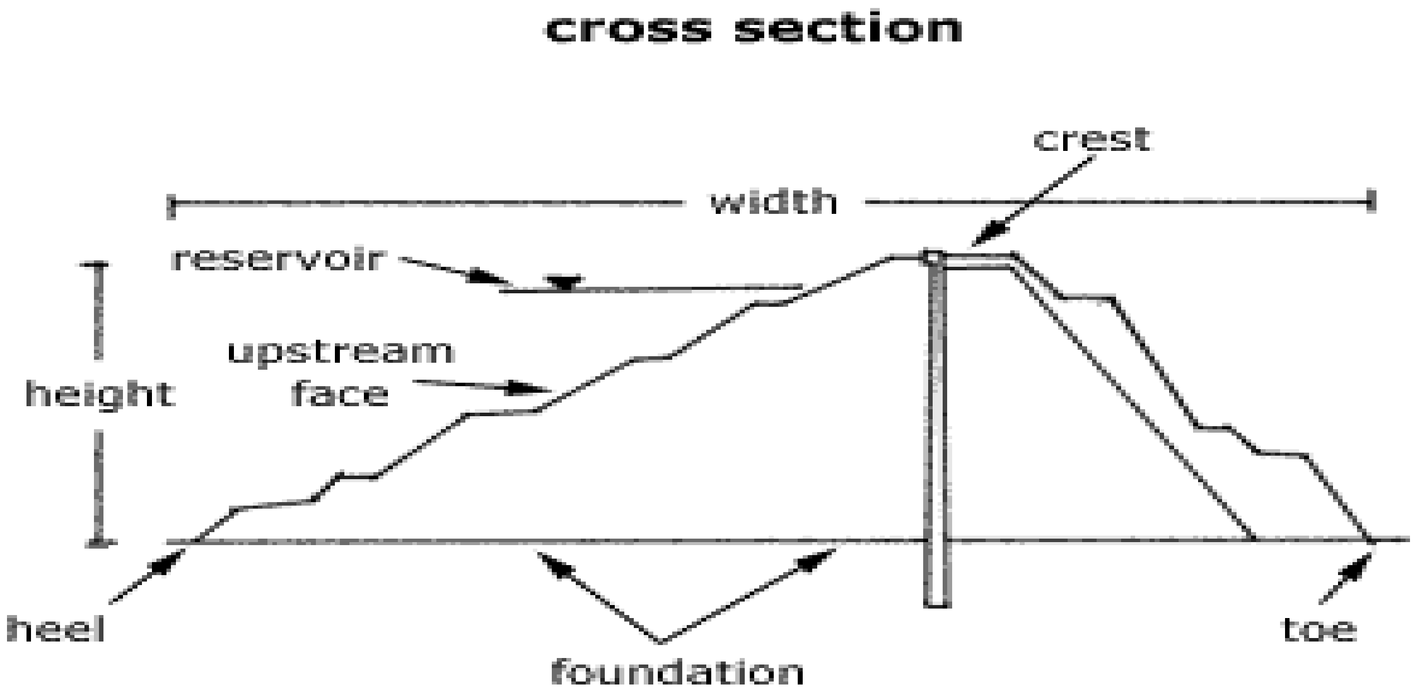
Dam Engineering

What is a dam?

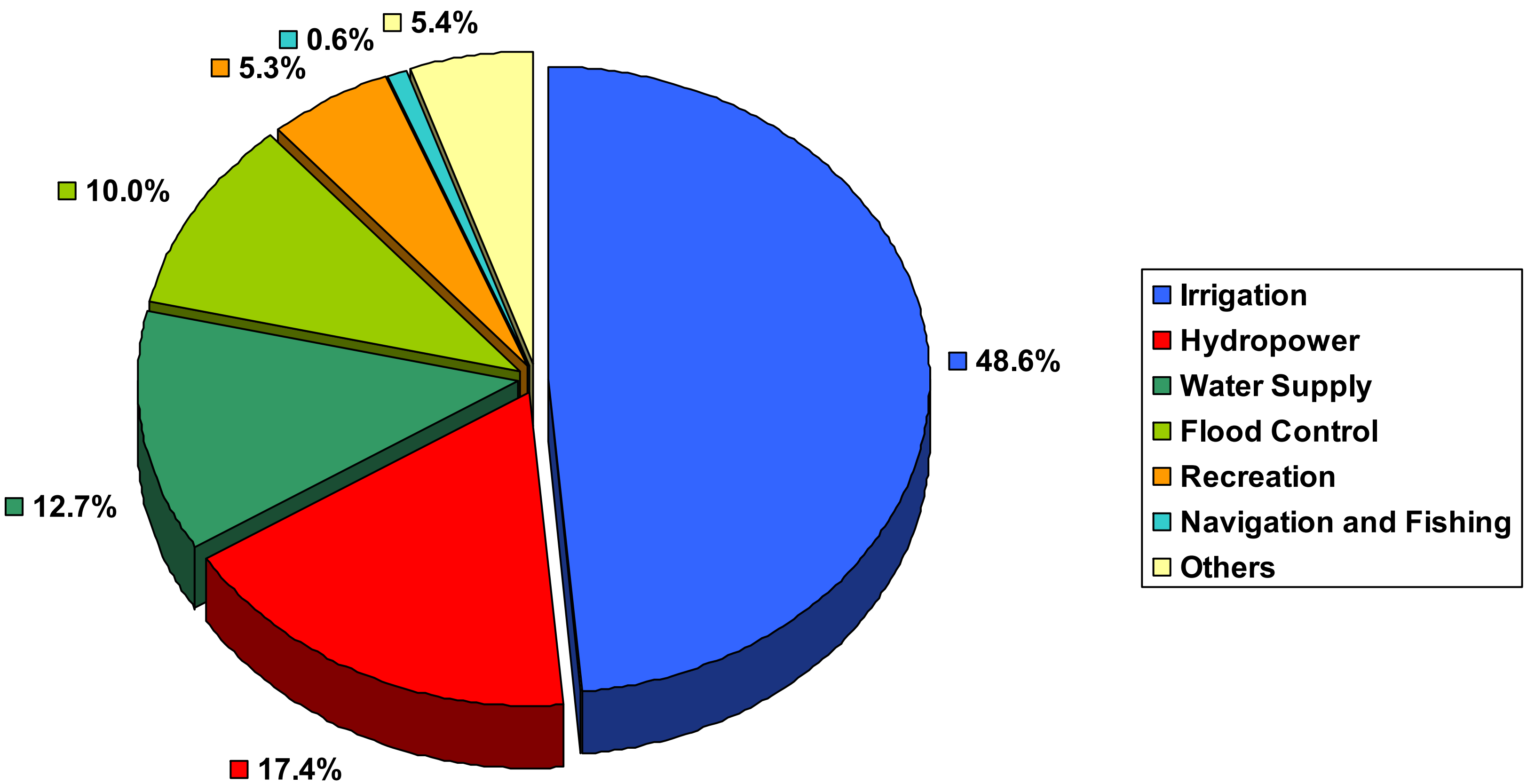
- A dam is a barrier built across a stream, river or estuary to hold and control the flow of water for such uses as drinking water supplies, irrigation, flood control and hydropower generation etc.



Benefits of Dams

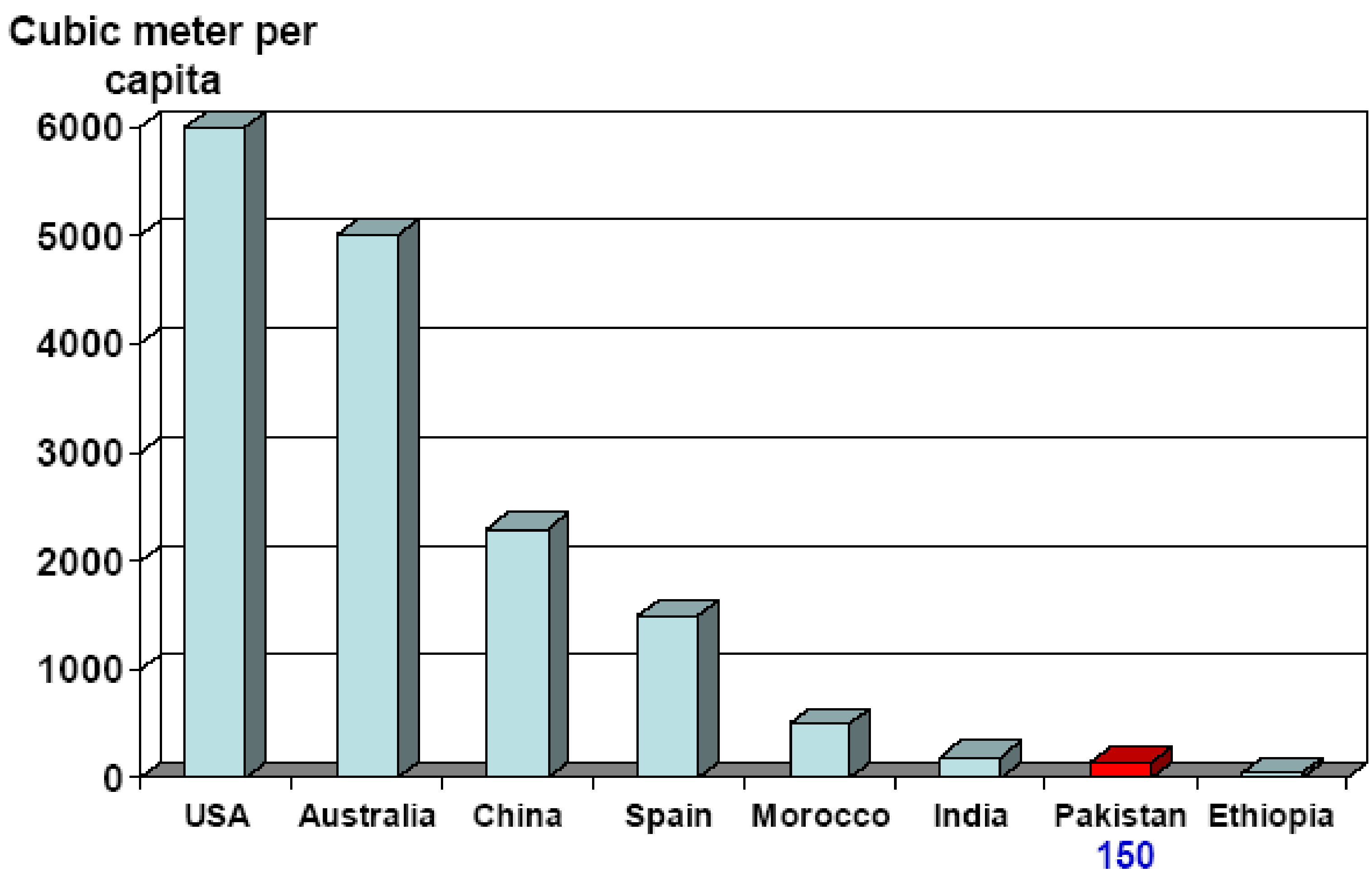
- The benefits of dams are usually to the advantage of humans. They may include:
  - Irrigation (12-15% of food production)
  - Hydroelectric production (19% of global electricity)
  - Flood control
  - Recreational opportunities
  - Navigation
  - Industrial and Domestic water supply (12% of Ind. & Domestic use)
- For animals the benefits may include:
  - Larger numbers of fish and birds in the reservoir
  - Greater habitat diversity

Purpose Distribution of Reservoirs



Source: International Commission on Large Dams (ICOLD)

Storage per capita in various semi-arid countries



Ref: Presentation by Chairman WAPDA, April 2007

Disadvantages of dams

- Changes in flow and temperature in the river downstream from the dam
- Loss of flowing water habitat and replacement with standing water (reservoir) habitat
- Interruption of animal/human movements along the course of the river
- Possible alteration of the fish community in the region of the river
- Reduction in the delivery of river nutrients to downstream section of the river because of entrapment by the reservoir
- The loss of the floodplain habitat and connectivity between the river and bordering habitats upland

Slogans by Anti-Dam Activists

Damn to Dam

Small is beautiful

WCD(2000) Recommendations

- Decision should be based on multi criteria analysis of technical, social, environmental, economic, and financial parameters.
- Decision should be based on
  - EQUITY,
  - SUSTAINABILITY,
  - EFFICIENCY,
  - PARTICIPATORY DECISION MAKING,
  - ACCOUNTABILITY.

Classification of Storage Dams

Dams are of numerous types and type classification is sometimes less clearly defined. An initial broad classification into generic groups can be made in terms of the principal of construction material employed:

- ✓ **Embankment Dams:** Constructed of earth-fill and/or rock-fill. Upstream and downstream face slopes are similar and of moderate angle, giving a wide selection and high construction volume relative to height.
- ✓ **Concrete Dams:** Constructed of mass concrete. Face slopes are dissimilar, generally steep downstream and near vertical upstream and dams have relatively slender profiles depending upon type

Note: Embankment dams are numerically dominant for technical and economical reasons, and account for over 85-90% of all dams build

Classification of Storage dams:

Dams are also classified on several aspects, some of the important aspects are as follow:

1) **Based on Hydraulic Design:**
   - Over flow dams (e.g. concrete dams)
   - Non over flow dams (e.g. embankment dams)
2) **Based on Structural Design:**
   - Gravity dams
   - Arch dams
   - Buttress dams
3) **Based on Usage of Dam:**
   - Storage dams
   - Diversion dams
   - Detention dams
   - Retention dams

Classification of Storage dams:

4) **Based on Construction Material:**

- Concrete / Masonary dams
- Earthfill dams
- Rockfill dams
- Earthfill rockfill dams
- Concrete faced rockfill dams (CFRD)

5) **Based on Capacity:**

- Small dams
- Large dams

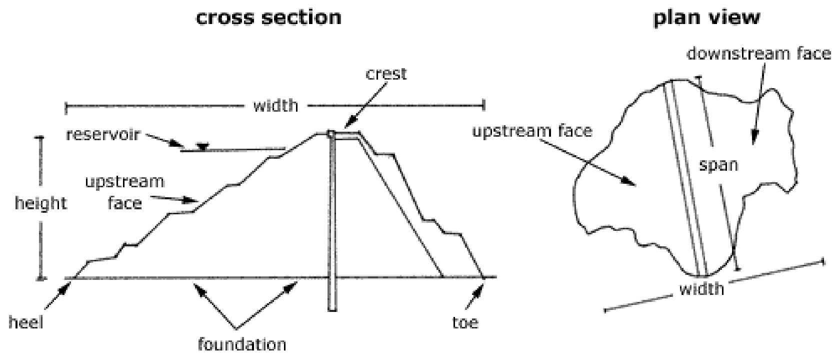
ICOLD defines large dams as dams exceeding 15 m in height or in case of dams of 10-15m, satisfying certain criteria e.g. a storage volume in excess of 1×10^6 m^3 or a flood discharge capacity of over 2,000 m^3/s

Classification of Storage Dams

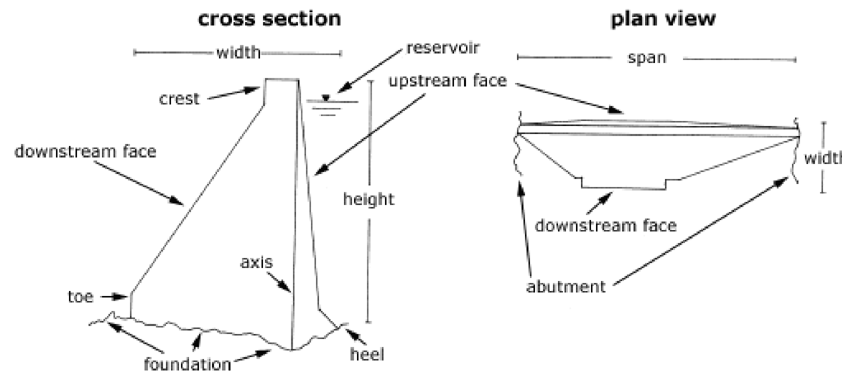
- Embankment Dams
  - Earth-fill Dam
    - Earth-fill dams, also called earthen, rolled-earth or simply earth dams, are constructed as a simple embankment of well compacted earth.
  - Rock-fill Dam
    - Rock-fill dams are embankments of compacted free-draining granular earth with an impervious zone. The earth utilized often contains a large percentage of large particles hence the term *rock-fill* is used.

