“The Russian Practice of Assessment of Earth Dam Seepage Strength”

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The method of evaluation of seepage strength for earth dams to provide reliable and safe operation of head earth structures had been developed in the USSR in the beginning of 70-s, XX centuary.

From 1973 this method was included into the state standard (SNiP) for earth dam construction. Since that time it is mandatory for application.

Long-term experience of operation of earth dams consructed with calculations by this method demonstrated that there were no serious emergency situations due to seepage strength disturbance of soils of the built dams and their foundations.

The method is based on a real physical picture of seepage processes in earth dams under seepage forces impact.

It is considered that seepage strength of both dams and foundations may be disturbed by various reasons in two events different from each other :

a) in the unknown beforehand places where computation conditions are of uncertain random character.

The examples : zones of loose soil ; ways of concentrated seepage due to internal suffosion, nonuniform deformations and so on. This seepage strength was called as general (casual)

b) in the known beforehand places of the profile dam and with known computation conditions.

The examples : on the contact of dan body soil with adjacent inverse filter ; in the area of seepage flow output into downstream (uplift) ; on the contact of coarse grained and fine grained soils.

The action of a seepage flow on soil skeleton is more often exposed as the following seepage deformations:

suffosion, uplift and colmatage.

Suffosion may be mechanical and chemical.

Dangerous internal suffosion is divided into internal, contact, (normal suffosion) and random (casual). The internal contact suffosion may appear on the contacts of coarse grained and fine grained soil. The casual suffosion may appear in different places due to different casual reasons : insufficcient compaction, nonumiform deformations, structure defects etc. This type may provoke quick formation of areas with strongly loose soil and development of dangerous ways of concentrated seepage.

Uplift – abruption or displacement of some soil volume by an upward seepage flow.

Colmatage is sediment of fine particles, carrying by a seepage flow, in soil pores.

Less often seepage deformations may be revealed in different forms such as soil separation, soil pouring into filter, indentation of filter into soil, soil disintegration (segregation), contact erosion (erosion).

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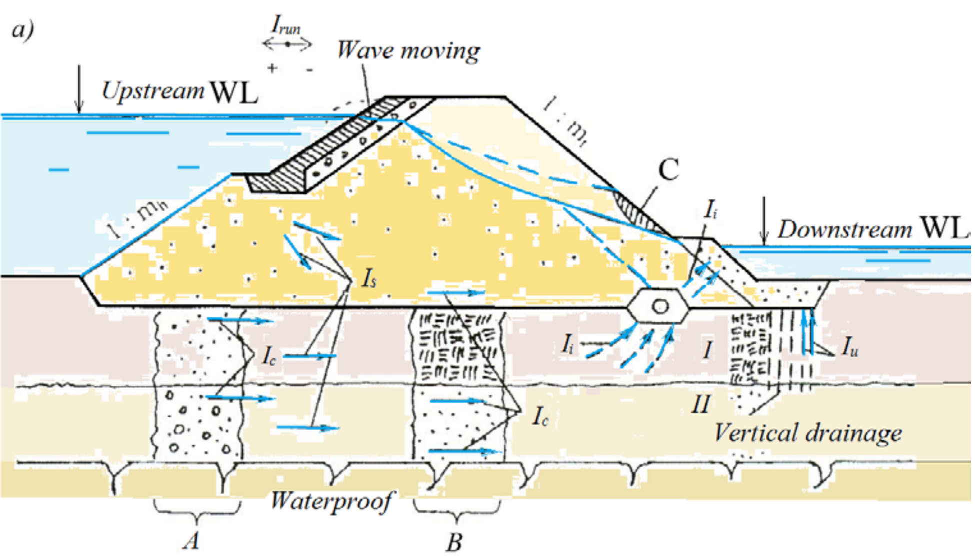
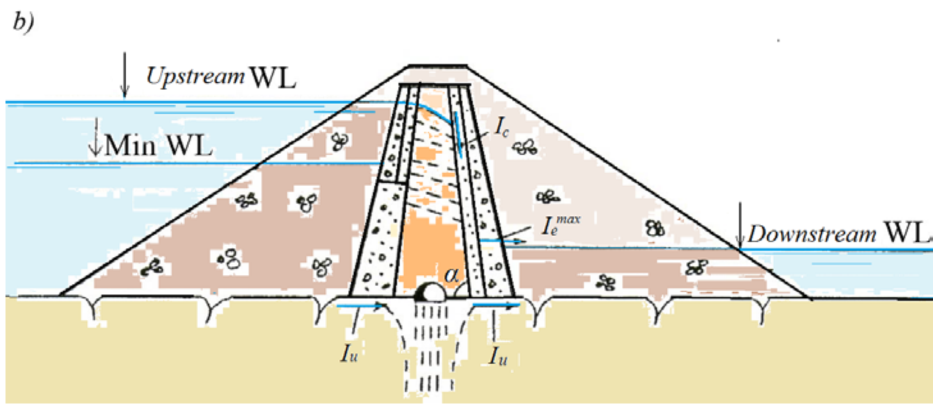
The cross-section of earth and earth-rock dam with main types and zones of seepage deformations, which may happen in dams and their foundations



