Presentation of
The Norwegian Tunnelling Society

29th of August 2019

NORWEGIAN
TUNNELLING SOCIETY

Motto

Surface challenges – underground solutions

Vision

The most important knowledge arena for use of rock and underground space

Values

What we do is based on knowledge, determination and engagement

Goals

- An industry that is safe and environmentally conscious
- An industry that is attractive and visible
- An industry that is viable, innovative and knowledge-based

The board of NFF represents the industry's value chain


Anne Kathrine Kalager
BaneNor


Amund Bruland
NTNU


Olaf Rømcke
Orica


Roar Sve
Skanska


Elin Morgan
Norconsult


Elin Hermanstad Havik
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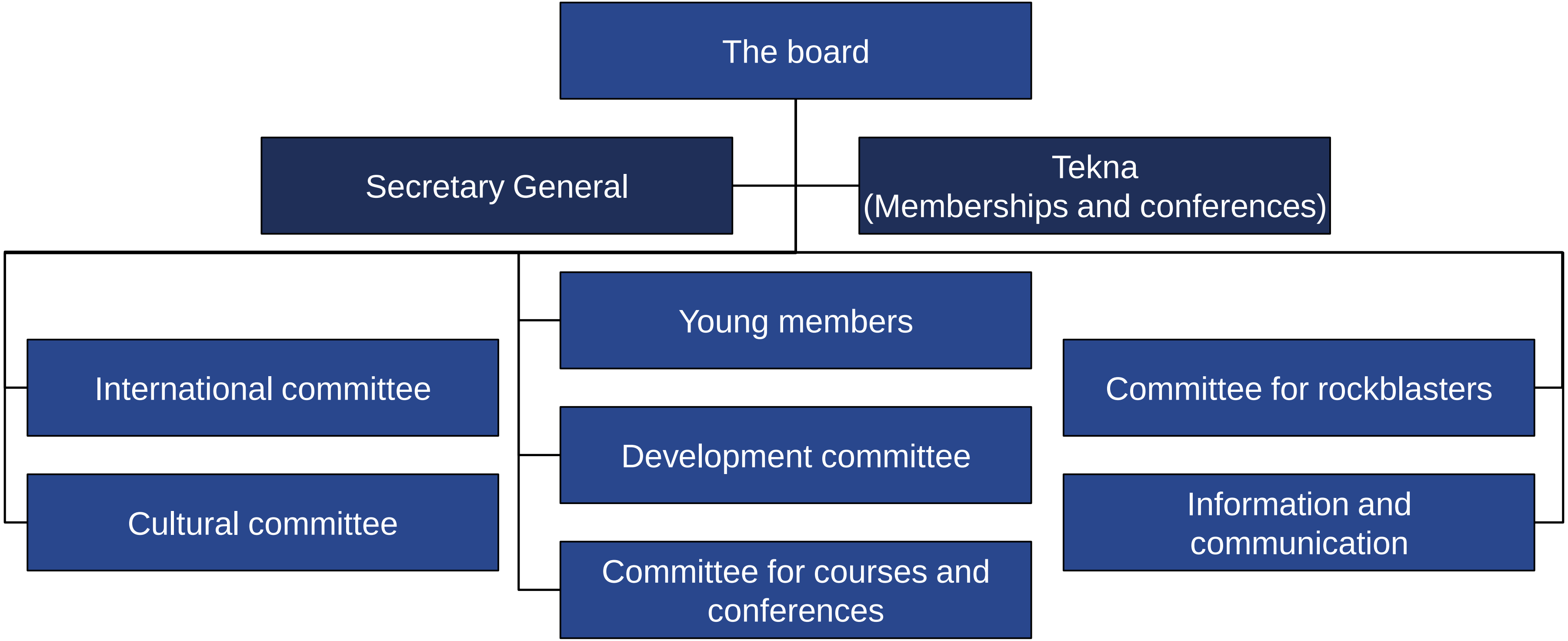
Kristian Kristoffersen Dahl
NGI


Sindre Log
The Robbins Company


Stein Bjøru
Veidekke

NFF is organised in several committees



Remember 5th of September

Utilization and planning of the underground

Antonia Cornaro
ITACUS

Ingelöv Eriksson
Oslo Municipality

Sindre Log
NFF

29.08.2019

BLASTING CLOSE TO EXCISTING INFRASTRUCTURE AND QUICK CLAY

ESPEN HUGAAS
TECHNICAL SERVICE LEAD
ORICA NORWAY AS

ORICA

Introduction

- Blast works inside the city limits → "Always" something sensitive nearby
- Oslo have presence of special ground conditions that must be taken into account
  - Rock types that responds different to blasting
  - Intrusions of harder rock types
  - Presence of quick clay

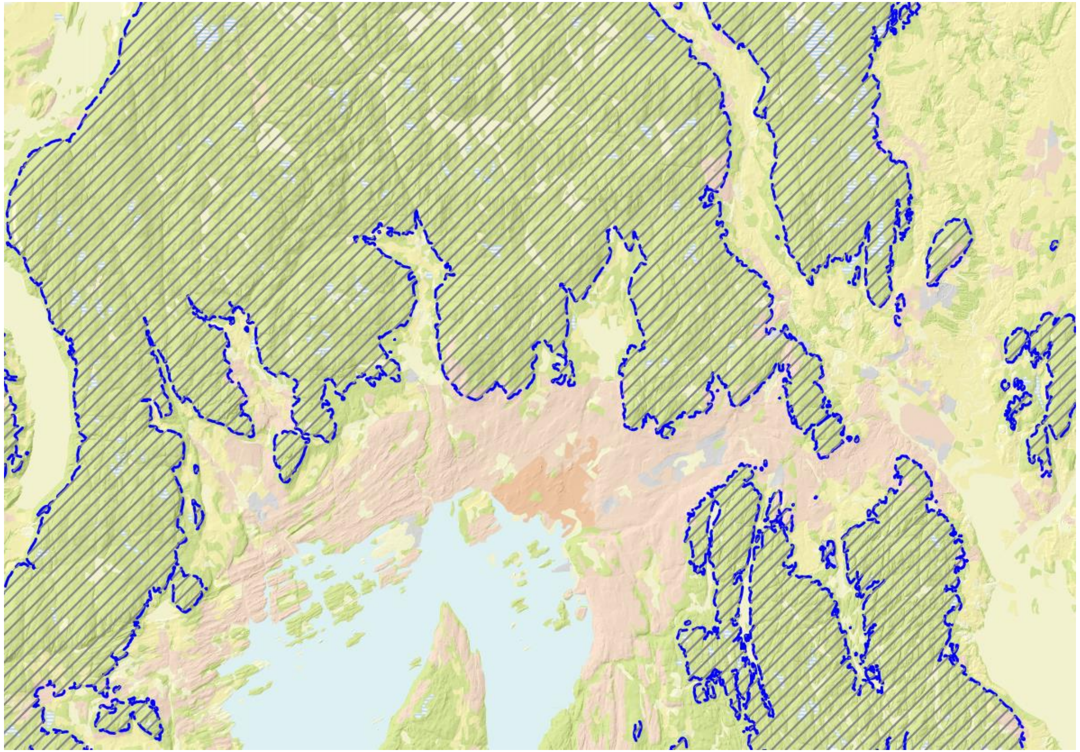
Presence of quick clay

- All areas below ~220 meters (marine limit)

→former seabed

→possibility of quick clay

- The Norwegian Water Resources and Energy Directorate (NVE) have national mapping programs for quick clay slides



Landslides in Oslo

- Landslide Bekkelaget 1953
- Overload by road and railway traffic

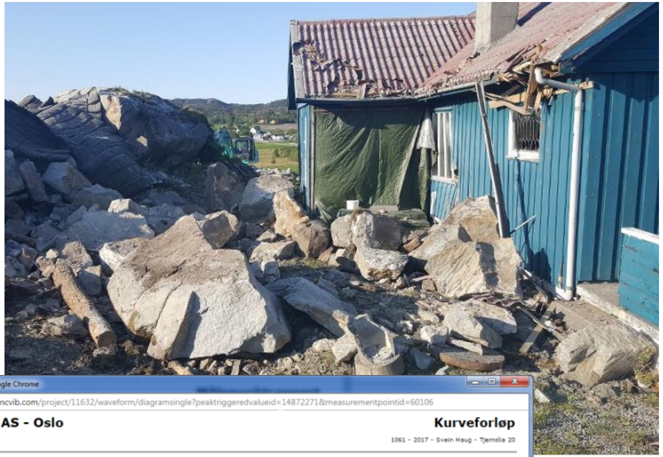
Blasting close to quick clay

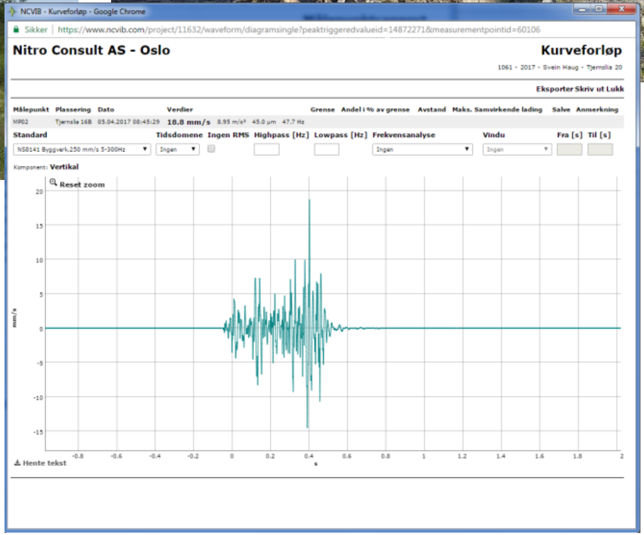
- Kattmarka landslide 2009 (Namsos, Trøndelag)
- Initiated by nearby blast work

HOW CAN BLAST WORKS AFFECT QUICK CLAY?

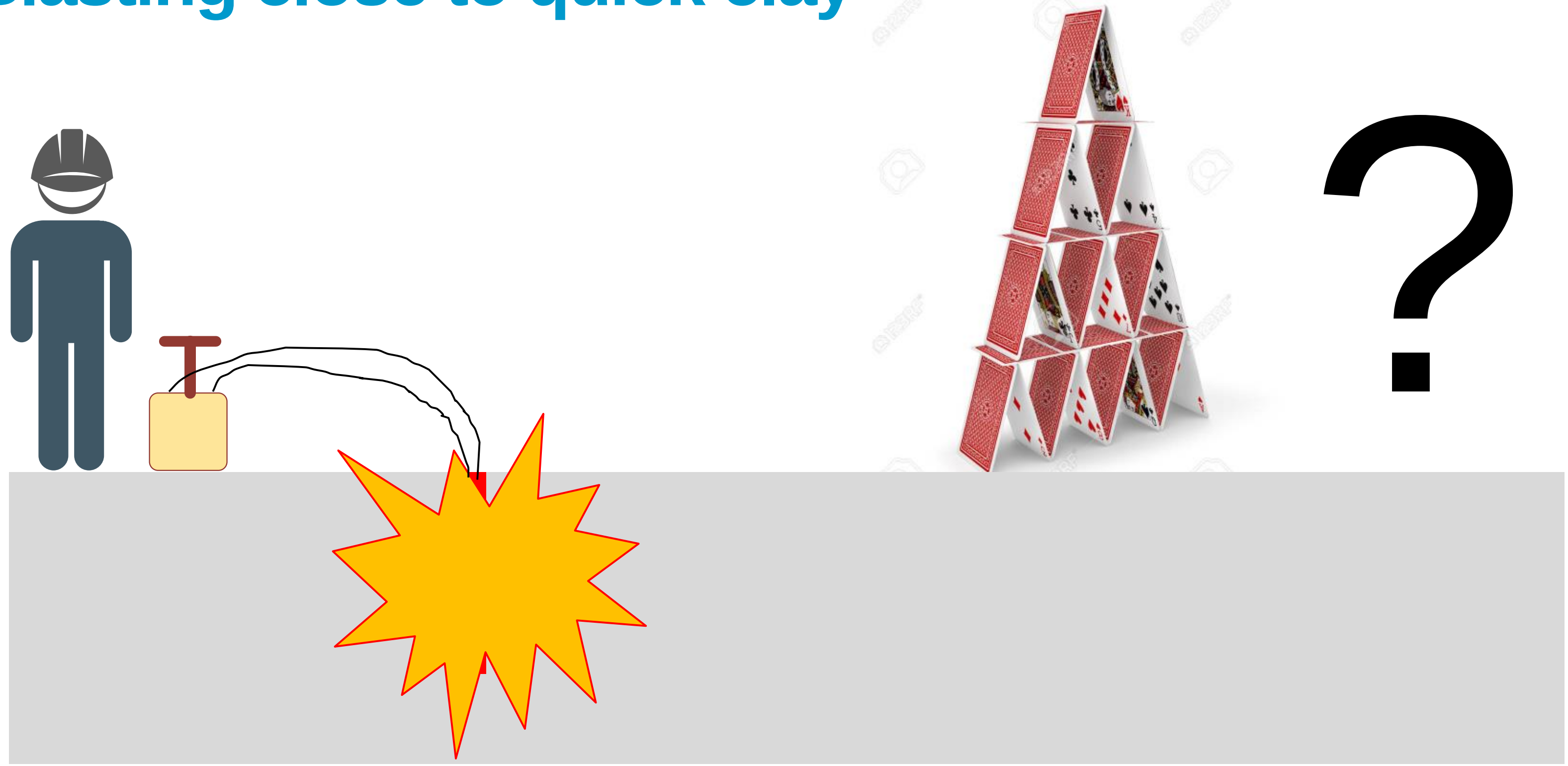
Main hazards related to blasting

- Flyrock
- Airblast
- Ground vibrations
- Wall collapse

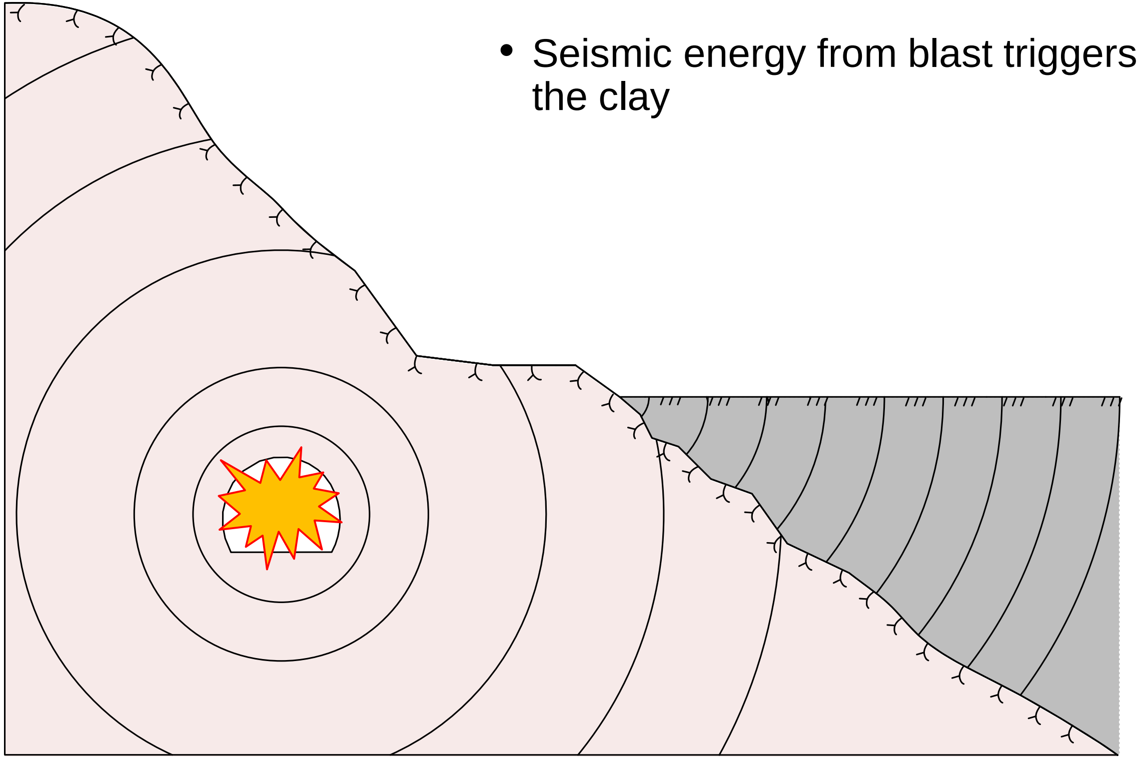




Blasting close to quick clay

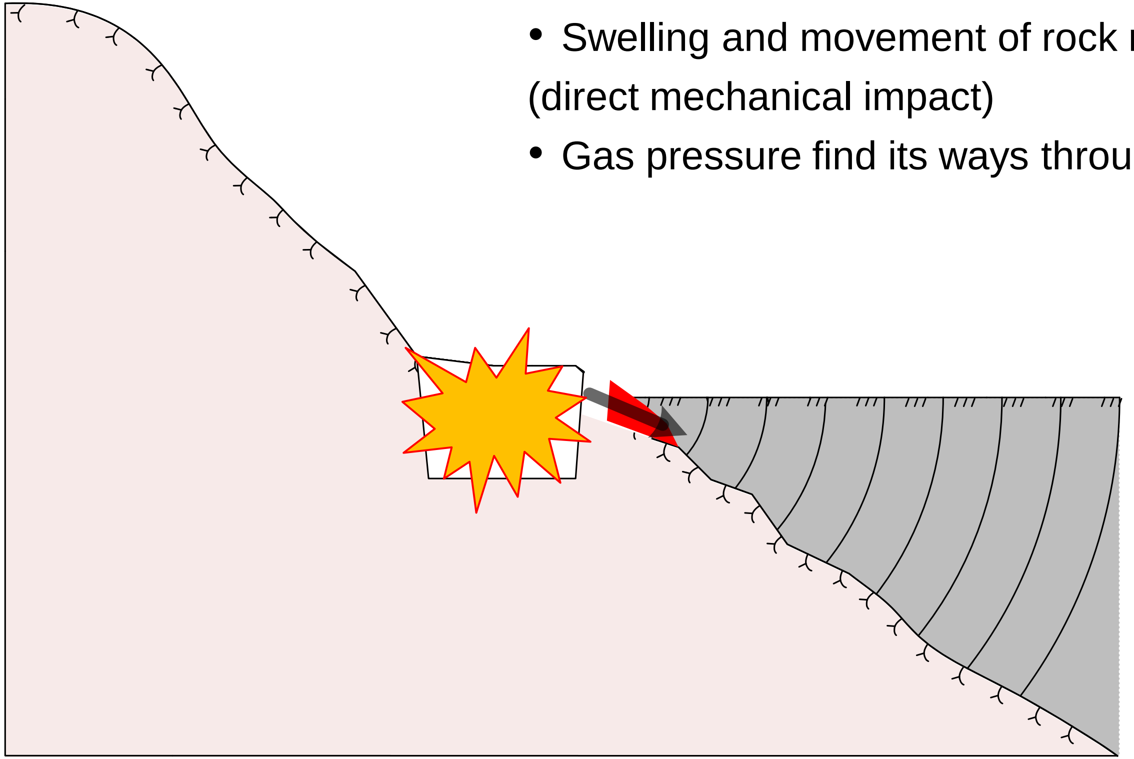


Blasting close to quick clay



- Seismic energy from blast triggers a collapse in the clay

Blasting close to quick clay



- Swelling and movement of rock mass into clay (direct mechanical impact)
- Gas pressure find its ways through cracks

General

Ground vibrations - Limits

- Constructions founded on quick clay get a limit from NS8141 (No frequency weighing)
- Norsk Standard (NS8141-3) specifies method for measuring vibrations in the clay
  - Frequency weighed
  - Multiple monitors

- OBS! Nearby infrastructure (roads and railway) may affect the measurements → review where monitors are positioned.

