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Hydraulic structures. Dams and reservoirs

Embankment dam engineering-4

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Embankment Dams

Stability and stress analysis

Slope stability is the most important consideration in the analysis and design of earth dams. Land slides in either the upstream or downstream face of an earthen dam can be disastrous. These slopes must satisfy the stability requirements.

Slope stability analysis methods:

Many methods of analyzing the slope stability are available but usually all these available methods are divided into following three categories:

1. Sliding surface method
2. Limit analysis method
3. Finite element method (FEM)

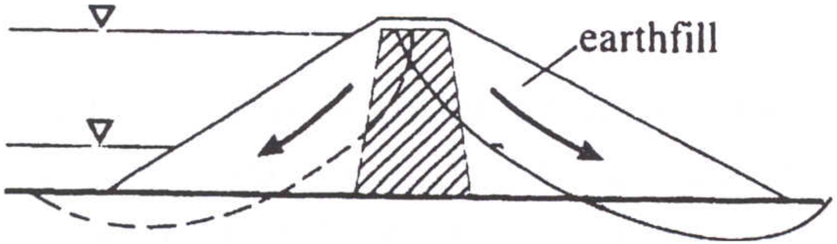
The validity of Column's law failure should be assumed for all these methods!

Two-dimensional limit-equilibrium method

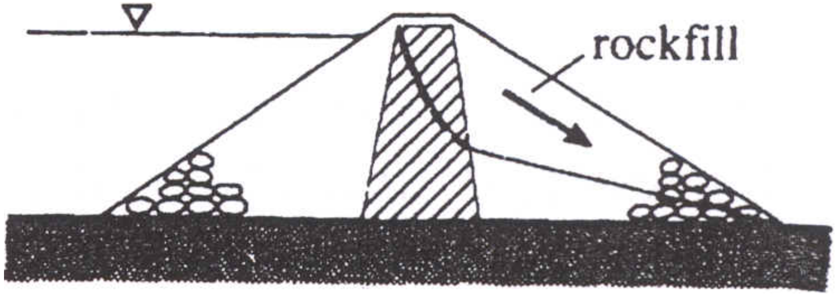
- *static equilibrium* of the potentially unstable 'active' mass of soil situated on a failure surface

Failure surface analysis

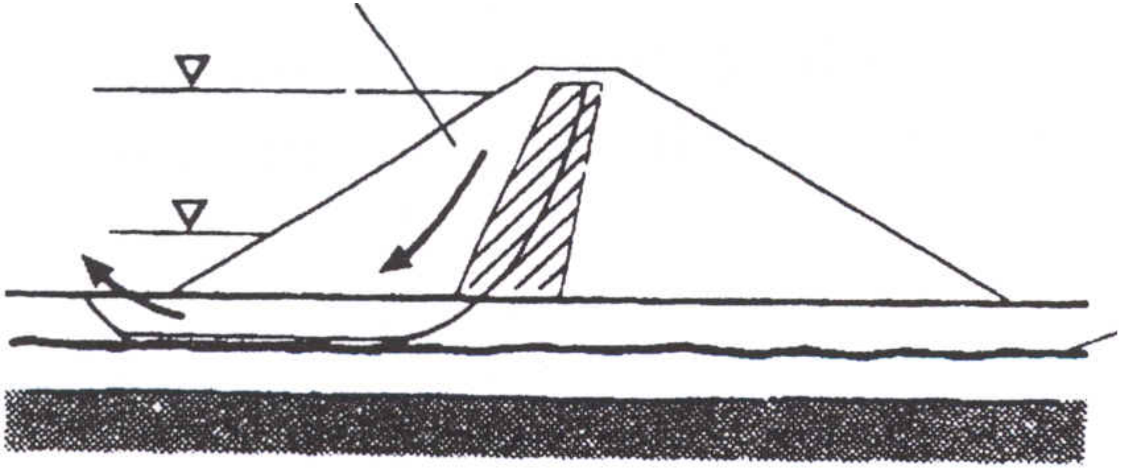
The stability analysis of a slope is difficult to perform. To determine soil stratification and its in-place shear strength may prove to be a threatening task. Seepage through the slope and the choice of potential slip surface add to the complexity of the problem.



(a) Relatively homogeneous embankment and soil foundation

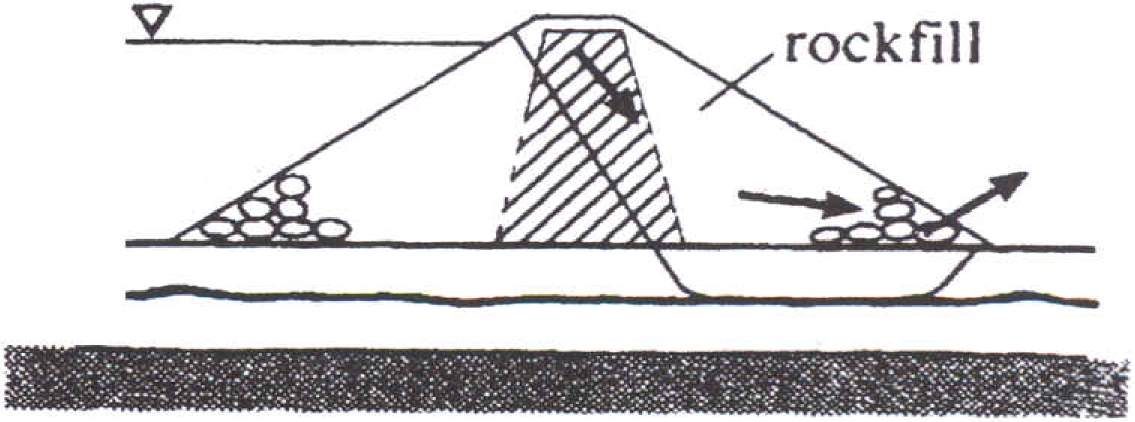


(b) Embankment on rock or 'stiff' foundation



soft clay

(c) Soft, compressible clay layer in foundation; drawdown-type failure



(d) Wedge-type active mass; sliding in part on soft horizon

Coulomb’s law of shear strength :

This law of shear strength was presented in 1773. The Shear strength of the soil is basically composed of two major components:

1. Friction
2. Cohesion

The inter granular friction is in directly proportional to the normal stress acting on shear surface. Which means that **if inter granular friction increases** the **normal stress** acting on the shear surface **also increases**. On the other hand the cohesion is dependent on the type of the soil, size of the soil grains and the packing of the soil grains and on the suction properties of the soil.

