Safe and reliable dams and tunnels – international experience

Nepal Power Investment Summit 2016

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Outline

- NGI
- History – Hydropower Experience
- Dam Design and Monitoring
- Tunnels and Caverns
- Geosurveys and Geological Mapping
- Geohazards and Risk Assessments
- Summary

Private foundation

R & D and consultancy

Staff

225 employees from ~30 nations

20-30 guest researchers every year

NGI - mission

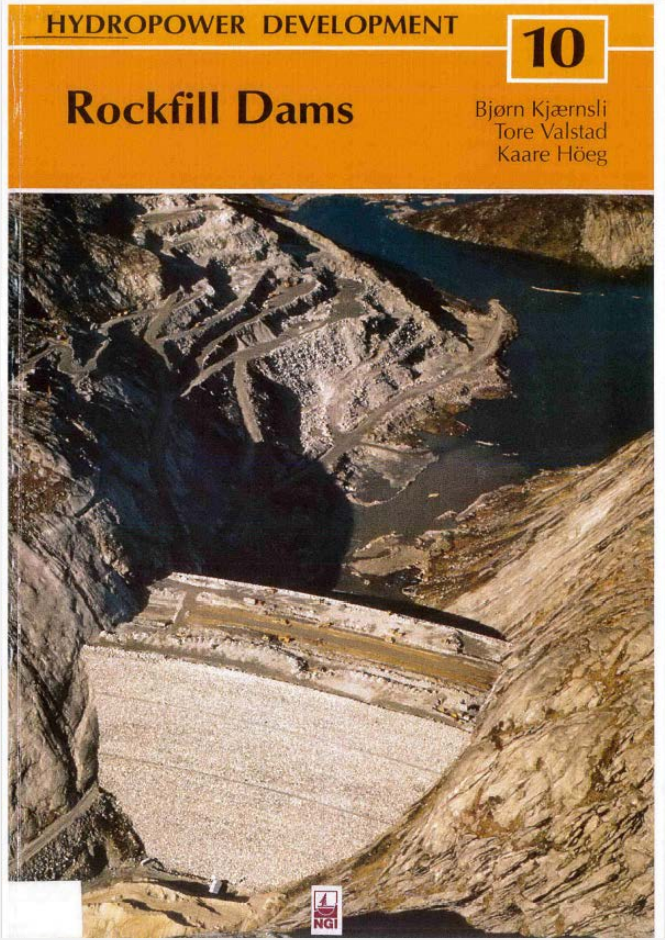
- An international source of geoscience expertise
- Proactively develop applicable knowledge and technology
- Continuous professional development and educational outreach

NGI - Markets

- Offshore Energy
- Natural Hazards
- Building, Construction and Transportation
- Environmental Engineering

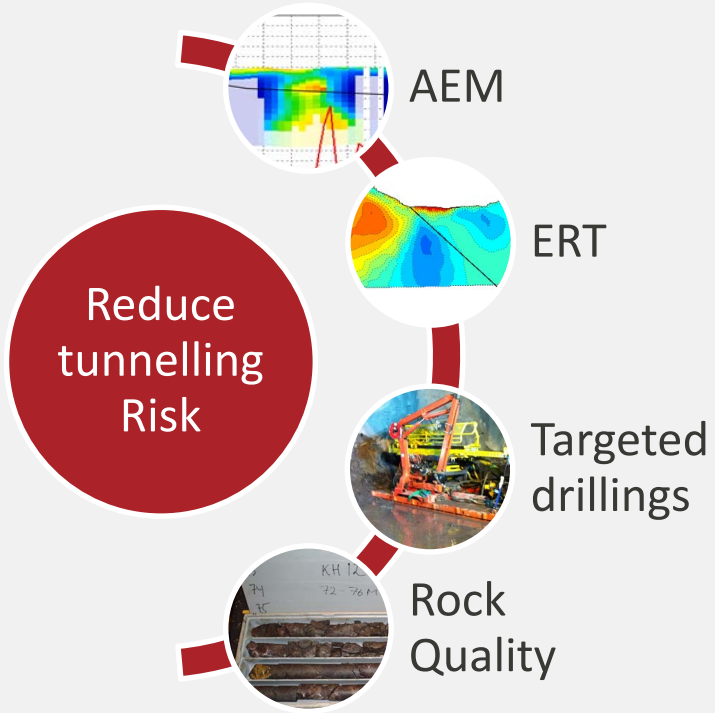
Hydropower history at NGI

- Involved in design, construction and instrumentation of dams, tunnels and caverns for hydropower since the 1950s.
- Designed 65% of norwegian embankment dams (115 dams) and several dams world-wide.
- Authors of Publication No. 10 *Rockfill Dams* in the Hydropower Development book series
- Active in international development of the asphalt concrete core concept in dam construction.



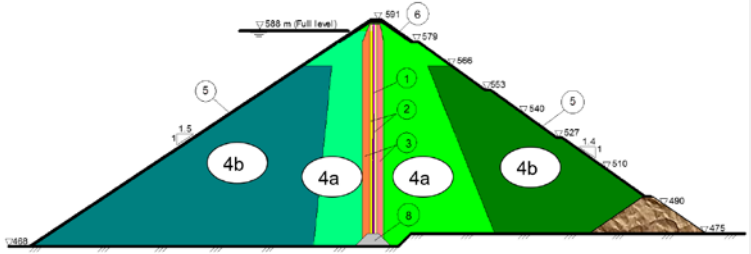
Hydropower history at NGI (2)

- Used risk assessments and reliability based design methods since early 1990's.
- Developed the Q-system for determination of rock quality and support systems in the early 1970's.
- Continuous research and application of new methods for more cost-effective geosurveys and mapping of geological conditions (e.g rock quality).