- Concrete Dams
  - Gravity Dam
- Gravity dams are dams which resist the horizontal thrust of the water entirely by their own weight. These are typically used to block streams through narrow gorges.
  - Buttress Dam
- Buttress dams are dams in which the face is held up by a series of supports. It can take many forms. The face may be flat or curved.
  - Arch Dam
- An arch dam is a curved dam which is dependent upon arch action for its strength. It is more thinner and therefore require less material than any other type of dam.
- Cupola or Double Arch (curved in plan and in section)

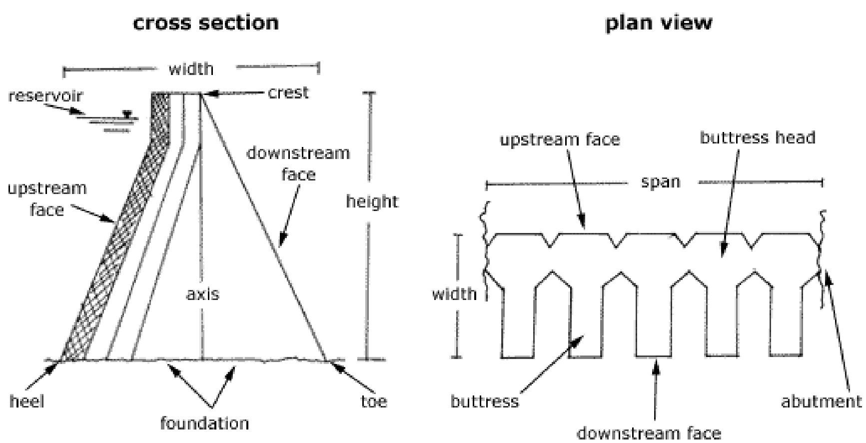
Types of Storage Dams



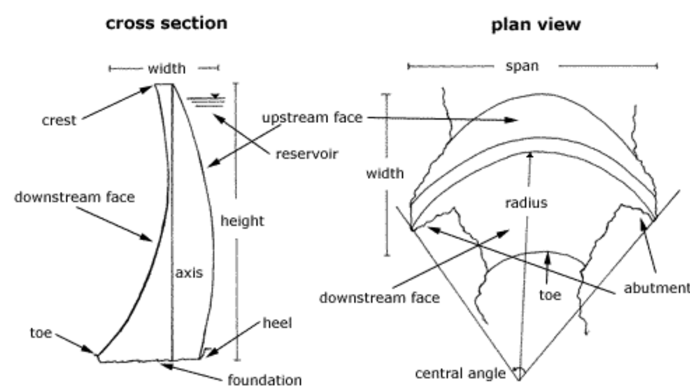
Embankment dam



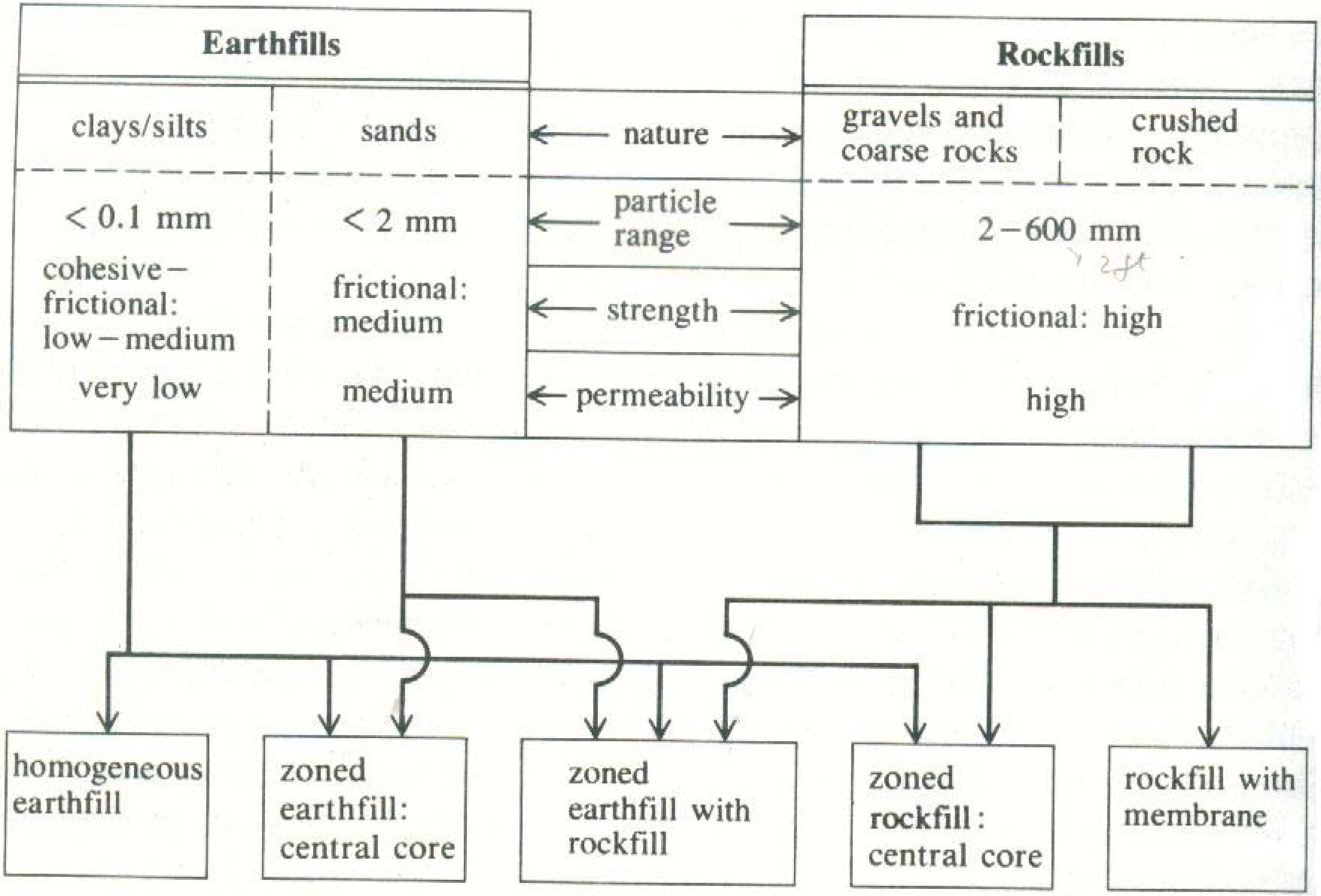
Gravity dam



Buttress dam

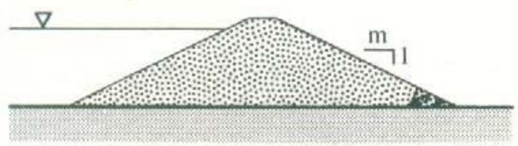


Arch dam

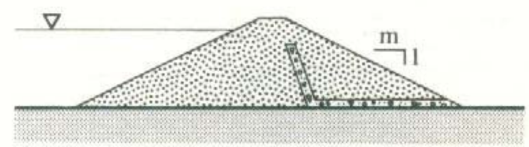


Earthfills and rockfills in dam construction.

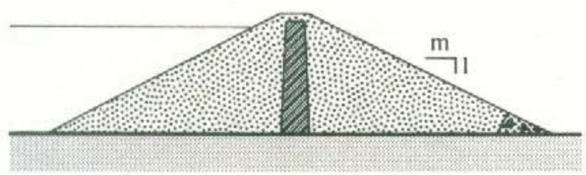
Principal variants of earth fill / rock fill embankment dams



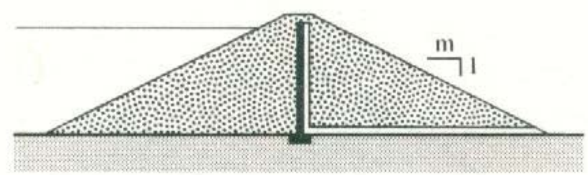
(a) **Homogeneous with toedrain: small secondary dams**
$m = 1.5-2.5$



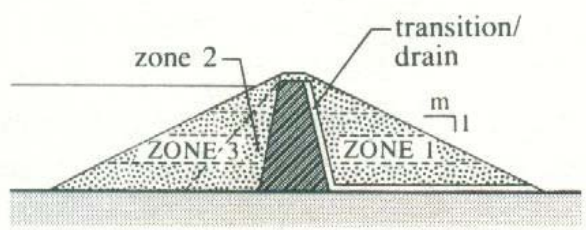
(b) **Modern homogeneous with internal chimney drain**
$m = 2.5-3.5$



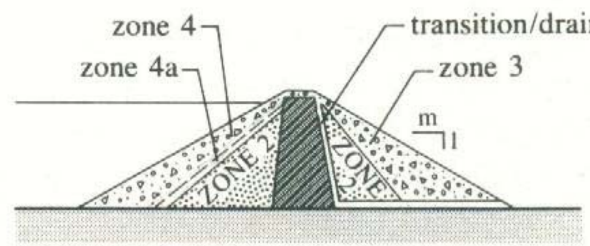
(c) **Slender central clay core: 19th-century 'Pennines' type – obsolete**
$m = 2.0-3.0$



(d) **Central concrete core: smaller dams – obsolescent**
$m = 2.0-3.0$

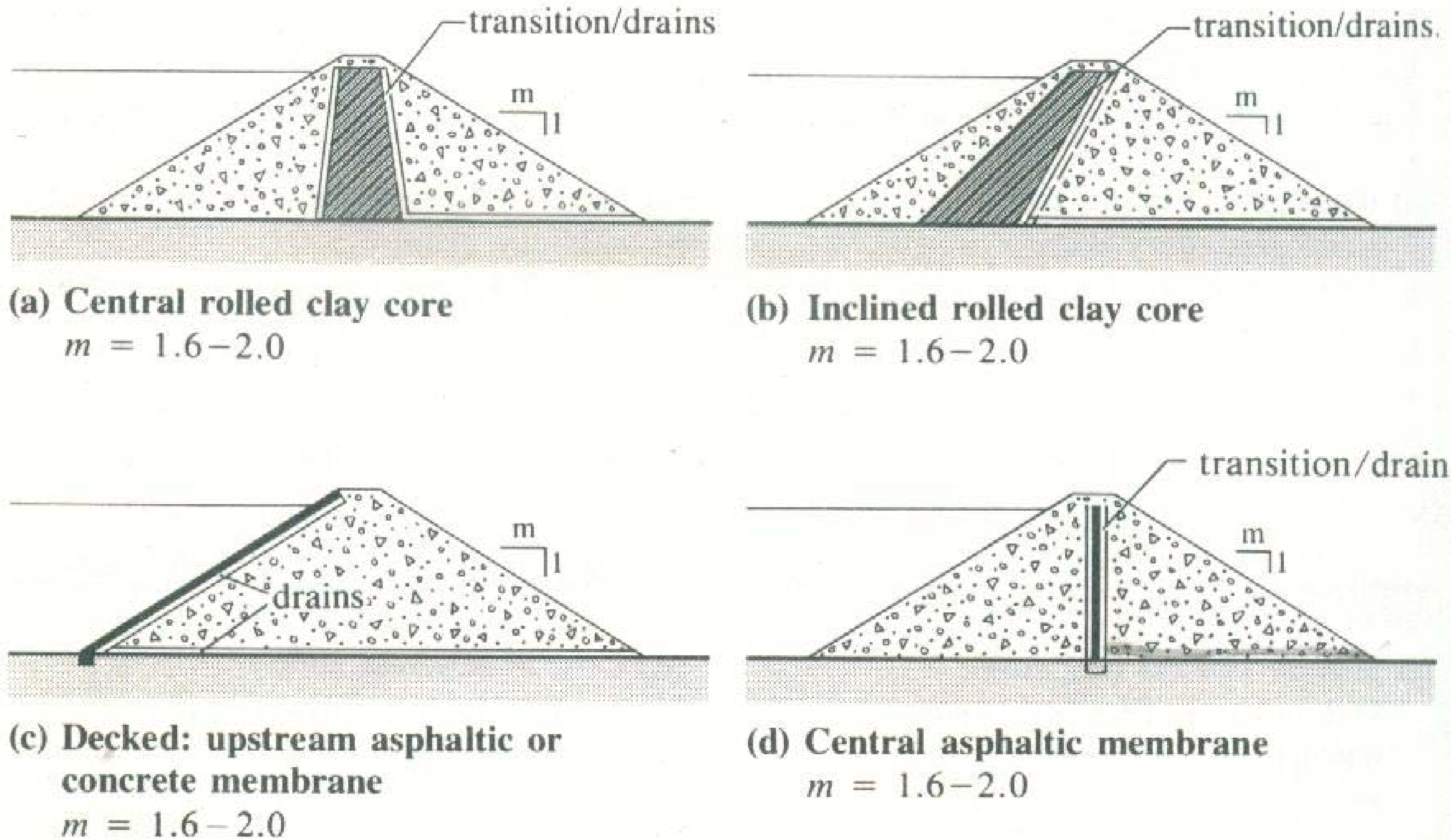


(e) **Rolled clay core: zoned with transitions and drains**
$m = 2.5-3.5$



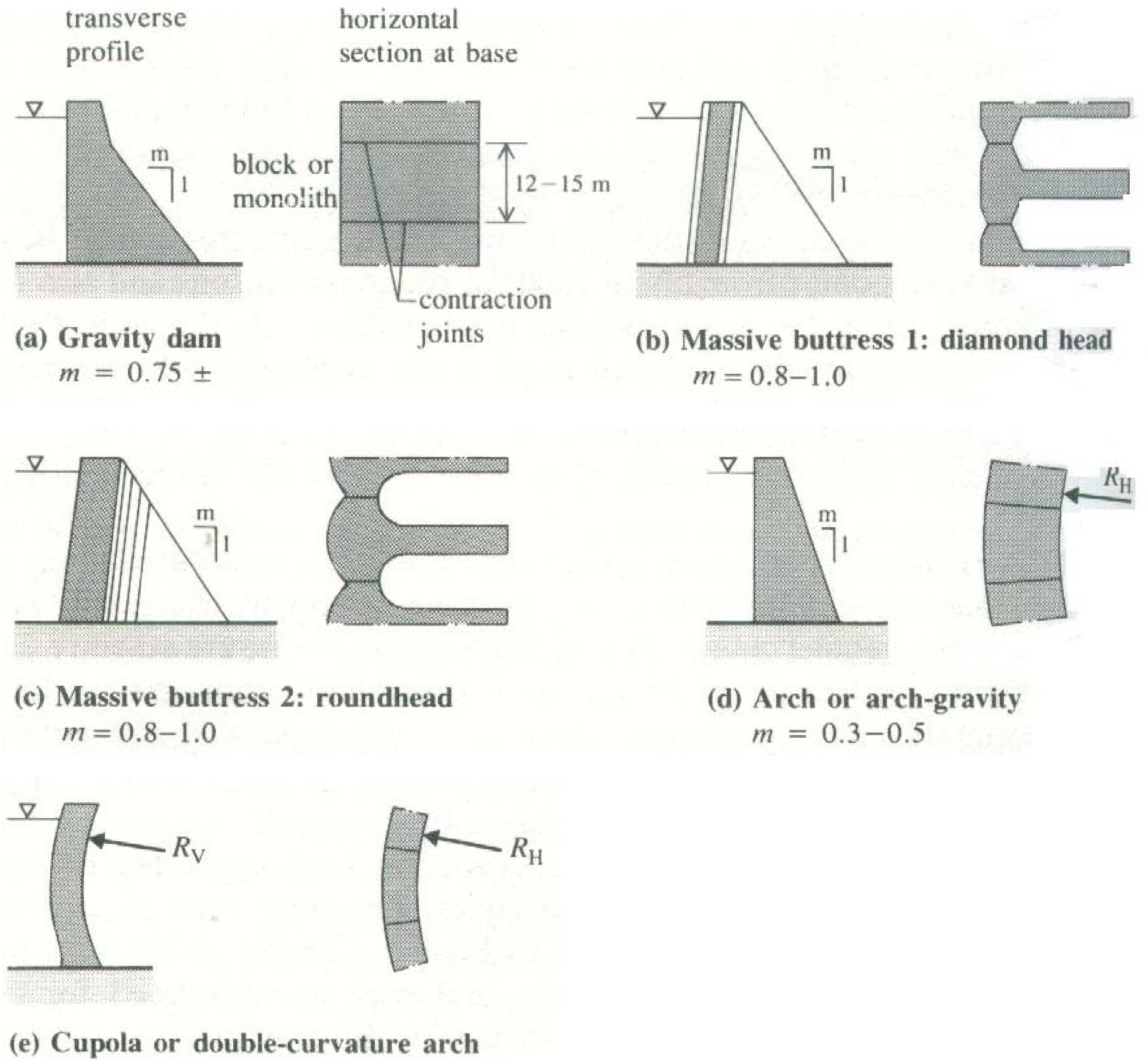
(f) **Earthfill/rockfill with central rolled clay core: zoned with transitions and drains** $m = 1.6-2.0$

Principal variants of rock fill embankment dams



Principal variants of rockfill embankment dams.

Principal variants of Concrete dams



Buttress Dam:

Ekbatan Dam (53 m high) , Iran

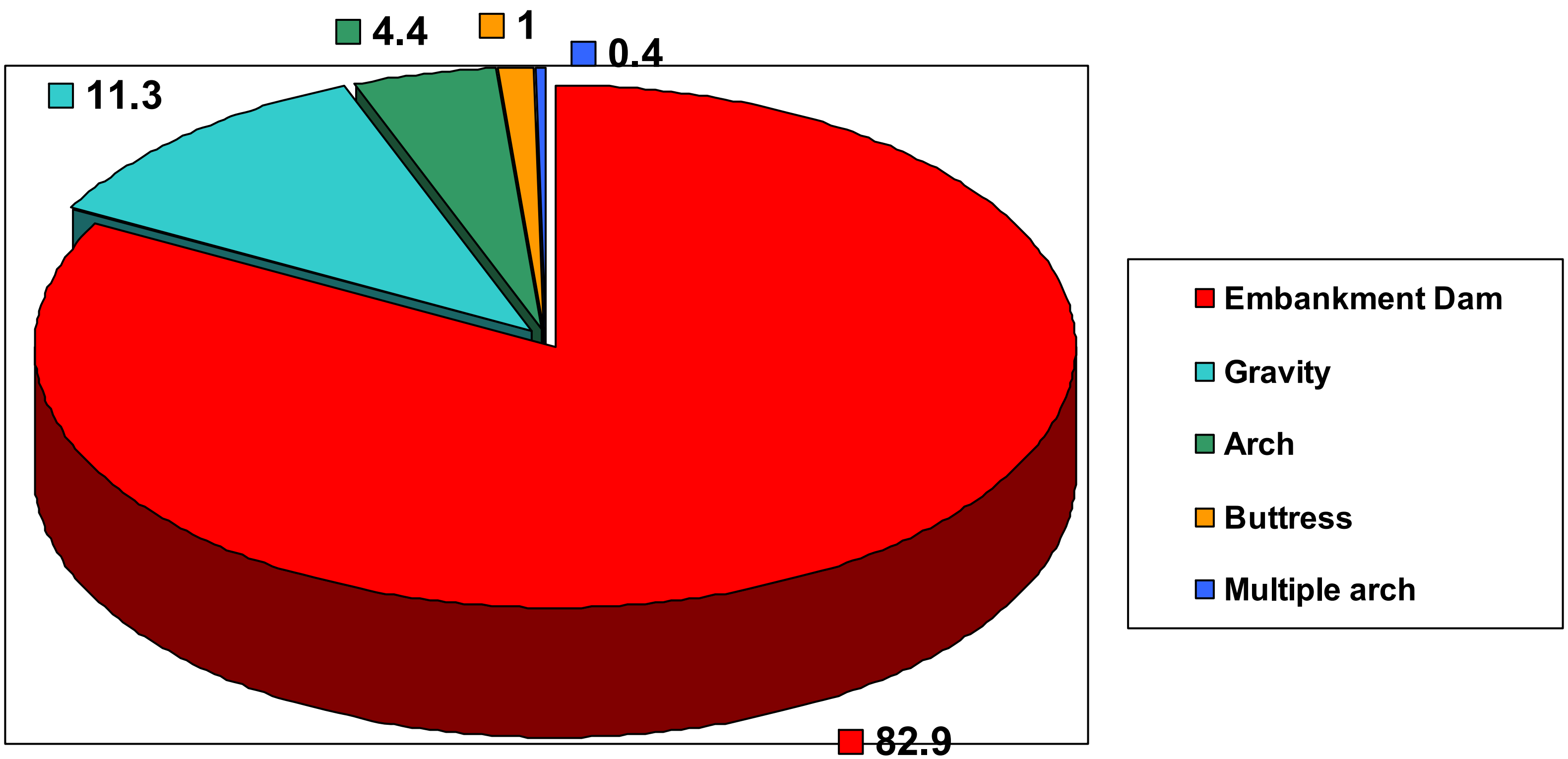
Large Dams: World Wide Registered Statistics (ICOLD 1998)

