HydroCen – WP 1.1 Tunnel Systems

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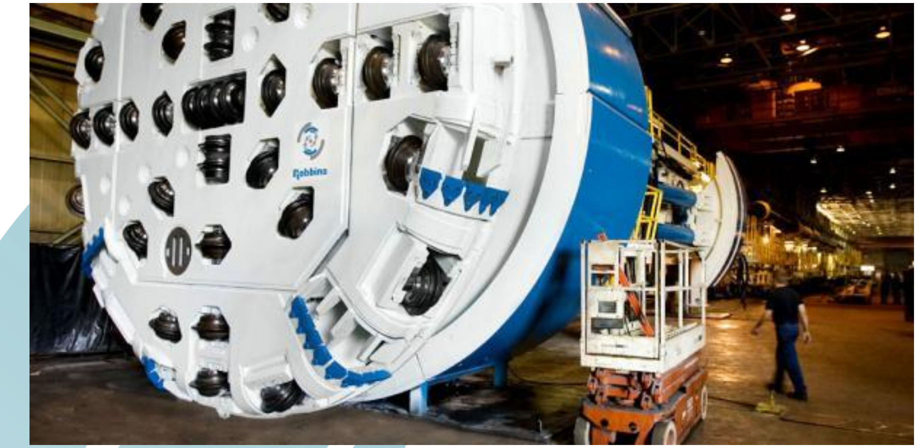

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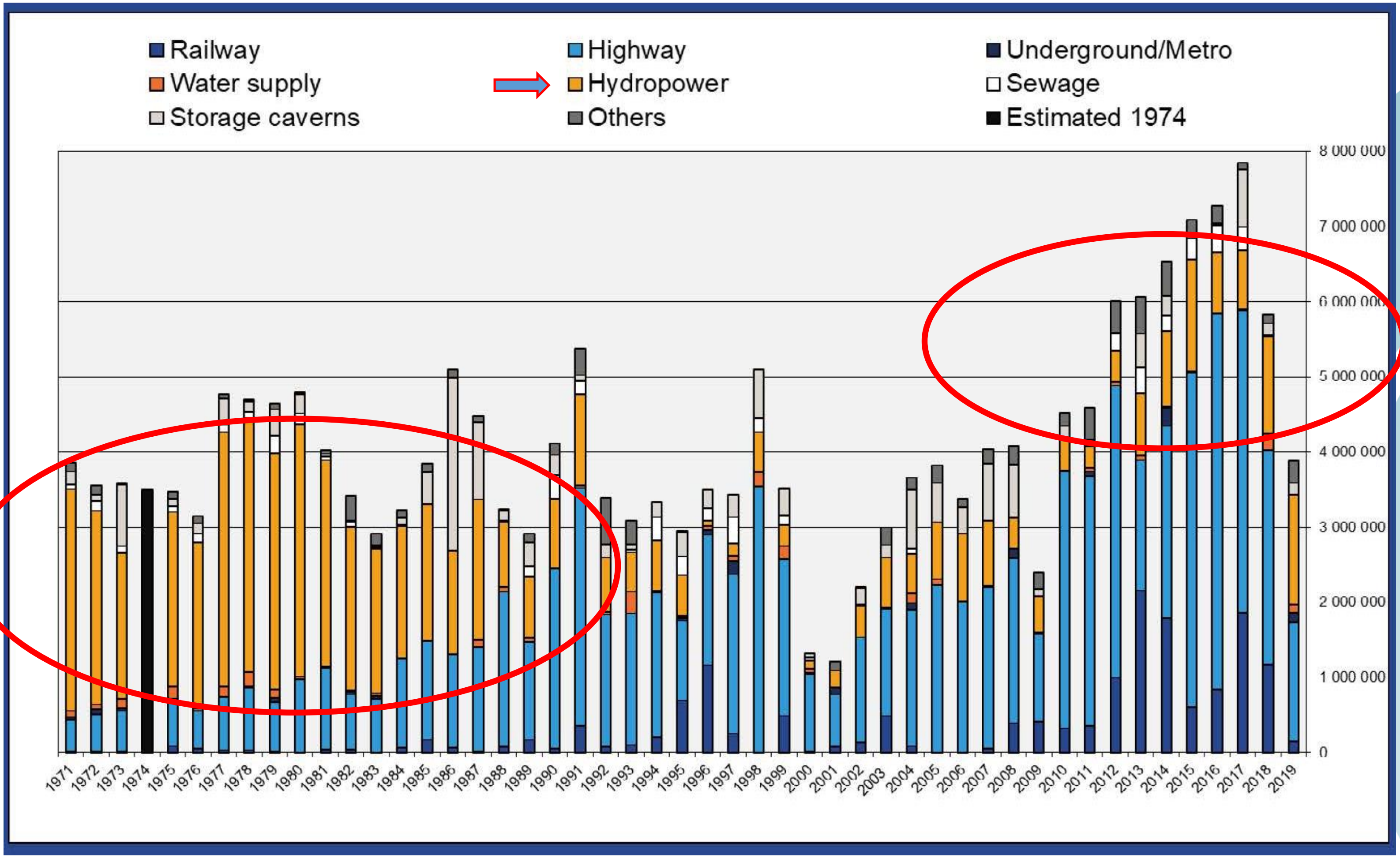
Main basis of Norwegian tunnelling technology: Hydropower development



