Co-funded by the Erasmus+ Programme of the European Union

Hydraulic structures. Dams and reservoirs

Embankment dam engineering-2

Assoc. Prof. Maria Mavrova
University of Architecture, Civil Engineering and Geodesy - Sofia

Sofia winter School 29 November – 10 December 2021
Date: **7 December 2021**

This project has been funded with support from the European Commission. This publication reflects the views only of the author, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

University of Nis

www.swarm.ni.ac.rs

Strengthening of master curricula in water resources management for the Western Balkans HEIs and stakeholders

Project number: 597888-EPP-1-2018-1-RS-EPPKA2-CBHE-JP

Q2: Embankment Dams

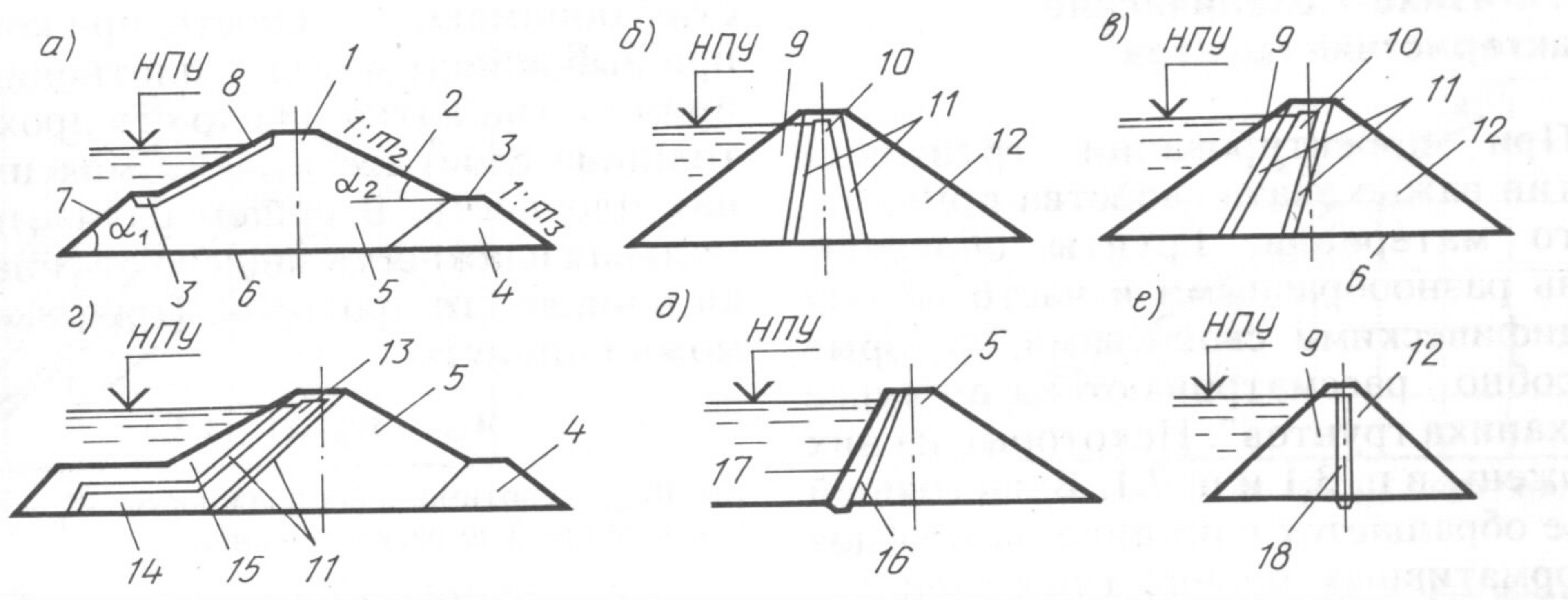
- **engineering soils** - *basic elements of soil mechanics and applied geology*
- **design principles and construction methods** - *seepage, stability and settlement*

Principles of embankment dam design

in principle, embankment dams required two component elements:

- **an impervious water-retaining element or core** of very low permeability soil (sandy clay)
- **supporting shoulders** of coarser earthfill (or of rockfill) to provide structural stability

Principles of embankment dam design

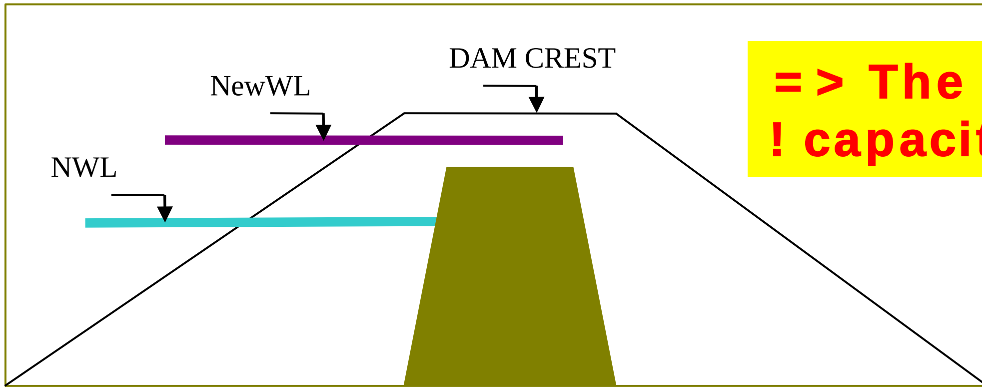


According to the principal risks we have to highlight the 5 principal design considerations:

