# Water control in TBM excavated tunnels

- Experience from the Follo Line Project

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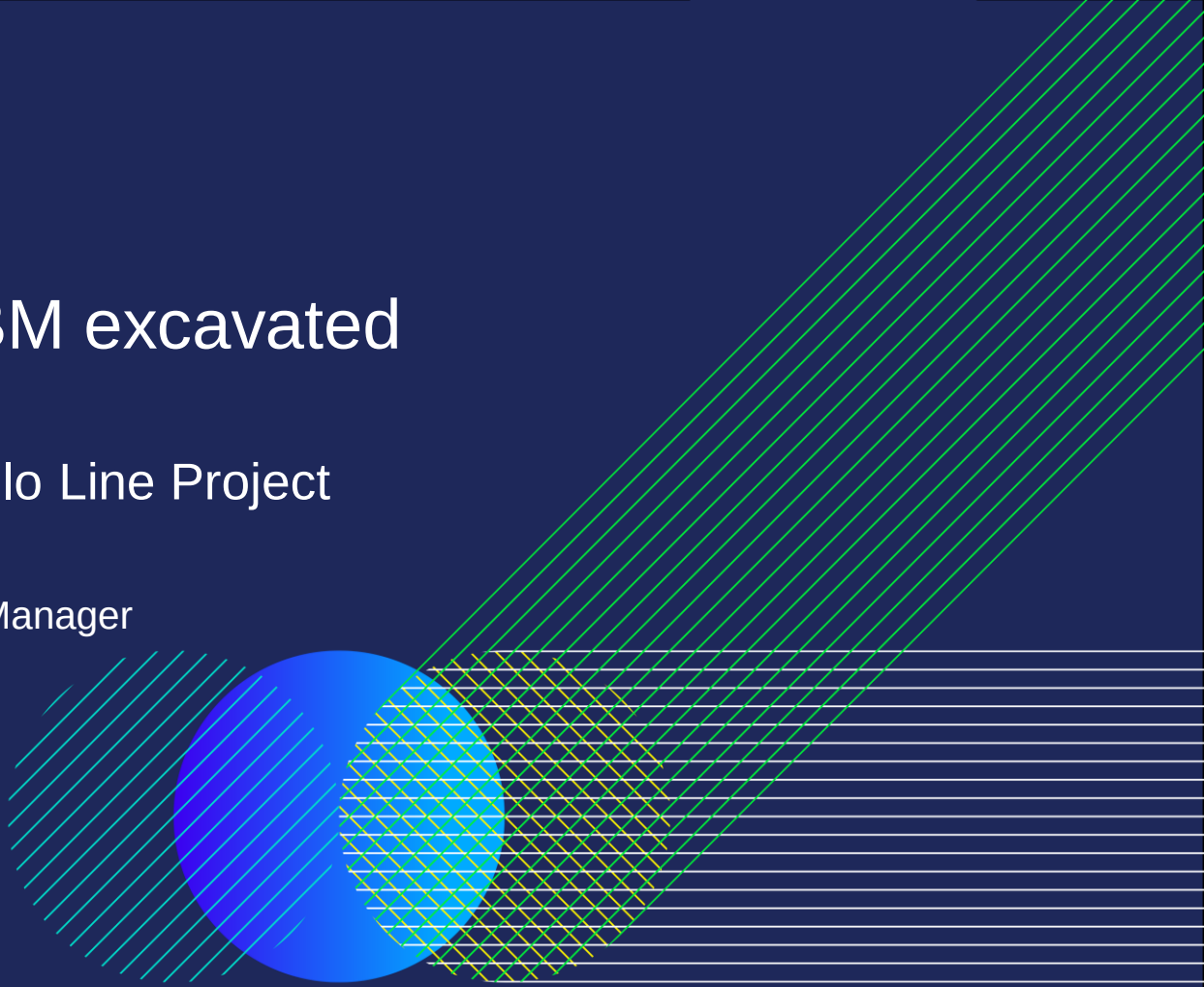
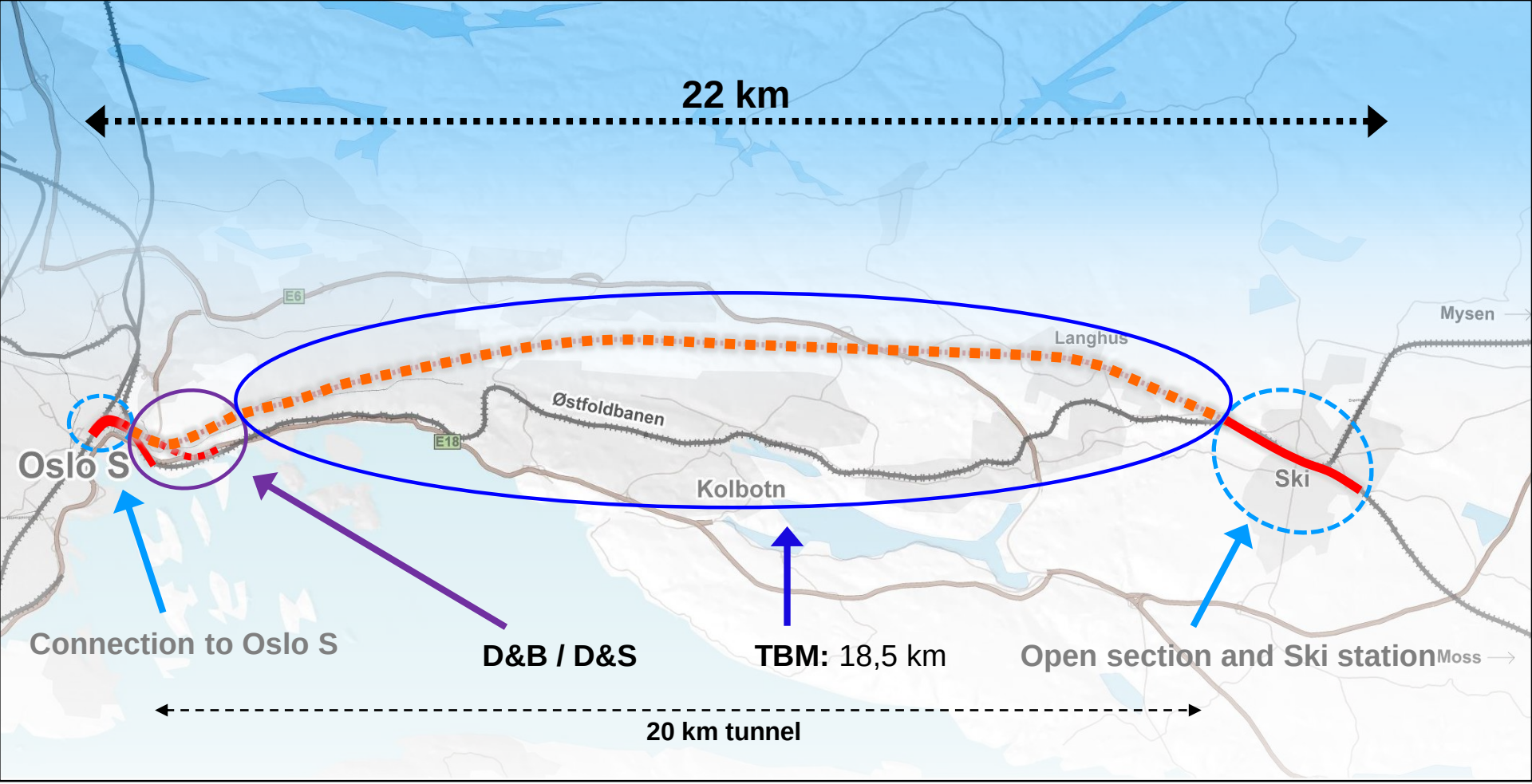
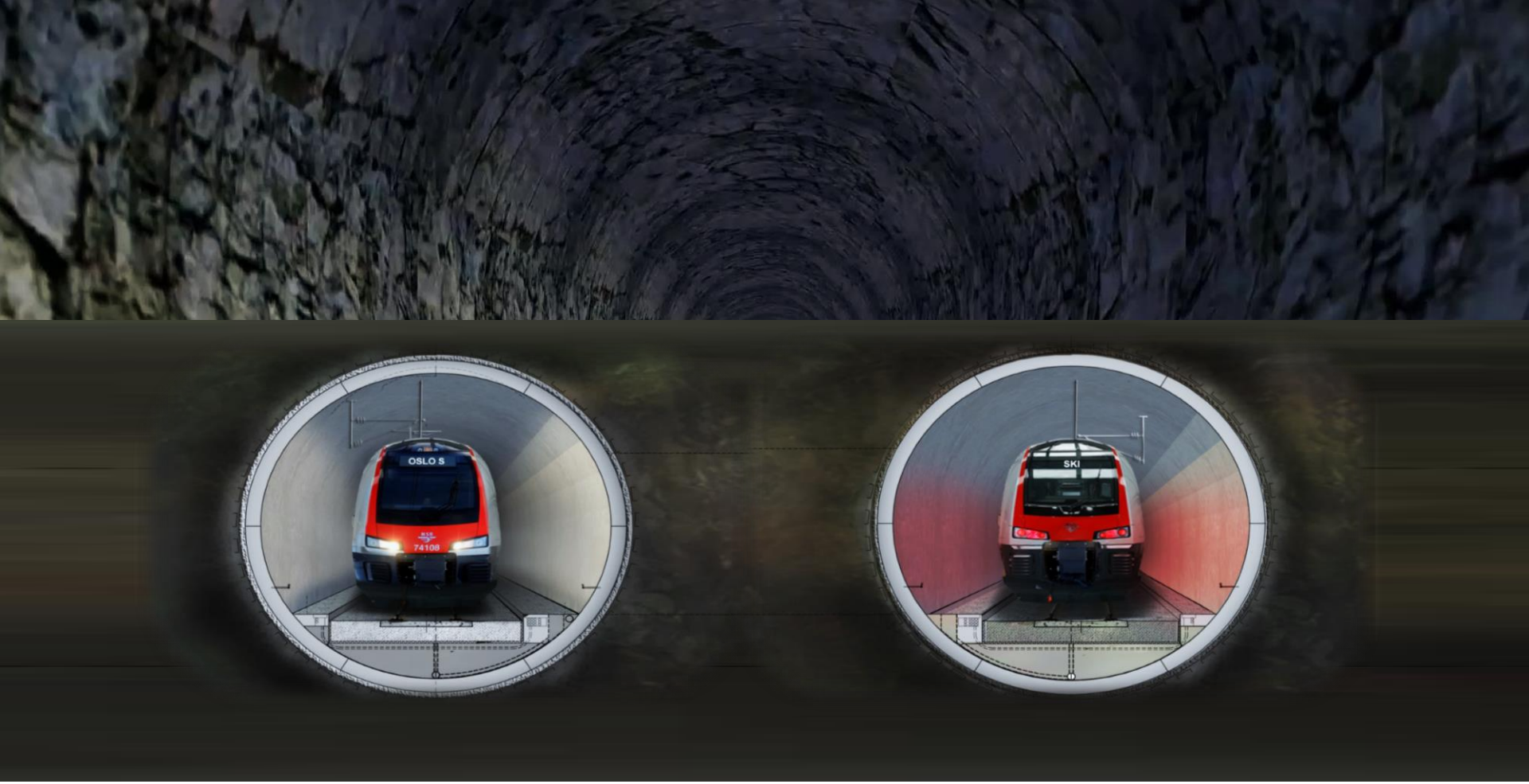







