ENERJiSA FICHTNER

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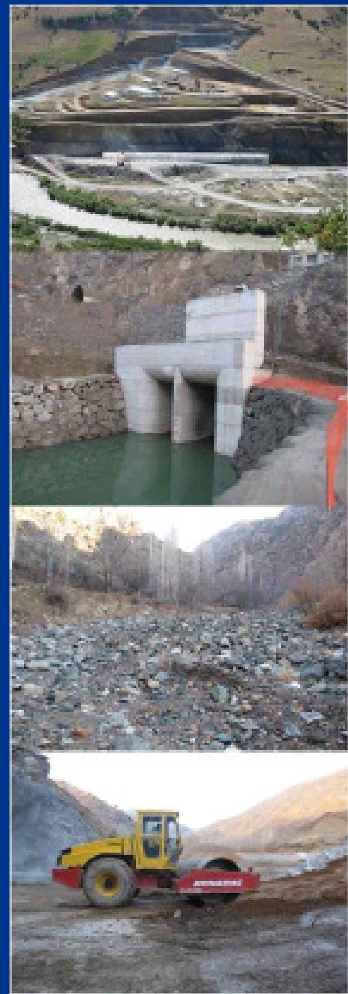
Content:

Seepage Control of Concrete Faced Dams with respect to Surface Slab Cracking



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Verbund | SABANCI

Outline

- Introduction
- Design Fundamentals for CFRD / CFSGD
- Cracking of Surface Slabs
- Seepage conditions due to Cracks in Surface Slabs
- Conclusion

General Information

Country

- Area: 779,452 km²
  10 x Austria / 2 x Germany / 8 x Portugal
- Location: 3% Europe + 97% Asia
- Population: 70.6 Mio. Inhabitants
  74% of population in major cities
  Austria: 8.2 / Germany: 82.3 / Portugal: 10.6
- Aver. Age: 27.3 a
  Austria: 42 / Germany: 41 / Portugal: 40
- Pop. density: 91 Inhabitants/km²
  Austria: 100 / Germany: 229 / Portugal: 119
- Religion: 99% Muslims

Energy Market / Hydropower

Prognosis of Energy Demand

- 2005: 160 10^3 GWh/a
- 2010: 242 10^3 GWh/a (+50%)
- 2020: 356 to 476 10^3 GWh/a (min +122%)
- Growth rate 8.2% in 2008 (economy 4%, pop. 1-2%)

Strategy in Hydropower Sector

- Utilization of Economically Feasible Energy Potential (EFEP) of Hydropower
- EFEP = 125 to 188 TWh/a
- Currently, 1/3 of EFEP is utilized
- Privatization of Energy Market 2000/01
- Expected Private Investment (~ 50,000 Mio. € in 2020!)
- Thread of Energy Deficit in 2012–2015 (2020)
- Currently, 2,000 HEPP in development

