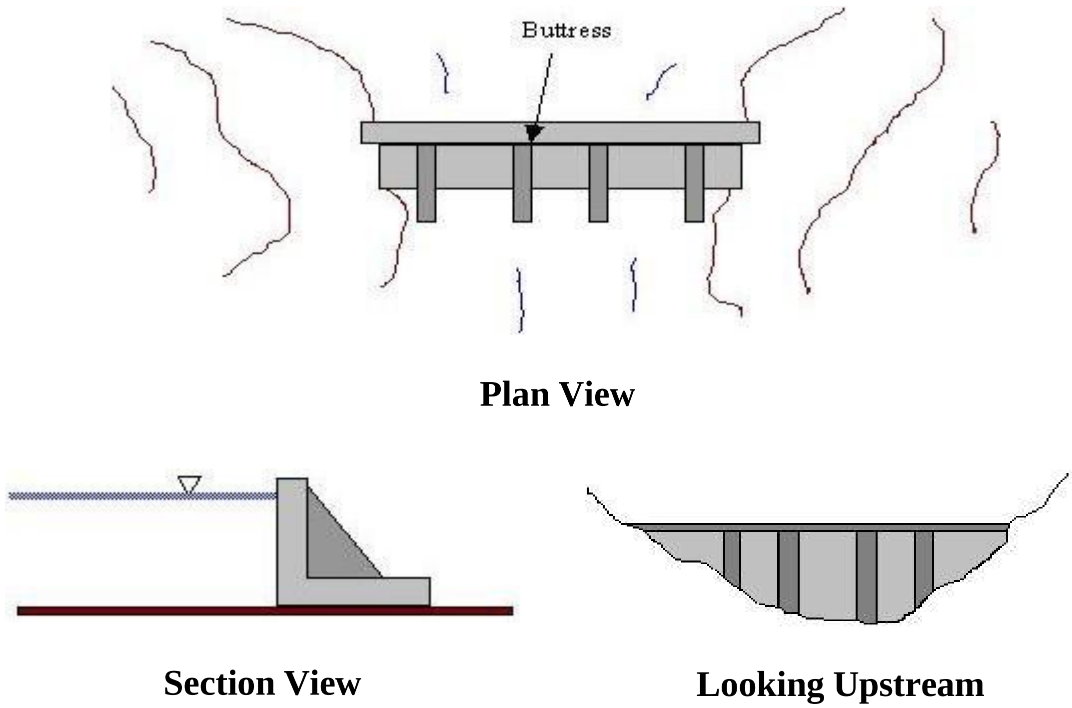


Figure 10.Buttress dam cross section ([19])

The uplift force at the base of a buttressed dam is negligible because of the effect of the buttress situated at the downstream side of the dam (see fig 12). One advantage of the buttress dam is that it does not overturn because of the batters.

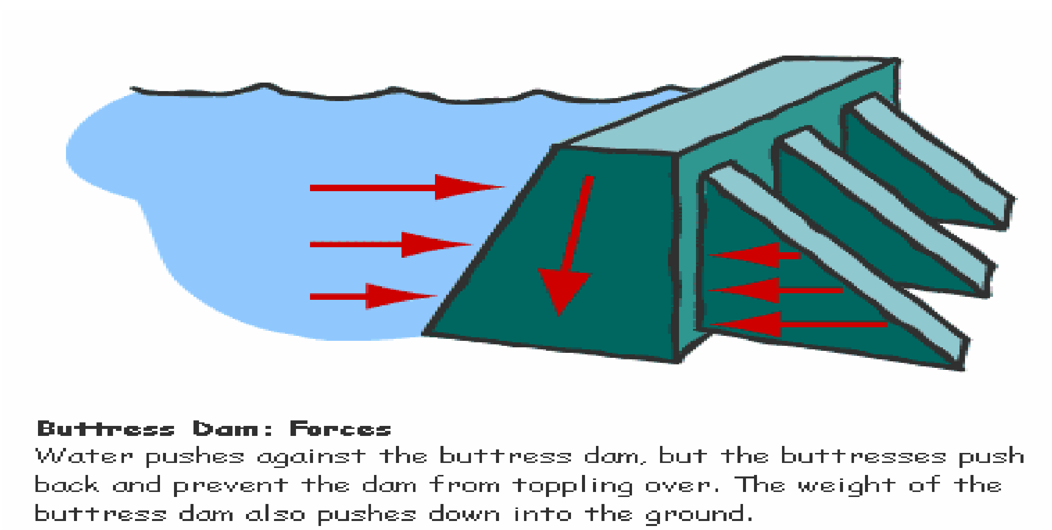


Figure 11.Forces on a buttress dam ([13])

__Multiple Arch Dam__

The multiple arch concrete dam is a combination of both buttress and arch dams (see fig 13). Its foundation need not be as strong as that of concrete arch dams. In building such a dam, less concrete quantities are needed than a buttress dam. If one part of this type fails, the whole structure will fail as well. From an economical point of view, both multiple arch dams and buttress ones are similar.

Concerning the uplift force, as in buttress dam, its effect is negligible due to the force exerted by the batter. Corrosion of these dams, like in buttress, is a major problem.

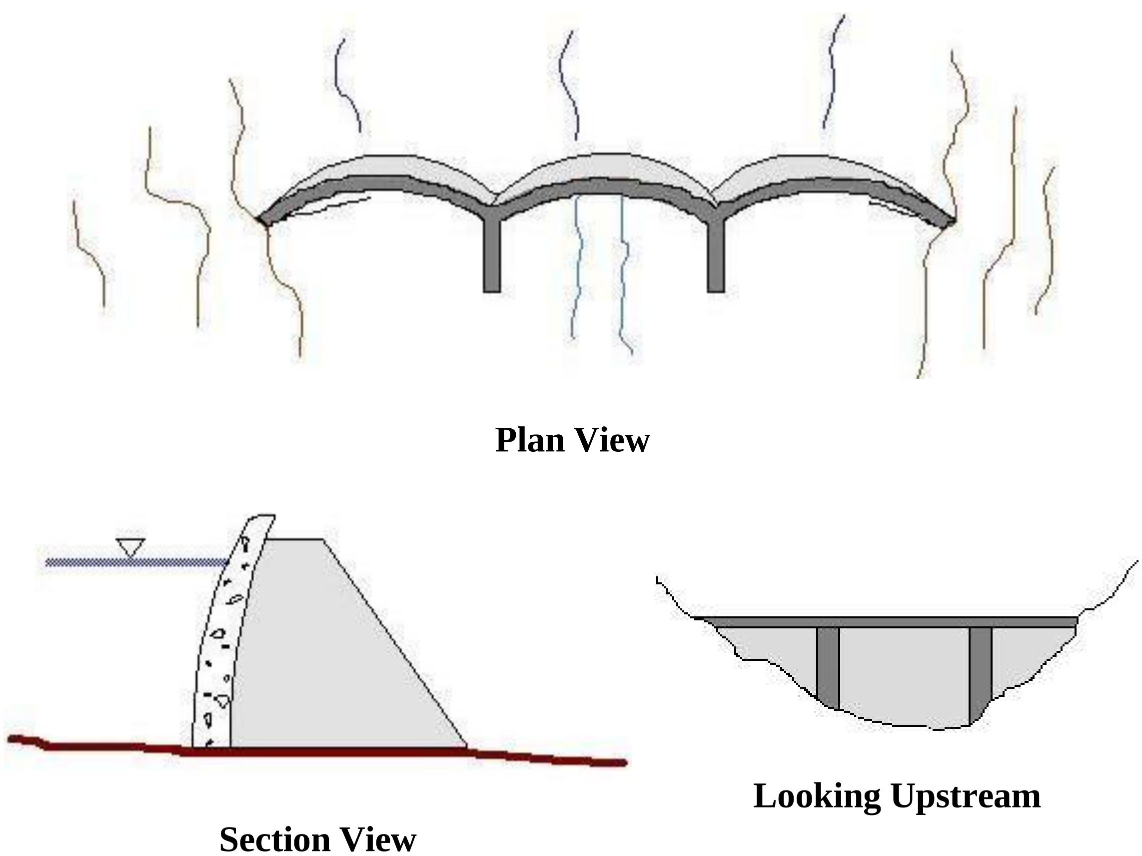


Figure 12. Multiple arch dam cross section ([19])

Steel Dam

This type is rarely used around the world. This type of dams is thought to be economical, but its problem is that it needs to be well anchored to the foundation ([9], p.43).