The civil work for Follo Line project is divided in four sub-projects




The longest railway tunnel within the Nordic countries so far.
The first tunnel in Norway with two separate tubes

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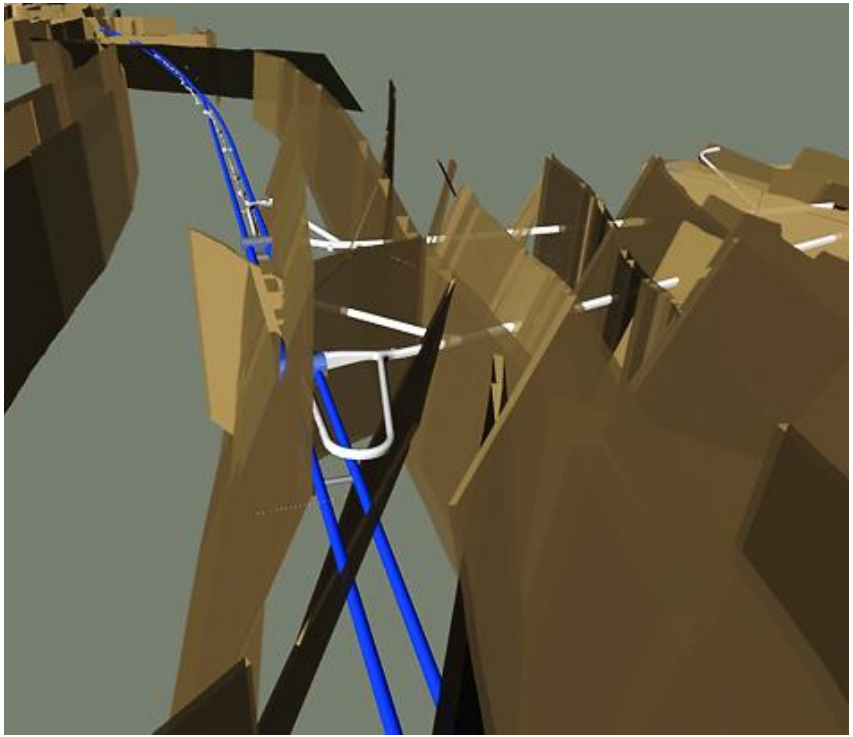
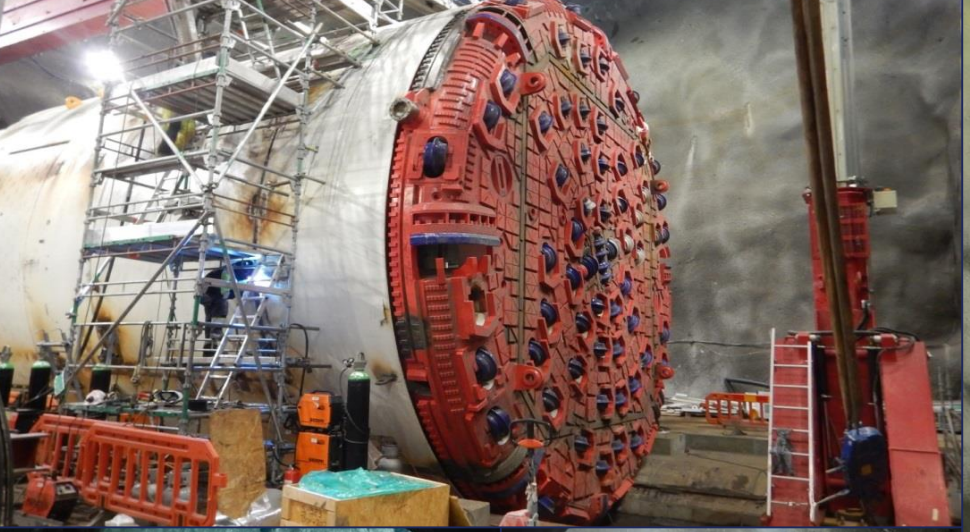
The rig area at Åsland between Oslo and Ski