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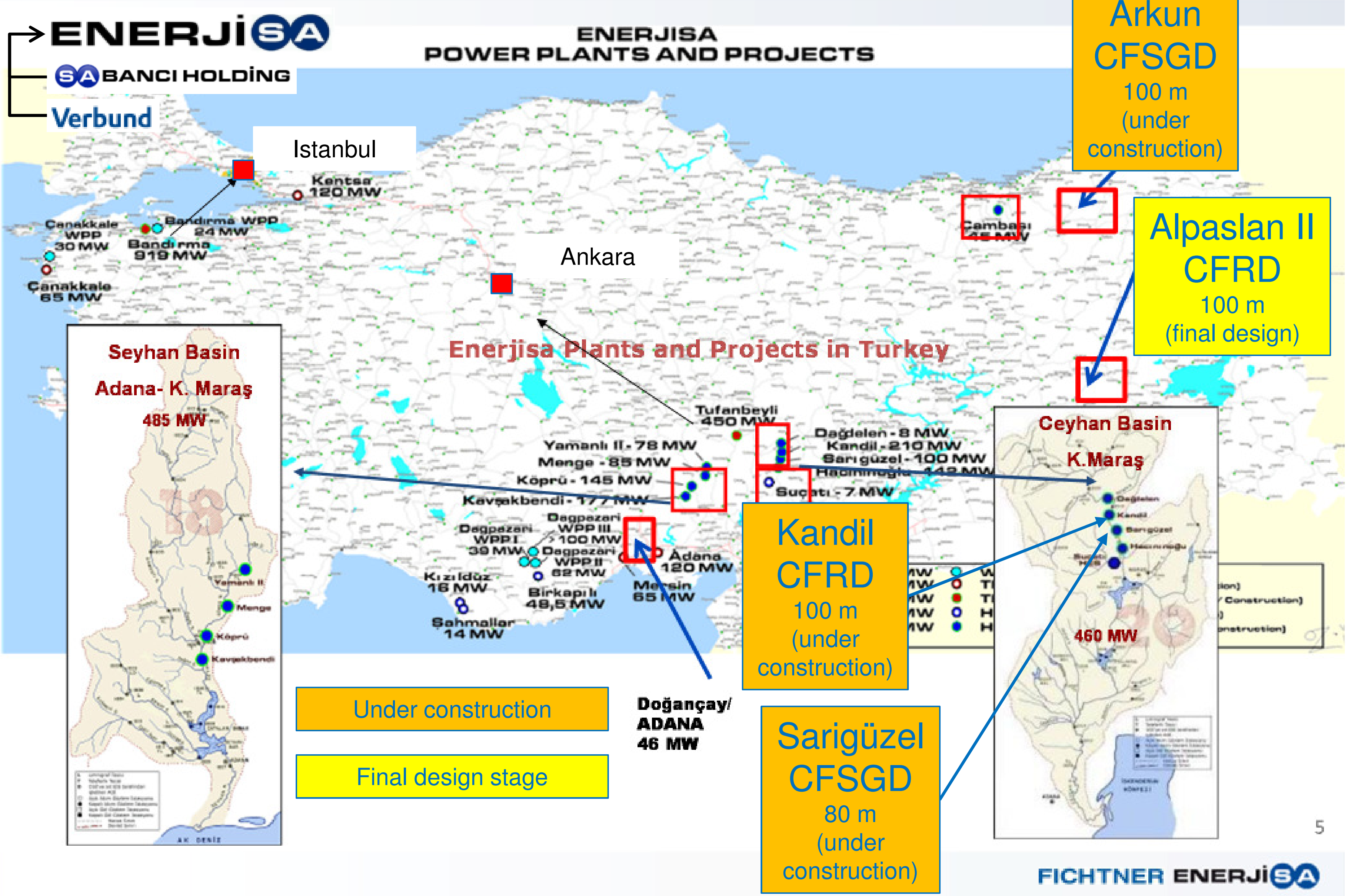
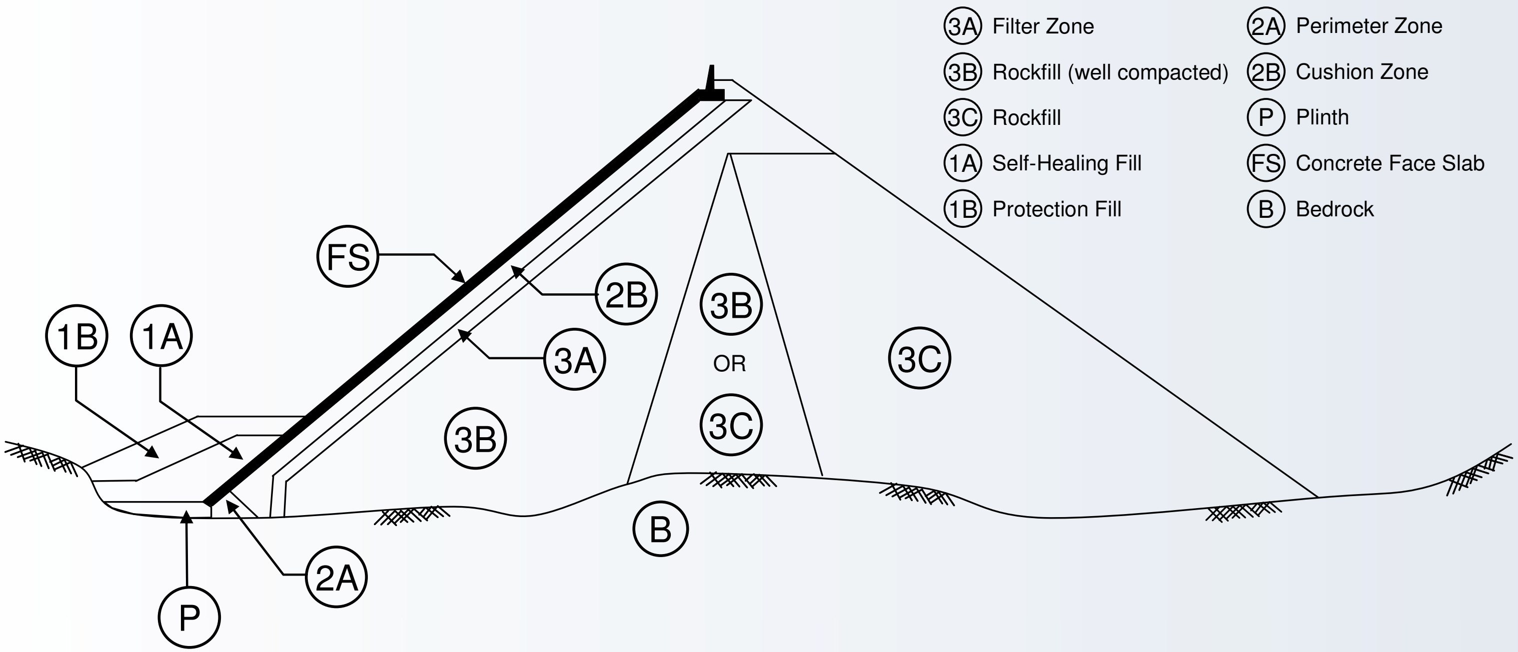
Seepage Control of Concrete Faced Dams with respect to Surface Slab Cracking



Typical Cross-Section CFRD

(adapted from ICOLD, 2005[A])

