SVENSKT CENTRUM
FÖR HÅLLBAR VATTENKRAFT

KTH ROYAL INSTITUTE
OF TECHNOLOGY

The significance of rock mechanics for stability of dams

Problems, solutions and planned research…

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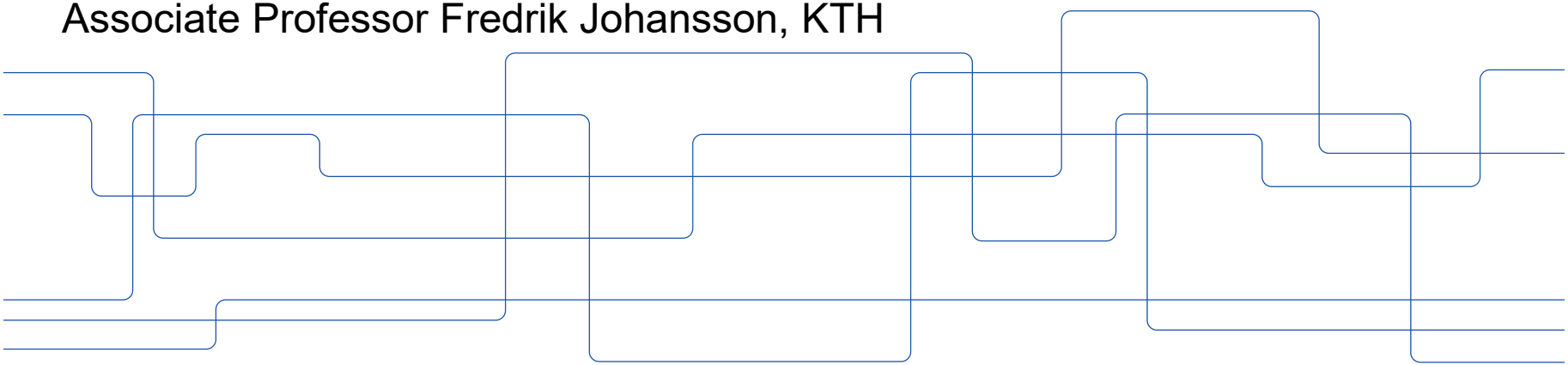
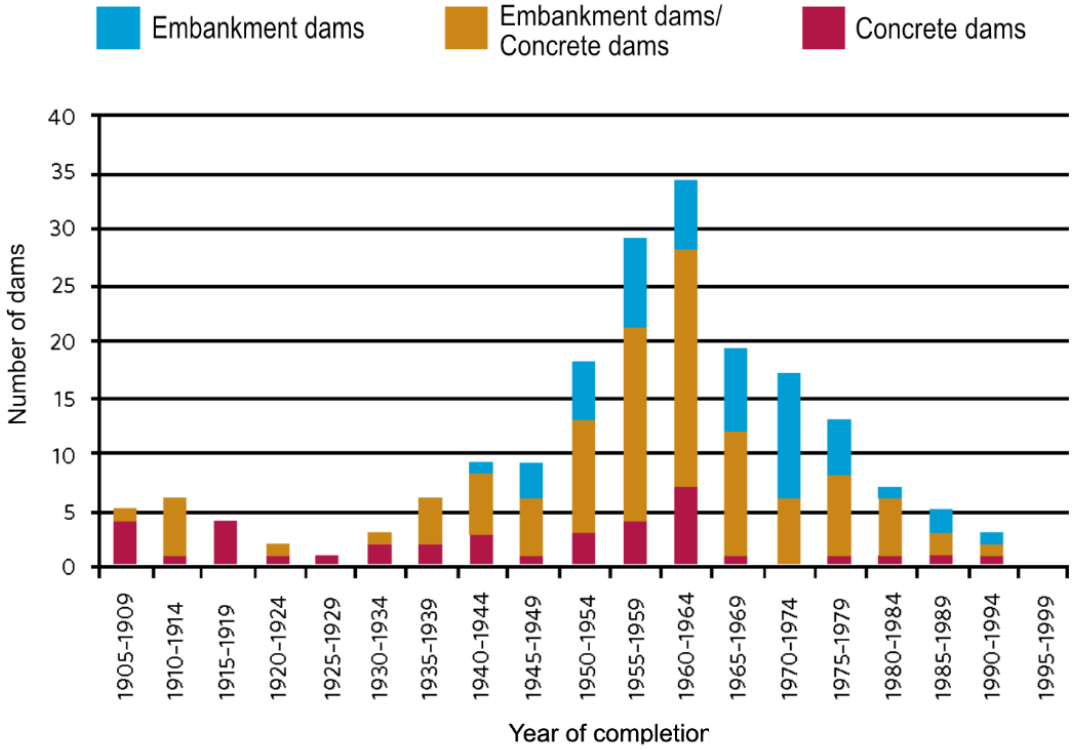