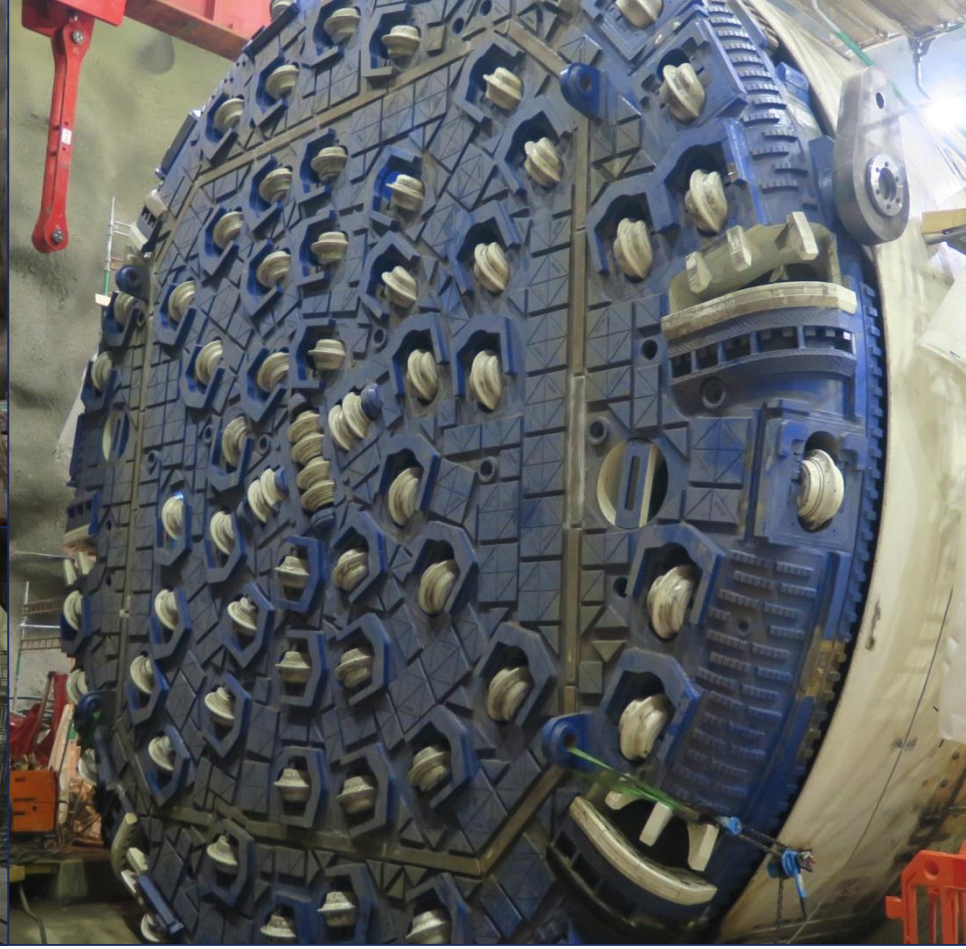
# Geology

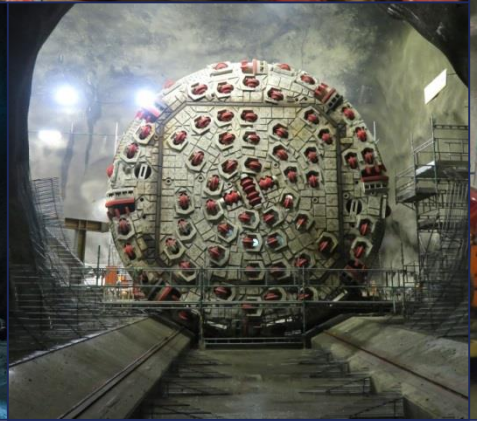
- Predominantly Precambrian gneisses – banding and lenses of amphibolite and pegmatite
- The rock mass is in general homogenous, abrasive and strong. Mean Uniaxial strength is 150 MPa
- Moderate jointing, but some groups of fractured zones intersect the tunnel and may act as drainage channels
- Average overburden approx. 80 meters – variations of between 5 to 170 meters
- Sedimentary shale in the northern part



The tunnel excavation: Was prepared for hard rock and several water bearing fracture zones







Four tailor-made tunnel boring machines (TBM) made for hard Norwegian rock and equipped to perform pre-grouting in areas where leakages were expected (Foto: Herrenknecht)