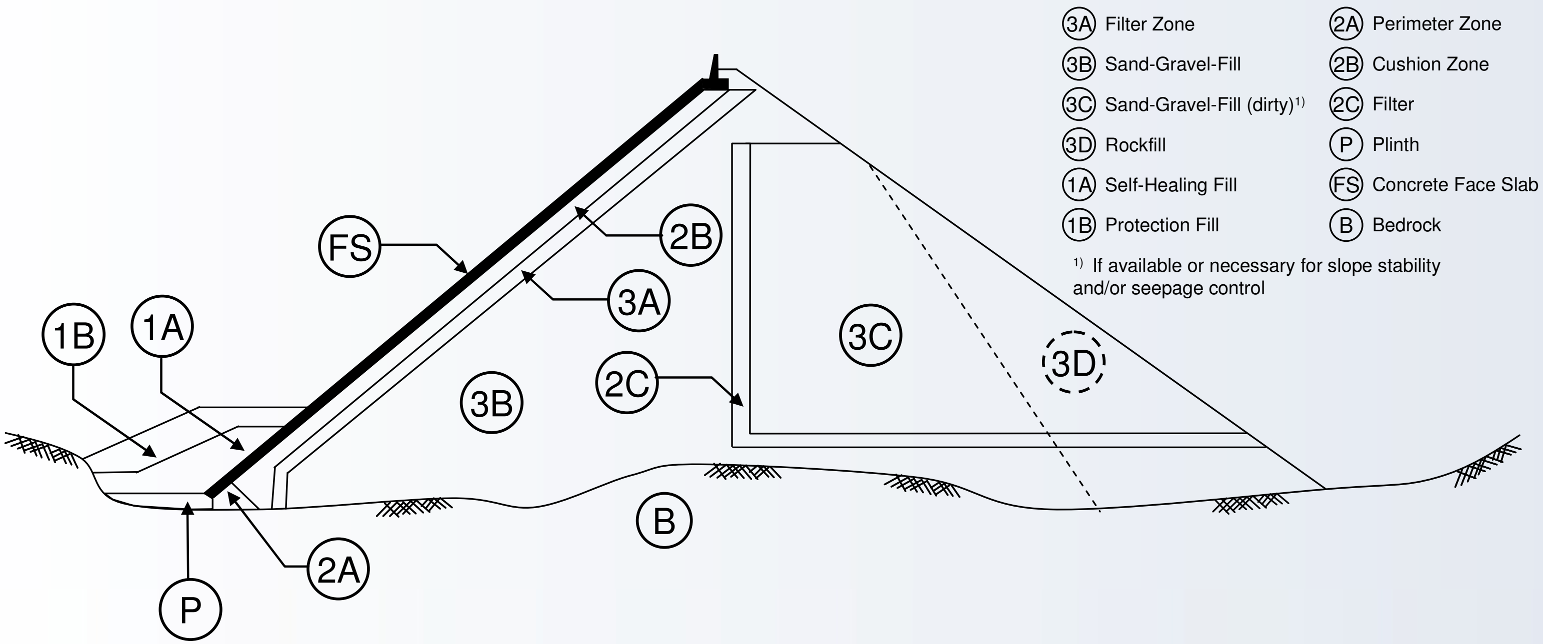


Literature:

[A] ICOLD, Concrete Face Rockfill Dams – Concepts for Design and Construction, International Committee on Large Dams, Committee on Materials for Fill Dams (Draft) (2005)

Typical Cross-Section CFSGD

(adapted from Fell et al., 2005[A])



Literature:

A) R. Fell, P. MacGregor, D. Stapledon, G. Bell, Geotechnical Engineering of Dams, A. A. Balkema Publishers, Leiden London New York Philadelphia Singapore (2005)

Sand-Gravel Fill vs. Rockfill

Comparison

Aspect	Rockfill	↔	Sand-Gravel
• Occurence:	Quarry - Processing	↔	Natural deposits (alluvium)
• Seepage:	Free draining[1)]	↔	Sand and fine particles
	Simple zoning	↔	Seepage control zoning
• Shear strength:	Crushed angular grains	↔	Rounded grains
	High friction angle	↔	Friction angle controlled by main components
• Stress:	Sensitive, weak materials	↔	Less dependent
• Deformation: (see next slide)	Less favourable	↔	High elasticity moduli

Notes:

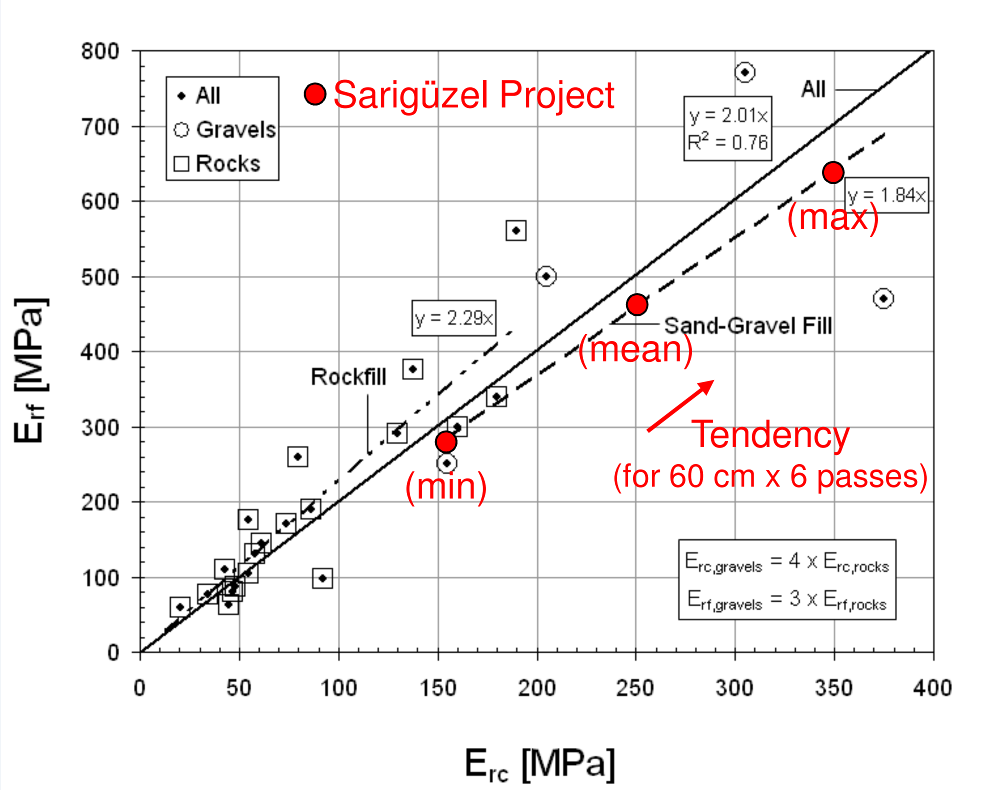
[1)] Considered loads and dam (seepage) conditions are not likely to allow extensive pore water pressures within the dam body.