Timber Dam

The most temporary type, although if it is well designed, constructed and maintained, it may last more than 50 years. But its maintenance costs are very high ([9], p.43).

Hydraulic Fill Dam

Hydraulic fill dams are suitable in valleys of soft materials and are constructed by pumping soft material up to moderate heights up to 100 ft ([14]).

Composite Dam

Sometimes, due to geological and topographical aspects of the sites, one dam can be of different types ([12]).

Causes and Solutions of Dam Failures

The main causes of failures of dams are ([11]; [17]):

- Overtopping
- Sliding
- Piping

. Internal seepage

. Overturning

. Overstressing

· Cracking

. Bearing capacity

· Maintenance

. Rapid drawdown

The percentage of failed dam in the world was about 2.1 before 1950, and around 0.3 after 1950([17]).

On average around 40 % of dam failures occurred due to overtopping where the design flood has been exceeded (see table 6).

Table 6.Reported causes of dam failures ([17])

Cause	Middlebrooks (1955)	Bureau of Reclamation (1984)
Erosion, piping &conduit failure	38%	37%
Overtopping (inadequate spillway capacity)	30%	40%
Slope instability &slope protection failure	20%	23%
Unknown causes	12%	-

In the following, a discussion of these mechanisms and their solutions is given.

Overtopping

When water passes above the dam’s crest, the dam will be gradually washed away for an embankment dam whereas it will be destroyed for a concrete dam. Another but rare cause for overtopping is when an earthquake hits the region where the dam is located creating a large water wave that can pass above the dam’s crest.

This type of failure may occur in any type of dams, but it is mostly dangerous for embankment dams because it washes away or erodes very quickly the dam's materials.

In order to prevent overtopping, the dam's height should be designed in a manner that it can handle the maximum expected conceivable flood (i.e. PMF). Moreover, the difference between the height of the dam and the expected height of the water behind the dam should be between 2 and10 ft. This distance is called freeboard and it represents a factor of safety against unexpected events. Also, the design height should account for the highest expected wave in the dam that can be caused by wind or earthquake.

Sliding

One of the reasons of sliding is the uplift pressure that is applied on the dam by the water seeping below its foundations. This will cause the dam to be uplifted but the dam's weight will act against the uplift force and in the opposite direction.

Normally, the main forces that influence the sliding behavior are ([7], p.398) (see fig14):

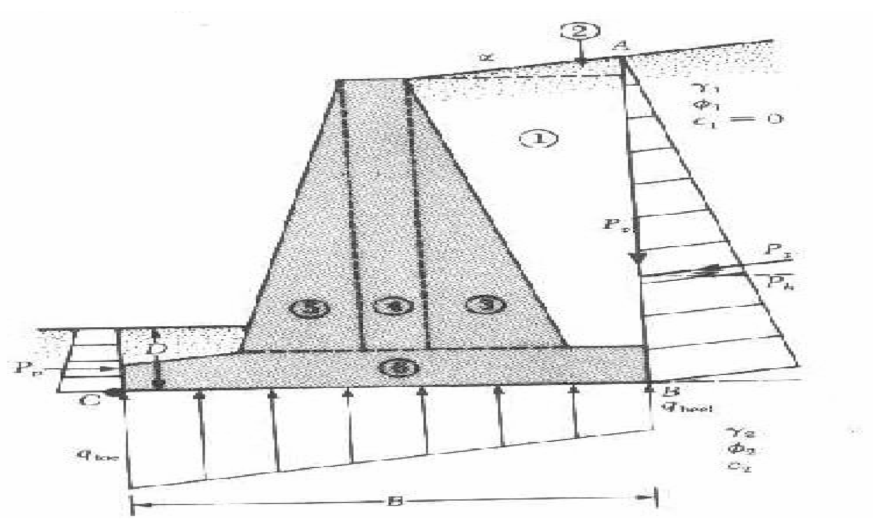


Figure 13.The main forces that may affect sliding ([7], p.396)

1-The active force, P_h that is exerted on the upstream side of the dam and is caused by the upstream water level and the upstream soil pressure. The active force is mainly a hydrostatic driving force for sliding.

2-The passive force that is applied on the downstream face of the dam is mainly represented as a hydrostatic force and /or a force applied by the soil. The passive force is a resisting force against sliding which acts in the opposite direction of the active force.

3-The weight of the dam that is concentrated at its center of gravity.

4-The uplift force exerted by the water seeping under the dam: this force depends on the height of the water stored behind the dam.

Therefore we can say that the higher the levels of water behind the dam, the bigger the hydrostatic force and uplift force is.

In order to decrease the effect of the uplift force that is caused by the uplift pressure, the design should either decrease the uplift pressure or increase the weight of the dam that usually acts in the opposite direction of the uplift force.

Most of the time, the first solution (decrease of pore pressure) is applied. This can be achieved by:

1- Introducing a drainage system (see fig 15):

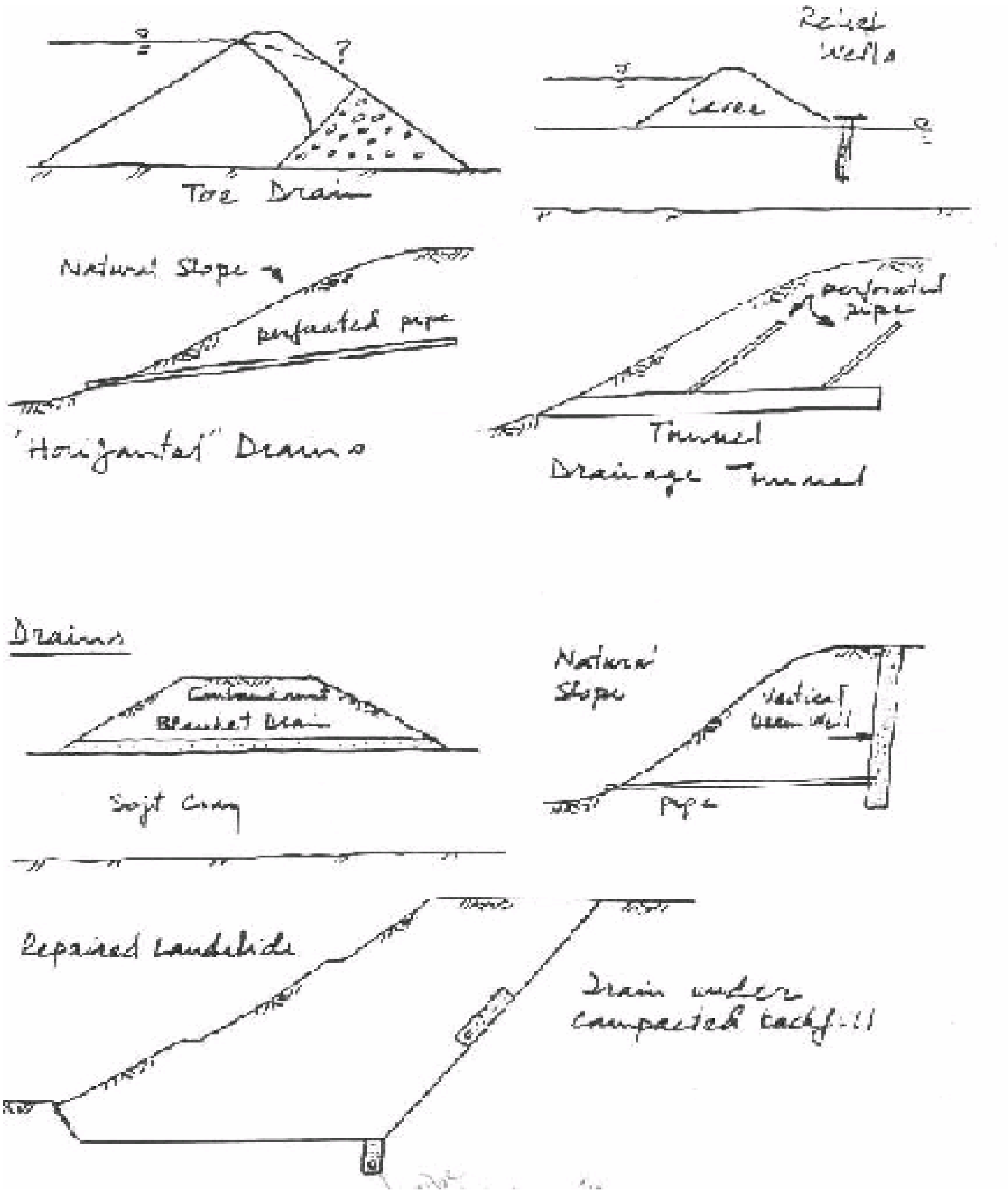


Figure 14. Drainage system ([17])