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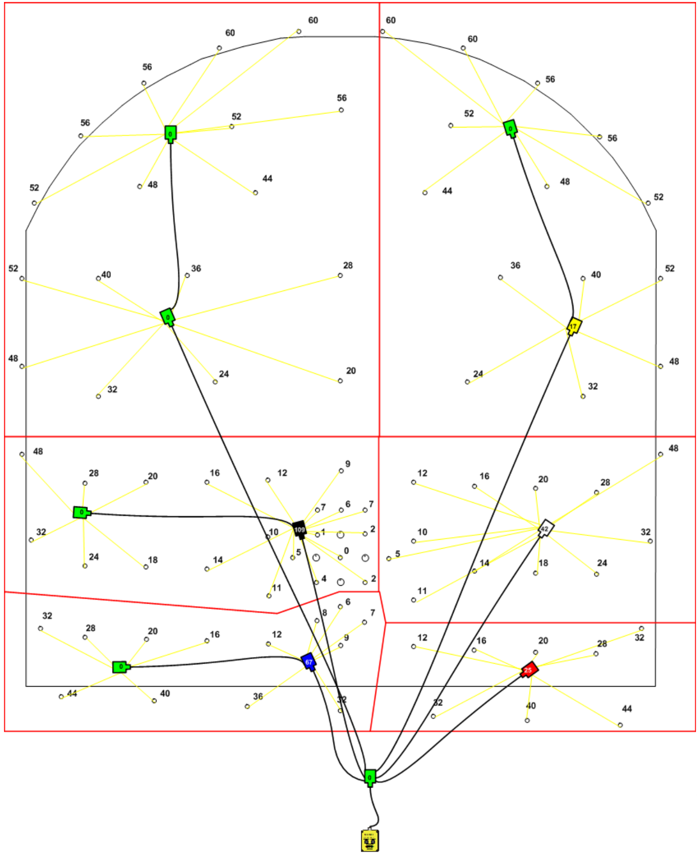
Cautious blasting

- Reduced blast size
- Support remaining rock to avoid fallout and unwanted ground movement (grouted rock bolts)
- Cautions perimeter blasting
- Seam drilling
  - – Ensure a smooth wall
  - – Ventilation of blast fumes

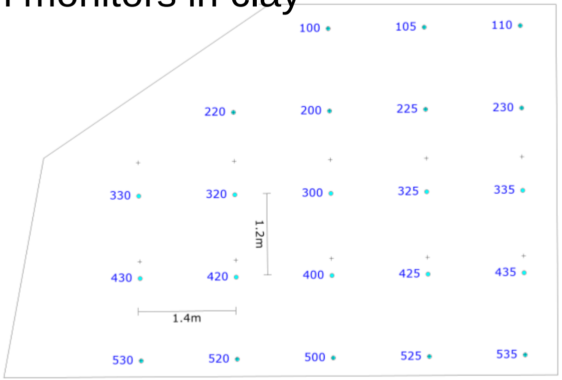
Underground blasting close to quick clay

- Adjust size of blasts to reduce vibrations
  - Short rounds
  - Single hole detonation
  - Use of surface delays to spread the inhole nominal times
  - Use of Electronic Blasting systems



Blasting close to quick clay

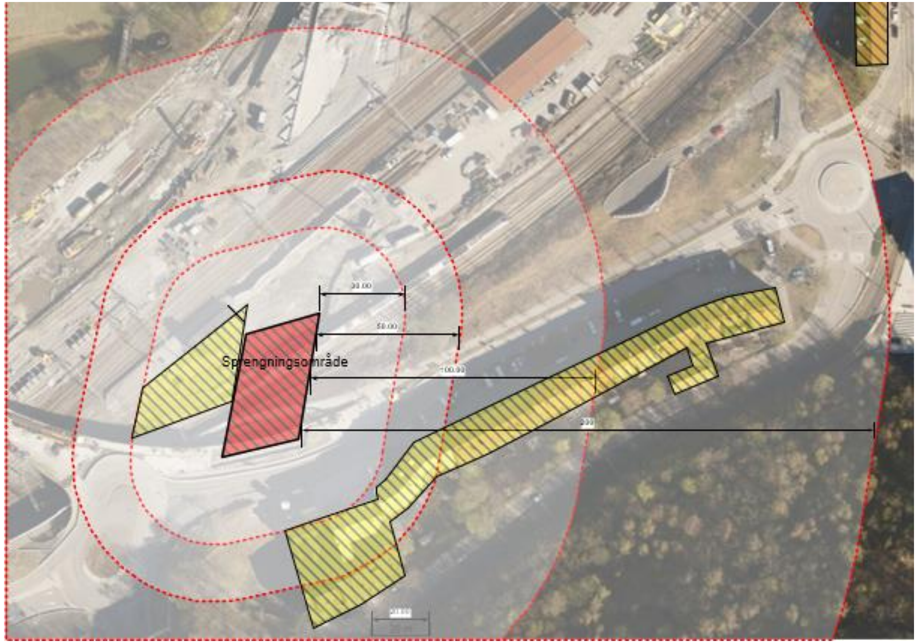
- Example from Follobanen railroad cut at Sørenga
  - Sheet piles anchored to solid ground
  - Small controlled blasts
  - Seam drilling
- Vibration monitors in clay



General

Summary

- Surrounding area must be mapped properly
  – Where does the rock end and clay starts?
- Adjust size of blasts to reduce vibrations
- Support remaining rock to avoid fallout and unwanted ground movement (grouted rock bolts)
- Cautions perimeter blasting
- Seam drilling
  – Ensure a smooth wall
  – Ventilation of blast fumes
- Monitor Vibrations



General

Thank you!

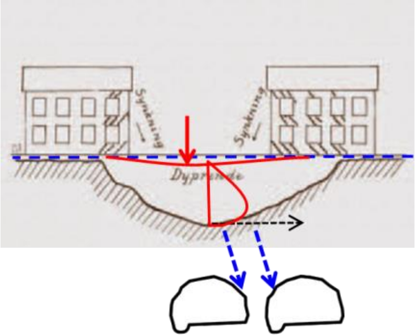
Sources:

- Slide 3 Map taken from Norges Geologiske Undersøkelse
  - https://www.ngu.no/emne/kart-pa-nett
- Slide 4 Taken from NGI report 20081717-00-1-R *Risiko for kvikkleireskred*, 2011
- Slide 5 Taken from Nordal et. al. *Skredet i Kattmarkvegen i Namsos 13. mars 2009*
- Slide 7 Flyrockphoto by the Police, published in Haugesund avis
  - https://www.h-avis.no/tysvar/bolig/naringsliv/hus-skadet-etter-sprengningsuhell-i-tysvar/s/5-62-264822
- Slide 11 Norsk standard
  - https://www.standard.no/nyheter/nyhetsarkiv/bygg-anlegg-og-eiendom/2013/revidert-standard-for-vibrasjoner-og-stot/?gclid=EAIaIQobChMIq9Li6oym5AIVzOWaCh0K4wOOEAAYASAAEgKl1fD_BwE

Rock Mass Grouting – Under Oslo

Chief scientist/Professor II Eivind Grøv SINTEF/NTNU

Rock Mass Grouting – Under Oslo



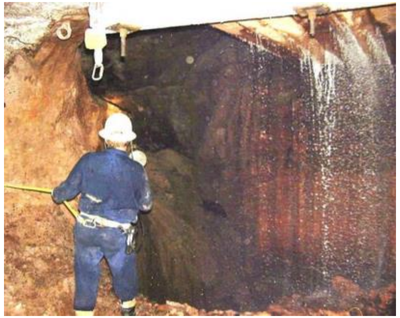
Welhavens gate 11–13.

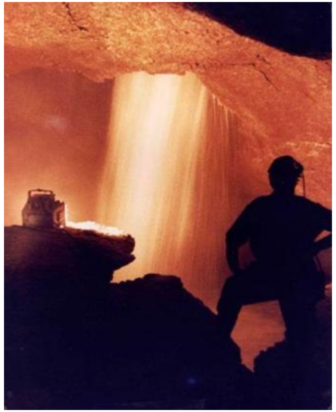
FROM THE HISTORY OF TUNNELLING IN THE OSLO AREA:

- Nature of problem realized in 1912-16 as the first subway tunnel through downtown Oslo (Holmenkoll-banen) was excavated - settlements of up to 40 cm of apartment and office buildings Karlsrud et. al (2001).
- Shallow tunnels 20-50 m in the Oslo area
- Sedimentary rocks, clay shales, nodular limestones and alun shale, with igneous dikes and intrusions being water bearing
- Cap of soft marine clay deposits above bedrock

Rock Mass Grouting – Under Oslo

Uncontrolled water seepage into rock tunnels would in circumstances as Under Oslo constitute a non-complying incident – Key questions are:





How can we control water inflow like these??

This we will discuss

What could the consequence of non-compliance be??

This we will NOT discuss

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Rock Mass Grouting – Under Oslo

Definition of rock mass grouting

Material is normally cement

"the introduction of a material under **pressure** into the ground (or a structure) with the goal of **waterproofing** and **consolidating** voids, cracks and porosity" quoted from Ola Woldmo

Yes indeed

No porosity in typical hard rock

Should be "sealing off" rather than "water proofing" in rock mass

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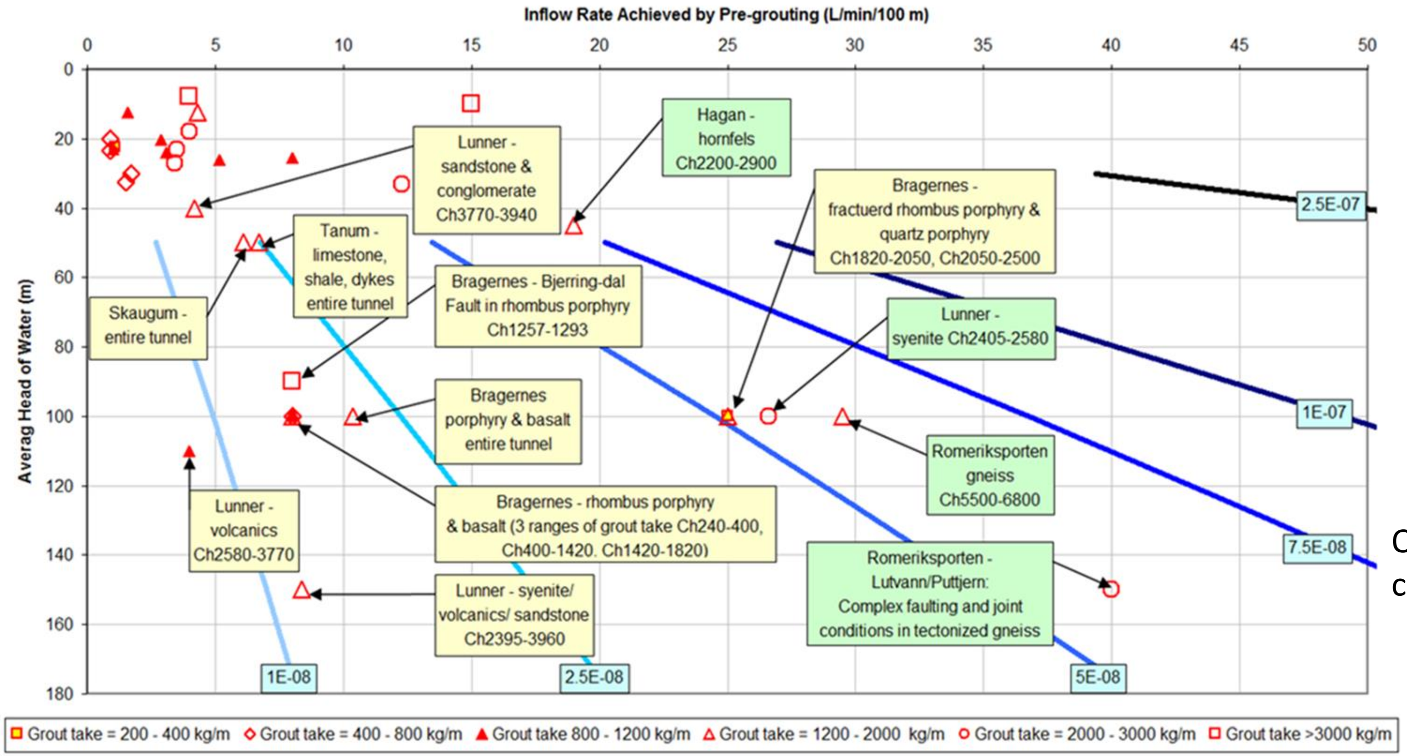
Rock Mass Grouting – Under Oslo

Inflow Rate Achieved and Grout Take for Pre-grouted Land-based Tunnels



Reference to Tattersall & Grøv 2009 based on input data from tunnelling projects in Norway (Publication 104)

Overall effective conductivity

In length of tunnel

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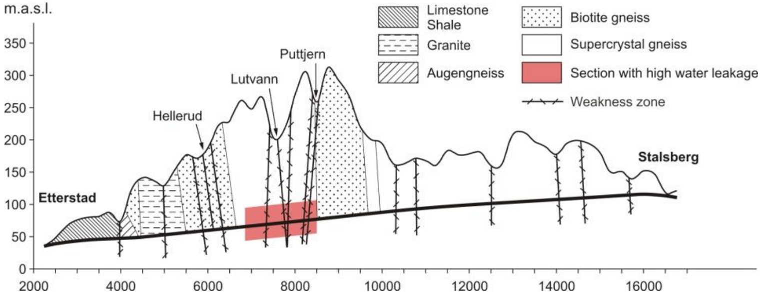
Rock Mass Grouting – Under Oslo

Some anecdotes from Norwegian tunnelling

- In previous hydropower tunnelling projects water inflow was a ”plus”, few, if any mentioned environmental impacts – focus on practicalities in tunnelling
- The construction of the Lieråsen tunnel 30 years ago drained a sumpy area to become valuable land for a new housing complex – would be totally unacceptable
- The Romeriksporten tunnel in late 90’es faced public, political, environmental and technical focus on a scale never experienced before

The 'unfortunate' affair at Romeriksporten triggered a new approach to water control in Norwegian tunnelling. And it became:

"A game changer in Norwegian Rock mass grouting"



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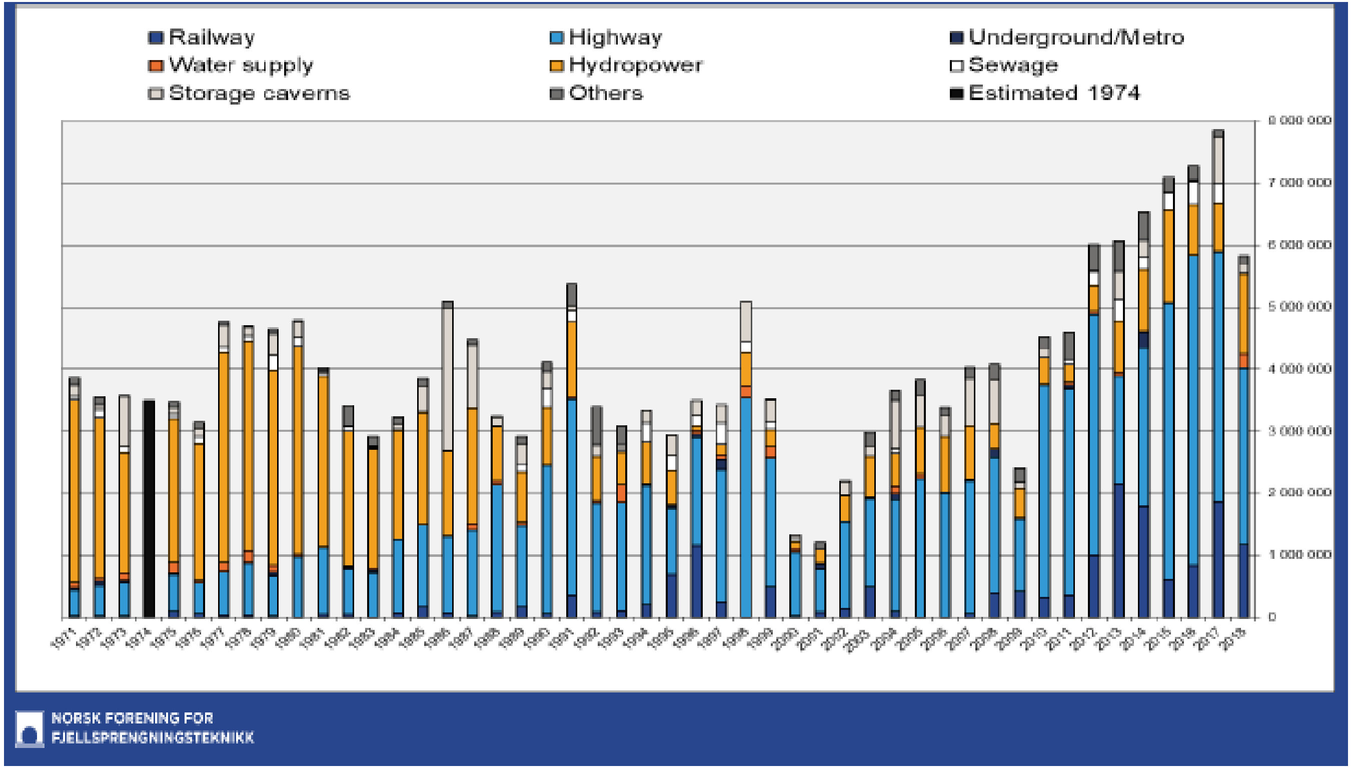
Rock Mass Grouting – Under Oslo



- Todays trende in application of tunnels is another "game changer"
- Increased projects in urban areas
- Increased need for grouting & tech-nology to do so

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Rock Mass Grouting – Under Oslo

SOME MAIN ASPECTS TO KEEP IN MIND,

NO MATTER CIRCUMSTANCES:

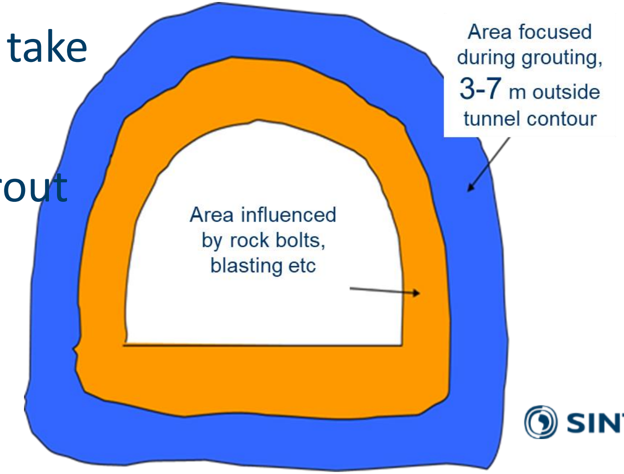
- Tight Enough For Its Purpose!
- Water Control - Not Water Proofing!
- Pre-excavation Grouting!
- Prevent - Not Cure!

These aspects must govern our approach to

Rock Mass Grouting – each tunnel is an unique one

Rock Mass Grouting – Under Oslo

- The purpose is to REDUCE the permeability of a limited zone around the tunnel periphery
- A reduction from 10^{-7} m/s to 10^{-9} m/s is likely achievable
- It is NOT the intention to repair the entire rock mass – thus focus on limiting the grout take
- Assess roughly the grout take and whenever the grout take exceeds expectations – take notice
- Note also; one big leaking joint will take most of the grout – limited grout to the smaller joints that need to be grouted to secure the leakage criteria
- Imagine an imperfect hose with small and large holes



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Rock Mass Grouting – Under Oslo


FJELLSPRENGNING - VEI - TUNNEL OG JERNBANE

Norske grunnprinsipper må gjelde

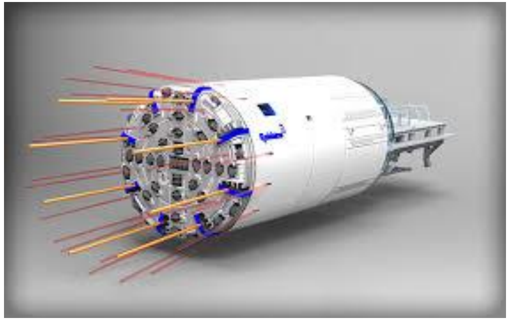
Grunnleggende prinsipp ved norsk tunnelteknologi må gjelde også ved TBM som drivemetode.

