



SVENSKT CENTRUM
FÖR HÅLLBAR VATTENKRAFT

Safe dams – A holistic approach for improved safety of concrete dams

Adrian Ulfberg

Project members:

Adrian Ulfberg, LTU

Professor Dr. Gabriel Sas, LTU

Dr. Jaime González-Libreros, LTU

Dr. Chao Wang, LTU

Dr. Marie Westberg-Wilde, KTH & AFRY

Professor Fredrik Johansson, KTH

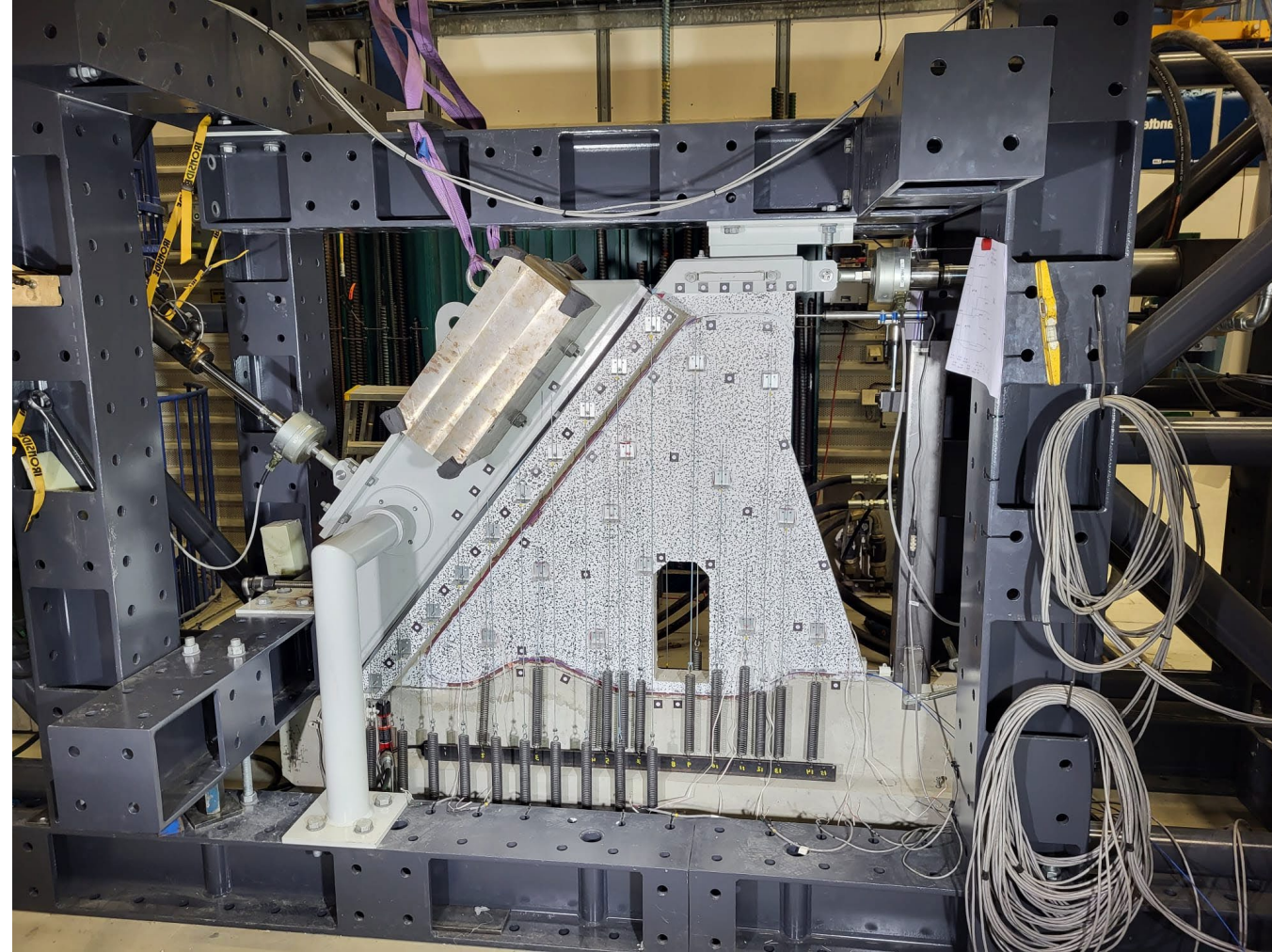
Dr. Richard Malm, FOI

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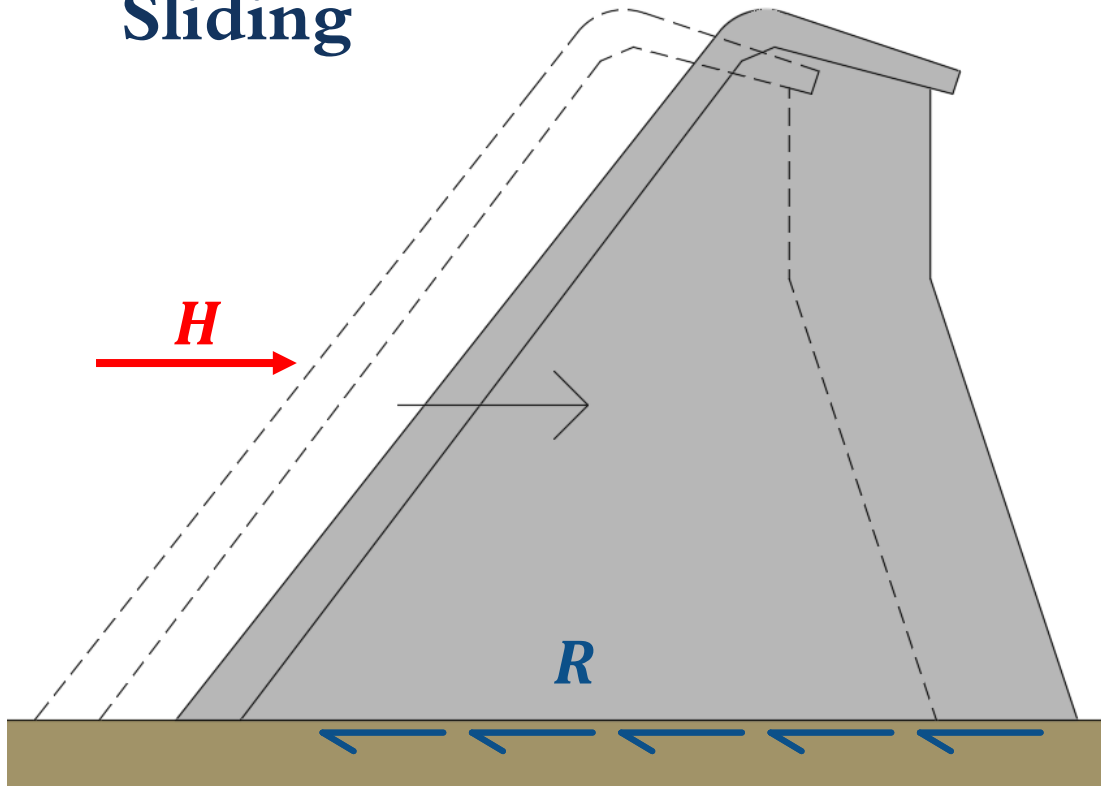
What, how, why?

- Develop/propose approaches to more accurately assess the safety of concrete dams
- Conservatism in traditional assessment methods
- Evaluate different analysis methods and probabilistic analysis