Sand-Gravel Fill vs. Rockfill

Elasticity Modulus

- Well-graded material (probably)
- Higher values for SG
- Less stress dependent
- → Less deformation

- Less layer height
- Number of passes 4-8



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Cracking of Surface Slabs

Experiences / Case Studies

- Seepage flow in CFRDs & CFSGDs
  - Ita (Brazil): 1,700 l/s; H = 125 m
  - Shiroro (Nigeria): 2,000 l/s; H = 125 m (→ 100 l/s after sealing joints)
  - Scofield (USA): 5,600 l/s; H = 40 m
  - Campos Novos (Brazil): 1,400 l/s; H = 202 m (50 MPa)
  - Barra Grande (Brazil): 1,300 l/s; H = 185 m
  - Aguamilpa (Mexico): 200 l/s; H = 187 m
  - El Cajon (Mexico): 150 l/s; H = 188 m
  - Shuibuya (China): 40 l/s; H = 233 m (80-100 MPa)
- Maximum slab deformation
  - Salt Spring (USA): > 1.0 % of height (dumped rockfill)
  - Shuibuya (China): 0.5 % of height (double of expected)

Cracking of Surface Slabs

Reasons for Cracking

- Deformation cracks are of major concern
- Tension / compression cracks
- 50% of deformation during „First impoundment“
- Likelyhood of cracking for E < 50 MPa and large dams is high

- Geotechnical investigation – lack of information/data
- Design inconsistencies (Gouhou dam (!), Aguamilpa)
- Unfavourable material properties
- Construction works
- Dynamic loads - Earthquake (next slide)
- ...

Cracking of Surface Slabs

Dynamic Loads - Earthquake

Direct impact

- Displacement of the surface slab blocks
- Failure of joint sealing components (copper inlays)
- Deformation, displacements of filter layers (functionality, seepage control)
- Loosening of soil/rock strength
- Liquefaction (should be excluded by choice of materials for SG or RF)

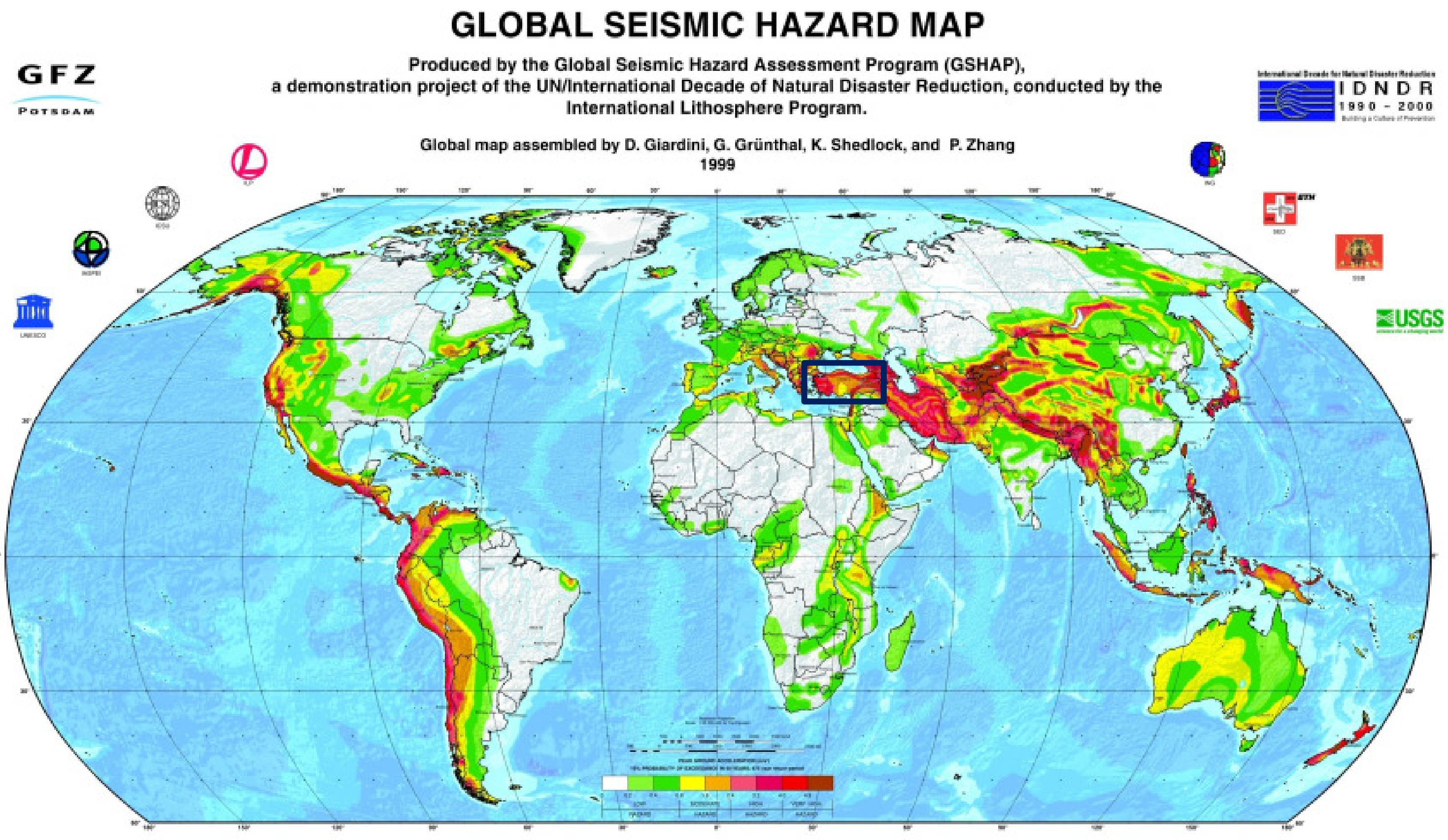
Indirect impacts

- Landslides → Impulse on dam body, surface slab, shock waves, overtopping...
- Rockfalls
- ...

