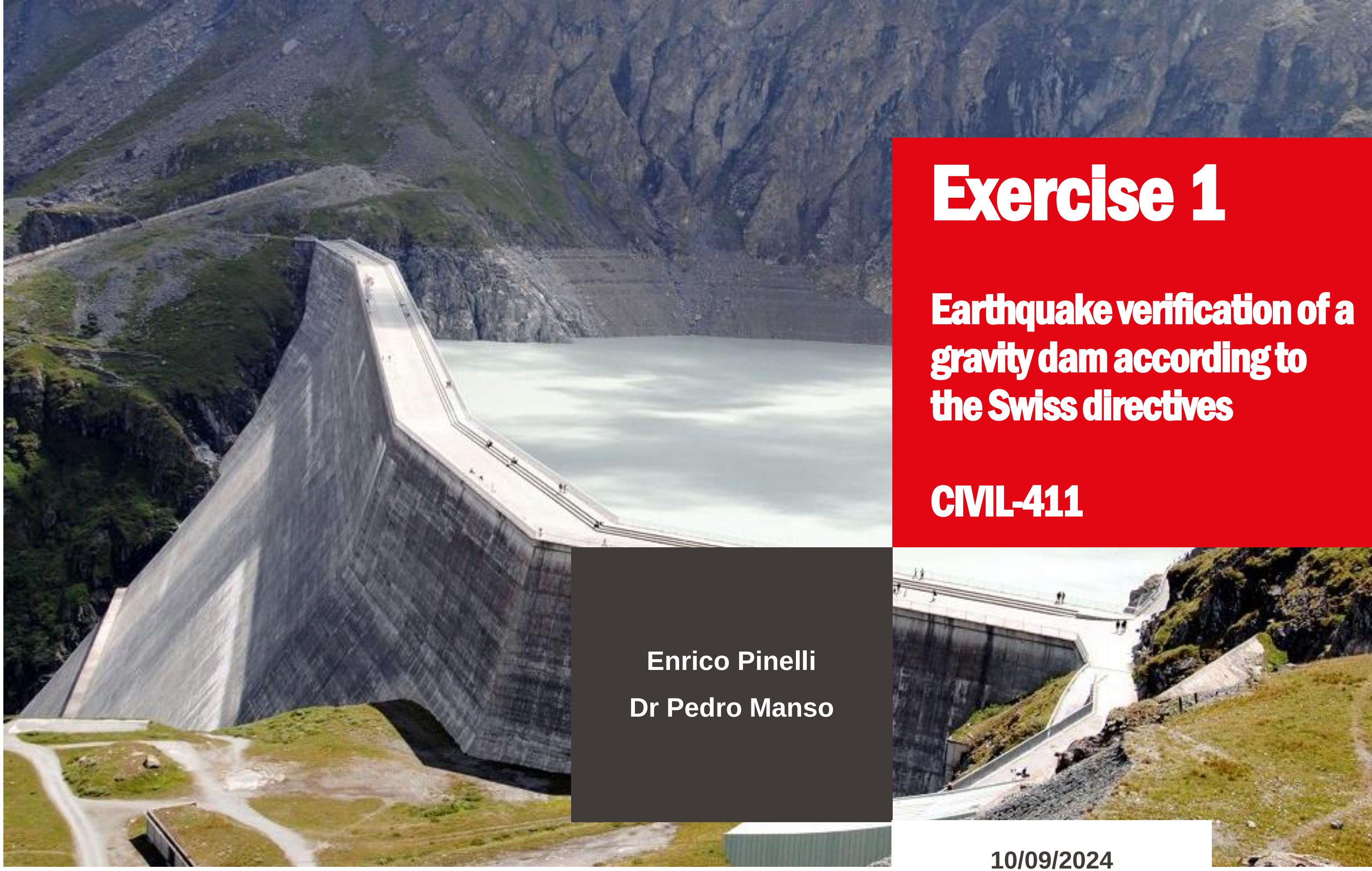

Exercise 1

Earthquake verification of a gravity dam according to the Swiss directives

CIVIL-411

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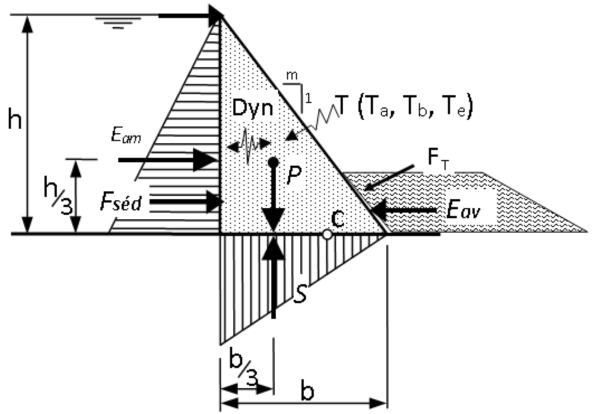
Introduction

- Earthquake verification of a gravity dam according to the Swiss directives
- Available documents:
  - Design, Safety and Operation of Dams (A.J. Schleiss and H. Pougatsch)
  - *Directive relative à la sécurité des ouvrages d'accumulation,* ***Partie C3*** *: sécurité aux séismes* [1]
- Analysis of the reservoir behavior during the earthquake (the behavior of the reservoir after the earthquake is not analyzed within this exercise).