2- Introducing a deep impermeable sheet or cutoff wall at the upstream side of the dam that will lengthen the water path, leading to the decrease in the head consequently in the uplift pressure (see fig 16).

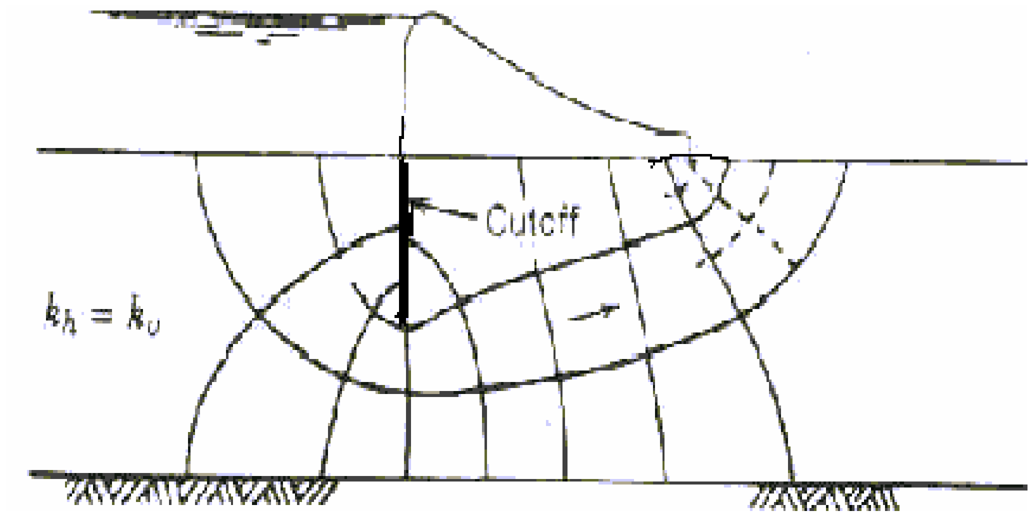


Figure 15. Sheet wall ([17])

For more information concerning sliding of dams, the factor of safety analysis against sliding is included in this report (see page 35).

Piping

When water seeps under the dam, with time, it may begin eroding the soil at the downstream side. As time elapses, this erosion may expand by moving gradually from the downstream to the upstream side of the dam creating a cavity (tunnel) under the dam (see fig 17). This tunnel, when expended, may cause failure of the dam.

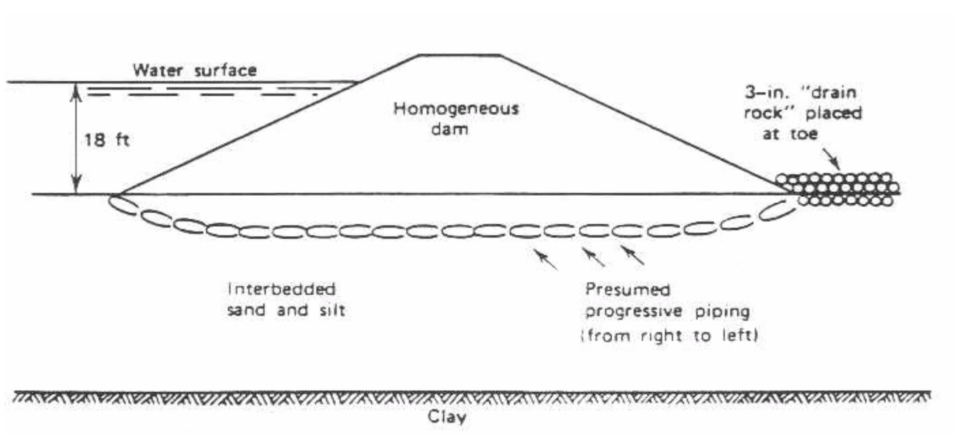


Figure 16.Piping mechanism and solution {filter) at the downstream ([17])

The extent of this seepage depends mainly on the type of soil underneath the dam, for example: a dam built on a rocky foundation will be safer against piping than a dam built on a sandy or loose soil. In other words, piping depends mainly on the hydraulic conductivity of the soil. This phenomenon may occur under any type of dam.

The most common solution (see fig 17) is the installation of a graded filter at this troublesome downstream region that enables the water to seep but, at the same time, it prevents the soil particles from being washed away.

Internal Seepage

This mode of dam failure depends on the type of dam.

For all types of dams, the internal seepage depends on the dam's construction quality, such as:

A-The conditions of the terrain: relief - flat, sloping, surface - smooth or rough, soft or hard.

B-The stiffness of the structure: the stiffer the structure is, the lower the seepage will be.

C-The skill and experience of the construction teams: the more experienced they are, the lesser the effects of seepage will be.

For concrete dams, the main causes of this internal seepage are:

1-The number of segments or junctions along the length of the dam: the less the number of junctions, the safer the structure is.

2-The measures used for sealing junctions: if junction sealing is not perfect, seepage between the junctions may take place.

In embankment dams, there is internal seepage (see fig 18). Sometimes, this internal seepage may cause erosion because water is able to seep through the dam's upstream shell to pass then through its relatively impermeable core. This erosion is mainly concentrated between the downstream shell of the dam and its core. This occurs, because the core's particles are much smaller than that of the downstream shell, thus the water passing through the core to the downstream shell may transport with it these tiny particles. This will cause the gradual loss of impermeable core's particles leading to its erosion. Therefore, with time, the core's particles will be washed away leading to the failure of the dam.

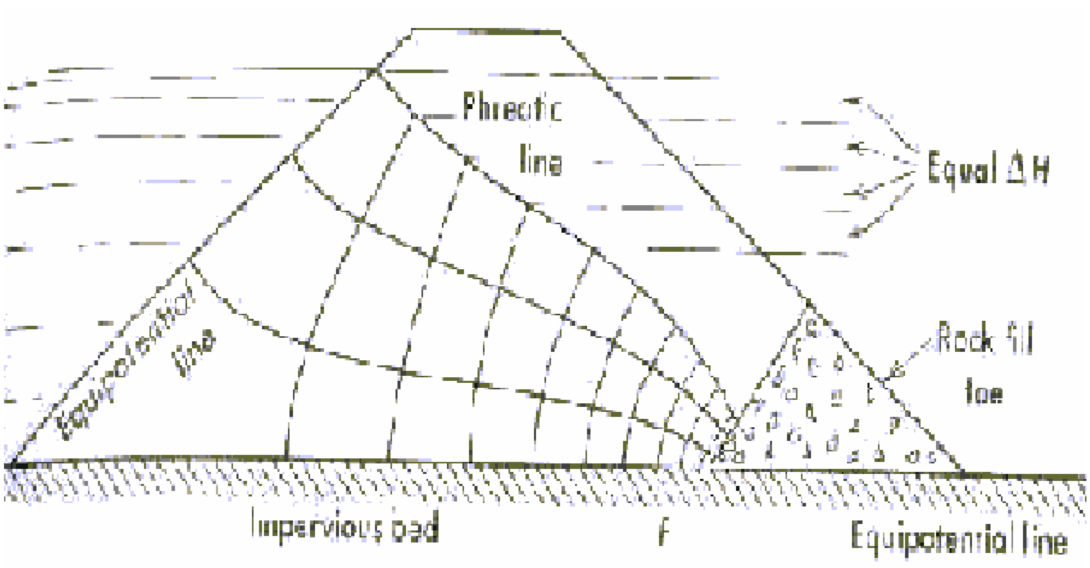


Figure 17.Internal seepage in an embankment dam ([17])

For all types of concrete dams, internal erosion may take place when there is, for a certain reason, an opening in the structure in which water can pass. With time, water will enlarge this opening by eroding the concrete and attacking the steel. The solution of this problem is by periodically maintaining the structure and closing these openings.