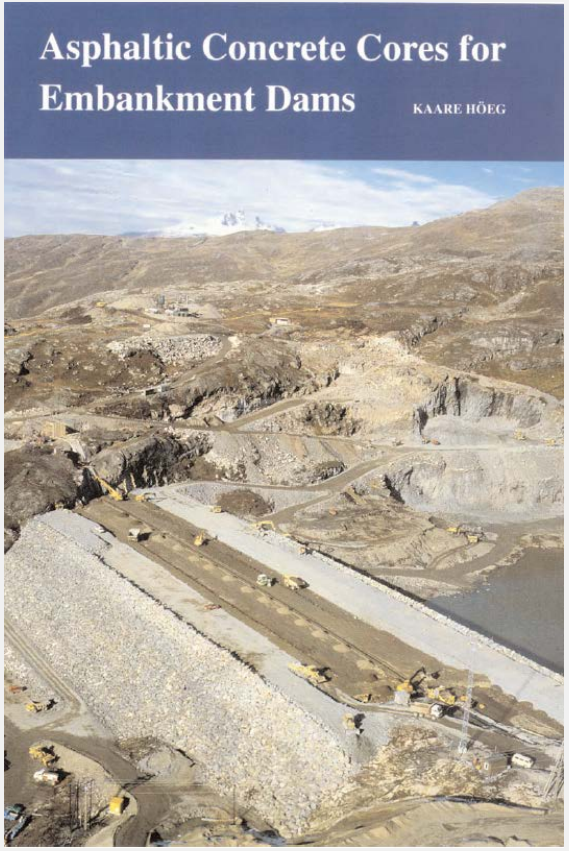


Asphalt Concrete Core Dams

- Using asphalt concrete as core material
- Simple and robust construction method
- High rate of construction
- Earthquake resistant, self-healing of any cracks

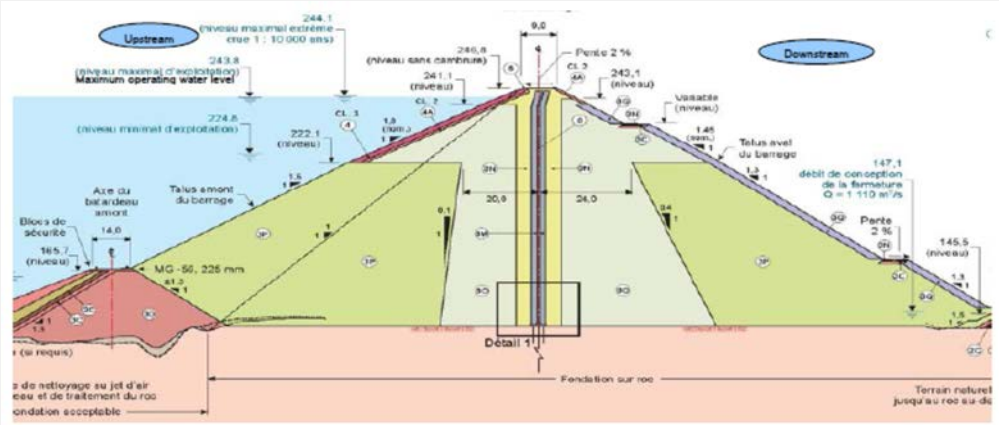


1. Asphalt core
2. Transition (0-60 mm)
3. Transition (0-150 mm)
4a. Quarried rockfill (0-500 mm)
4b. Quarried rockfill (0-1000 mm)
5. Slope protection (blocks min. 0.5m^3)
6. Crown cap (blocks)
7. Toe drain (blocks, min. 0.5 m^3)
8. Concrete plinth (sill) for core



