HARD ROCK SUBSEA TUNNELS -
Investigation, planning, excavation and rock support

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PRESENTATION OUTLINE

- GEOLOGICAL OVERVIEW
- CHARACTERISTICS OF NORWEGIAN SUBSEA TUNNEL PROJECTS
- GEOLOGICAL CONDITIONS, INVESTIGATIONS
- DESIGN
- EXCAVATION
- STABILITY AND ROCK SUPPORT
- WATER CONTROL, GROUTING
- OPERATIONAL EXPERIENCE
- FUTURE PLANS
NORWEGIAN BEDROCK

Precambrian: 53 %
Late Precambrian (Eocambrian): 15 %
Paleozoic: 30 %
Permian: 2 %

=>
• MAINLY VERY OLD
• OFTEN GOOD QUALITY
  (but not always!)

NORWEGIAN SUB SEA TUNNELS

STATUS TODAY:
• FOR ROAD: ~30 TUNNELS
  50-78m²
  Longest: 7.9 km (Bømlafjord)
  Deepest: -287m
• FOR OIL, GAS, WATER: ~15
  20-70 m²
  Piercing at -180m
CHARACTERISTICS OF TYPICAL FJORD CROSSING TUNNEL

- PROJECT AREA COVERED BY WATER
- CROSSING MAJOR FAULTS / WEAKNESS ZONES
- INCLINED FROM BOTH SIDES
- UNLIMITED LEAKAGE RESERVOIR
- SALTY LEAKAGE WATER

FRØYA SUBSEA ROAD TUNNEL (1997-2000)
GEO-INVESTIGATION PRIOR TO EXCAVATION

TYPICALLY A FIVE-STEP PROCEDURE:
1) DESK STUDY / REVIEW OF AVAILABLE INFO
2) ON SHORE FIELD MAPPING
3) ACOUSTICAL PROFILING
4) REFRACTION SEISMIC PROFILING
5) DRILLING

TYPICAL INVESTIGATION COST: ~8% OF EXCAVATION COST
PRE-CONSTRUCTION INVESTIGATIONS – "BASIC APPROACH"

EXAMPLE:
KARMSUND TUNNEL

EXAMPLE ASSUMED vs. ENCOUNTERED: FRØYA SUBSEA ROAD TUNNEL
REQUIREMENTS FOR SUBSEA ROAD TUNNELS (NPRA, 2010)

- MAX. GRADIENT 8%
- MIN. ROCK COVER: 50m, UNLESS FAIR ROCK MASS CONDITIONS HAVE BEEN DOCUMENTED

EXCAVATION AND ROCK SUPPORT

- SO FAR: ALL DRILL AND BLAST - DUE TO FLEXIBILITY & EFFICIENCY
- NORMAL ROUND LENGTH: 5m
- MOST COMMONLY: TRADITIONAL UNIT RATE CONTRACT
- TYPICAL COST, SUBSEA ROAD TUNNEL: 15,000-20,000 USD/m
INVESTIGATION DURING EXCAVATION

• PROBE DRILLING AHEAD OF FACE
• CONTINUOUS MAPPING OF EXCAVATED FACE
• SAMPLING/TESTING
• MONITORING

CHARACTERISTICS OF FAULTS / WEAKNESS ZONES

• WIDTH OFTEN > 20m
• HEAVILY CRUSHED AND/OR WEATHERED ROCK MASS
• SWELLING CLAY COMMON
• HIGH SWELLING PRESSURE (up to 2 MPa)
• OFTEN RELATIVELY DRY,
  BUT NOT ALWAYS!
ROCK SUPPORT IN DIFFICULT GROUND CONDITIONS

SHOTCRETE RIBS

- Radial bolts (on long)
- Fans of 8m long spring bolts
- Rock anchors
- Shotcrete rib and rock bolts
- Rock bolts (alternatively concrete)
- Reduced length of steel round

CT-BOLT

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CHARACTERISTICS OF WATER LEAKAGES

• PERMEABILITY OF MOST FAULTS/WEAKNESS ZONES IS LOW
• MAIN LEAKAGE NORMALLY IN DISTINCT SINGLE JOINTS (OFTEN NEAR MAJOR FAULTS)
• SEA BOTTOM OFTEN COVERED BY LOW PERMEABILITY LAYER
  => MAIN LEAKAGE NOT ALWAYS UNDER SEA!

