European Commission

Hydraulic failure

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Contents

- Definitions
- Verification against failure by uplift
- Verification against failure by heave
- Internal erosion
- “Verification” against failure by piping

10.1 General

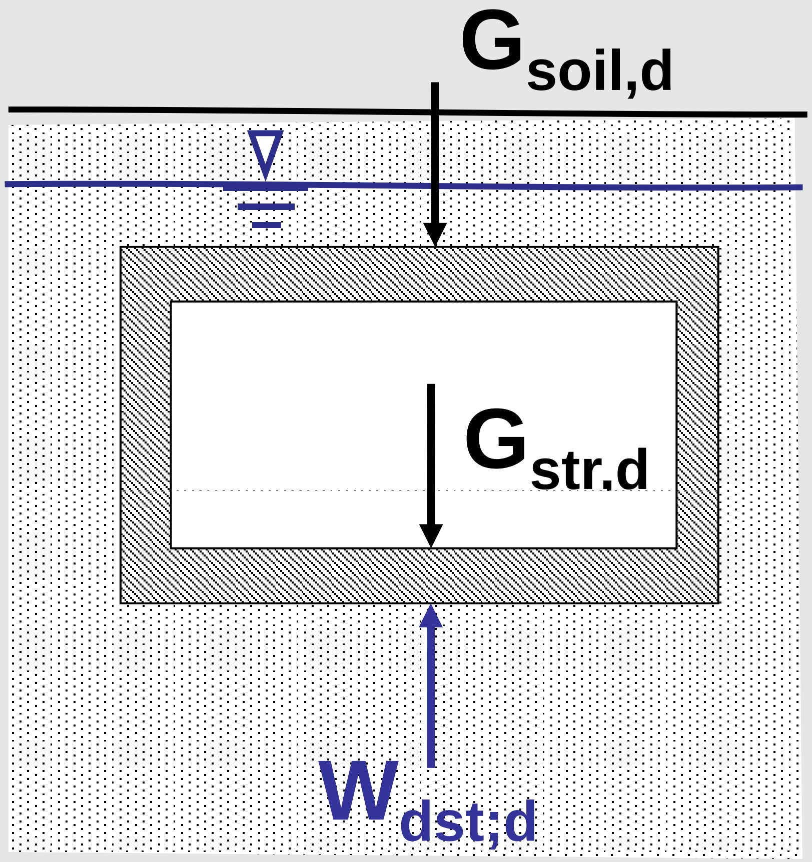
(1)P The provisions of this Section apply to **four modes** of ground failure induced by pore-water pressure or pore-water seepage, which shall be checked, as relevant:

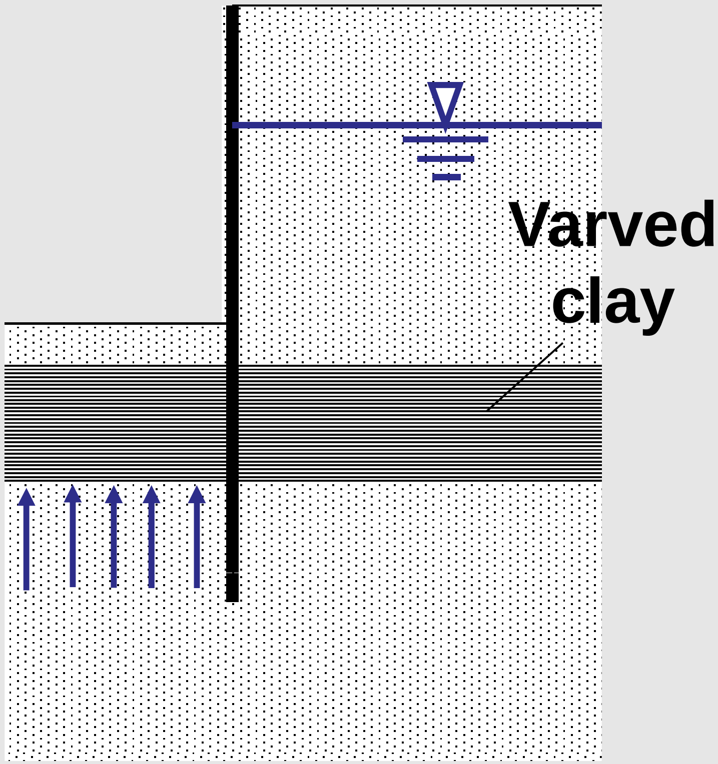
- failure by uplift (UPL);
- failure by heave;
- failure by internal erosion;
- failure by piping.