Uniform dam on stratified foundation



Earth-rock dam on rock foundation

A, B –conjugation of non-cohesive and cohesive soils of foundations;

C –area of local soil uplift in case of spill down the slope;

I_e^{max} - calculated (maximum) hydraulic gradient in the area of seepage flow infiltration on downstream water level;

α - inclination angle of downstream side of core to horizon;

I_s, I_c, I_u, I_i, I_{run} - hydraulic gradients corresponding to the type of seepage deformation: suffosion, contact erosion, uplift (*I* - clay layer, *II* - sand layer), seepage flow input to drainage, pulsation in reverse filter from splash and fall

Estimation method of general seepage strength

This method was proposed by professor R.R.Chugaev. Basic dimensions of an earth dam are determined applying this method: foundation width, drainage location, thickness of a core, face or blanket.

General (casual) strength of earth dam body soil will not be disturbed if

$$I_{est,m} \leq \frac{1}{\gamma_n} I_{cr,m} \qquad (1)$$

Where

$I_{est,m}$ – average head gradient acting in the analysed seepage zone;

$I_{cr,m}$ – average critical hydraulic gradient taken on the basis of soil testing in conditions representing operational conditions at the dam;

γ_n – reliability factor which depends on the social and economic consequences of failure of the dam.

Calculations by the inequality (1) are of checking character. With dam profile for its body and foundation the values $I_{est,m}$ and $I_{cr,m}$ are assigned and then the profile is checked according to the inequality (1).

If there are no the exact values of averaged critical hydraulic gradients, it is recommended to get their approximate values from the Tables of normative documents based on statistical processing of data from successfully operating earth dams.

Estimation method of local seepage strength

Local seepage strength of any dam element depends, mainly, on the value of actual hydraulic gradients and seepage-suffosion properties of soils. The following basic condition has to be fulfilled to provide local seepage strength

$$I_{est} \leq I^{norm} \tag{2}$$

where I_{est} – the actual hydraulic gradient in the considered area.

I^{norm} – the admissible hydraulic gradient for the specific event where

$$I^{norm} \leq \frac{1}{\gamma_n} I_{cr} \tag{3}$$

It is required to define main types of seepage deformations and determine their quantitative (numerical) values in every specific event.

To examine local seepage strength we need to determine a great number of different parameters of contacting soils and get their numerical values : grain-size composition, density. porosity, seepage factor, moisture etc. Besides it is necessary to estimate suffosion processes in soils, diameter of arch-forming and suffosion particles, velocities and hydraulic gradients of seepage and suffosion, their critical values and so on.