Group	Type	ICOLD* Code	%
Embankment Dam	Earth Fill	TE	82.9
	Rock Fill	ER	
Concrete Dams including Masonry dams	Gravity	PG	11.3
	Arch	VA	4.4
	Buttress	CB	1.0
	Multiple arch	MV	0.4
Total Large Dams (as on 1998)	41,413		

ICOLD= International Commission of Large Dams

ICOLD 1998: More than 25,000 large dams > 30 m
ICOLD 2009: More than 30,000 large dams > 30 m

Types of dams



Distribution of dams worldwide

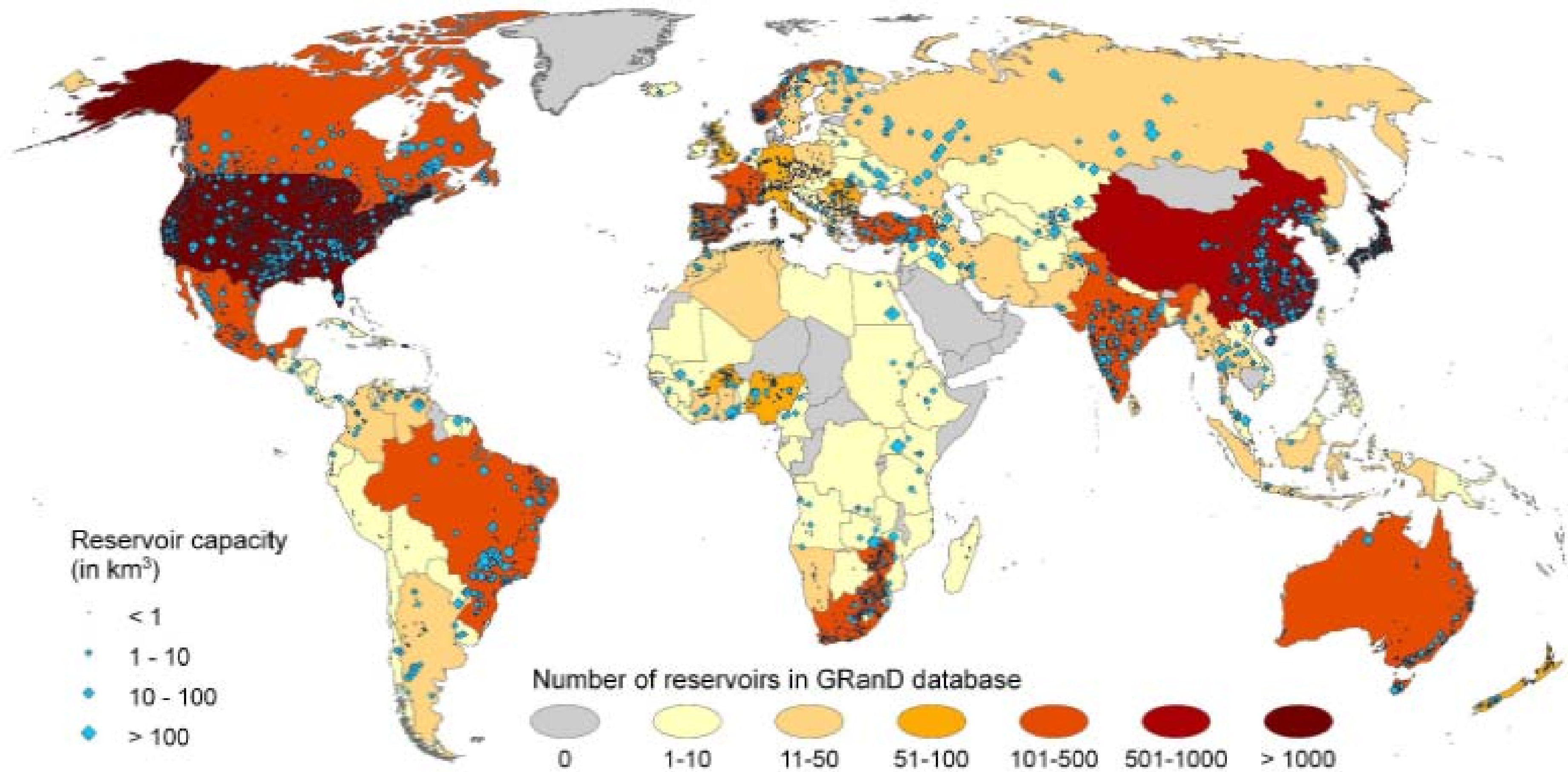


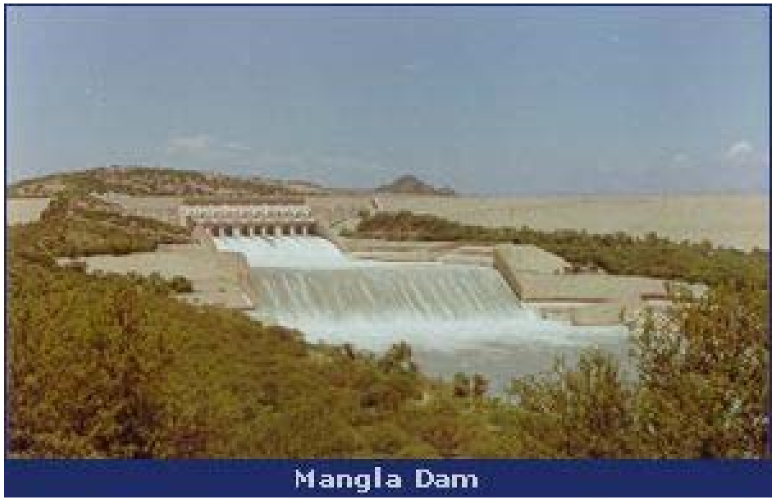
Figure 1: Global distribution (by country) of large reservoirs in GRanD database.

Ref. Global Reservoir and Dam Database, **Germany 2011**

Panoramic Views of Dams

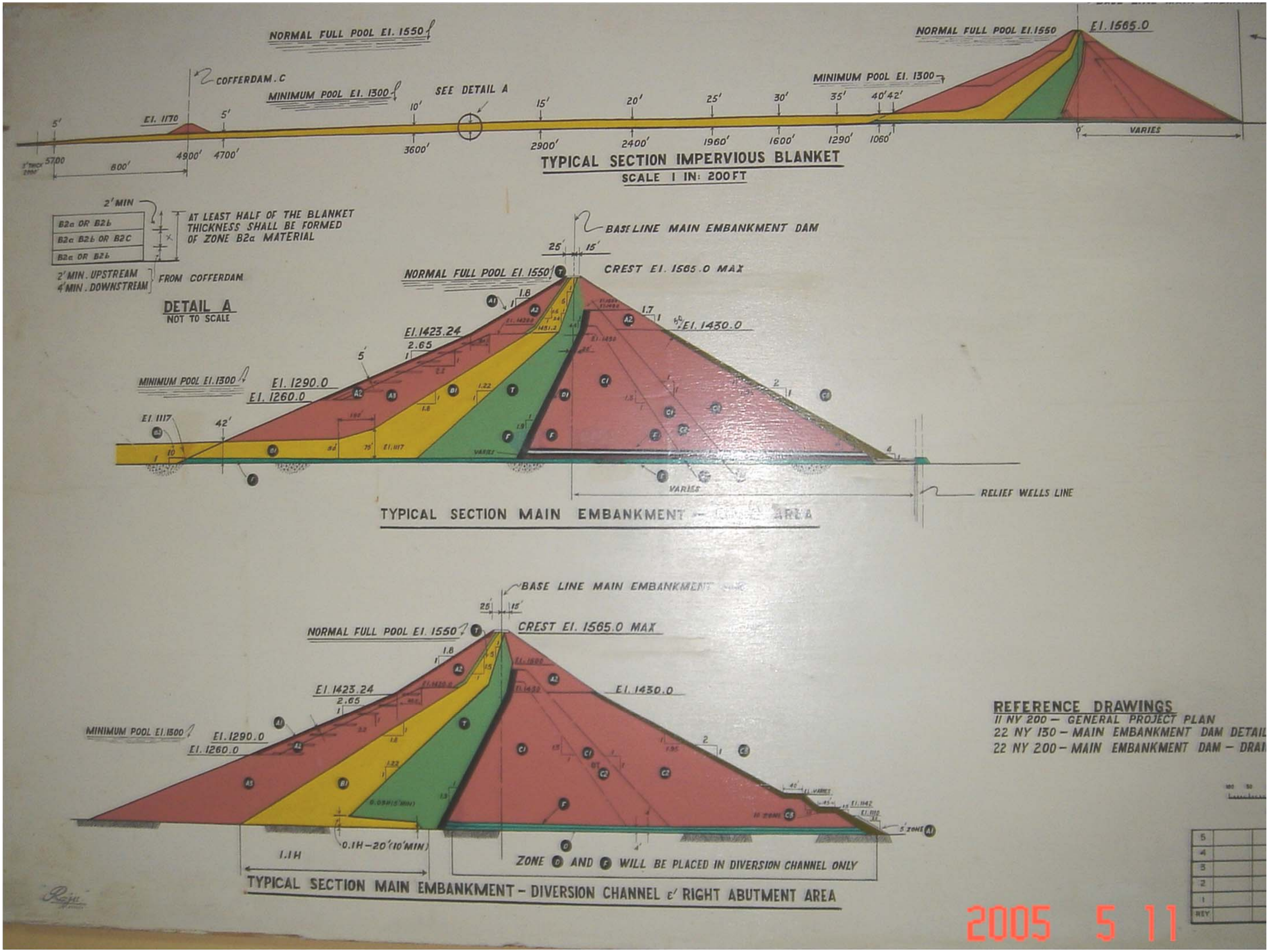
Tarbela Dam: Earth and Rockfill Dam

Warsak Dam: Gravity dam



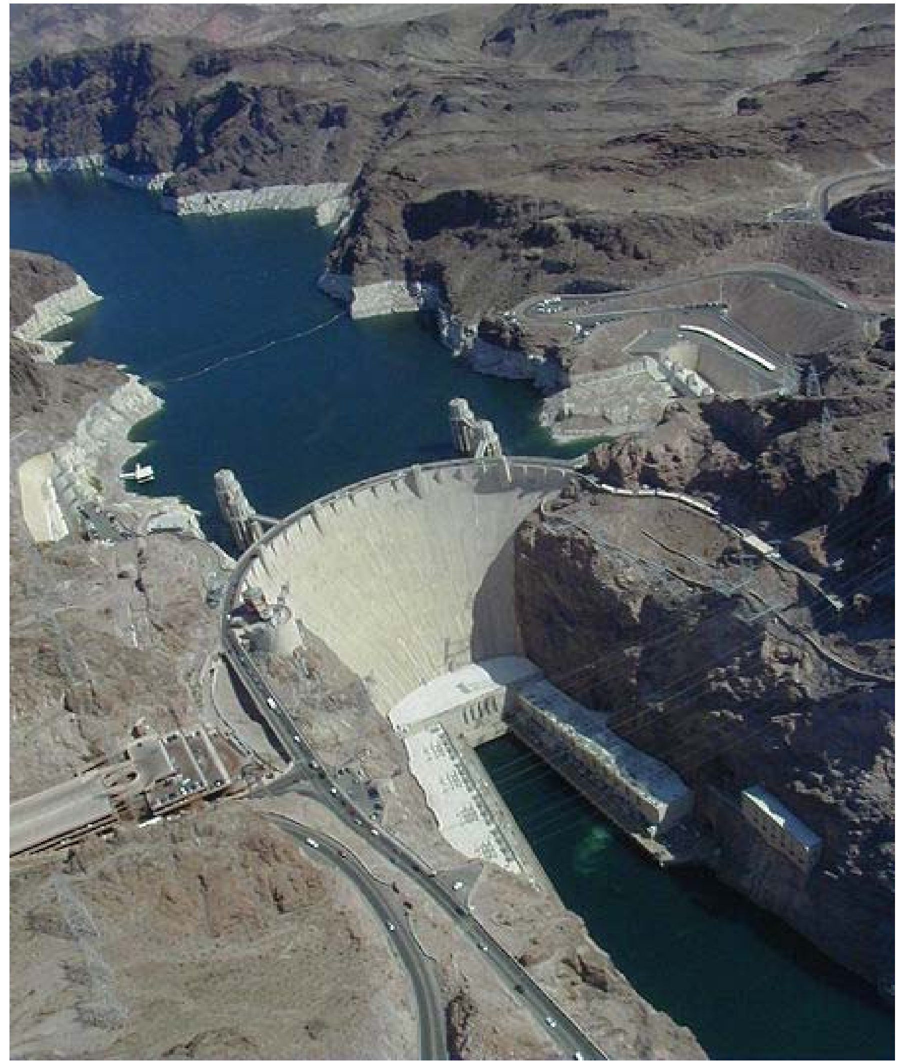
Mangla Dam: Earthfill


COFFERDAM C
INDUS RIVER
DIVERSION CHANNEL
INTAKE CHANNEL
BUTTRESS DAM
IMPERVIOUS BLANKET
IRRIGATION TUNNEL
SERVICE SPILLWAY
SERVICE SPILLWAY CHUTE
AUXILIARY SPILLWAY
AUXILIARY DAM 2
SPILLWAY OUTLET CHANNEL
MAIN EMBANKMENT DAM
SWITCHYARD
TAILRACE
POWER HOUSE
IRRIGATION OUTLET
POWER TUNNELS
ATION TUNNEL
N STRUCTURES
ATION TUNNEL
AKE
VER INTAKES
615,000
420,000
415,000
425,000
430,000
605,000
600,000


NORMAL FULL POOL El. 1550
COFFERDAM .C
MINIMUM POOL El. 1300
SEE DETAIL A
El. 1170
El. 1565.0
MINIMUM POOL El. 1300
VARIES
TYPICAL SECTION IMPERVIOUS BLANKET
SCALE 1 IN: 200 FT
2' MIN
B2a OR B2b
B2a B2b OR B2C
B2a OR B2b
AT LEAST HALF OF THE BLANKET THICKNESS SHALL BE FORMED OF ZONE B2a MATERIAL
2' MIN. UPSTREAM
4' MIN. DOWNSTREAM
FROM COFFERDAM
DETAIL A
NOT TO SCALE
BASE LINE MAIN EMBANKMENT DAM
NORMAL FULL POOL El. 1550
CREST El. 1565.0 MAX
El. 1423.24
El. 1430.0
MINIMUM POOL El. 1300
El. 1290.0
El. 1260.0
El. 1117
RELIEF WELLS LINE
TYPICAL SECTION MAIN EMBANKMENT
BASE LINE MAIN EMBANKMENT
NORMAL FULL POOL El. 1550
CREST El. 1565.0 MAX
El. 1423.24
El. 1430.0
MINIMUM POOL El. 1300
El. 1290.0
El. 1260.0
0.1H-20' (10' MIN)
1.1H
ZONE AND WILL BE PLACED IN DIVERSION CHANNEL ONLY
TYPICAL SECTION MAIN EMBANKMENT - DIVERSION CHANNEL & RIGHT ABUTMENT AREA
REFERENCE DRAWINGS
11 NY 200 - GENERAL PROJECT PLAN
22 NY 130 - MAIN EMBANKMENT DAM DETAIL
22 NY 200 - MAIN EMBANKMENT DAM - DRAI
REV
2005 5 11