NOTE 1 Failure by uplift (UPL) occurs when pore-water pressure under a structure or a low permeability ground layer becomes larger than the mean overburden pressure (due to the structure and/or the overlying ground layer).

NOTE 2 Failure by heave occurs when upwards seepage forces act against the weight of the soil, reducing the vertical effective stress to zero. Soil particles are then lifted away by the vertical water flow and failure occurs (boiling).

Examples of failure by uplift





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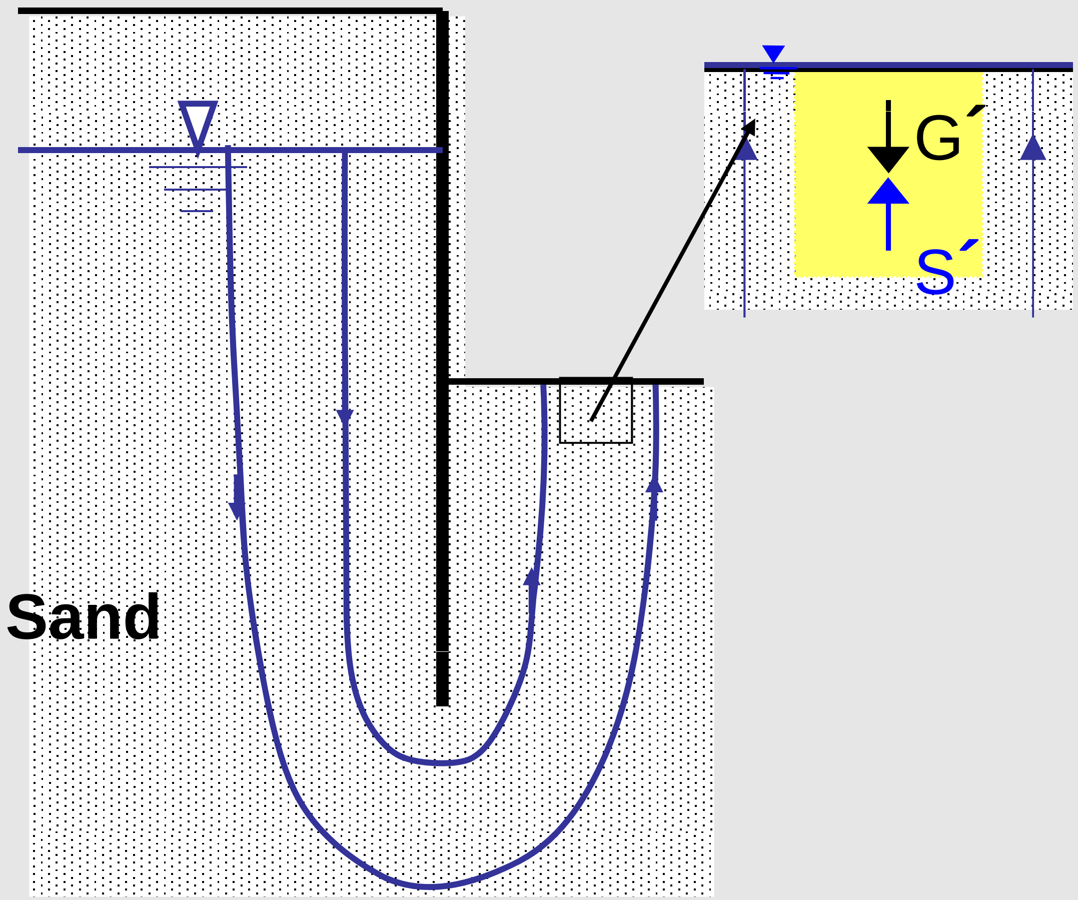
10.3 Failure by hydraulic heave HYD