Coulomb in 1773 governed the shearing strength of the soil by a straight line equation in Coulomb’s law of shear strength:

$\tau_f = \sigma \, tg\varphi + c$

Where: c = apparent cohesion
σ = the normal stress
φ = the angle of internal friction or shearing resistance of the soil.

When this equation was put forward in 1773, the concept of effective stress even then was not introduced.

Effective stress and Pore water pressure

Effective stress:

σ_{eff} - The stress carried by the solid particles or the solid portion of the soil is known as effective stress.

Pore water pressure:

p_w - The stress carried by the pore water is known as pore water pressure.

Total stress:

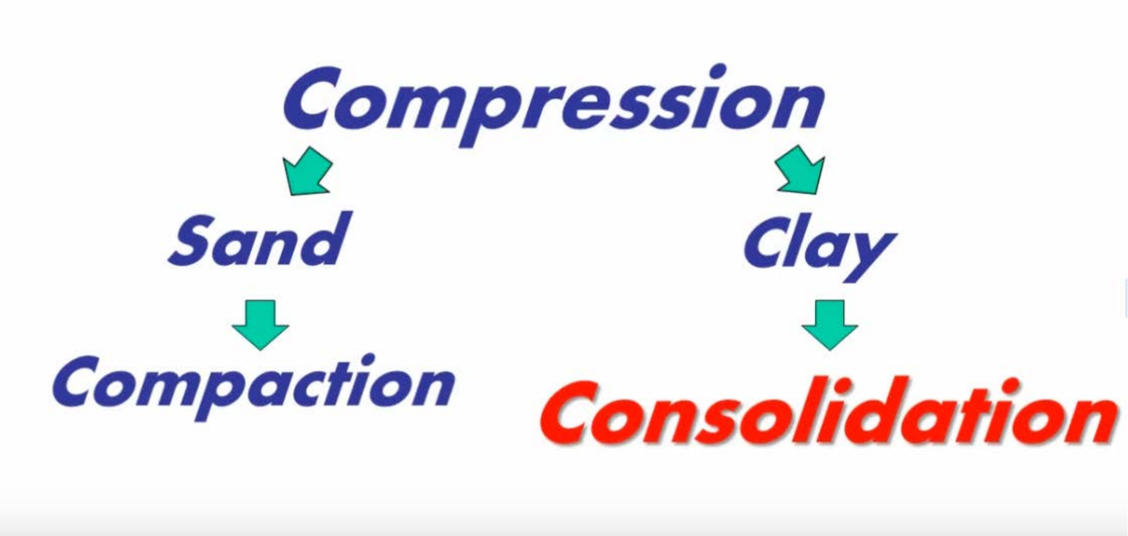
σ- The compressive stress at a point is carried partially by the solid portion of the soil and partially by the pore water. Geotechnical engineers call this stress *total stress* because it is the sum of stresses carried by these two portion of the soil i.e solid portion and pore water.

Inter granular friction in the Coulomb's law of shear strength:

$\tau_f = (\sigma - p_w)\, tg\varphi + c = \sigma_{eff}\, tg\varphi + c$

p_w – pore water pressure

- Seepage
- Consolidation



Factor of safety

$$F=?$$

$$F=\Sigma\tau_f/\Sigma\tau$$

τ_f - unit shear resistance

τ - unit shear stress acting

unit shear resistance (strength) **of soils**

$\tau_f = \sigma \operatorname{tg}\varphi + c$, **Coulomb's law of shear strength**

$\tau_f = (\sigma - p_w) \operatorname{tg}\varphi + c = \sigma_{eff} \operatorname{tg}\varphi + c$