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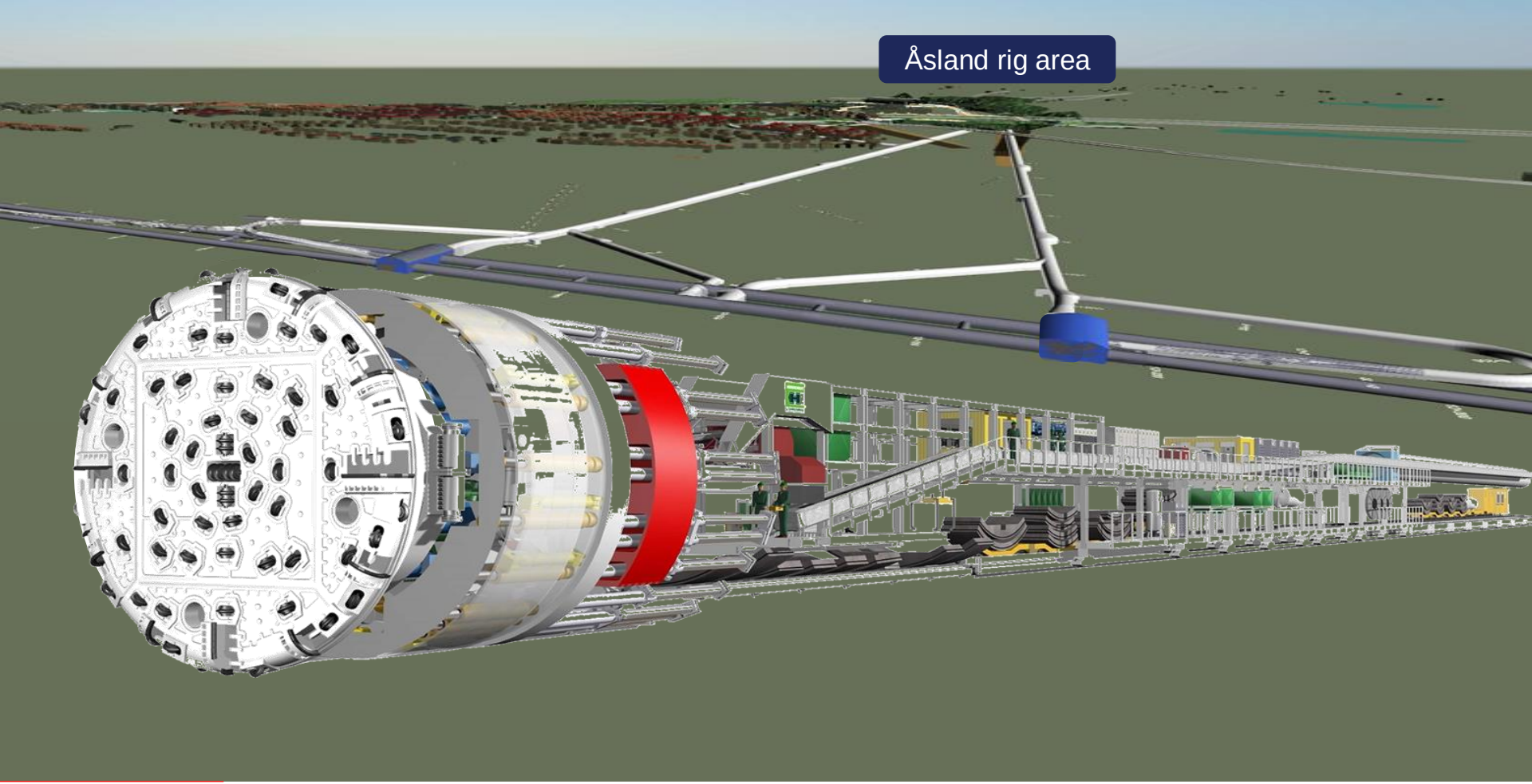
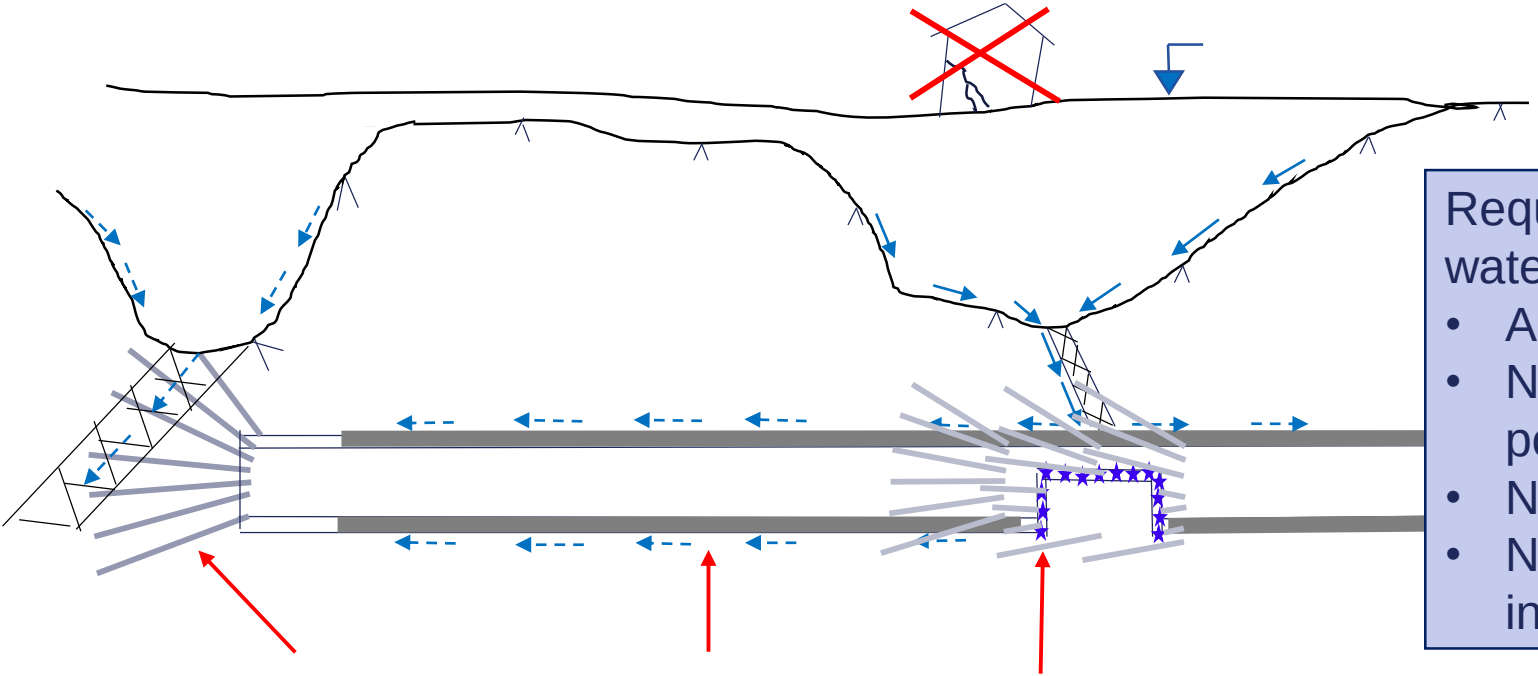



Some facts about the TBM: length 150 m, weight 2400 tons, diameter 9,96 m, 71 cutters

- Produced at site: 141 000 segments for the lining of  the long waterproof tunnel and 20 000 invert segments



Requirements for a water tight tunnel:

- A water-tight lining
- Not lowering the pore-pressure
- No settlements
- No permanent infiltration of water

Mitigations:

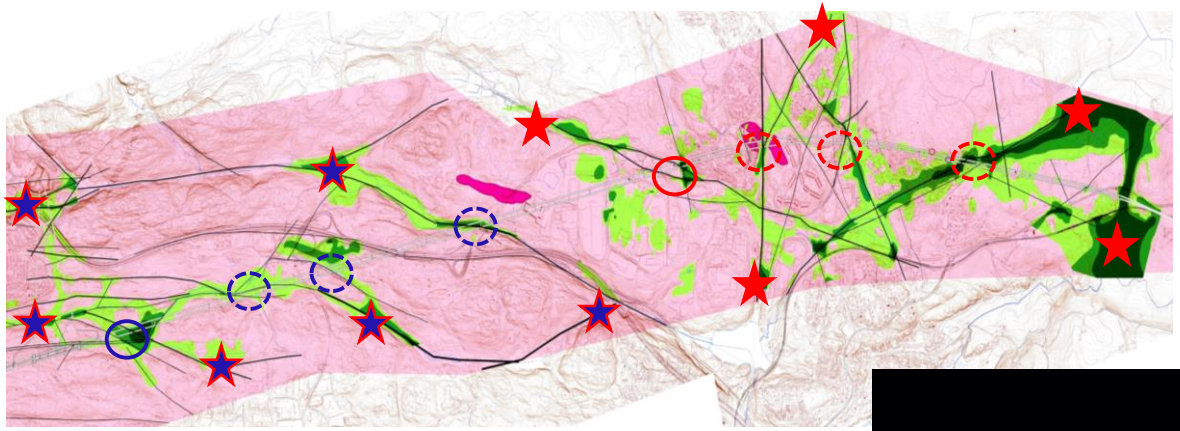
Limit the leakages by pre-grouting

Back-fill to stabilize the segments and to achieve control of the flow of water behind the lining