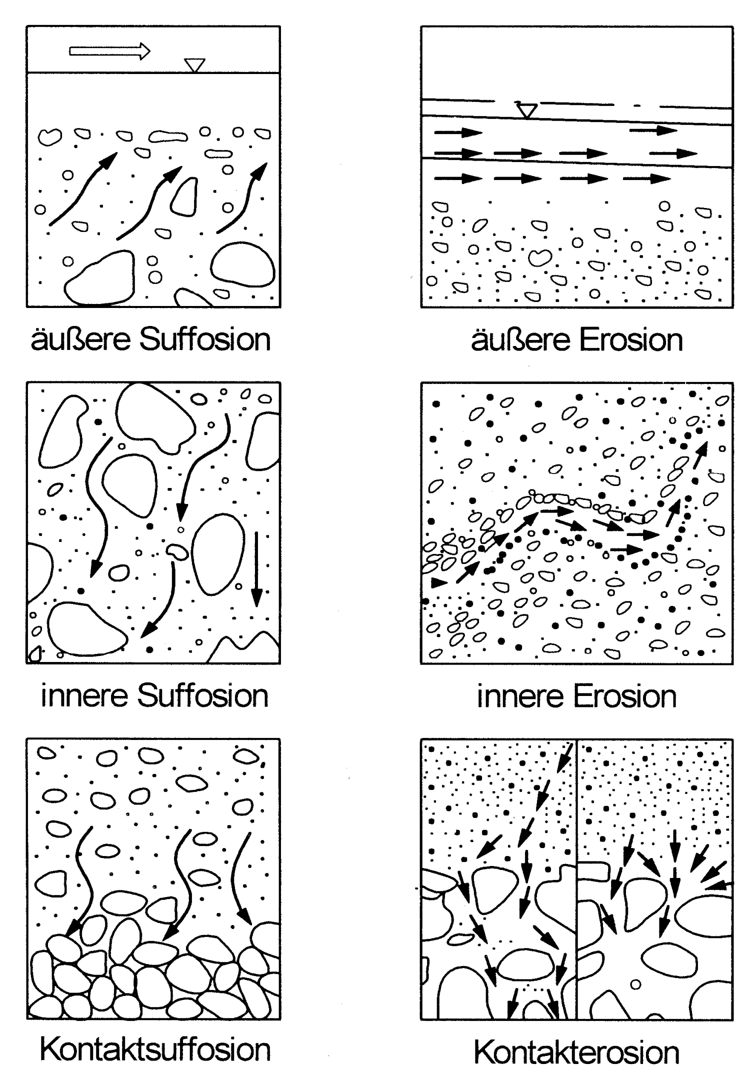
10.1 General

NOTE 3 Failure by internal erosion is produced by the transport of soil particles within a soil stratum, at the interface of soil strata, or at the interface between the soil and a structure. This may finally result in regressive erosion, leading to collapse of the soil structure.

NOTE 4 Failure by piping is a particular form of failure, for example of a reservoir, by internal erosion, where erosion begins at the surface, then regresses until a pipe-shaped discharge tunnel is formed in the soil mass or between the soil and a foundation or at the interface between cohesive and non-cohesive soil strata. Failure occurs as soon as the upstream end of the eroded tunnel reaches the bottom of the reservoir.

10.1 General

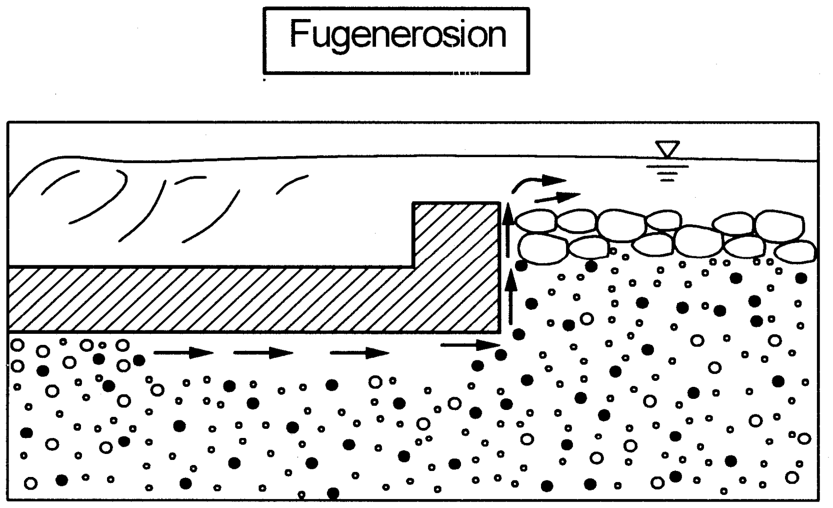
Types of erosion



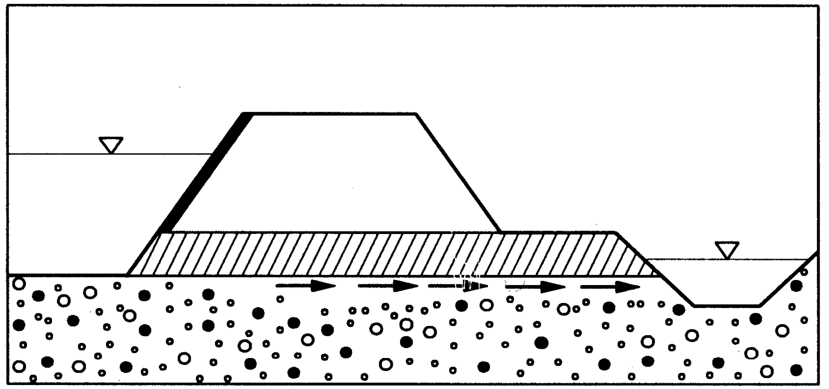
10.1 General

Erosion at interfaces:

- Soil-structure interface
- at interface between layers



Fugenerosion bei Bauwerken



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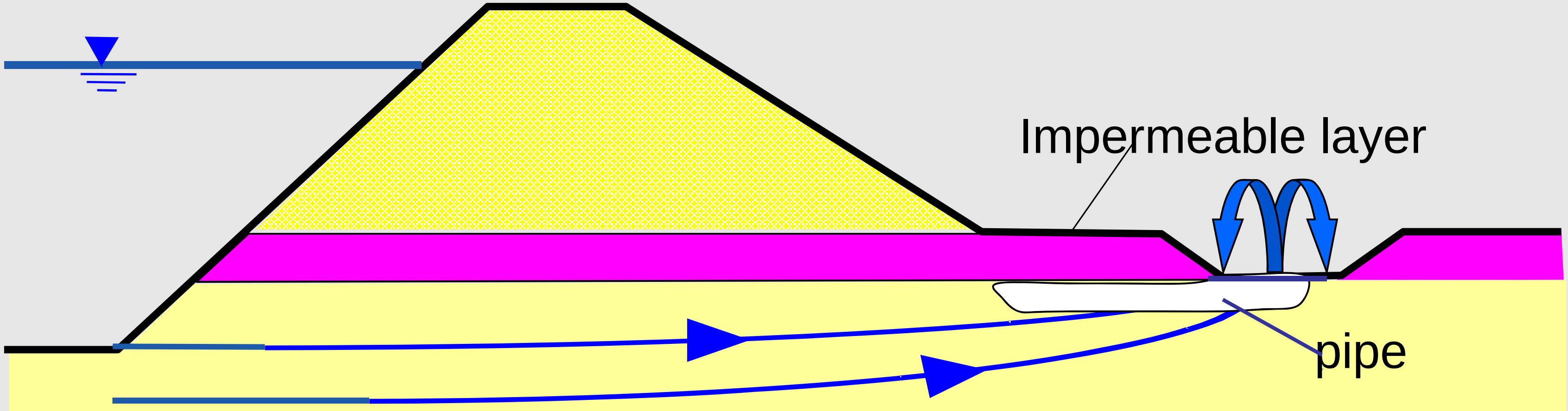

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10.2 Failure by uplift UPL

Verification against failure by uplift

(1)P The stability of a structure or of a low permeability ground layer against uplift shall be checked by comparing the permanent stabilising actions (for example, weight and side friction) to the permanent and variable destabilising actions from water and, possibly, other sources.

2.4.7.4 Verification of uplift

(1)P Verification for uplift (UPL) shall be carried out by checking that the design value of the combination of **destabilising** permanent and variable vertical actions ($V_{dst;d}$) is less than or equal to the sum of the design value of the **stabilising** permanent vertical actions ($G_{stb;d}$) and of the design value of any additional resistance to uplift (R_d):

$$\boldsymbol{V_{dst,d} \leq G_{stb;d} + R_d} \qquad (2.8)$$

where

$$\boldsymbol{V_{dst,d} = G_{dst;d} + Q_{dst;d}}$$

(2) Additional resistance to uplift may also be treated as a stabilising permanent vertical action ($G_{stb;d}$).

10.2 Failure by uplift UPL

Table A.15 - Partial factors on actions (γ_F)

Action	Symbol	Value
Permanent Unfavourable[a] Favourable[b]	 $\gamma_{G;dst}$ $\gamma_{G;stb}$	 1,0 0,9
Variable Unfavourable[a]	$\gamma_{G;stb}$	1,5