KOMMENTAR

Eivind Grøv

In principle; no matter excavation method the same concept of water control applies

'Rock mass grouting is 'first line of defence'



TBM to be equipped to perform probe drilling and pre-grouting

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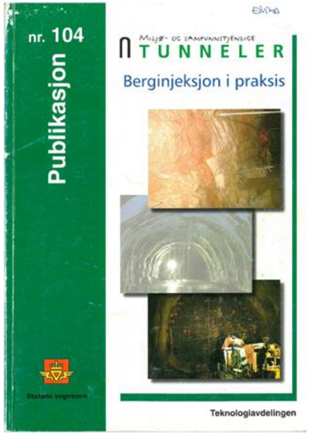
Rock Mass Grouting – Under Oslo



In 2004 'Active Grouting' was created

- Defined as continuous pressure build up
- As high pressure as possible as stop criteria
- Up to 100 bar if conditions allow (1000m H_2O)
- Gradual pressure increase - balanced with varying W/C-ratio
- As low W/C-ratio as practically possible
- Requires continuous monitoring and follow-up
- Low W/C-ratio causes pressure reduction to prevent long distance grout penetration damaging surroundings
- Drill many grout holes, also at tunnel face

But, is this the way it is performed and what if it is not?

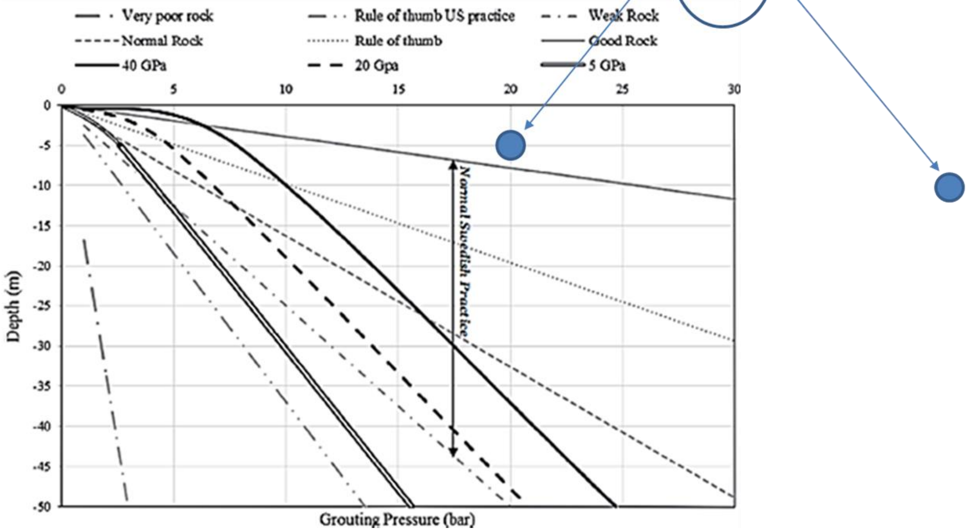
Rock Mass Grouting – Under Oslo

Do we follow the principles of Active Grouting?

High pressure is a benefit, may have to reduce the focus on the pressure as a primary stop criteria – and focus on time and quantity

Maksimaltrykk skal overholdes:

OVERDEKNING	MAKSIMALTRYKK Borehull heng/vegg	Borehull såle/stuff
0 – 5 m	20 bar	30 bar
5 – 15 m	40 bar	60 bar
> 15 m	100 bar	100 bar



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Rock Mass Grouting – Under Oslo

Experience from a paper presented by Davik et al in 2002 in NFF Publication no 12 – I keep these as valid point still – with some caution!

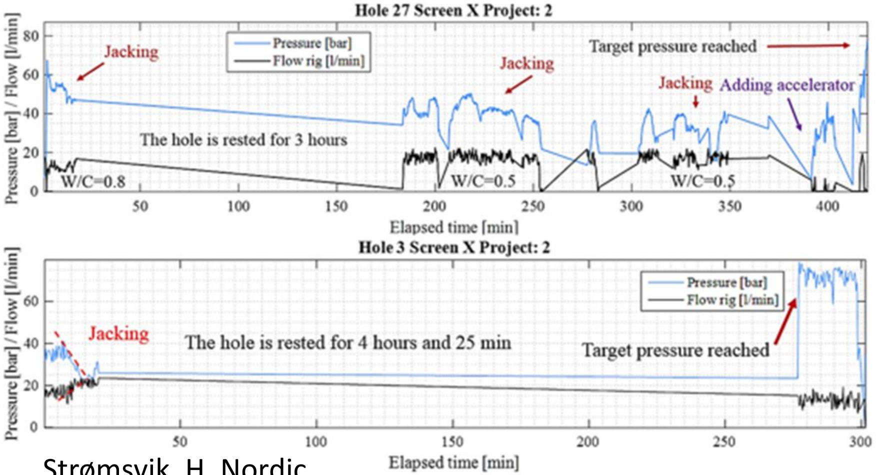
- Standarized, systematic grouting is most advantageous for ground water control and also for the excavation cycle
- Increased drilling capacity allow a greater amount of holes for optimal grouting
- Superplastizers and silica additives increase the penetrability and pumpability for grouting – TIGHT indicates that not all products go together well
- Grouting pressure up to 100 bars yields better penetrability and grouting capacity – but the number of jacking events is high
- Reduce w/c ratios to improve quality of the grout, and stable cement grout micro-cement dmax< 20mikron & 0 bleeding
- One point to add! Caution on flow rate – not too high – grout is incompressible

Rock Mass Grouting – Under Oslo

A (sad) experience; little interaction / cooperation during grouting between Owner and Contractor

This is particularly sad when grouting today probably constitute 1/3 of the tunnelling costs

A flow – pressure diagram combined with data loggers at the grout rig plus Bever Control system constitute a good tool to real time follow-up at the face – joint effort to improve the grouting



Strømsvik, H. Nordic Grouting Symp. 2016

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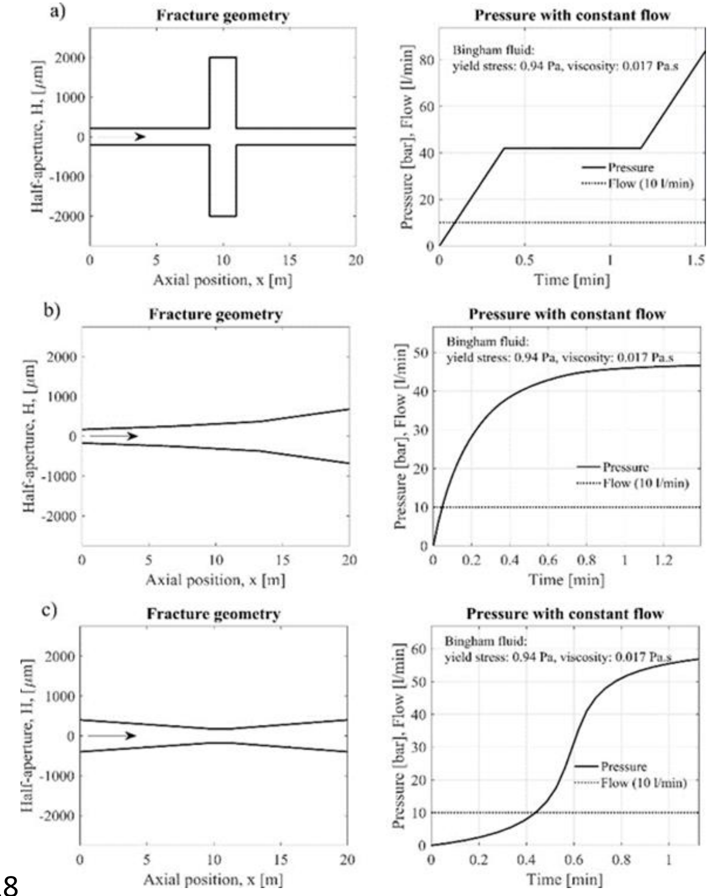
Rock Mass Grouting – Under Oslo

Numerical models show that if flow remains constant pressure reduction occurs only if;

- Erosion or washing out of joint material/filling
- Change in viscosity of flow of grout/change in grout rheology
- Hydraulic jacking



Strømsvik, H. TUST 2018

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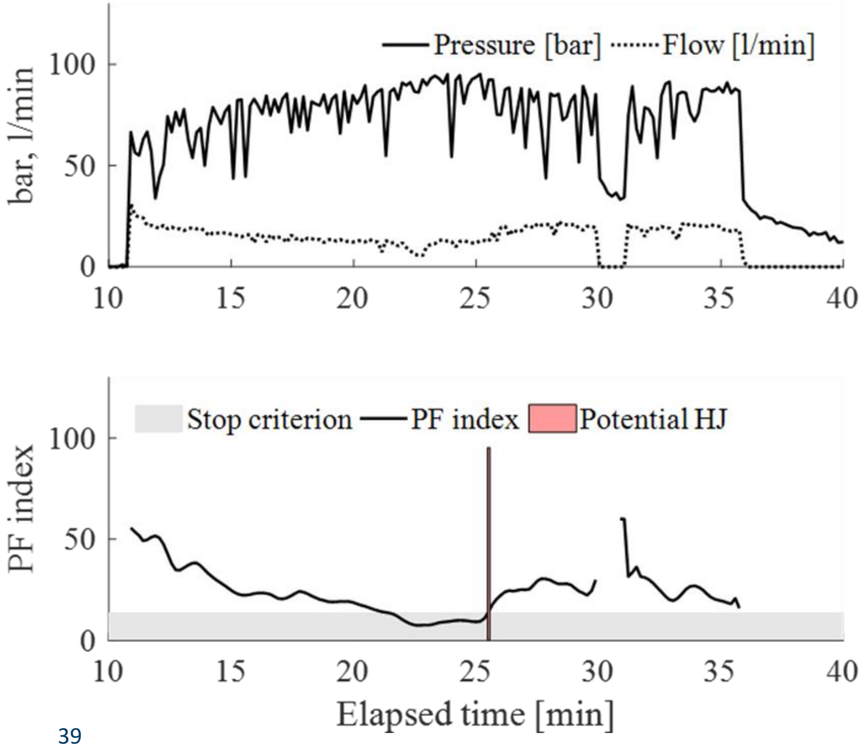
Rock Mass Grouting – Under Oslo

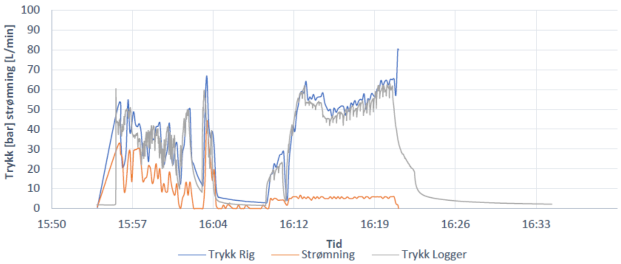


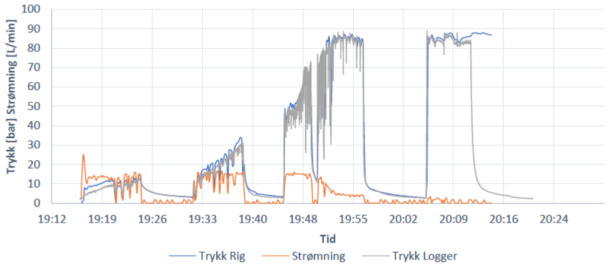
The PF-Index is an algorithm developed by Helene Strømsvik in her PhD in TIGHT - studying a large number of grouting rounds at different projects.

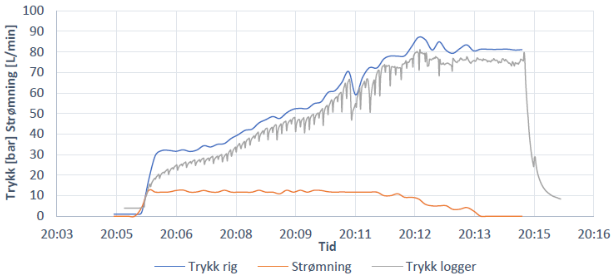
A tool to follow-up grouting works and identify jacking

(Strømsvik et al 2018)

Rock Mass Grouting – Under Oslo







A recent MSc-thesis (not sensured yet) has looked at data that NGI collected for TIGHT

How does grout pressure develop into the borehole?

The results show that for MC there is good coherence between grout pressure at the rig and measured in the hole.

It is wrong to assume high pressure loss from rig to hole

Water was also tested with poor coherence between pressure at the rig and pressure in the hole

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Rock Mass Grouting – Under Oslo

Jacking- an incident of postive or negative impact? (1)

All groups seem to accept that jacking occur when the grout pressure exceed the normal stresses acting over a fracture.

Higher pressure will give a faster flow

Jacking implies that the fracture aperture will increase.

The increase of fracture aperture will depend on the excess grout pressure and the spread of the grout.

Jacking- an incident of postive or negative impact? (4)

Some issues to be further discussed

What happen with the spread and peneration of the grout into the finer fractures?

Lack of experiences from the field?

How to keep jacking under control? Stop criterion and indicators from monitoring of the grout course?

1. Jacking when grouting – an incident of positive or negative impact – wanted or unwanted?
2. How can we balance high pressure as something required for good quality grouting with the risk of jacking?

Jacking- an incident of postive or negative impact? (2)

All groups seems to consider that jacking may have negative effect.

Common negative effects are lose of control and higher grout consumption. Some group have also take up the risk for open up new larger water channels. Some groups have indicated the risk for the workers.

How to balance high pressure and good quality grouting (1)

Many groups suggest that the pressure should be close to the jacking pressure. Some groups indicate that a short period of higher pressure in the very start can be allowed.

Many groups suggest that monitoring should be used to control that jacking will not occur. Stop criterion is mandatory. (*N.B not stop pressure*).

Adapt the rheological properties to the actual situation. Use stable grout. Investigation of the insitu stresses and geology. Education of people involved.

Jacking- an incident of postive or negative impact? (3)

All groups have indicated that under some circumstances jacking may be beneficial.

In general the positive effect can be utilised for deep and rural tunnels. The effect may be a better pentrabillity, less risk for clogging and faster flow of the grout.

Some groups have pointed out that this require that resonable stop criterion is established and used to be in control and to prevent high grout consumption.

What about hydraulic jacking – which is the consequence of too high pressure?

Investigating grout holes suggest that hydraulic jacking appears very frequent – more frequent than many would like to accept

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Rock Mass Grouting – Under Oslo

Improving the Rock Mass Quality by grouting – impact on rock mass quality

- This is debated in the industry and cannot be said to be fully documented
- Though; grouting prevents washing out of fine material in weakness zones
- And it glues cracks and fissures and thus stabilize rock blocks from fall
- Grout may improve Jw in the Q-systemet from e.g. 0,66 to 1.0
- Potentially improving other parameter(s) of the Q-system – Jr or/and Ja?
- "Pre-stressing" effect of the grouting on the rock mass improves the stability of the tunnel and reduce relative joint displacements (Karlsrud 2001)
- A MSc-student starts up investigating the effect of hardened cement along joint surfaces

Rock Mass Grouting – Under Oslo

Improving the Rock Mass Quality by grouting

Before Grouting	After Grouting
Q = 0.8 (very poor)	Q = 16.7 (good)
Qc = 0.4	Qc = 8.3
Vp = 3.1 km/s	Vp = 4.4 km/s
Emass = 7 GPa	Emass = 20 GPa
Sigmacm = 9 MPa	Sigmacm = 25 MPa
Pr = 13.6 t/m2	Pr = 4.9 t/m2
L = 2.5 Lugeon	L = 0.1 Lugeon
K = 2.5 x 10-7 m/s	K = 10-8 m/s
Δ = 25 mm	Δ = 1 mm
FC = 14º	FC = 63º
CC = 1.7 MPa	CC = 8.3 MPa
B 1.6m c/c	B 2.4m c/c
S(fr) 10 cm	None

Barton claims that it grout is increasing the rock mass quality

Question; are we able and can we take this into account in the support design

REFERENCE
An example of improvements achievable by pre-injection with fine, cementitious multi-grouts. (See Barton, Buen & Roald 2000)

Rock Mass Grouting – Under Oslo

First line of defence in water control!

TIGHT + last 15 years of experience since Samfunnstjenlige Tunneler has brought new understanding–still need to move Technology Front!

Don't forget to sign up for NFF course in Rock Mass Grouting

Thank you for your attention!

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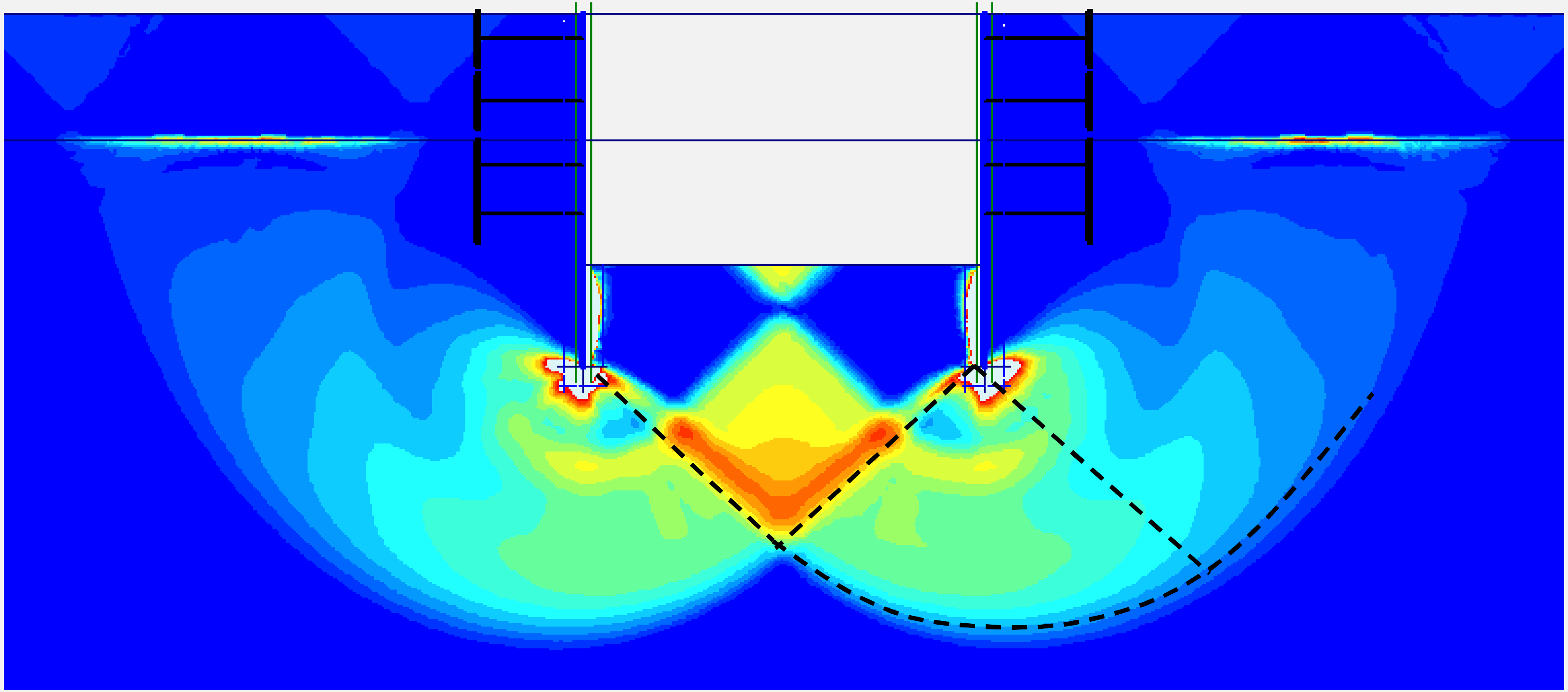
Under Oslo-How can stabilizing measures contribute to solutions