- The analysis of the case with **full reservoir** is generally sufficient for checking the seismic safety of reservoirs.

[1] Directive C3

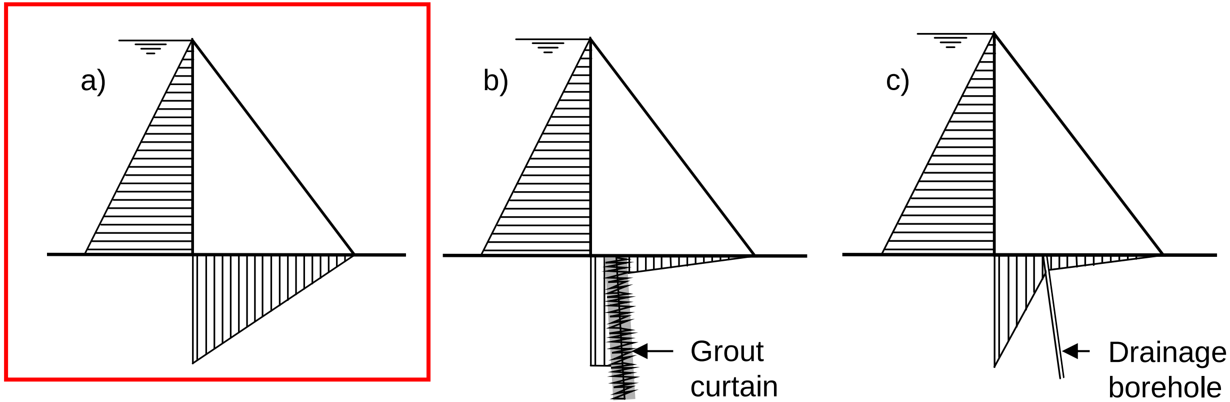
Gravity dam

- Static principle:
  - Self-weight counters the water pressure by the resulting friction
  - Each element is stable (no arch or bi-directional effect)
  - Normal load case: only compressive stresses (non-reinforced concrete)
- Principal forces acting on a gravity dam:
  - Self-weight
  - Upstream water pressure
  - Downstream water pressure
  - Uplift
  - Active earth pressure (sediments)
  - Ice load
  - Seismic load
  - Temperature