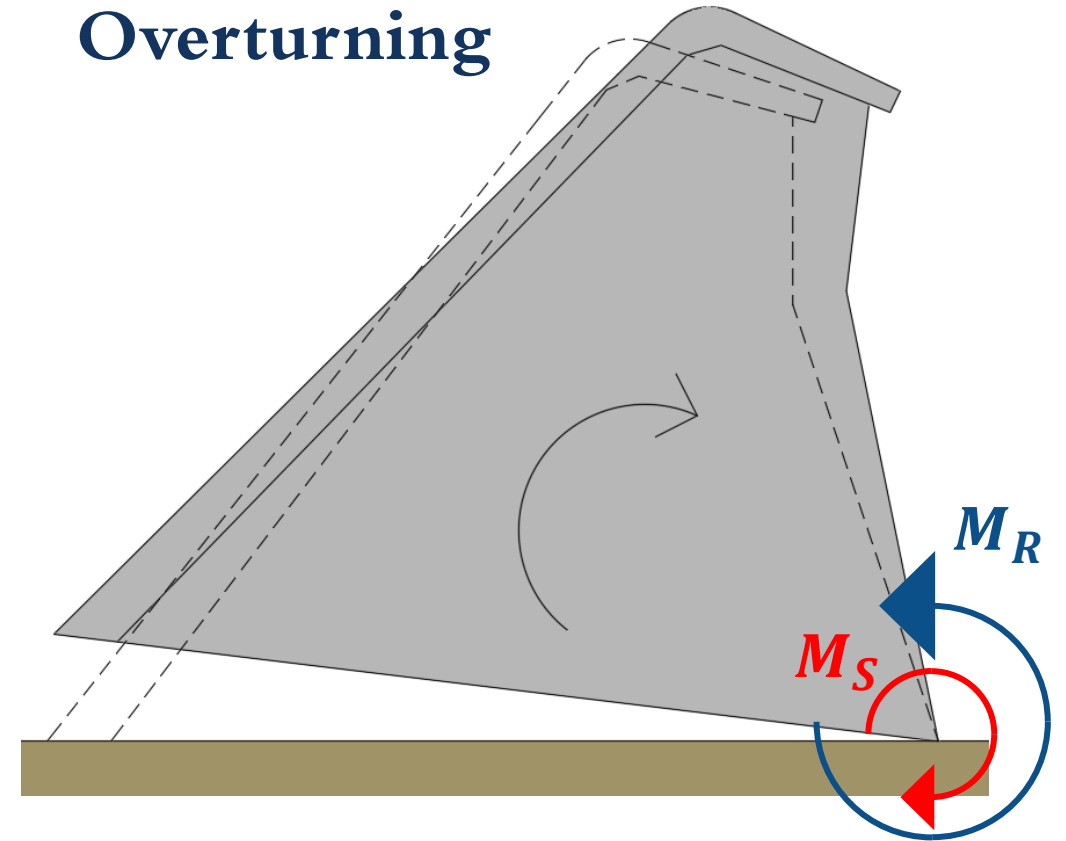
Traditional failure modes

Sliding



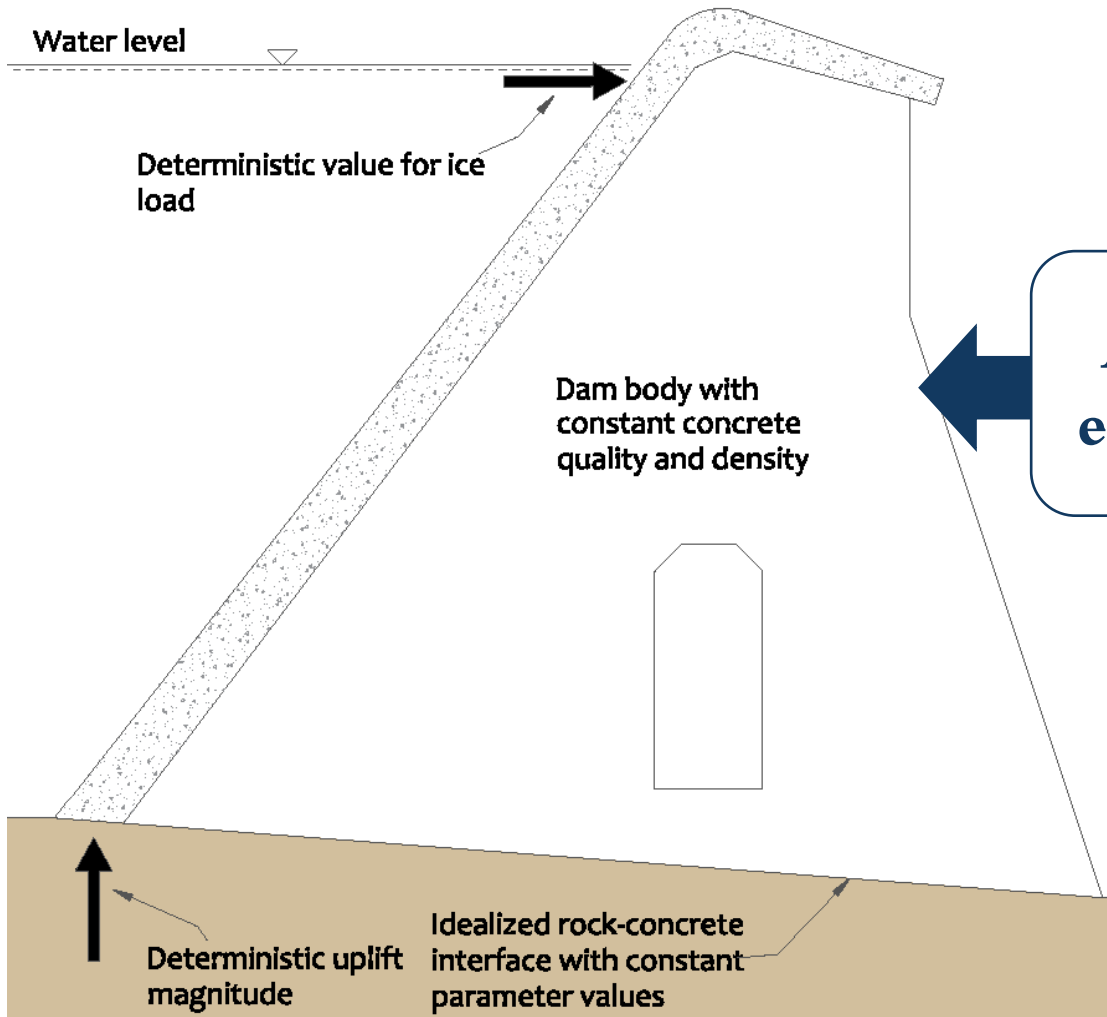
$$SF = \frac{R}{H} = \frac{\text{Shear resistance}}{\text{Shear force}}$$

Overturning



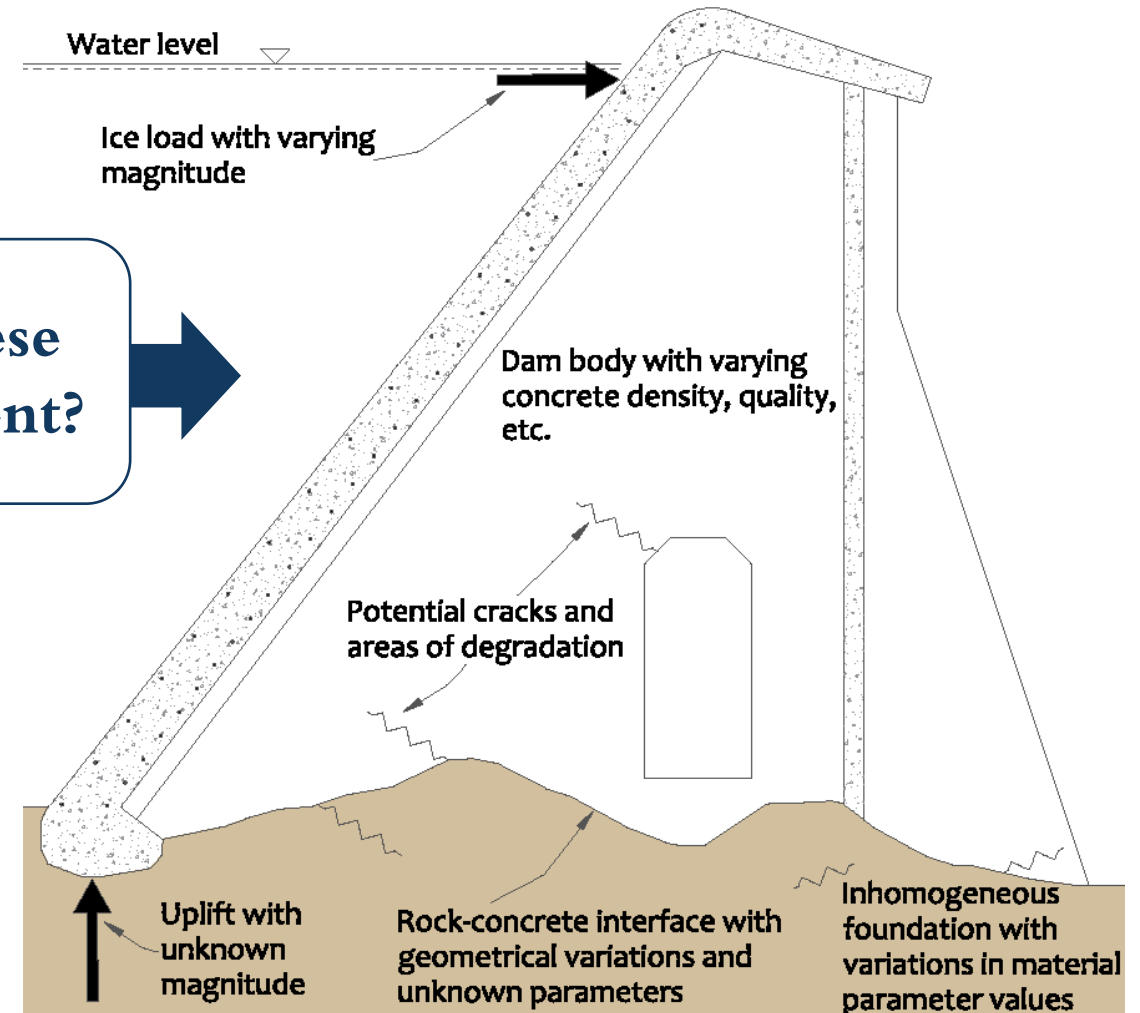
$$SF = \frac{M_R}{M_S} = \frac{\text{Stabilizing moment}}{\text{Destabilizing moment}}$$