Kjell Karlsrud, NGI

Trond Øiseth, eget firma

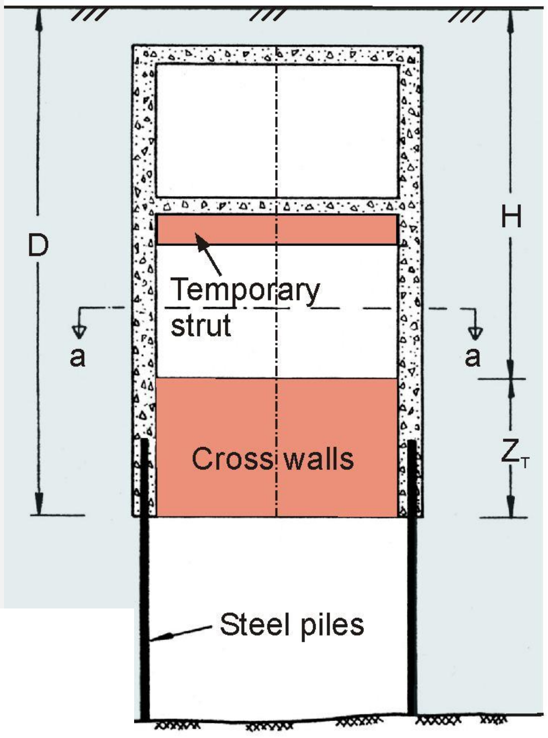
Safety against bottom heave failure is a critical element for safety of open braced excavations (etter Karlsrud & Andresen, 2008)

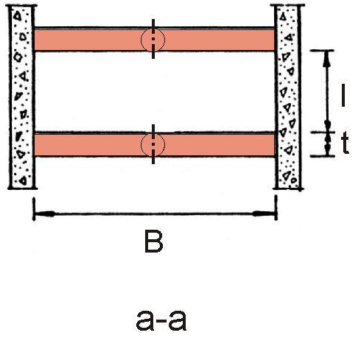


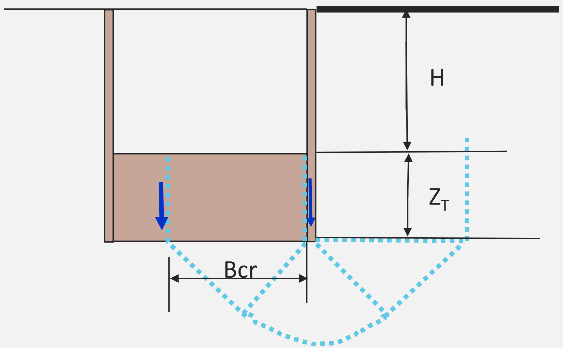
Measures to improve stability

- Sectional excavation and casting of bottom slab
- Deep wall with very high bending moment capacity
- Excavation under water and casting of underwater slab
- Constructing cross-wall panels under base of excavation using:
  - Diaphragm walls
  - Overlapping jet-grouted columns
- Ground improvement with DDM, DWM or MDDM in panels or massively

Diaphram wall cross-panel (DWCP) concept first used for tunnel Nationalteateret –Stortinget 1973-77 (Etter Eide et al, 1973)







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Picture from construction phase in 1974

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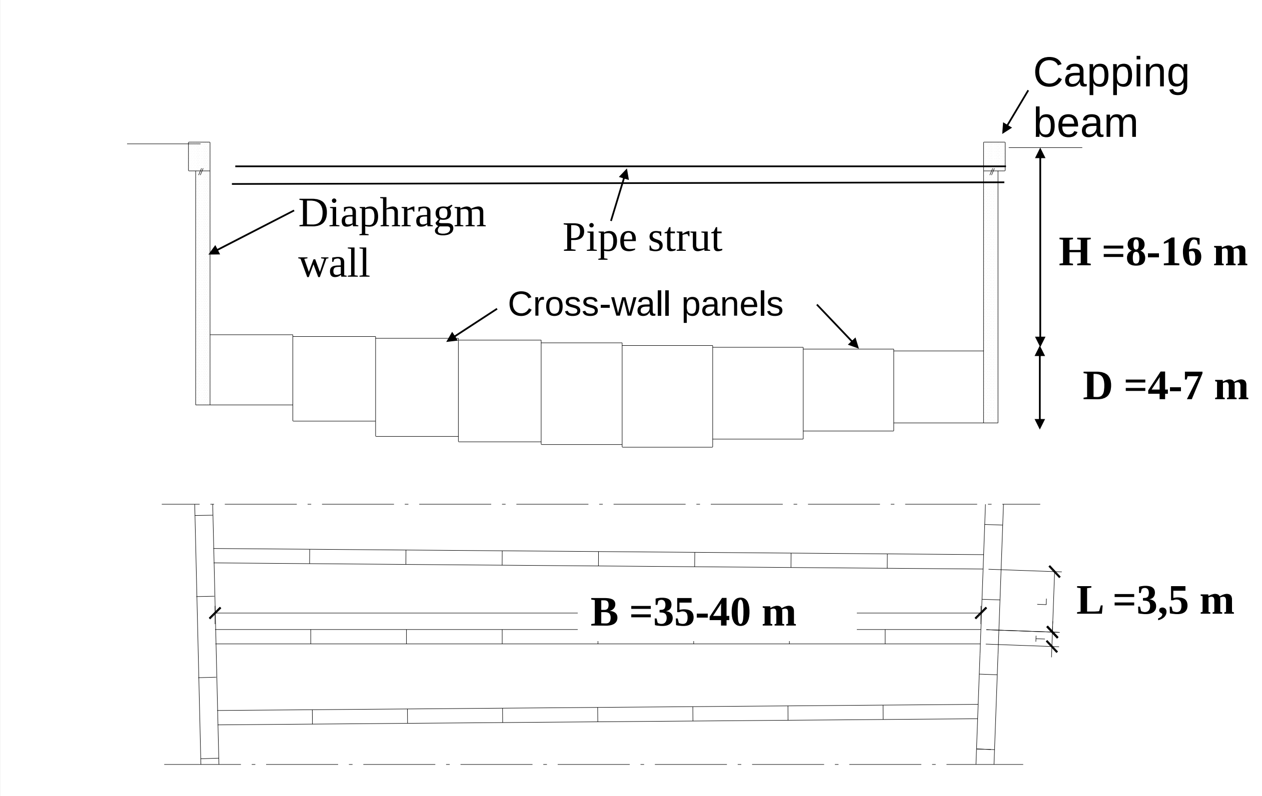
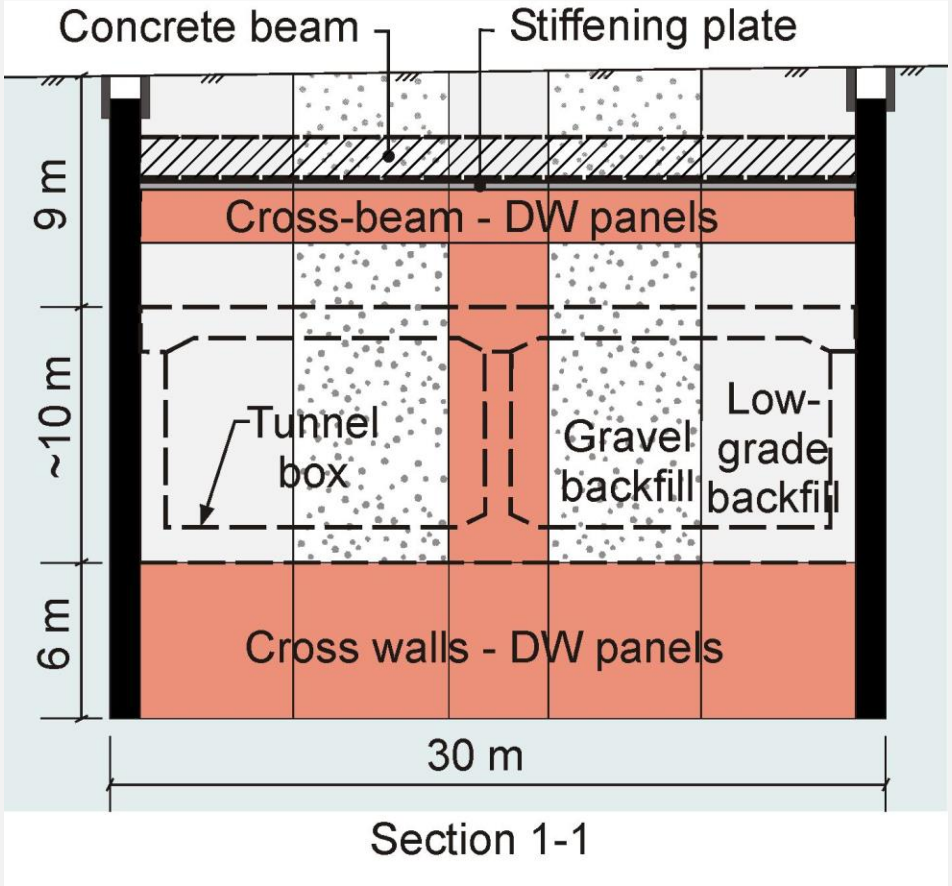
Later application of DWCP concept for road tunnel in Gothenburg (etter Karlsrud et al, 2005)



Application of DWCP concept for E18- accross Sørenga in Oslo (etter Karlsrud, 2007)



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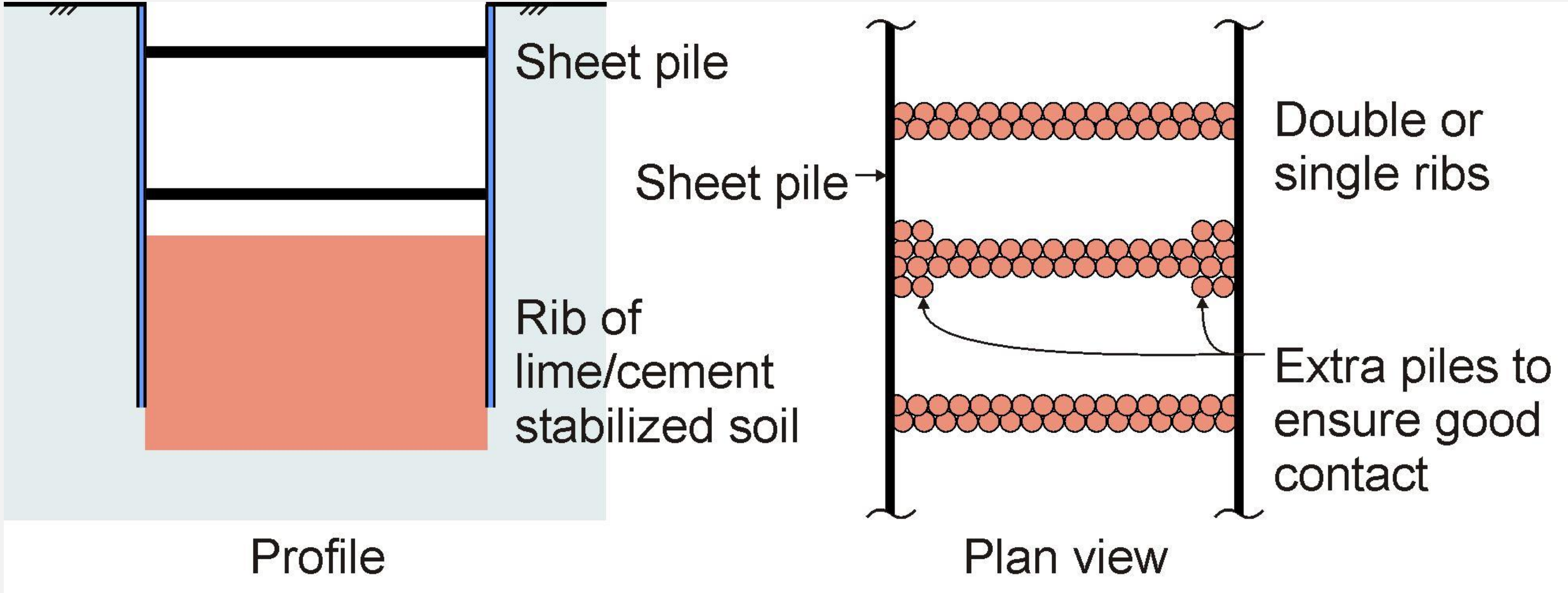
Main stabilising measures for soft clays

- Deep Dry Mixing method (DDM) with lime , cement + other binders
- Deep Wet Mixing method (DWM) with cement slurry
- Modified (MDDM) using dry binder + water
- Jet-grouting

Deep Dry Mixing (DDM) methods with Lime/Cement

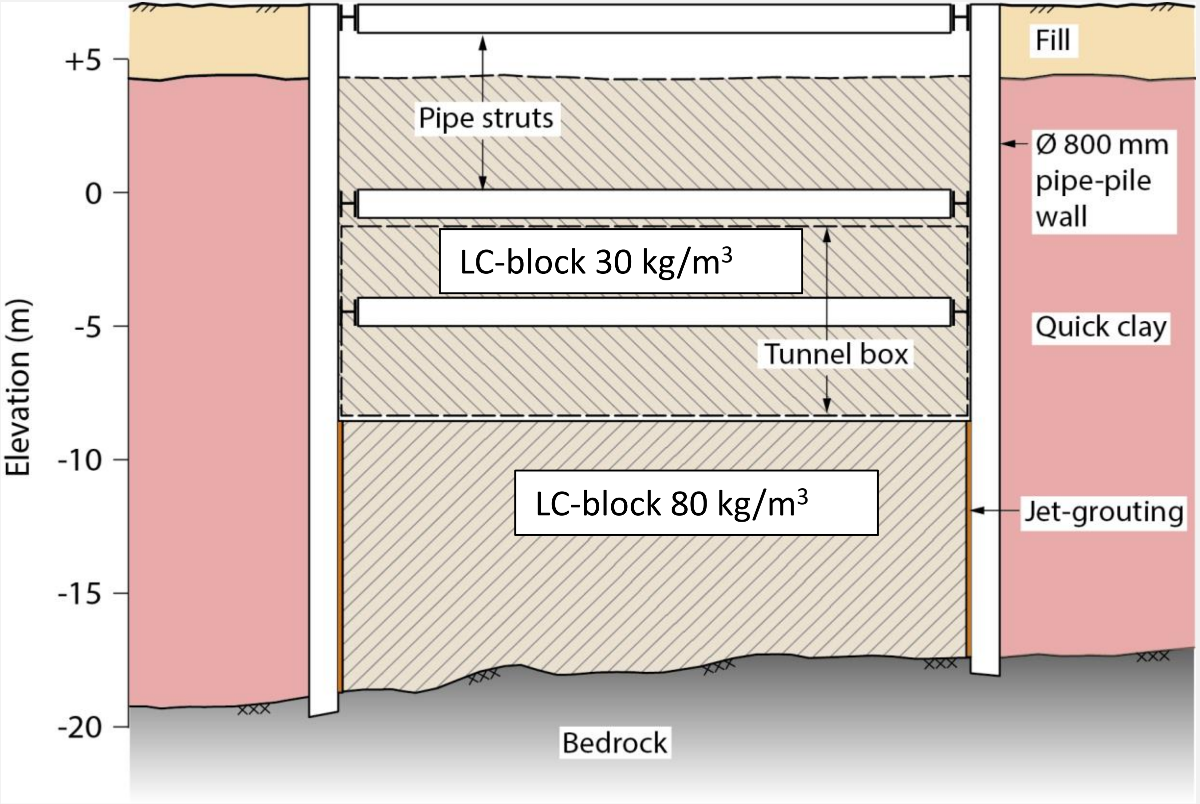
- Applicable only to soft clays
- Mixing head diameter 50 to 100 cm
- Achievable strength 150-500 kPa (Max 250 kPa used so far in design)
- Cost typically 350-400/m3
- Fast method!
- Getting through dense coarse soil can be a problem

DDM mixed panels have been extensively used in Norway for cuts and braced excavations since late 1970’s



Example of DDM mixed panel

Example of DDM block stabilized excavation for the Møllenberg tunnel in Trondheim 2012 (etter T. Haugen)



D&B contract by NCC Constr. for NPRA

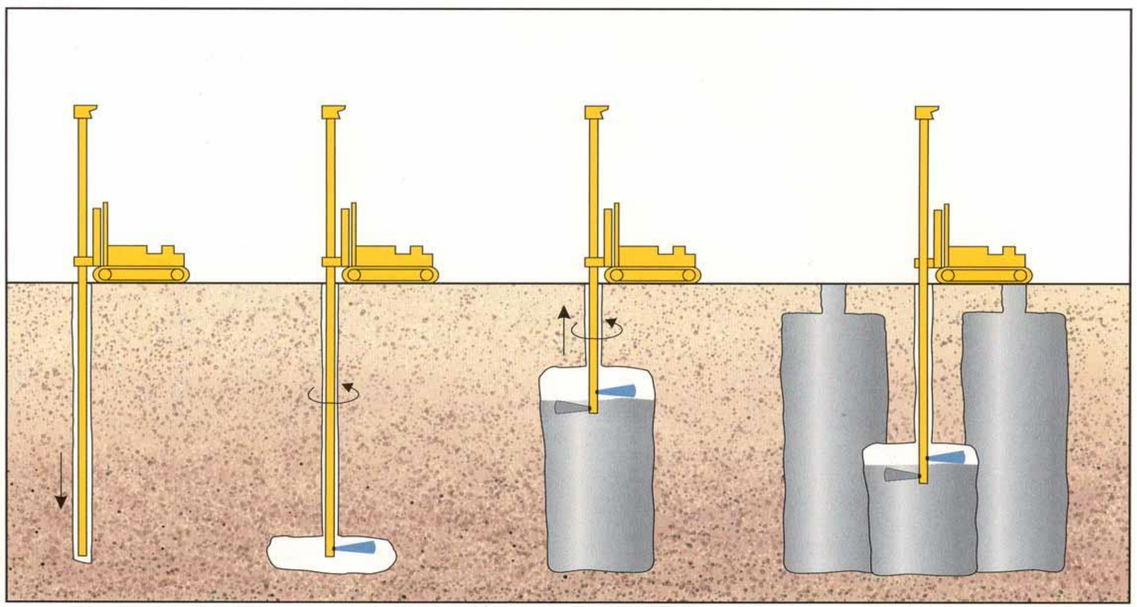
NGI

Deep Wet Mixing (DWM) with cement slurry has been more common outside Scandinavia

- Makes primarily use of cement slurry
- A multiple mixing head is commonly used, can make 4 m long panels at a time
- Applicable also to coarser grained soils (not only clay)
- Fast method
- Shear strength of 1-2 MPa may be reached
- Higher cost than DDM, but not known in Norway