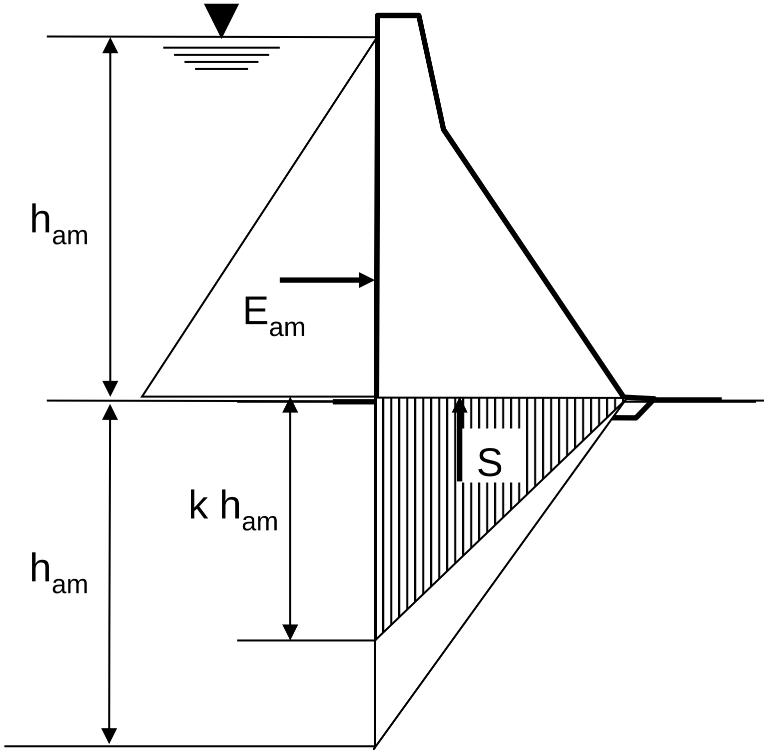


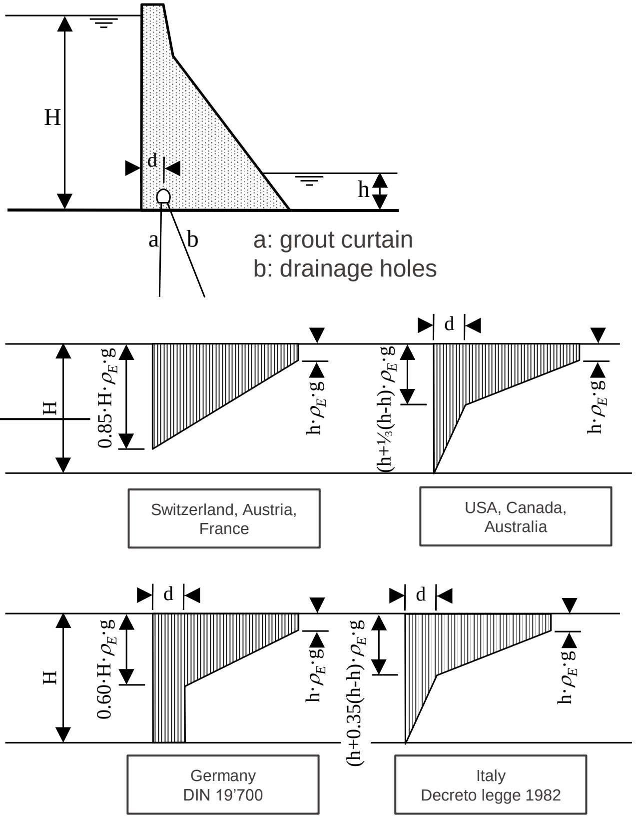
Uplift

- Important active hydrostatic force (especially for gravity dams)
- Difficult to assess: many assumptions about its distribution
- Acts both inside the concrete and the foundation
- Establishment of a flow pattern inside the concrete and the rock mass



Uplift


h_{am}
E_{am}
$k\ h_{am}$
S
h_{am}


H
d
h
a
b
a: grout curtain
b: drainage holes
H
$0.85 \cdot H \cdot \rho_E \cdot g$
$h \cdot \rho_E \cdot g$
Switzerland, Austria, France
d
$(h+1/3(H-h)) \cdot \rho_E \cdot g$
$h \cdot \rho_E \cdot g$
USA, Canada, Australia
d
H
$0.60 \cdot H \cdot \rho_E \cdot g$
$h \cdot \rho_E \cdot g$
Germany
DIN 19'700
d
$(h+0.35(H-h)) \cdot \rho_E \cdot g$
$h \cdot \rho_E \cdot g$
Italy
Decreto legge 1982