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Determination of suffosion processes (non-suffosion processes) in soils and percent of carrying-out of suffosion particles

Dimension of maximum seepage pores in soil is determined by the geophysical parameters of the investigated soil and according to the equation [Pavchich]:

$$d_0^{\max} = 0{,}46\,\chi\sqrt[6]{K_{60,10}}\,\frac{n}{1-n}d_{17} \qquad (4)$$

where

χ –is a variation factor of particle spreading in soil or coefficient of suffosion locality, determined by experimentation,

$K_{60,10}$ – a factor of grain size distribution determined as the ratio d_{60}/d_{10},

d_{60} (d_{10}) is the diameter so that 60% (10%) of soil particles is the same size or smaller than d_{60} (d_{10})

The maximum dimension of particles that may be carried away from soil by a seepage flow is determined by

$$d_{sp}^{\max} = 0{,}77\,d_0^{\max} \qquad (5)$$

If $d_{sp}^{\max} < d^{\min}$, this soil should be considered as non-suffosion soil

If $d_{sp}^{\max} > d^{\min}$, such soil should be considered as suffosion soil

Particles with size less or equal to $d_{sp}^{\max}$ may be carried away if the seepage velocity (hydraulic gradient) is more than critical one $v_{cr,s}\,(I_{cr,s})$.

Determination of critical suffosion gradients

Critical hydraulic gradient ($I_{cr,s}$) relatively to mechanical suffosion, at which suffosion particles d_{sp} beginning from $d_{sp}^{\max}$ and less may be carried out from soil, are determined by the equation [Patrashev, Pravedny 1965]:

$$I_{cr,s} = \varphi_0 d_{sp} \sqrt{\frac{n \cdot g}{\nu} \cdot k} \qquad (6)$$

here: n – soil porosity; g – acceleration of gravity;
ν – kinematic factor of water viscosity; k – permeability factor;
φ_0 – critical velocity factor depending on jamming degree of carrying-out particles, their shape and location in pores and also on direction seepage velocity.

To prevent mechanical suffosion and soil strength disturbance it is necessary that

$$I_{est} \leq I_s^{norm}$$

Estimation of suffosion process of loose various-grained soils by graphical method

For loose various-grained soils [Burenkova and Makran, 1983, 1992] developed a method to represent soil consisted of more coarse particles of "skeleton" and "aggregate" particles inside pores of "skeleton".

For the known granulometric composition by three typical diameters of particles d_{90}, d_{60}, d_{15} and their relations $h^{/} = d_{90} / d_{60}$ and $h^{//} = d_{90} / d_{15}$ it is possible to determine promptly whether the considered composition is in the suffosion zone or not

The value of the diameter dividing soil into "skeleton" and "aggregate" – d_{div} can be determined by the equation:

$$0.55 \cdot (h^{//})^{-1.5} < d_{div} / d_{max} < 0.15 \cdot (h^{/})^{-1.5} \qquad (7)$$