Panoramic Views of Dams

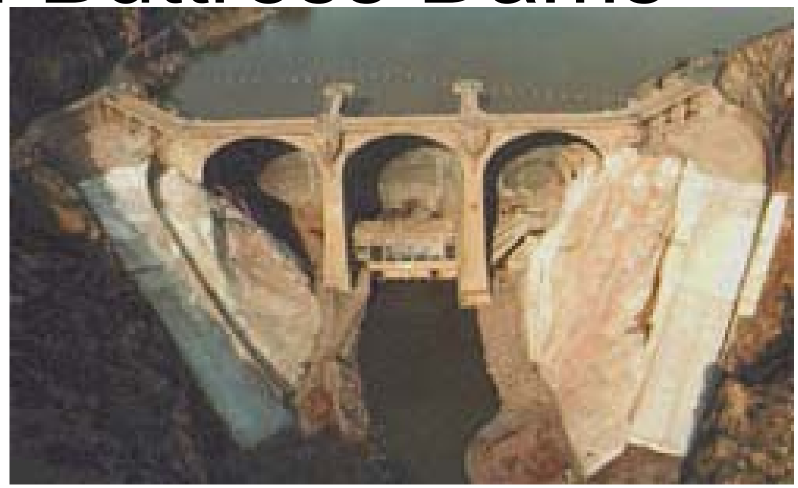
Gordon Dam: Arch Dam



Hoover Dam: Arch Dam

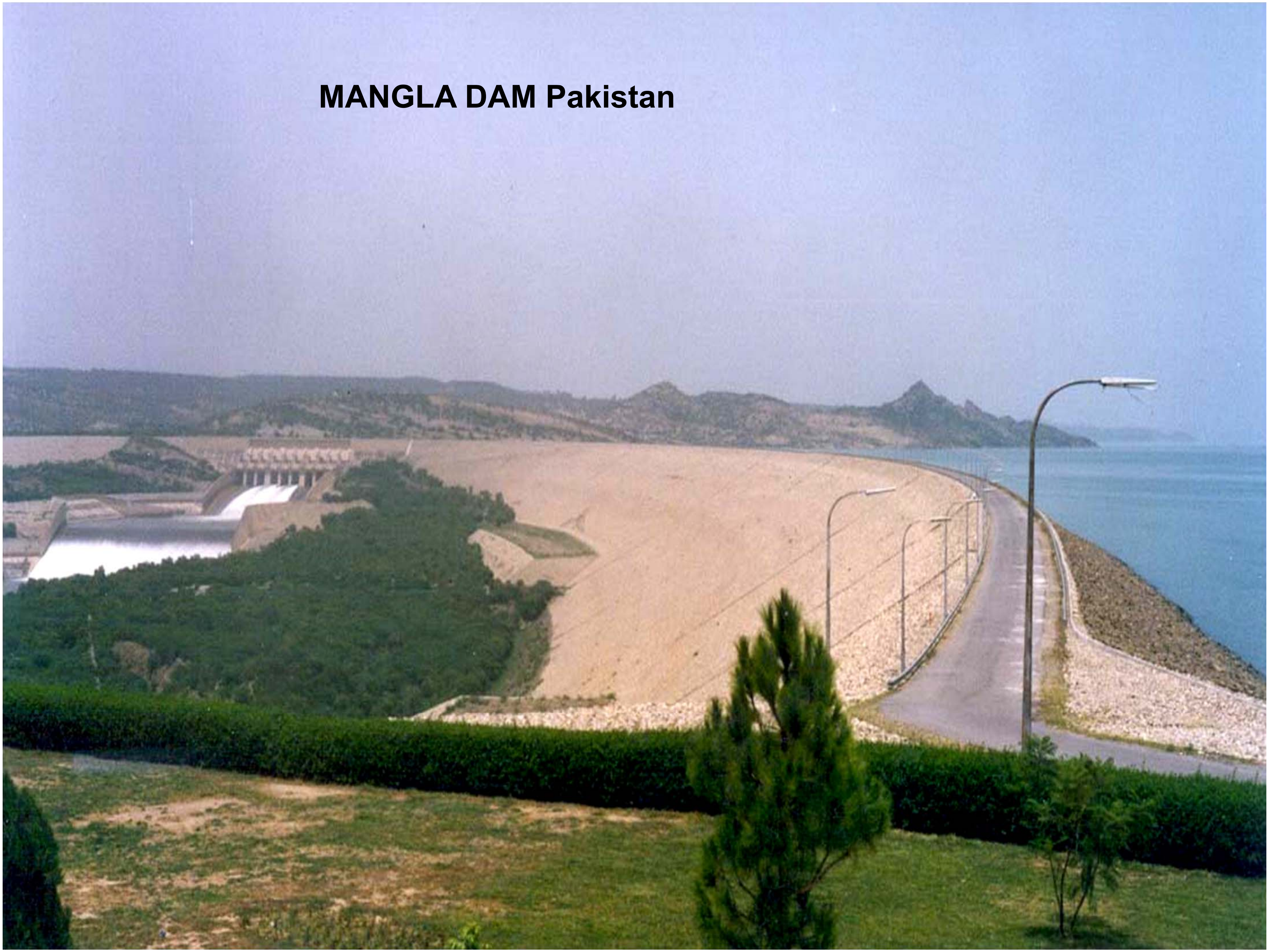
Panoramic Views of Buttress Dams

Hume Dam: Buttress dam



Coolidge Dam: Buttress dam

Le Prele Dam: Buttress dam


MANGLA DAM Pakistan

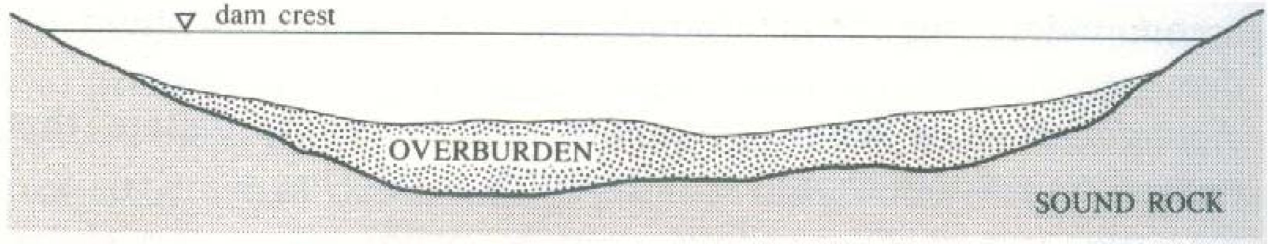

Bli Buray
Chornar
Mainstem Jhelum Pocket
Poonch Pocket
Kanshi Pocket
Khad Pocket
Main Mangla Pocket
Main Spillway
Main Dam
Jari Pocket
N
W
E
S
Image © 2006 TerraMetrics
©2005 Google
Pointer 33°08'25.88" N 73°38'35.69" E elev 1088 ft
Streaming |||||||||| 100%
Eye alt 14.97 mi

Selection of dam Type:

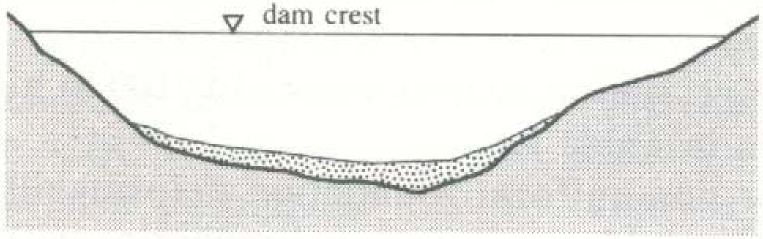
The choice of dam is decided upon by examining foundation conditions, load strains, temperature and pressure changes, chemical characteristics of ground water and possible seismic activity.

Following the important factors considered for the selection type of dams:

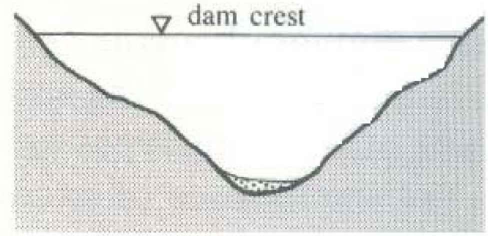
1) **Topography**
2) **Geology and nature of foundation**
   - Bearing capacity of the underlying soil
   - Foundation settlements
   - Permeability of the foundation soil
3) **Material availability**
4) **Spillway location**
5) **Safety considerations**
6) **Earthquake considerations**
7) **Purpose of dam and economics**
8) **Aesthetic view**



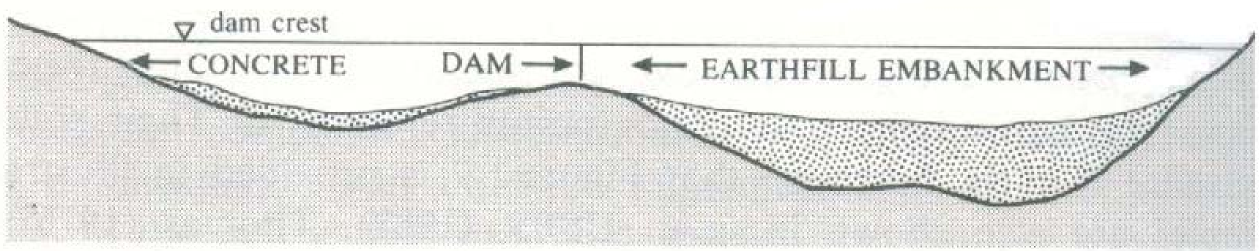
(a) Wide valley with deep overburden:
morainic or alluvial deposits over 5 – 10 m: favours earthfill embankment dam



(b) Valley with little overburden:
suitable for embankment, gravity, or buttress dam



(c) Narrow valley, steep sides, little overburden:
suitable for arch, cupola, or rockfill embankment dam



(d) Valley with irregular depth of overburden:
possible composite solution as shown; spillway on concrete dam

Illustrative examples of valley profile in relation to dam type.

Site selection of a dam:

Following are the important factors considered for the selection of site for a dam:

1) **Catchment characteristics**
2) **Length of dam**
3) **Height of dam**
4) **Foundation conditions**
5) **Availability of suitable Spillway location**
6) **Availability of suitable construction materials**
6) **Storage capacity**
7) **Construction and maintenance cost**
8) **Access to the site**
9) **Options for diversion of river during construction**

Site selection of a dam:

10) Compensation cost for property and land acquisition
11) Quality of water
12) Sediment transport
13) Environmental impact
    1) Resettlement
    2) U/S Impacts
    3) D/S Impacts
    4) Flood Agriculture
    5) Navigation
    6) Occupations
    7) Fisheries
    8) Delta

Merits & Demerits of Embankment Dams

- **Merits:**
- It may be equally suitable at sites in wide valleys and relatively steep-sided gorges.
- Its adaptability to a broad range of foundation conditions, ranging from competent rock to soft and compressible or relatively pervious soil foundations.
- The use of natural material, minimizing the need to import or transport large quantities of processed materials or cement to the site.
- Subject to satisfying essential design criteria, the embankment design is extremely flexible in it ability to accommodate different fill materials, e.g earth-fills and/or rock-fills if suitably zoned internally
- The construction process is highly mechanized and is effectively continuous.
- Unit cost of earth-fill and rock-fill i.e cost per m^3 is lower compared with the concrete dams.

Merits & Demerits of Embankment Dams

- **<u>Demerits:</u>**
- Inherent great susceptibility to damage or destruction by <u>overtopping</u>, with a consequent need to ensure adequate flood relief and separate spillways.
- <u>Vulnerable</u> to concealed leakage and internal erosion in dam or foundation.

Merits & Demerits of Concrete Dams

- **Merits:**
- Concrete gravity dams are suitable to the site topography of wide or narrow valleys alike, provided that a competent rock foundation is available at shallow depth.
- Concrete dams are not sensitive to overtopping even under extreme flood conditions.
- Can accommodate a crest spillway, if necessary over entire length, provided that steps are taken to control downstream erosion and possible undermining of the dam.
- Outlet pipe work, valves, and other ancillary works are readily and safely housed in chambers or galleries within the dam body.

Merits & Demerits of Concrete Dams

Demerits:

- Concrete dams are relatively demanding with respect to foundation conditions, requiring sound rock.
- Concrete dams require processed natural material of suitable quality and quantity for aggregate and the importation to site and storage of bulk cement and Aggregates.
- Traditional mass concrete construction is labor intensive and relatively discontinuous and require certain skills e.g. formwork, concreting etc.
- Complete unit cost for concrete dams, i.e. cost per m^3 is relatively higher compared with the embankment dams. This is seldom counter-balanced by the much lower volumes of concrete required in a dam of given height.

Dam selection: type characteristics.

Type	Notes and characteristics
Embankment	
earthfill	Suited to rock or soil foundation, can accept limited differential settlement given relatively wide and plastic core. Cut-off to sound material required. Low contact stresses. Requires range of materials, e.g. core, shoulders, internal filters etc.
rockfill	Rock foundation preferable; can accept variable quality and limited weathering. Cut-off to sound material required. Rockfill suitable for all-weather placing. Requires material for core, filters etc.
Concrete	
gravity	Suited to wide valleys, provided that excavation depth is less than 5–10 m. Limited weathering of rock acceptable. Check discontinuities in rock relative to sliding. Low contact stress. Requires imported cement.
buttress	As gravity dam, but higher contact stresses require sound rock. Concrete saved relative to gravity dam 40–60%.
arch and cupola	Suited to narrow gorges, subject to uniform sound rock of high strength and limited deformability in foundation and abutments. High abutment loading. Concrete saving relative to gravity dam is 50–85%.

Spillway Outlets and Ancillary Works

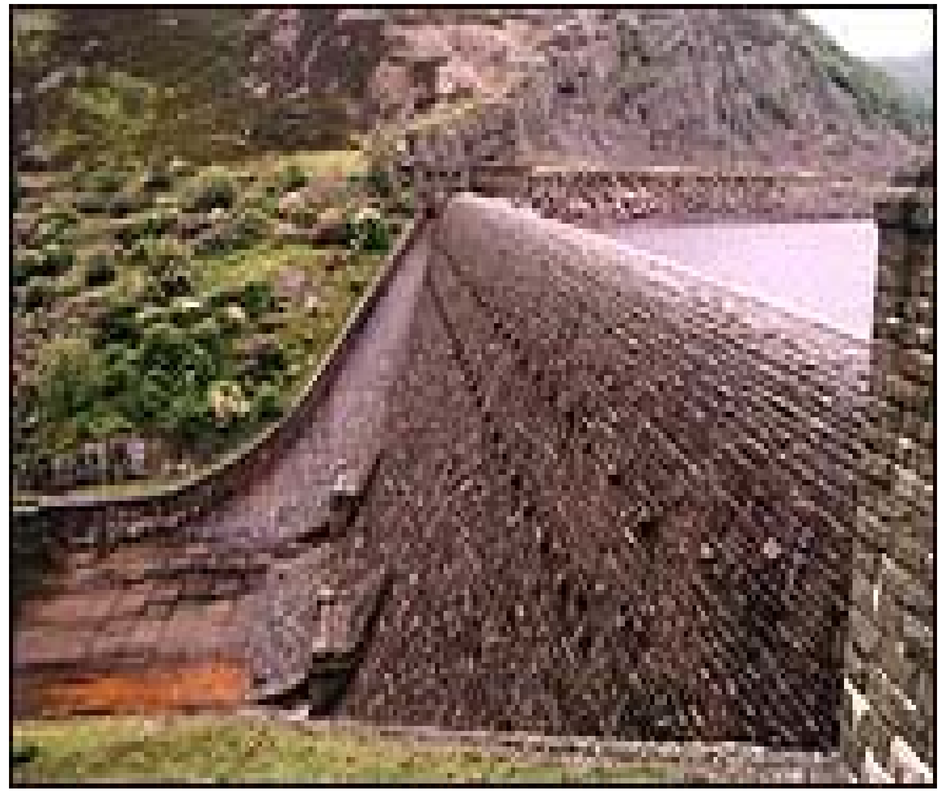
- Spillways:
  - The purpose of spillway is to pass flood water safely downstream when the reservoir is full.
  - It has two principle components
    - Spillway weir
    - Spillway Channel (Its purpose is to conduct flood flow safely downstream of dam)
  - The Spillways can be
    - Uncontrolled (Normally)
    - Controlled
  - The Spillway capacity must accommodate the maximum design flood.

- Note: Concrete dams normally incorporate an overfall or crest spillway, but embankments generally require a separate side-channel or shaft spillway structure located adjacent to the dam.

Other Outlets

- Tunnels, Penstocks and Pipe works with their associated control gates or valves.
- A bottom outlet facility, of reasonably high capacity, is provided in most of dams to provide additional measure of control and to allow emptying of reservoir.

OVER FLOW SPILLWAYS



SIDE CHANNEL SPILLWAYS

Side channel spillway at Hope Dam in Scotland

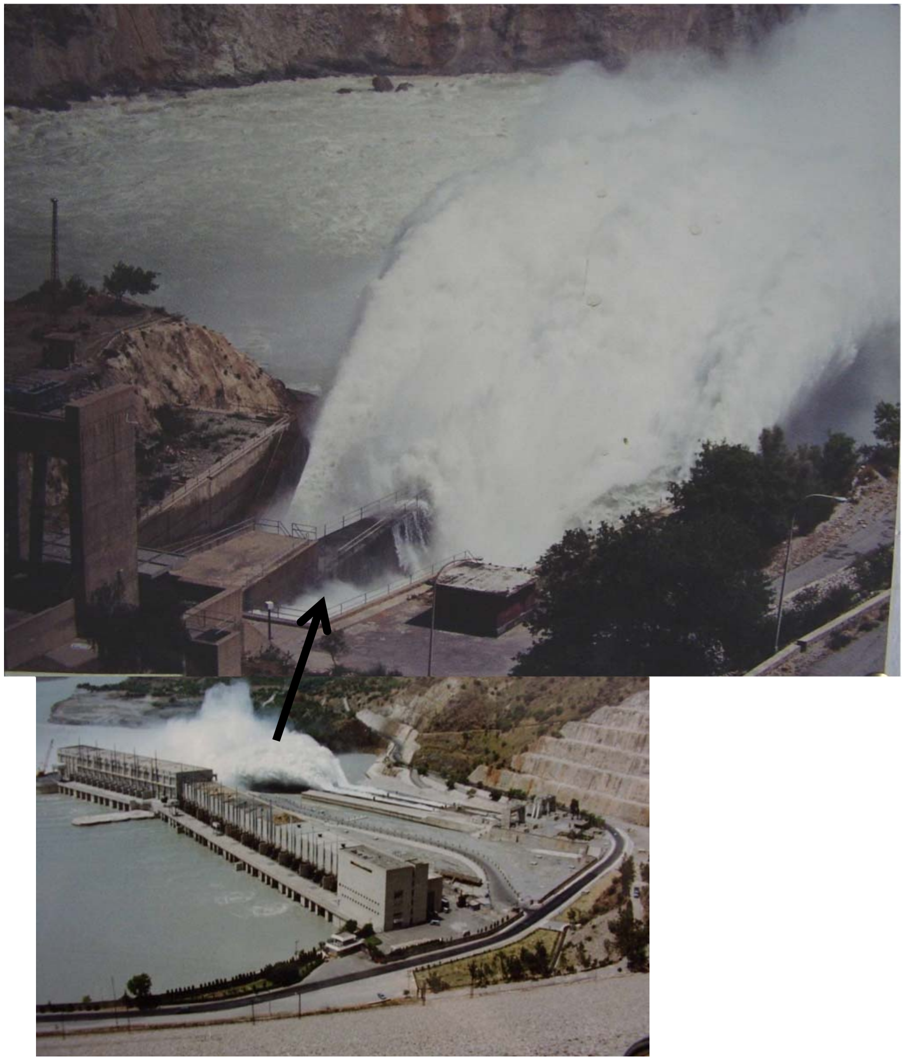
spillway chute from side channel to river

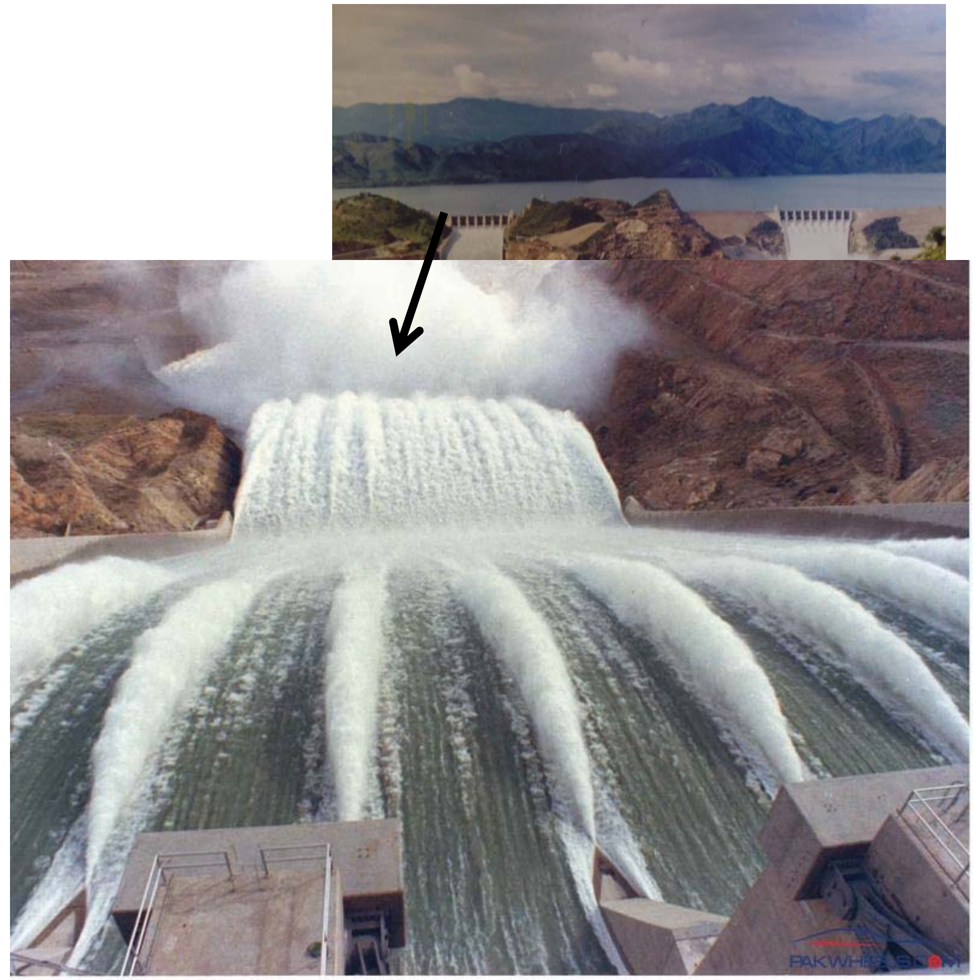
CHUTE SPILLWAYS

Auxiliary Spillway of Tarbela Dam

Service Spillway of Tarbela Dam

A few pictures of the Tarbela Dam Pakistan





Tarbela dam is one of the largest Earth & Rock filled dam in the World (Embankment volume =106 Million m^3)

Ancillary Works

- River Diversion:
  - Necessary to permit construction to proceed in dry condition.
  - An outlet may be adapted to this purpose during construction and subsequently employed as a discharge facility for the completed dam.
  - Alternate of such tunnel can be cofferdams.