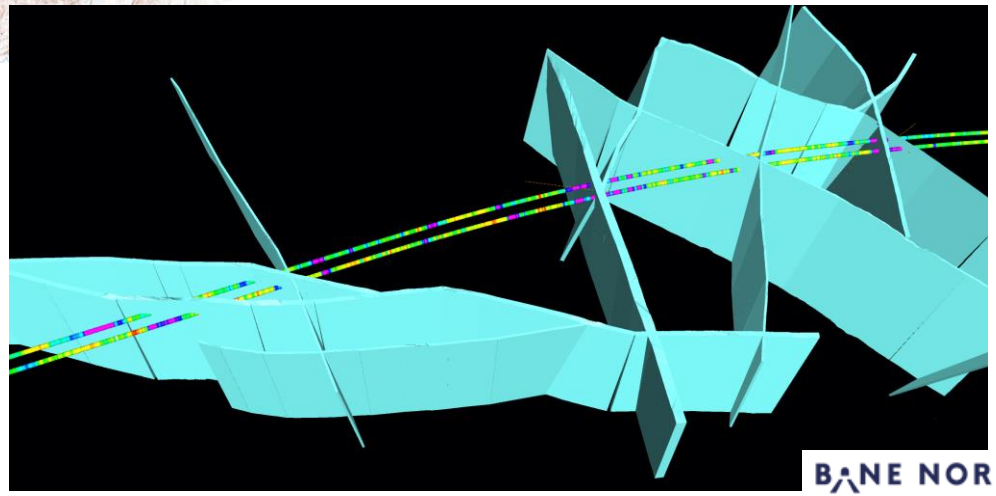
Contact-grouting and pre-grouting before opening up for the CP

**An undrained/ water-tight tunnel-solution - excavated by a shield-TBM in combination with installation of a water-tight lining in the main tunnel and in the CP's**

# Leakages from fracture-zones could affect the pore-pressure within a large area



Identified fracture zones with a thickness of > 1 meter.
The tunnels are with different angels crossing these zones.
The fracture-zones spans from vertical to horizontal.



The fractures were connected to each other.
Intersecting a fracture-zone may influence on the pore-pressure far away from the tunnel

No fractures – Less penetration
More fractures – Higher penetration

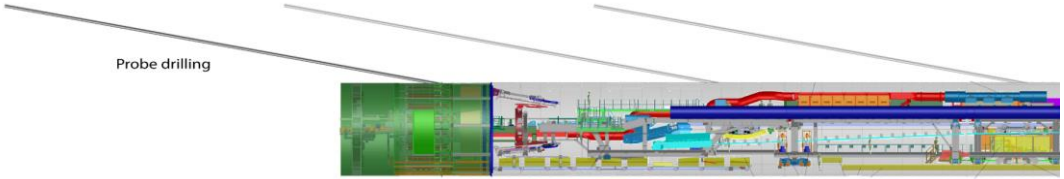
# Sensitivity zones

Based on knowledge of the geological conditions, the entire tunnel-section was divided in different sensitivity classes

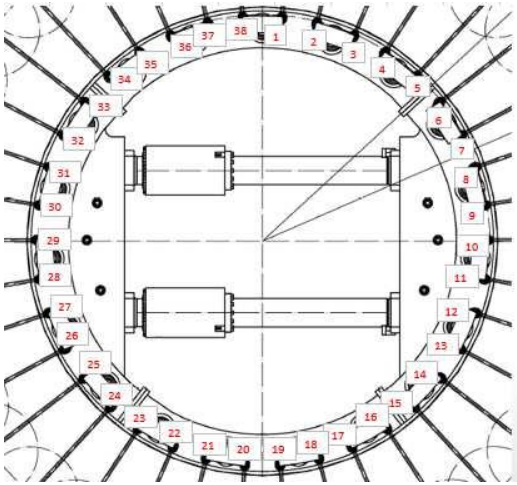
| **Sensitivity class** | **Likelihood of settlements** |
|---|---|
| Small sensitivity | Low |
| Very sensitive | High |

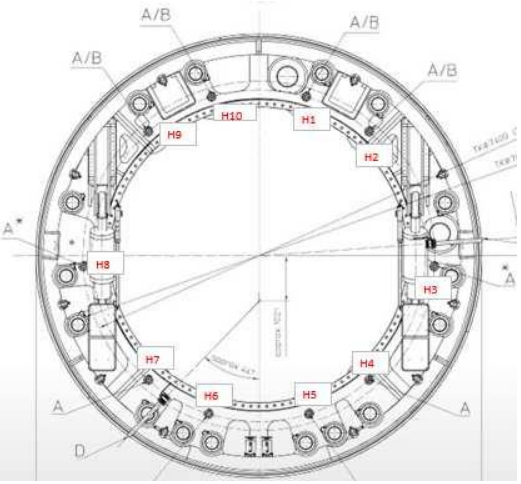
| Km | Location | Area classification of pore pressure sensitivity | Comments |
|---|---|---|---|
| 2.8 – 4.0 | Below Ekeberg (to Holtet) | Small sensitivity | Excisting caverns and tunnels in the area |
| 4.0 - 5.0 | Holtet -Lambertseter | Moderate sensitivity | |
| 5.0 – 7.8 | Nordstrandsplatået | Sensitive | |
| 7.8 – 8.5 | Ljanselva -Gjersrudbekken | Small sensitivity | |
| 8.5 – 9.0 | Bjørnerud | Moderate sensitivity | The escape tunnel in this area will be constructed by D&B |
| 9.0 – 11.2 | Grønliåsen north | Small sensitivity | The escape tunnel in this area will be constructed by D&B or TBM |
| 11.2 – 12.0 | Grønliåsen | Moderate sensitivity | The installation caverns and associated tunneling systems will be constructed by D&B |
| 12.0 – 15.7 | Snipetjern -Assurdalen | Sensitive | |
| 15.7 – 18.9 | Assurdalen - Sloraveien | Moderate sensitivity | |
| 18.9 – 20.6 | Sloraveien – Ramstad S | Very sensitive | The most sensitive area above the tunnel is at Sloraveien and Ramstad |
| 20.6 – 21.3 | Ramstad – Portal Langhus | Moderate sensitivity | |