1. **To prevent Overtopping.** Spillway and outlet capacity must be sufficient to prevent overtopping, Freeboard - to prevent overtopping by wave action. Settlement.
2. **Stability.** In construction and operation.
3. **Control of seepage.** Seepage within and under the embankment must be controlled to prevent internal erosion and migration of fine materials (from the core), or external erosion
4. **Upstream face protection.** The upstream face must be protected against local erosion as a result of wave action, ice movement, etc.
5. **Outlet and ancillary works**. Care must be taken to ensure that outlet or other facilities constructed through the dam do not permit seepage water along their perimeter

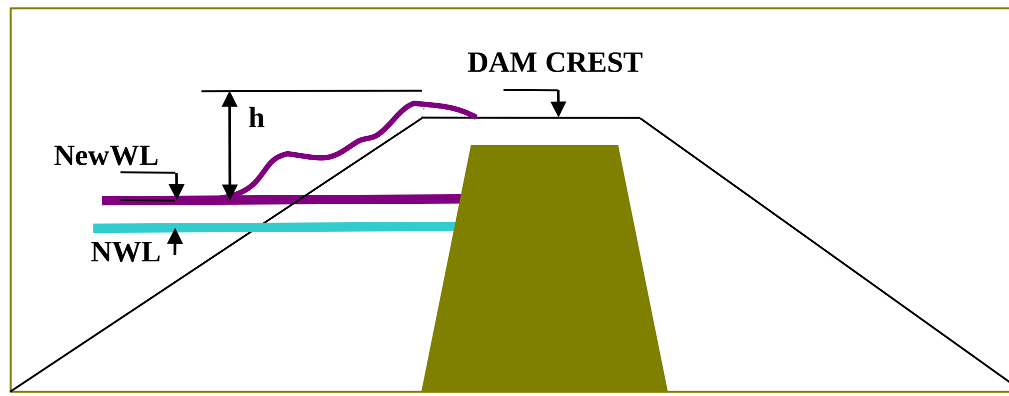
1. OVERTOPPING: TWO BASIC SCENARIOS

HWater level > clay core



=> The Crest of the Core > MWL
! capacity of the Spillway and Outlet(s)

Overtopping of the dam crest by Wind Waves



⇒ **Wind wave action analysis to prevent Dam crest overtopping**

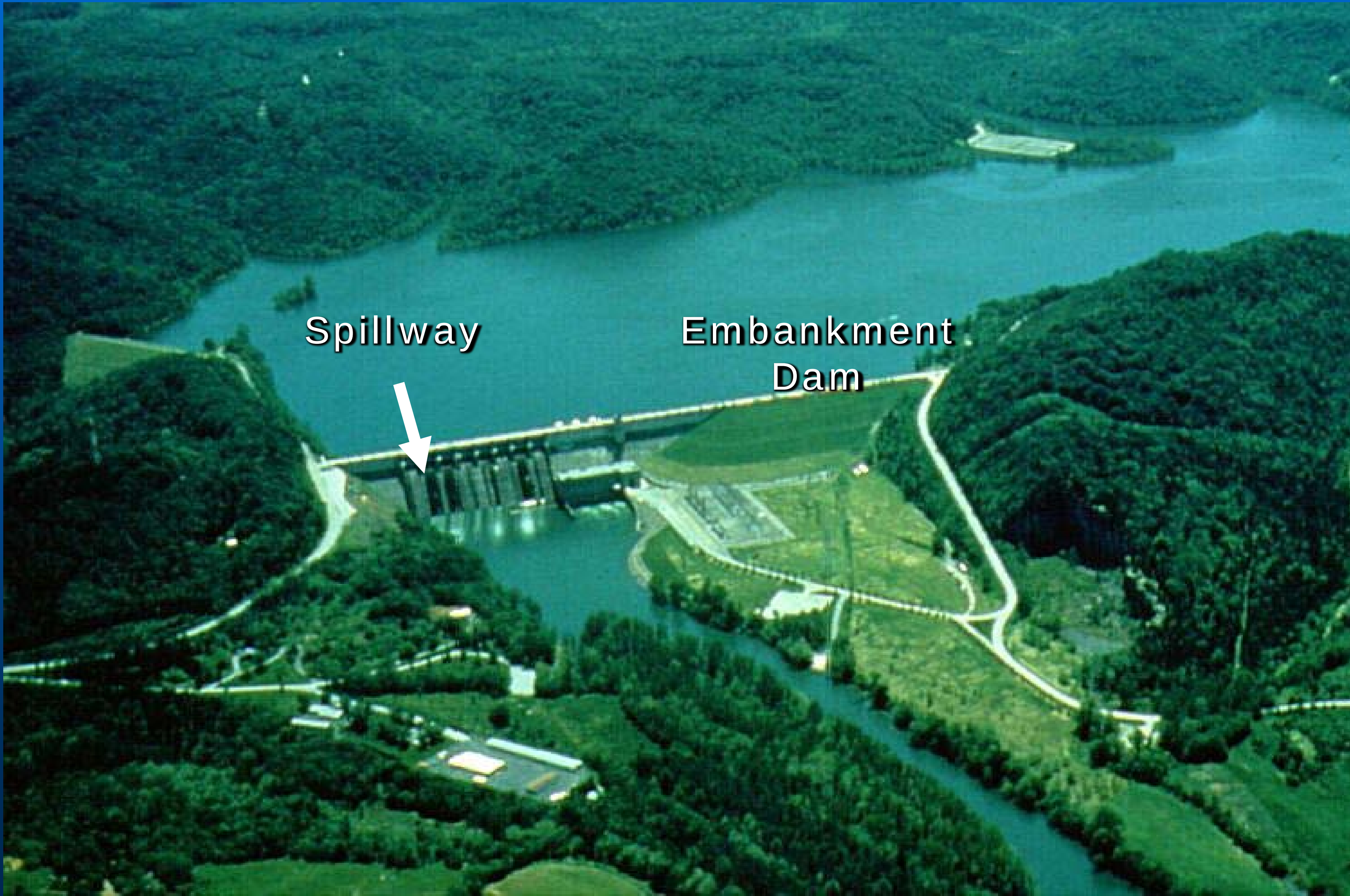
⇒ **FREEBORD**

OVERTOPPING: 1. Spillway and outlet

- **Spillway location** - to minimize the risk of damage to the dam under flood conditions the spillway and discharge channel are therefore generally built on natural ground outside of the embankment.
- **Capacity** must be sufficient to prevent overtopping, a risk-based approach to determine the probability of the design flood.