- Cut-offs:
  - Used to control seepage around and under the flank of dams.
  - Embankment cutoffs are generally formed by
    - Wide trenches backfilled with rolled clay,
    - Grouting to greater depths.

Ancillary Works

Internal Drainage:

- Seepage is always present within the body of dam. Seepage flows and their resultant internal pressure must be directed and controlled.
- In embankment dams, seepage is intercepted by suitably located pervious zones leading to horizontal blanket drains or outlets
- In concrete dams vertical drains are formed inside the upstream face, and seepage is relieved into an internal gallery or outlet drain.
- In arch dams, seepage pressure in rock abutments are frequently drained by purpose built system of drainage ADITS.

Ancillary Works

- Internal Galleries and Shafts

- Galleries and shafts are provided as means of allowing internal inspection, particularly in concrete dams.

- These can be used to accommodate structural monitoring and surveillance purpose.

FORCES on DAMS

Forces on Dams

- **Primary Loads:** are identified as those of major importance to all dams irrespective of type, e.g. water and related seepage loads and self weight load.

- **Secondary Loads:** are discretionary and are of lesser magnitude (e.g. Sediment load) or alternatively are of major importance only to certain type of dams (e.g. thermal effects within concrete dams)

- **Exceptional Load:** are so designated on the basis of limited general applicability or having a low probability of occurrence. (e.g. tectonic effects, or the inertial loads associated with seismic activity)

Forces on Dams

- **Primary Loads:**

  (a): Water Load: Hydrostatic distribution of pressure with horizontal resultant force.

  (b): Self Weight load: Determined w.r.t. an appropriate unit weight for the material. For simple elastic analysis the resultant is considered to operate through the center of the section.

  (c): Seepage Loads: Equilibrium seepage pattern will establish within and under the dam, e.g. in pores and discontinuities, with resultant vertically loads identified as internal and external uplift respectively.

Forces on Dams

- **<u>Secondary Loads:</u>**

(a): Sediment load: Accumulated silt etc. generate a horizontal thrust, considered as an equivalent additional hydrostatic load with horizontal resultant.

(b): Hydrodynamic wave load: Transient load generated by wave action against the dam. (not normally significant)

(c): Ice Load: Ice thrust may be significant in more extreme climatic conditions.

(d): Thermal Load: (concrete dams), Internal, generate by difference associated with change in ambient temperatures and with cement hydration and cooling.

(e): Interactive effect: Internal, arising from relative stiffness and differential deformation of dam and foundation.

(f): Abutment hydrostatic load: internal seepage load in abutment rock mass(This is of particular concern to arch and cupola dams)

Forces on Dams

- **Exceptional Load:**

(a): Seismic Load: Horizontal and vertical inertia load are generated with respect to dam and the retained water by seismic disturbance.

(b): Tectonic Loads: Saturation, or disturbance following deep excavation in rock, may generate loading as result of slow tectonic movements

Combination of Loads

- A dam is designed for the most adverse combinations of loads as have reasonable probability of simultaneous occurrence.

- ***For construction conditions*** dam is completed, reservoir is empty, no tail water
  i. With earthquake forces
  ii. Without earthquake forces
- ***For normal operating conditions,*** reservoir full, normal weather tail water conditions, normal uplifts and silt load
  i. With earthquake forces
  ii. Without earthquake forces
- ***For flood discharge conditions,*** reservoir at max flood level, all spillway gates opened, tail water at flood levels normal uplifts and silt load

Safety Criteria

- Safety against Overturning.

$$FOS = \frac{\sum Stabilizing\ Moment}{\sum Overturning\ Moment}$$

Should be > 1.5

- Safety against Sliding

$$FOS = \frac{\sum (W - u)\tan\phi}{P}$$

Should be > 3

Should be > 1.2 if EQ is considered

- Safety against Crushing

$$P_{\max} = \frac{W}{B}\left(1 + \frac{6e}{B}\right) \qquad P_{\min} = \frac{W}{B}\left(1 - \frac{6e}{B}\right)$$

$$f = 25 - 30 Kg / cm^2$$

- Safety against Tension

Gravity Dams are not designed to take any tension load.

W= weight of dam

u= uplift force

Φ= coefficient of friction (sliding)

tanΦ= 0.65-0.75

P= Horizontal Force

f= Allowable stress in concrete

Principle and Shear stresses

- Principal Stress

$$\sigma_n = P_n \sec^2 \alpha$$

- Shear Stress

$$\tau = P_n \tan \alpha$$

Numerical

Numerical problem:

- **A concrete gravity dam has the following dimensions:**
  - Max water level = 305 m
  - Bed level of river = 225 m
  - Crest level = 309 m
  - D/s face slope starts at 300 m
  - C/L of drainage galleries at 8m d/s of u/s face
  - Uplift pressures:

    at Heal = 100 %

    at Toe = 0 %

    at drainage gallery = 50 %

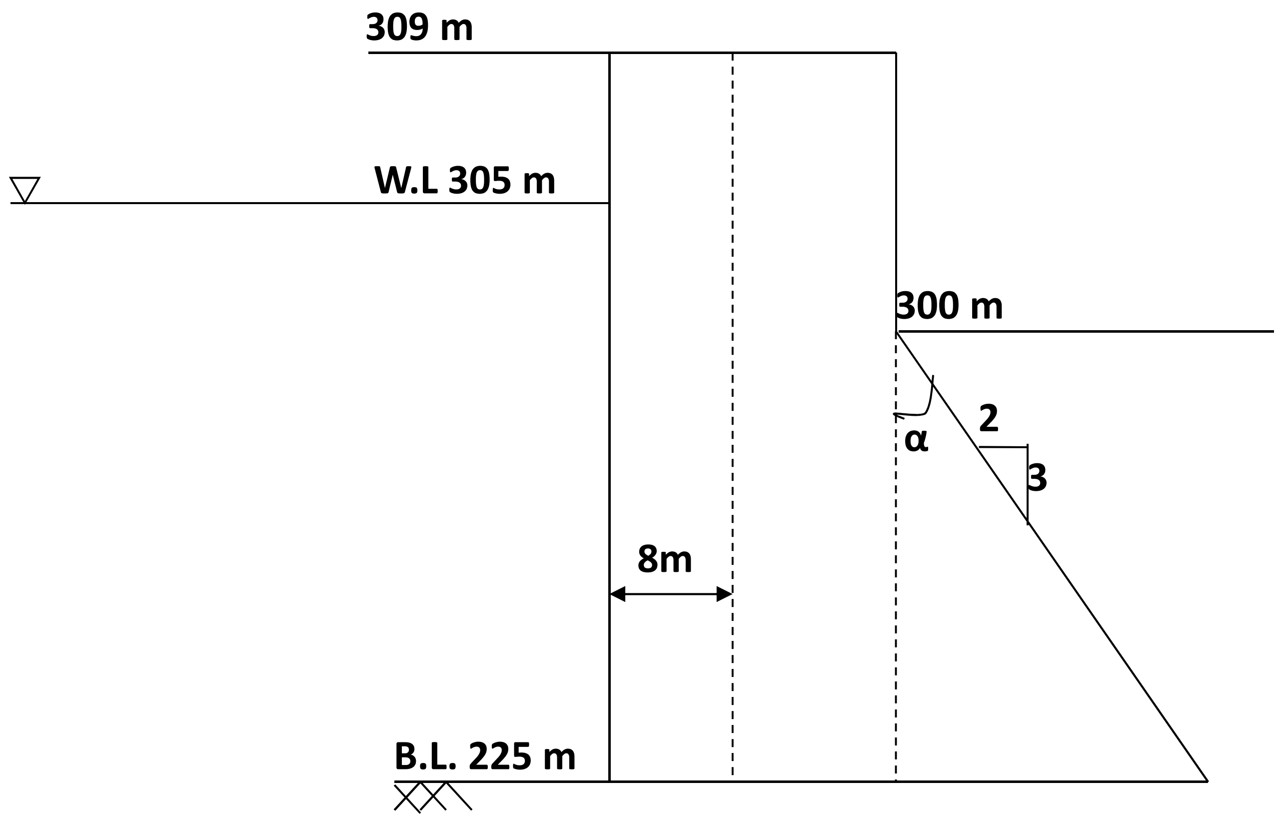
Numerical problem:

- Density of concrete = 2400 kg/m^3 (2.4 $mtons/m^3$)
- No tail water
- Consider self weight, hydrostatic pressure and uplift pressure

Calculate:

- Max. vertical stresses at heal and toe of the dam.
- Major principal stress at toe of dam and intensity of shear stress on horizontal plane near the toe.
- Check the stability of dam against overturning and sliding for the given conditions

Numerical problem:



Solution

Determine width of crest, Wc=?

$$Wc = \sqrt{\text{Height of Dam}}$$

$$Wc = \sqrt{309 - 225} = \sqrt{84}$$

$$= 9.16 \approx 12$$

Determine the weight of Dam

$$W1 = 12 \times 84 \times 2400 / 1000$$

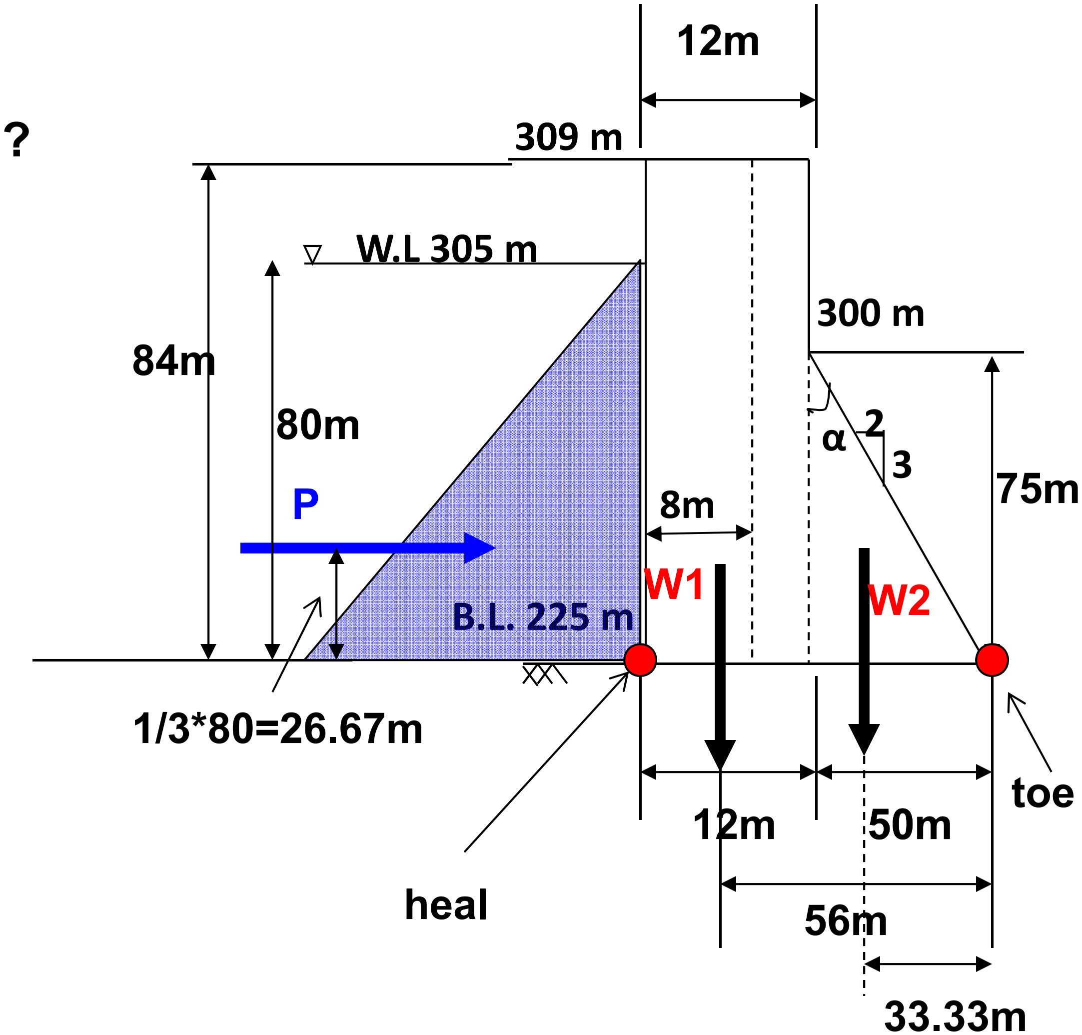
$$= 2419.2\ tons$$

Acting 56m from toe

$$W2 = \frac{1}{2} \times 75 \times 50 \times 2400 / 1000$$

$$= 4500\ tons$$

Acting 33.33m from toe



Determine the hydrostatic pressure

$$P = \gamma_w h^2 / 2$$

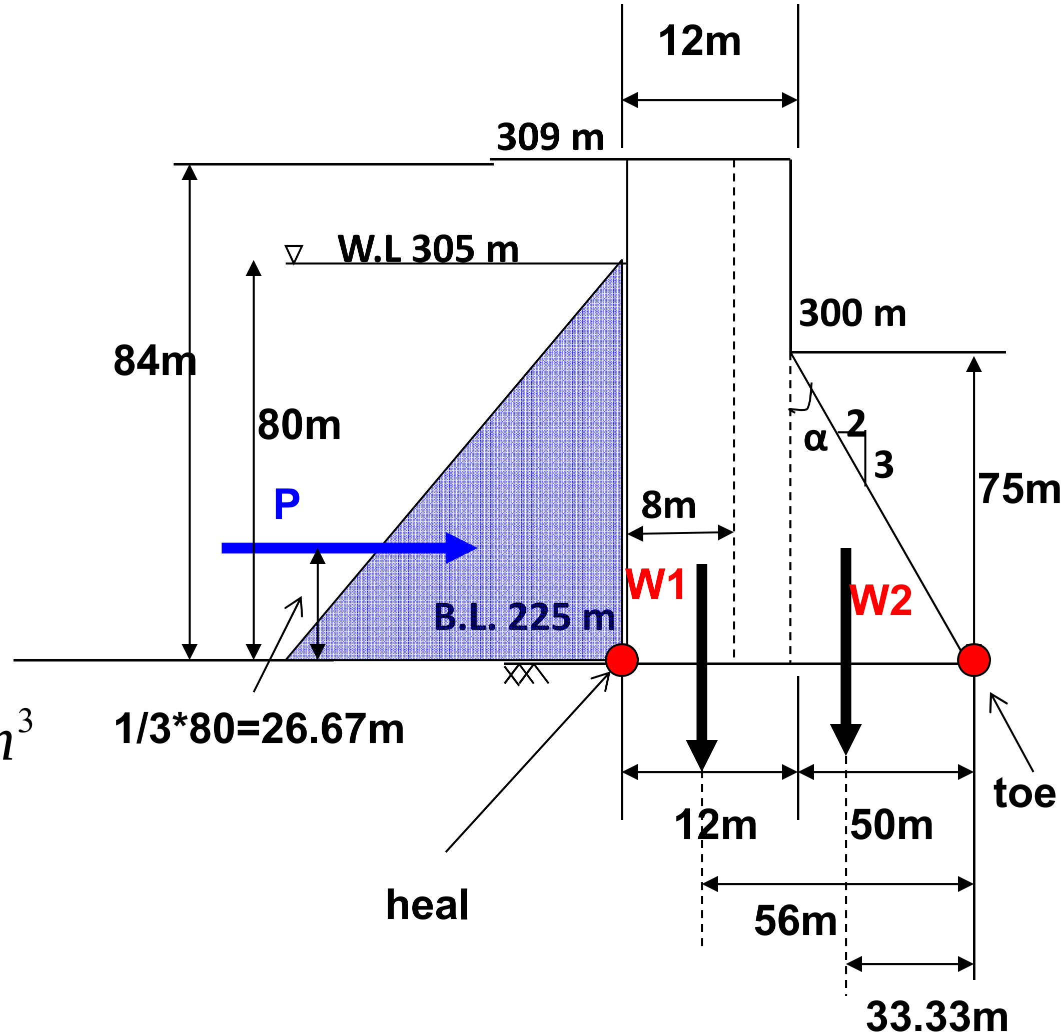
$$= \frac{1}{2} \times 1 \times (305 - 225)^2$$

