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

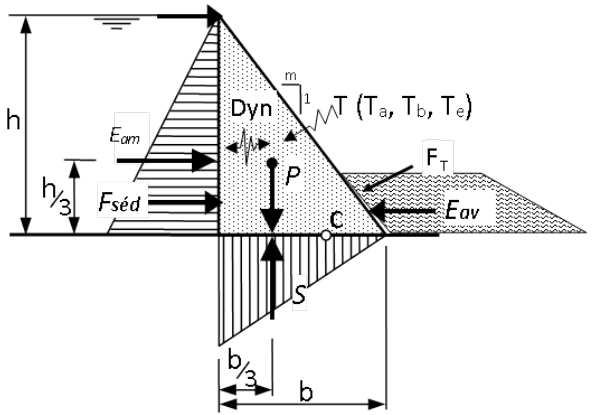
- Available documents:
  - *Design, Safety and Operation of Dams, A.J. Schleiss and H. Pougatsch*
  - *Directive relative à la sécurité des ouvrages d'accumulation,* ***Partie C3*** *: sécurité aux séismes* [1]

- 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

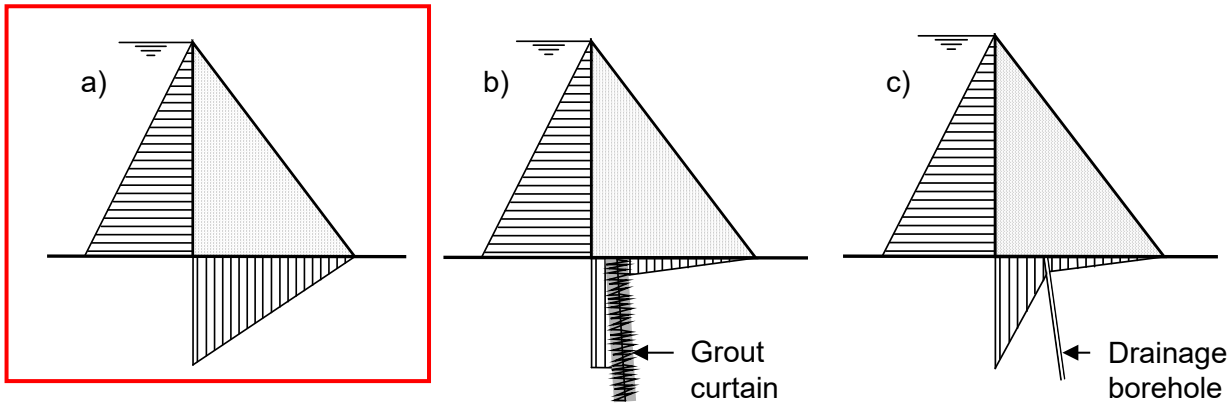
Gravity dam

- Static principle:
  - Self-weight counters the water pressure by the resulting friction at the base
  - Each block element is stable (no arch or bi-directional effect)
  - In 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