NGI

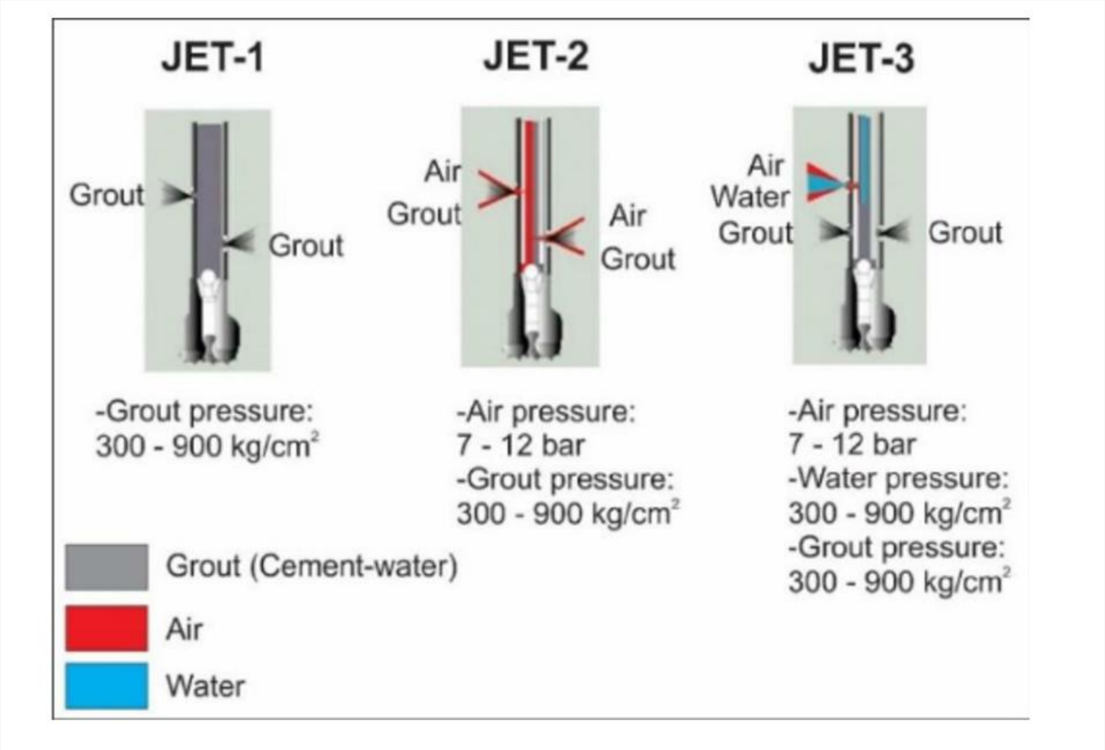
Jet-grouting principals



- Open drillstring with cutting shoe and jetting nozzle at the end
- Nozzle typically 20 cm above tip-allows good contact to bedrock
- Outer casing desireable to have good control of return spoil

Example of drill string with jetting nozzle (after Klemm)

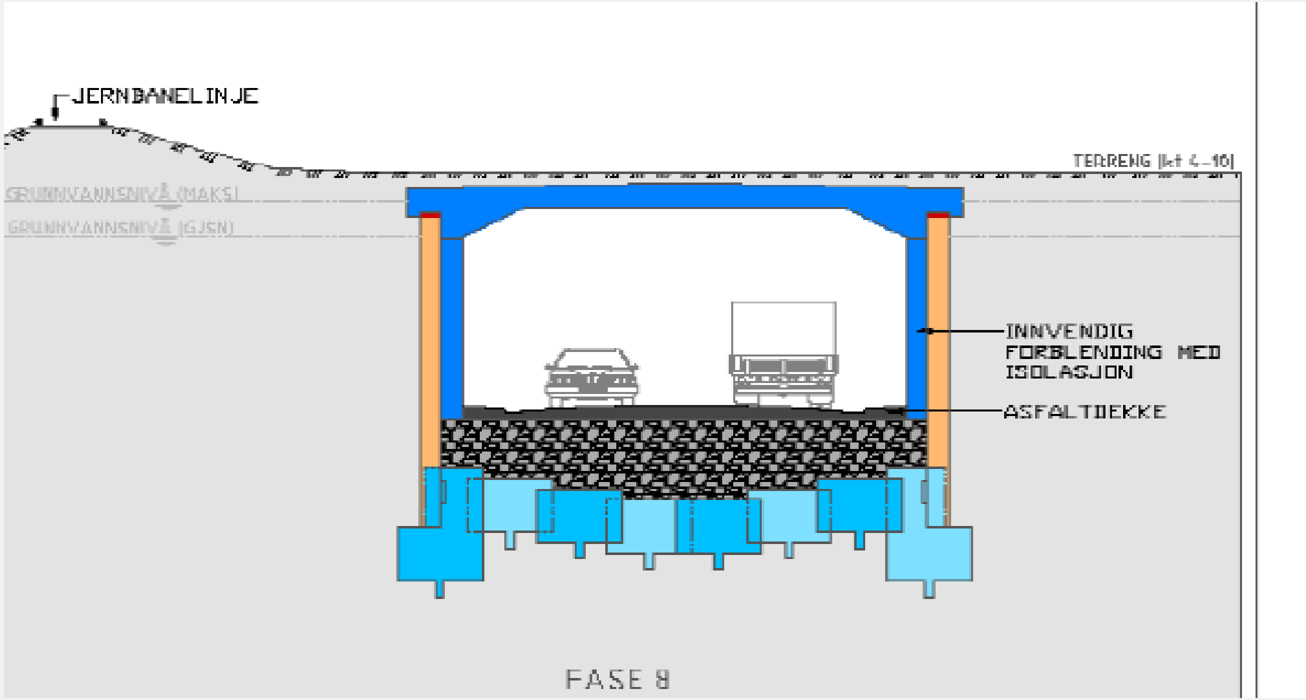
Different jetting principles in use



- Achievable strength 2 to 10 Mpa
- EC1 method developed by Jetgrunn can replace jetted soil with full grade concrete.
- Time consuming method
- Cost from about 1000-6000 kr/m3, depending on desired strength

NGI

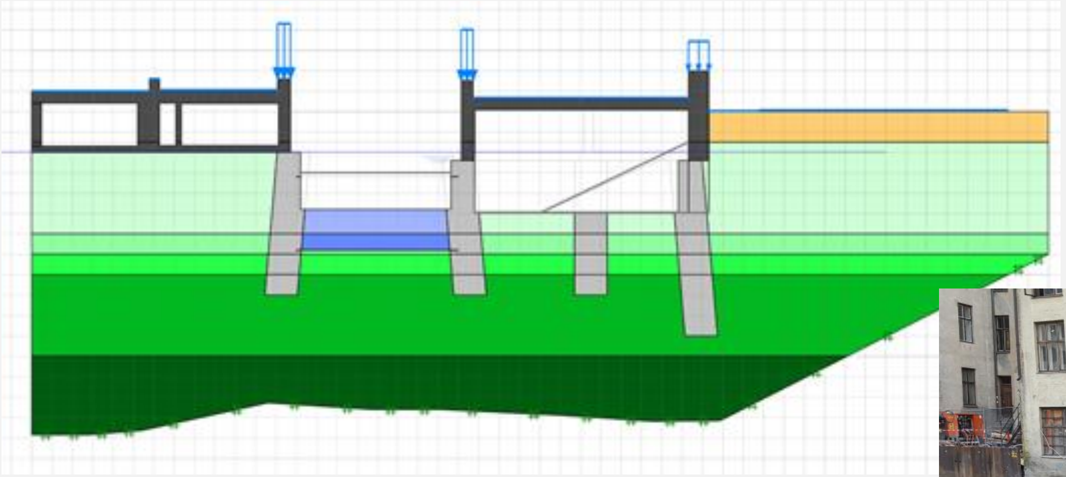
Successful example of jet-grouted bottom slab for the Hovenga tunnel in Porsgrunn (from Jetgrunn AS)



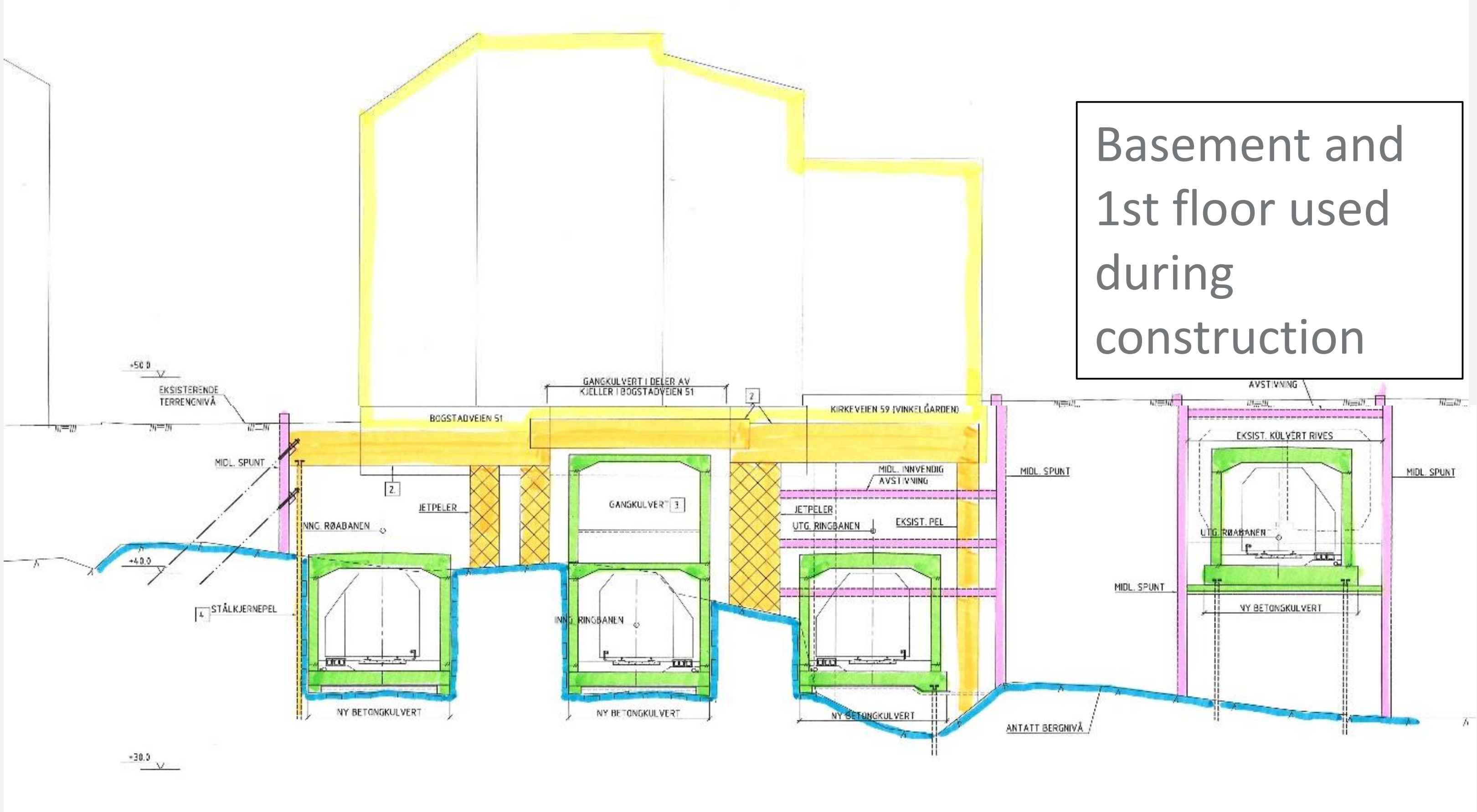
NGI

Example of jet-grouting used for deepening of basement and underpinning at Valkyrigaten 1-3 in Oslo

(Karlsrud et al, 2018)



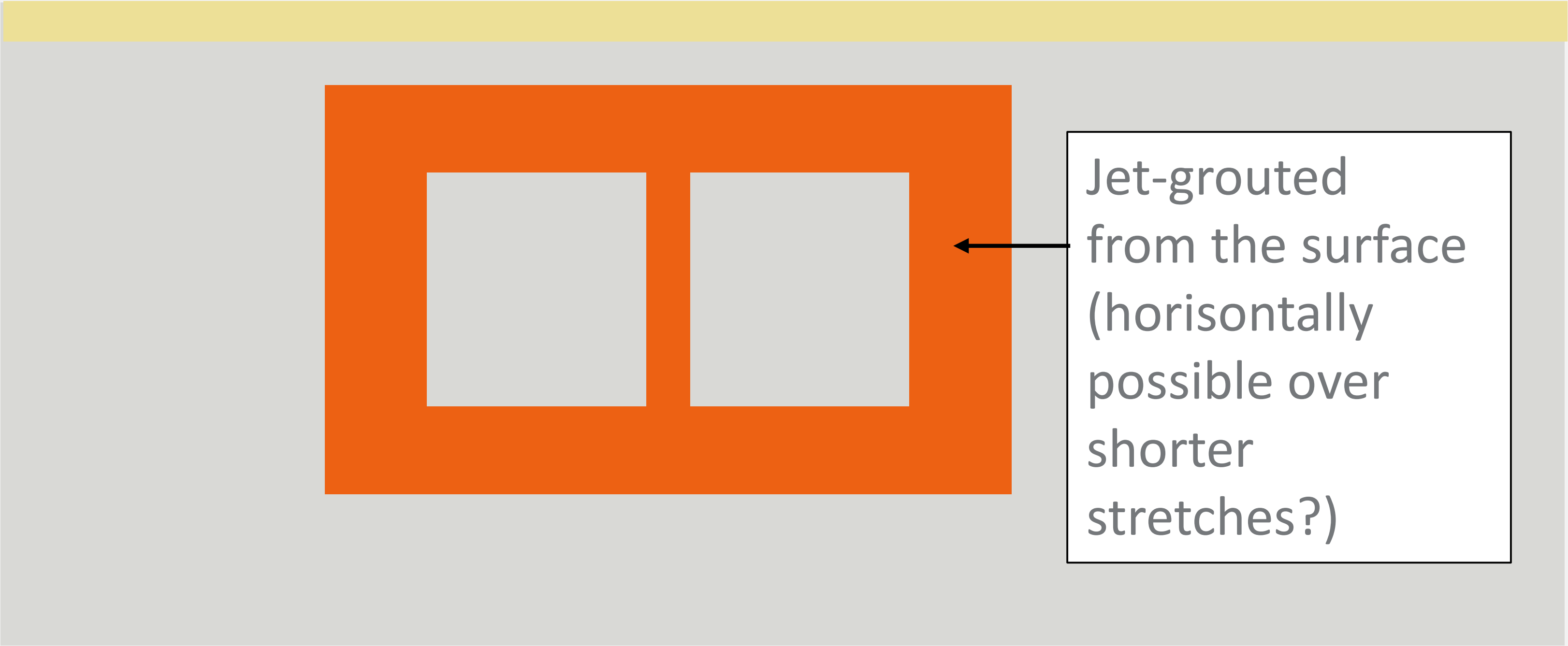
Making tunnels underneath existing buildings with little or no rock cover is complex and costly (AAJ/Vianova)



Basement and 1st floor used during construction

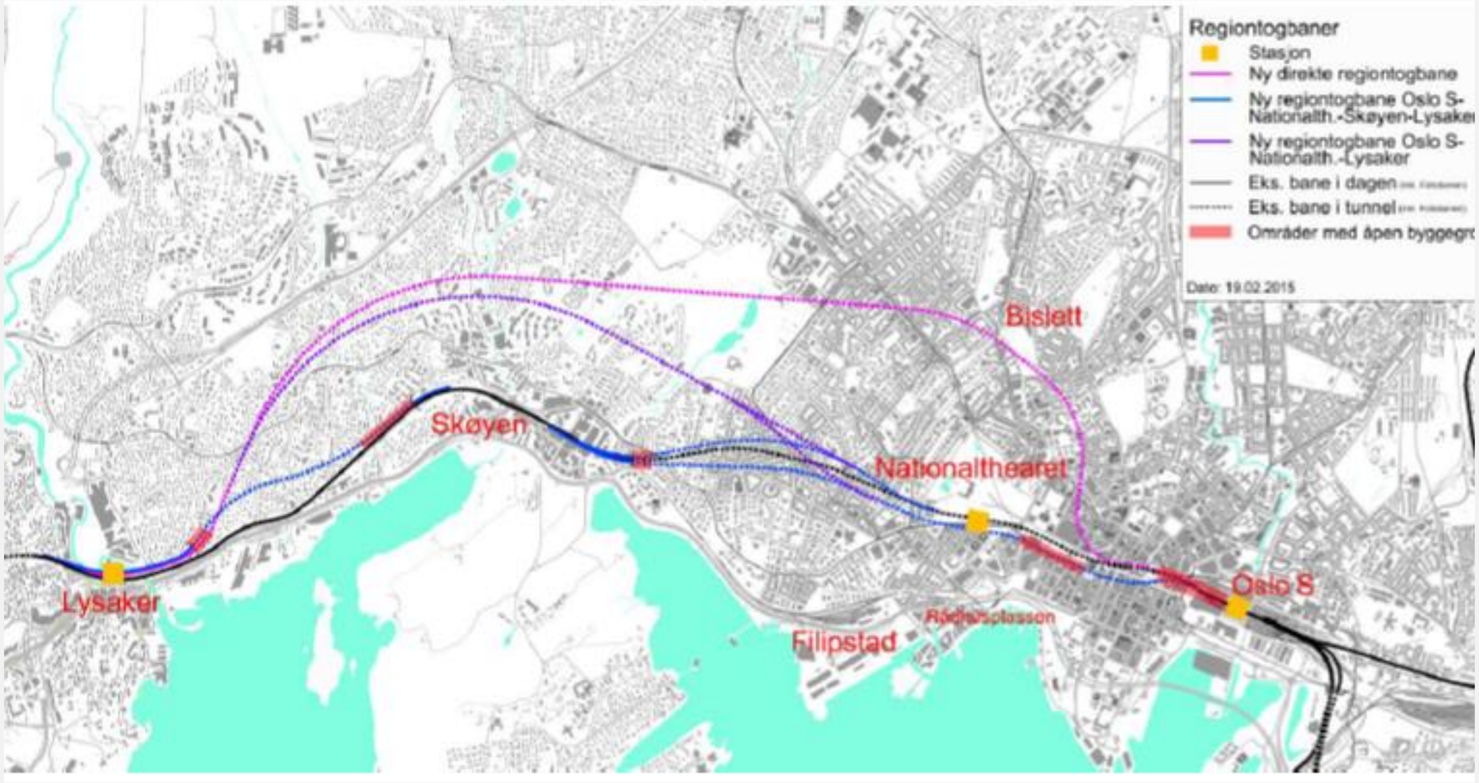
NGI

Use of jet-grouting combined with sectional excavation can make ordinary tunneling possible through soft clays



Oslo Navet-railway allignments considered

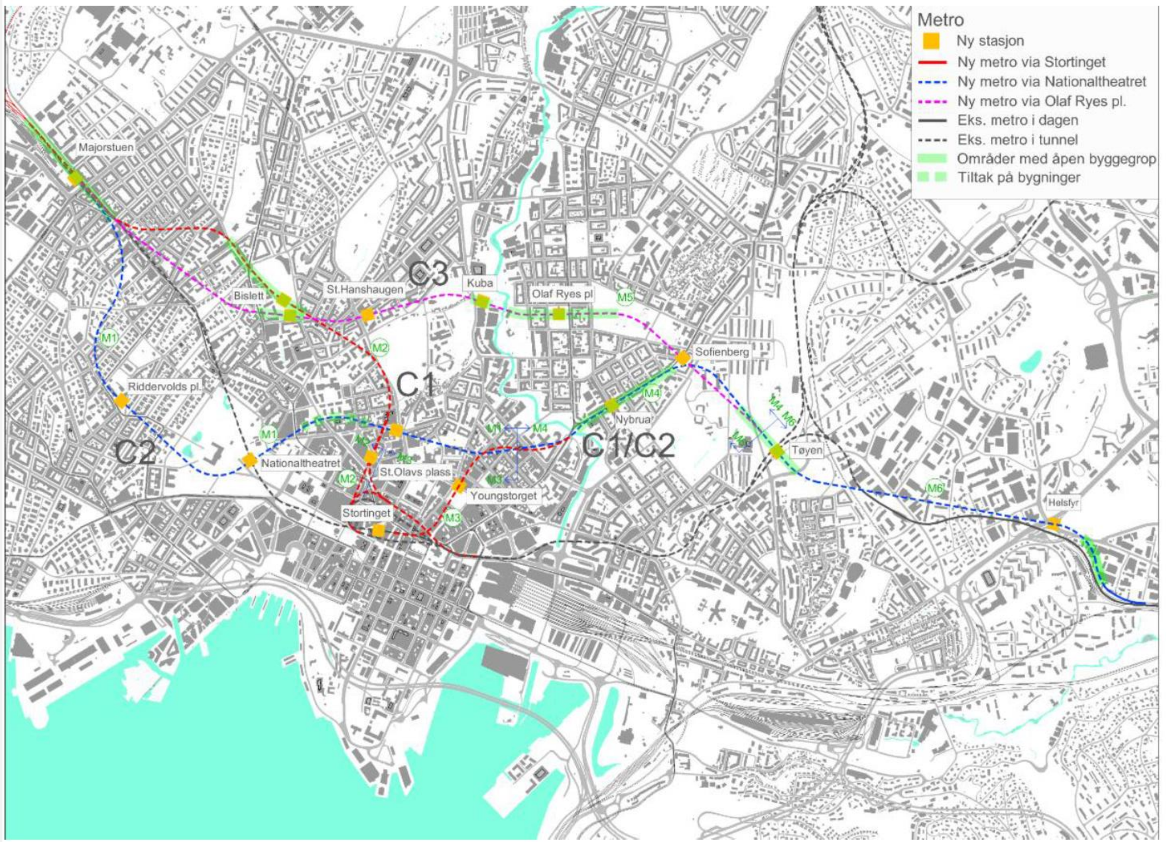
(AAJ/ Vianova/ Geovita, 2015)



NGI

Oslo Navet- Subway allignments considered

(AAJ/ Vianova/ Geovita, 2015)



NGI

Special challenges

- Crossing of clay-filled depressions
- Under existing buildings with little or no rock cover – needs for extensive work of re-transferring loads to new foundations and ground improvement by JG
- Making new tunnel very close to existing ones-space limitations!
- How to combine new and existing station areas

Anyone that seriously considers alternative tunneling methods must be aware of these challenges!