$$= 3200\ tons$$

Acting 26.67m from BL in horizontal direction

where

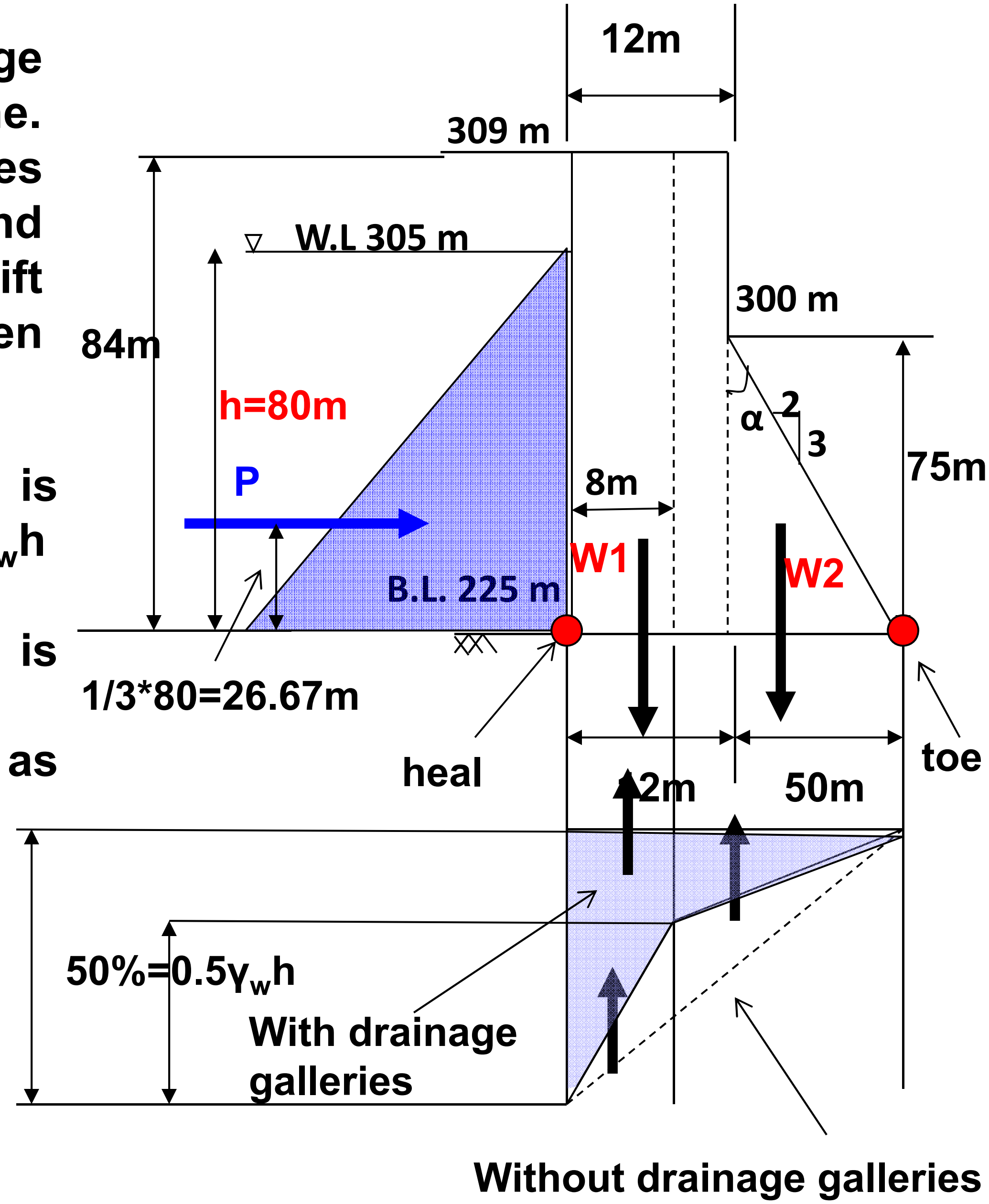
$$\gamma_w = 1000kg/m^3 = 1\ mton/m^3$$



Determine the uplift pressure

The uplift pressure without drainage galleries is represented by dash line. However, the drainage galleries control the pressure distribution and in present problem, the uplift pressure at drainage gallery is given as 50% of total uplift pressure

The uplift pressure at the heal is taken equal to heal of water. i.e., $\gamma_w h$
$\gamma_w x80$
While at the drainage gallery it is 50% of $\gamma_w x80$. i.e., $\gamma_w x40$
And at the toe it becomes zero as there is no tail water.



where

100%=$\gamma_w h$

h=80m

γ_w=1000kg/m3=1mton/m3

Determine the uplift forces

$$U1 = 0.5\gamma_w h \times 8$$

$$= 0.5 \times 1 \times 80 \times 8 = 320\ ton$$

Acting 58m from toe

$$U2 = 0.5(0.5\gamma_w h) \times 8$$

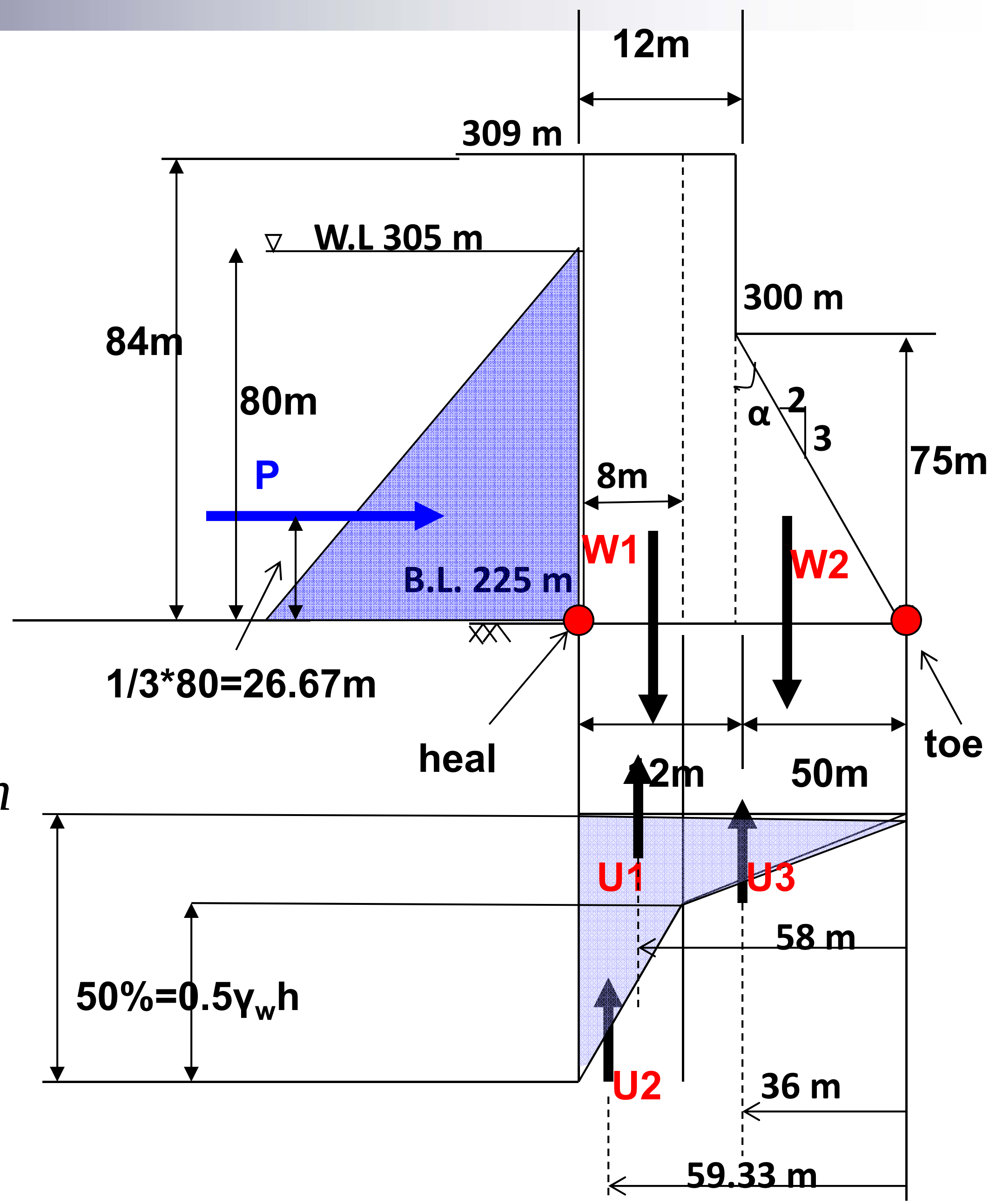
$$= 0.5(0.5 \times 1 \times 80) \times 8 = 160\ ton$$

Acting 59.33m from toe

$$U3 = 0.5(0.5\gamma_w h) \times (50 + 4)$$

$$= 0.5(0.5 \times 1 \times 80) \times 54 = 1080\ ton$$

Acting 36m from toe



Net uplift forces

$$U = U1 + U2 + U3$$

$$= 320 + 160 + 1080 = 1560\ ton$$

Determine the eccentricity and position of resultant

$$e=\frac{B}{2}-\bar{x},\ \ where,\ \ \bar{x}=\frac{\sum M}{\sum V}$$

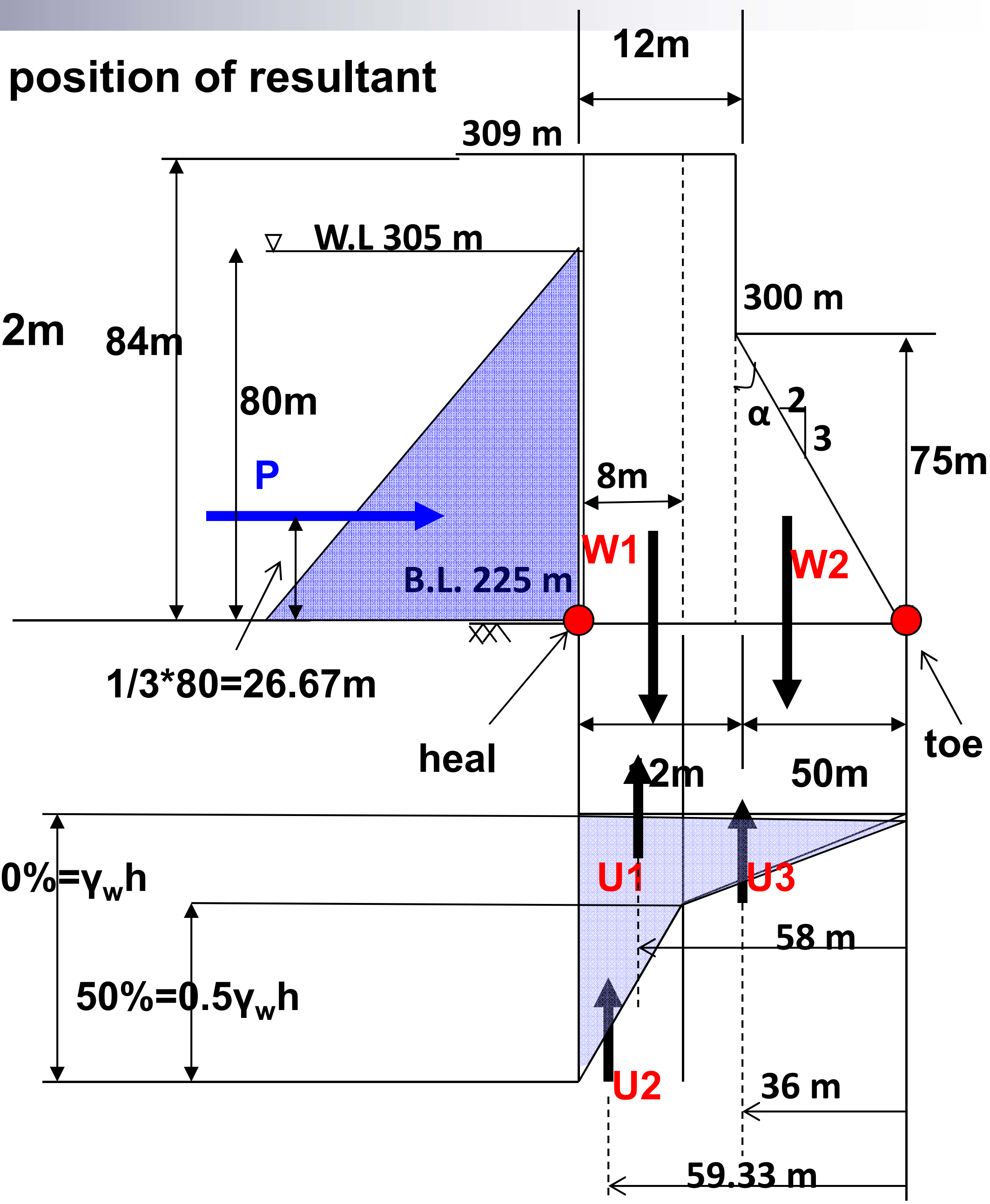
B is the based width of dam=62m

$$\sum V = \text{Total vertical forces}$$
$$=W1+W2-U$$
$$=4500+2419.2-1560$$
$$=5359.2\,ton$$

$$\sum M = \text{Total moment at toe}$$
$$=W1\times 56+W2\times 33.33$$
$$-U1\times 58-U2\times 59.33-U3\times 36$$
$$-P\times 26.67$$
$$=133183.4\ ton-m$$

position of resultant

$$\bar{x}=\frac{133183.4}{5359.2}=24.85m$$



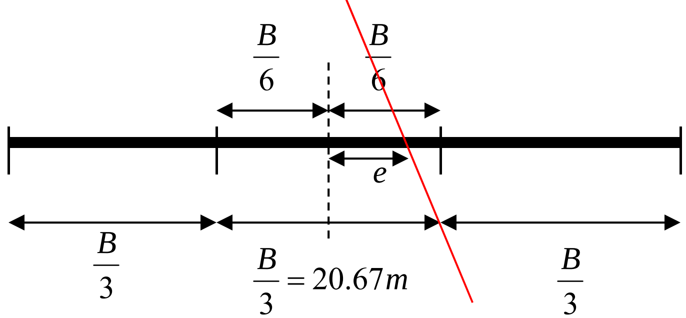
Determine the eccentricity and position of resultant

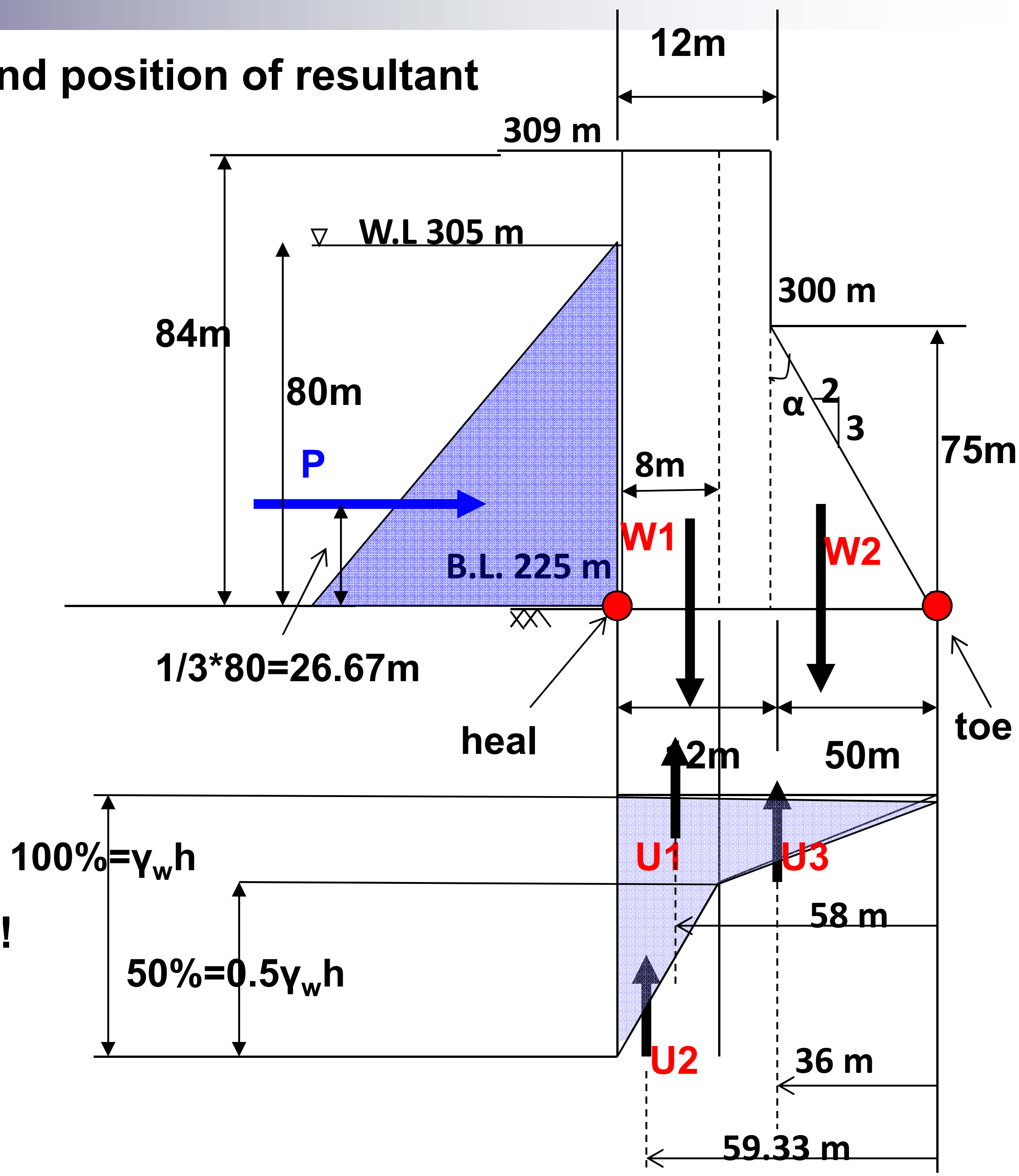
$$e = \frac{B}{2} - \bar{x}, \ \ where, \ \ \bar{x} = \frac{\sum M}{\sum V}$$

$$\bar{x} = \frac{133183.4}{5359.2} = 24.85m$$

$$e = \frac{B}{2} - \bar{x} = \frac{62}{2} - 24.85$$

$$= 6.15m \qquad e < B/6$$





If $e > B/6$ tension will develop !