Spillway location

Spillway location



Spillway capacity

an example

For **a large dam of 1-st class** (category), Bulgarian code

- **Spillway capacity = max outflow from the reservoir**

Design flood $\mathbf{Q}_{\mathbf{0,01\%}}$ $[m^3s^{-1}]$

- 1 in 10 000 year flood (frequency)
- or ***p***=0.01% (annual probability of exceedance)

- **max head on the spillway H=MWL – NWL**

Classification according to Bulgarian design standard

DAM TYPE	SOIL TYPE of THE FOUNDATION SURFACE	DAM CATEGORY			
		I	II	III	IV
		Dam height [m]			
Embankment dams	Rock	above 100	between 50 and 100	between 15 and 50	up to 15
	Sandy, gravel, clay in solid or semi-solid state	above 70	between 35 and 70	between 15 and 35	up to 15
	Clay, water saturated in plastic state, find sand	above 40	between 20 and 40	between 10 and 20	up to 10
Concrete and reinforced concrete dams	Rock	above 100	between 50 and 100	between 20 and 50	up to 20
	Sandy, gravel, clay in solid or semi-solid state	above 40	between 20 and 40	between 10 and 20	up to 10
	Clay, water saturated in plastic state, find sand	above 20	between 15 and 20	between 10 and 15	up to 10

Classification according to ICOLD and DIN

	Height [m]	Volume [m^3]
Class1: Large dams	> 15	> 1 000 000
Class2: Small dams	< 15	< 1 000 000

Bulgarian Rules for design of spillways

- Design flood ->outflow from reservoir

DAM CATEGORY	I	II	III	IV
Discharge probability of exceedance [%]	0,01	0,1	0,5	1,0

OVERTOPPING: 2. Freeboard

Freeboard

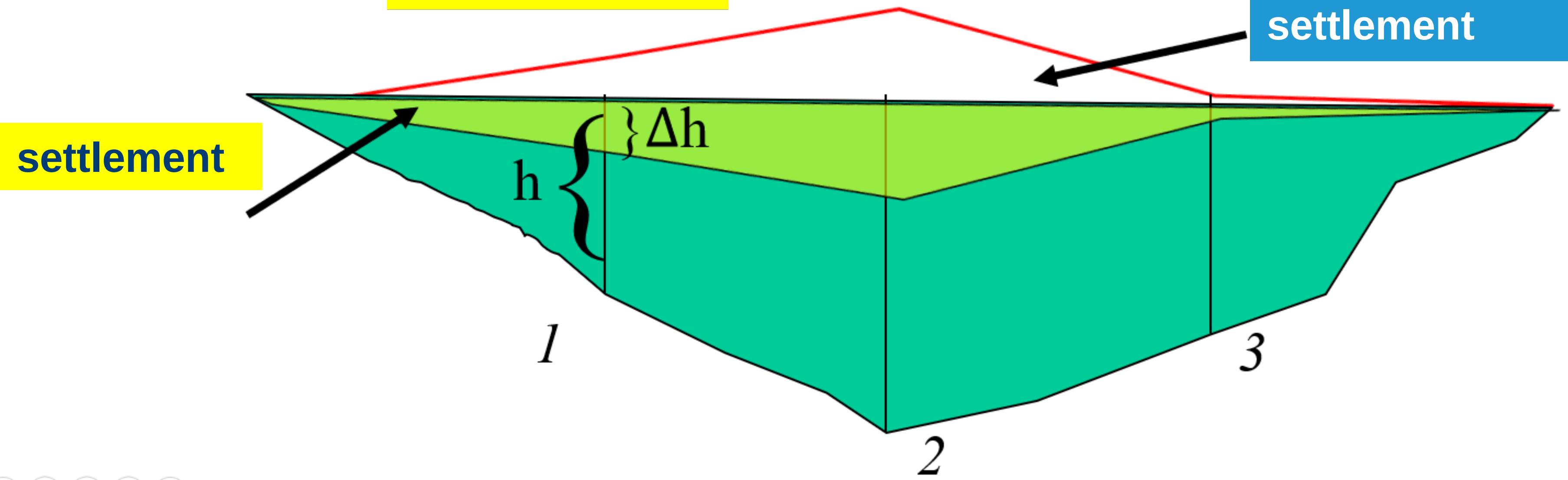
to prevent overtopping by wave action.