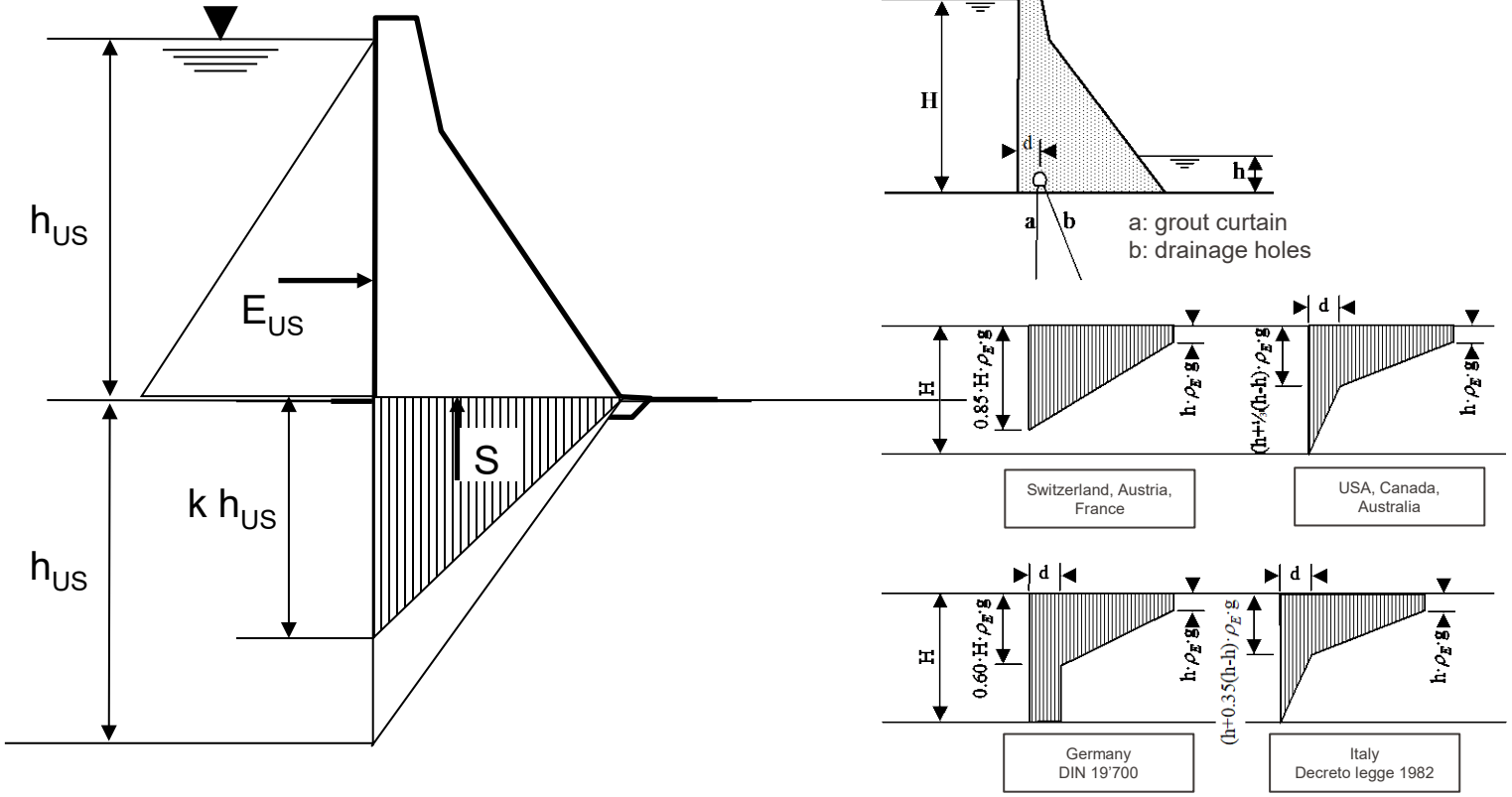


Uplift

- 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_{US}
E_{US}
S
k h_{US}
h_{US}
H
d
h
a
b
a: grout curtain
b: drainage holes
H
0.85·H·ρ_F·g
h·ρ_F·g
(h+½(h-h)·ρ_F·g
d
h·ρ_F·g
Switzerland, Austria, France
USA, Canada, Australia
H
0.60·H·ρ_F·g
h·ρ_F·g
d
(h+0.35(h-h)·ρ_F·g
d
h·ρ_F·g
Germany DIN 19'700
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:
  - **Carry out the analysis for full reservoir**
  - 1 x-section only: **typical cross-section**
  - Exercise in 2 parts:
    1. Static analysis
    2. 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