- Road tunnels (~1200/850 km)
- Railway tunnels (~700/260 km)
- Hydropower tunnels (4000 km)
- Powerhouse caverns (~200)
- Air cushion chambers
- Oil and gas storage caverns
- Freeze storage caverns
- Drinking water storage caverns
- Waste water treatment plants
- Waste disposal caverns
- Sports utility halls, and more

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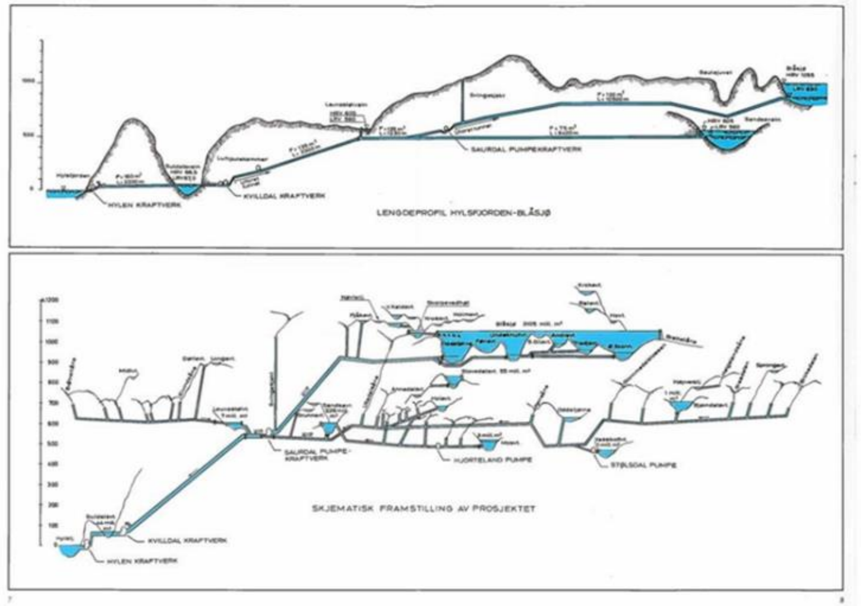
Norwegian underground hydropower projects - some key figures

- 4000 km tunnels and shafts
- 200 powerhouse caverns
- unlined tunnels, up to 100 bar hydrostatic pressure
- 10 air cushion chambers,
  air pressure of up to 77 bar/volume up to 100,000 m^3

- Much of the potential is developed, but some new, large projects are still beeing built
- Considerable activity related to upgrading/ converting of existing powerplants,
- Increased focus on more flexible operation – «peak operation»



Ulla Førre: 2100 MW/4.1 TWh
Kvilldal: 1240 MW

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WP1.1 –Tunnel systems

- Research to a great extent organized through PhD-projects - 5 started 2017:

  1. Lena Selen, IGP: *Consequences of swelling rock mass for stability and support requirement*
  2. Bibek Neupane, IGP: *Consequences of peak operation on stability and rock support*
  3. Henki Ødegaard, IGP: *Test methods for optimum design of transistion zone in unlined pressure tunnels*
  4. Livia Pitorec, IBM: Rebuilding of *tunnel systems for upgrading to peak operation and pumped storage*
  5. Ola Haugen Havrevoll, IBM: *New concepts/new design for sand traps in pressure tunnels*

For more details see: https://www.ntnu.edu/web/hydrocen/hydropower-structures

Stability problems in hydropower tunnels

- Full blocking not common (around 15 cases known from total tunnel lenght around 400 km)
- Very expensive when it occurs (50 MNOK+)
- Most common: ½ - 2 years after water filling
- In some cases after many years of operation; i.e.