Idealizations vs reality



Idealized dam

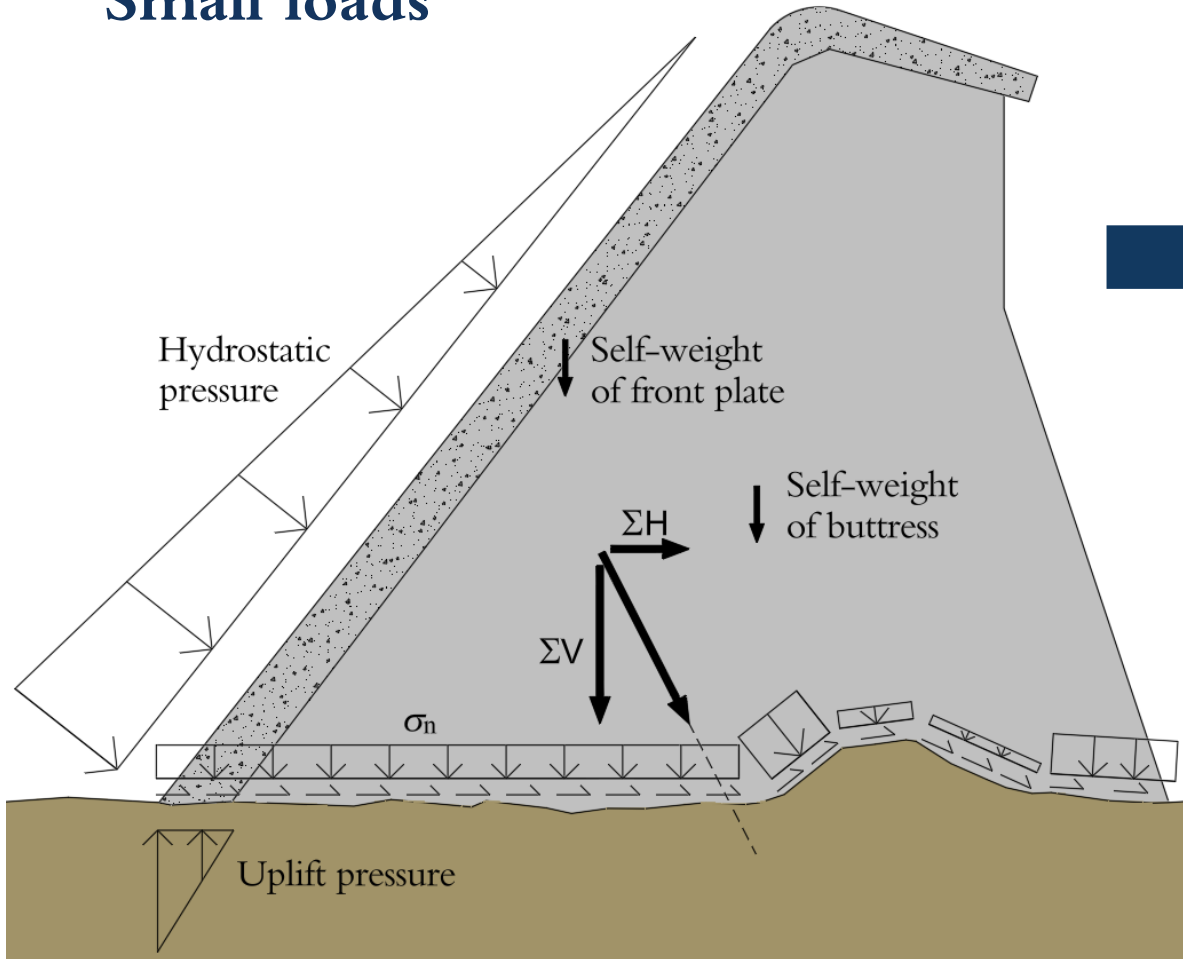
Are these equivalent?