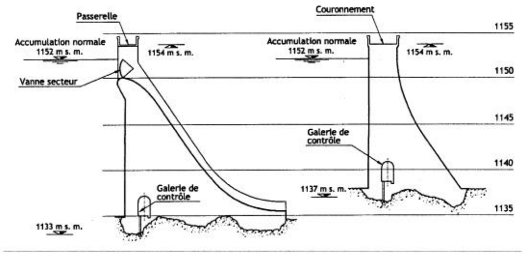
Exercise 1

- Essential controls for gravity dams:
  - Safety against overturning → Dam stability
  - Safety against sliding → Dam stability
  - Safety against internal failure → Concrete strength (stresses)
  - (safety against lifting)

- In this exercise:
  - **Only full reservoir**
  - 2 x-sections only: **typical XS**, **spillway chute XS**
  - Exercise in 2 parts:
    - Static analysis
    - Dynamic analysis (pseudo-static)
  - Triangular distribution (a) of uplift
    - Static analysis: k=0.4
    - Dynamic analysis: k=1 (considered during earthquakes)
  - Temperature effects will be neglected
  - *Bonus: Empty reservoir + eligibility of the dam for simplified verification*

Spillway chute cross section

Typical dam cross-section



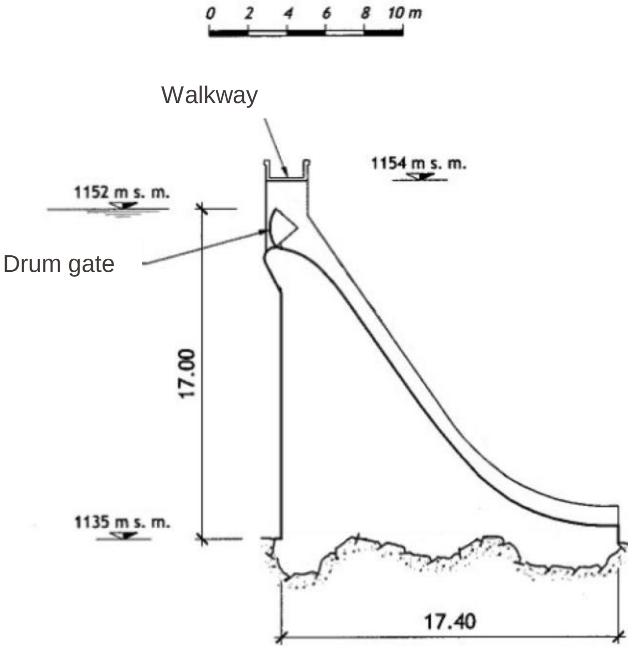
Exercise 1

- **Part 1: Static analysis**
  - Friction angle ground-concrete to be determined according to Barton
  - Verification of dam stability
    - Safety against failure (stresses) not necessary for part 1
    - Generalized safety against overturning ($S_{O,stat} >> 1$)
    - Generalized safety against sliding ($S_{S,stat} >> 1$)
  - Normal load case (to be defined)
  - Comment on results: Importance of the uplift coefficient k?
- **Part 2: Dynamic analysis**
  - Earthquake verification according to current Swiss directives (dynamic analysis)
    - Safety against failure: stress verification (compare with materials strength)
    - Safety against sliding
    - Safety against overturning ($S_{O,dyn} > 1.1$)
  - Exceptional load case (earthquake)
  - Pseudo-static analysis (with the Westergaard method)