Dam is unsafe again tension.
Size of dam can be increased to enhance stability

Note: The resultant must pass through the middle third

Determine the stress at toe and heal of dam

Normal shear stress at toe

$$P_{max} = \frac{\sum V}{B}\left(1+\frac{6e}{B}\right)$$

$$= \frac{5359.2}{62}\left(1+\frac{6*6.15}{62}\right)$$

$$= 137.89 ton/m^2$$

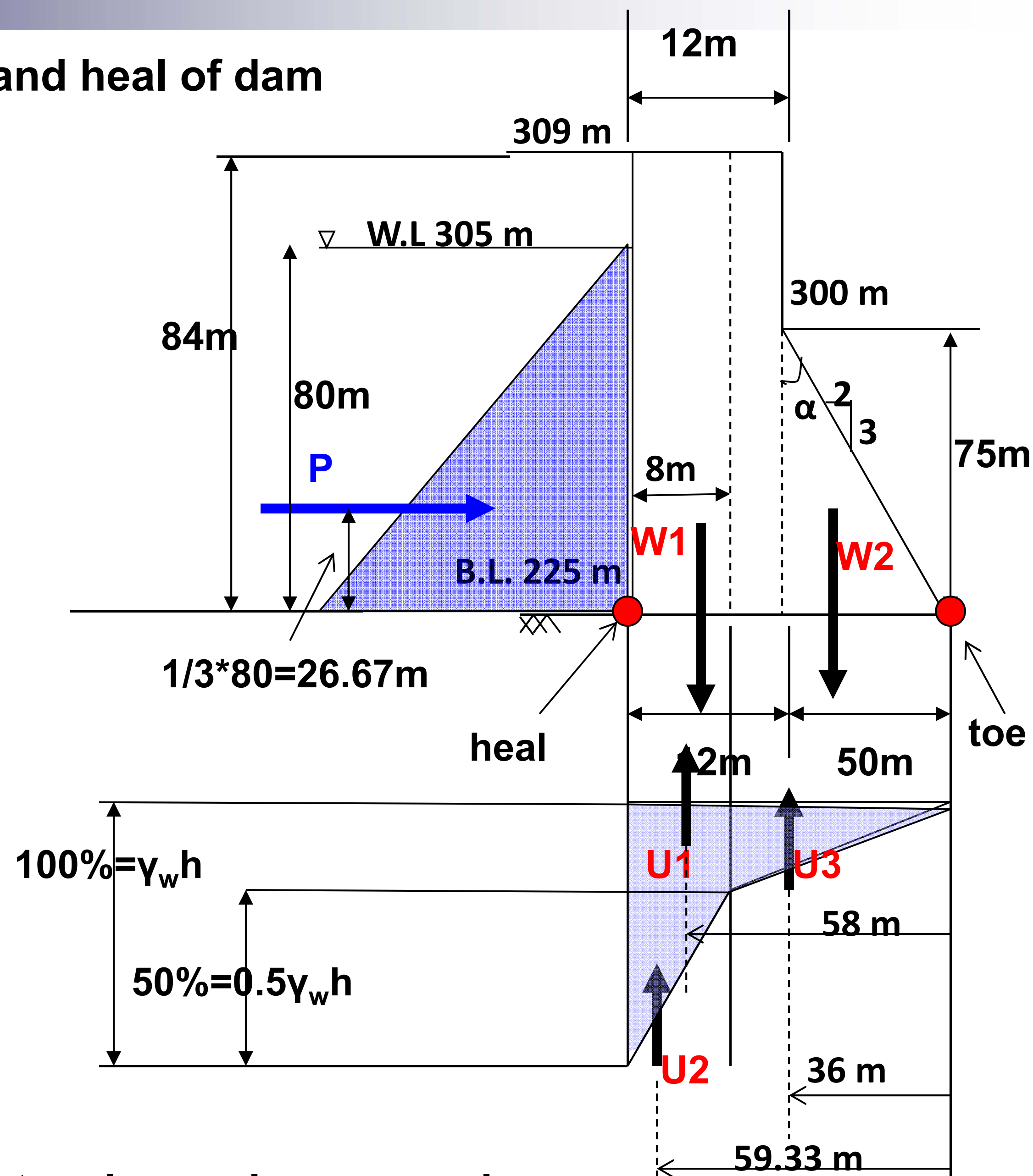
Normal shear stress at heal

$$P_{min} = \frac{\sum V}{B}\left(1-\frac{6e}{B}\right)$$

$$= \frac{5359.2}{62}\left(1-\frac{6*6.15}{62}\right)$$

$$= 34.99 ton/m^2$$

Allowable stress=25 kg/cm²
=250 ton/m²



Therefore, dam is safe against tension and compression

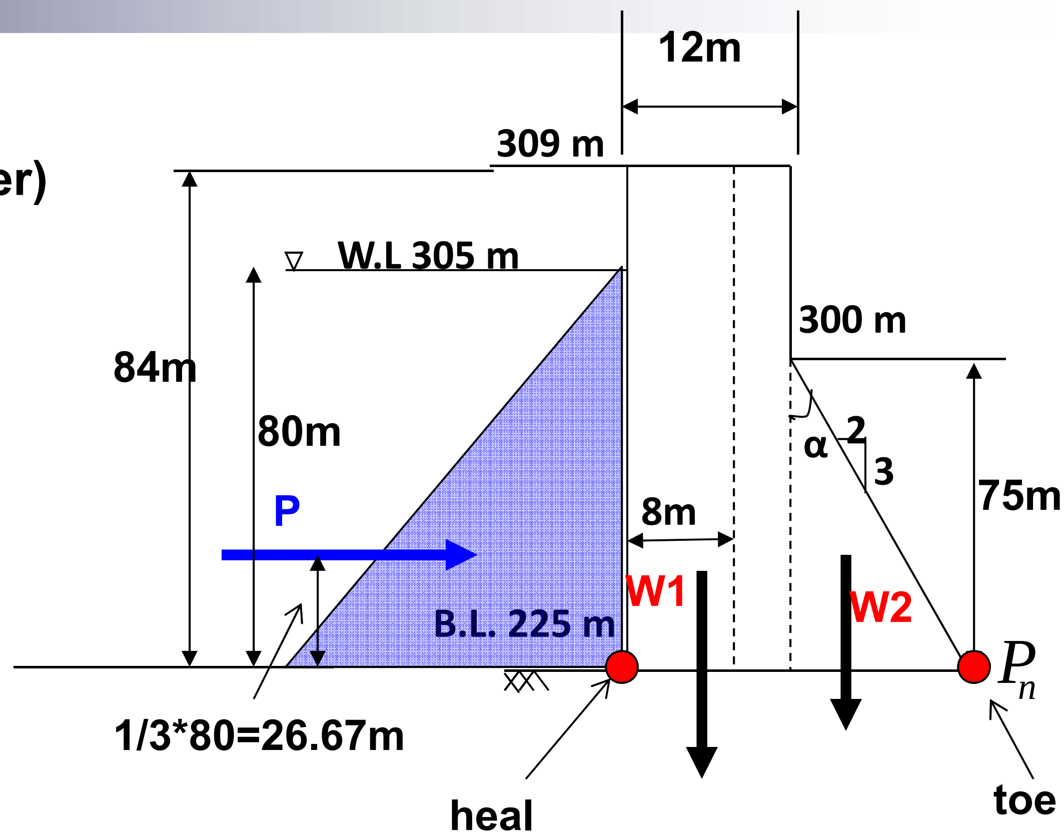
Determine the Principal stress

Principal Stress (without tail water)

$$= P_n \sec^2 \alpha$$

where

$P_n =$ **Normal stress at toe**



Principal Stress

$$= P_n \sec^2 \alpha$$

$$= 137.89 \times 1.44 = 199.16 ton/m^2$$

Intensity of shear stress at toe (without tail water)

$$= P_n \tan \alpha$$

$$= 137.89 \times (2/3) \quad = 91.92 ton/m^2$$

Note

$$\sec^2 \alpha = 1 + \tan^2 \alpha$$

Determine Stability against sliding of dam

$$FOS = \frac{(W-U)\tan\theta}{P} = \frac{\mu\sum V}{\sum H}$$

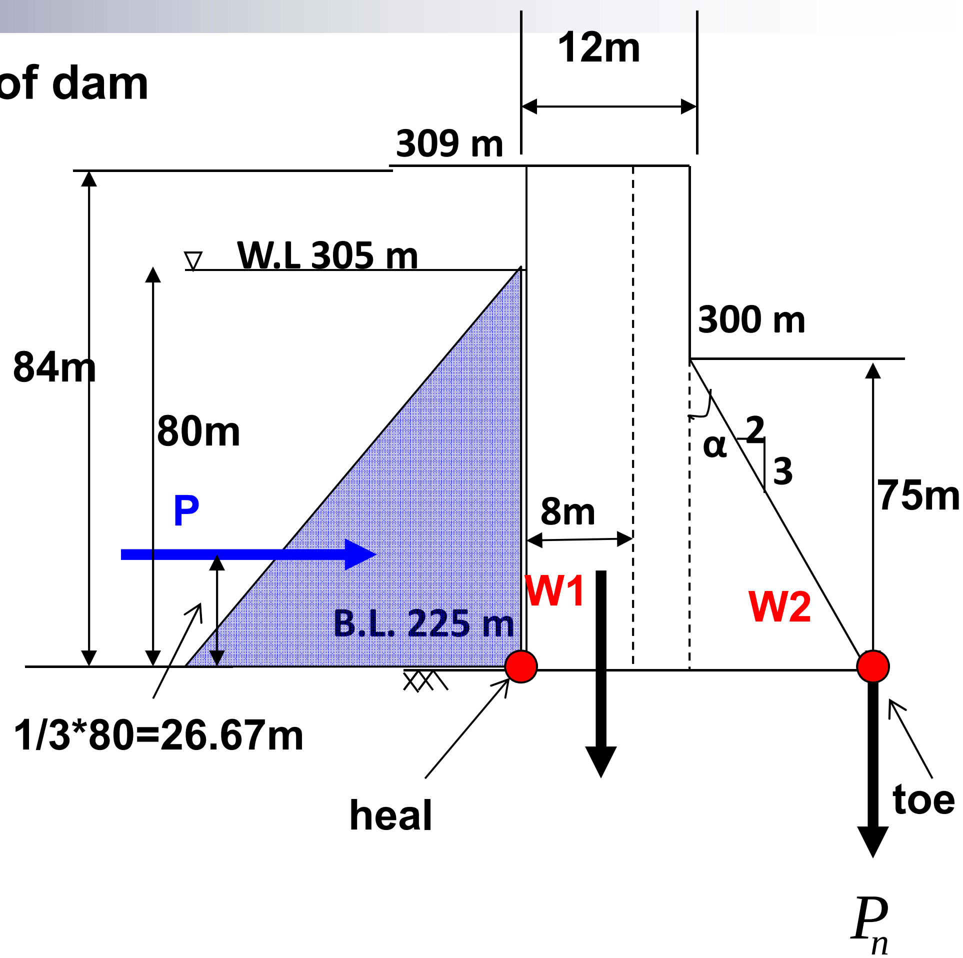
$$where, \mu = \tan\theta \approx 0.8$$

$$FOS = 0.8 \times 5359.2 / 3200$$

$$FOS = 1.3 \ > 1$$

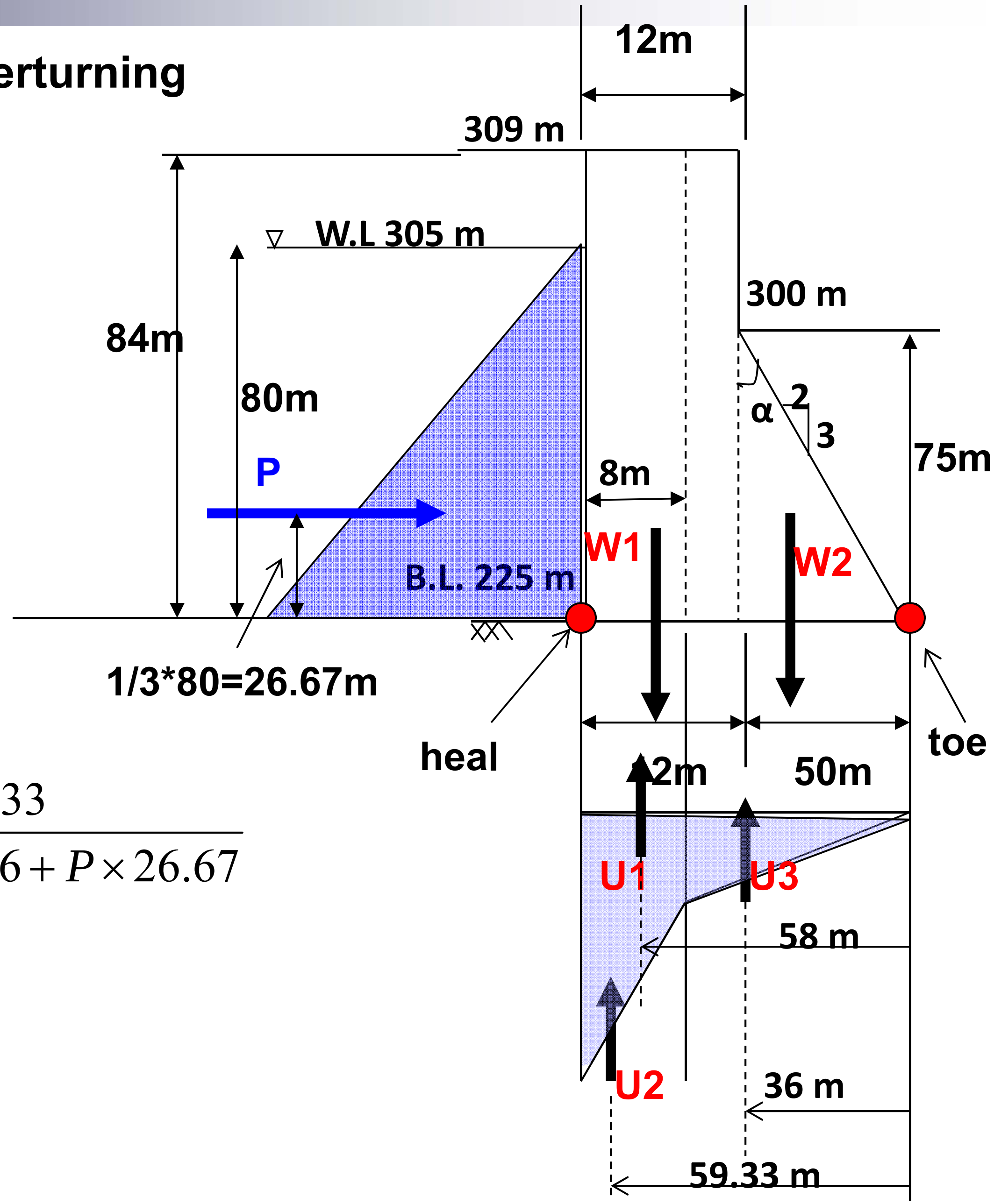
It ranges from 1.0~3

Dam is safe against sliding



Determine Stability against Overturning

$$FOS = \frac{Stabilizing\ moment}{Overturning\ moment}$$



Taking moment at toe of dam

$$FOS = \frac{W1 \times 56 + W2 \times 33.33}{U1 \times 58 + U2 \times 59.33 + U3 \times 36 + P \times 26.67}$$

$$FOS = 1.87 \quad > 1.5$$

It ranges from 1.5~2.5

Dam is safe against moment

Problem:

- **A concrete gravity dam has the following dimensions:**
  - Max water level = 915 m
  - Bed level of river = 825 m
  - Crest level = 920 m
  - D/s face slope starts at 908 m
  - C/L of drainage galleries at 9m d/s of u/s face
  - Uplift pressures:

    at Heal = 100 %

    at Toe = 0 %

    at drainage gallery = 40 %

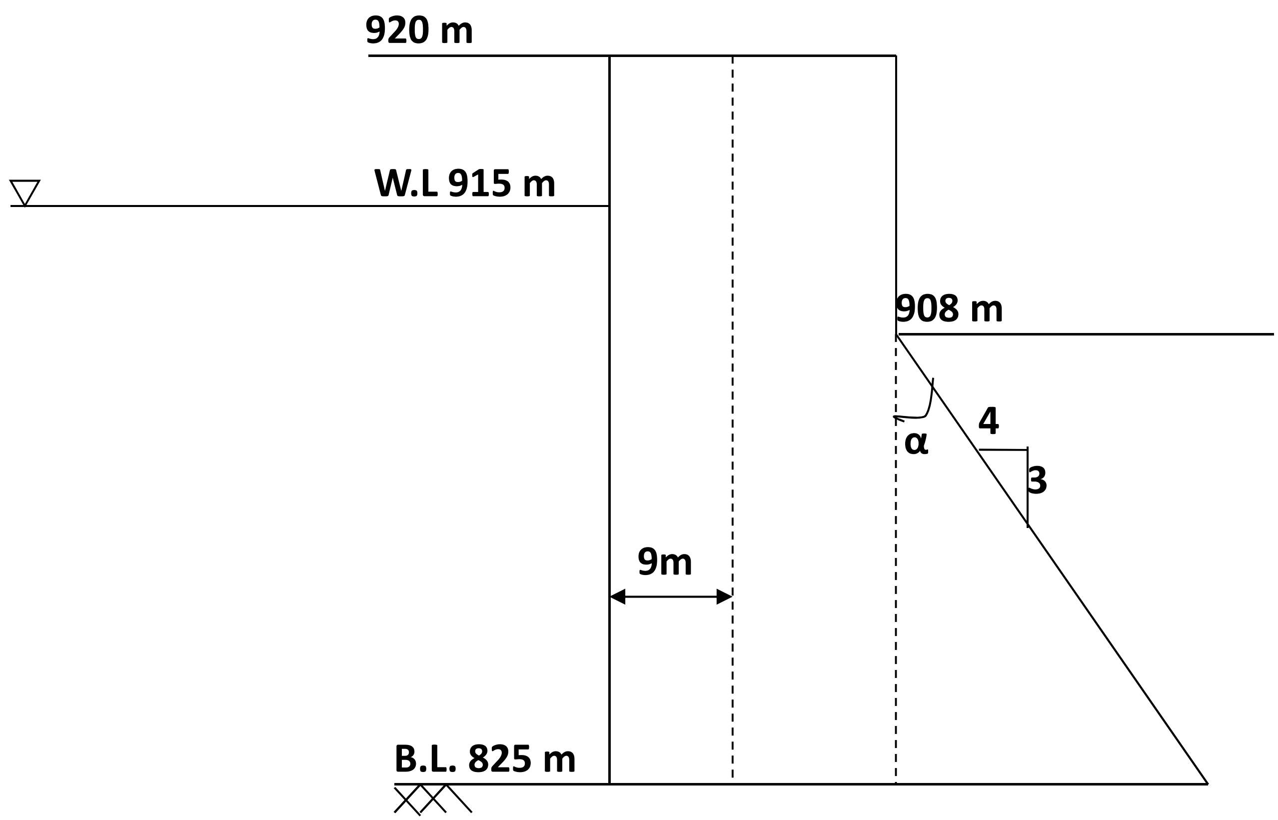
Numerical problem:

- Density of concrete = 2350 kg/m^3 ($mtons/m^3$)
- No tail water
- Consider self weight, hydrostatic pressure and uplift pressure

Calculate:

- Max. vertical stresses at heal and toe of the dam.
- Major principal stress at toe of dam and intensity of shear stress on horizontal plane near the toe.
- Check the stability of dam for the given conditions

Numerical problem:



Reservoir Regulation

What is a Reservoir?