Background to the competence area

- Sweden has approximately 200 dams higher than 15 meters.
- Their average age is over 80 years old and some over 100 years old (Bernstone 2006).
- Re-assessment of their structural safety is becoming increasingly important to ensure that failure does not occur because of material deterioration in the dam body or foundation.

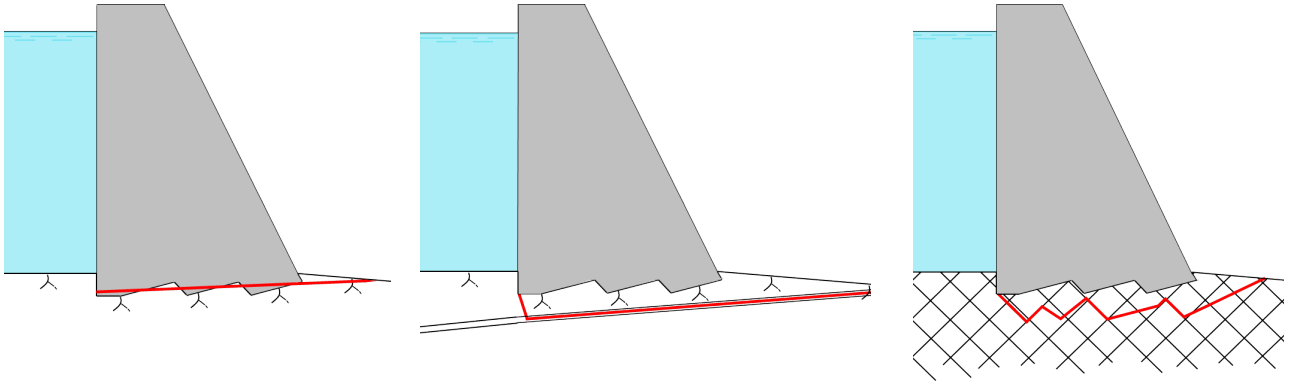


Background to the competence area

- Safety evaluations of existing dams (SEED) showed difficulties in assessing the safety against sliding.
- Difficult to assess the peak shear strength of persistent sub-horizontal rock joints or at the concrete rock interface.
- Many dams strengthened with pre-stressed anchor cables.
- Necessary?

Example of stability enhancing measures, pre-stressed anchor cables at Storfinnforsen buttress dam (Photo Svenska Kraftnät)