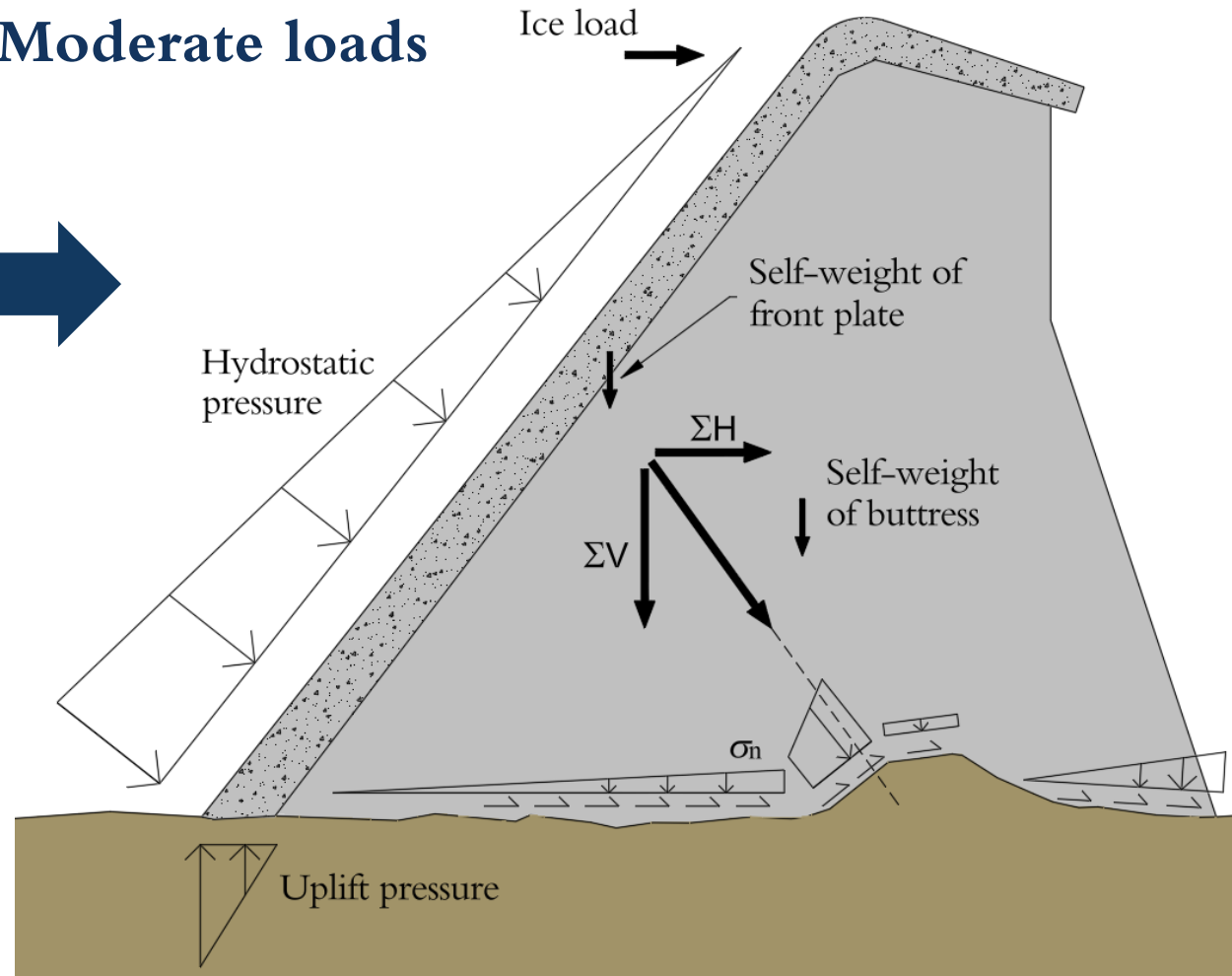
Real dam

Actual failure mechanism and evolution of stresses

Small loads

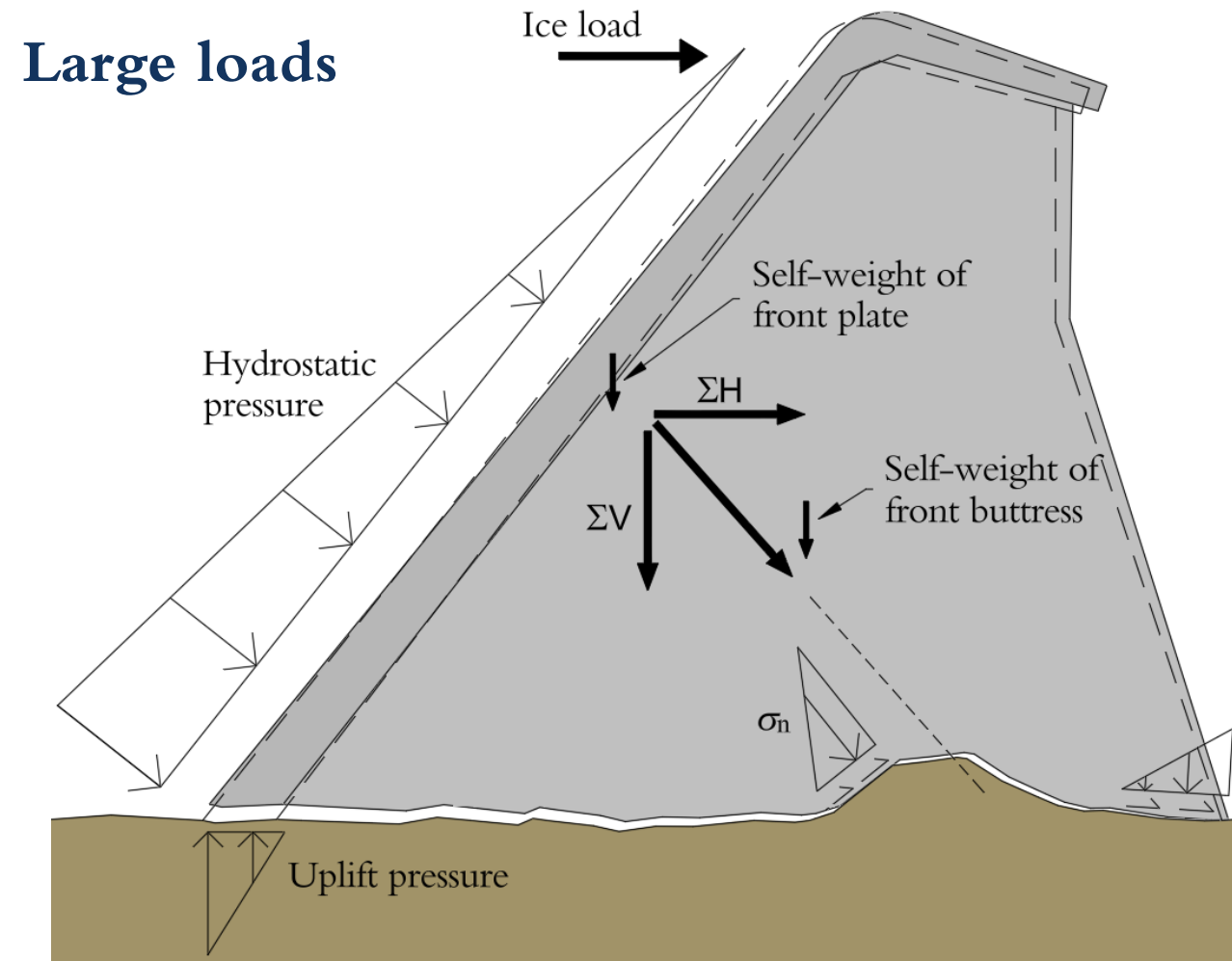


Moderate loads



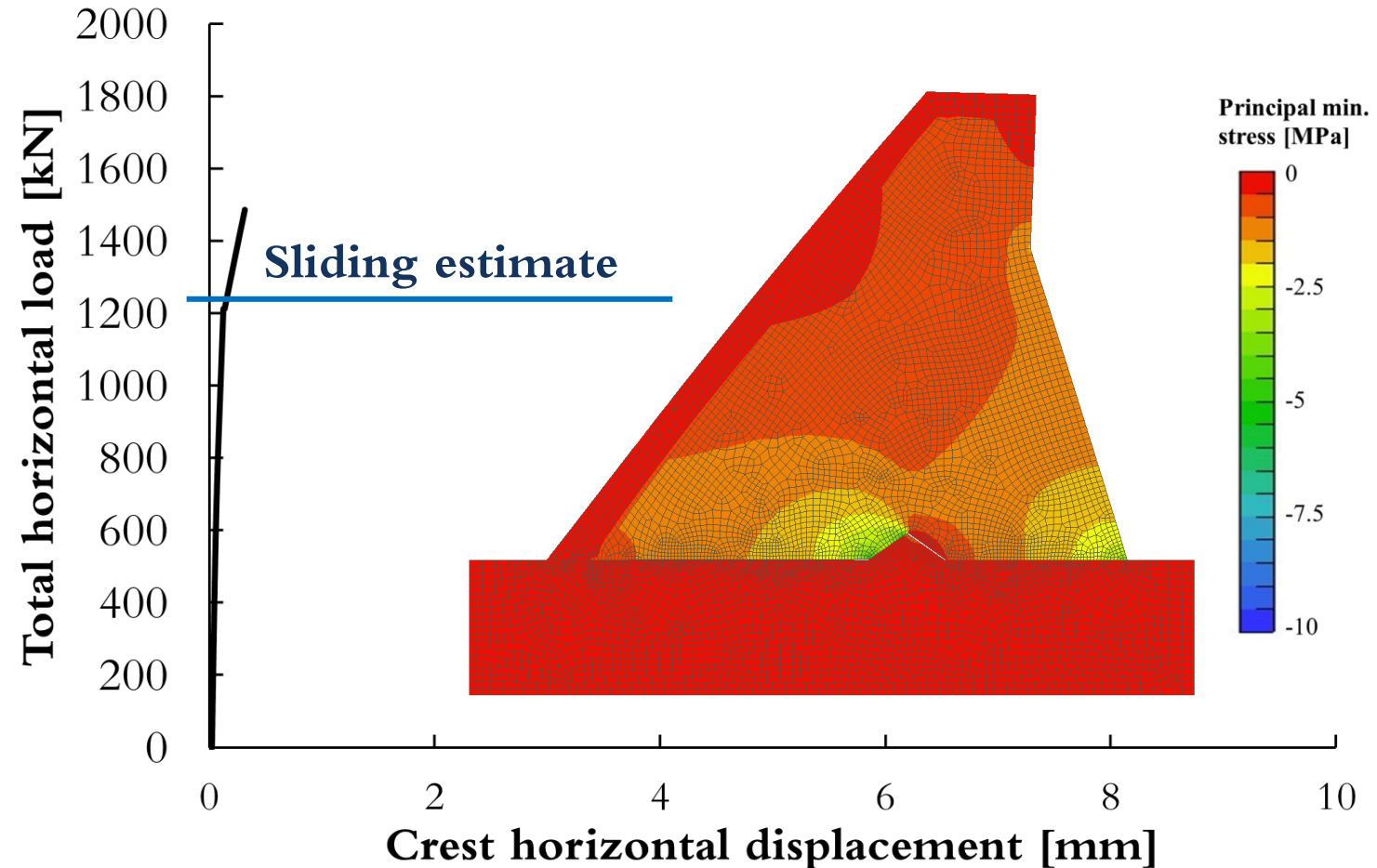
Failure mechanism and evolution of stresses

- Fails by a combination of sliding and overturning (CSO)
- Stresses redistribute to inclined surfaces as interface fails locally
- Line of action
- Rotation causes second point of contact at the heel or toe



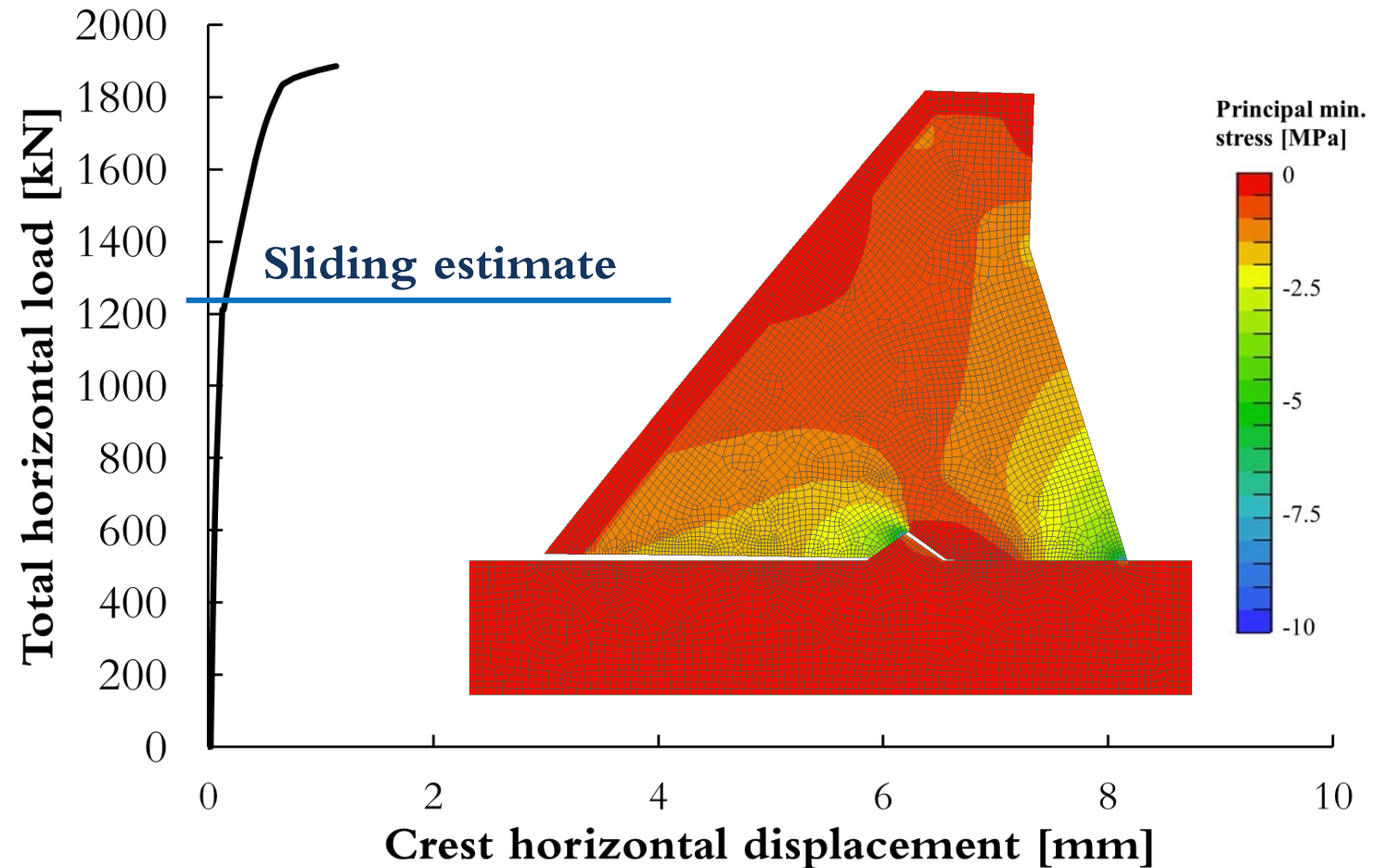
Combined sliding and overturning (CSO)