In a zoned embankment dam, in order to prohibit the core's fine particles to leave the core, a filter should be placed between the core and the downstream shell of a zoned dam (see fig 19). The role of this filter is to stop the fine core's particles to be transported but at the same it enables the water to seep as usual (see fig 20). If the dam is not zoned (refer to fig 18) a rock toe can be put at the toe of the dam in order to let water seeping through the dam go out.

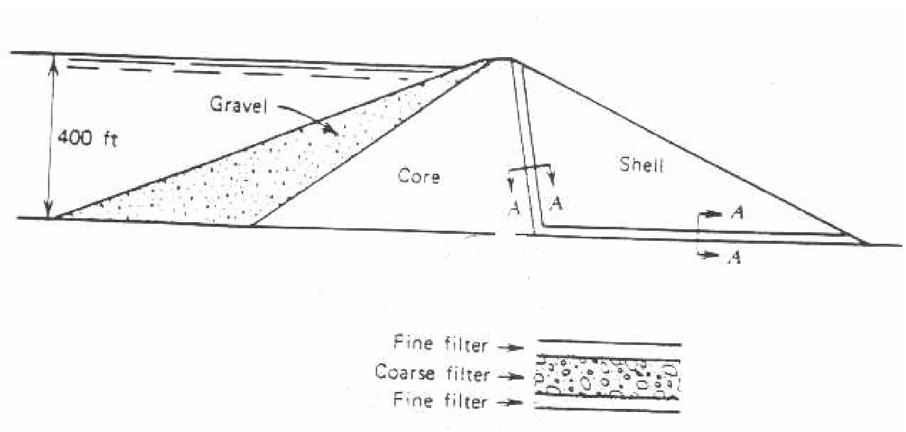


Figure 18.The filter in a zoned dam ([17])

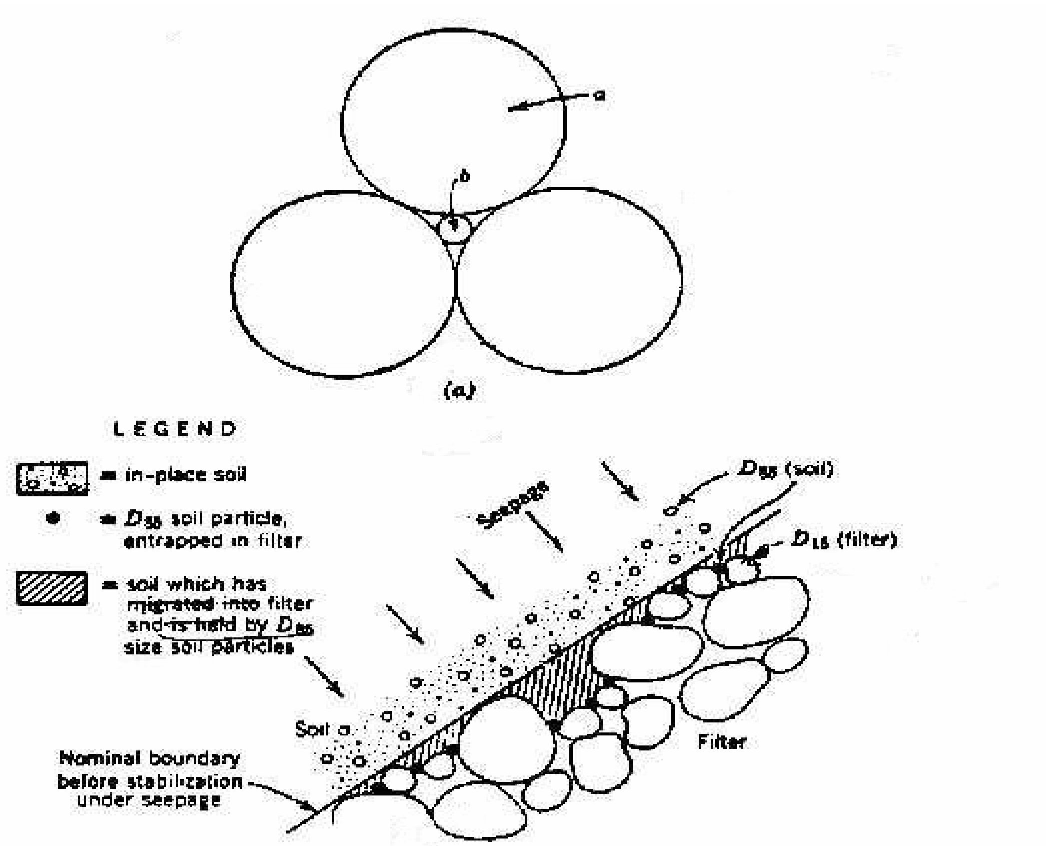


Figure 19. Illustration of how core's fine particles are entrapped by the filter ([17])

For all types of concrete dams, internal erosion may take place when there is, for a certain reason, an opening in the structure in which water can pass. With time, water will enlarge this opening by eroding the concrete and attacking the steel. The solution of this problem is by periodically maintaining the structure and closing these openings.

Overturning

It is mainly caused by the imbalance of the acting moments on the structure. Design against overturning is not crucial for embankment dams because the structure does not behave as one body. Overturning is mostly frequent in gravity dams due to the materials forming it (concrete and steel), which make it one entity ([7], p.396). The forces discussed in the sliding section are the same that affect overturning (see fig 14).

In order to be safe against overturning, the resisting moments and the overturning ones should be balanced. The analysis for the factor of safety against overturning is discussed later in this report in page 35.

Overstressing

As flood flows enter the reservoir, the water level in the reservoir will rise, causing a sudden increase in the loading status on the dam ([6], p.5). If the Dam is not designed to sustain such event, either the whole dam or a part of it will be overstressed, leading to an overturning, a sliding or a failure of a specific structural components ([6], p.5).

Concerning the Embankment dams, they may be in danger if the increased water levels results in increasing pore pressures and seepage rates, which exceed that of the design ([6], p.5).

Cracking

This can be caused by movements such as the natural settling of a dam or due to an earthquake that hit the dam. In this case, the dam is weakened and cracks appear leading to the dam failure.

If a crack takes place in the dam, it should be directly cured and repaired in order to prevent its enlargement with time that may lead to the dam's failure.

Bearing Capacity

If the foundation on which the dam is built cannot hold the dam anymore for several reasons like it has become weak with time, the dam will be subject to failure. As long as the dam is in place, the foundation should be able to bear it. Otherwise the failure will occur.

Maintenance

If a dam is not well maintained (i.e. the clogging of the gates by the sediments) the dam will be subject to failure. Removing sediments from the stream, checking the outlet structures of the dam and other steps are the main solutions for maintaining a dam.

Rapid Drawdown

This is mostly significant in embankment dams, where its materials are made from disconnected soil particles (sand or rock). An example of rapid drawdown is the emptying of a reservoir at a very fast rate, leading to a landslide in the upstream face of the dam.

In order to prevent rapid drawdown, an embankment dam should not be emptied in a very abrupt way, it should be gradual.

How Each Type of Dams Fails?