[a] Destabilising;
[b] Stabilising

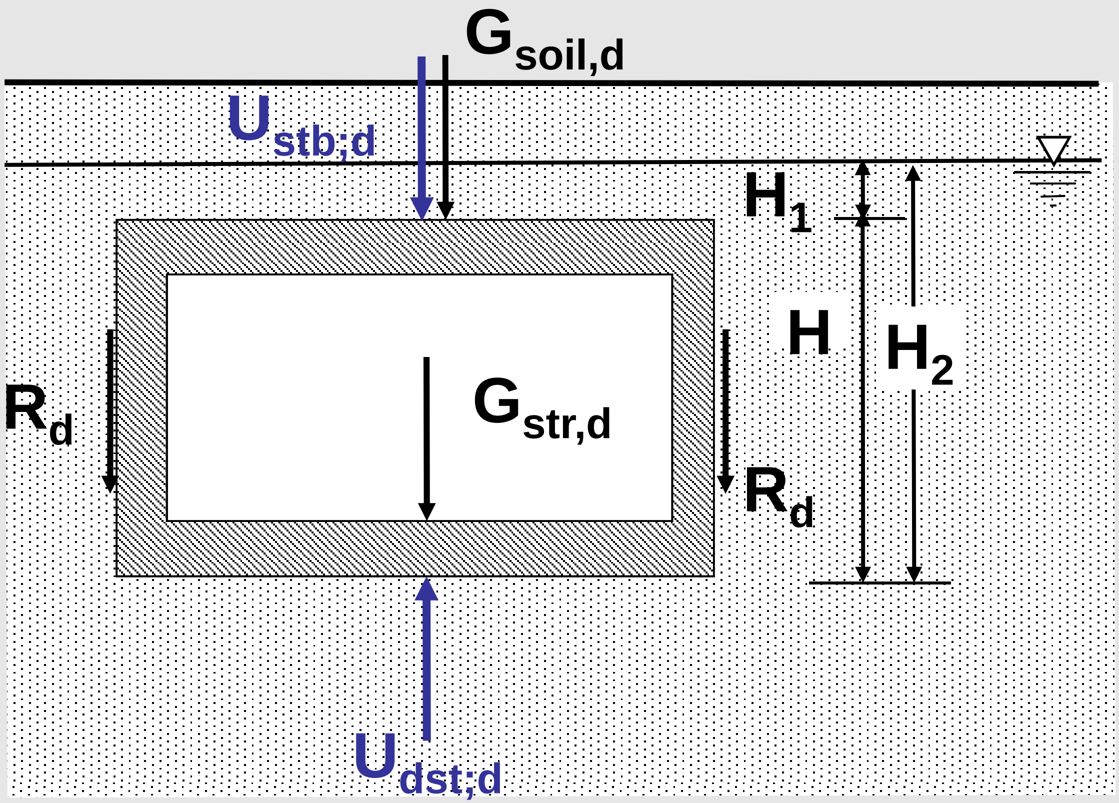
Table A.16 - Partial factors for soil parameters and resistances

Soil parameter	Symbol	Value
Angle of shearing resistance a	$\gamma_{\varphi'}$	1,25
Effective cohesion	$\gamma_{c'}$	1,25
Undrained shear strength	γ_{cu}	1,40
Tensile pile resistance	$\gamma_{s;t}$	1,40
Anchorage resistance	γ_a	1,40

[a] This factor is applied to tan φ'

10.2 Failure by uplift

Example: Tunnel below the ground water table



2.4 Geotechnical design by calculation

2.4.2 Actions

(9)P Actions in which ground- and free-water forces predominate shall be identified for special consideration with regard to deformations, fissuring, variable permeability and erosion.

NOTE Unfavourable (or destabilising) and favourable (or stabilising) permanent actions may in some situations be considered as coming from a single source. If they are considered so, a single partial factor may be applied to the **sum of these actions** or to the sum of their effects.

10.2 Failure by uplift

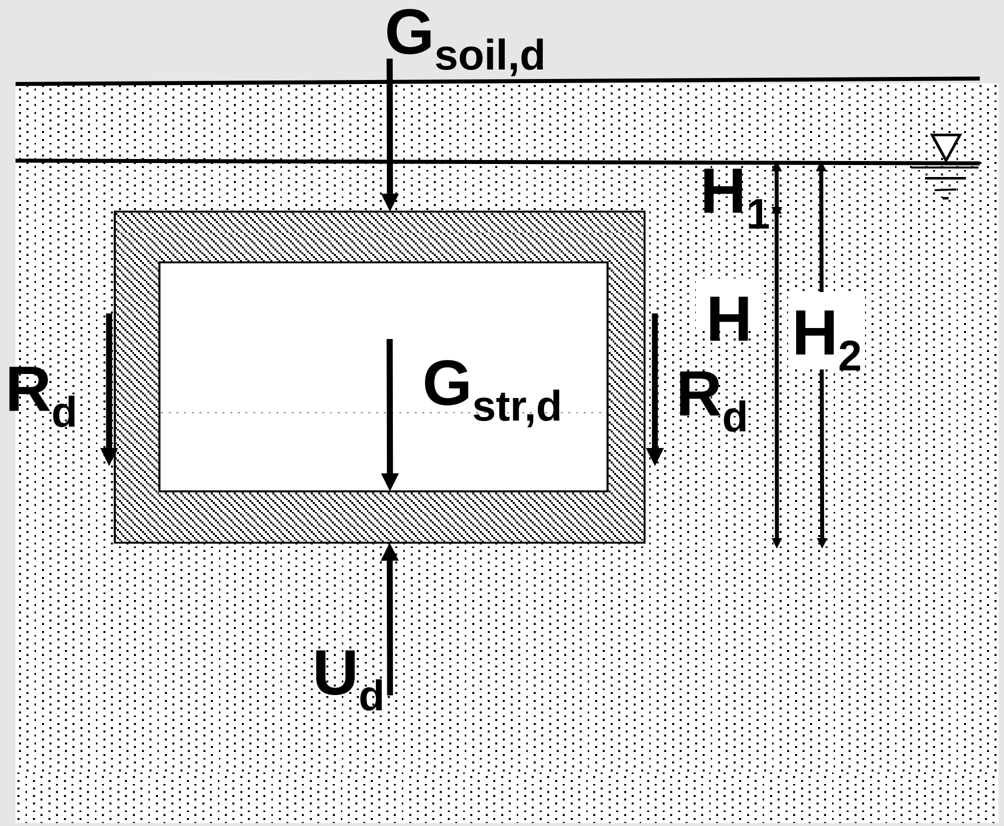
Example: Tunnel below the ground water table