- FE-models behave consistent with assumptions for CSO



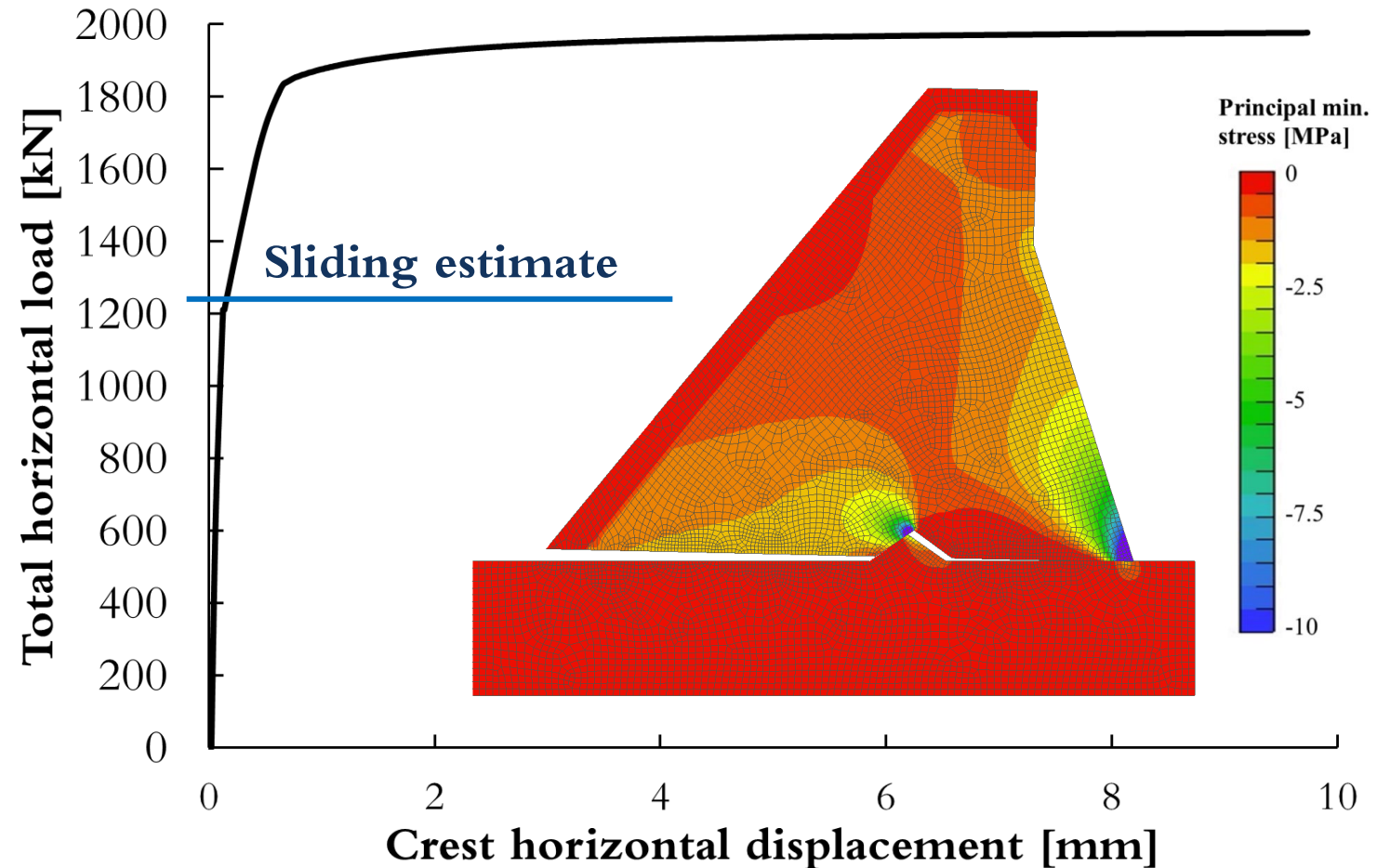
Combined sliding and overturning

- FE-models behave consistent with assumptions for CSO



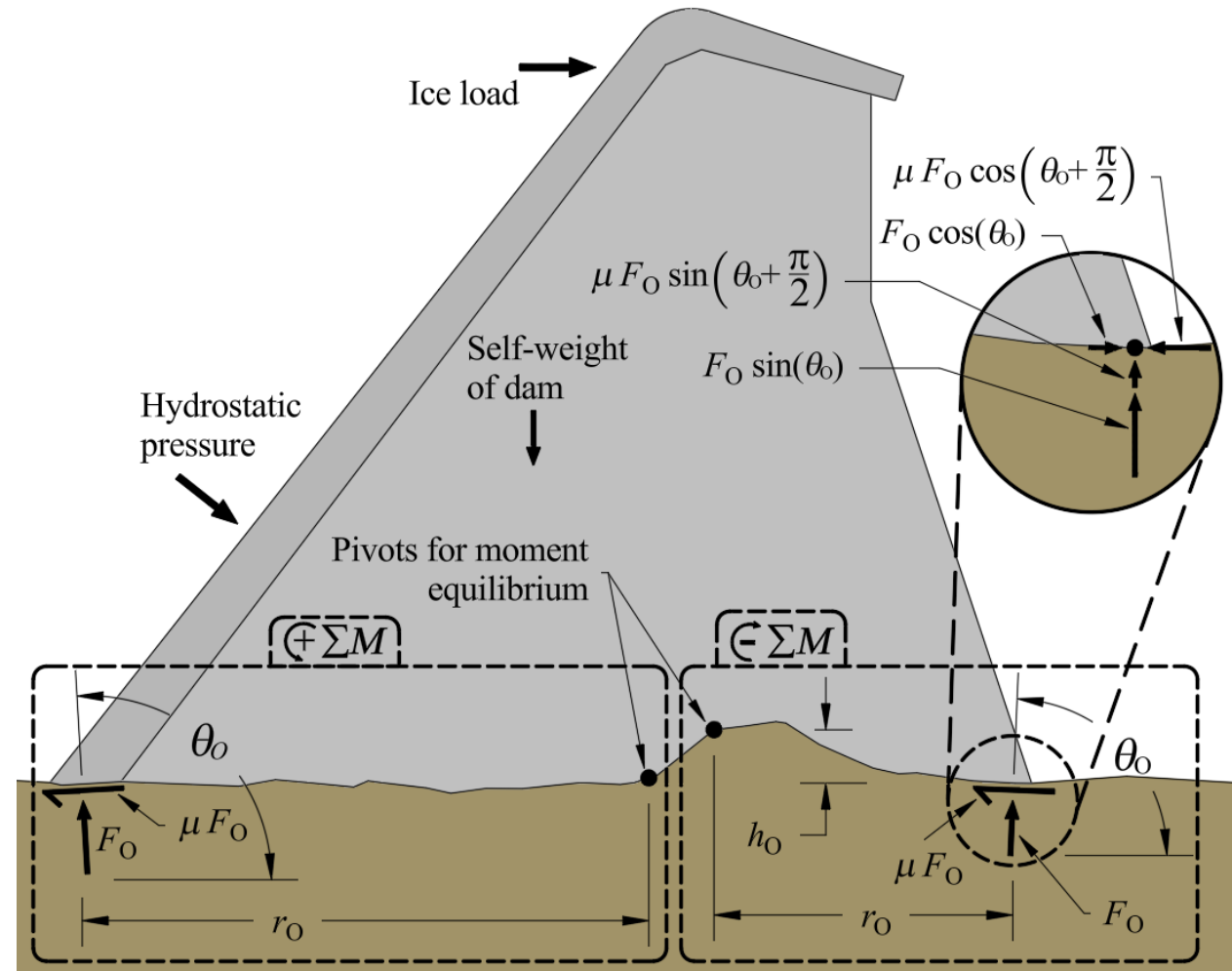
Combined sliding and overturning

- FE-models behave consistent with assumptions for CSO



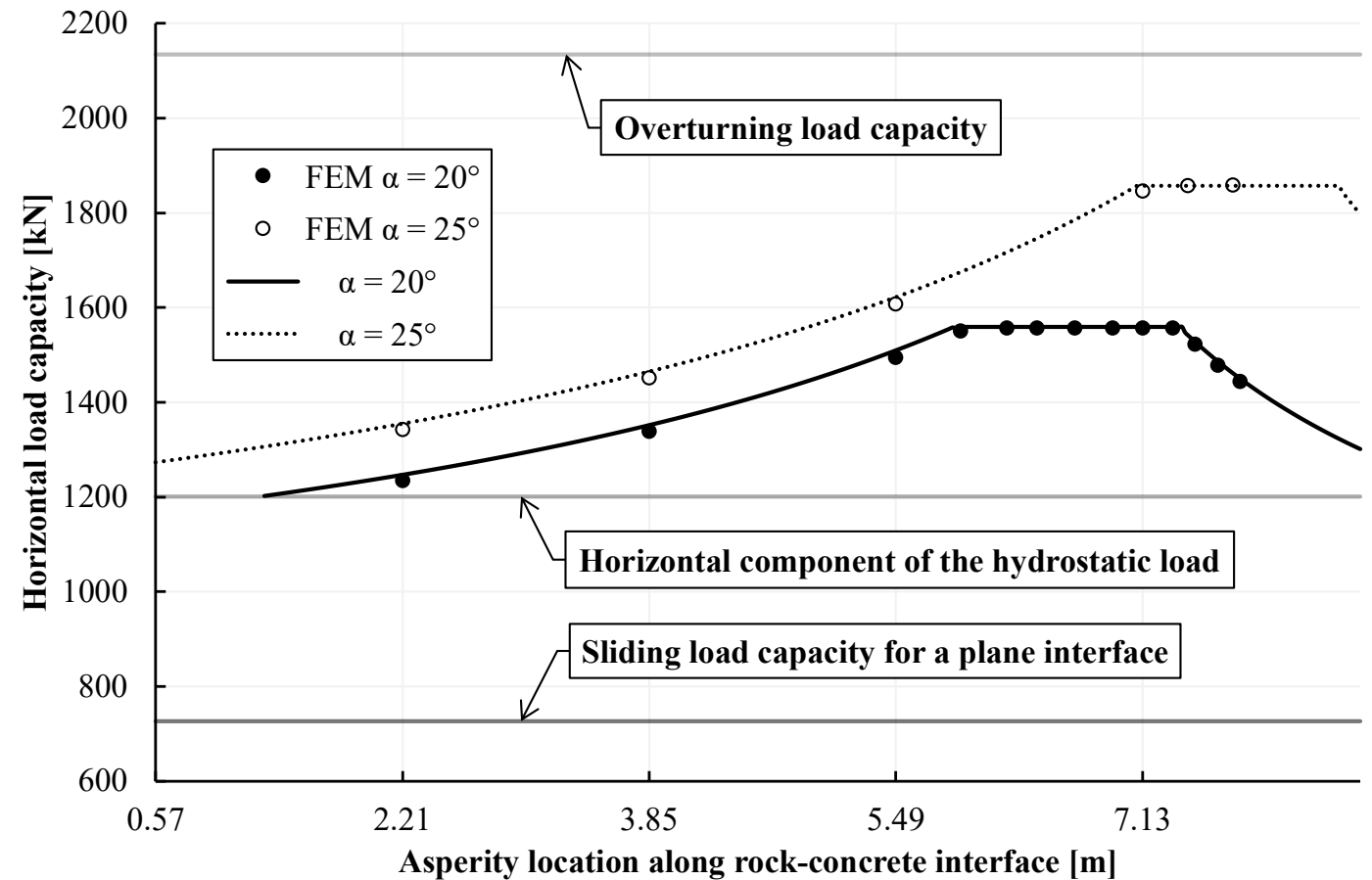
Combined sliding and overturning

- FE-models behave consistent with assumptions for CSO
- Analytical formulation