- **long-term settlement** -It is common practice **to construct the crest of the dam to a longitudinal camber** to accommodate the predicted consolidation settlement.
- **freeboard design-** minimum freeboard should be at least 1.5 m

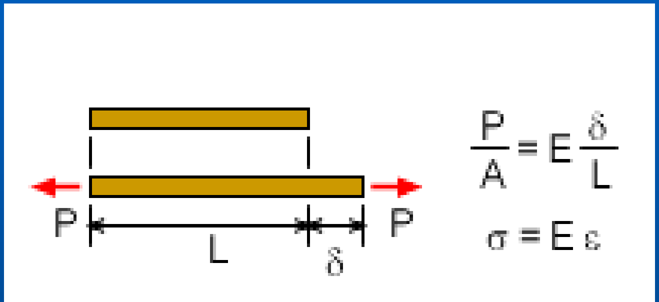
settlement

To construct the crest of the dam to a longitudinal camber
to accommodate the predicted consolidation settlement

$$\Delta h = S = \varepsilon h$$

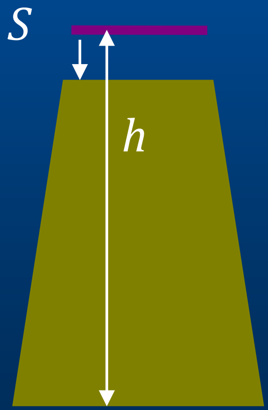


settlement



$$\varepsilon = \frac{\delta}{L}$$

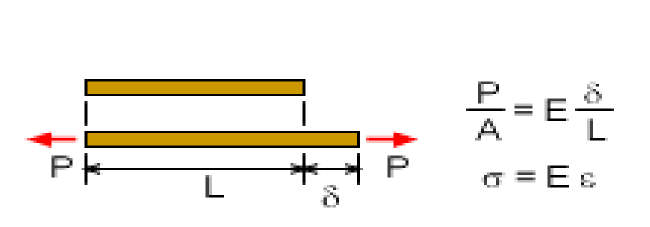
deformation



$$\varepsilon = \frac{Settlment}{h} = \frac{S}{h}$$

$$Settlment = S = \varepsilon h$$

settlement



One Dimensional Hooke's Law

$$\sigma = E\varepsilon$$

$$\varepsilon = \sigma/\mathrm{E}$$

settlement

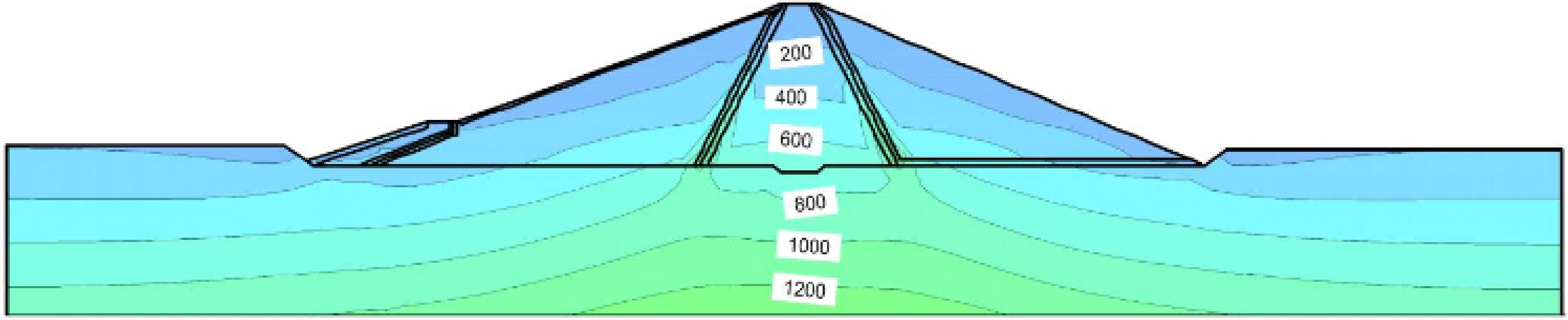
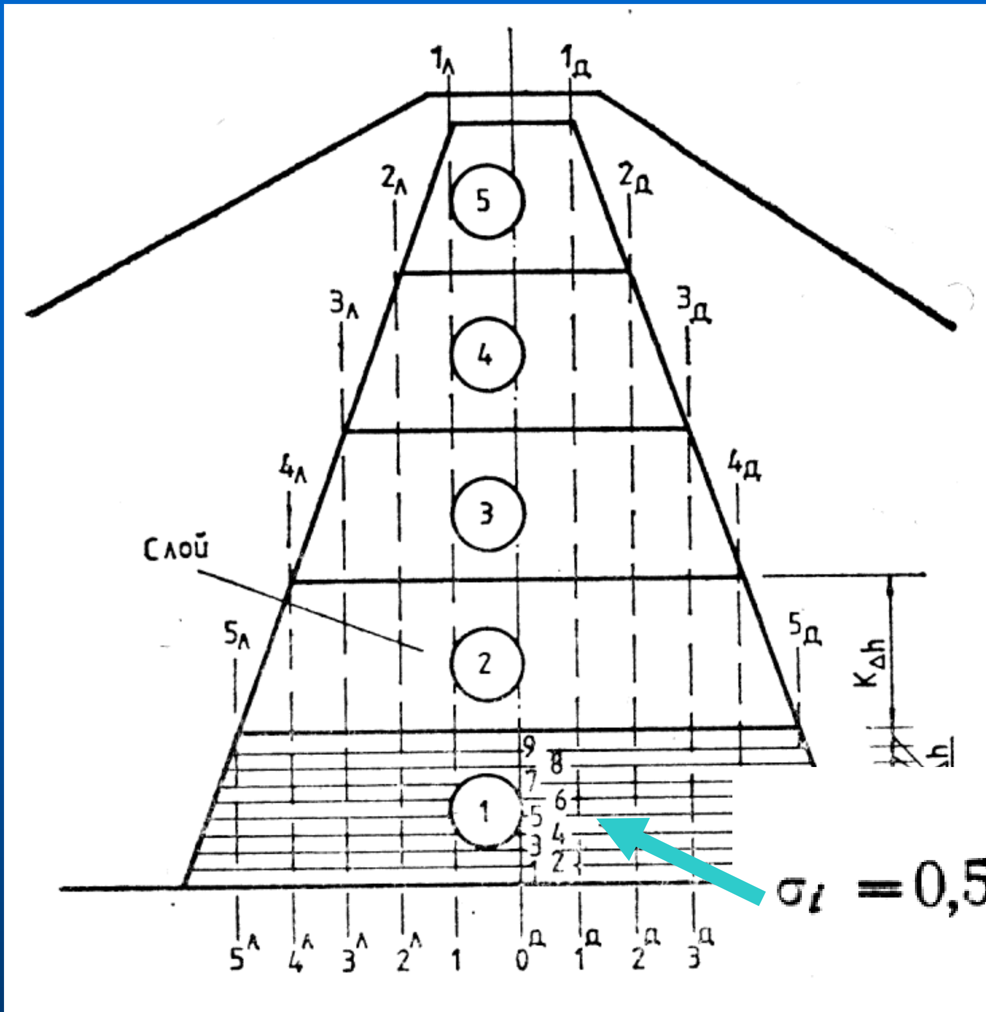