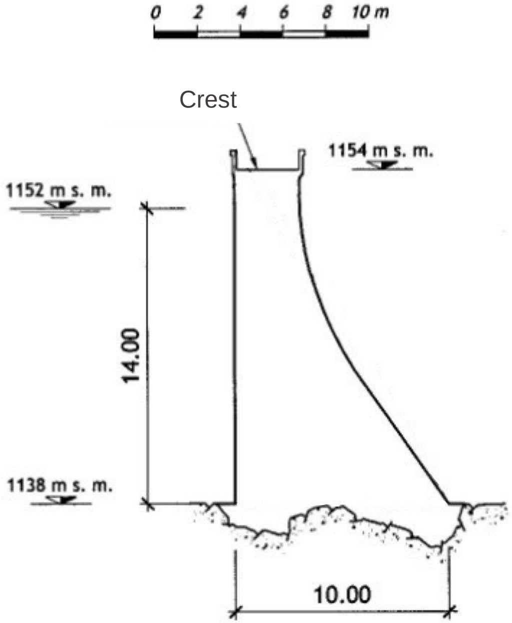
Considerations for exercise 1

Geometry

Chute section

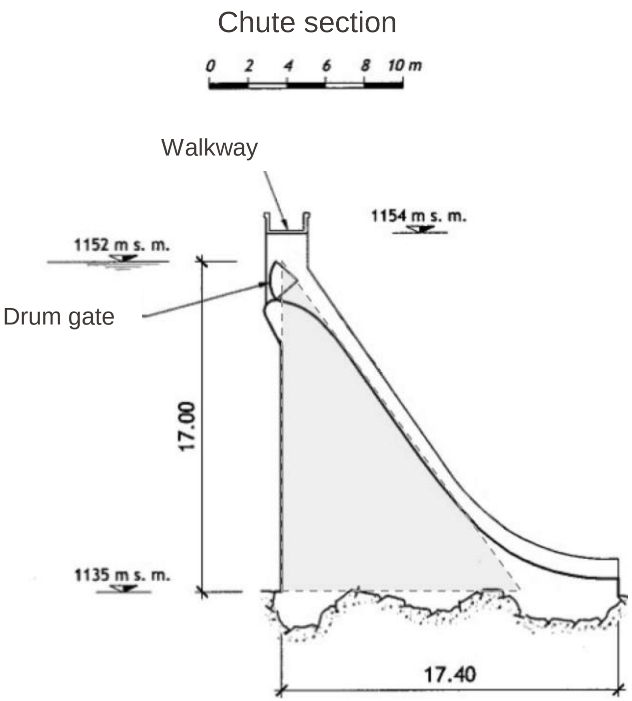


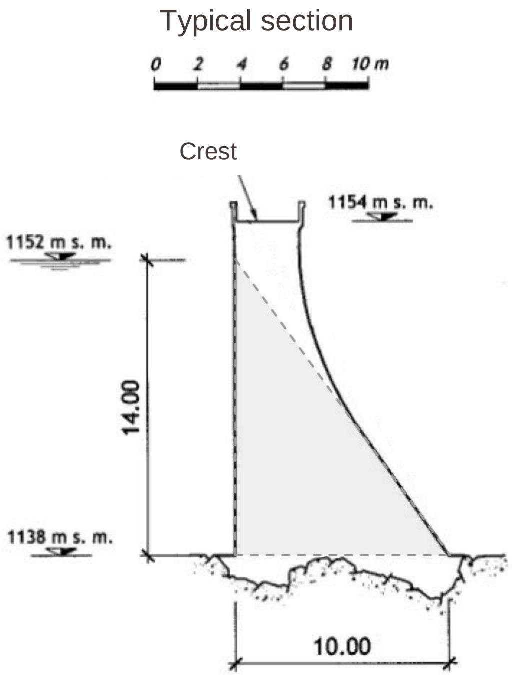
Typical section



Considerations for exercise 1

Geometry





Friction angle at ground-dam interface

- To determine according to Barton

$$\Phi' = \Phi_r + [JRC \cdot \log(JCS/\sigma_n')]$$

  - Φ_r: residual friction angle
  - JRC: Geometric joint roughness coefficient
  - JCS: Equal to the simple compressive strength of the rock
  - σ'_n: Normal effective stress

