Challenges and possibilities in construction ultra high head in HPP

On behalf of Geminicenter
Underground technology

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Pumped HPP using ultra high head in unlined tunnels

What characterizes the typical Norwegian HPP scheme?

Large upper reservoirs at high elevations, long tunnels (head race up to 50km), small cross-sections (15-30m²), high heads (1000m +), continuous production, low water velocity (appr. 1m/sek)

Concept driven by topography, consumers location and demands ++

Bogna HPP, Courtesy NTE
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The development of Norwegian high head HPP concepts:

Note the following:
- High heads
- Unlined tunnelling
- Taking advantage of the capacity of the rock mass as construction material
- In-situ stress situation is crucial
- Tunnelling is a robust and viable construction method and element

These aspects materialized the concept
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New Tyin used the existing concessions and reservoir regulations
Reached above 1000 m head
World record in unlined head race tunnels

Between the 80’ies and today a stand still in development, but it should have been way beyond the 1000m in New Tyin
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In Italy some high head pumped storage facilities have been built. Likely not unlined! The others are low to medium head. Information on lining concept, or unlined is not disclosed. Have to assume that they are lined and that Norway is front runner in unlined concepts.
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On invitation from CEDREN the tunnelling research community at SINTEF/NTNU made a joint report in 2011

Develop 20,000 MW pumped storage in 15 years!! Current 30,000 MW in Norway took a hundred years appr.

This study triggered the idea of introducing Ultra High Head
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We used the following as standard solutions for the study:

1000 MW plant and 250 MW plant, head of 445m and 291m respectively, efficiency coeff. = 0.8.
Flow velocity set to 2.3 m/s.
1000 MW has 4 power generation units, 250 MW has 2 units
Layout of each plant is similar to conventional HPP plants consisting of long headrace tunnel, surge shaft, 45° inclination pressure shaft, underground power house, tailrace and access tunnels, approx. 2mill m3 (1000MW) and 0.5mill m3 (250MW) of underground excavation
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The conclusions we arrived at in short?

- A demand on appr. 2000m³ rock to be excavated per 1MW installed production capacity
- Average excavation is estimated to be in the range of almost 3 million m³ per year
- Costs in the range of 3mill NOK per MW
- The peak reaching more than 10 million m³ annually
- 30,000 man years during the 15 years period
- Is such a development possible???
- If the entire tunnelling industry is involved in HPP-projects only, then **YES (Maybe!)**
- If other projects are ongoing, then **NO (Definitely)**
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Annual excavation volume in Norwegian tunnelling industry
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Then there is a need to develop new concepts – or new methods!

How can we cut the volume of rock excavation to reduce the construction time and resources needed to produce 1MW?

Man power and equipment constitute a limited resource!

Compact and efficient plants, could be a solution, and included in this is Ultra High Head
Objective 1:
• Utilize the backbone of Norwegian high head tunnelling technology
• Unlined tunnels, in-situ stresses constitute the confinement
• Increase the head beyond existing utilization of appr. 1000m
• Develop new concepts and increase the compactness of underground HEP facilities

Objective 2:
• Develop and apply new technology for future pumped storage
• Thus reduce the ratio volume of rock/MW installed capacity

Objective 3
• Develop concepts for cables in long dedicated cable tunnel
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Possibilities:

- Ultra High Head up to eg. 2000m to reduce flow rate
- Reduce the ratio of excavated rock per MW installed capacity
- Reduce the construction time and thus the financial investment
- Improve the stability of the plant during operation
- Increase the efficiency of the plant
- Maintain the upper and lower reservoirs with no additional regulations
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Could we solve this by Ultra High Head??

Project: Ultra high head, unlined head race tunnels, head > 1100 m

Rock and tunnell engineering

New and Innovative solutions
Optimization of high head HPP

Electrical and Mechanical engineering

Turbines and turbine design
To be identified
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OUT OF THE BOX APPROACH

Reaction of Rock Mass  
Dynamic Capacity of Rock Mass  
Handling of dynamic loads

Ultra high head

Confinement unlined: 2000m = 700m rock cover

New and Innovative Solutions

- Underground Pumped Hydro Energy Storage
- Closed Loop  
  Seawater Based
  Upper and/or Lower magazines in rock caverns

- Abandoned Mines

- Coupled with Existing HP Project  
  Super efficient design

- High Head combined with Pumping to Lower Magazine
  To be further identified

- Reduced Ratio Excavated Rock per MW installed capacity
- Construction methods  
  Design and layout

- Compact Plants

- Cable Tunnels
  Real Tunnels Dia > 3m
  Small tunnels dia < 1m
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CONVENTIONAL APPROACH

- TBM
- Slashing
- Mechanical smoothening
- Contour quality
- Inner lining
- Sprayed concrete

Optimization
- Tunnels and caverns
- TBA
- Head Loss Reduction
- Standard solutions
- Large Plant: 1000MW or more
- Small plant: 250 MW
- Shafts, connecting tunnels
- Geometry of project
- Size, shape, excavation method, design
- Sammenkoping
- Access tunnels
- Pilars
- Safe zones
- Operation rooms etc
- Excavation

Plant Layout
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Developing 20,000MW implies that the topographical implications call for new solutions to bring the electricity to distant consumers. If 'giant masts' is not acceptable, long tunnels 10-20-30km blind boring.
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"Compact & efficient pumped hydro power facilities" and "Ultra High Head" needs to study further a variety of aspects, including but not being limited to such as:

- The geometry and layout of the plant
- The hydrodynamics of the plant
- The headrace tunnel system
- The shaft configuration
- The tunnel roughness and possible need of concrete/steel lining
- The surge development and need of surge chambers, surge shafts or other damping
- The excavation method to be employed
- The water velocity
- The turbine and generators specifications
- The downstream configuration of tunnels
- The construction time and costs

At the moment a bunch of ideas on research topics
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The main challenges today:

We don’t know exactly how to get there, what measures to take or what detailed research is needed.

We know though that high ambitions are required to move the traditional HPP forward to "Compact & efficient pumped hydro power facilities" and that Ultra High Head is a possible solutions.

THANKS!