Table 7 shows the likely failure modes fro the different types of dams (X means that this type of dams fails under this mode).

Table 7.Modes of failure that can hit different types of dams

	Embankment	**Gravity**	**Buttress**	**Arch**	**Multiple Arch**
Sliding	X	X	X		
Piping	X	X	X	X	X
Overturning		X		X	
Overtopping	X	X	X	X	X
Maintenance	X	X	X	X	X
Cracking	X	X	X	X	X
Rapid drawdown	X				
Internal erosion	X	X	X	X	X

Factors of Safety

The factors of safety are crucial in the design of dams. The most known factors of safety for dams are: 1-sliding 2-overturning 3-bearing capacity. For the sake of giving a general idea about the factor of safety, the discussion will be focused on a gravity concrete dam. But to be consistent, the factors of safety apply also to different types of dams (refer to table 4).

Forces on a Gravity Dam

The major forces acting on a gravity dam are given in figure 21([5], p.230-234):

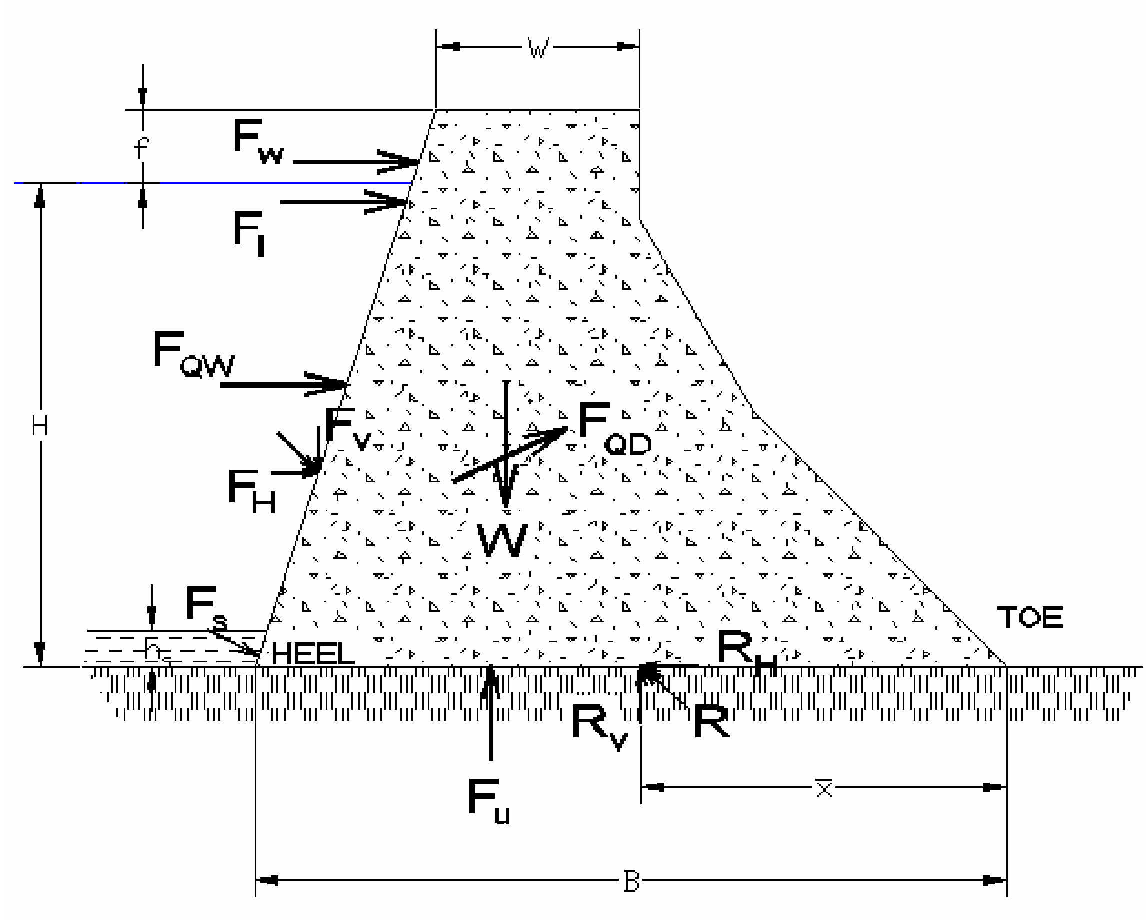


Figure 20. Forces on a gravity dam ([5], p.230)

Where:

1. W= the weight of the dam. In this case W=1/2 HBS where S= specific gravity of concrete.

2. F_U=the uplift force on the base of the dam which is found by using flow net analysis below the dam.

3. F_H =the horizontal force of hydrostatic pressure, acting along a line H/3 above the base =1/2 H^2, where =water specific weight

4. F_V =the vertical force of the hydrostatic pressure = Weight of fluid mass vertically above the upstream face, acting through the center of gravity of that water mass.

5. F_{QW} = the earthquake force due to acceleration of water behind the dam

6. F_I= the force caused by ice on the surface of the lake against dam which is approximately equal to $5000h_I$, where h_I is the freezing depth.

7. F_S= additional hydrostatic force due to silt deposits near the heel, which is approximated by 1/2 $(S_s-1)h_s^2$ with h_s is the depth of silt and S_s is the specific gravity of the water-silt mixture.

8. F_{QD} = force caused by an earthquake applied on the dam

= (W/g)a, where the acceleration is usually taken as 0.1g in the horizontal direction, and about (1/12)g in the vertical direction, acting the center of gravity of the dam.

9. F_{QW} = the earthquake force due to acceleration of water behind the dam.

10. F_I= the force caused by ice on the surface of the lake against dam which is approximated to be $5000h_I$, where h_I is the freezing depth.

11. R = reaction of the ground.

From the horizontal forces equilibrium we have:

$R_H - F_H - F_S - F_{QD} - F_{QW} - F_I = 0$

In which: R_H = the horizontal component of the ground reaction R.

And for the vertical forces equilibrium, we have:

$R_V - W - F_V - F_U - F_{QD} = 0$

In which: R_V = vertical component of the ground reaction.

In what follows, in order to simplify the analysis, some minor forces will be dropped. The ground reaction R acts at a distance “x^{-}” from the toe that needs to be determined. When there is impending motion, there is frictional resistance $R_{H, friction} = R_V M$ where R_V is the normal force transmitted across the surface of contact.

In order to check the stability of a dam, the dam’s design should include the calculation of the factor of safety against sliding, overturning and bearing capacity.

Here we will only focus on both sliding and overturning.

Sliding

The factor of safety against sliding is a measure of the forces needed to overcome the frictional resistance. It is defined as ([5], p.232):

$$FS_{sliding} \quad \frac{MR_V}{R_H}$$

Or in geotechnical engineering, it can be written as ([7], p.398):

$FS_{sliding} = (W-F_u) \tan'6 / F_H$

Where is an angle dependant on the foundations ‘characteristics. On average tan has a value equal to 0.4.

In order to be safe against sliding, the factor of safety against sliding is recommended to be bigger than 1.5.

Overturning

The factor of safety against overturning about the toe is defined as the ratio of the resisting moments to the overturning ones.

The resisting moments are all moments with counterclockwise direction. In this case (see fig 21):

$M_{resisting} = Wa + F_v b$ (2)

Where a and b are the distances from the toe to the lines of action of W and F_v respectively.

The overturning moments tend to topple the dam about its toe. These moments are all clockwise moments .In this case:

$M_{overturning} = F_H Z_H$ (3)

Where Z_H is the vertical distance from the point of application of F_H to the toe.

If the dam were to overturn, R would move to the toe and will not have any moment about the toe due to R (and in particular due to R_V). Therefore, the factor of safety against overturning is given by:

$$FS_{overturning} = \frac{M_{resisting}}{M_{Overturning}}$$

Or

$$FS_{overturning} \quad \frac{Wa \quad F_v b}{(Wa \quad F_v b) \quad R_v x}$$

Usually, the factor of safety against overturning should be between 2 and 3 in order to be safe.