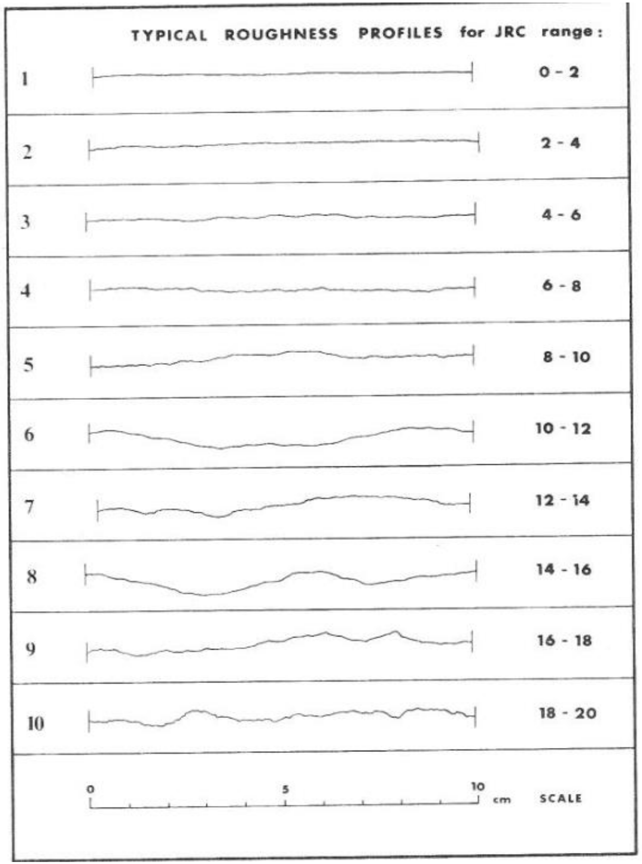
Considerations for exercise 1

Friction angle at ground-dam interface

$$\Phi' = \Phi_r + [JRC \cdot \log(JCS/\sigma_n')]$$

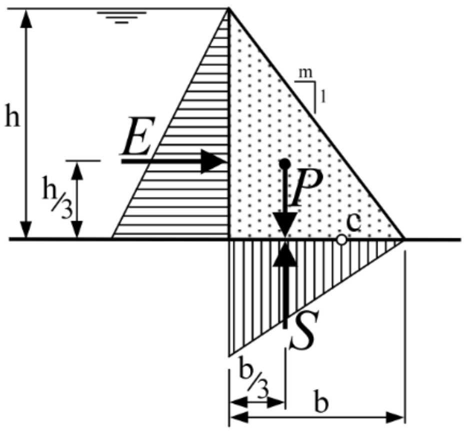
Values for the angle of friction (tanϕ´)

			tanϕ´
1	Concrete-concrete	Fissure in the dam body, crack	: 2.0 à 3.0
		Lift joint, neat (soigné)	: 1.5 à 2.1
2	Concrete-rock	Good rock quality	: 1.5 à 1.9
		Bad to medium rock quality	: 0.5 à 1.5
3	Rock-rock	Good quality and few joints	: 1.0 à 1.9
		Medium quality and a lot of joints	: 0.5 à 1.0

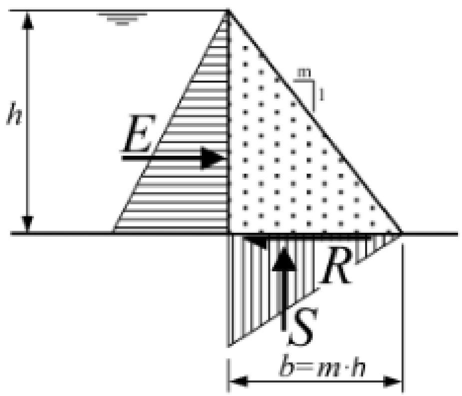


Part 1: Static analysis

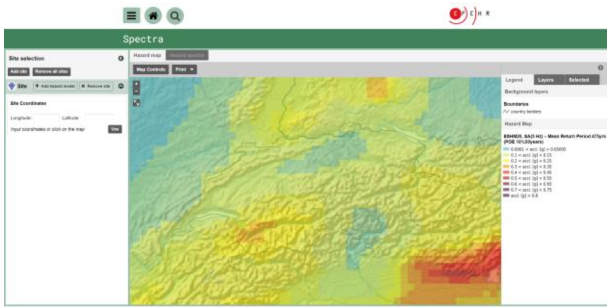
Safety against overturning



Safety against sliding



Part 2: Dynamic analysis



- Spectral acceleration:

  1. Determine the reference acceleration $S_{a0.15SED}$ from the hazard spectrum [2] at the provided location

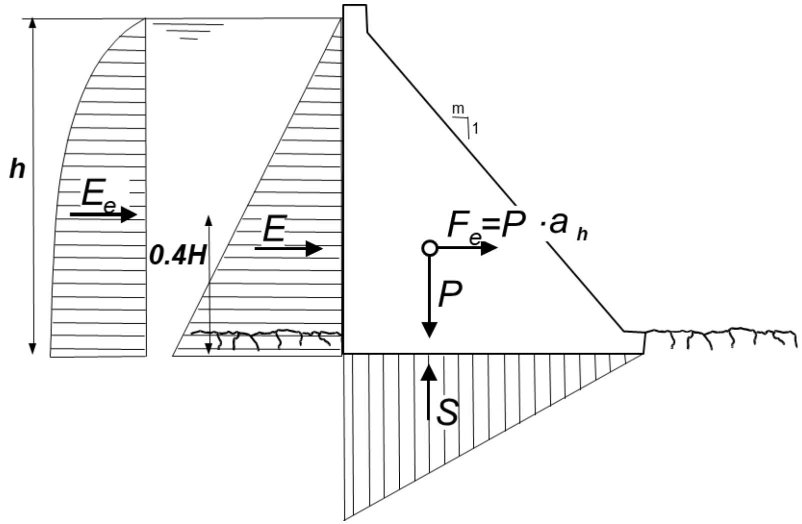
  2. Compute the peak ground acceleration a_{gd} according to the C3 directive [4.3.2]

  3. Determine the elastic spectral acceleration S_e according to the C3 directive [4.3.4] depending on:
     - Fundamental period Ts
     - Foundation characteristics
     - Damping

[2] EFEHR: hazard spectra

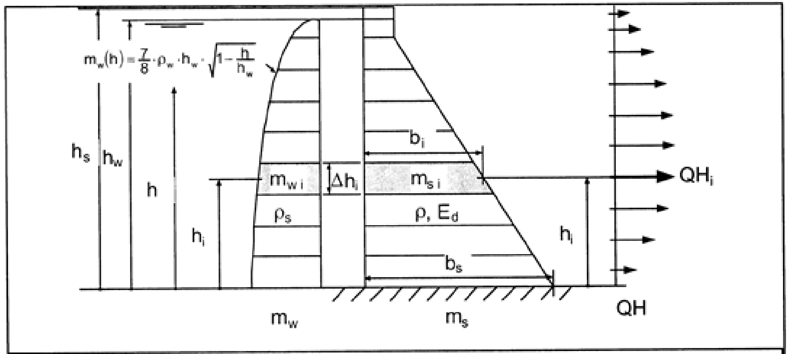
Part 2: Dynamic analysis

- Pseudo-static method:
  - The inertial forces of the dam (F_e) and the reservoir (E_e) are added to the forces P-E-S
  - No reduction of the uplift (hypothesis of a rupture of the grout curtain: k=1)



Part 2: Dynamic analysis

- Slice method:
  - Seismic substitution forces acting on slice i
  - Added-mass of according to Westergaard



m_s :	Dam mass	Δh_i :	Depth of band I
m_{si} :	Dam mass within band i	b_s :	Dam width
m_w :	Water mass	b_i :	Width of band I
m_{wi} :	Water mass within band i	ρ :	Dam density
h_s :	Dam height	ρ_w :	Water density
h_w :	Water height	E_d :	Dynamic elasticity modulus
h :	Height (variable)	QH :	Horizontal substitution for seismic forces
h_i :	Band height i	QH_i :	Substituted seismic forces acting against band I

Hand-in

- Hand-in as technical calculation note
  - Report PDF
  - Directly on Moodle

- Contact:
  - enrico.pinelli@epfl.ch

Hand-in date: According to program