$$V_{dst,k} = U_k$$
$$U_k = \gamma_w \cdot (H_2 - H_1) \cdot A$$
$$U_k = \gamma_w \cdot H \cdot A$$

$$V_{dst,d} = U_d = \gamma_{G,dst} \cdot \gamma_w \cdot H \cdot A$$

$$\boldsymbol{V_{dst,d} \leq G_{stb;d} + R_d}$$

$$U_d \leq G_{str,d} + G_{soil,d} + R_d$$



Measures against failure by uplift UPL

(4) The measures most commonly adopted to resist failure by uplift are:

- increasing the weight of the structure;
- decreasing the water pressure below the structure by drainage;
- anchoring the structure in the underlying strata.

(5)P Where piles or anchorages are used to provide resistance against failure by uplift, the design shall be checked according to 7.6.3 or 8.5, respectively, using the partial factors given in 2.4.7.4.

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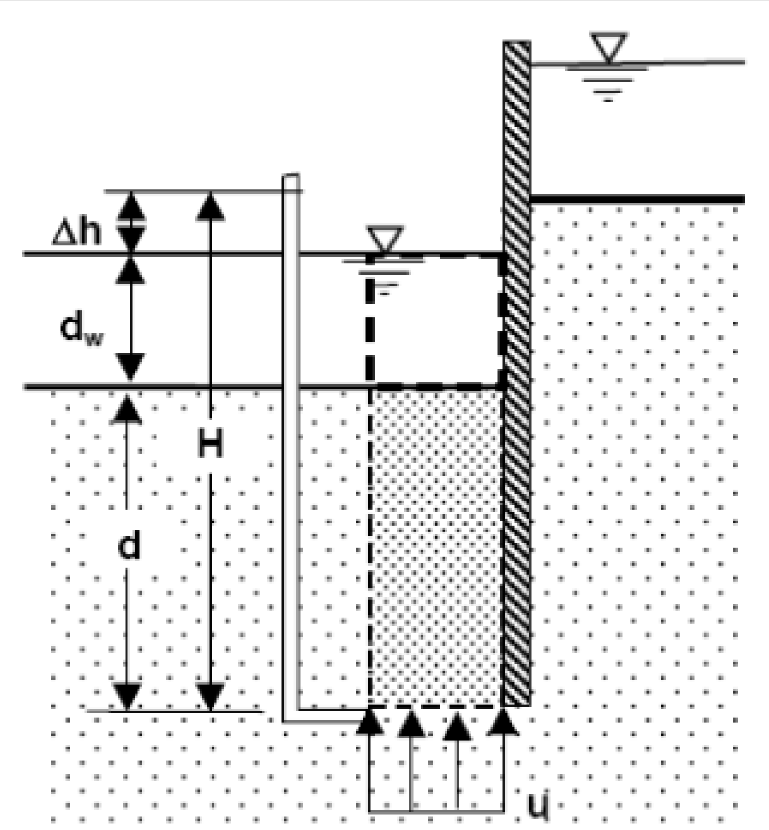
2.4.7.5 Verification of failure by heave