Environmental Effects of Dams

The human interference near or on a stream, may introduce a drastic change to the ecology and species living there. The more the development on a river, the less rich will the river be in organisms and nutrients. Therefore, building a dam in a river will change significantly the river's biology and ecology. On the other hand, there is a tight link between the environment and the population's social needs. These effects are discussed in the following.

Loss of Aquatic Habitats and Fish

By definition, a habitat is a place where a plant or animal grows or live naturally. By building a dam, the habitat in stream channels will be inundated leading to the extinction of some aquatic species. Most often, after building the dam, different types of fish and aquatic species will substitute the original ones ([1], p.73).

Wildlife Habitats Loss

Many wild species living in the streams eat from the vegetation that is along and near the stream or from trees and brush ([1], p.73). When a dam is built, all those food sources will be inundated, consequently lost. This may lead to the extinction of animals feeding from these sources.

Enhancing other areas along the stream may solve this problem, but this is very expensive.

The Change of the Channel's Geometry

Usually, a decrease in the peak flow of a river will cause a decrease in the river width. This usually occurs due to ([20]):

- The low floods that pass the river that are unable to scour its sides

- The sediments transported by the tributary channel that will coalesce and encroach to the sides of the main channel.

Sometimes, if tributary channel are present downstream, in addition to the narrowing of the river, there will be is a decrease in its depth (see fig 22). This occurs due to the accumulation of sediments (resulting from the tributaries) in the river where they cannot be transported further due to the low flow.

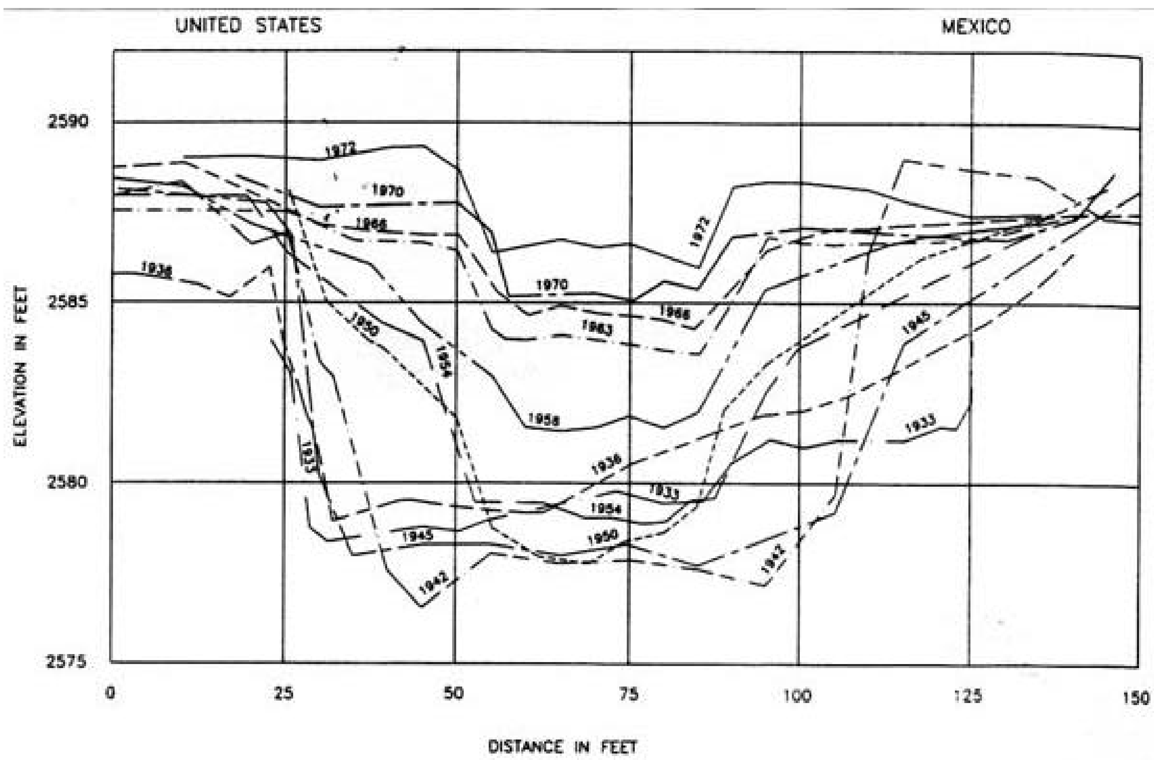


Figure 21.Example of the change, with time, of the cross section of a river downstream of a dam ([20])

This decrease in the river's geometry will affect negatively the people living on its sides. The negative effect arises if a high flood passes the river; in this case, the narrow channel will not be able to handle this flood that may cause the inundation of the area.

Bed Degradation

Because of the dam, most often streambeds are scoured and their elevation is decreased (see fig 23)([20]). Near the dam, high velocity of water is the main cause for scour. Further downstream, the deficiency of needed sediments that are accumulated behind the dam will cause scouring. Because river needs sediments, and these sediments are not available, it will scour its streambed as a way for compensation.

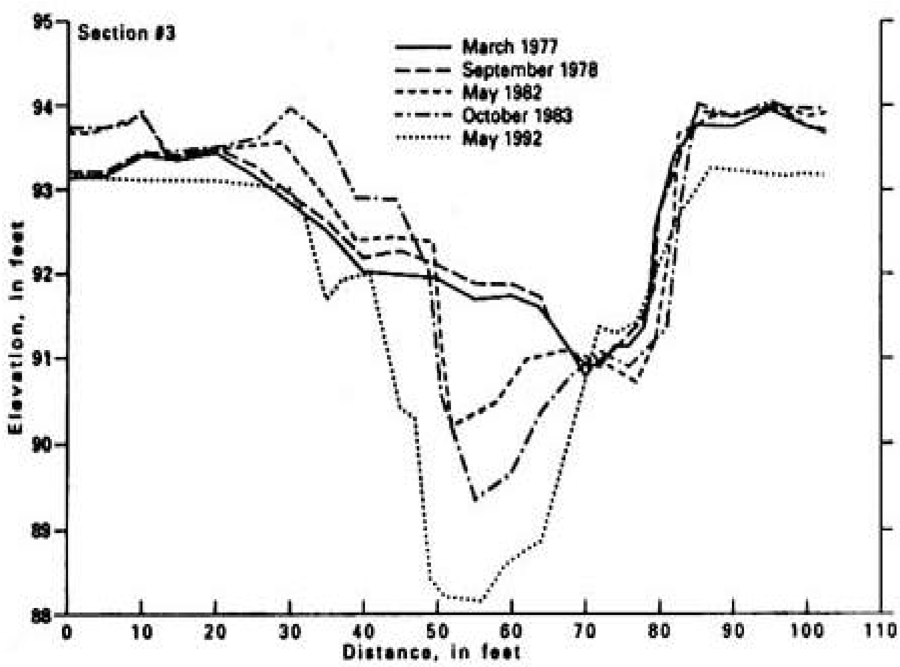


Figure 22.An example of narrowing and deepening of a channel in 15 years time span ([20])

This phenomenon causes a problem for bridges that have foundation in these eroded streambeds. It seems that the biggest degradation occurs near the dam and as you go downstream, degradation will decrease. This means that the decrease of the elevation near the dam is bigger than that of the downstream. It leads to a decrease in the river slope.

Bed Armoring

Building a dam will cause degradation of particles: the average river particle size will increase ([20]). This size will be transported downstream, whereas everything bigger than that will accumulate. These accumulated particles will, with time, stick together and form an armor, with very high strength, on the river bed. For example, On Bear Creek in Colorado, the mean particle size increased from 0.48 millimeters before the dam, to 30 millimeters after only 5 years of dam operation.

Bed armoring is not always bad because there are some examples where those new rigid beds can decrease appreciably the effect of bed erosion. On the other hand, the bad effect of bed armoring is the formation of rapids. These rapids, by the reduction of peak flow, will become more stable. More stable rapids lead to more water turbulence. This issue is unsafe if the main channel is connected to tributary channels. Those tributary channels transport, to the main channel, relatively big particles that will be deposited there because of the low flows. These large particles (i.e. boulders) will be very dangerous for rafters. Moreover rapids will become more dangerous with time.