- It is an storage developed due to construction of dam.

Tarbela Dam

JungHua Dam (Taiwan)

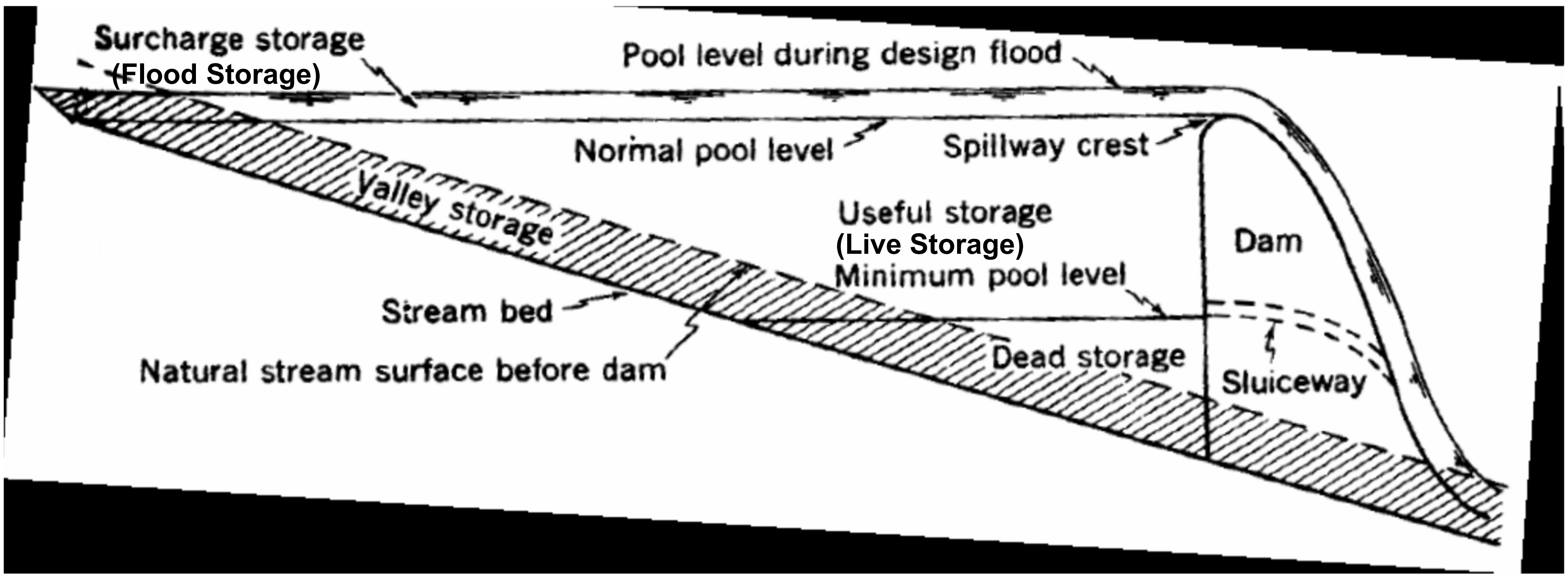
Classification of Reservoirs?

- **Storage Reservoirs:** Storage reservoirs are also called conservation reservoirs because they are used to conserve water. Storage reservoirs are constructed to store the water in the rainy season and to release it later when the river flow is low
- **Flood Control Reservoirs:** A flood control reservoir is constructed for the purpose of flood control. It protects the areas lying on its downstream side from the damages due to flood.
- **Retarding Reservoirs:** A retarding reservoir is provided with spillways and sluiceways which are ungated. The retarding reservoir stores a portion of the flood when the flood is rising and releases it later when the flood is receding.

Classification of Reservoirs?

- **Detention Reservoirs :** A detention reservoir stores excess water during floods and releases it after the flood. It is similar to a storage reservoir but is provided with large gated spillways and sluiceways to permit flexibility of operation.
- **Distribution Reservoirs:** A distribution reservoir is a small storage reservoir to tie over the peak demand of water for municipal water supply or irrigation. The distribution reservoir is helpful in permitting the pumps to work at a uniform rate. It stores water during the period of lean demand and supplies the same during the period of high demand
- **Multipurpose Reservoirs:** These are constructed for more than single purpose
- **Balancing Reservoirs:** A balancing reservoir is a small reservoir constructed d/s of the main reservoir for holding water released from the main reservoir.

Basic Terms and Definitions



Basic Terms and Definitions

- **Full reservoir level (FRL):** The full reservoir level (FRL) is the highest water level to which the water surface will rise during normal operating conditions.
- **Maximum water level (MWL):** The maximum water level is the maximum level to which the water surface will rise when the design flood passes over the spillway.
- **Minimum pool level:** The minimum pool level is the lowest level up to which the water is withdrawn from the reservoir under ordinary conditions.
- **Dead storage:** The volume of water held below the minimum pool level is called the dead storage. It is provided to cater for the sediment deposition by the impounding sediment laid in water. Normally it is equivalent to volume of sediment expected to be deposited in the reservoir during the design life reservoir.

Basic Terms and Definitions

- **Live/useful storage:** The volume of water stored between the full reservoir level (FRL) and the minimum pool level is called the useful storage. It assures the supply of water for specific period to meet the demand.

- **Flood/Surcharge storage:** is storage contained between maximum reservoir level and full reservoir levels. It varies with spillway capacity of dam for given design flood.

- **Bank storage:** is developed in the voids of soil cover in the reservoir area and becomes available as seepage of water when water levels drops down. It increases the reservoir capacity over and above that given by elevation storage curves.

- **Valley storage:** The volume of water held by the natural river channel in its valley up to the top of its banks before the construction of a reservoir is called the valley storage. The valley storage depends upon the cross section of the river.

Basic Terms and Definitions

- **Yield from a reservoir:** Yield is the volume of water which can be withdrawn from a reservoir in a specified period of time.
- **Safe yield (Firm yield):** Safe yield is the maximum quantity of water which can be supplied from a reservoir in a specified period of time during a critical dry year
- **Secondary yield:** is the quantity of water which is available during the period of high flow in the rivers when the yield is more than the safe yield.
- **Average yield:** The average yield is the arithmetic average of the firm yield and the secondary yield over a long period of time.
- **Design yield:** The design yield is the yield adopted in the design of a reservoir. The design yield is usually fixed after considering the urgency of the water needs and the amount of risk involved.

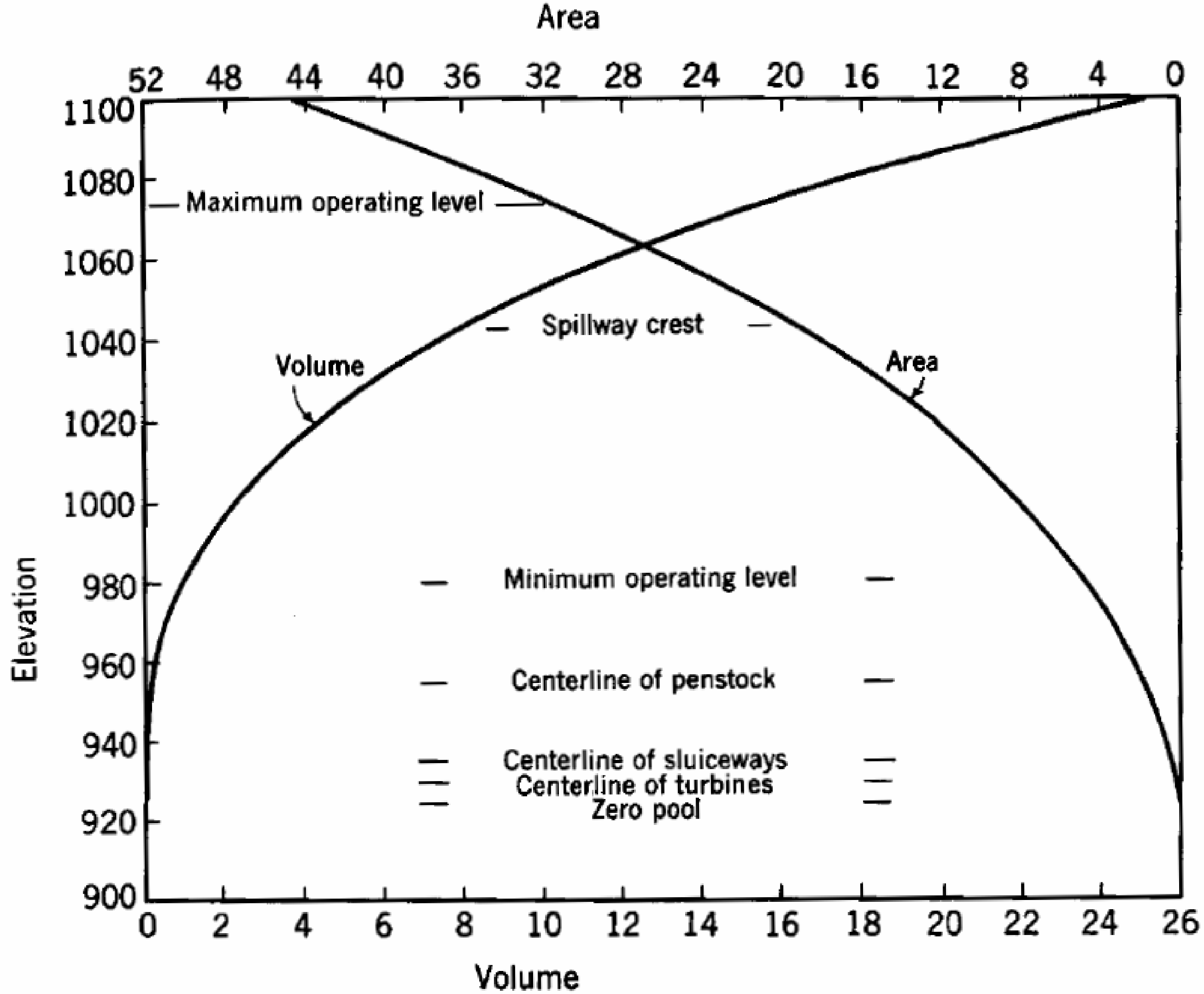
Storage Capacity of Reservoirs

- Whatever may be the use of a reservoir, its most important function is to store water during floods and to release it later.
- The storage capacity of a reservoir is, therefore, its most important characteristics.
- The available storage capacity of a reservoir depends upon the topography of the site and the height of dam.
- To determine the available storage capacity of a reservoir up to a certain level of water, engineering surveys are usually conducted.
- The storage capacity and the water spread area at different elevations can be determined from the contour map

Storage Capacity of Reservoirs

- **(a) Area-Elevation Curve:** From the contour plan, the water spread area of the reservoir at any elevation is determined by measuring the area enclosed by the corresponding contour. Generally, a planimeter is used for measuring the area. An elevation-area curve is then drawn between the surface area as abscissa and the elevation as ordinate.
- **(b) Elevation-Capacity Curve:** The storage capacity of the reservoir at any elevation is determined from the water spread area at various elevations. An elevation-storage volume is plotted between the storage volume as abscissa and the elevation as ordinate. Generally, the volume is calculated in Mm3 or M ham. The following formulae are commonly used to determine the storage Capacity.

Storage Capacity of Reservoirs



It is the usual practice to plot both the elevation-area curve and the elevation-storage curve on the same paper.

Storage Capacity of Reservoirs

- The following formulae are commonly used to determine the storage capacity
- **1. Trapezoidal formula:** According to the trapezoidal formula, the storage volume between two successive contours of areas A_1 and A_2 is given by

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

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

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

where n is the total number of areas.

Storage Capacity of Reservoirs

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

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

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

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

The total storage volume is

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

The prismoidal formula is applicable only when there are odd numbers of areas (i.e. n should be an odd number).

In the case of even number of areas, the volume up to the second last area is determined by the prismoidal formula, and that of the last segment is determined by the trapezoidal formula.

Storage Capacity of Reservoirs

- **4. Storage Volume from cross-sectional areas:**

  - In the absence of adequate contour maps, the storage volume can be computed from the cross-sectional areas of the river. Cross-sectional areas (a1, a2 ... etc) are obtained from the cross sections of the river taken upstream of the dam up to the u/s end of the reservoir at regular interval d. The volume is determined from the prismoidal formula. The formula is applicable for odd number of sections

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

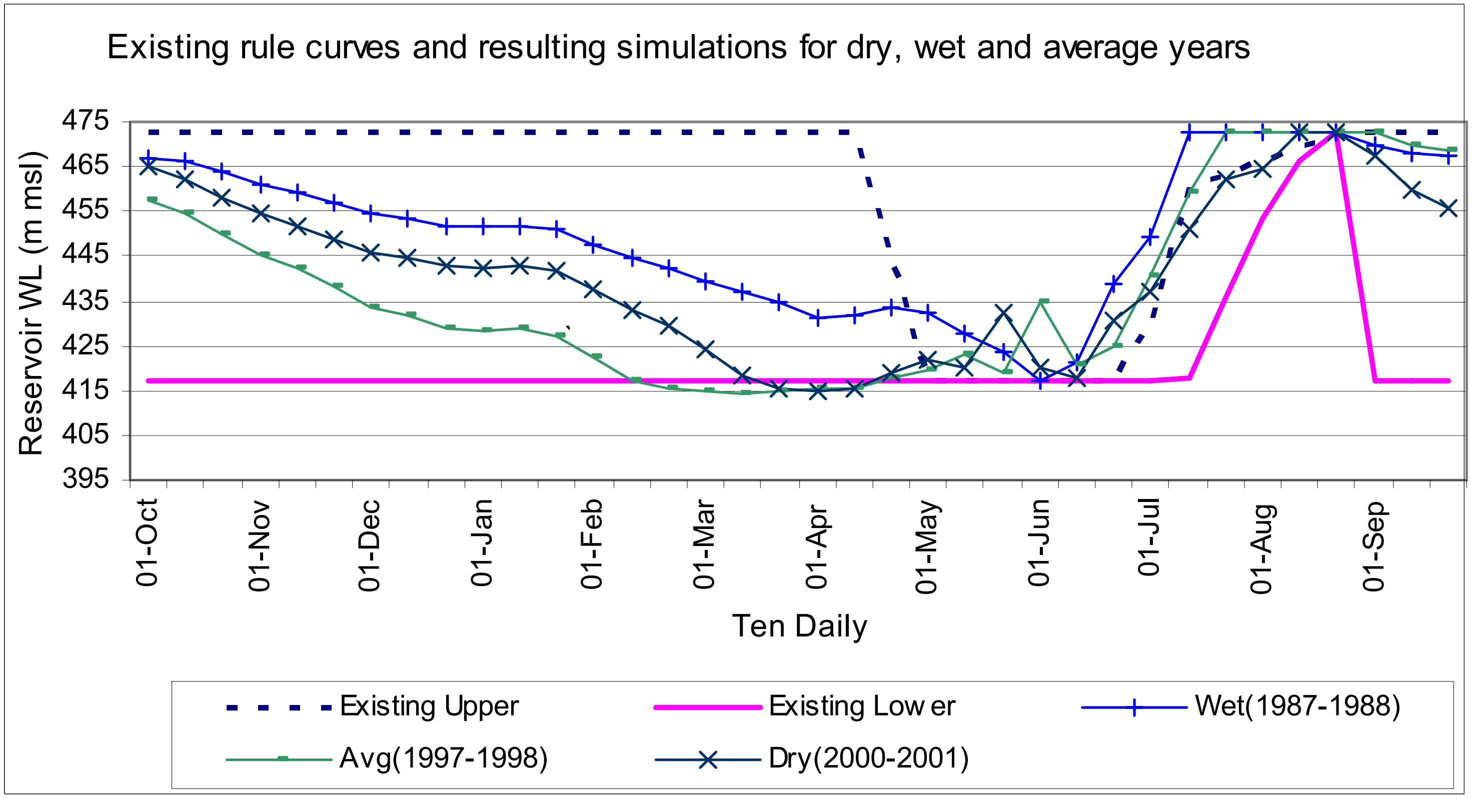
Reservoir Regulation

- Reservoir regulation is controlling of the reservoir water using predefined rules and criteria for safe and efficient use of the reservoir.
- It requires:
  - Control Structure (Spillways, Low level outlets)
  - Regulation Rules (storage rules, flood management rules, emptying criteria for safety of slopes, etc
  - Rule Curves
    - Rule curves are guide lines for operator of the reservoir. These show preferable range of the water levels (storage) in the reservoir at a certain time of year.

Reservoir regulation

- Regulation is dependent on purpose of the reservoir
- Safety of the project is the prime crietria. After Safety, optimum use of the reservoir should be assured:
- For Storage Reservoir, usually criteria is:
    - Reservoir should be full at end of the monsoon season, and
    - It should not be full (preferably empty) at start of the monsoon season
    - It should be kept empty (or at dead level) for some time (in early part of high flow season) for sediment removal
- For Hydropower Power reservoir, a high water level in reservoir is preferable.
- For Flood Control reservoirs, keeping a suitable storage (or keeping reservoir empty) for flood is necessary.
- Multipurpose reservoir has a combination of above, so a complicated and well thought regulation scheme is developed by the designers.

A view of rule curves and resulting water levels for normal, dry and wet years



Ref: PhD thesis, AIT