Embankment Dams – examples

La Romaine 2 (130 m), asphalt core

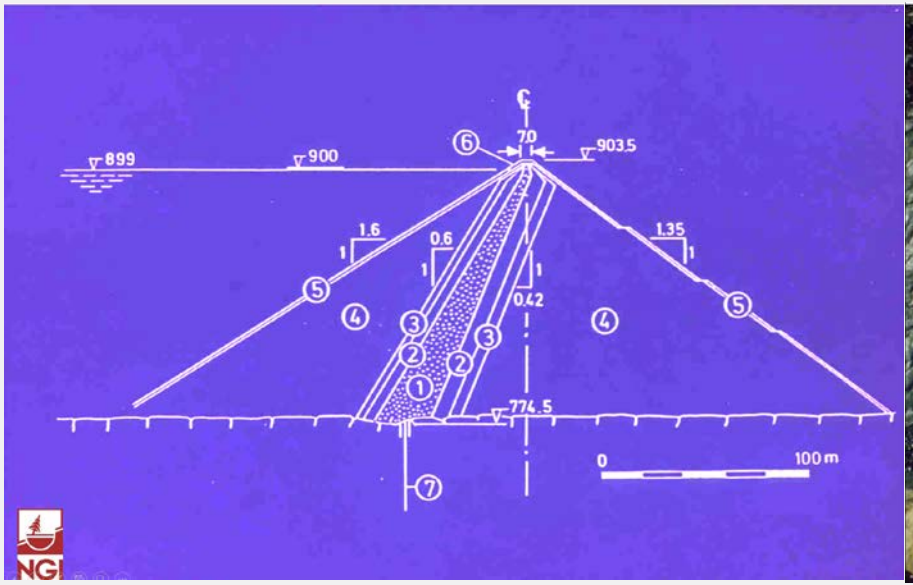


La Romaine 2: 640 MW

Whole La Romaine River Project: 1550 MW

Embankment Dams – examples

Svartevann Dam (129 m), Norway



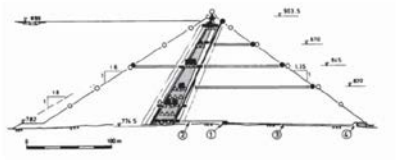
Constructed between 1973 and 1976

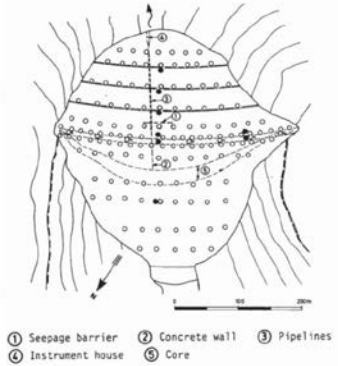
Heightening in 2011

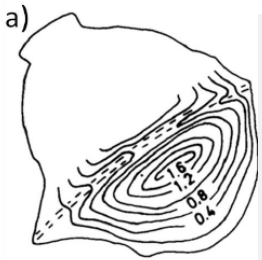
NGI

Embankment Dams – examples

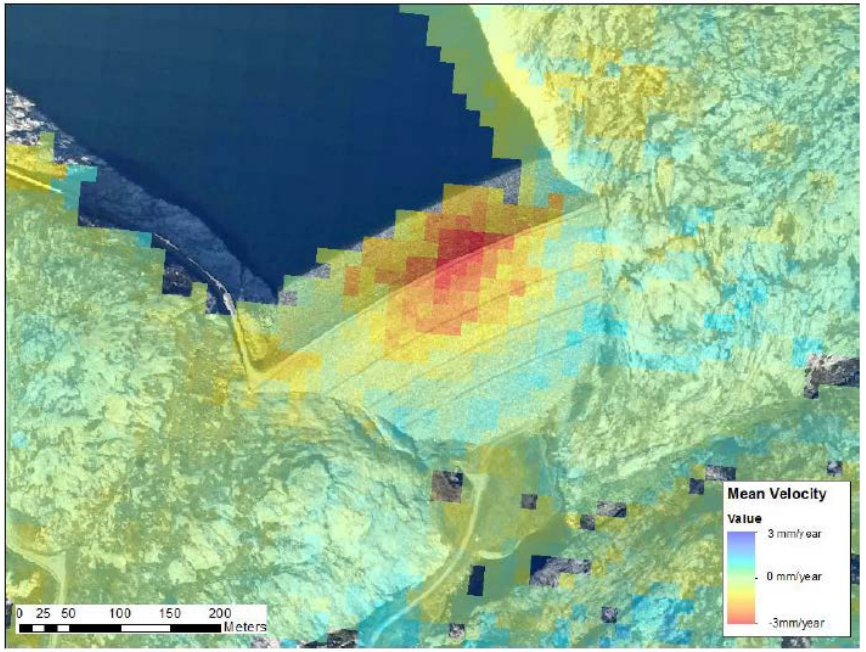
Monitoring of Svartevann Dam (129 m), Norway







DiBagio et al, 1982



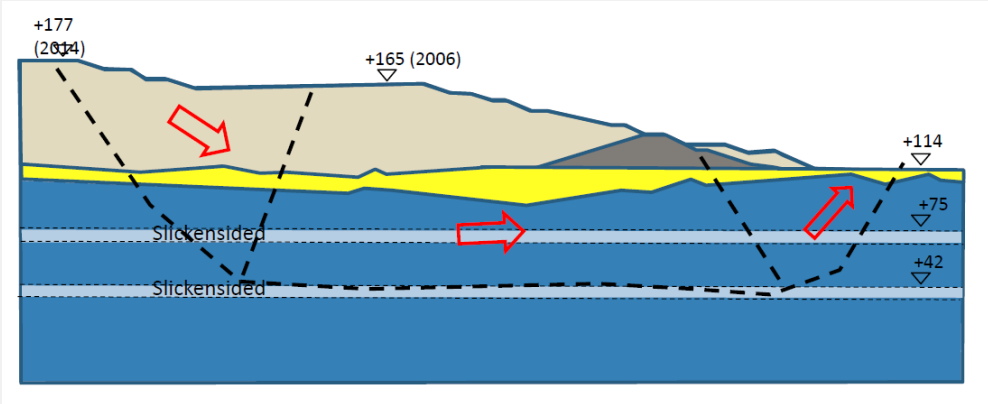
Vöge et al, 2013

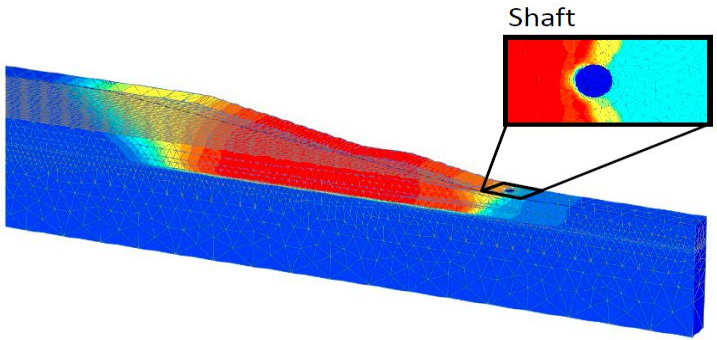
SAR allows mapping of very local displacements at the dam

The method has a great potential for cost-efficient long-term monitoring.