Loss of Access to Minerals

A mine, located in an anticipated reservoir site, would be closed after the construction of this dam. This action would cause an economical loss ([1], p.74).

A typical example of environmental loss is the inundation of deposits within a reservoir site that are not currently used but will be of potential value and need in the future. Studies projecting the future use of these resources should be conducted before building the dam depending on both the future possible needs for these minerals and their availability elsewhere.

Loss of Flat Areas in Mountainous Terrain

Usually, in mountainous regions, dams are built on flat areas. This represents both an economic and environmental loss, because people would use later such flat areas for different purposes ([1], p.74).

The Inundation of Historical and Archeological Sites

Most of the important archeological sites have been found on relatively high altitudes because the ancient rulers preferred to construct these sites in such places in order to be more able to resist the enemy ([1], p.75). But in order to have sufficient water supply for surviving, these sites were mostly located near rivers. The construction of a dam on these rivers will perhaps inundate part or most of these archeological sites. Therefore at such sites, an archeological survey should be conducted in order to know if this reservoir site is of an archeological value. Small artifacts may be taken to museums, but large archeological features may create a big problem for the construction of the dam.

A typical example is the construction of the Aswan dam on the Nile River in Egypt that was supposed to fully inundate great monuments of the old Egyptian civilization. The most important of these large monuments were removed to locations that are slightly above the maximum expected headwater of the reservoir.

The Inundation of Important Geological Formations

A reservoir site may inundate fully or partially some important geological features such as ([1], p.74): Waterfalls, large springs, geothermal displays and caves. A typical example is a reservoir in the Colorado River that was not constructed because part of the Grand Canyon national park would be inundated.

Aquatic Life Reduction

During the construction of a dam, the river will be diverted causing the reduction of the water level downstream, which in its turn reduces the downstream fish and aquatic habitats ([1], p.75). If all water is diverted, the river's downstream will be completely dry causing the death of many species in the river.

On the other hand, dam can, in dry seasons, be a relief for such species where the river is dry and the release of water from dams will let these species able to survive.

Reduction of Flushing Flows in the Stream

When a dam is built, most large flows are controlled and blocked by the dam ([1], p.75). Usually, without the presence of a dam, these large flows flush and transport the sediments the farthest possible downstream. But after blocking these flows by the dam, this flushing capability is lost. Several tributary streams connected to the river and carrying sediments, will reach the main stream and will deposit these sediments in it. These sediments, with time, will accumulate there because of lack of flushing flow.

Change of Water Quality

The parameters of water quality that are mainly affected by the building of a dam are: oxygen content, organic matter content, turbidity and temperature ([1], p.75).

1-Oxygen content: dissolved oxygen in the stored water behind the reservoir may deplete due to the decomposition of organic substance in the water. Deep zones of the reservoir have less oxygen content. The amount of available oxygen depends on organic materials present in the reservoir.

2-Organic matter content: decomposition of organic matter in the reservoir enhances the nutrients in water. This decomposition forms gases that may lead to localized pollution in the reservoir.

3-Turbidity: water stored in a reservoir contains initially sediments that vary from fine to coarse particles. The coarse particles settle much faster than the finer ones.

Under normal conditions, water released from a dam is slightly clear because it is drawn from its bottom where all particles have settled. But if a flood takes place, the stored water will become turbid.

The solution for this problem is the use of selective level outlets that may stabilize the turbidity and water temperature of the reservoir's released water.

4-Temperature: in a reservoir, the water at the top is warm and becomes colder as you go down. But the released water from the reservoir has a different temperature than that of the natural flow. Usually, water is drawn from low depth from the reservoir, thus the released water is colder than the natural stream flow.

Blocking the Way for Anadromous Fish

Anadromous fishes are the ones that migrate from the sea or ocean to a river and vice versa ([1], p.77). Dams are built in many of these streams. These structures represent a barrier for such fishes because they block their migration routes. The best solution for this problem is Fish hatcheries that are constructed at or near dams in order to maintain the fish in numbers at least equal to those existing under previous natural conditions. Another case is the fishes that migrate within the same stream going from its upper part to its lower one and vice versa. The same problems discussed for anadromous fish will occur. Also the hatcheries represent a suitable solution for such problem.

Blocking the Migration Routes of Species

Several animals like deers migrate, according to the season, in order to search for food ([1], p.77). Sometimes the migrations routes pass through a stream or tributary channel. But after building a dam on these streams, the route will be disturbed. For example, many animals can cross a river with low water level but they cannot cross a reservoir with high water level. Therefore, building dams may change or disturb the life style of some animals.

Unsightly Excavation and Waste Sites

Not all dam’s construction materials are available on site. Therefore, these materials will be imported from other sites ([1], p.78). Also there will be a lot of cut materials (wastes) due to the construction of a dam such as foundations excavation .The cut materials should be properly disposed.

Erosion Caused by Temporary Roads

Building temporary roads near a dam is usually done without satisfying the minimum roads' requirements such as the presence of a drainage system ([1], p.78). If these temporary roads remain in place after the dam is completed, they will cause a lot of erosion because no minimum provisions are applied for the roads. Moreover, roads constructed on steep slopes near the dam abutments may cause landslide or rocks' slide. The solution for these problems is the construction of roads satisfying the minimum requirements such as the presence of a drainage system.

Changes in Vegetation Due to the Reduced Downstream Flows

When a dam is constructed, many downstream types of vegetations will be replaced by new ones ([20]). Usually, in such cases, vegetation increases due to several reasons (see fig 24):

-The narrowing of the river: there will be more available area on which plants can grow.

-The reduction of large flows: usually a large flow destroys or removes the plants across a river and it creates floodplain scour that washes away the roots of plants. Therefore, reducing large flows enables more plants to grow along a river.

- The increase of low flows: these flows usually make the soil more saturated and raise the water table which enhances the growth of new vegetation.

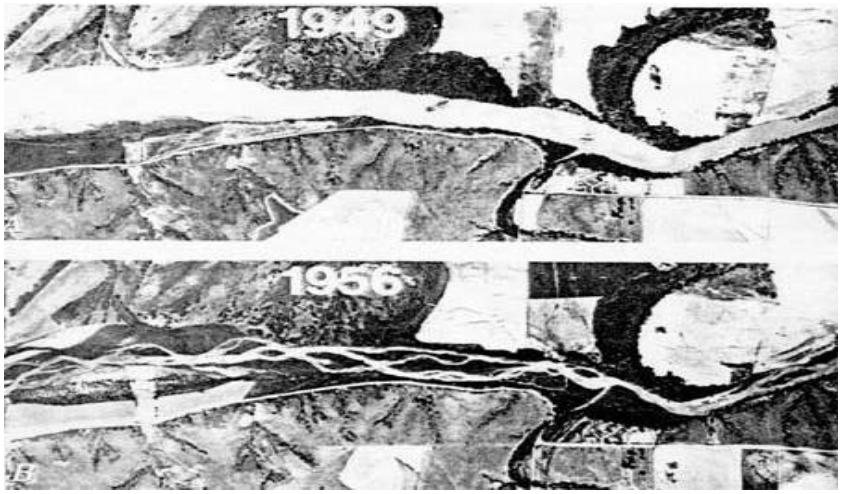


Figure 23.A comparison of the downstream vegetation of a river before (1949) and after the building of a dam (1956) ([20])

Dams Decommissioning

The decommissioning of a dam means the deactivation of some of its key functions such as ([15]; [22]; [25]; [26]):

-No more stored water: this is achieved by opening the gates forever

-Partial removal of the structure by breaching a part of the dam

-Complete removal.

In this section of the paper, the focus will be on the complete dams' removal.

After a long time of using the dam, its damages to the ecosystem and communities may outweigh its benefits. Dam removal may become a desired alternative for many deteriorating, unsafe or abandoned dams. In many cases, dam removal is more economical than its repair. All around the world, a new axiom "dams are not forever" is spreading.