Exercise 1

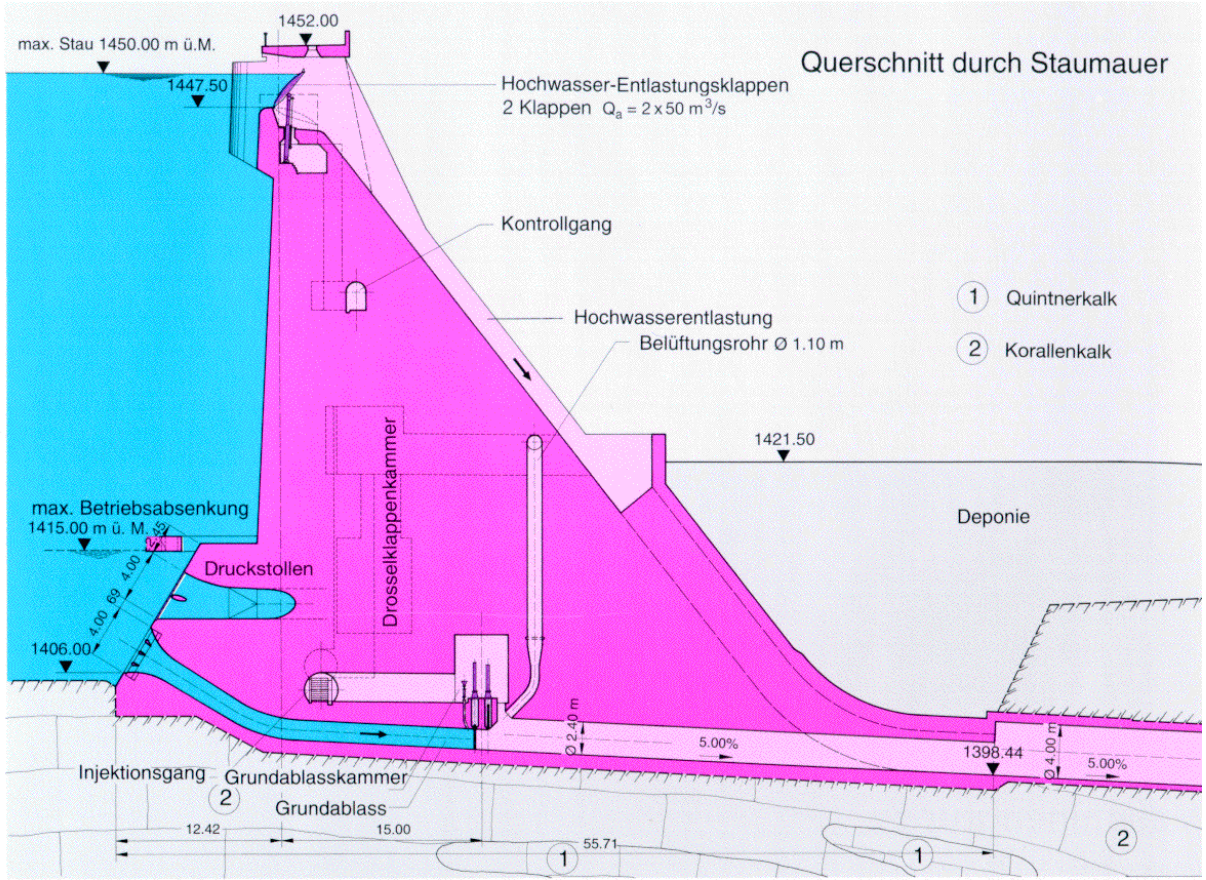
- **Part 1: Static analysis**
  - Friction angle ground-concrete to be determined according to Barton
  - Verification of dam stability
    - Safety against failure (stresses) not necessary for part 1
    - Safety against overturning ($S_{O,stat} >> 1$)
    - Safety against sliding ($S_{S,stat} >> 1$)
  - Normal load case (to be defined)
  - Comment on results: Importance of the uplift coefficient k?
- **Part 2: Dynamic analysis**
  - Earthquake verification acc. to the Swiss directive C3 Ed. 2025 (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