- Determination of design parameters & evaluation of impact difficult

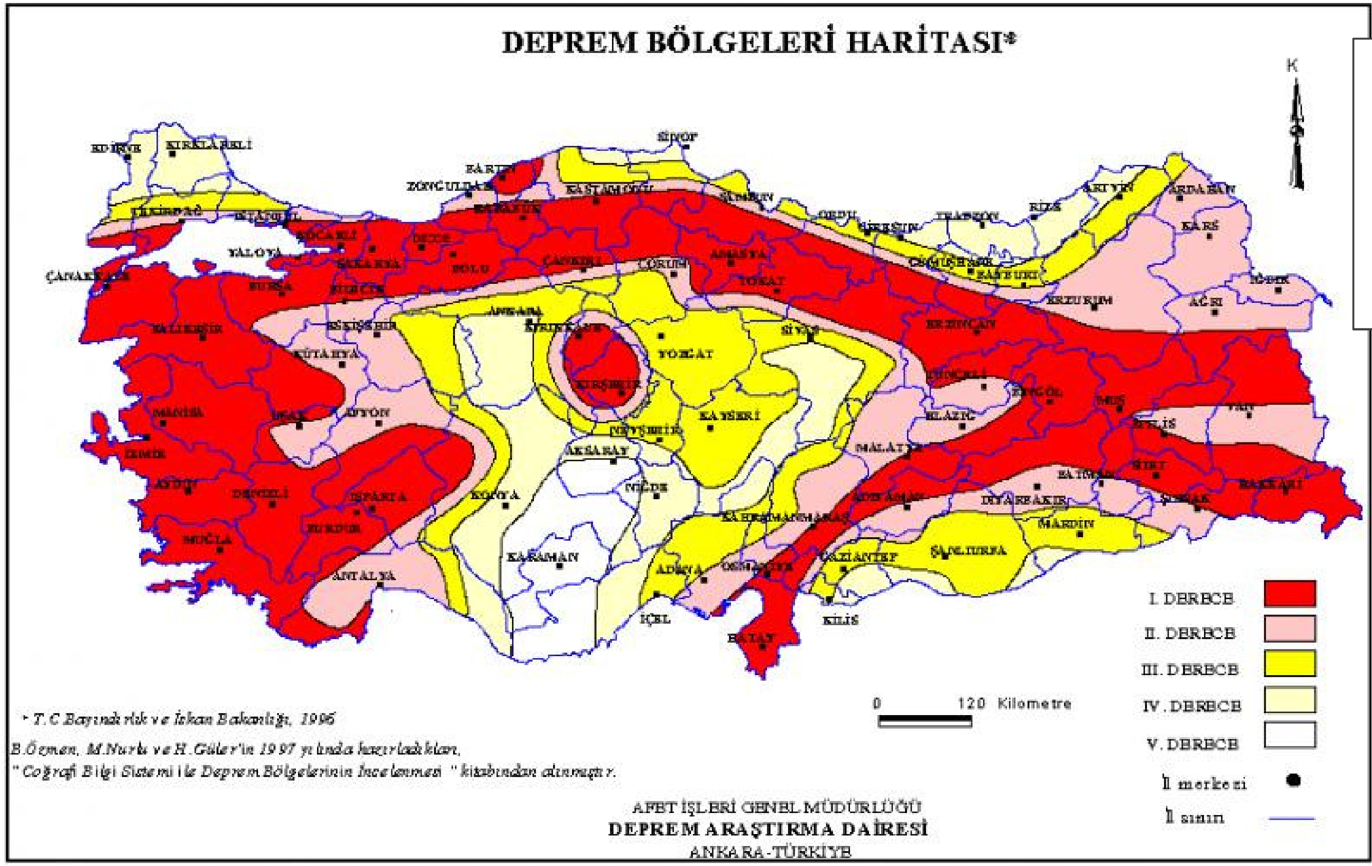
Cracking of Surface Slabs

Earthquake in Turkey



Cracking of Surface Slabs

Earthquake in Turkey



PGA values
1st: > 0.4g
2nd: 0.3g - 0.4g
3rd: 0.2g - 0.3g
4th: 0.2g - 0.1g
5th: <0.1g