Most of the removed dams were in the US, where more than 75000 dams over 6 feet high exist. In the past 75 years, several hundreds of dams have been removed all around the US.

Causes of Dams Removal

The main causes for removal of a dam are discussed in detail in this section. These include:

Better Understanding of Dams' Bad Impacts

Many studies have demonstrated that, with time, the cost (the harmed stream ecology) of the dam will outweigh its benefits (water storage, navigation purposes, power generation…). Therefore, after several years of using a dam, it will be more beneficial to remove it.

The Substitutes of Dams

A dam can be also removed if there is an alternative that is able to offer the same functions for which the dam has been built. For example, instead of building a hydropower plant for supplying power to a region, another source of power (i.e. nuclear) may satisfy this demand. Restoring wetlands, maintaining riparian buffers and relocating homes and business far from the floodplain can substitute the dams used mainly for flood protection. Renovating irrigation systems can reduce significantly the dependence on dams.

The Aging of Dams in the US

In the US, one reason for the increase in decommissioning activities is the poor condition of the nation's dams, where approximately 1800 of them are officially predicted unsafe. By 2020, 85% of the US government owned dams would be at least 50 years old that is the typical life span. Many of these dams have lost their main purposes and do not have any useful role. Some old dams require much more maintenance than before, therefore removing these old structures would be more economical than maintaining them.

The Relicensing Procedure

Another reason for dam removal is the license renewal given by the Federal Energy Regulatory Commission (FERC) for private hydropower dams (around 2400 all around the country) that enables them to operate for another 30 to 50 years. At least 500 such licenses will expire by year 2010. The main purpose of license renewal is to reevaluate the effects of dams, like the protection of endangered species and existing aquatic life and the quality of the environment. In many cases, the removal of unsafe or not useful dams will be the best solution for river management.

The Restructuring of Power Sources

The shift to more efficient electrical resources (i.e. the nuclear and solar power) will diminish significantly the use of hydropower sources. Moreover, as the licenses of some dams should be renewed by the Federal Power Act, new environmental constraints will be imposed where few or none had previously existed on these dams, making those dams uneconomical.

The Media's Concern in Dams Removal

Lately, actual dam removals cases were covered in almost all major newspapers. The focus of the media on this issue has offered to the public some knowledge about the economical and environmental benefits of removing dams that have lost their intended functions

Decommissioning Methods

These methods depend on project's characteristics like the size, type, dam location, river characteristics and intended objectives of decommissioning (fisheries restoration, land reclamation and recreation). Dam decommissioning is thus highly site-specific. The different decommissioning methods are:

1-Complete removal: which is often accomplished by first diverting momentarily the river, and destroying the dam

2-The creation of a Breach in the dam: that enables the river to flow around the dam's structures. Heavy machinery is usually used to breach earthen parts of dams located in relatively wide river corridors. It is advised to have a breach for partial dam removal, and this option is an inexpensive decommissioning option for larger structures, if it can be done.

3-The use of explosives: which is mostly used for destroying concrete dams.

4-The combination of heavy machinery and explosives: that is especially needed for large projects.

Removing Accumulated Sediments

Dams catch huge quantities of river sediment. It is estimated, on average, that each year, around 0.5% to 1.5% of the reservoir's storage capacity is filled with sediments. Therefore, if there is a dam removing plan, a special care concerning the accumulated sediments should be taken. Sediments removal represents the most costly and technically intensive job in removing large dams.

Specific sediment removal techniques are used according to the quantities and types of the available sediments, age of the dam and the effectiveness of periodical flushes. The sediment removal techniques must be accurately conducted because intensive removals may destroy some habitats in the river downstream side. For example, on Elwha River, a gradual sediment drawdown had been used in order to preserve the habitats of juvenile Salmon. A problem that may occur, when sediments are flushed, is the spreading of the accumulated contaminants or hazardous wastes into fisheries or water supplies leading to the disturbance of the aquatic life. For instance, after the removal of a 9-meter-high dam on New York's Hudson River in 1973, several tons of accumulated toxins spread downstream and killed a big part of the aquatic life in the river.

Another possible problem that can be faced when removing a dam is the spreading of hazardous waste present in sediments that are very dangerous to aquatic life and water quality. Thus a careful planning against spreading of the wastes should be taken care of when removing a dam.

Environmental Benefits of Decommissioning

The most important benefits when a dam is removed are:

1. Normalization of sediments and energy transports
2. The stabilization of the temperature in different part of the river
3. The enhancement of water clarity
4. Re-connection of important seasonal fish habitats
5. The enhancement of the concentrations of dissolved oxygen
6. The Help in establishing more biological diversity.

Examples of Removed Dams

Hundreds of dams have been removed all around the world, but most of them took place in the USA.

In what follows, some examples of removed dams in the US are discussed.

Woolen Mills Dam, Wisconsin

In 1919, a concrete gravity dam 18-foot high was built in the Milwaukee river for the Wisconsin Power and Electric (see fig 25) to produce electricity. By 1959, the dam was not profitable. The company abandoned the dam and the City of West Bend became the new owner. In 1988, the dam was removed because it became structurally unsafe and the cost of removing it is much lower than that for its rehabilitation.

Figure 24.Woolen Mills Dam before removal ([15])

The reservoir behind the dam became very shallow due to the accumulation of sediments. Water quality was bad, oxygen content was at its lowest level, and the water was turbid, aquatic life decreased and a large amount of pollution in the sediments was there due to the impoundment from a near landfill. There were no appreciable recreational uses near the dam.

The cost of rebuilding the dam was estimated to be 3.3 millions dollars, whereas the estimated removal cost will not exceed 5 % this amount. This is why the city proposed to remove the dam .The financing of this action is from the Federal government.

The dam 's removal cost was $86,000 (see fig 26). Both the state and city paid for seeding the previous reservoir area, design and engineering work, stabilization and vegetation.

Figure 25. Milwaukee River after dam removal ([15])

The river was restored to a rock-bottomed channel with meanders, riffles, pools and rapids. After the removal:

- The water quality has enhanced gradually and the water was well oxygenated.
- The city has restored 61 acres of land. This area became a park.
- The aquatic and fish life have improved significantly.
- The value of properties along the previous impoundment has increased significantly.
- The recreational opportunities near the site have greatly increased.

Lewiston Dam, Idaho

This dam was constructed in 1927 in the Clearwater River in Idaho. It was a semicircular earth dam, 45 feet high, with a1060 feet long concrete spillway and a powerhouse of 10 megawatts capacity .At the time of removal; Washington Water Power was the owner of this dam. This dam was removed in 1973.

The main problem of the Lewiston Dam was its bad impact on anadromous fish migration and their passage in the Clearwater River. A lot of different species also died due to the presence of this dam. In 1967, the Army Corps of Engineers decided to build the Lower Granite Dam that is located at the downstream side of the Lewiston Dam. The Lower Granite Dam was supposed to interfere with the impoundment of the Lewiston Dam. This project requires the removal of the Lewiston Dam. All the parties accepted the deal, and the structural removal cost was $ 633428 and began in December 1972. Moreover, Washington Water Power was paid $2.7 million in compensation for the loss.

The removal procedure was as follows:

1-Emptying the reservoir by opening the spillway gates

2-The bridge and spillway gates were removed

3-The concrete spillway was destroyed using dynamite (see fig 26).

Figure 26. Dynamite is used for removing the Lewiston Dam ([15])

All the waste, without the steel, was deposited on the north side of the river and covered with soil and vegetation. The removal of sediments behind the dam was critical because of the fear that the huge quantities of sediments will flow downstream the removed dam and will reach the Lower Granite Dam. The used procedure was to remove the dam in a period of the year in which there is a low flow of water in the river that is unable to transport the sediments downstream. The removal was terminated in April 1973.

The benefits of this project are:

-No more maintenance for an unused structure

-No more obstruction for recreational boats

-The migration all along the river, for several types of fish, has been restored.

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