Zelazny Most Dam, Poland

- The dam is displacing with increased velocity
- NGI using monitoring and numerical analyses to predict future behaviour of the dam
- Analyses of deformations, stability and seismic response
- Mitigations to increase the lifetime (i.e years of operation)

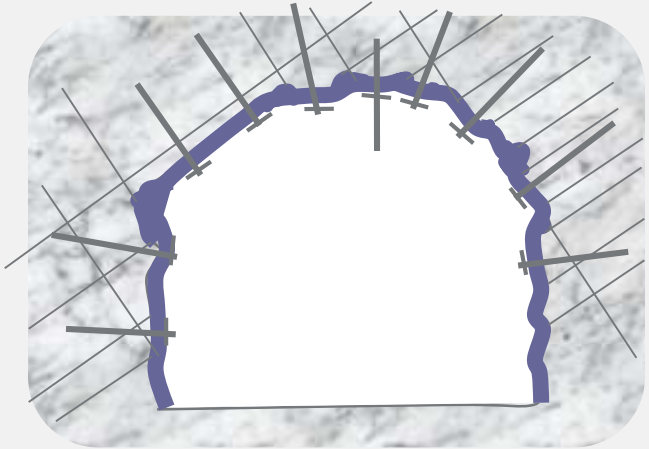




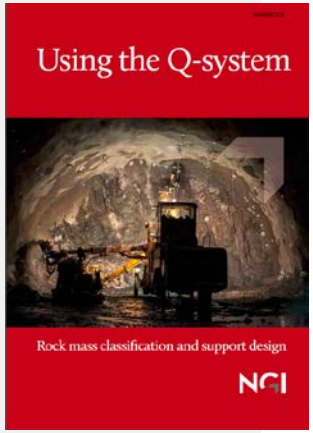
Tunnels and caverns

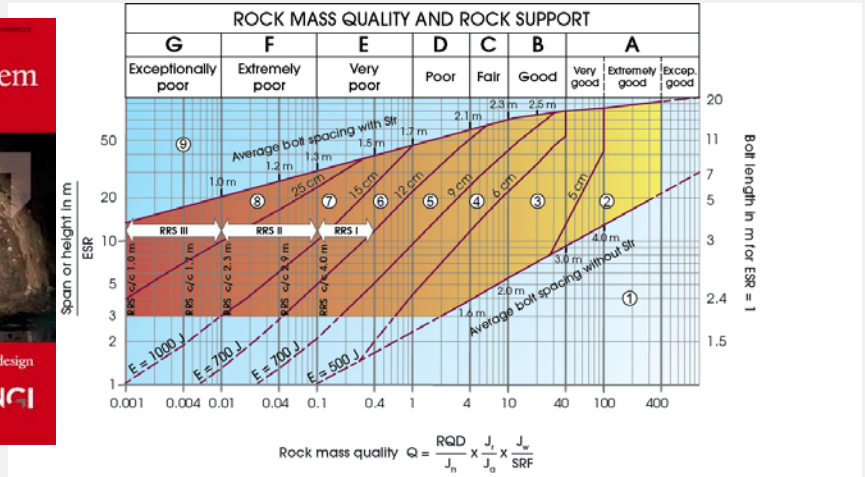
Tunneling in Norway:

- 1000 road tunnels (900 km)
- 710 railroad tunnels (320 km)
- 290 hydropower tunnels/shafts (3100 km)
- >50 small diameter TBM-tunnels
- 200 underground hydropower stations
- 36 subsea tunnels
- 10-20 oil and gass storage facilities
- Unknown no. of rock caverns



Rock support and reinforcement





Support categories

① Unsupported or spot bolting
② Spot bolting, **SB**
③ Systematic bolting, fibre reinforced sprayed concrete, 5-6 cm, **B+Sfr**
④ Fibre reinforced sprayed concrete and bolting, 6-9 cm, **Sfr (E500)+B**
⑤ Fibre reinforced sprayed concrete and bolting, 9-12 cm, **Sfr (E700)+B**
⑥ Fibre reinforced sprayed concrete and bolting, 12-15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E700)+RRS I +B**
⑦ Fibre reinforced sprayed concrete >15 cm + reinforced ribs of sprayed concrete and bolting, **Sfr (E1000)+RRS II+B**
⑧ Cast concrete lining, **CCA** or **Sfr (E1000)+RRS III+B**
⑨ Special evaluation

Bolts spacing is mainly based on Ø20 mm
E = Energy absorbtion in fibre reinforced sprayed concrete
ESR = Excavation Support Ratio
Areas with dashed lines have no empirical data

RRS - spacing related to Q-value

I
Si30/6 Ø16 - Ø20 (span 10m)
D40/6+2 Ø16-20 (span 20m)

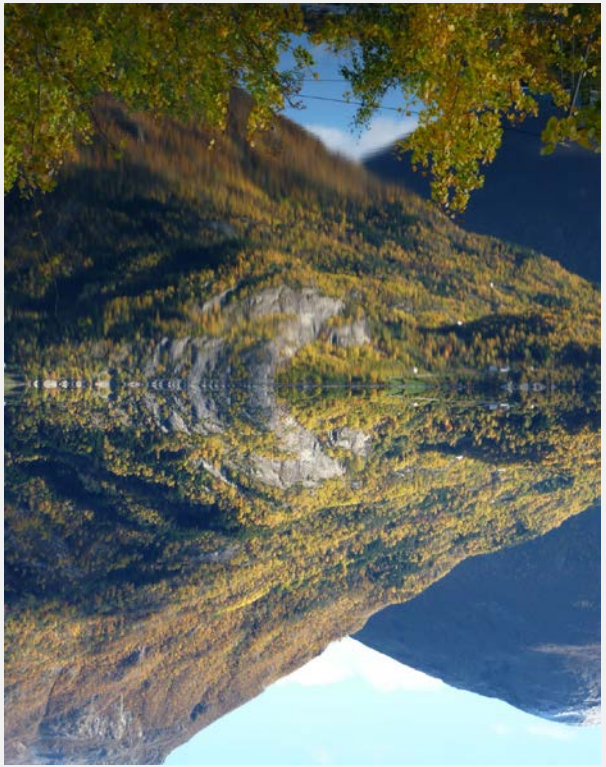
II
Si35/6 Ø16-20 (span 5m)
D45/6+2 Ø16-20 (span 10m)
D55/6+4 Ø20 (span 20m)