Cracking of Surface Slabs

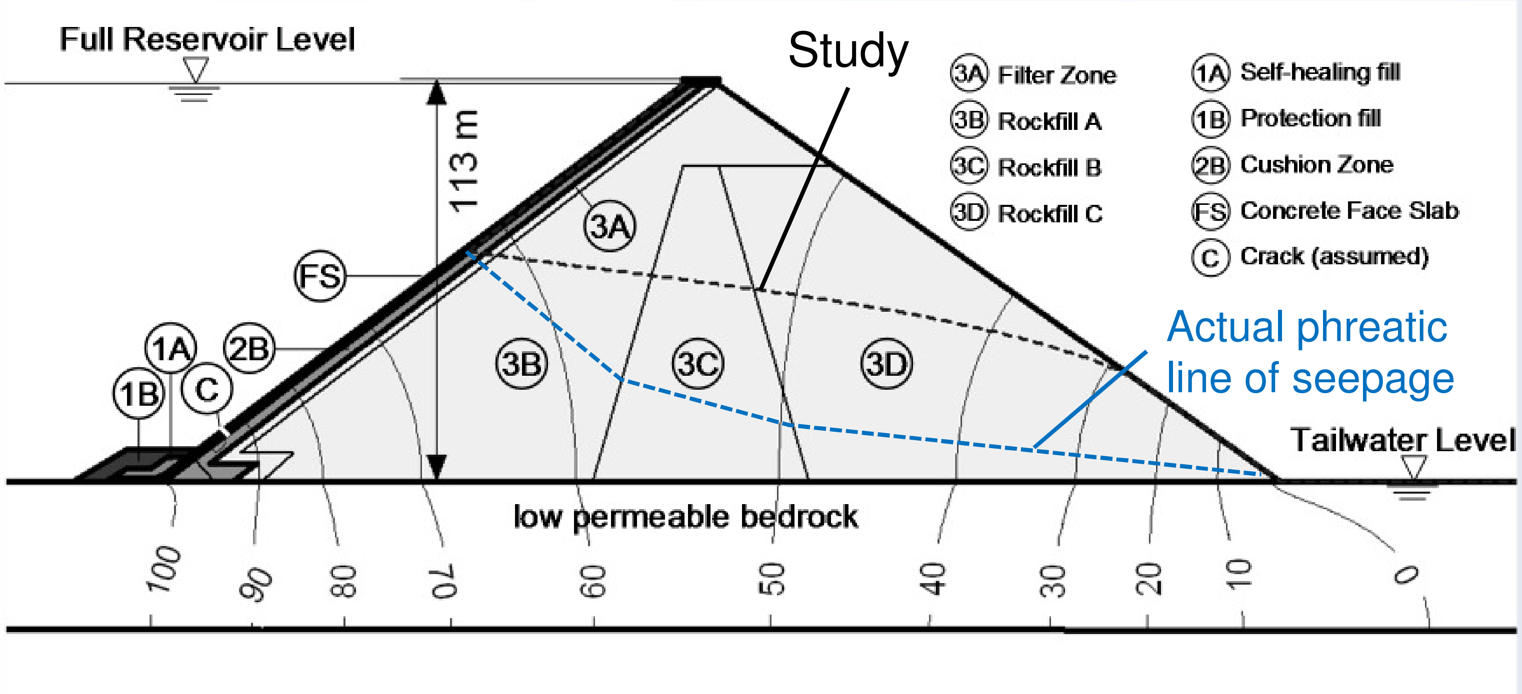
Consequences & Countermeasures

- Seepage intrusion/increase
  - → Pore water pressures
  - → Hydrodynamic soil deformation (erosion, suffusion)
  - → Seepage losses (electricity generation!)
  - → Damages & failure
  - → Fatalities (!) & economic/social impacts

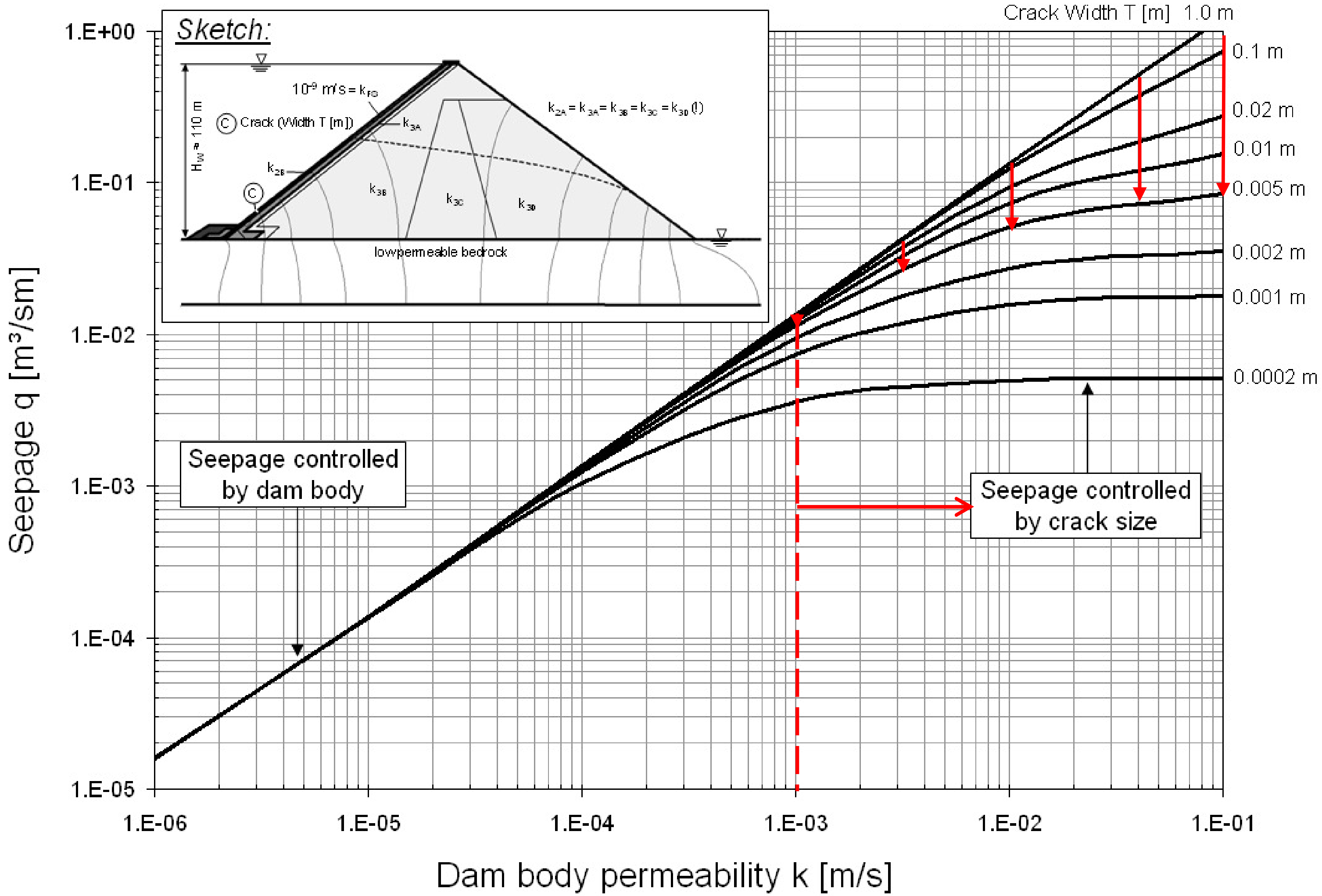
- Rapid drawdown (if possible, stability of upstream slope)
- Addition of silty sand, flyash, bentonite...
- Joint design → More joints more flexibility
- Proper choice of the deformation parameters of different zones
- Local increase of slab thickness
- Zoning for seepage control & self-healing zone 1A
- Refurbishment measures (concrete, geomembranes...)