EXAMPLE: ELLINGSØY TUNNEL

WATER CONTROL

1) PROBE DRILLING

MOST COMMONLY:
REGISTRATION OF WATER INFLOW IN PERCUSSIVE DRILL HOLES
MWD – MEASURING WHILE DRILLING

EXAMPLE: KARMSUND TUNNEL
INTERPRETATION OFTEN UNCERTAIN - BUT GREAT POTENTIAL

Red/blue: hard/strong
Yellow/brown: weak

Red: highly fractured
Yellow: medium

Blue: water

WATER CONTROL:
2) PRE-GROUTING

Typical curtain length: 18-24m

Preset quantity for economical pumping: ~300 l/min per km

Grouting pressure up to 10 MPa
**PRE-GROUTING IN 110m² TUNNEL**

Length of grout pipe: 1-6m. Most commonly: 3m

Starting at bottom
For safety reason: pipes secured with chain

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**FINAL LINING**

- Basic concept: drained tunnel
- Some water inflow accepted (200-300 l/min per km)
- Pump sump at low point

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CASE EXAMPLE:
ATLANTIC OCEAN TUNNEL, 5727m (2006-2009)

ATLANTIC OCEAN TUNNEL

• Rock cover: 45m
• Water depth: 160m
• Fault zone with large water inflow encountered

Applied support (grouting, spiling, shotcreting and radial bolting) insufficient
=>
after 24 hours: approx. 10m high cave-in

MEASURES FOR REGAINING CONTROL:
• Backfilling against tunnel face followed by casting of 23m long concrete plug!
• Extensive grouting
• Stepwise further excavation with short round lengths and extensive rock support
Back at original face:
very poor rock mass quality,
St. 6245

Excavation through major weakness zone at Atlantic Ocean tunnel

WATER INFLOW
• up to 500 l/min in one hole
• pressure up to 23 bar

GROUTING
• 1,000 tons in total!
• mainly micro
• also some PU
• up to 70-80 bar
• 5m tubes needed some places
• face to be reinforced
OPERATIONAL EXPERIENCE RELATED TO WATER INFLOW

- WATER INGRESS REDUCED BY UP TO 50% (SELF SEALING EFFECT)
- ALGAE GROWTH IN SOME TUNNELS
- PERIODICAL REPLACEMENT OF INSTALLATIONS REQUIRED

![Leakage in some subsea tunnels](image)

FUTURE PLANS FOR NORWEGIAN SUBSEA ROAD TUNNELS

MANY MORE - INCLUDING MUCH LONGER AND DEEPER:

- Rogfast: 24 km / 400 m.b.s.l.
- Hareid-Sula: 17 km / 630 m.b.s.l.

![Map of Norwegian subsea tunnels](image)
FUTURE PLANS: OIL MINING – TBM EXCAVATION

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Sixth Symposium on Strait Crossings
Extreme Crossings and New Technologies

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- Early registration: 1 February 2013
- Final paper submission: 1 April 2013
- Final registration: 1 May 2013
- Congress: 16–19 June 2013

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- The Norwegian Public Roads Administration
- Tekna: The Norwegian Society of Civil Engineers and Geotechnical Engineers
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Key dates
- Abstract submission: Extended to 1 December 2012
- Abstract acceptance: 15 January 2013
- Submission of papers: 15 March 2013
- Paper acceptance: 30 April 2013
- Completion of symposium proceedings: 31 May 2013

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