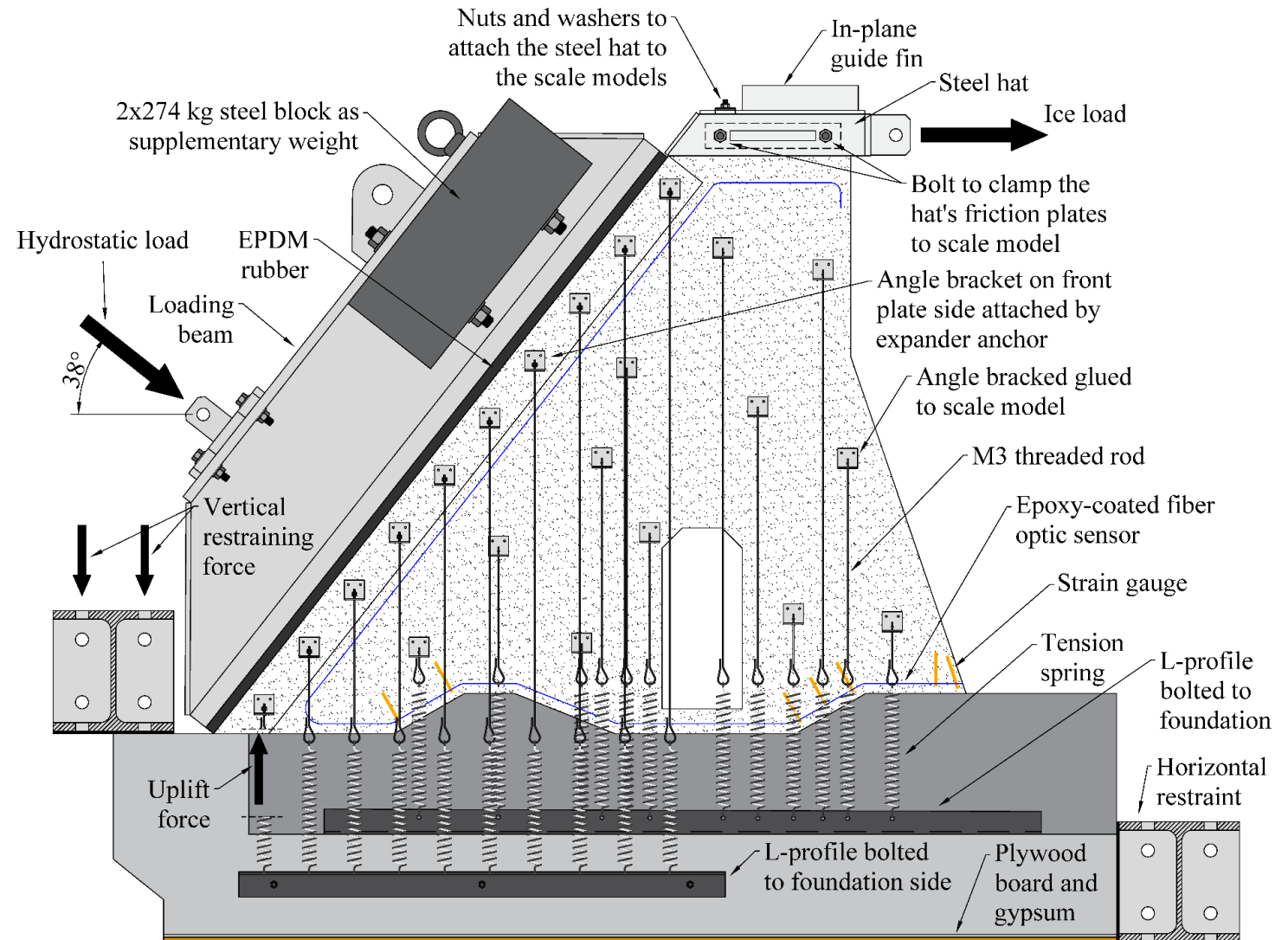
Combined sliding and overturning

- FE-models behave consistent with assumptions for CSO
- Analytical formulation
- CSO provides results in between sliding and overturning



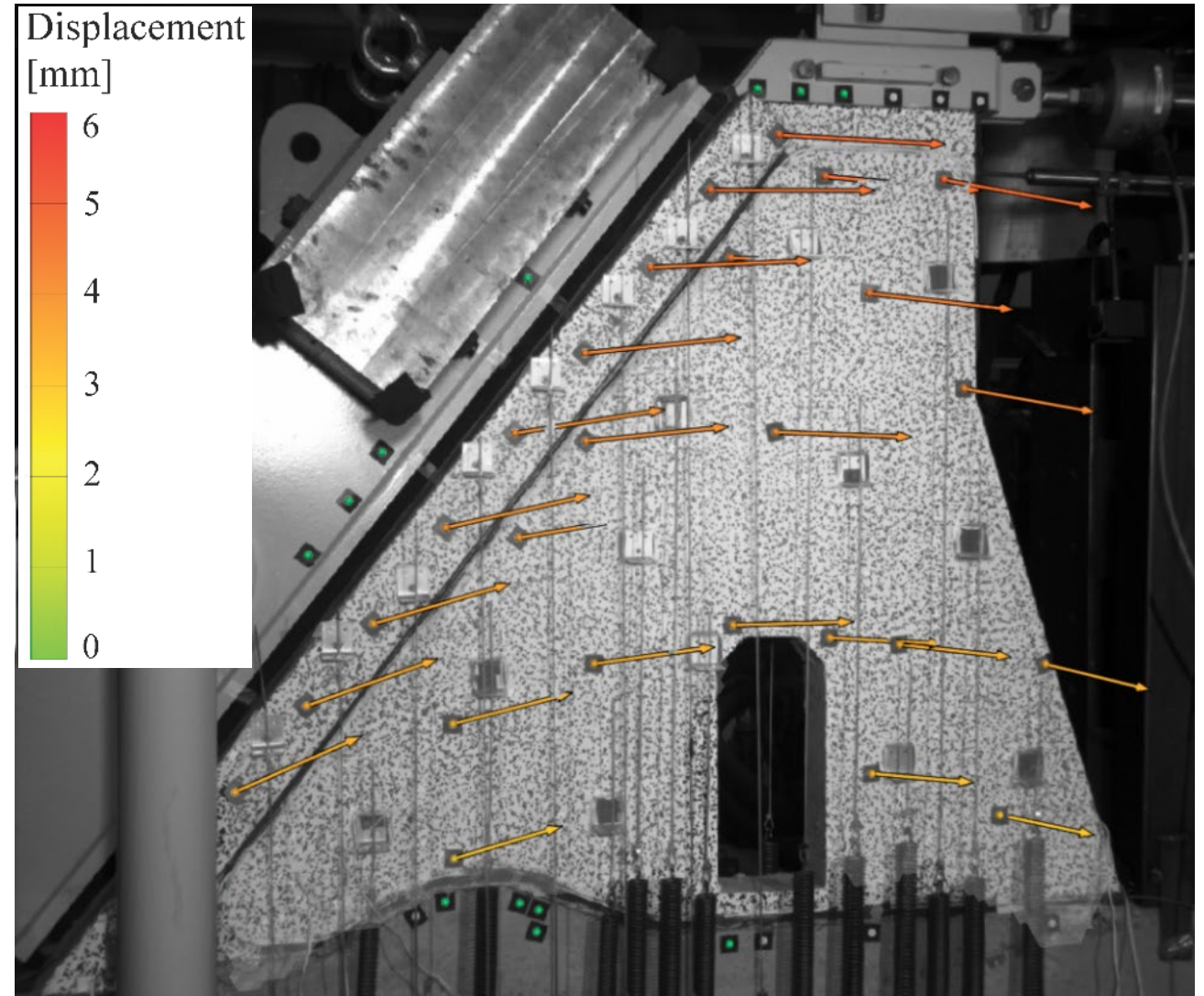
Scale model tests

- Scale model tests to verify the assumed behavior beyond linear elastic FEM
- 12 scale models constructed in scale 1:5
- Rock bolts, reinforcement, and shallow rock joints
- 3 different rock-concrete interface geometries