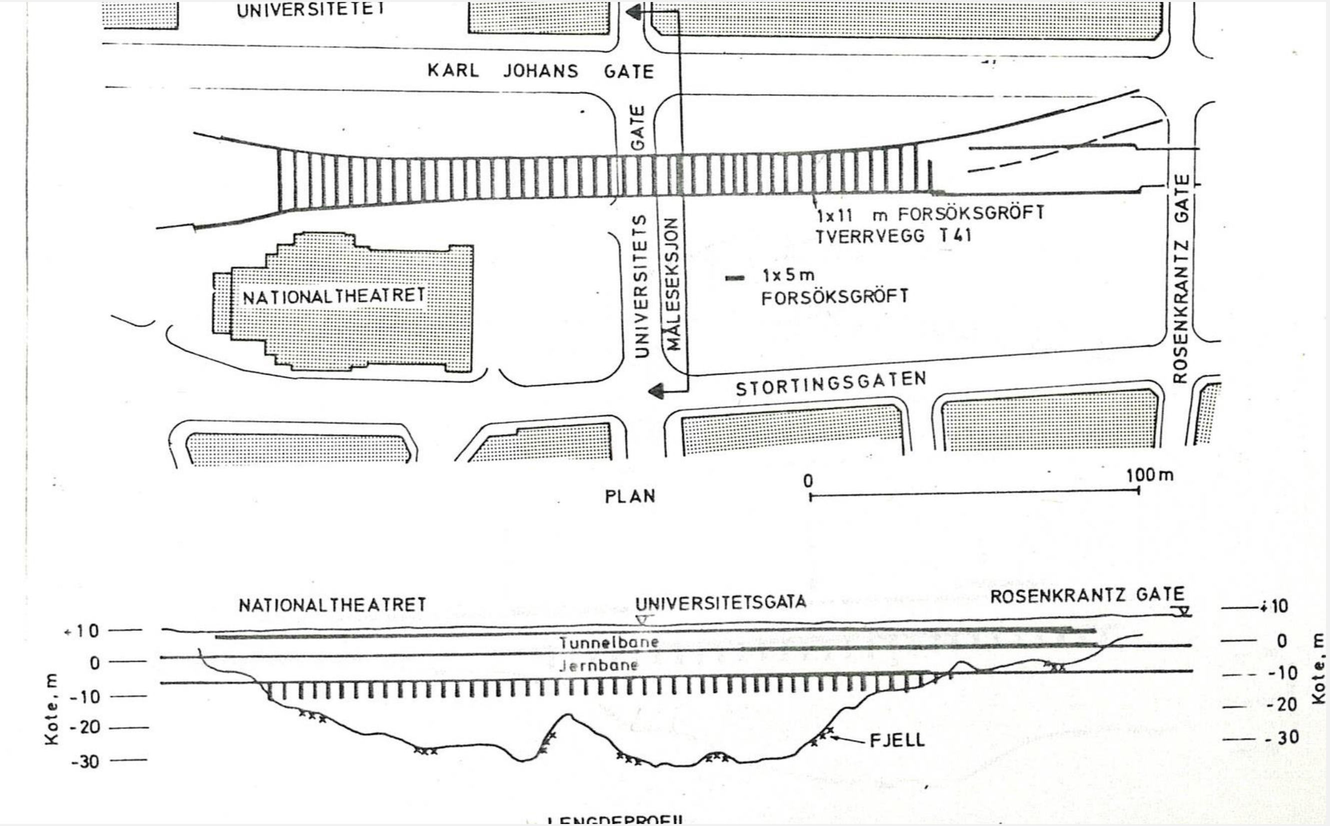
NGI

Comments from Trond Øiseth

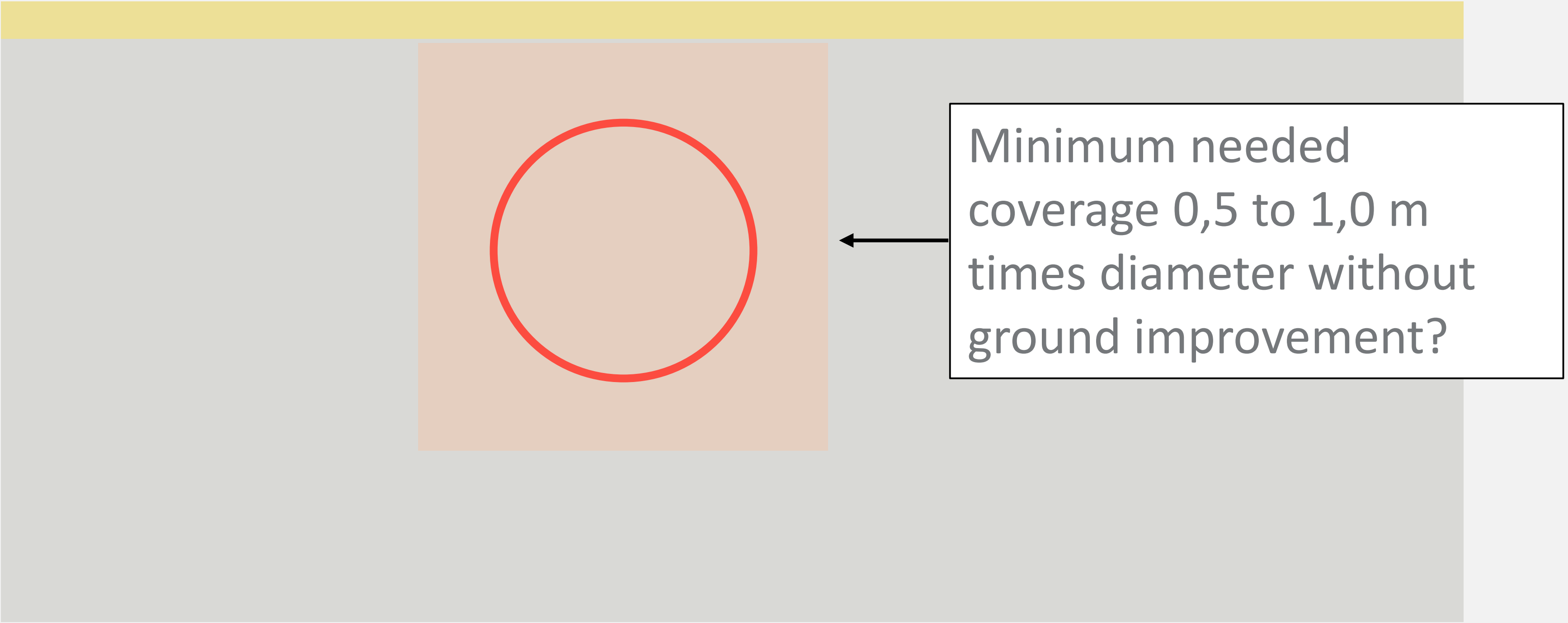
- Is it possible to avoid open cut excavations in most public sensitive areas, for instance along Stortingsgaten?

NGI

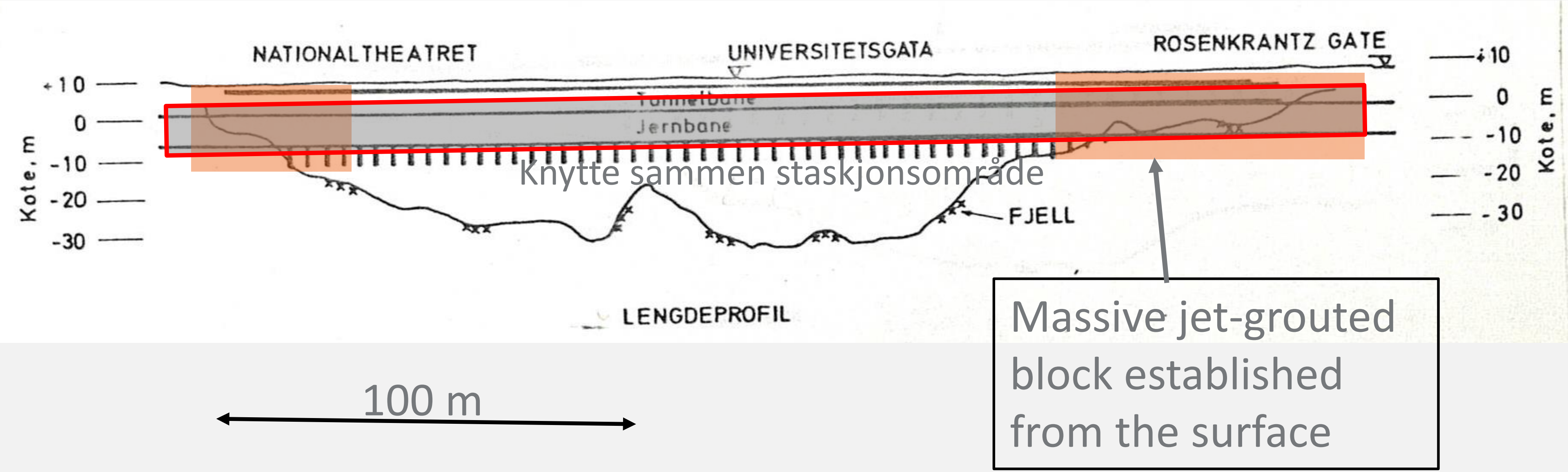
Profile along present tunnel N.teateret-Stortinget (NGI, 1973)



What coverage is needed for TBM tunneling through the Oslo soft clays?



Tunneling with EPB or SS shields may be possible if the transition zones clay/rock are treated with jet-grouting



NGI

Under Oslo 2019
Excavations in black shales

Practical measures to avoid reduced stand-up time and negative environmental impacts

Erik Endre

Structor Geomiljø AS

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Functional prerequisites

- No drained solution
- Keep water table intact
- No allowance for swelling pressure – remember this is a chemical system that has to be controlled (that means control over chemical and physical conditons).
- When no mobile water is present, there will be no environmental issue for the surrondings

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What is Shale

- A fine-grained sedimentary rock that forms from the compaction of silt and clay-size mineral particles that we commonly call "mud."
- This composition places shale in a category of sedimentary rocks known as "mudstones."
- Shale is distinguished from other mudstones because it is fissile and laminated.
- "Laminated" means that the rock is made up of many thin layers.
- "Fissile" means that the rock readily splits into thin pieces along the laminations.

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Rock mechanical classification of black shales

No clear preference on which rock mass classification system to describe black shales.

LONG-TERM PERFORMANCE OF THE ROCK

The second part of a classification system for weak rock involves evaluating the long-term performance of the ground in a tunnel. Some weak rocks will deteriorate, swell, or continue to deform (squeeze) after exposure in the tunnel environment. Most of the rocks that exhibit these behaviors have a high clay mineral content such as

Table 3. Rock mass condition based on discontinuity spacing (after Bieniawski, 1984)

Description	Discontinuity Spacing	Rock Mass Condition
Very Wide	> 2 m	Solid
Wide	0.6 to 2 m	Massive
Moderately Close	0.2 to 0.6 m	Blocky/Seamy
Close	60 to 200 mm	Fractured
Very Close	< 60 mm	Crushed/Shattered

Steve Klein, Jacobs Associates: An approach to the classification of weak rock for tunnel projects

Structor

Rock mechanical characteristics changes with time

Main reasons

- Sulfide content
- Degree of fissile/laminated structure
- Degree of clay mineral content
- Degree of contact metamorphism (heating and chemical and structural changes due to heating and exchange of elements)
- Degree of water/moisture triggering chemical and physical changes

Material characteristics black, grey and calcareous shales

Concequences for design and solutions

- Depositional environment – degree of anoxic or oxygen deficient environment
- Material sources
  - Sea water
  - Land based eroded and river transported material
  - Air transported material
  - Extra terrestric material
- Geological history
  - Caledonian orogeny
  - Permian rifting
  - Erosion of land surfaces
  - P, T path (pressure and temperature in geological context)

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Black shale must be considered as a chemical system

- Black shales contains <u>sulfides</u>
- Mainly two sulfides causes problems
  - Pyrite – di-sulfide FeS_2
  - Pyrrhotite (Magnetkis) – mono-sulfide $Fe_{(1-x)}S$
- <u>Fissile texture</u> prerequisite for accelerated weathering contact area between sulfide grains, moisture/water and oxygen
- Each shale horizon has different chemical and mechanical characteristics
- Each shale horizon has different weathering characteristics
- Grey shales may develop swelling pressure given the «right» physical and chemical conditions

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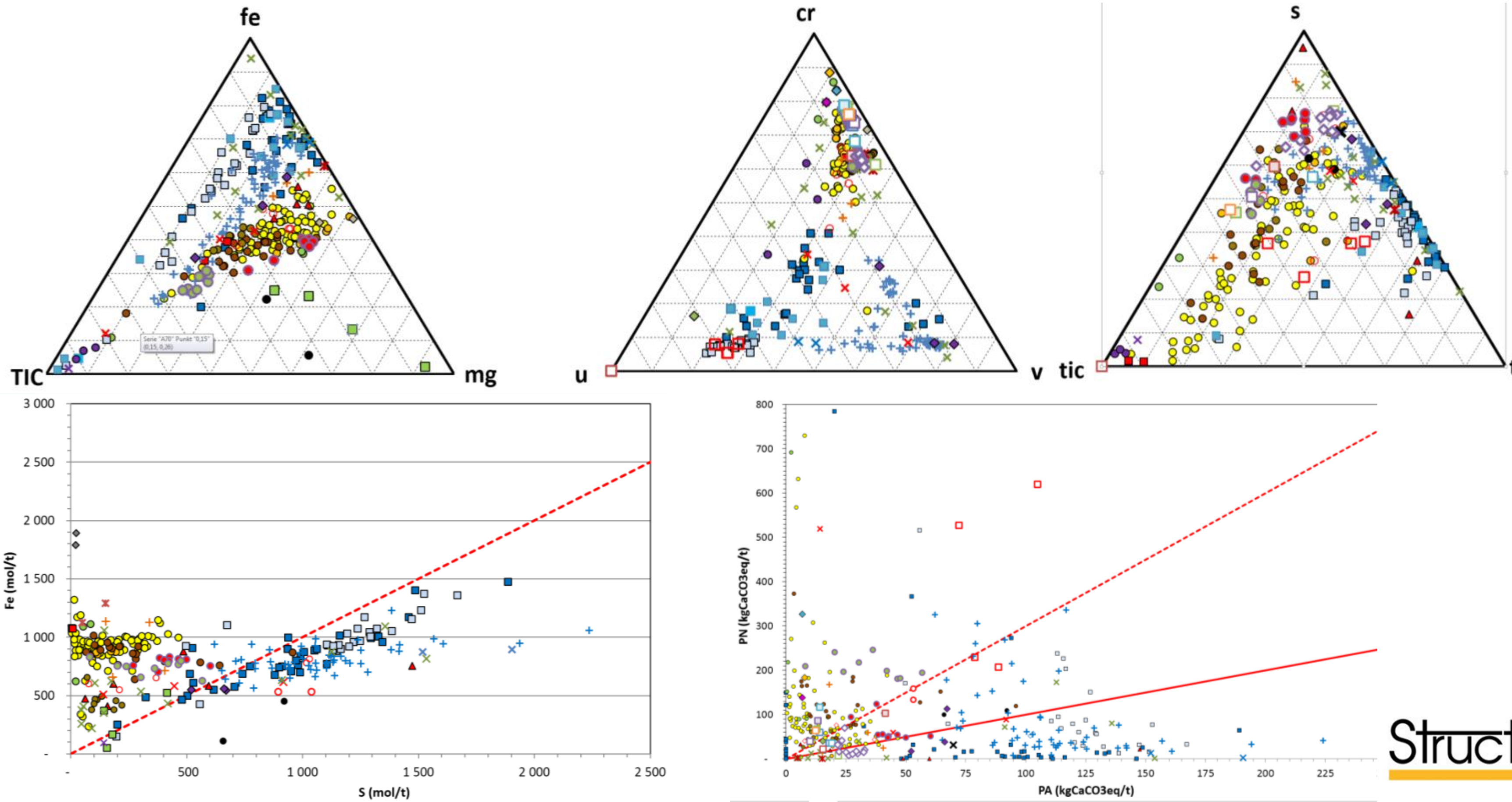
Chemical fingerprint – identification of shale horizons to foresee conditons for tunneling and excavations



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Etasje	Oslo-Asker Formasjon	Oslo-Asker Ledd	Hadeland Formasjon	Hamar Formasjon	NGU inndeling på kart	Mektighet (m)	Alder	
4d					Oslo		Sen Ordovicisk	471-443 mill. år
4cα	Venstøp		Lunner*		Oslo	Oslo 7-10m Lunner fm <185m		
4bδ	Solvang				Oslo	12-20	Midt Ordovicisk	
4bγ	Nakkholmen				Oslo	13-20		
4bβ	Frognerkilen				Oslo	10-20		
4bα	Arnestad		Arnestad/ Furuberget	Arnestad/ Furuberget	Oslo	22-40		
4aβ	Vollen			Vollen/ Hovinsholm	Oslo	> 45		
4aα	Elnes	Håkavik Engervik Sjøstrand Helskjer	Elnes	Elnes/Bjørge	Oslo	60-80		
3cγ	Huk	Svartodden	Huk3	Svartodden Herran/Stein	Røyken	2-5 m	Tidlig Ordovicisk	488-471 mill. år
3cβ		Lysaker	Huk2		Røyken	2-5 m		
3cα		Hukodden	Huk1		Røyken	2-5 m		
3bβ	**Tøyen**	**Galgeberg**	**Galgeberg**	**Galgeberg**	Røyken	5-10 m		
3bα		Hagaberg	Hagaberg	Hagaberg	Røyken	3-8 m		
3aγ	Bjørkås-holmen		Bjørkås-holmen	Bjørkås-holmen	Røyken	1-2 m		
3aα, 3aβ	**Alunskifer-3**		**Alunskifer-3**	**Alunskifer-3**	Røyken	~80 m men stor variasjon		
2a-2e	**Alunskifer-2**		**Alunskifer-2**	**Alunskifer-2**	Røyken		Sen kambrium	501-488
1	Alunskifer-1		Alunskifer-1	Alunskifer-1	Røyken		Midt kambrium	513-501
	-		-	**Biri Brøttum**	Biri Brøttum	1500 m	Eokambrium	<542