p_w – pore water pressure

FEM Slope stability analysis

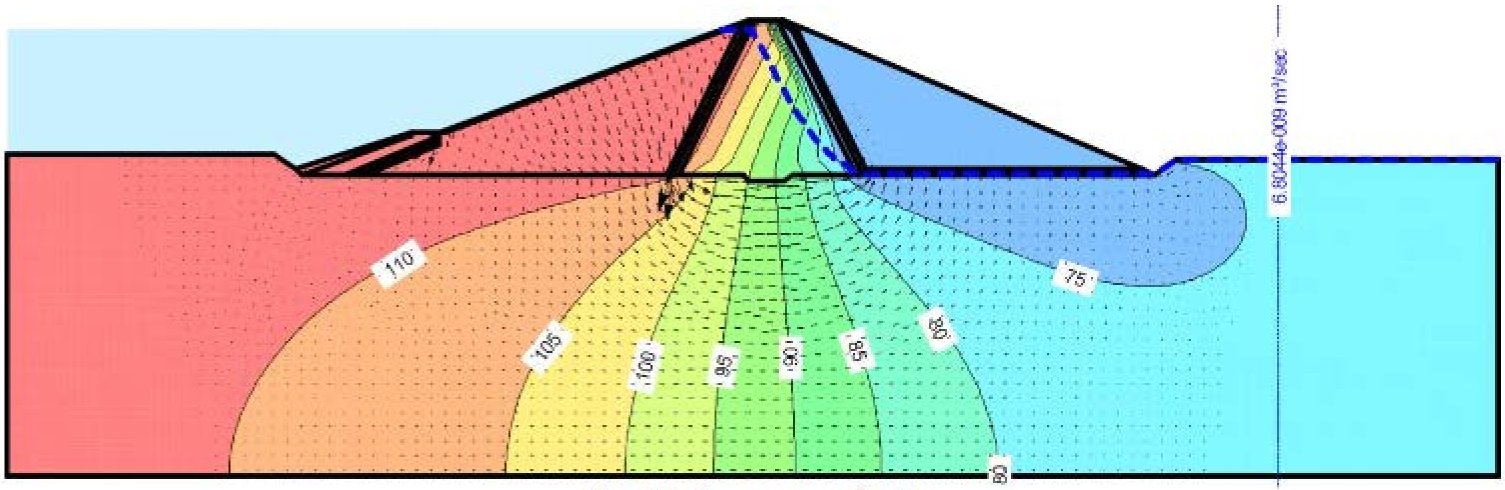
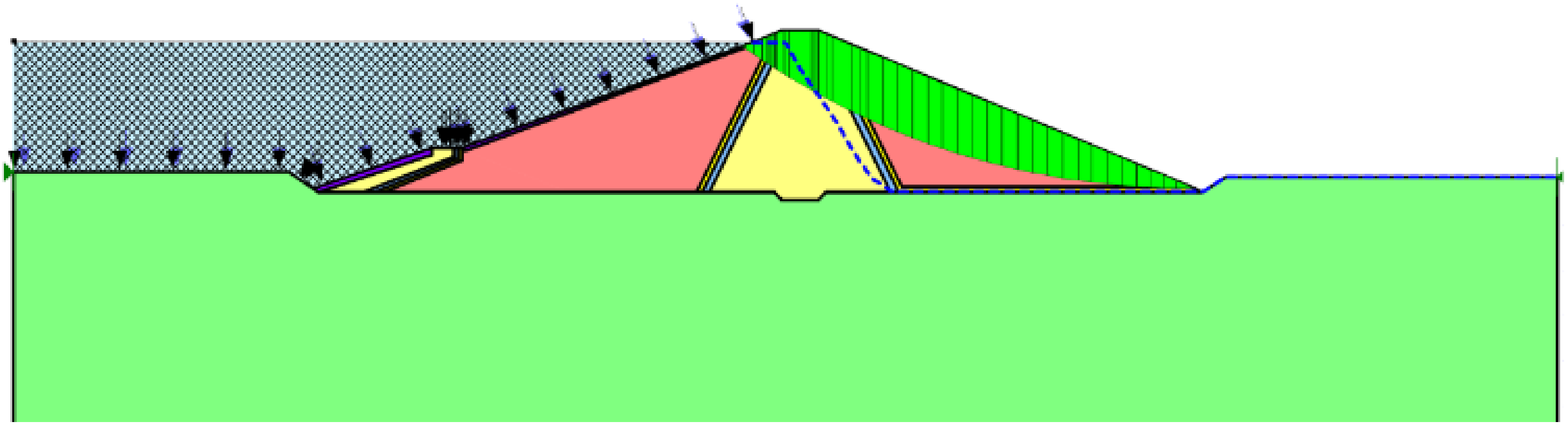


Fig. 11 Seepage analysis

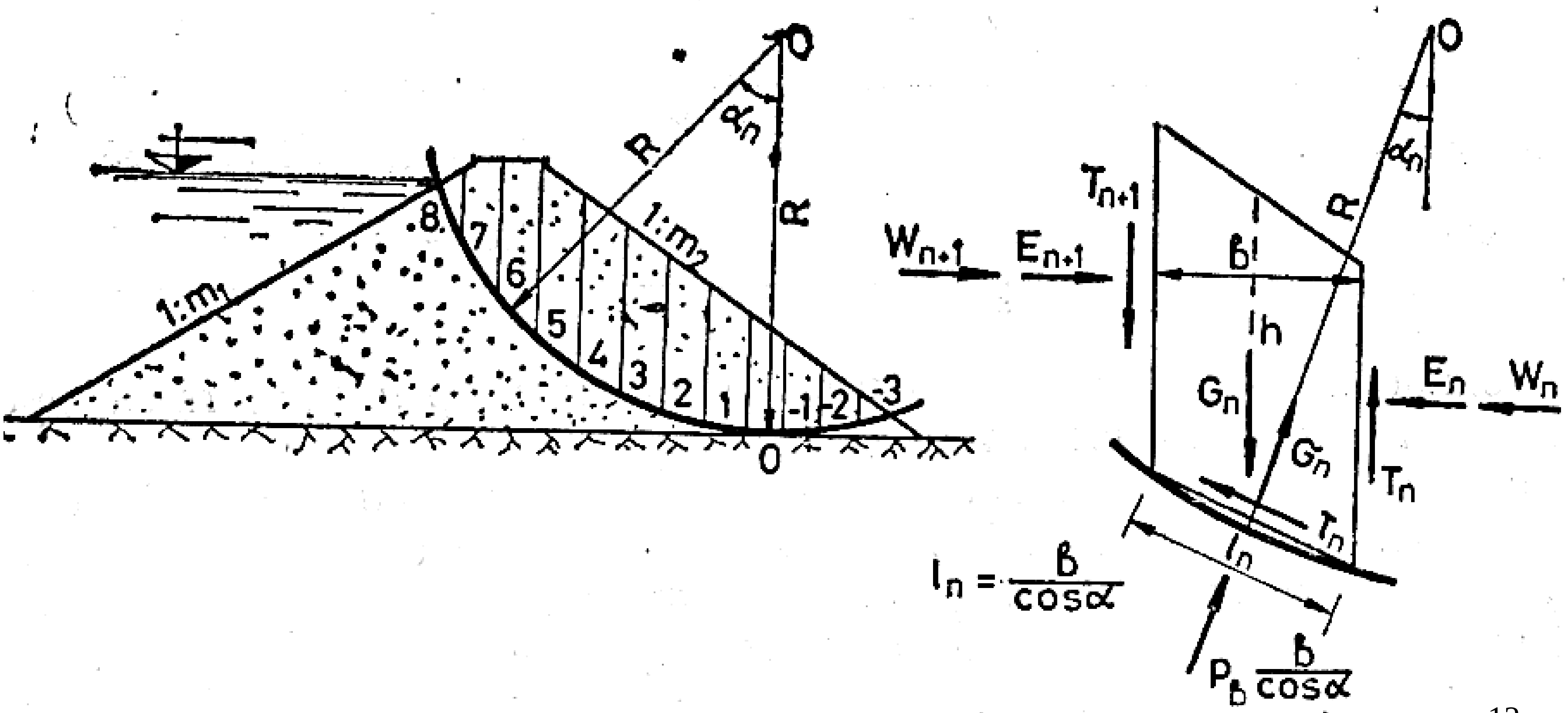


The following critical conditions must be analyzed:

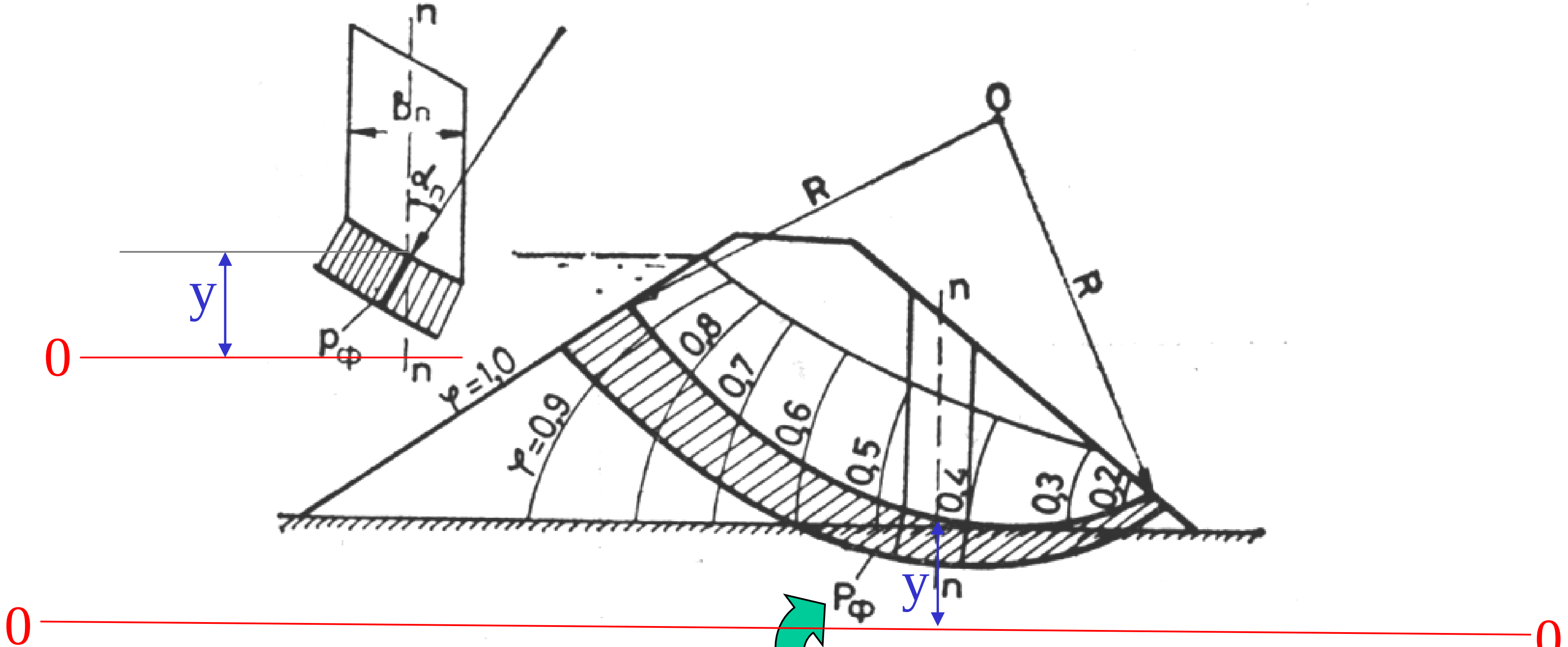
LOADING COMBINATIONS

1. end of construction (both slopes);
2. steady state, reservoir full (downstream slope critical);
3. rapid drawdown (upstream slope critical);
4. **seismic loading** additional to 1,2 and 3, if appropriate to the location.

Slope stability limit-equilibrium analysis
Fellenius solution: Circular Arc Surface



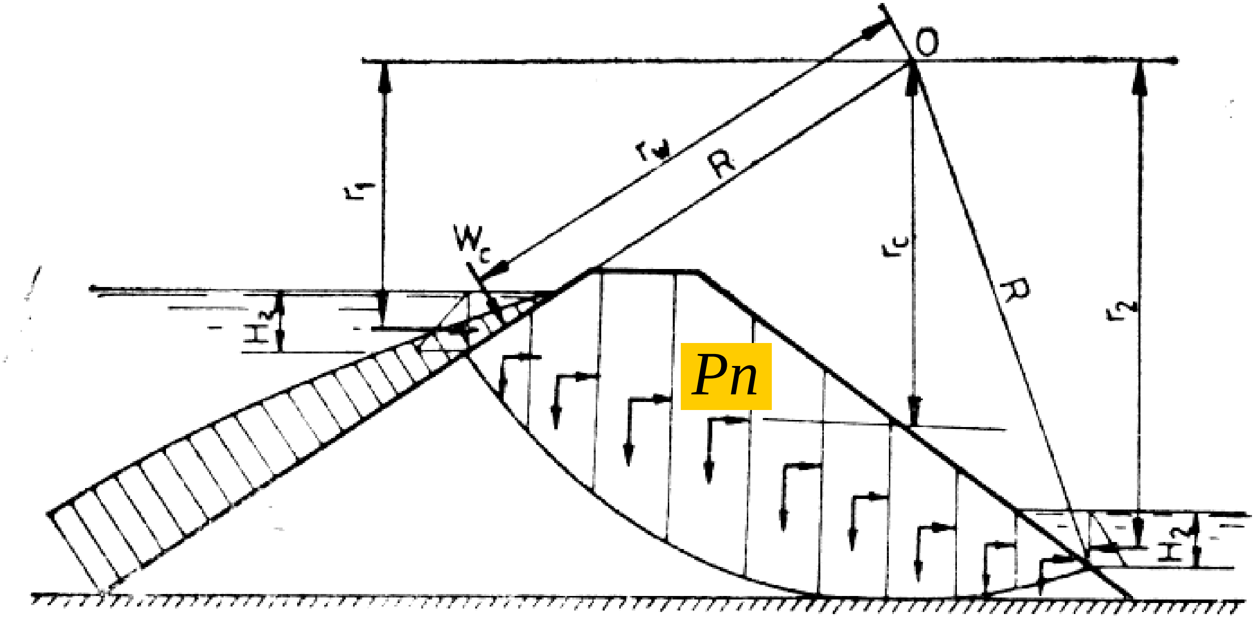
Seepage forces:



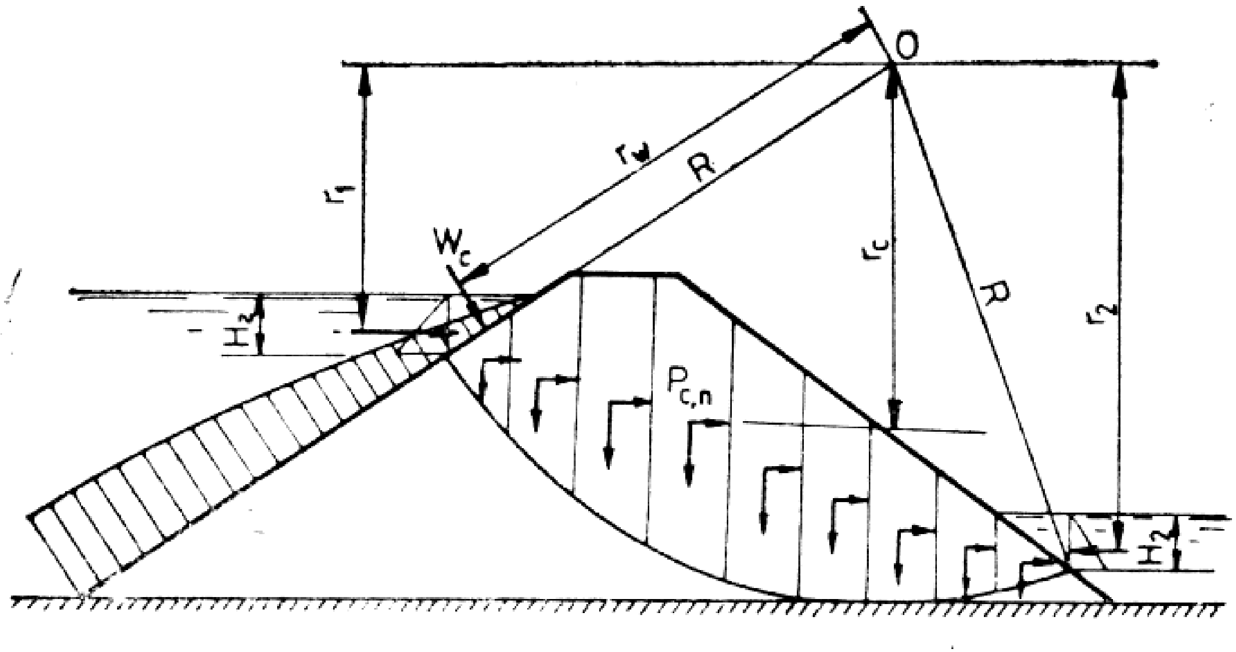
$\tau_f = (\sigma - p_w)\, tg\varphi + c = \sigma_{eff}\, tg\varphi + c$

$p_w = (H - y)\gamma_w = (\varphi H_{max} - y)\, \gamma_w$

Seismic forces:



$$P_{in} = cRK_c\beta_i\eta_{ik}Q_n$$



$$F=\Sigma\tau_f/\Sigma\tau$$

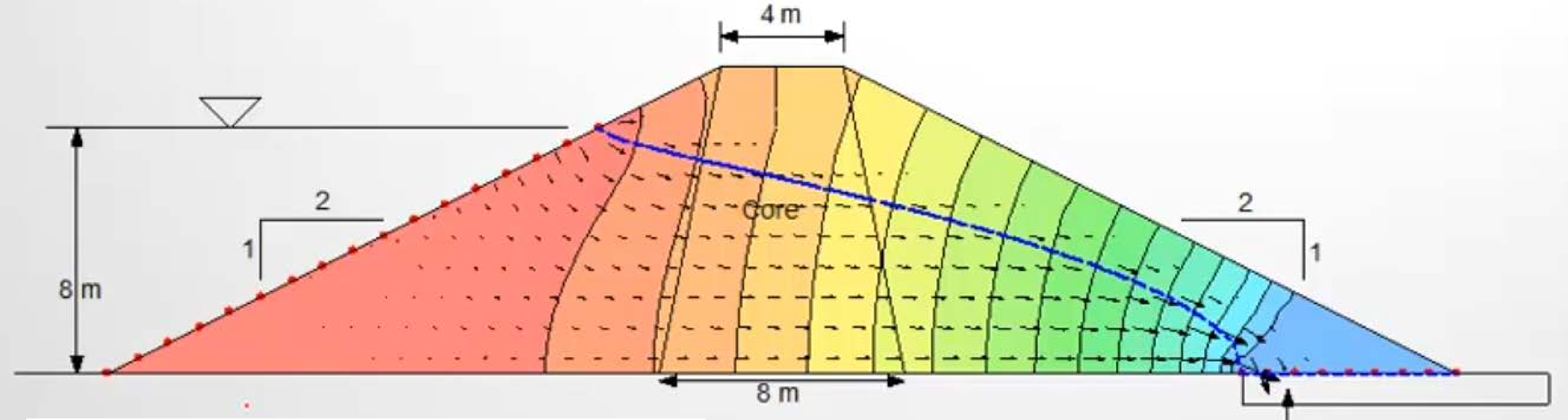
$$F=\frac{\sum_n\left(G_n\cos\alpha_n-p_{\text{в}}\frac{b_n}{\cos\alpha_n}\right)\operatorname{tg}\varphi_n+\sum_n c_n\frac{b_n}{\cos\alpha_n}}{\sum_n G_n\sin\alpha_n+\frac{\gamma_{\text{в}}H_{\text{г}}^2 r_1-\gamma_{\text{в}}H_{\text{д}}^2 r_2}{2R}+\sum_n P_{\text{c},n}\frac{r_{\text{c}}}{R}+W_{\text{c}}\frac{r_W}{R}}$$