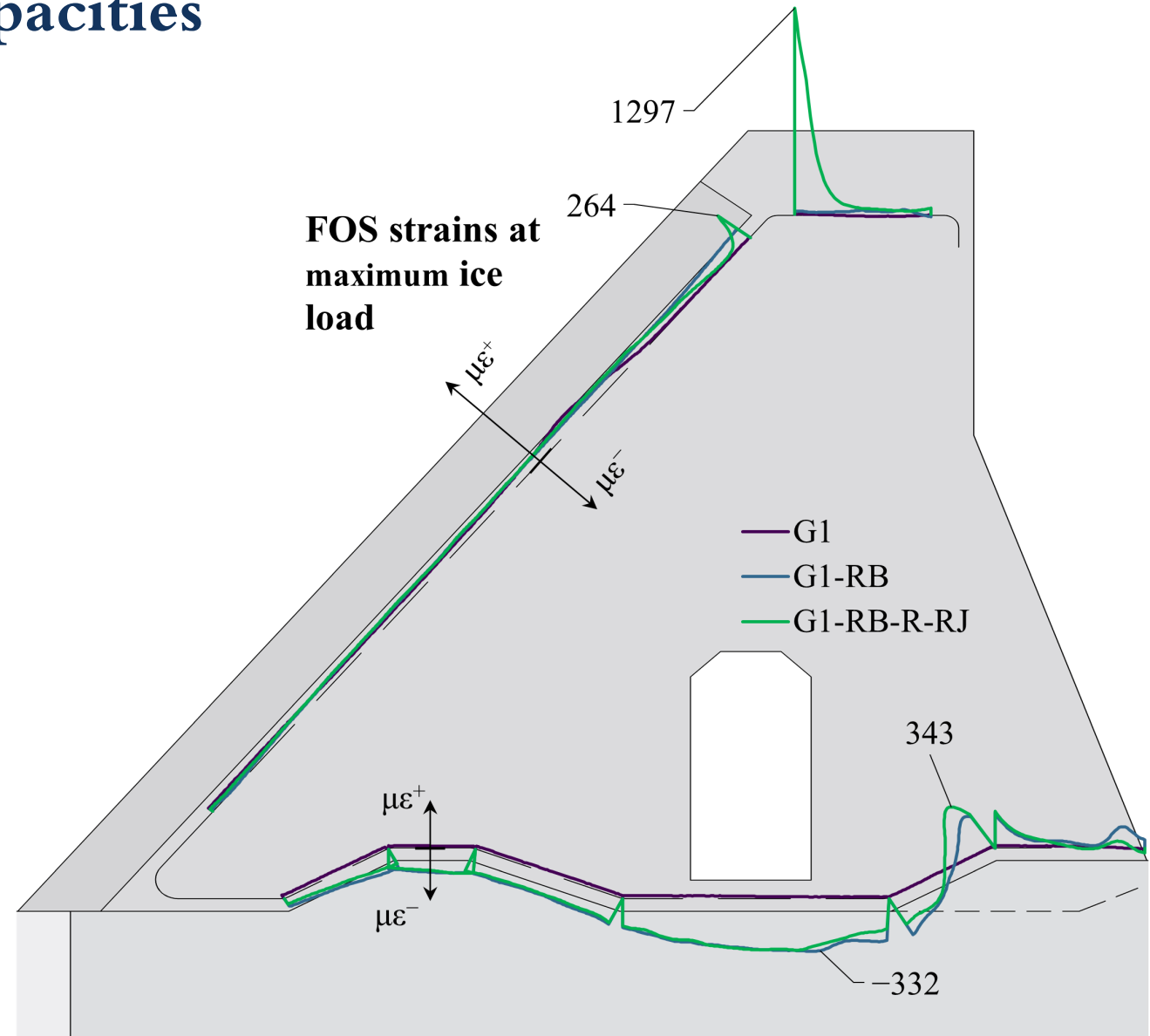
Scale model displacements and failure behavior

- Combined sliding and overturning was observed for the models
- Consistent behavior regardless of rock bolts and reinforcement
- Rock joints may change failure behavior



Scale model strains and load capacities

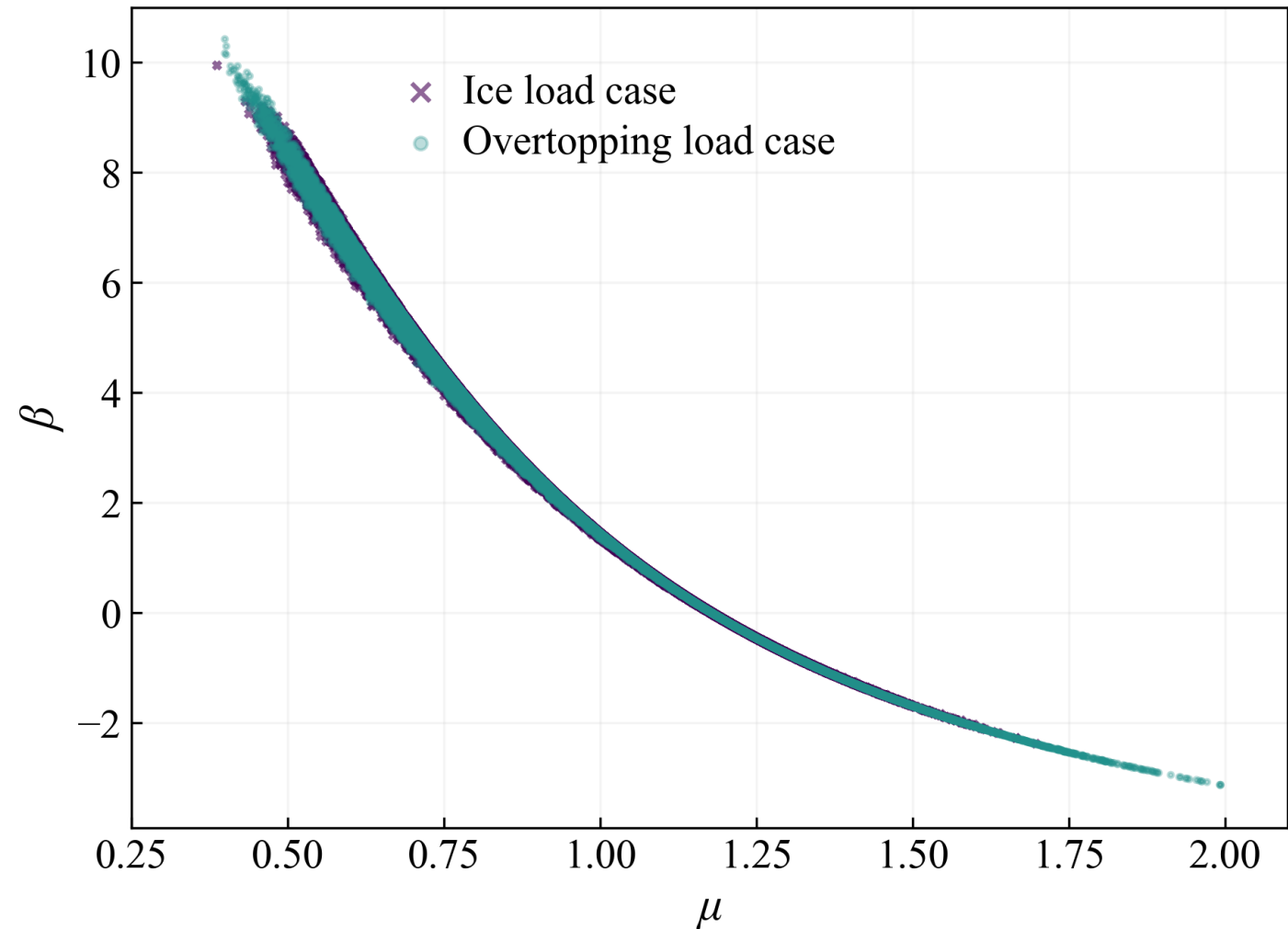
- Greatest strains at the tip of the asperity
- Rock bolts significantly increased the load capacity
- Rock joints decreased the load capacity
- Reinforcement had no influence



Reliability analysis

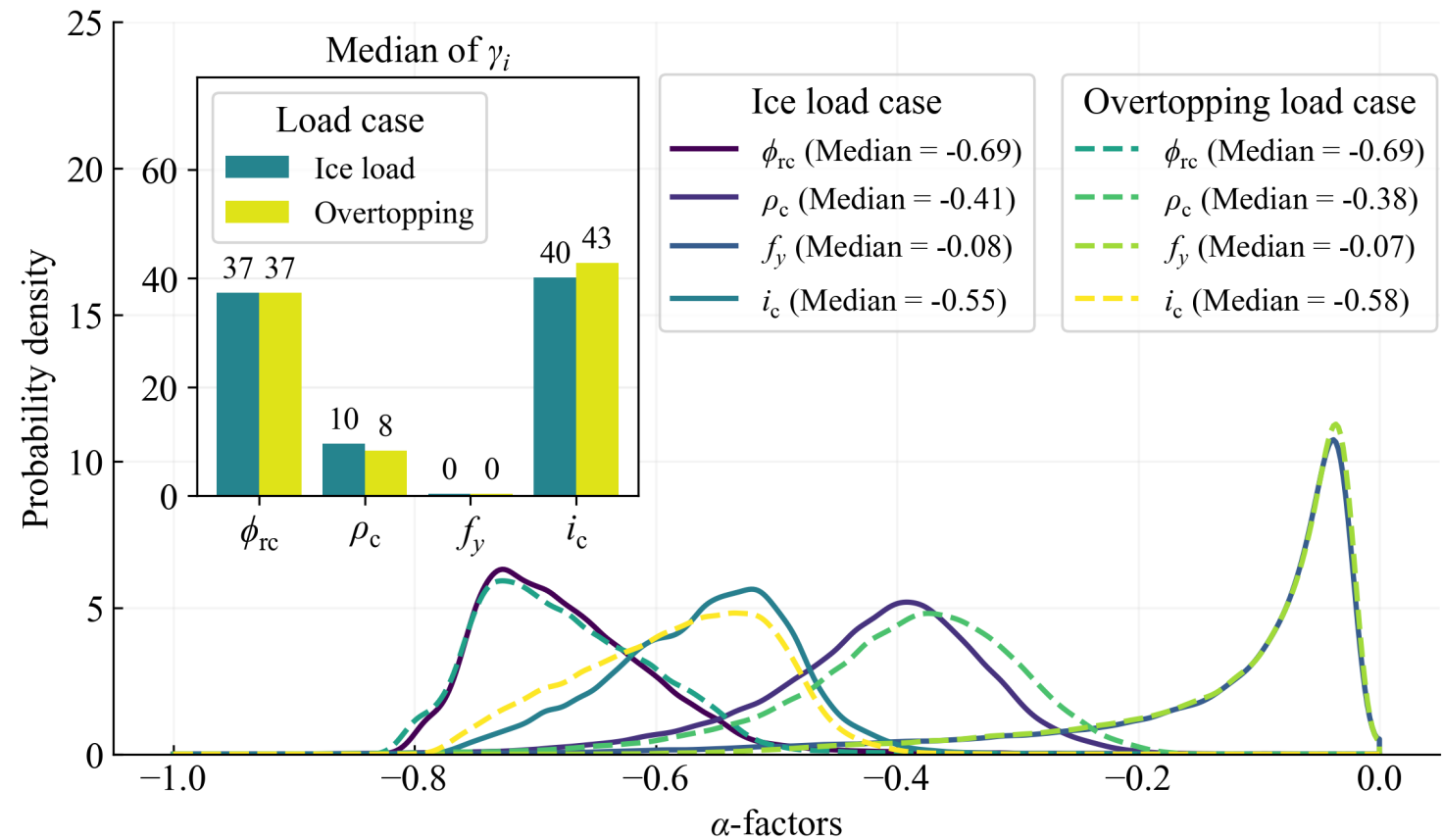
- Good correlation between reliability index and traditional deterministic safety factors
- Sliding provided lowest reliability
- Overturning is negligible for most cases