(1)P When considering a limit state of failure due to heave by seepage of water in the ground (HYD, see 10.3), it shall be verified, for every relevant soil column, that the design value of the destabilising total pore water pressure ($u_{dst;d}$) at the bottom of the column, or the design value of the seepage force ($S_{dst;d}$) in the column is less than or equal to the stabilising total vertical stress ($\sigma_{stb;d}$) at the bottom of the column, or the submerged weight ($G'_{stb;d}$) of the same column:

$$\boldsymbol{u_{dst;d} \leq \sigma_{stb;d}} \qquad \textbf{(2.9a)}$$

$$\boldsymbol{S_{dst;d} \leq G'_{stb;d}} \qquad \textbf{(2.9b)}$$



10.3 Failure by hydraulic heave HYD

$$u_{d;dst} \leq \sigma_{d;stb} \qquad (2.9a)$$

$$\gamma_{G;dst} \cdot u_{k;dst} \leq \gamma_{G;stb} \cdot \sigma_{d;stb}$$

$$u_{k;dst} = \gamma_w \cdot (\Delta h + d_w + d)$$

$$\sigma_{k;stb} = (\gamma' + \gamma_w) \cdot d + \gamma_w \cdot d_w$$

$$\sigma_{k;stb} = \gamma' \cdot d + \gamma_w \cdot (d + d_w))$$

$$\gamma_{G;dst} (\gamma_w \cdot \Delta h + \gamma_w \cdot (d + d_w)) \leq \gamma_{G;stb} ((\gamma' d + \gamma_w \cdot (d + d_w))$$

Therefore eq. 2.9b should be used!

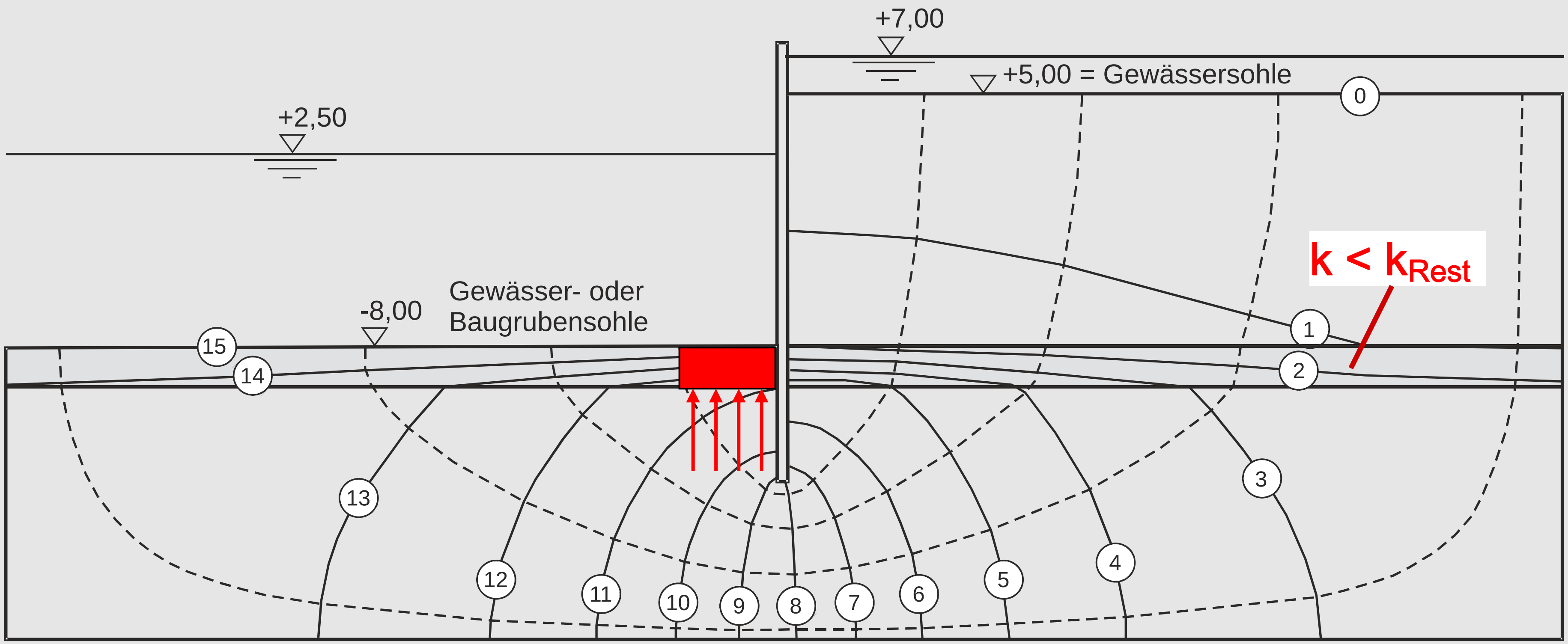
10.3 Failure by hydraulic heave HYD

(2)P The determination of the characteristic value of the **pore-water pressure shall** take into account all possible unfavourable conditions, such as:

- thin layers of soil of low permeability;
- spatial effects such as narrow, circular or rectangular excavations below water level.