Fig. 7 Stress distribution for initial static analysis(kPa)

$$\sigma_i = 0{,}5\gamma_i h_i + \sum_{j=i+1}^{n} \gamma_j h_j.$$

settlemen



$$\varepsilon = \frac{\sigma}{E}$$ Hooke's Law

$$\sigma_i = 0{,}5\gamma_i h_i + \sum_{j=i+1}^{n} \gamma_j h_j.$$

$$Settlment = S = \varepsilon h = \sum \frac{\sigma_i h_i}{E_i}$$

OVERTOPPING: 2. Freeboard

Freeboard

to prevent overtopping by wave action.

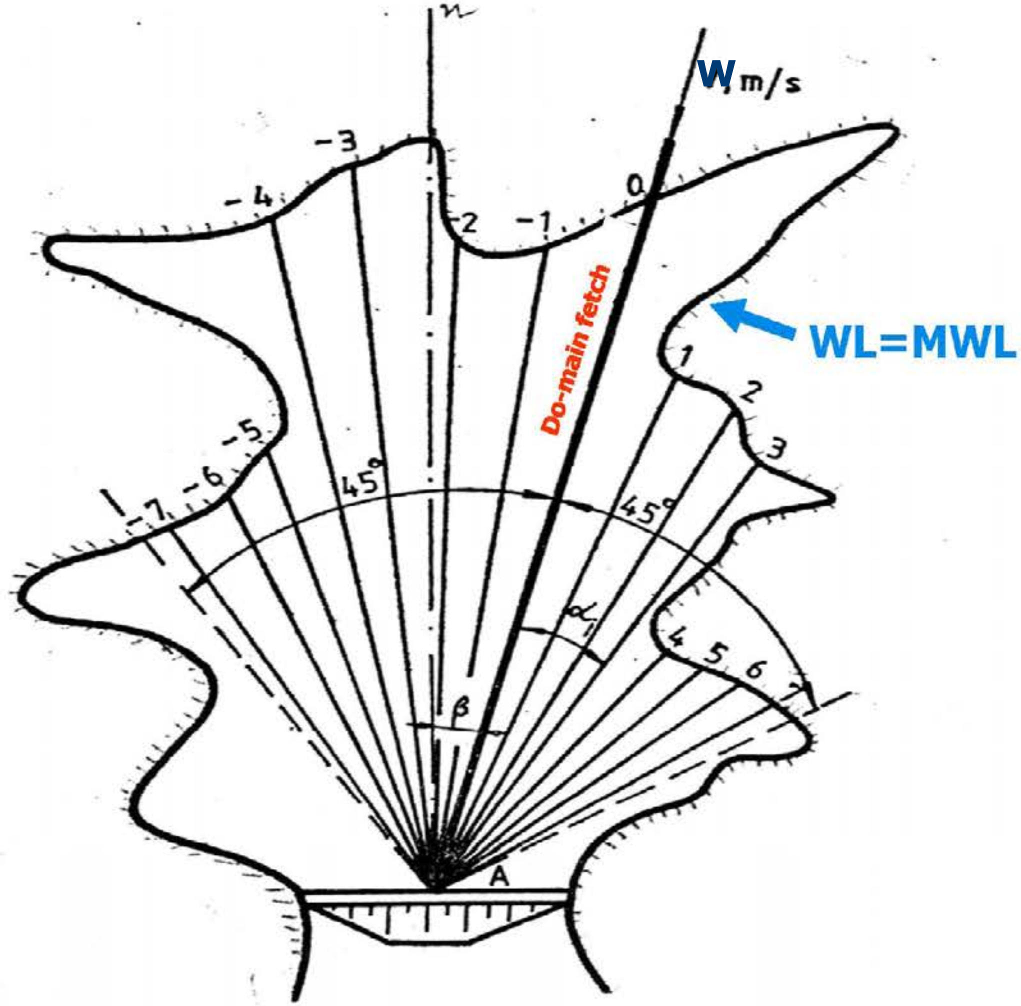
- **long-term settlement** -It is common practice **to construct the crest of the dam to a longitudinal camber** to accommodate the predicted consolidation settlement.
- **freeboard design-** minimum freeboard should be at least 1.5 m

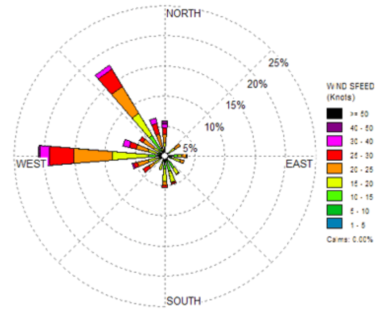
The effective fetch: (2)