Seepage Conditions CFRD

- Dam Zoning / Foundation on Bedrock



Seepage Conditions CFRD



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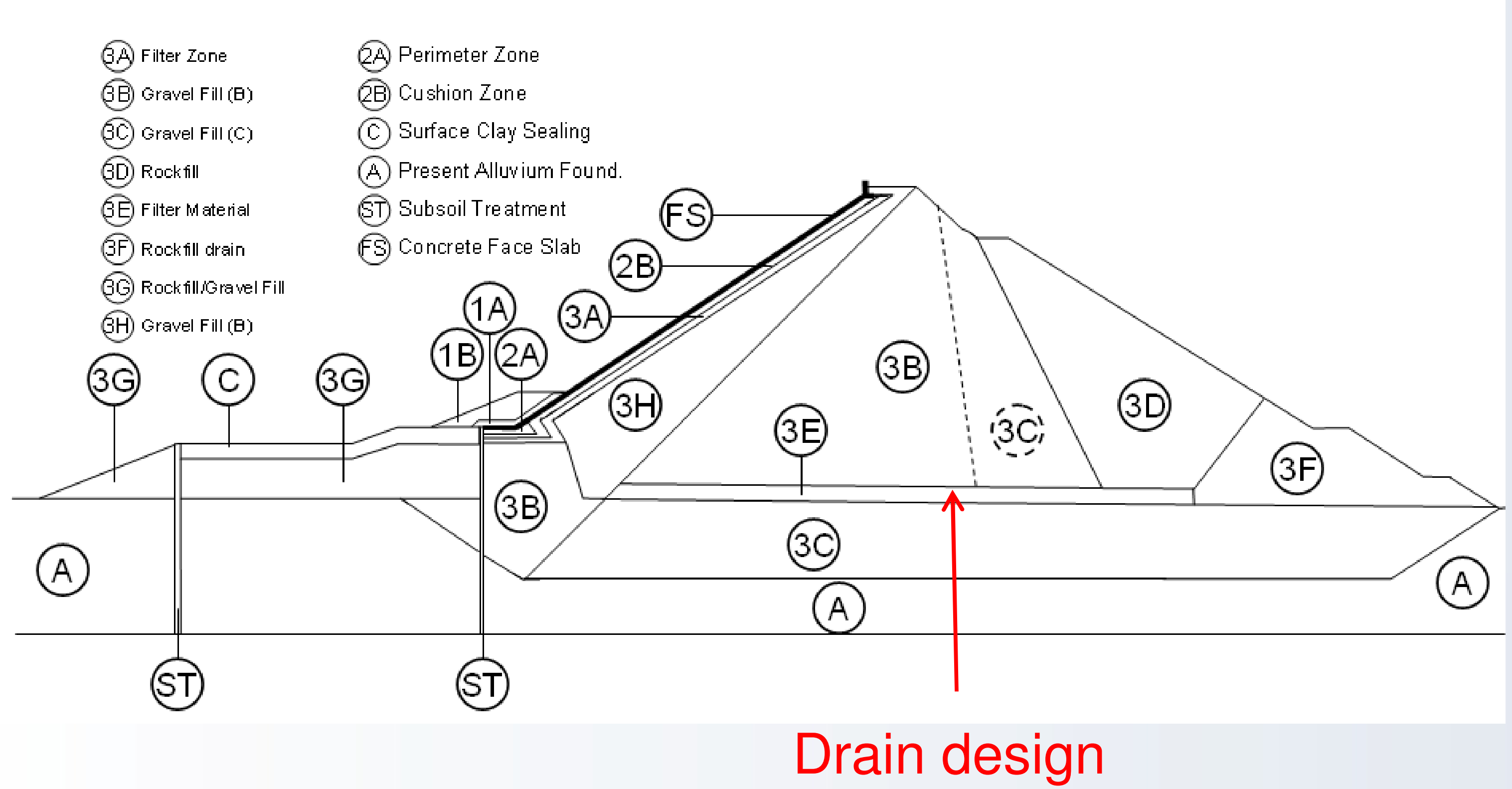
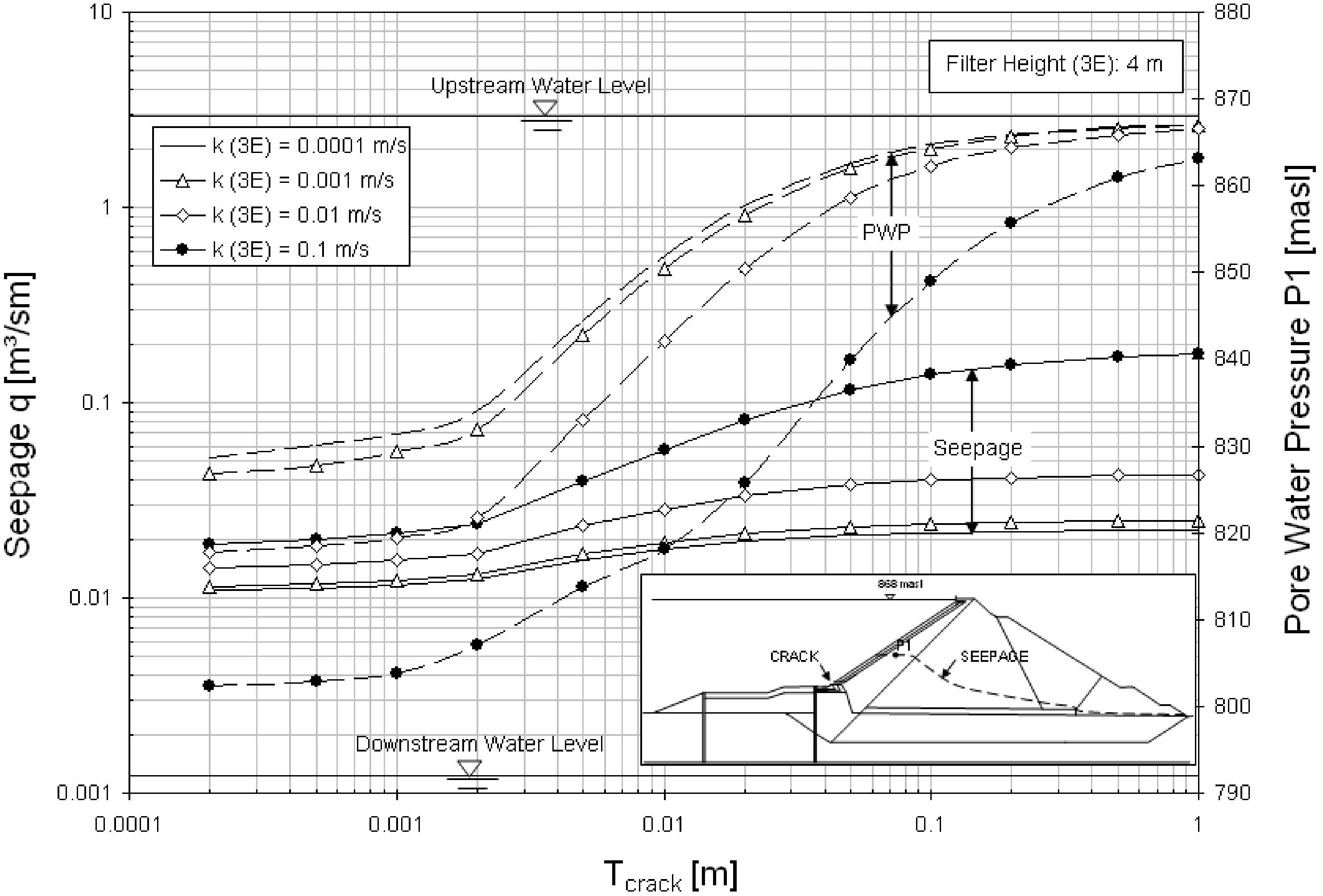
Seepage Conditions CFSGD