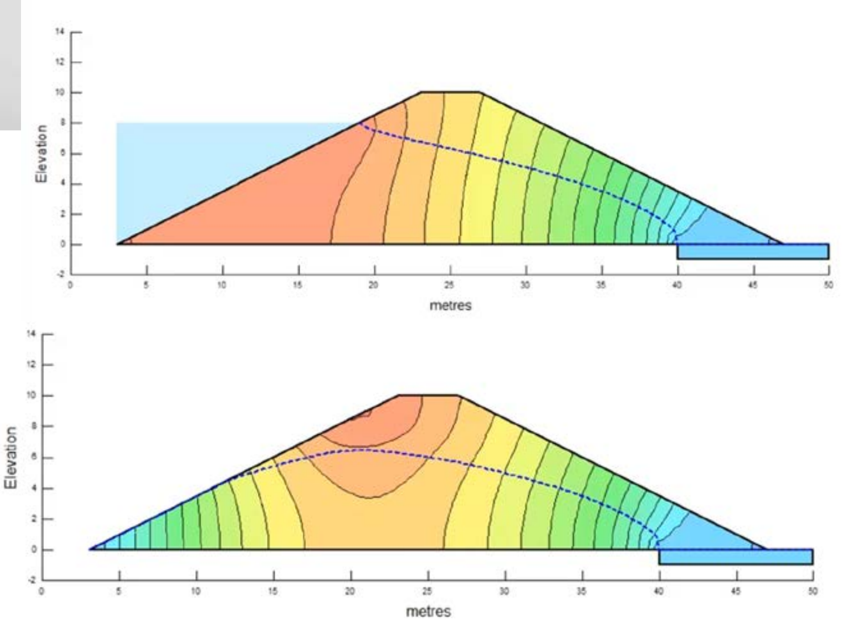
$: R$

$: R$

Upstream slope stability analysis- rapid drawdown of the reservoir

Equipotential lines, steady state case NWL

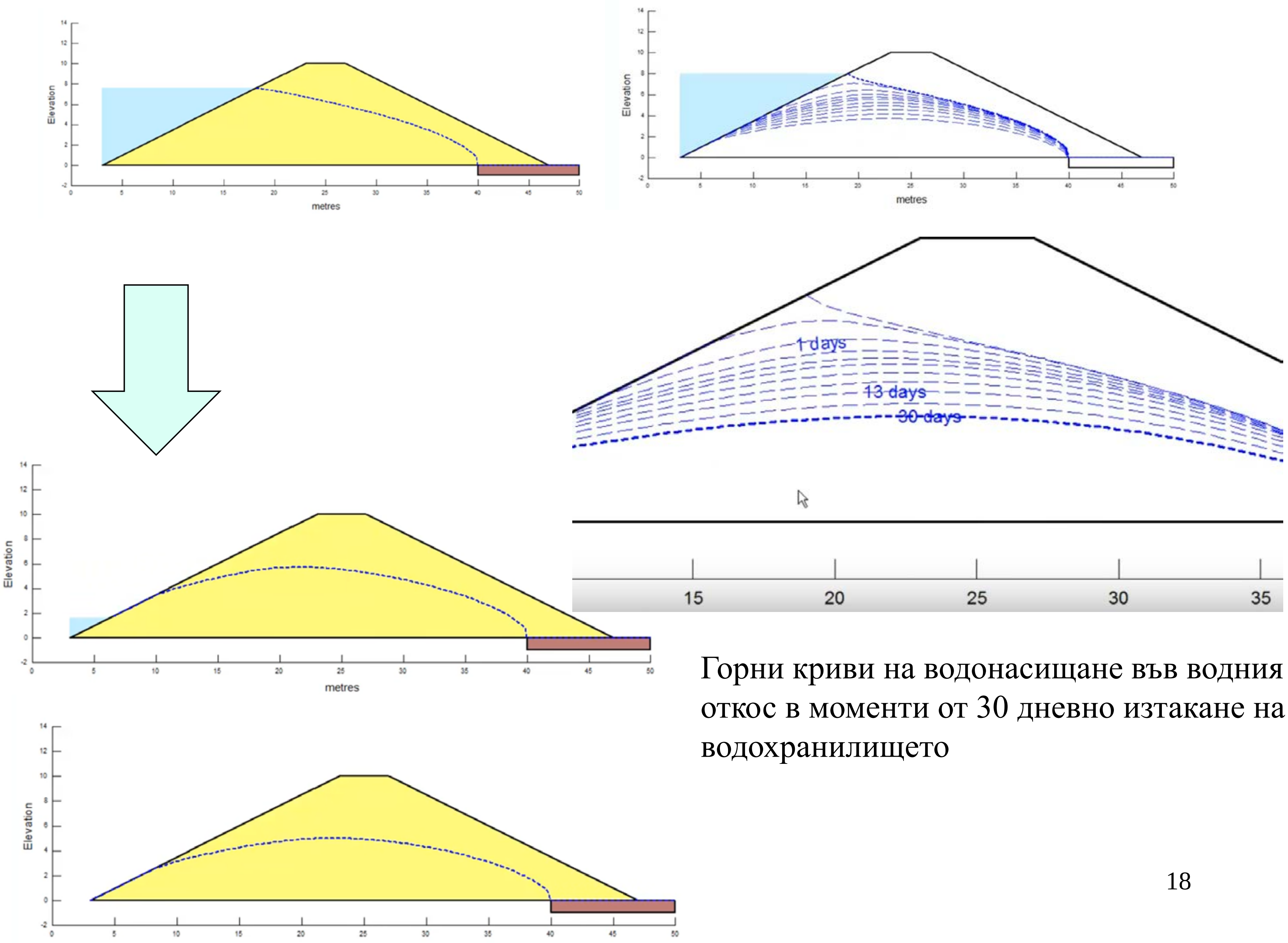




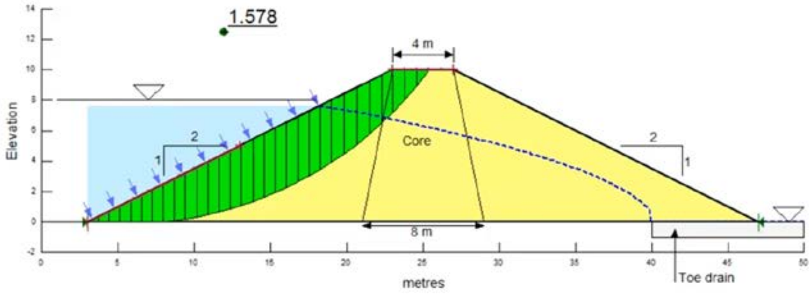
1 day

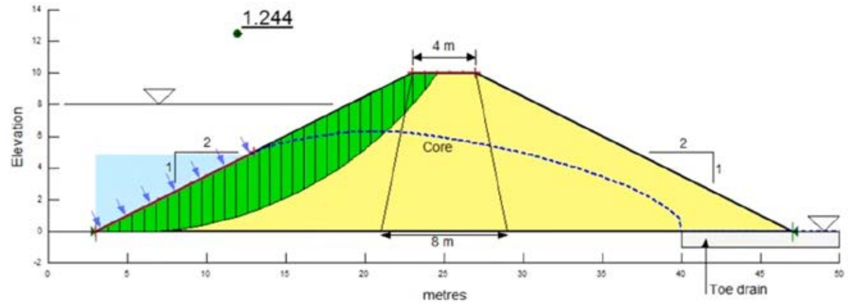
12 day

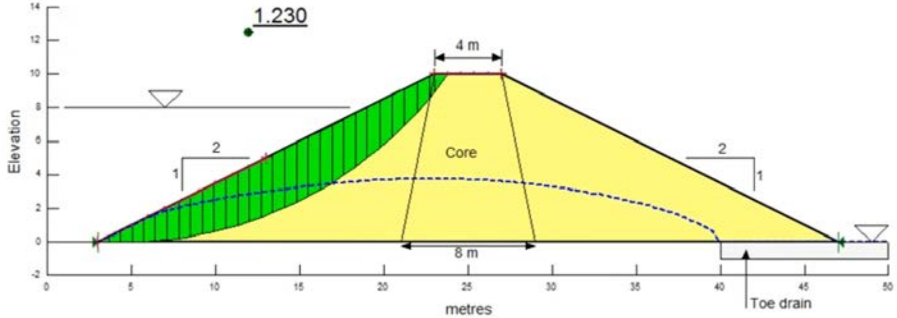
Equipotential lines, rapid drawdown



Горни криви на водонасищане във водния откос в моменти от 30 дневно изтакане на водохранилището







Коеф. на сигурност е най-малък в момент на частично пълно водохранилище, в сравнение със съвсем празно. Безопасната скорост на понижение трябва да се докаже (за първо приближение 10-30см/денонощие)