Typical section

Flapgate



Considerations for exercise 1

Geometry

Typical section

Height

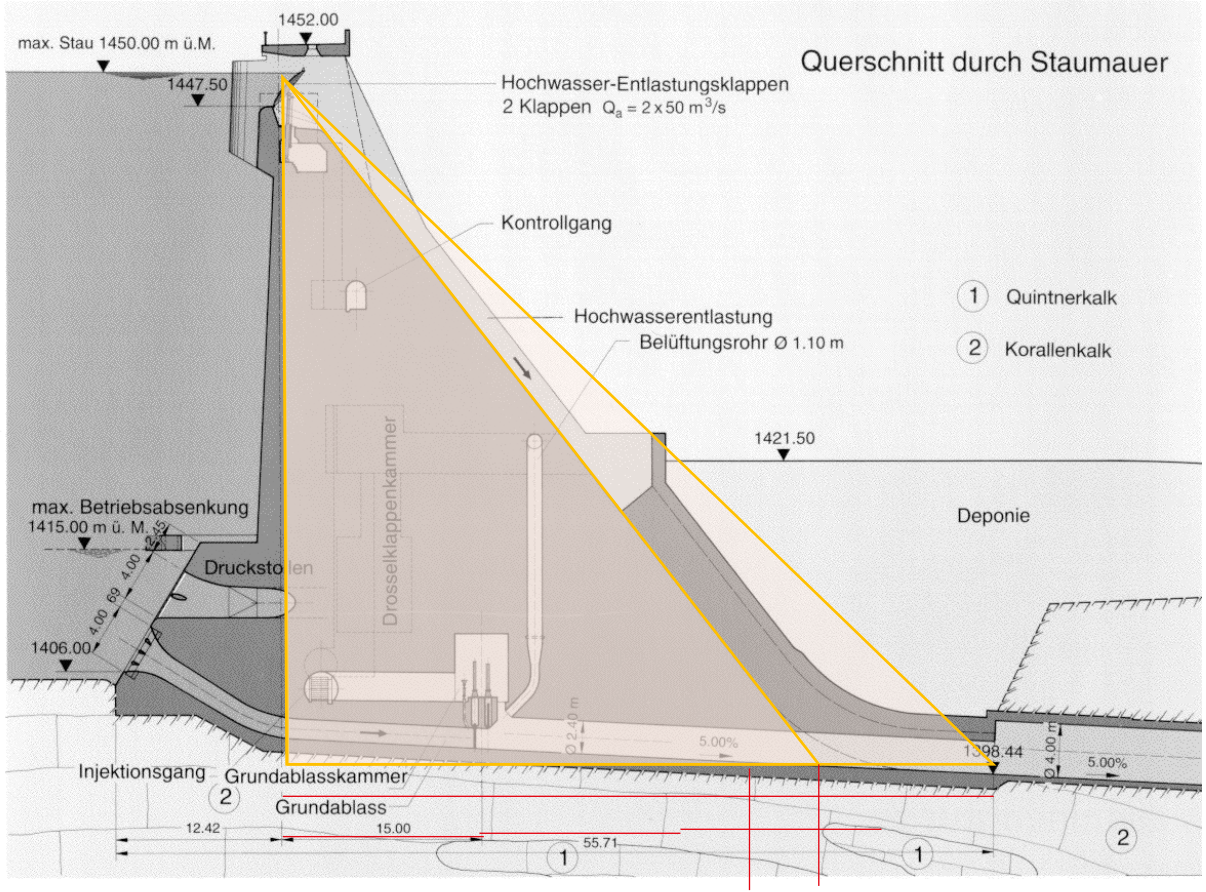
1450 – 1399 = 51 m

Base

15 +15 + 15x 2/3 = 40

D/s face slope

40 / 51 = 0.78



Considerations for exercise 1

Friction angle at ground-dam interface

- To determine according to Barton

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

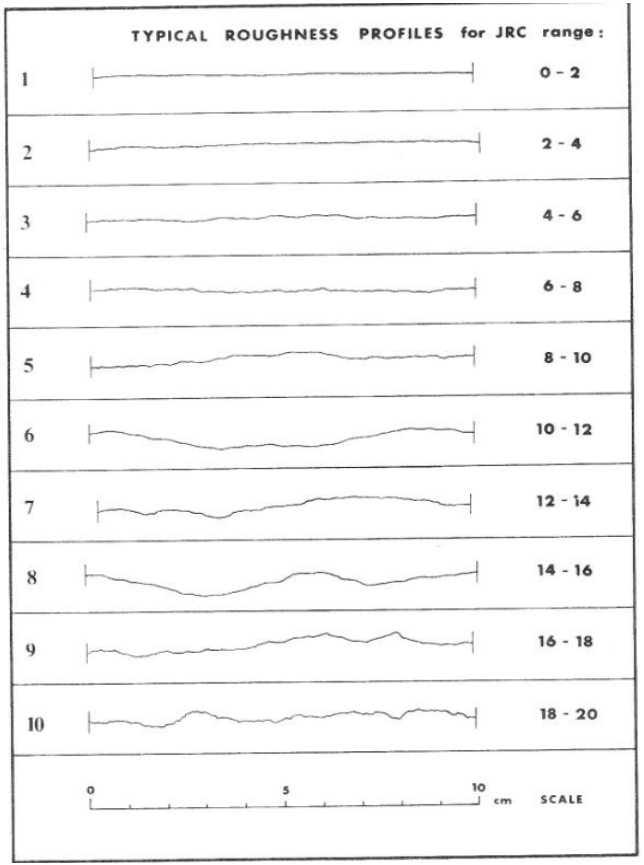
- Φ_r: residual friction angle
- JRC: Geometric joint roughness coefficient
- JCS: Equal to the simple compressive strength of the rock
- σ_n': Normal effective stress

Friction angle at ground-dam interface