# Daily Probe-drilling to detect water leakages ahead of the TBM




Probe-drilling was performed on a daily basis. This gave an overlap of the probe-holes and were used to complete the picture of the geological conditions




Probe-drilling and pre-grouting from 38 different positions around the shield

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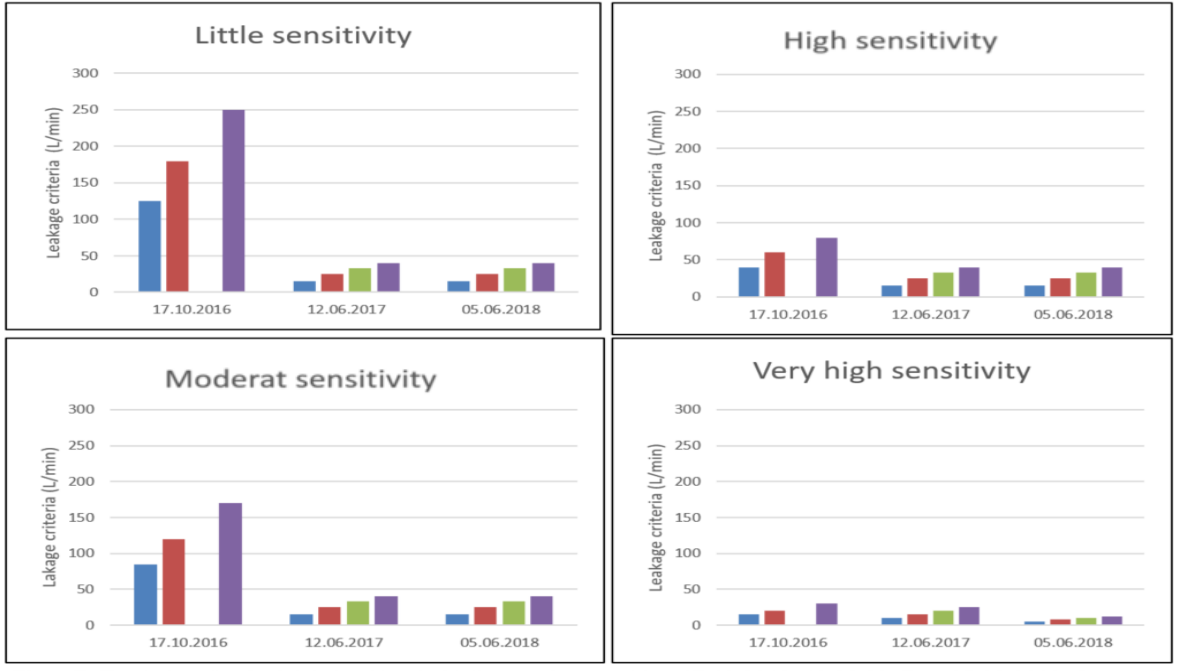
# The number of probe-holes and trigger-values

- Orientation of the probe-holes
- The number of probe-holes
- How much leakages could be accepted

More probe-holes distributed around the cross-section increased the likelihood of detecting water

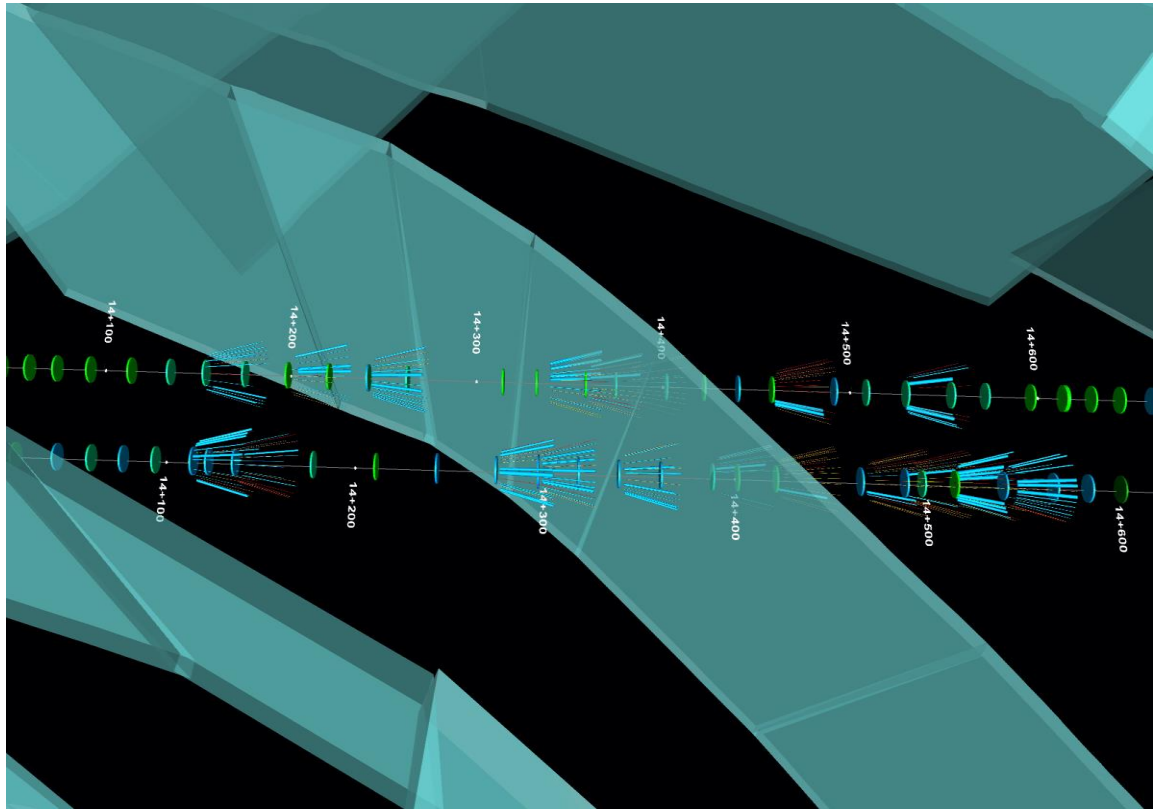
Blue = 1 probe hole. Read = 2 probe holes. Green = 3 probe holes. Purple = 4 probe holes.