10.3 Failure by hydraulic heave HYD

Example of the influence of a layer of low permeability



10.3 Failure by hydraulic heave HYD

Determination of the seepage force

- measurement of the pore water pressure in the soil
- approximative solutions from handbooks
- graphical determinations of the flow- and potential field
- numerical methods

Measures against failure by hydraulic heave

(3) The measures most commonly adopted to resist failure by heave are:

- decreasing the water pressure below the soil mass subjected to heave;
- increasing the resisting weight.

10.3 Failure by heave

(2)P The determination of the characteristic value of the **pore-water pressure shall** take into account all possible unfavourable conditions, such as:

- thin layers of soil of low permeability;
- spatial effects such as narrow, circular or rectangular excavations below water level.

NOTE 1 Where the soil has a significant cohesive shear resistance, the mode of failure changes from failure by heave to failure by uplift. The stability is then checked by using the provisions of 10.2 (uplift) where additional resisting forces may be added to the weight.

Uplift

Table A.15 - Partial factors on actions (γ_F)

Action	Symbol	Value
Permanent		
Unfavourable[a]	$\gamma_{G;dst}$	1,0
Favourable[b]	$\gamma_{G;stb}$	0,9
Variable		
Unfavourable[a]	$\gamma_{Q;dst}$	1,5

[a] Destabilising;
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Hydraulic heave

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Permanent		
Unfavourable[a]	$\gamma_{G;dst}$	1,35
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Variable		
Unfavourable[a]	$\gamma_{Q;dst}$	1,50

a Destabilising
b Stabilising

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10.4 Internal erosion

(1)P Filter criteria shall be used to ~~limit~~ asses the danger of material transport by internal erosion.

(5)P If the filter criteria are not satisfied, it shall be verified that the critical hydraulic gradient is well below the design value of the gradient at which soil particles begin to move.

(6)P The critical hydraulic gradient for internal erosion shall be established taking into consideration at least the following aspects:

- direction of flow;
- grain size distribution and shape of grains;

10.4 Steps to check internal erosion

Check of the geometrical criteria:
(filter criteria)

↓

at interface between two soil layers: filter criteria

soil layer itself divide in a coarse and a fine part: apply filter criteria

↓

Check hydraulic criteria:
is the hydraulic gradient sufficient to transport soil particles?

↓

Check the effect of internal erosion:
assess the soil mass displaced by water

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10.5 Failure by piping

(3)P Failure by piping shall be prevented by providing sufficient resistance against internal soil erosion in the areas where water outflow may occur.

(4) Such failure can be prevented by providing:

- sufficient safety against failure by heave where the ground surface is horizontal;
- sufficient stability of the surface layers in sloping ground (local slope stability).

Verification against failure by piping

(5)P When determining the outflow hydraulic conditions for the verification of failure by heave or of local slope stability, account shall be taken of the fact that joints or interfaces between the structure and the ground can become preferred seepage paths.

Table: Examples for the assessment of the development of gaps or preferred flow paths for structures in dams[1)]

Areas percolated by water	Normal reduction of the hydraulic potential	No reduction of the hydraulic potential gaps can not be ruled out
at the interface between soil and a driven sheet pile wall	x	
at the interface between soil and a vertical, smooth wall back-filled with non-cohesive soil	x	
at the interface between soil and a cast in place concrete element or foundation	x	
at the interface between soil and a prefabricated concrete element or foundation		x
below a piled raft		x

1) BAW Code of Practice - Stability of Embankments at German Inland Waterways

Steps to check of the failure by piping:

1. Assess where **preferred flow paths** already exist or may develop.
2. **Determine the flow-net** taking into account the hydraulic assumptions and boundary conditions assessed in the first stage.
3. Investigate the areas where the water comes to the ground. Check whether there is
   - **sufficient safety against failure by heave** where the ground surface is horizontal or
   - **sufficient stability of the surface layers** in sloping ground (local slope stability).
4. Check the susceptibility of the ground of the top layer to internal erosion.

Reference:

BAW Code of Practice - Stability of Embankments at German Inland Waterways

directly downloadable

> www.baw.de

> publications

> codes of practice

> MSD (2011)

European Commission

Geotechnical design with worked examples

eurocodes.jrc.ec.europa.eu