The Cambro-Silurian succession og black, grey and calcareous shales under Oslo

This succession is vital information

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Excavations – what should be avoided

- Reduced life-time
- Negative environmental impacts
- Unnecessary construction costs
- Unnecessary maintainance costs
- Potential unwanted consequences for third part

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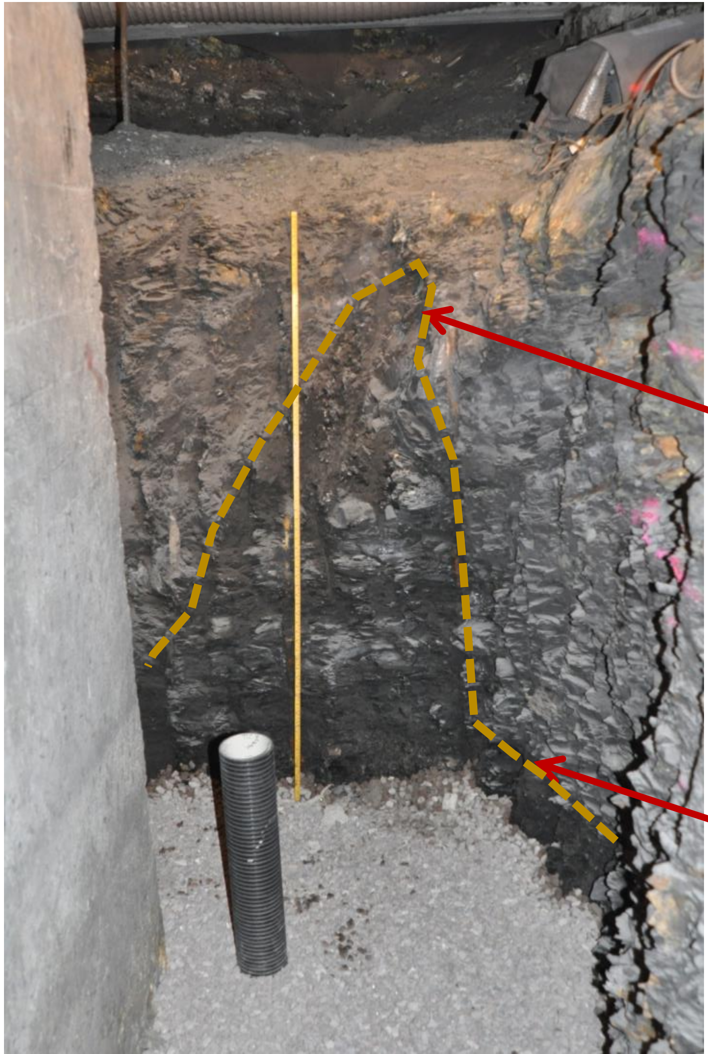
Water-Source of information and the bad guy

- All unwanted chemical and physical reactions are triggered in the presence of water/moisture
- All new minerals and reaction products contain water molecules in their formula
- Water chemical analysis is a fingerprint of the water-rock interaction



How watertight is alumshale?

Groundwater profile in height leap, central Oslo
Ground water level follows layering in the shale, which here is folded
Possible capillary forces

Groundwater seepage.
Drilled hole is filled with water whithin days.

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Simple chemical logic

A + B → C + D drained solution

~~A~~ + B ~~→~~ C + D undrained solution

A + ~~B~~ ~~→~~ C + D undrained solution

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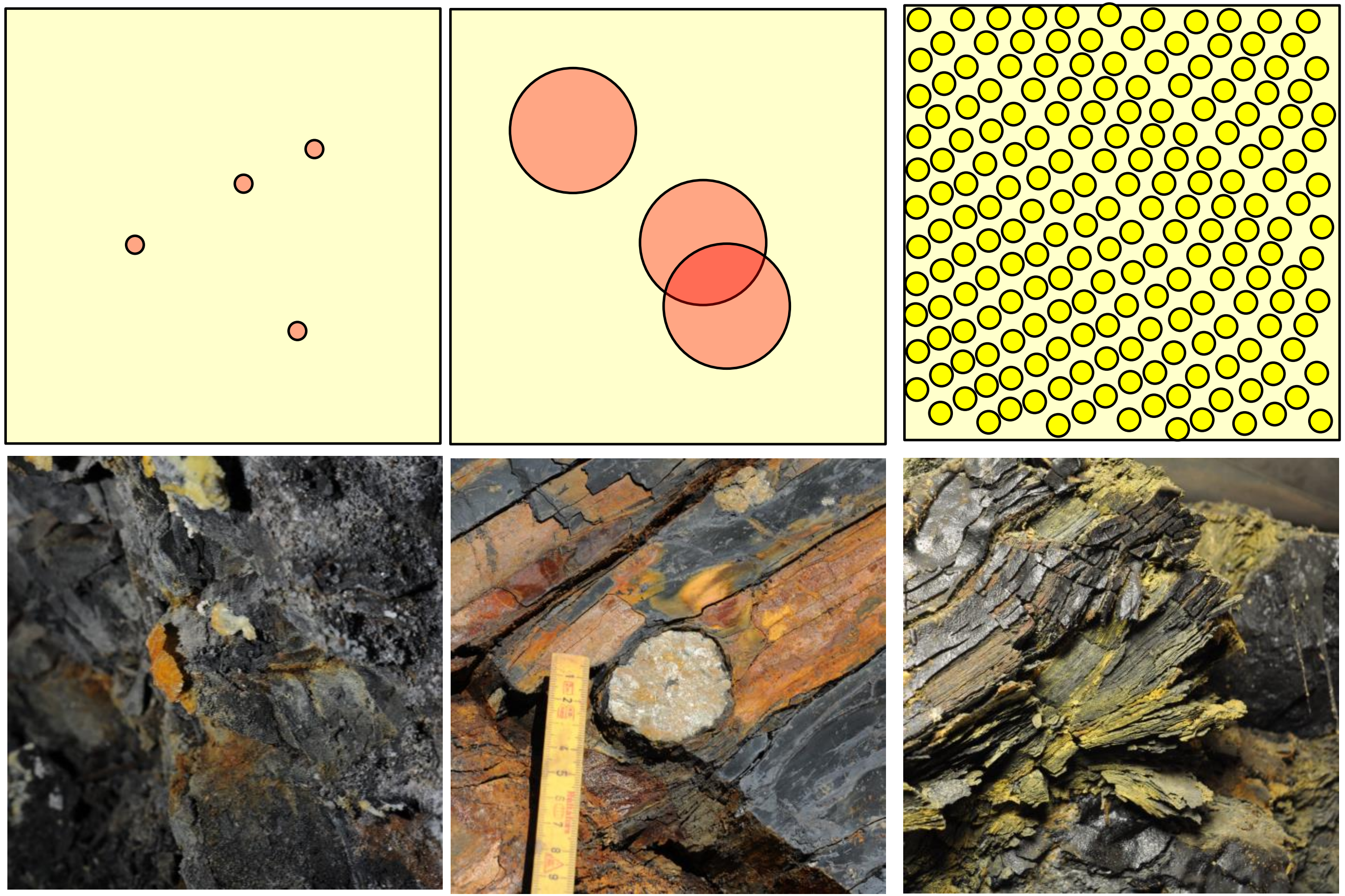
Fissile texture – surface area + size sulfide grains



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Galgeberg unit (3bβ) in the Tøyen formation (3b). This black shale does not exhibit the same degree of lamination and fissile characteristics as in the alum shale (level 2). At Galgeberg the sufide grains/aggregates are encapsulated in baryte. The surface area accessible between sulfides and oxygen/moisture is consequently much lesser. Lower AP/NP potential Mechanical characteristics differs form alum shale. Joint characteristics are also different and clay mineral/mica content is lower

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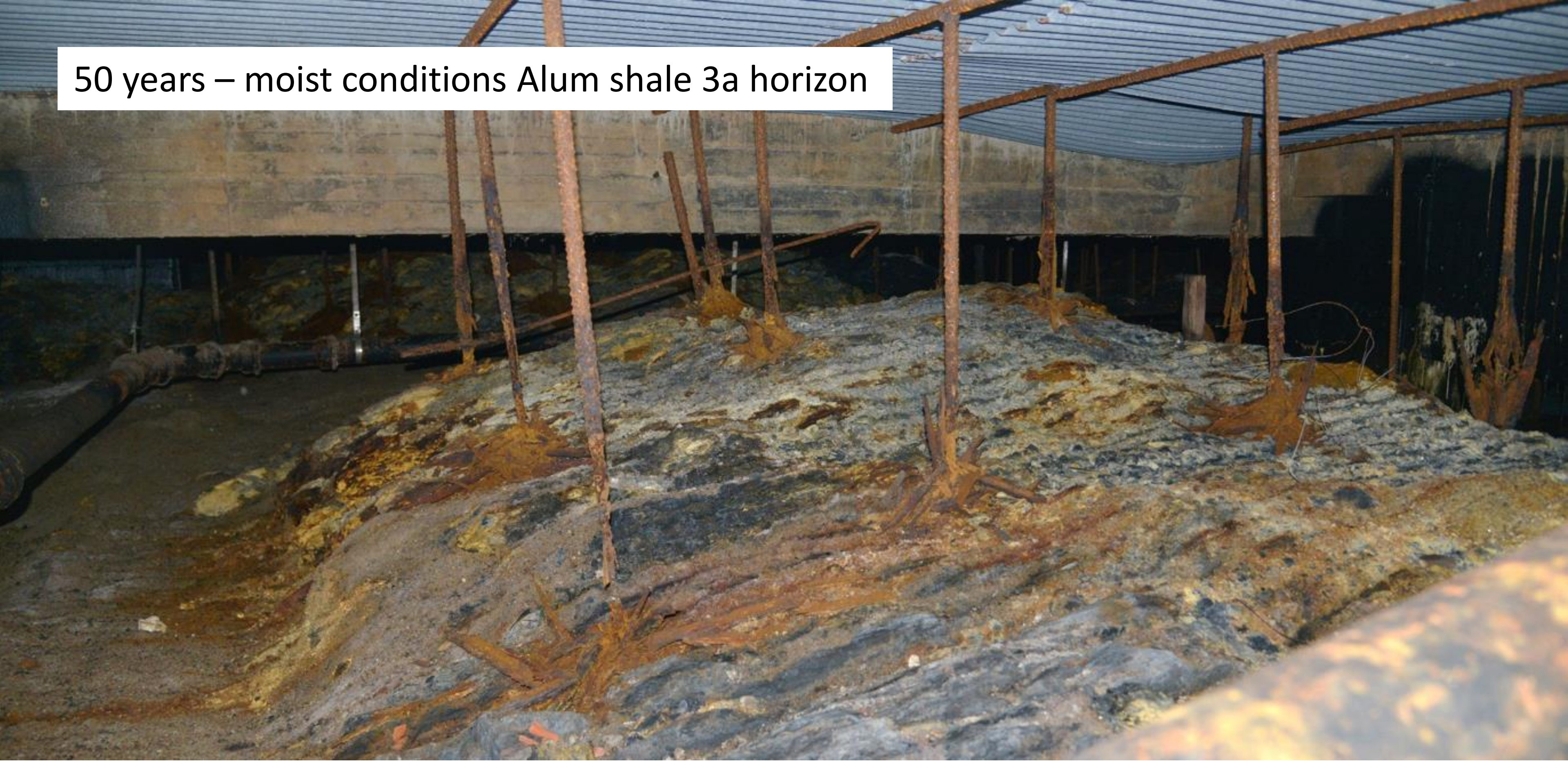
50 years – moist conditions Alum shale 3a horizon



Pouring the first concrete layer as the first step in a sandwich construction

Alum shale surface impregnated with NaOH/KOH emusion
before covering with concrete, membrane and a new layer concrete to make up the basement floor

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Pressure loss measurement

- Lugeon is not so well suited
- Better to measure the water pressure curve
- Measurement levels must be adapted to rock characteristics
- Three orders of cracks/joints
  - Larger cracks joints vertical /sub vertical associated Permian (formation of the Oslo rift) and cracked permian rocks
  - Lesser thinner sub-horisotal cracks associated with Caledonian mountain chain formation and horizontal compression
  - Thin microcracks in the whole shale body

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Grouting

- Main topic:
  - stop water movement in the surrounding ground
  - Avoid ground water table lowering
  - Avoid unwanted water chemistry pumped out in the surroundings or sewage system

  Permian vertical faults

  Permian intrusive dikes or larger bodies

  Caledonian sub horisontal shearzones

  Micro-cracks

Grouting Bingham liquids

- Flow characteristics
- Grouting pressure should not be too high and grout inflow should not be maximized
  - Different approaches
  - Grouting strategy (philosophy)
- Topic also dealt with in earlier presentation /Grøv

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Grouting –particle free liquids («Newtonian»)

Epoxy
- Mechanical strength
- Dry og moist
- Viskosity
- Working time < ca 40 min
- Might heat up in pump
- Organic

Polyurethane
- Grouting
- Expands in water contact
- Cell structure? Water uptake?
- Soft
- Organic

Colloidal silika
- Viskosity like water
- Very low strength
- Working time flexible
- Inorganic
- Should be injected at least 1 meter in fromsurcace

Na-silicate
- Time before reaction…
- pH oppetid
- Mechanical strength
- In-organic

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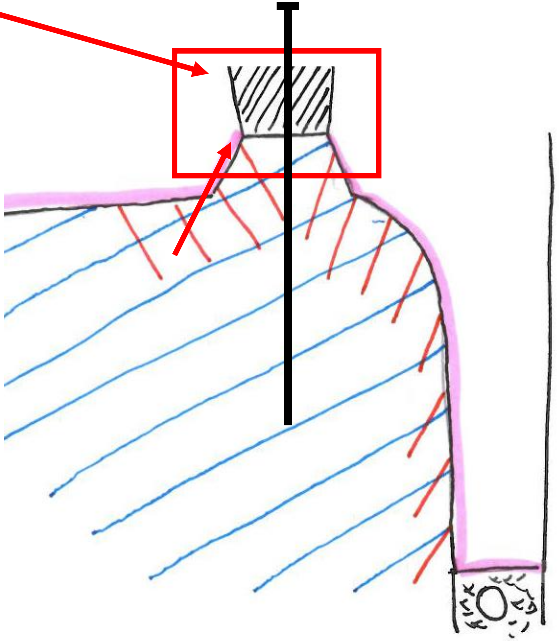
Grouting examples

- G5-7 Colloidal silika
- KJ14 Epoksy

Reduce amount of open cracks (lamination - fissile development) in alum shale under point load foundation close to height lep (not ideal geometry)



Red lines shows 12 mm, 70 cm lengths iron bars mounted in a cross pattern 25 x 25 cm To strenghten the alum shale body

- Foundation reinforcement with epoxy injected into cracks in the alum shale
- Epoxy seals surfaces prone to fissile development and glues the shale to make the volume stronger
- 12 liter epoxy in average per injection point

Epoxy is injected with moderate pressures, documenting lots of open cracks

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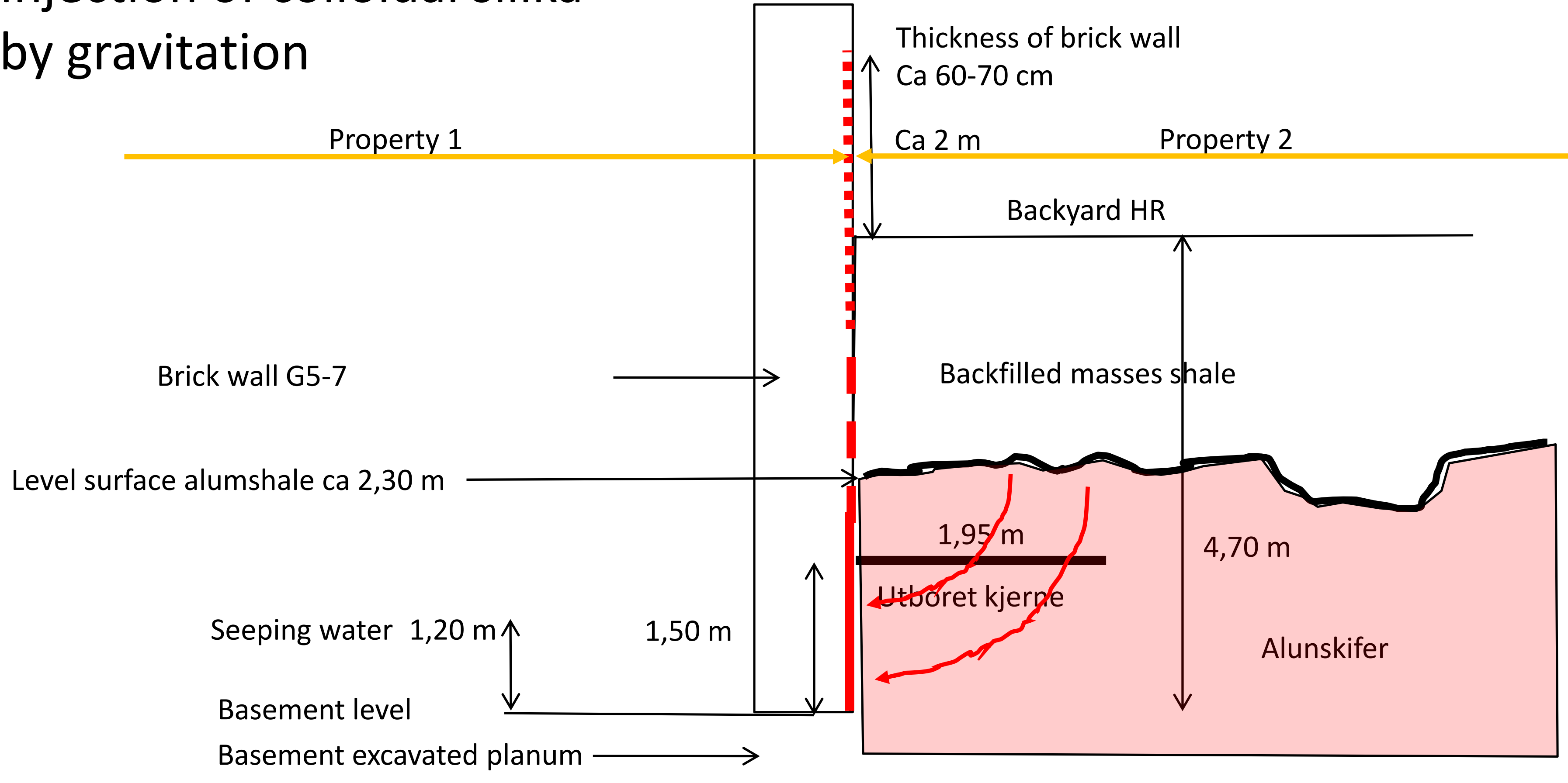
Injection of colloidal silika by gravitation



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Backfilling with alum shale masses.....

Not in my backyard.....