Reliability (β) vs “sliding factor” (μ)



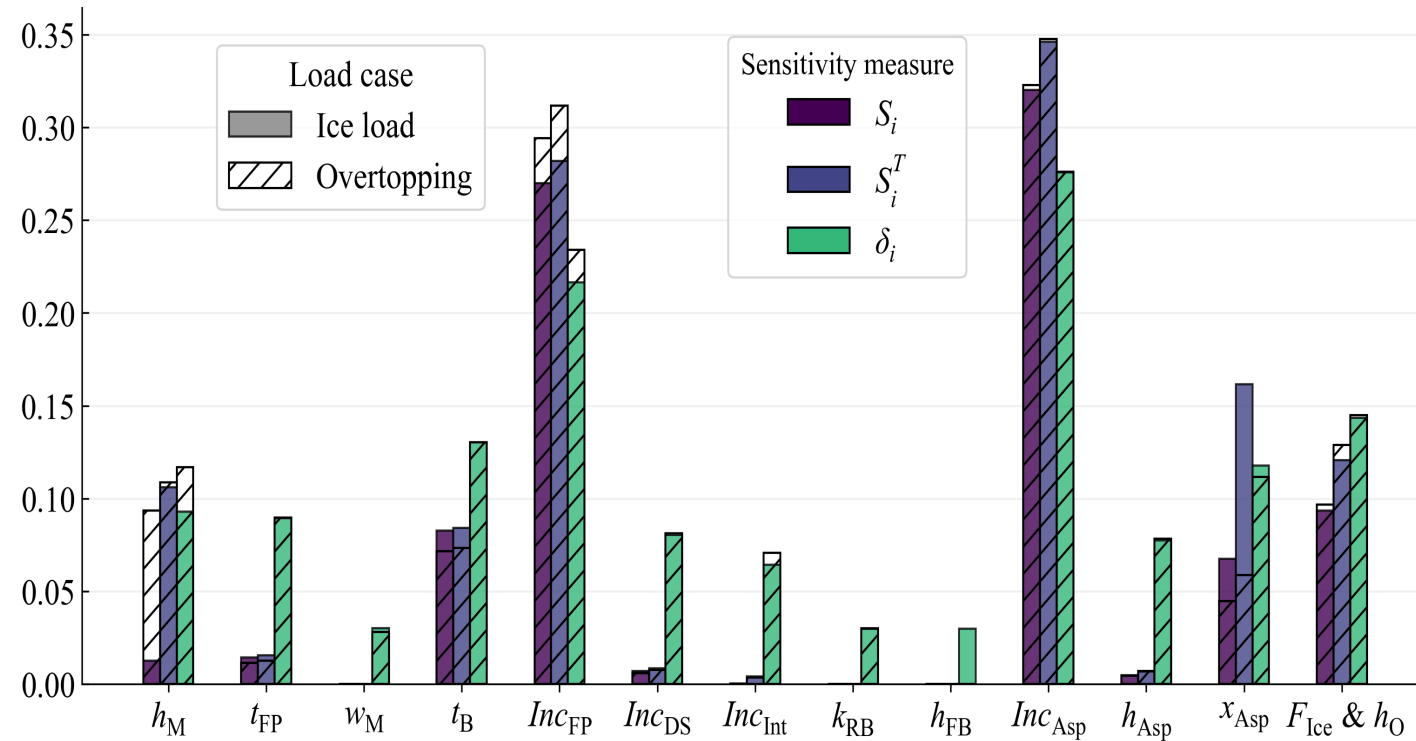
Sensitivity analysis (material parameters)

- Friction parameters were the most influential random variables overall
- Rock bolt yield stress generally uninfluential
- Concrete density moderately influential



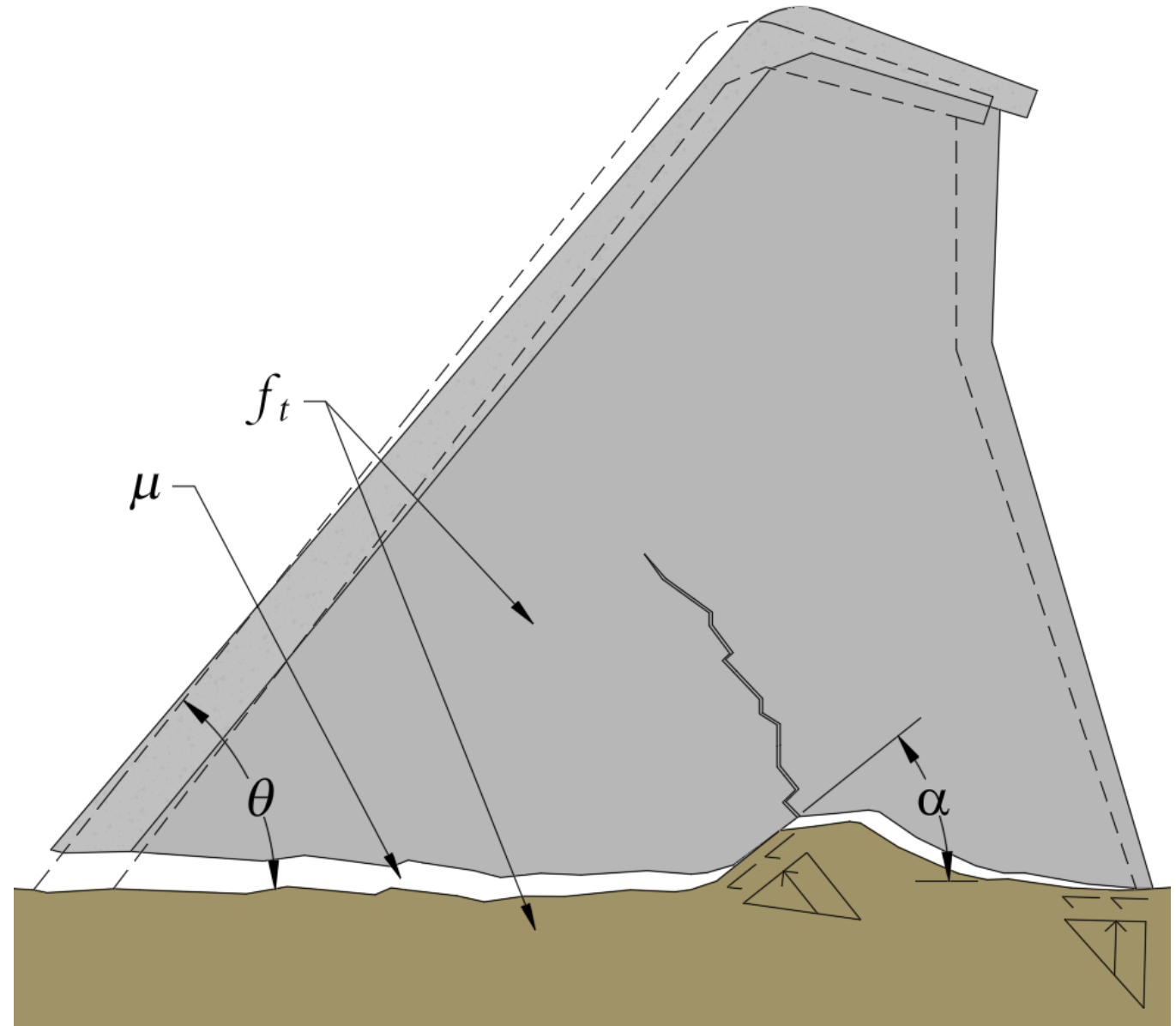
Sensitivity analysis (geometry/design)

- Front plate and large-scale asperity inclination (**Very influential**)
- Monolith height, buttress thickness, load magnitude, location of asperity (**moderately important**)
- Freeboard height, width of monolith, rock bolt content (**negligible influence**)



Conclusions

- Combination of sliding and overturning
- Load capacity greater than sliding estimates
- Stress concentrations
- Interface friction
- Inclination of front plate and asperities



Thank you!



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