- After >20 years: Kvænangsbotn (1987)
- After ~30 years: Svandalsflona (2008)
- Most cases are quite old (more than 20 years)

Cave-in/blocking of recent date

Matre Haugsdal 2017, ~20-30m³

- After 1 year of operation
- New adit and bypass required
- Cost of repair ~40 MNOK

Nedre Vinstra 2015, ~2.500m³

- In TBM tunnel, after 26 years of operation
- Bypass required
- Estimated annual energy loss: 15 GWh

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Swelling rockmass in hydropower tunnels

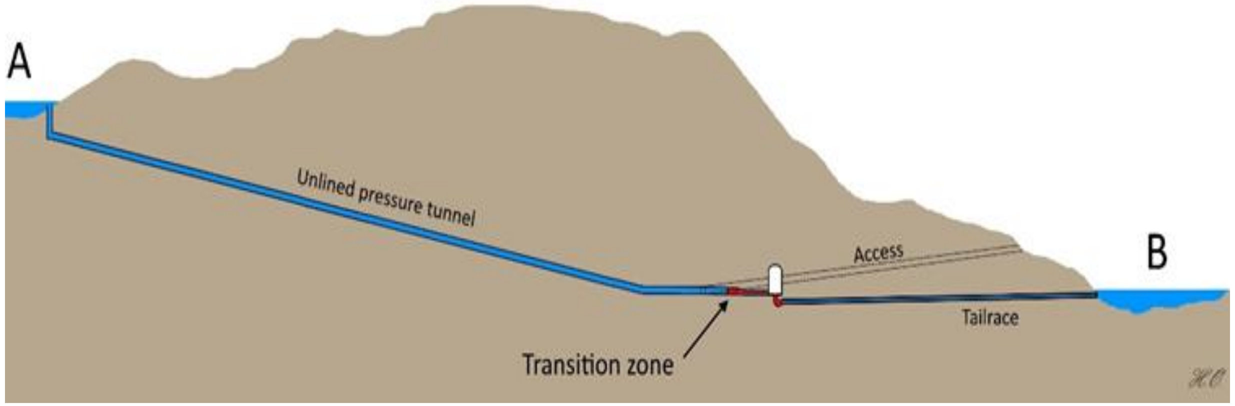
- Alternative methods for testing swelling pressure (SP) in lab
- Significance of slake durability (SD)
- Development of laboratory test methods more representative of in- situ conditions
- Instrumentation of support structures for in-situ monitoring of SP
- Optimization of support design in swelling conditions

Rockmass stability in peaking power tunnels

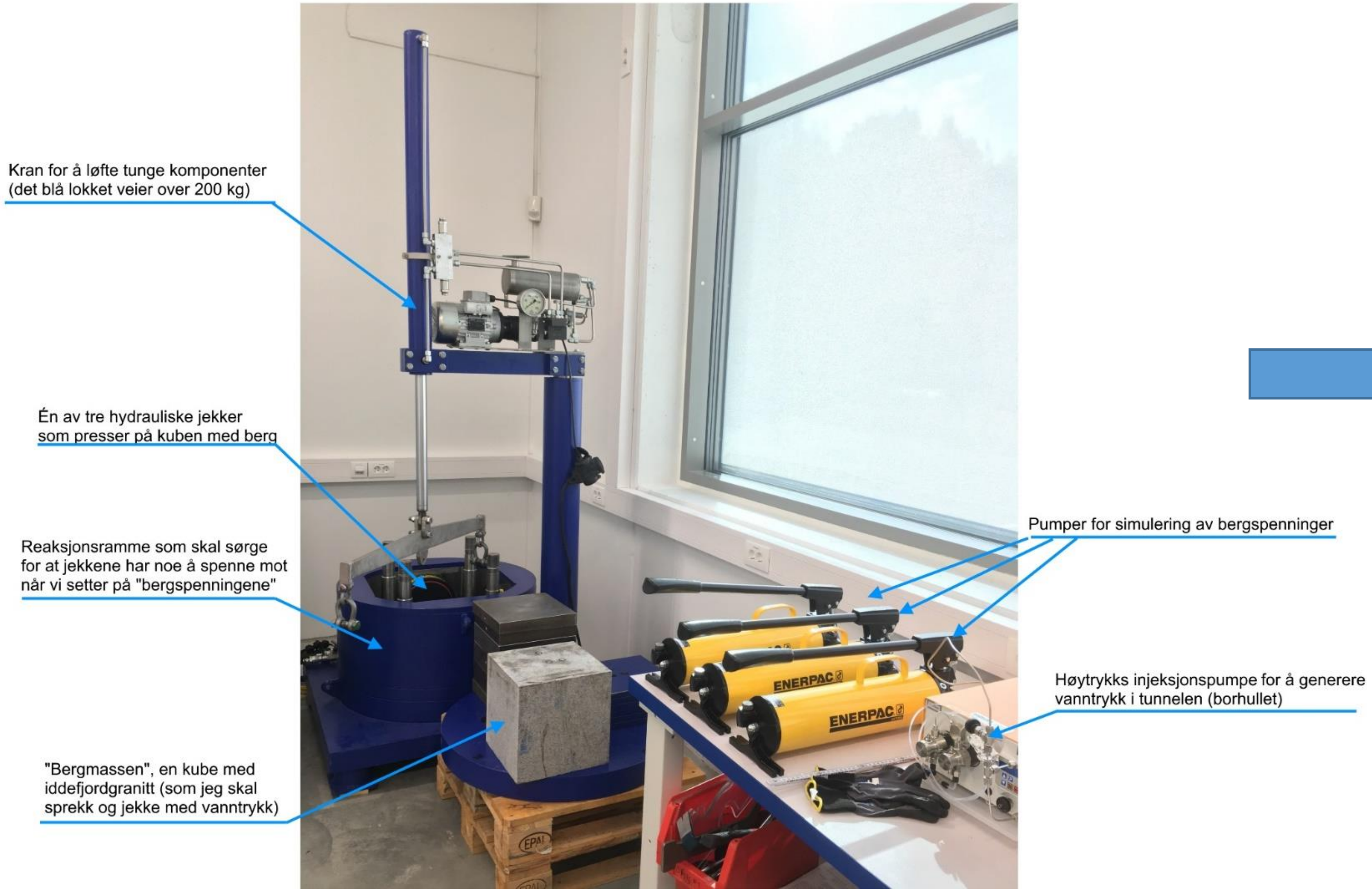
- Dynamic effects on support structures due to variations in water flow and oscillating pressure fluctuation
- Instrumentation, monitoring and measurement of pore pressure fluctuation in the rock mass
- Numerical analysis of selected cases
- Long term behavior and durability of rock support