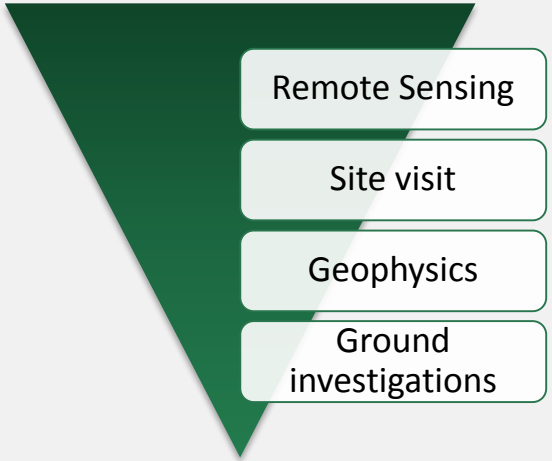
III
D40/6+4 Ø16-20 (span 5 m)
D55/6+4 Ø20 (span 10 m)
D70/6+6 Ø20 (span 20 m)

Si30/6 = Single layer of 6 rebars, 30 cm thickness of sprayed concrete
D = Double layer of rebars
Ø16 = Rebar diameter is 16 mm
c/c = RSS spacing, centre - centre

Barton, Lien and Lunde (1974)

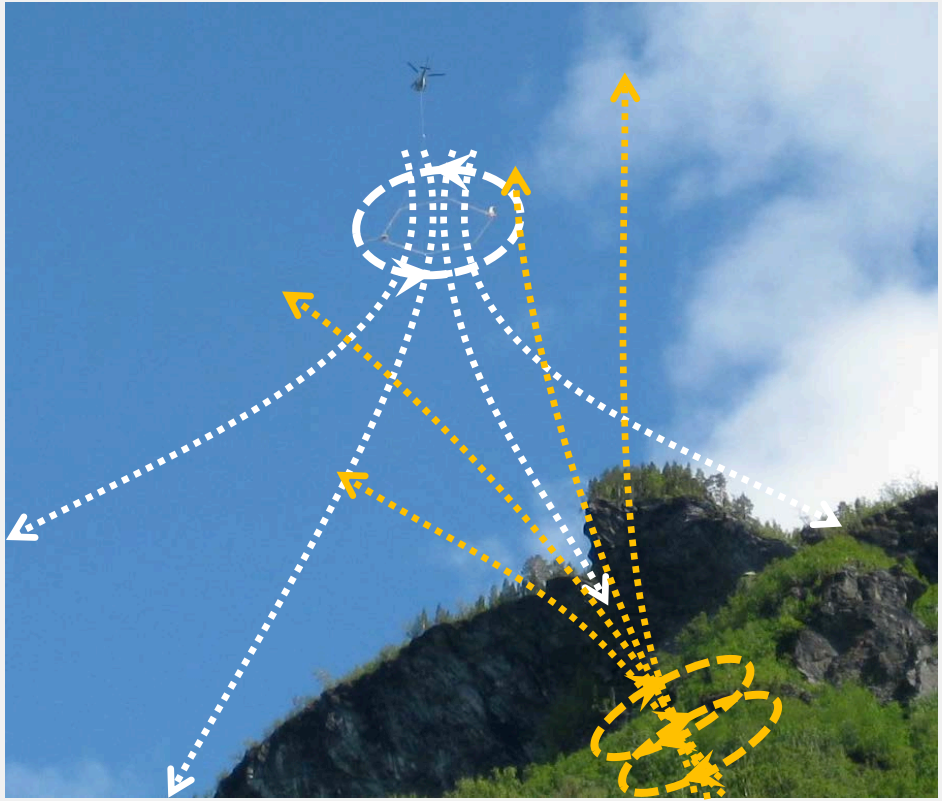
Geosurveys. Bottom-up approach

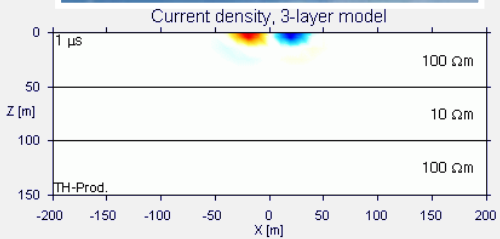


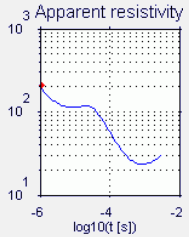


- Important to understand the geology in early stage of a project to get the best design solutions and avoid redesign and delays.
- Remote sensing and geophysics to focus and increase efficiency.
- (not as a additional method)