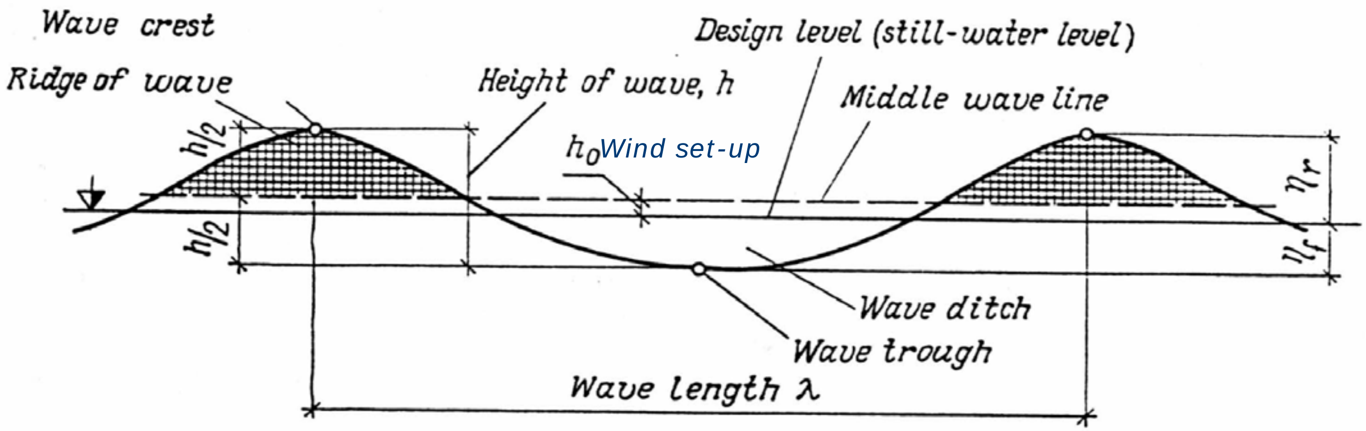
$$D_{Eff} = \frac{\sum_{-n}^{+n} D_i \cos^2 \alpha_i}{\sum_{-n}^{+n} \cos \alpha_i} \quad \text{m},$$

Where: Di - the fetch length on "i"direction

- Wind fetch ***D*** is a straight distance from the bank to structure;
- Wind speed ***W*** in the direction of fetch is determined by wind rose







Water areas

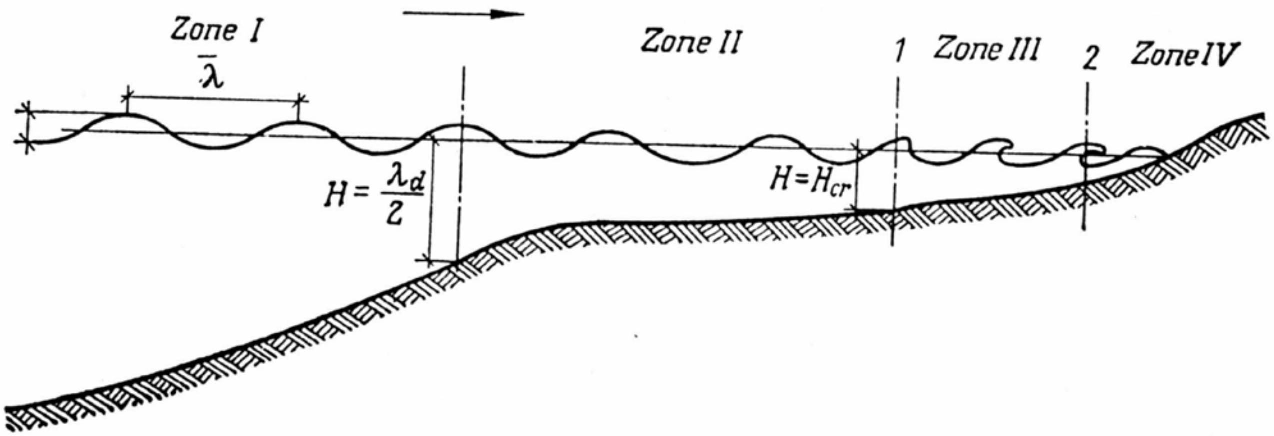


Fig. 2.8. Division of water area into zones by depth

I—deep-water zone; *II*—shallow-water zone; *III*—zone of surfs; *IV*—zone located near the shore line; *1*—section line of first fall of waves; *2*—final fall