- CFSGD Zoning / Foundation on Alluvium
  - → Principle Dam Design of Case Study



Seepage Conditions CFSGD



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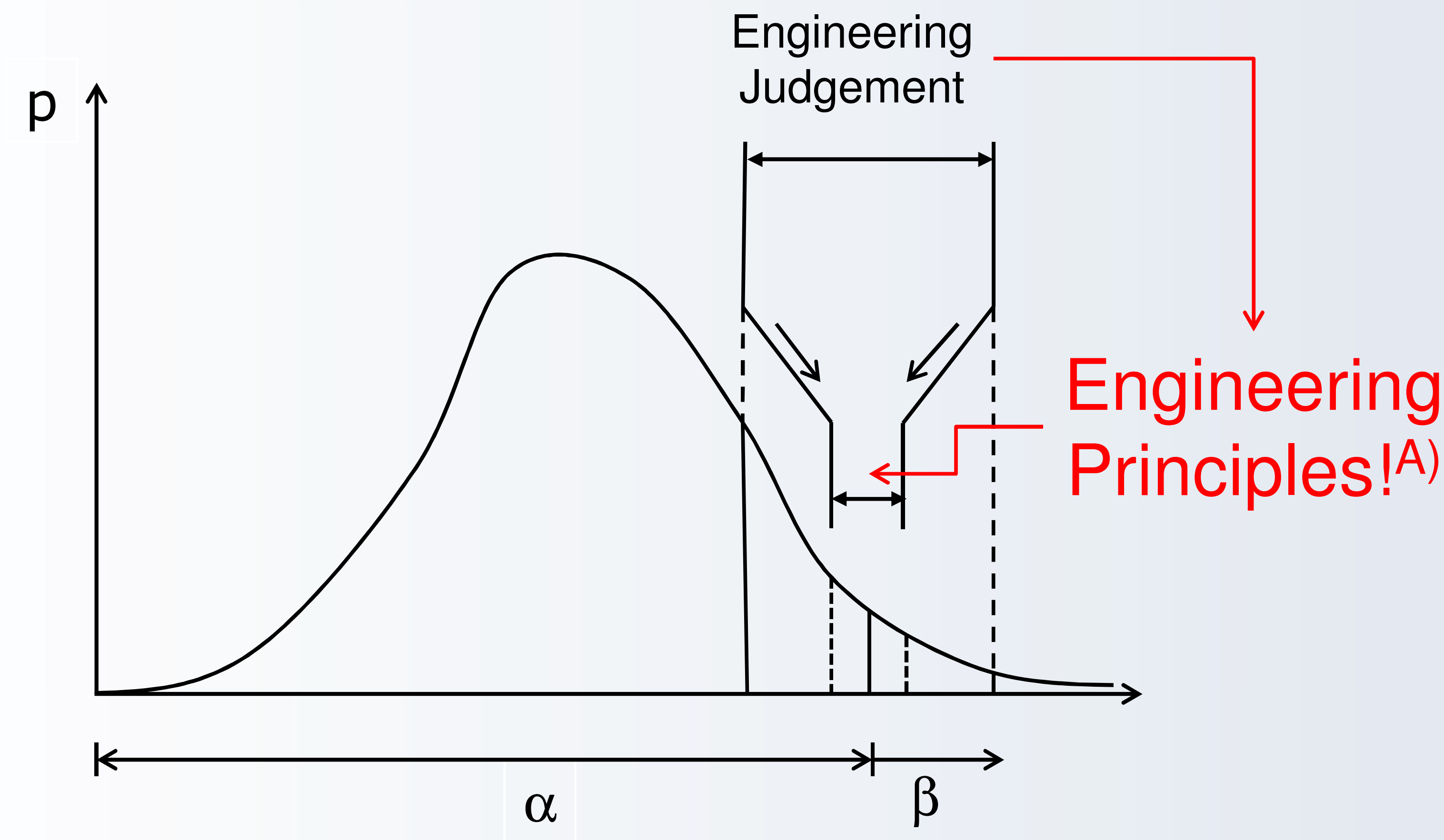
Conclusion

- Static loads → Cracking „predictable“ for the case of reliable construction works and constant material quality
- Dynamic loading → Cracking „hardly predictable“ (case studies? Wenchuan China 2008)

- Adaptation of zoning/design in order to control seepage conditions in case of cracking
    - Pore water pressures → Draining
    - Erosion/suffusion → Filter

→ Direct consequences of cracking to be controlled

Thank you.



Reference:
A) Hartford, D. (2011): Risk management in embankment dams – Geotechnical component. Session 4: Future Directions: beginnning by going back to the scientific foundations. LNEC, Portugal