Design of unlined tunnels/penstocks

- Critical review and evaluation of data from previous jacking and fracturing tests
- Parallel testing in projects under construction
- Analysis and comparison of alternative testing/monitoring methods
- Development of systematic methodology for testing and design as basis for design



Laboratory rig for hydraulic fracturing



In-situ testing

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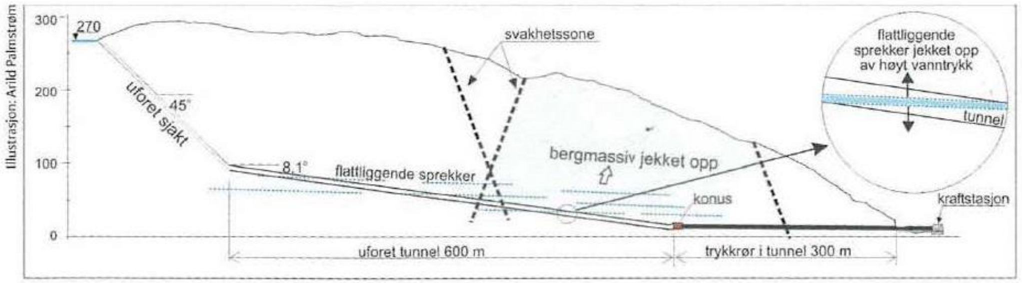
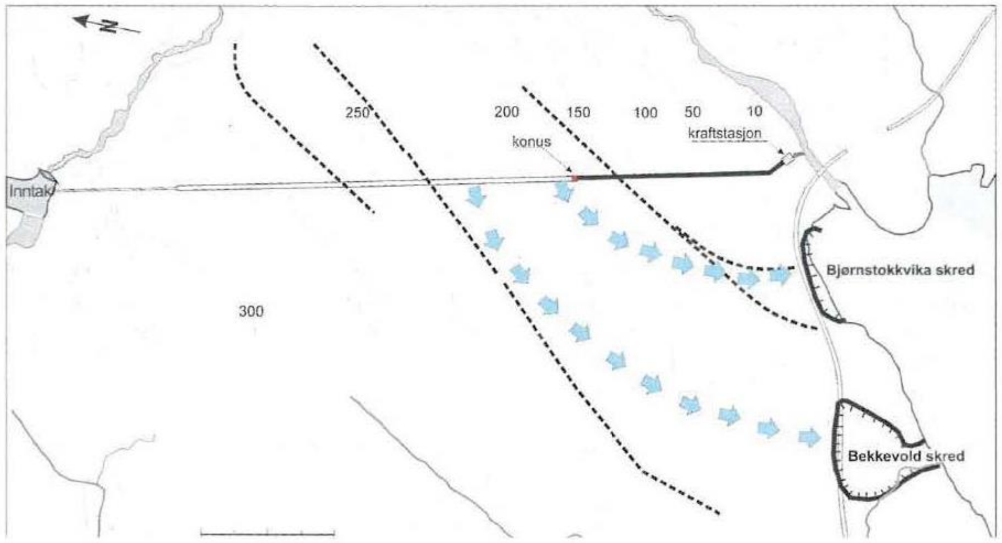
Recent case of hydraulic jacking caused by insufficient rock stress: Tosbotn





(From Helgelendingen, 2018)

Tosbotn 1.-2.4.2016 => clay slide along highway

Total repair cost: >100 MNOK

(From Palmstrøm & Buen, 2017)

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