Failure modes for sliding



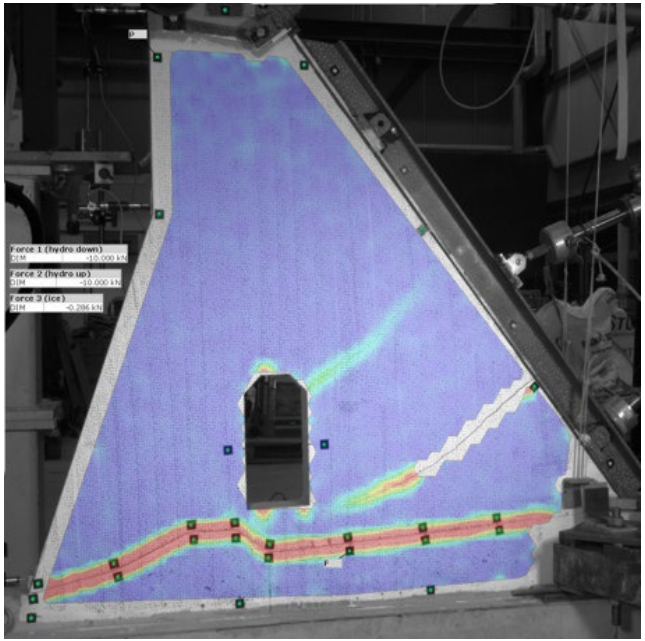
Concrete-rock interface

Persistent rock joint

In the rock mass

- **The weakest of these potential failure modes decide where the failure occur.**

Prediction of shear strength for concrete-rock interface



Model test of scaled monolith from Kalhovd dam in the Stable dams project, Photo Gabriel Sas, LTU.

- The concrete-rock interface is usually assumed as a **linear sliding plane**.
- No influence from **large** scale rock **asperities** are accounted for.
- In a previous collaboration project between LTU, NTNU and KTH this was investigated with **scaled model tests**.
- As expected capacity **significantly higher** if asperities are accounted for.
- However, the scaled models did not account for **joints in the foundation**, influence from **reinforcement** in concrete or **rock bolts,** which will now be studied in ongoing PhD project.

Prediction of in-situ shear strength for rock joints

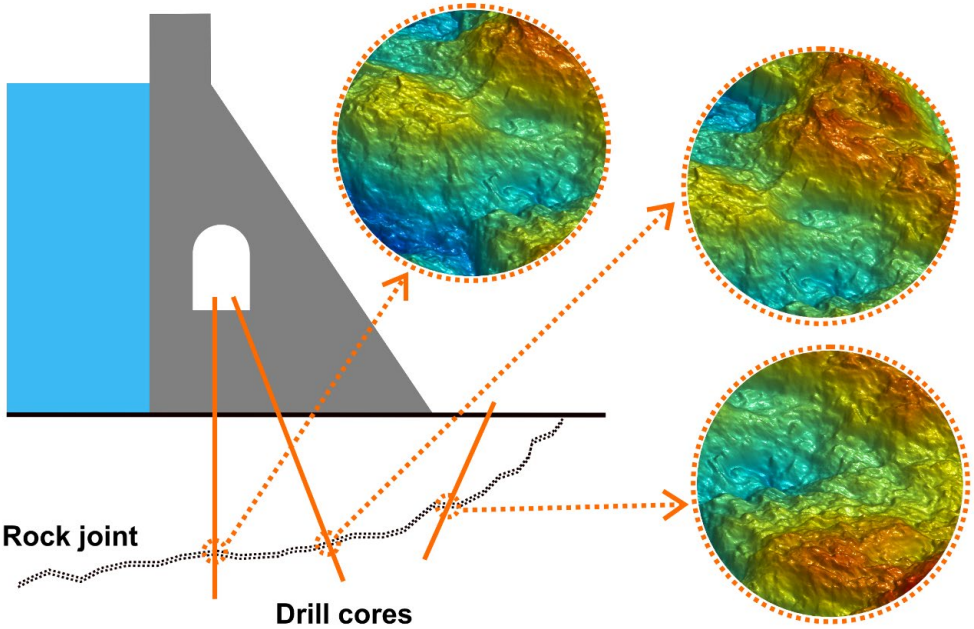
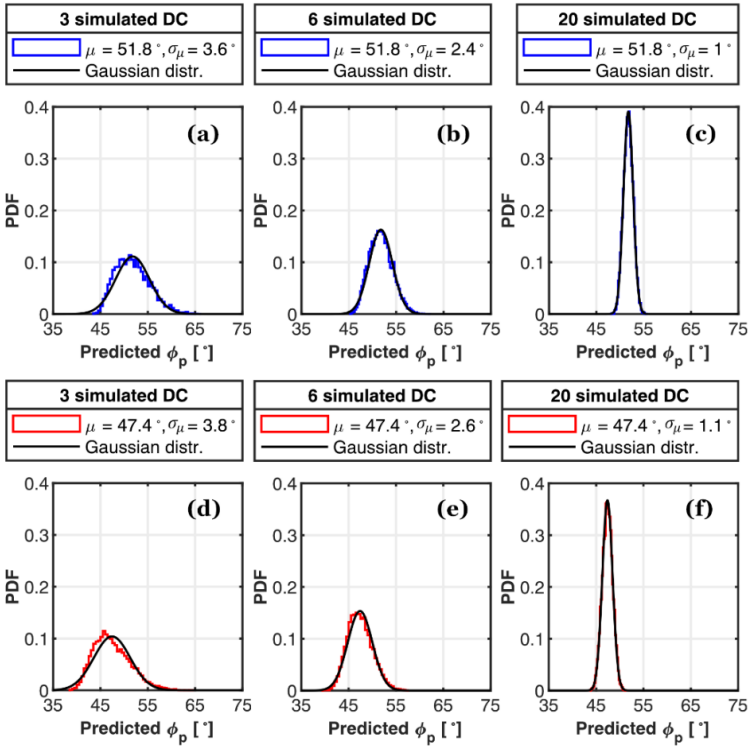