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

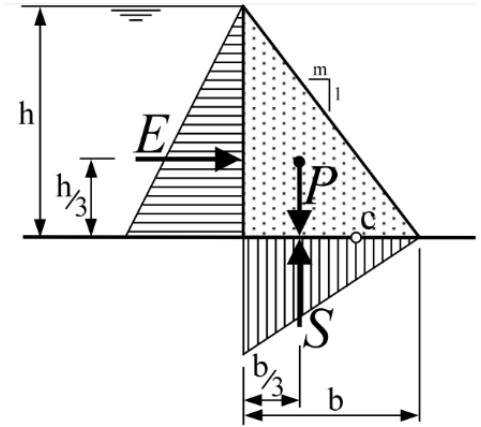
Values for the angle of friction (tanϕ´)

			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

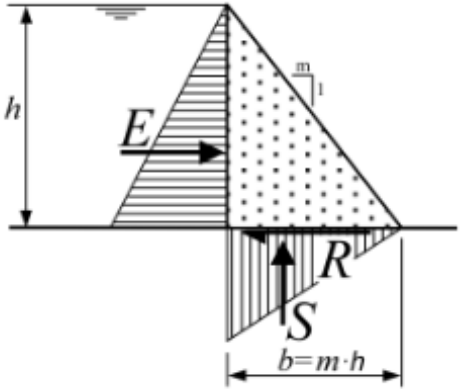


Part 1: Static analysis

Safety against overturning



Safety against sliding



Part 2: Dynamic analysis

- Spectral acceleration:

1. Determine the reference acceleration at the provided location for the prescribed return period using C3 Appendix A and SFOE's excel table C3-HDT (Path 1a), $PPSA_x$

2. Compute the Pseudo Spectral Acceleration

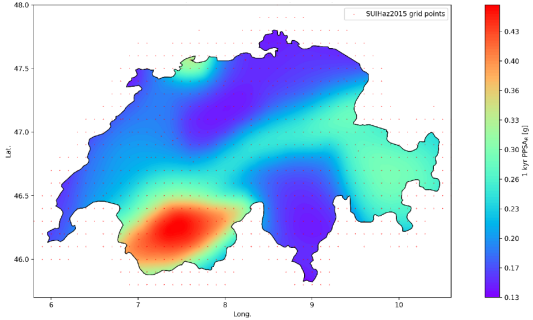
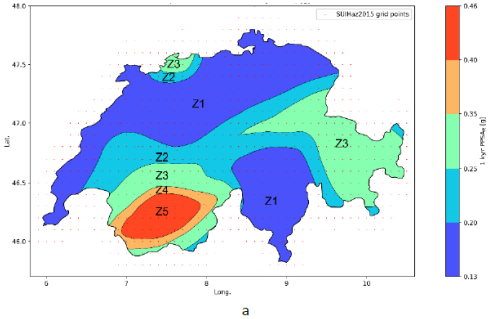