Sliding Stability – Rockfill dams

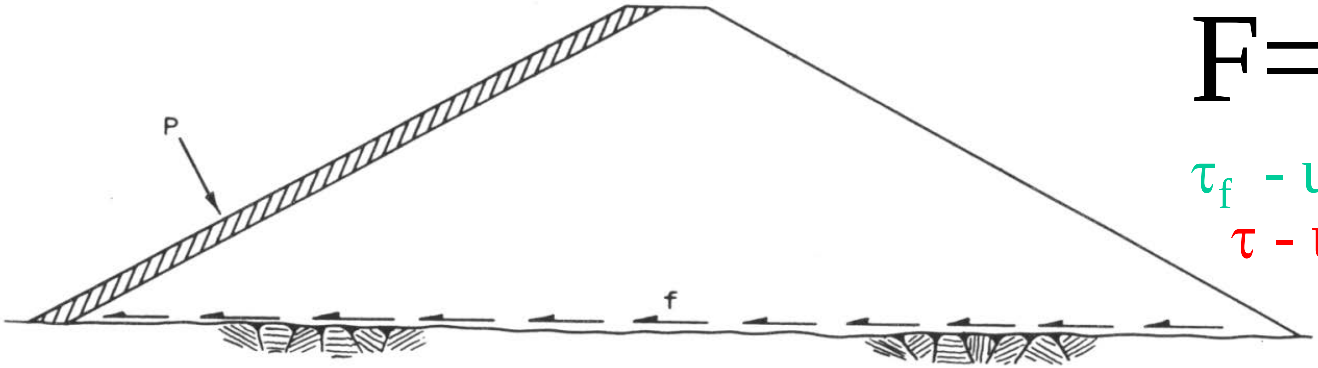
$$F=\Sigma\tau_f / \Sigma\tau$$

τ_f - unit shear resistance

τ - unit shear stress

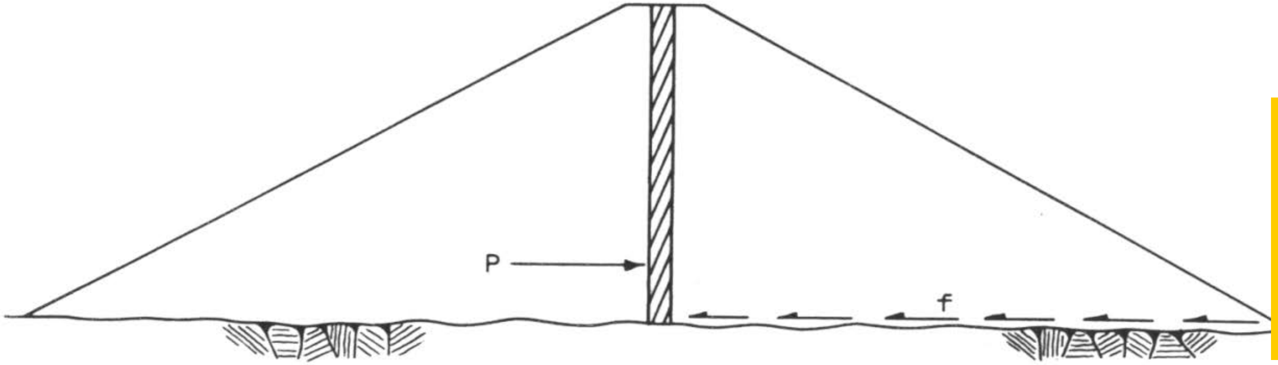
$$\Sigma\tau_f \geq \Sigma\tau$$

$$n_c H s l \leq \frac{m}{k} H$$



(A) UPSTREAM MEMBRANE

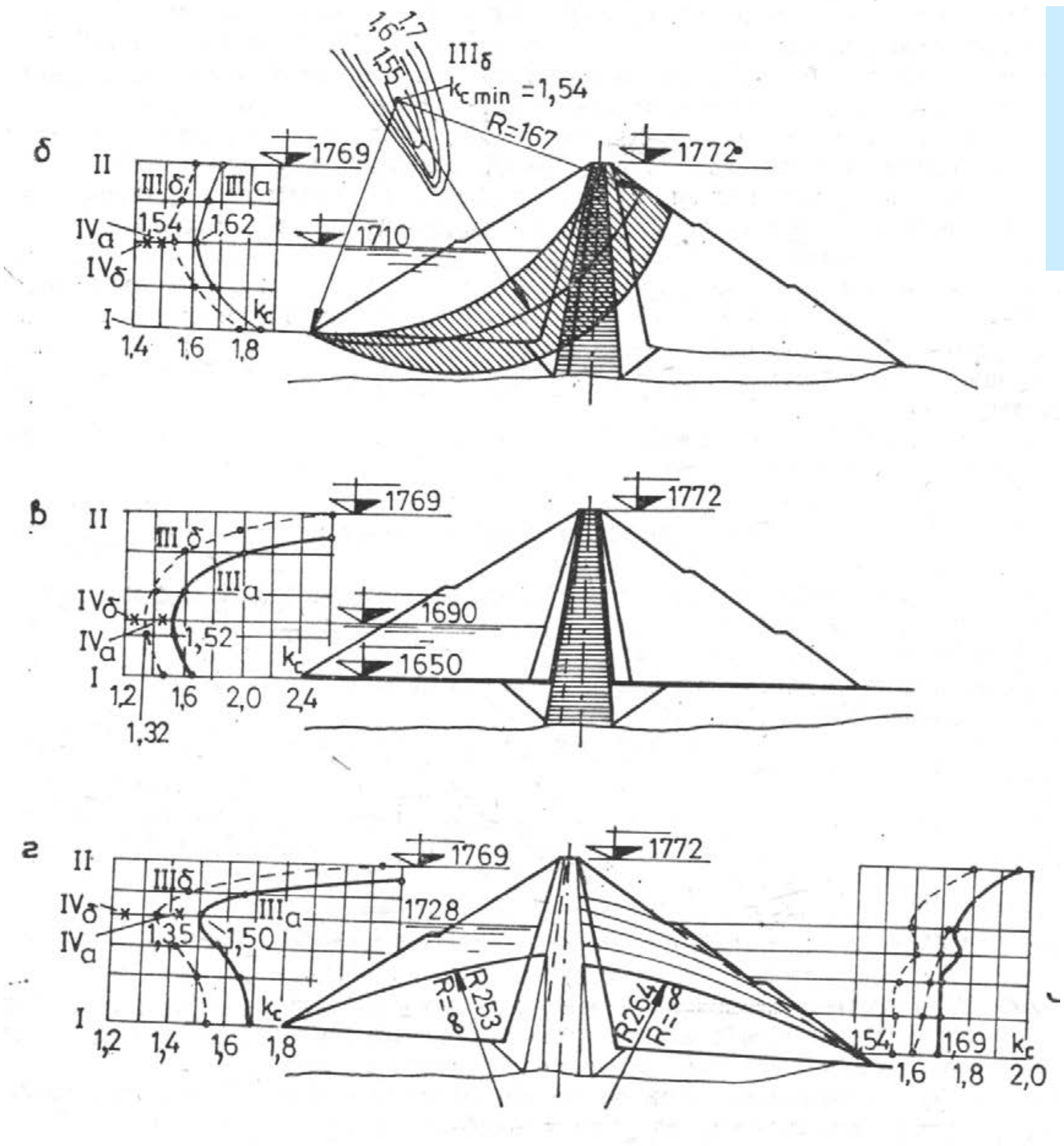
P = Resultant water force
f = Friction forces resisting sliding



(B) CENTRAL MEMBRANE

Figure 7-1.—Resistance to sliding for embankments. 288–D–2796.

Slope Stability



Фиг. 9. 29. Изследване на устойчивостта на язовирната стена „Гепач“ (Австрия)

$$n_c Ma \le \frac{m}{k} Mp$$

$$n_c Pa \le \frac{m}{k} Pp$$