Illustration of core drilling through a dam for location and characterization of rock joints (Illustration Francisco Rios Bayona).

- One of the main problems in **re-assessments** of existing concrete dams is that the joints are located in the rock mass under the dams.
- Can large scale peak shear strength be estimated based on information available from **small scale core-drilling**.
- According to a new failure criterion for rock joints by previous PhD student Francisco Rios Bayona this **is possible**.

Prediction of in-situ shear strength of rock joints

- The proposed methodology implies a **statistical uncertainty**.
- The peak shear strength is dependent on the **number of tests**.
- In addition, the peak shear strength has a **natural variability** for different joints.
- How to **account** for these **uncertainties** in the assessment of sliding stability is going to be studied in coming project by a Post-Doc student.



Monte Carlo simulation of friction angle for two large scale rock joints samples (Rios Bayona et al. 2022)

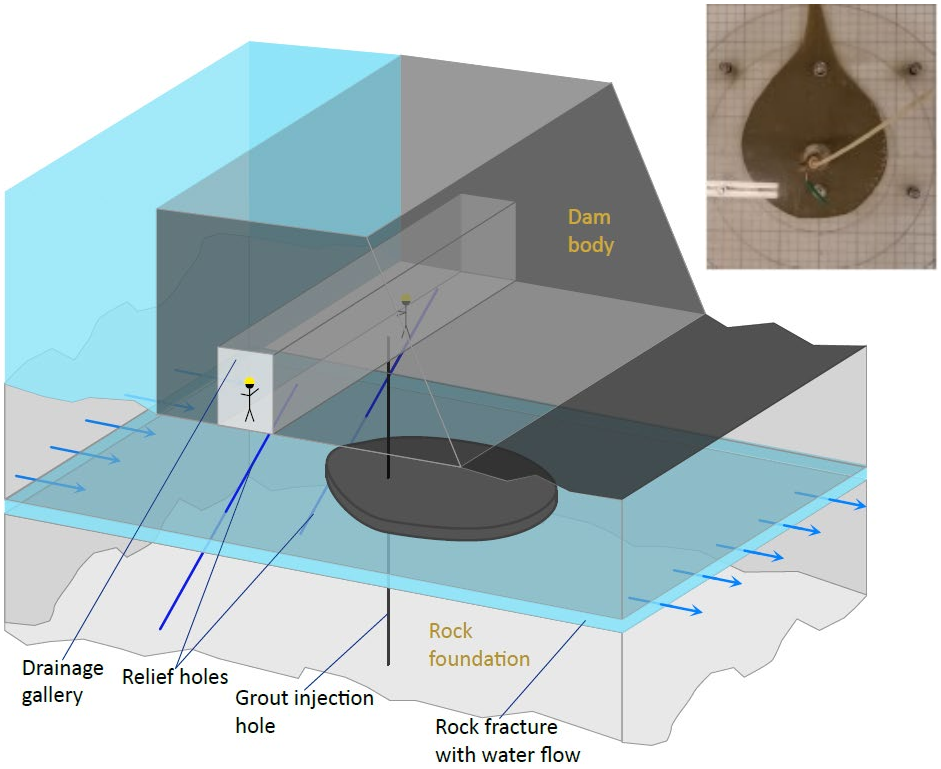
Pore pressure in the foundation

Storfinnforsen buttress dam (Photo: Fortum).