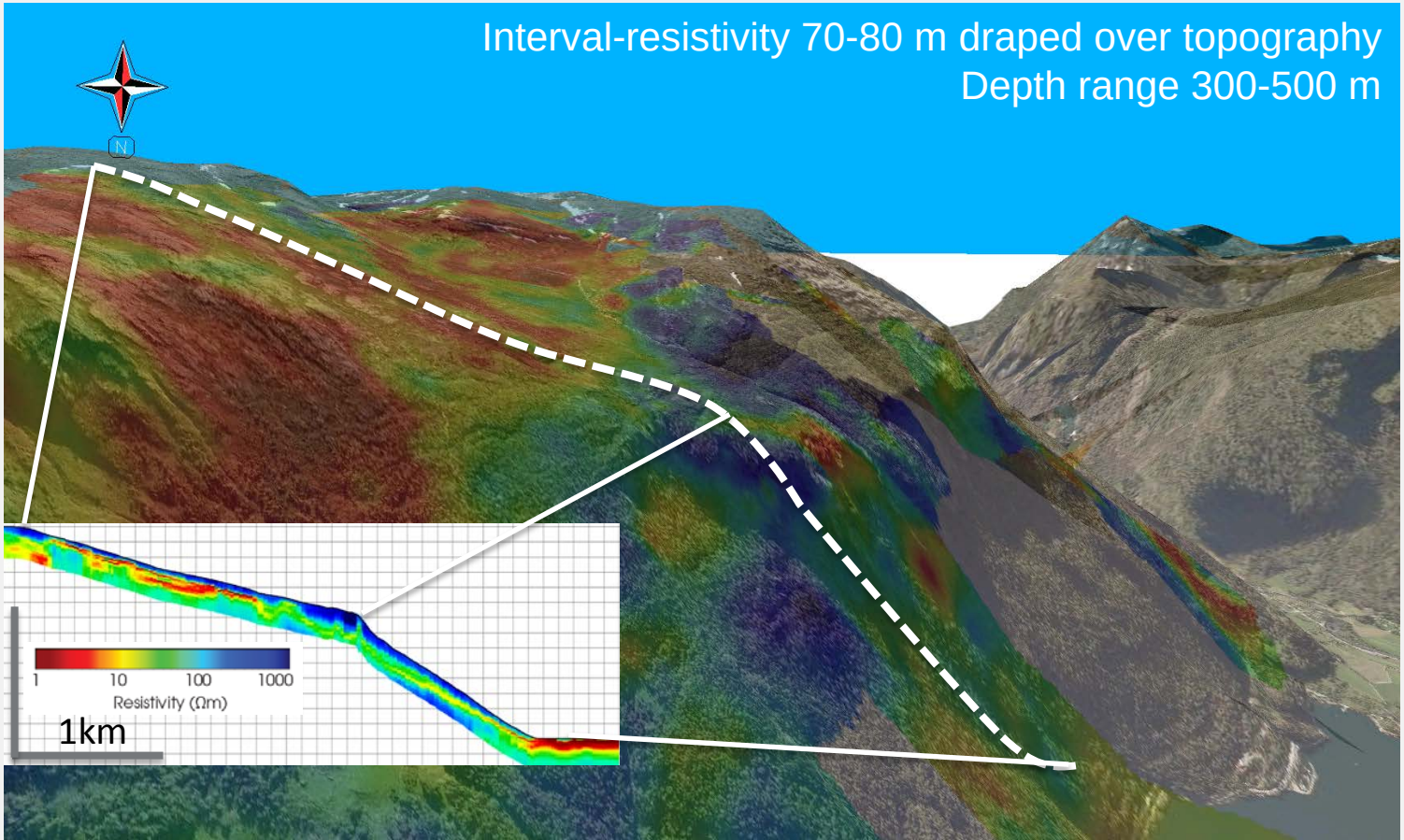
Airborne geophysics (EM)