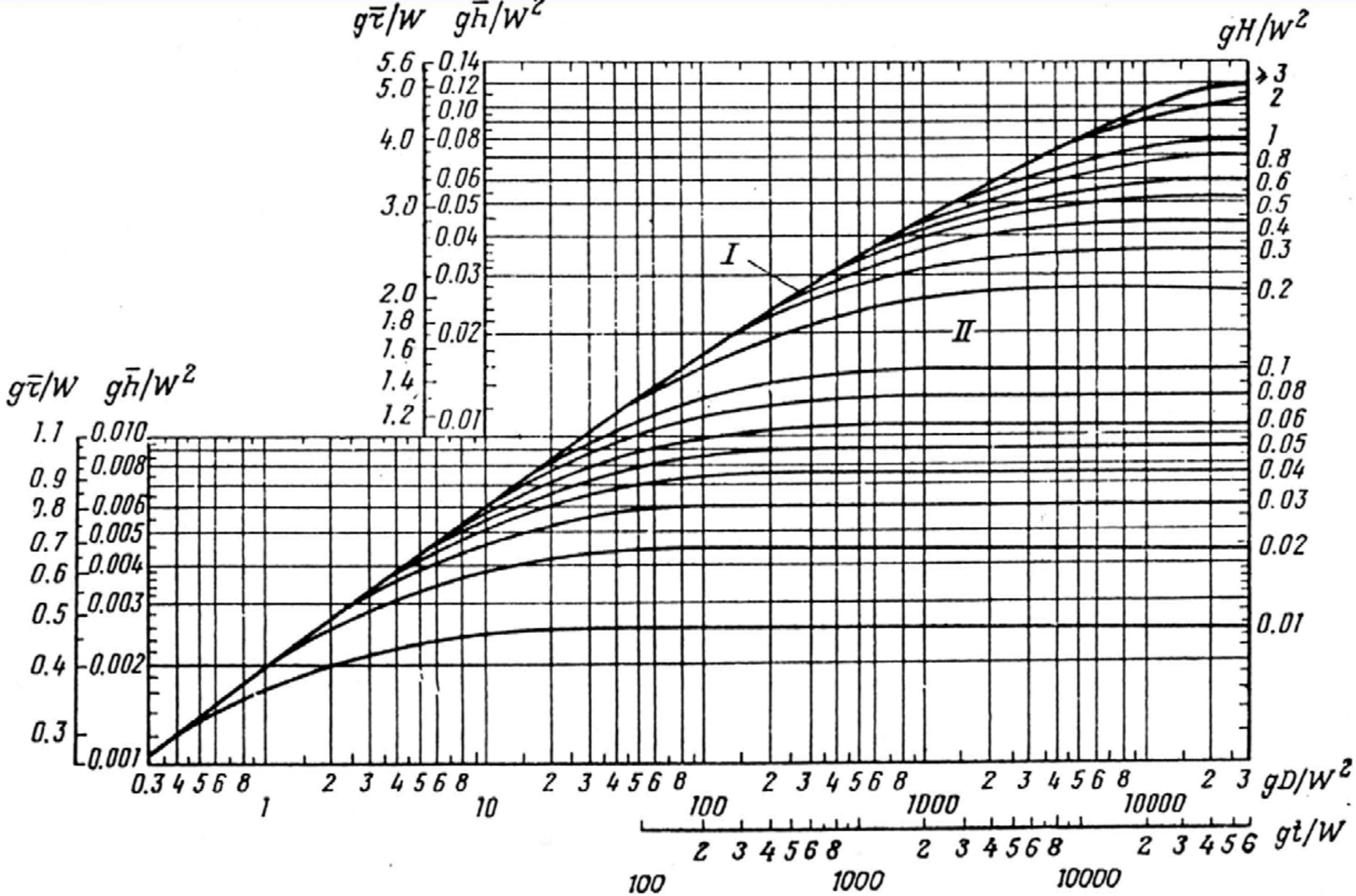


Fig. 2.9. Graphs for the determination of average parameters of wind-induced waves in deep-water (*I*) and shallow-water (*II*) zones (for a slope of bed $i \leqslant \leqslant 0.001$)

DAM CREST EL.= WL+FREEBOARD

The freeboard has several components:

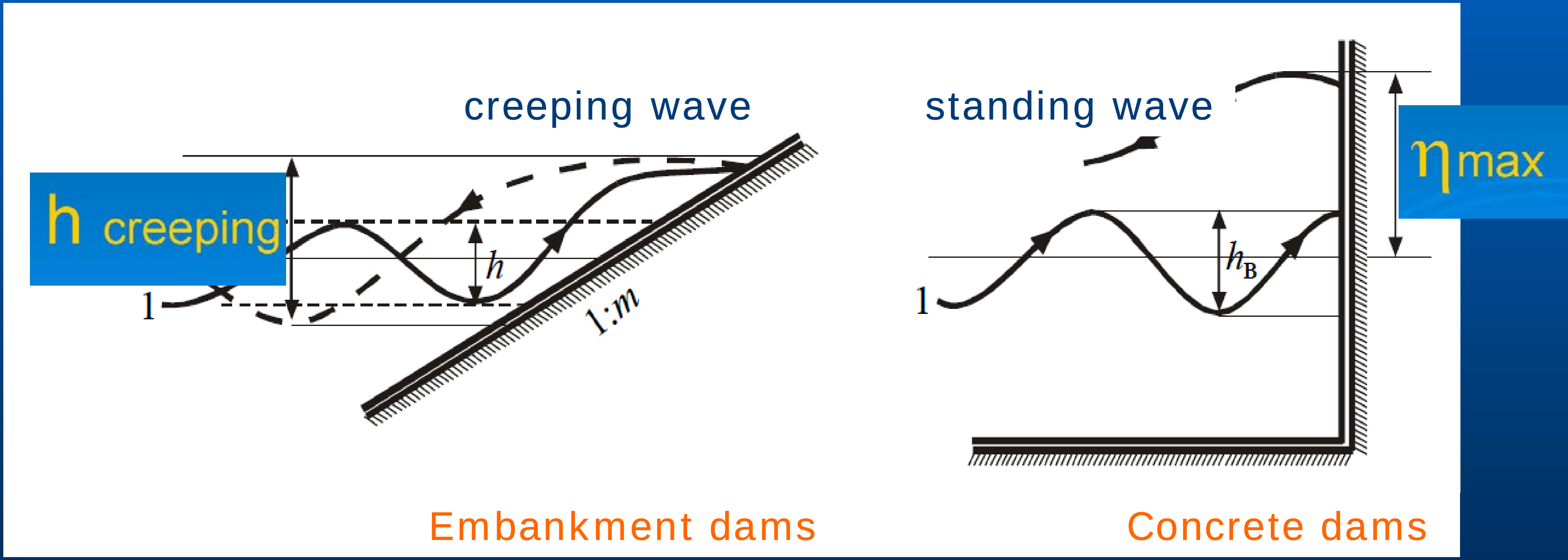
1. rise in reservoir level due to flood routing;