here d_{max} – maximum size of soil particles

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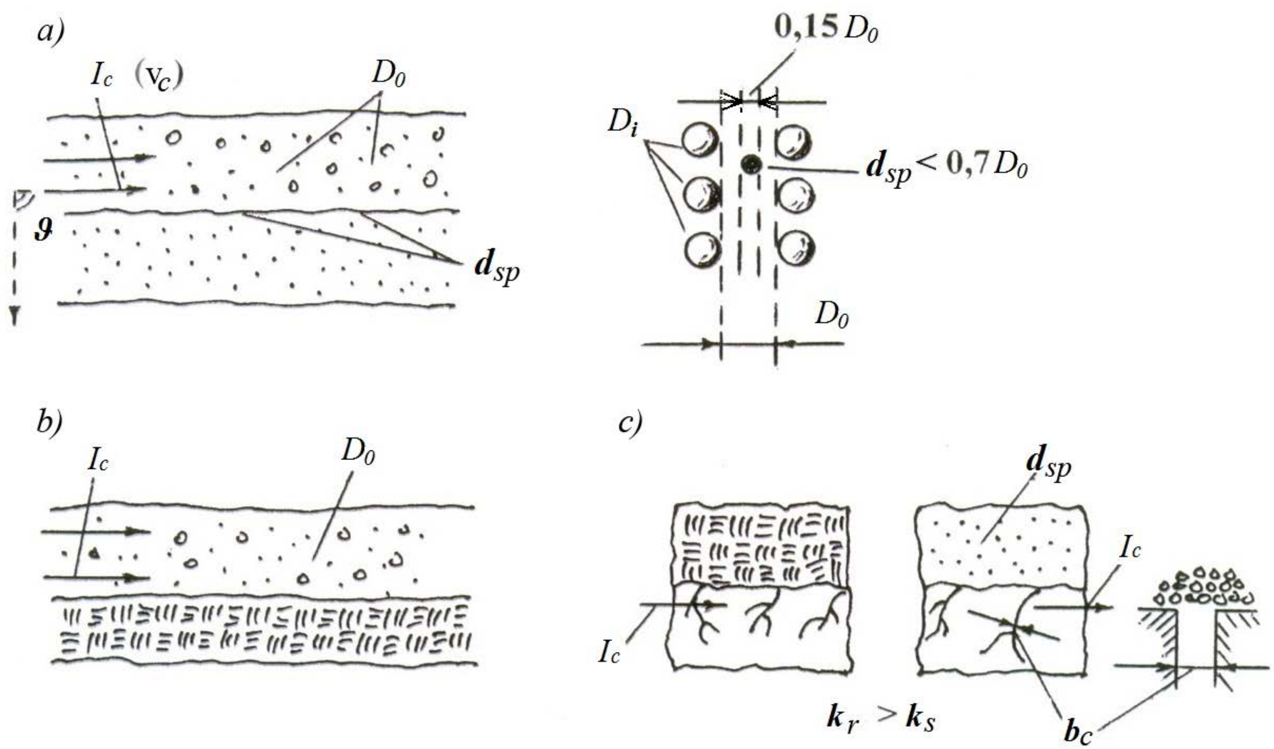
Determination of critical gradients of contact erosion of non-cohesive and cohesive (clay) soils



Contact erosion of soil

a –coarse-grained soil – fine-grained soil; b - coarse-grained soil – clay (cohesive) soil;

c –cracked rock – clay or fine-grained soil; ϑ - angle between directions of seepage velocity and gravity force;

D_o –average size of coarse-grained soil seepage pores;

d_{sp} –dimension of (suffosion) fine-grained soil particles which may be carried out by seepage flow;

k_r – permeability factor of rock; k_s – permeability factor of soil; b_c – crack width

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Determination of critical gradients of contact erosion of non-cohesive soils

If two nonuniform non-cohesive soils (or soil with cracked rock) contact between each other, the critical gradient of fine-grained soil erosion and dimensions of carrying-out particles with the diameter ≥ 3% is determined by the experimental equation [Pravedny]:

$$I_{cr,c} = \frac{1}{\sqrt{\varphi_1}}\left(2{,}3 + 15\frac{d_{sp}}{D_0}\right)\frac{d_{sp}}{D_0}\sin\left(30^\circ + \frac{\vartheta}{8}\right) \qquad (8)$$

φ_1 – the coefficient accounting for the shape and roughness of soil fractions

Determination of critical gradients of contact erosion of cohesive (clay) soils

In case there are contacts between cohesive (clay) soil and coarse-grained material or with cracked rock, the cohesive soil may be eroded.
The value of the critical erosion gradient at contact seepage: cohesive (clay) soil with plasticity index - coarse-grained soil (or cracked rock), may be determined by the experimental equation [Pravedny]:

$$I_{cr,c} = \frac{1}{\sqrt{D_0^{\max}}} - 0.75 \qquad (9)$$

$D_0^{\max}$ – is determined by the equation (4) for coarse-grained soil, at that ≤ 0.018 m

$D_0^{\max}$ > 0.018 m the cohesive soil will be separated in pores of coarse-grained material, the contact erosion).

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