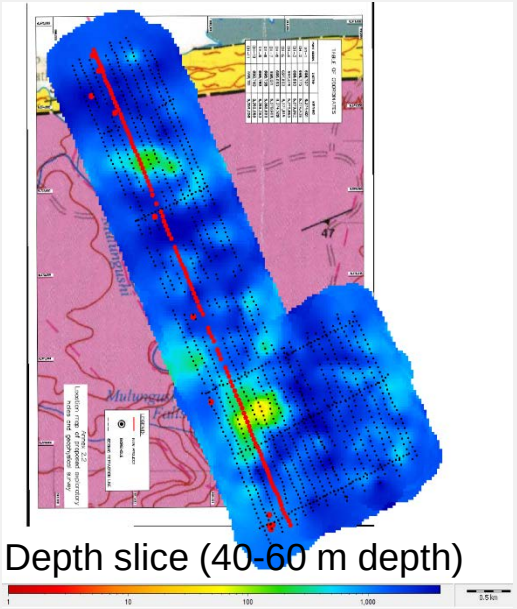


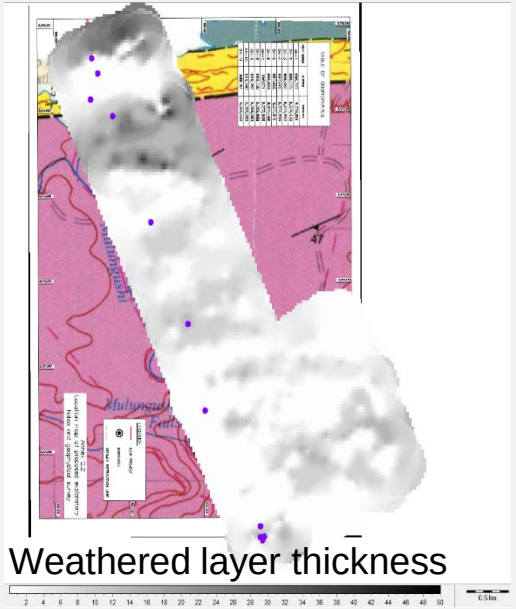
Anomalies linked to low rock quality



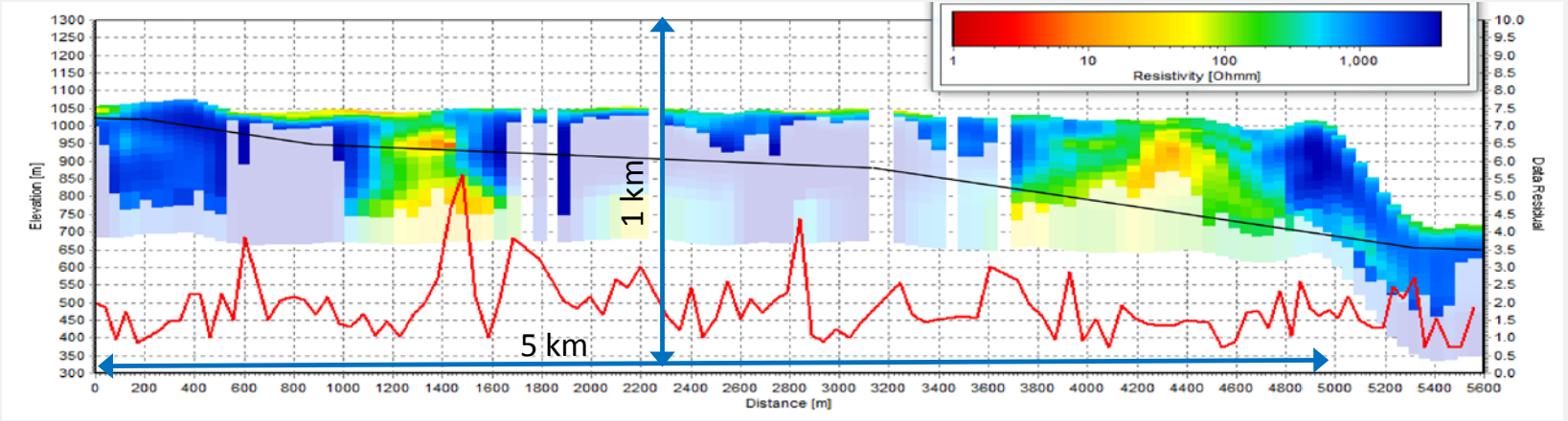
Hydropower tunnel

Weakness zones identified in a gneiss area

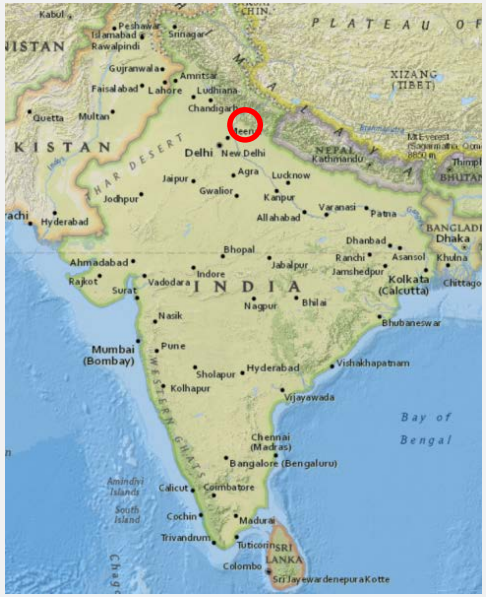




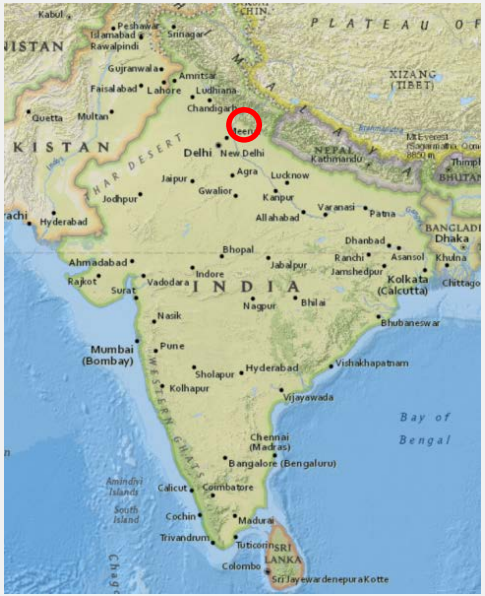
Resistivity section along tunnel



Deep seated landslide Nainital, India:



Deep seated landslide Nainital, India:



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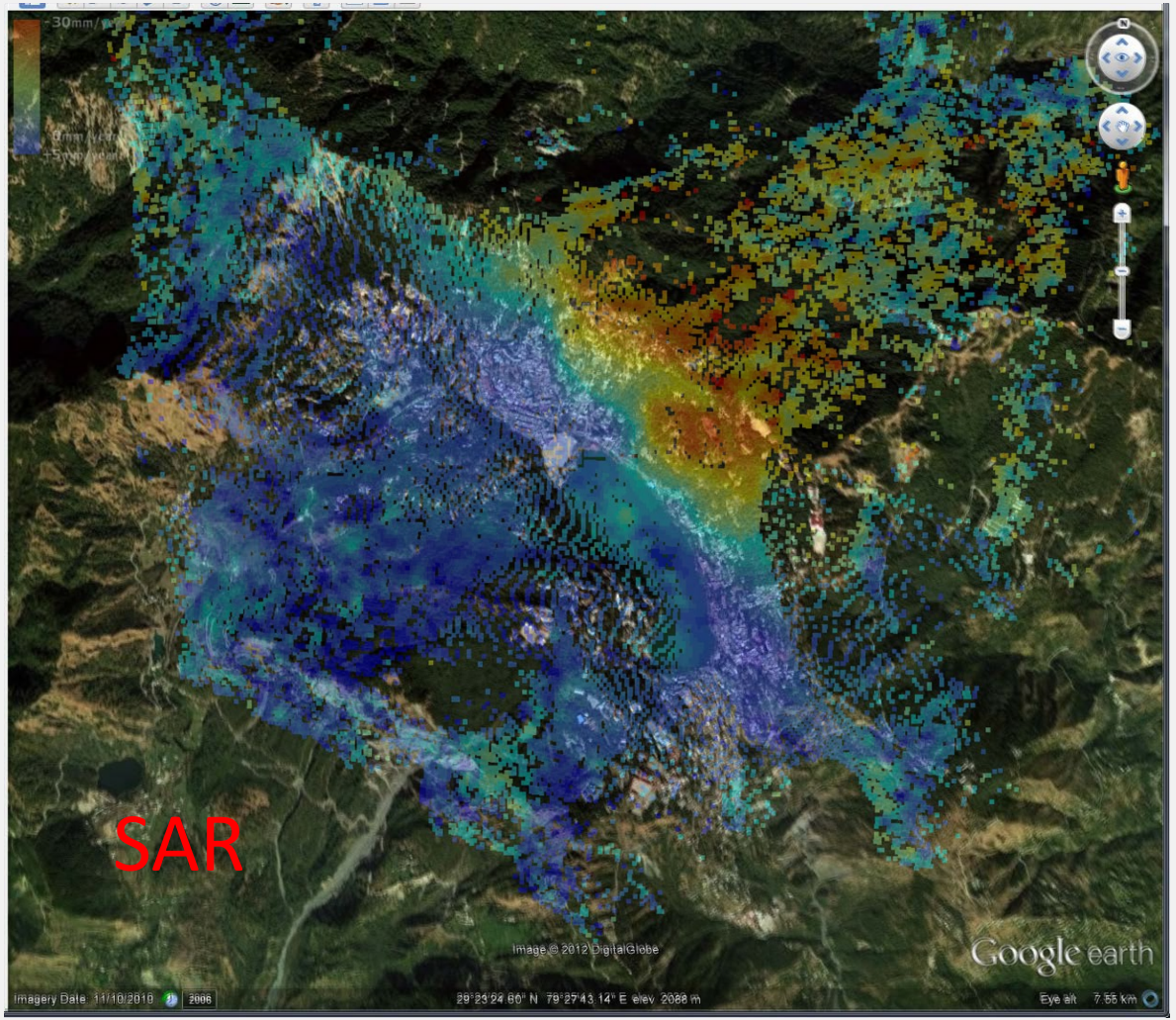
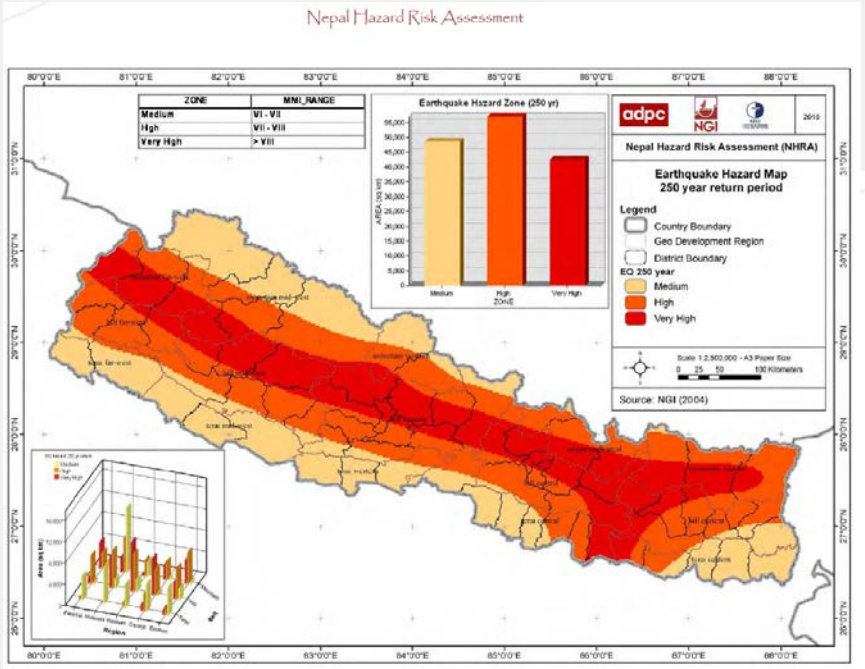
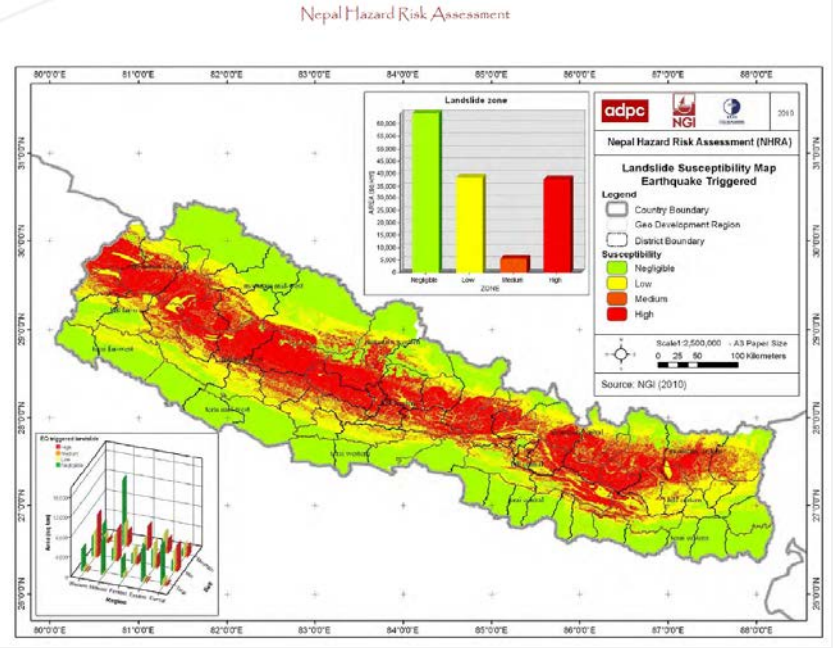


Hazaed Risk Assessments in Nepal

Earthquake and earthquake induced landslide hazard maps





Study for ADPC, 2010.

Financed by Global Forum for Disaster Risk Reduction and the World Bank.

Summary

- Efficient and effective geo-survey
  - Reducing risk of unexpected ground conditions
- Dam and tunnel engineering expertise
  - Enabling safe, cost effective solutions
- Slope stability expertise
  - Enabling safe infrastructure (services roads, transmission)

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