Ramsele buttress dam (Photo: Fortum).

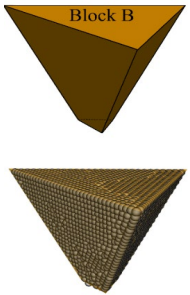
- The uplift in the rock foundation is **difficult** to estimate.
- Today, the knowledge is limited on **the variation** in uplift and how it is influenced by factors such a degraded grout curtain and clogging of the drains, etc.
- In a rehabilitation and life extension program of two buttress dams in Sweden, the Storfinnforsen and Ramsele dams, new drains was drilled and 270 piezometers were installed in the rock foundation downstream the front plate of the monoliths.
- By using these data, is it possible to determine the **natural variation** of the **pore pressure** in the rock joints in the foundation of these dams?
- How should **alarm-limits** be **determined** to also account for time to implement **countermeasures** if needed? These questions will be studied in coming PhD project.

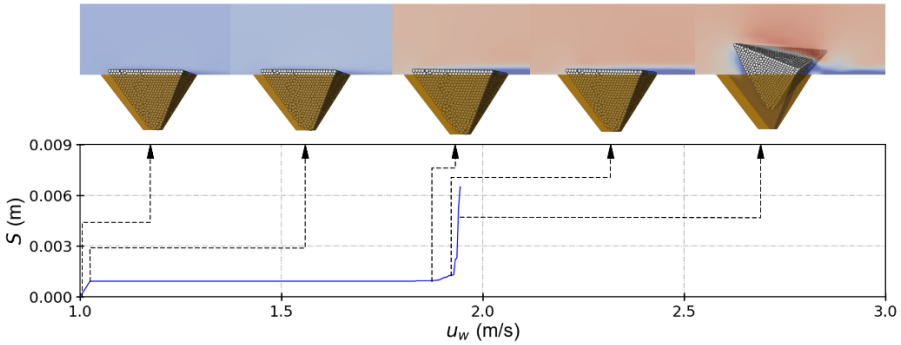
Remedial grouting in rock foundations under dams



- Degradation of grout curtains can induce **excessive pore pressure**, affecting the sliding stability.
- **Remedial grouting** can be necessary.
- Large gradients imply risk for **erosion of grout**.
- **How** should the remedial grouting be **performed** to avoid erosion?
- Currently being studied in ongoing PhD project.

Block erosion in spillway channels





- Excessive **block erosion** can influence the **stability** of the dam.
- Erosion **difficult** to model and **predict**. Influenced by several parameters, which in combination cause the erosion – both rock mechanic and hydraulics are needed.
- In a recently performed project, a combined **CFD-DEM model** has been **validated** for the erosion of a **single block**.
- How can this model be **implemented** to **predict block erosion** in real spillway channels? This will be studied in a coming Post-Doc project where competence in both hydraulics and rock mechanics will collaborate at KTH and LTU.

Planned research activities coming years

- Continued model tests, combined with numerical analyses, for determination of actual shear strength in the interface where the influence from reinforcement in concrete and rock bolts are accounted for.
- Methodology for derivation of design values for the shear strength of rock joints including different types of uncertainties such as number of tests and natural variability.
- Description of pore pressure and alarm thresholds for probabilistic assessment of sliding stability for concrete dams
- Design methodology for remedial grouting in rock foundations under dams
- Degradation mechanisms of the grout curtains – which factors are governing the degradation process and what are the expected technical life-length of the curtains.
- Development of methodology for prediction of block erosion in spillway channels