   WL= NWL or **MWL**

2. seiche effects;
3. wind set-up of the water surface - $\mathbf{h_o}$;
4. wave action and run-up of waves on the dam-

   h creeping or ηmax

Interference –
overlay reflected with an incoming wave



DAM CREST EL.= WL+FREEBOARD

Concrete dams

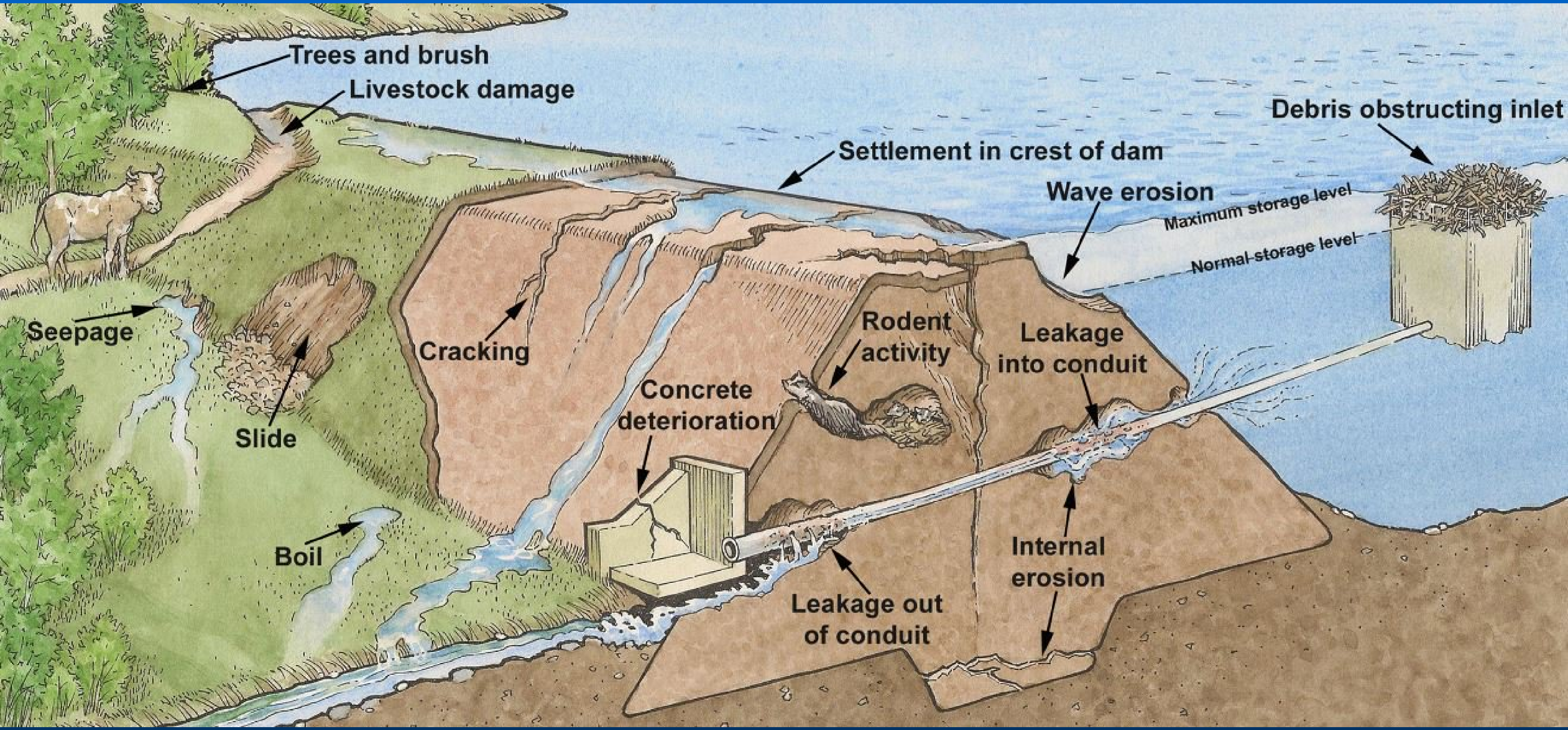
FREEBOARD $d = ho + \eta_{max} + a$

η_{max} - deep water zone, steep upstream slope

Embankment dams

FREEBOARD $d = ho + h_{cr} + a$

$h_{creeping}$ - near the shore line, gentle upstream slope;



Trees and brush
Livestock damage
Debris obstructing inlet
Settlement in crest of dam
Wave erosion
Maximum storage level
Normal storage level
Seepage
Cracking
Rodent activity
Leakage into conduit
Slide
Concrete deterioration
Boil
Internal erosion
Leakage out of conduit

According to the principal risks we have to highlight the principal design considerations:

1. **To prevent Overtopping.** Spillway and outlet capacity must be sufficient to prevent overtopping, Freeboard - to prevent overtopping by wave action.
2. **Stability.** In construction and operation.
3. **Control of seepage.** Seepage within and under the embankment must be controlled to prevent internal erosion and migration of fine materials (from the core), or external erosion
4. **Upstream face protection.** The upstream face must be protected against local erosion as a result of wave action, ice movement, etc.
5. **Outlet and ancillary works**. Care must be taken to ensure that outlet or other facilities constructed through the dam do not permit seepage water along their perimeter