Trigger-values were lowered to achieve control of the water balance

# Face-mapping, probe-drilling and pre-grouting

- Good correlation between detected water leakages and identified fracture zones
- Similar correlation with the amount of micro-cement pumped into the different holes.
- Normally 20 holes in the umbrella




No water detected during face-mapping

Water detected during face-mapping

No water detected during probe-drilling

Water detected during probe-drilling and pre-grouting

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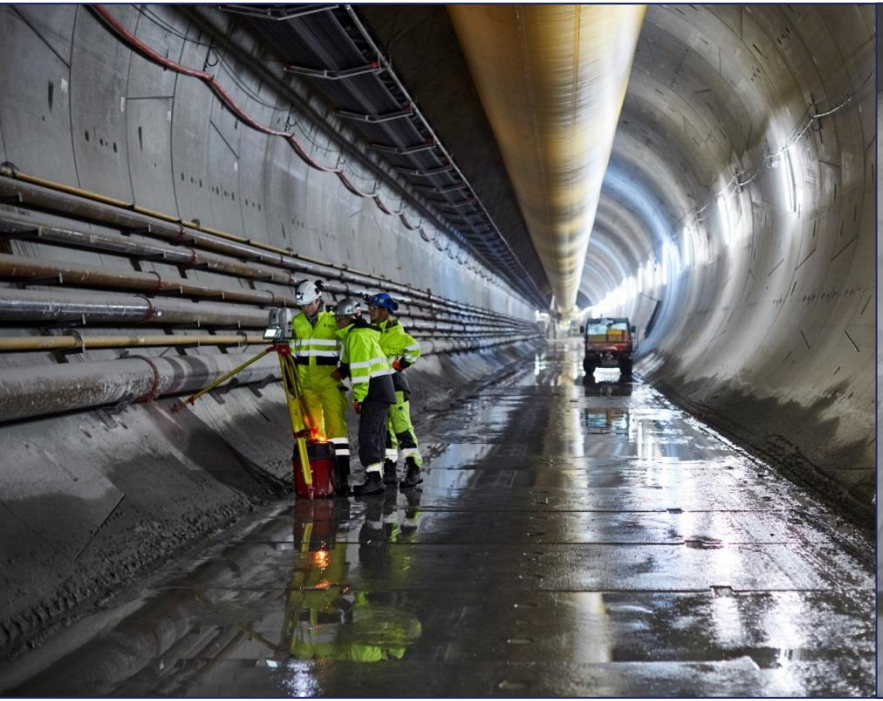

Total excavation: 36 027 meter tunnel – 100 % finalized tunnel
7 500 meter of the tunnel-length have been pre-grouted



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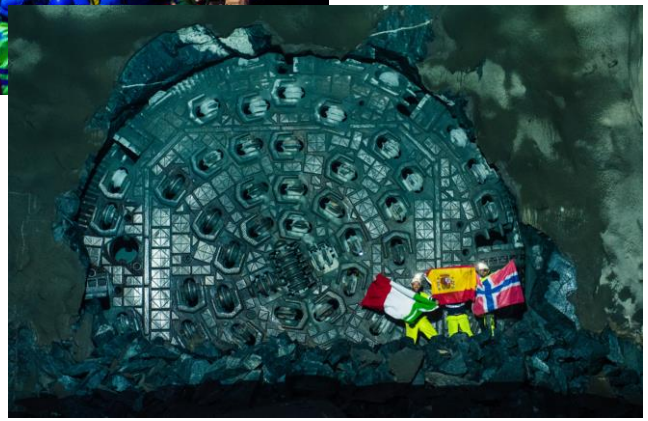
# Two successful double break-throughs



Each TBM has excavated
9 km of tunnel and
in total 7.5 km have been pre-grouted



Double Break-through in the north
11th of September 2018
2 years after start-up

Double Break-through in the south
26th of February 2019
2 years and 3 months after start-up

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# Lessons learned

- Detailed geological mapping and clear requirements regarding probe-drilling and pre-grouting in the contract
- Install efficient probe- and pre-grouting equipment on the TBMs
- Skilled personnel with experience with high pressure pre-grouting
- Fracture-zones are connected to each other, so a penetration of one zone may affect the pore-pressure within a large area
- Probe-drilling and pre-grouting procedure must be tailormade and flexible during the excavation
- By installing a water-tight lining, the pre-grouting just need to limit the amount of leakages – not stop it completely

The need for doing pre-grouting to achieve control of water-leakages is NOT a show-stopper for using TBM

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# Thank you for your kind attention!