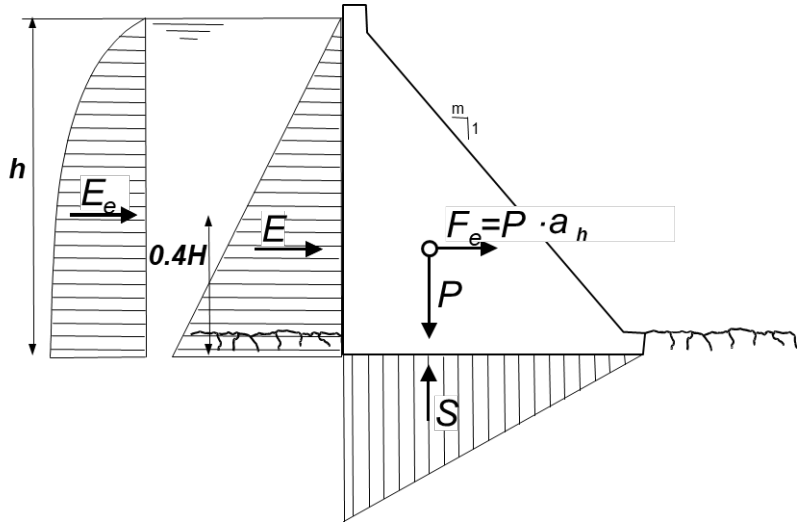
Figure A1: The map of $PPSA_R$ for Safety Evaluation Earthquake with return period of 1'000 years



a

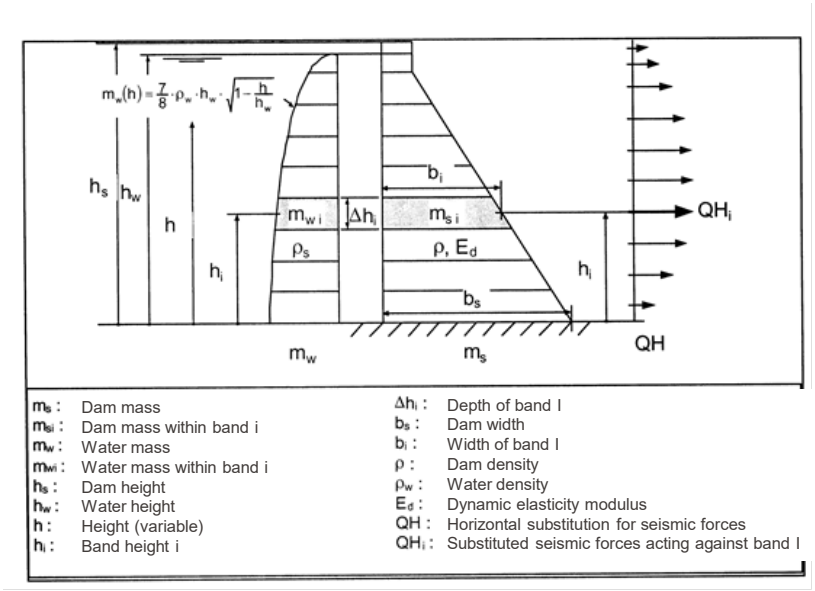
Part 2: Dynamic analysis

- Pseudo-static method:
  - The inertial forces of the dam (Fe) and the reservoir (Ee) 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



Hand-in

- Hand-in as technical calculation note
  - Report PDF (max 10 pages)
  - Directly on Moodle

- Contact:
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Hand-in date: 05/10/2025