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Chemical grout – colloidal silika, viscosity like water.
Long reaction time (> 12 hours) to secure optimal infiltration along the waterway.
Gravity driven infiltration of colloidal silika

EER_4725 2013-07-04

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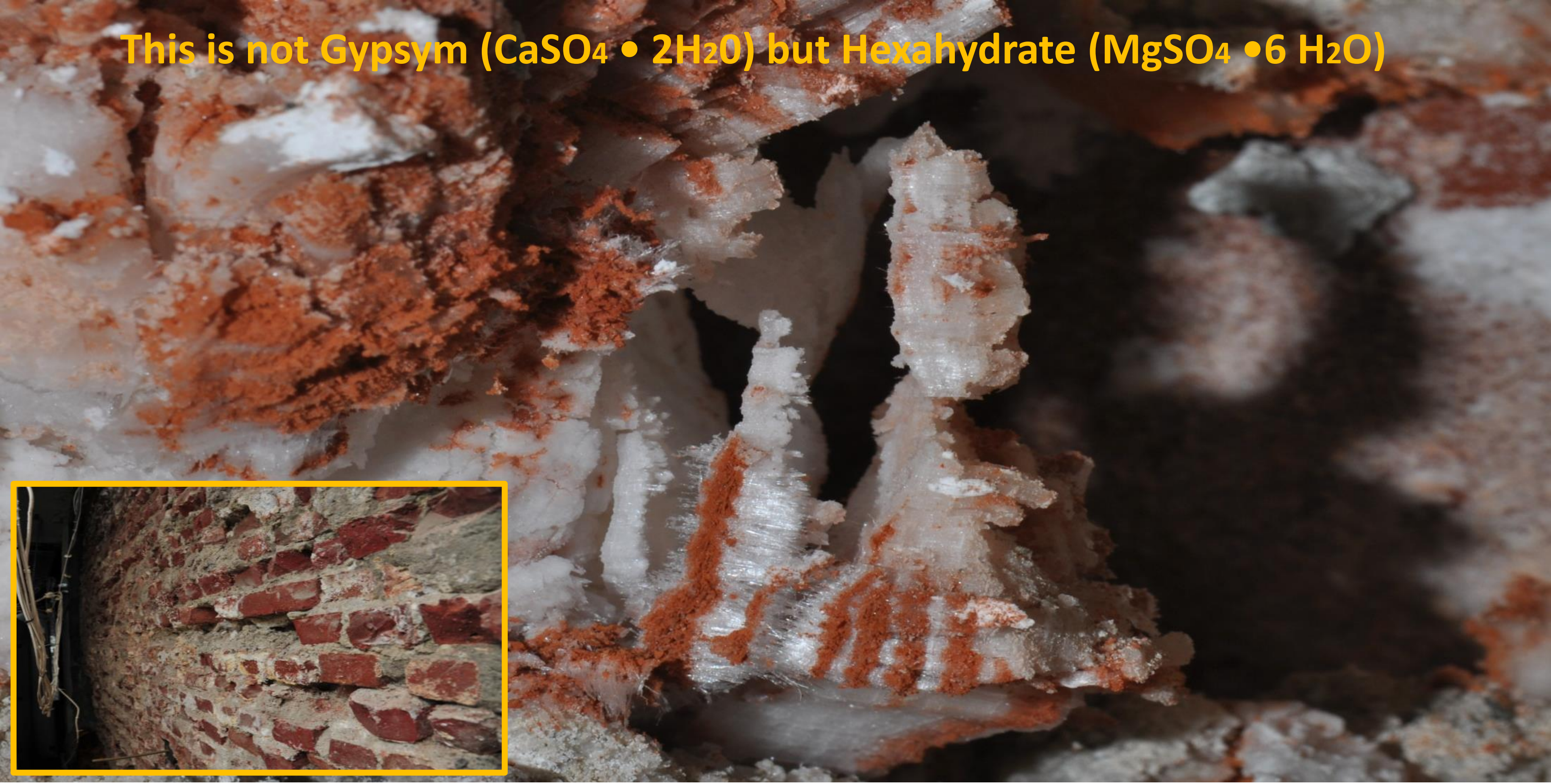
This is not Gypsym ($CaSO_4 \cdot 2H_2O$) but Hexahydrate ($MgSO_4 \cdot 6\ H_2O$)



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Water chemistry erroneously mistaken for calcareous water

ELEMENT	SAMPLE	G5-7 Sigevann
Dekantering		JA
Ca	mg/l	475
Fe	mg/l	2810
K	mg/l	<20
Mg	mg/l	1200
Na	mg/l	61,3
Al	µg/l	1110000
As	µg/l	1470
Ba	µg/l	<50
Cd	µg/l	828
Co	µg/l	6470
Cr	µg/l	1470
Cu	µg/l	17600
Hg	µg/l	<0.02
Mn	µg/l	32600
Ni	µg/l	43600
Pb	µg/l	<30
Zn	µg/l	30800
U	µg/l	25200
DOC	mg/l	2,24
Alkalinitet	mmol/l	<0.150
Klorid (Cl-)	mg/l	58,8
Sulfat (SO4)	mg/l	19,1
Bikarbonat (H	mg/l	0
pH		2,62
Ledningsevne	mS/m	1210
Nitrat (NO3)	mg/l	<0.38

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Ground water sump dried out!!
No further seepage of water
coming from the neighbour

Sealing with sprayable membranes - Three ”main” types

EVA (Ethyl-vinyl-acetate based)	Bitumen-polymer-water-based	Polyurethane
Makes «monolithic binding with shotcrete/Cement	High flexibility	Good adhesion
Large scale or small scale execution	Low adhesion	Strong
Flexible execution	Low water pressure capacity	Low friction surface
Needs time to achieve strength	Quick execution	Sprayed or paint with brush
Both horisontal and vertical surfaces	Mostly horisontal surfaces	
Needs protection layer	Needs protection layer	

All three are easy to repair

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Water table – water pressure behind membrane or under membrane

Sandwich EVA membrane:

1. **Shotcrete with large PP-fibres (it is better with steel fibre)**
2. **Smoothening surface with fiber free shotcrete**
3. **Membrane**
4. **Shotcrete without fiber for membrane protection and to better withstand water pressure behind the membrane.**

It is critical to as quickly as possible achieve sufficient strength on the membrane for finishing thesandwich construction

- Membrane should harden for at least one week
- Build up of water pressure behind membrane
- Protection cover (sprayed concrete) over membrane
- Water/moisture will cuase the mebrane to swell and lose strength before it is hardened

KJ14 – sandwich

- Cast concrete construction – sandwich
- Water tight basement construction under ground water table
- **No drained solution**

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Large scale performance of EVA based membrane

Shotcrete surface must be smoothend. The surface in the picture is too coarse

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Too thick layers will cause cracking

Flexible solution EVA based membrane in sandwich construction

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EVA based membrane

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Polurethane based membrane

- Strong
- Good adhesion to underlying material
- Surface is smooth, easy to clean
- Hardens rather quickly
- Sprayed or brush/roll
- Small and large scale

Polyurethane sealing directly on alum shale surface. Spraying must be executed by trained personell. Painting may be executed by non-trained personell. In this case it was decided not to use a shotcrete cover on the alum shale surface before spraying the membrane. It was expected that further rehabilitation/refurbishing was expected in approx ten-fifteen years time

Polyurethane surface is non-sticky and easy to wipe over and clean

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Polyurethane paint in ceiling may also be used for sealing alum shale
Epoxy paint has almost the same characteristics as polyurethane based paint

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Asphalt-bitumen water based membrane
High stretching capacity, Low strength
Primarily used on horisontal surfaces
Effective sealing, large areas, specialized equipment and personell
White spotted areas are excess water form the hardening process

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ARD-NRD

Acidic Rock Drainage

- There is much concern on ARD
- ARD means low pH and accelerated dissolution of minerals

Neutral Rock Drainage

- Theres is little concern on NRD
- NRD is more selective in which mineral phases are dissolved

NRD may come first, followed by ARD

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Water chemistry – environmental impact, example Uranium

Two factors:

1. Concentration
2. Total amount

- Example 1: Tunnel system total amount of water pumped into the municipal pipe system
- **Age of tunnel > 50 years**
- 200-250 µg/liter Uranium is 0,2 – 0,25 mg/l
- 100 litre/hour
- 2400 litre/24 hour gives ca 0,5 g uran/døgn og ca. 175 g per 365 days

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ELEMENT	SAMPLE	1 pumpe sump	. pumpe sump	2 indre nedre	2 indre nedre	re høyre nedre	øyre ytre nedre	re indre nedre	re indre nedre	dt midt i nedre	yre midt midt i	/5 nedre høyre	/5. indre høyre
Ca (Kalsium)	mg/l	173	176	128	136	359	347	136	137	129	125	90	86,7
Fe (Jern)	mg/l	0,0628	0,0413	0,0617	1,14	13	3,42	0,0982	0,674	1,38	0,544	1,59	0,557
K (Kalium)	mg/l	24,3	24,1	22,4	22,2	27,8	28,4	27,3	29,8	26,9	27,5	34,8	31,2
Mg (Magnesiu	mg/l	78,7	78,4	89,5	91,7	101	104	68,7	68,4	56,2	55,9	52	51,8
Na (Natrium)	mg/l	189	184	200	203	171	177	249	250	104	105	301	306
Al (Aluminium)	µg/l	18,5	10,8	20,9	270	1110	255	<100	187	122	59	582	122
As (Arsen)	µg/l	1,57	<0.8	1,72	2,98	16	4,18	<80	<1	1,88	1,15	2,37	1,66
Ba (Barium)	µg/l	11,3	10,6	9,92	20,8	47	21,5	20,2	25	11,2	9,02	29,6	23,2
Cd (Kadmium)	µg/l	0,154	0,147	0,115	1,14	1,57	0,609	3,99	0,168	0,887	0,371	0,583	0,216
Co (Kobolt)	µg/l	0,22	0,223	<0.2	3,3	6,78	1,89	1,64	0,53	1,26	0,578	1,24	0,427
Cr (Krom)	µg/l	<0.9	<0.9	<0.9	1,46	2,41	<0.9	5,33	1,19	2,72	2,49	1,71	<0.9
Cu (Kopper)	µg/l	1,6	1,81	2,4	8,02	23,6	10,3	<10	3,05	5,8	3,76	12,4	3,16
Hg (Kvikksølv)	µg/l	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Mn (Mangan)	µg/l	8,75	8,82	38,1	776	504	150	11,6	77,9	245	103	136	166
Mo (Molybden)	µg/l	91,2	88,2	59,2	65,2	121	112	31,7	31	59,5	59,9	22,8	17,6
Ni (Nikkel)	µg/l	22,7	23,8	18,5	64,6	74,8	36,9	16,4	4,84	67,6	44,1	11,1	8,47
Pb (Bly)	µg/l	<0.5	<0.5	4,1	66,7	8,55	2,43	25,9	1,99	3,67	1,55	4,77	6,47
Zn (Sink)	µg/l	6,32	7,51	26,1	78,1	163	60,3	<10	23,3	78,2	32,8	72,5	34
V (Vanadium)	µg/l	0,445	0,376	0,454	1,58	9,34	2,13	4,33	1,06	1,36	1,2	1,97	1,12
Th (Thorium)	µg/l	<0.2	<0.2	<0.2	<0.2	0,59	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
U (Uran)	µg/l	227	246	150	156	591	578	290	121	149	149	136	116
Sulfat (SO4)	mg/l	865	793	815	874	1170	1280	589	676	599	555	594	672
Bikarbonat (H	mg/l	195	196	182	181	182	181	166	165	192	193	158	159
Nitrat (NO3)	mg/l	14,7	13,8	18,2	19,7	9,57	10,6	9,5	11	16,6	15,1	17,9	20,4
Klorid (Cl-)	mg/l	207	188	234	254	199	219	272	313	138	127	251	276
Alkalinitet pH 4	mmol/l	3,19	3,22	2,99	2,97	2,98	2,97	2,72	2,7	3,15	3,16	2,59	2,61
Alkalinitet pH 8	mmol/l	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150	<0.150
DOC	mg/l	2,6	1,37	1,68	1,77	0,87	0,9	0,59	0,66	2,4	2,5	<0.50	<0.50
Ledningsevne	mS/m	204	207	204	209	276	275	214	217	151	151	216	209
pH		8,1	8,11	8,16	8,02	7,98	7,98	8,11	8,11	8,14	8,15	8,18	8,2

Checkpoint NRD or ARD buffered? Aluminium source is normally silicates

An overall higher concentration on most elements indicates buffered ARD

Uranium to the surroundings

Example 2

This water is not treated or cleaned before pumped over to the municipal sewage system.

Concentrations and pH exceeds by far limits for allowance

- 26500 µg/l U = 26,5 mg/l
- Per year with 1 liter/24 hours: 9672,5 mg (9,7 gram uranium)

Water chemistry erroneously mistaken for calcareous water

ELEMENT	SAMPLE	G5-7 Sigevann
Dekantering		JA
Ca	mg/l	475
Fe	mg/l	2810
K	mg/l	<20
Mg	mg/l	1200
Na	mg/l	61,3
Al	µg/l	1110000
As	µg/l	1470
Ba	µg/l	<50
Cd	µg/l	828
Co	µg/l	6470
Cr	µg/l	1470
Cu	µg/l	17600
Hg	µg/l	<0.02
Mn	µg/l	32600
Ni	µg/l	43600
Pb	µg/l	<30
Zn	µg/l	30800
U	µg/l	25200
DOC	mg/l	2,24
Alkalinitet	mmol/l	<0.150
Klorid (Cl-)	mg/l	58,8
Sulfat (SO4)	mg/l	19,1
Bikarbonat (H	mg/l	0
pH		2,62
Ledningsevne	mS/m	1210
Nitrat (NO3)	mg/l	<0.38

Structor

Deres prøvenavn	K32-2 grunnvann	
Labnummer	N00135087	
Analyse	**Resultater**	**Usikkerhet (±)**
Dekantering*	**ja**	
Ca	**524**	57
Fe	**42.9**	3.9
K	**19.6**	1.6
Mg	**170**	15
Na	**43.9**	3.8
Al	**29000**	2480
As	**23.9**	6.4
Ba	**133**	11
Cd	**50.2**	7.1
Co	**384**	36
Cr	**9.63**	1.81
Cu	**484**	38
Hg	**0.0679**	0.0140
Mn	**5890**	546
Ni	**3550**	306
Pb	**6.62**	1.13
Zn	**2850**	273
U	**1080**	187
Th	**5.39**	0.90
V	**51.8**	6.3
DOC	**4.29**	0.86
Alkalinitet	**<0.150**	
pH	**4.27**	0.08
Ledningsevne (konduktivitet)	**328**	32.8
Sulfat (SO4)	**2210**	442
Sulfid (S2-)	**<0.050**	
Bikarbonat (HCO3)	**0**	
Klorid (Cl-)	**153**	30.6
Nitrat (NO3)	**<0.27**	
O	**8.22**	0.83

Deres prøvenavn	K32-1 grunnvann		
Labnummer	N00135085		
Analyse	**Resultater**	**Usikkerhet (±)**	**Enhet**
Dekantering*	**ja**		
Ca	**558**	61	mg/l
Fe	**22.9**	2.1	mg/l
K	**18.9**	1.6	mg/l
Mg	**130**	12	mg/l
Na	**42.1**	3.9	mg/l
Al	**8700**	744	µg/l
As	**11.7**	3.2	µg/l
Ba	**101**	9	µg/l
Cd	**39.5**	5.6	µg/l
Co	**356**	34	µg/l
Cr	**3.45**	0.63	µg/l
Cu	**241**	22	µg/l
Hg	**0.187**	0.032	µg/l
Mn	**4720**	437	µg/l
Ni	**2800**	242	µg/l
Pb	**5.02**	0.87	µg/l
Zn	**2920**	280	µg/l
U	**648**	112	µg/l
Th	**1.75**	0.29	µg/l
V	**17.9**	3.3	µg/l
DOC	**15.2**	3.04	mg/l
Alkalinitet	**1.26**	0.190	mmol/l
pH	**6.14**	0.08	
Ledningsevne (konduktivitet)	**308**	30.8	mS/m
Sulfat (SO4)	**2560**	512	mg/l
Sulfid (S2-)	**<0.050**		mg/l
Bikarbonat (HCO3)	**77.2**		mg/l
Klorid (Cl-)	**168**	33.7	mg/l
Nitrat (NO3)	**<0.27**		mg/l
O	**7.58**	0.77	mg/l

Structor

Principles design tunnels – rock mechanical issues (1)

- The geological setting of the The Oslo area is a rift system which died out
- Vertical faults N-S direction (ca. 270 mill years)
- Local intrusions dikes and some larger bodies
- Caledonian thrusting (foreland) mostly slightly tilting (dipping 20-40° NW) shearzones is to be expected. Slaty cleavage overprints fissile primary bedding.
- Clay-like material in sheared zones varying thickness centimeter – meter scale
- Micro cracks throughout the shale body, specially Alum shale

Principles design tunnels – rock mechanical issues (2)

- Each black shale (and grey and calcareous shale) has distinct rock mechanical characteristics and chemical characteristics.
- Stressrelaxation due to intensity of lamina/fissile texture and joint frquency
- Table in previous slide Cambro-Silurian succession

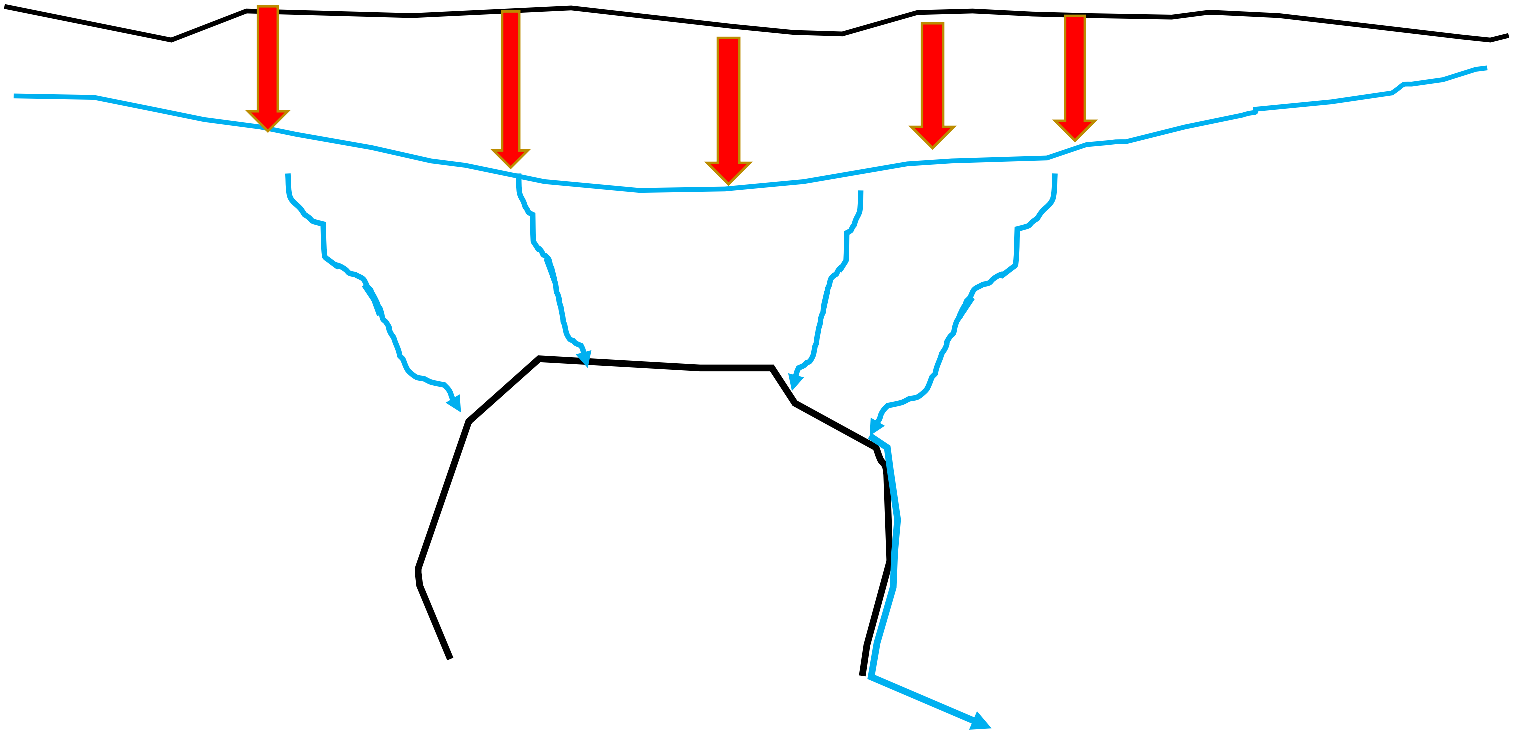
Principles sustainable tunnel design

Main principle: Undrained solution

Why:

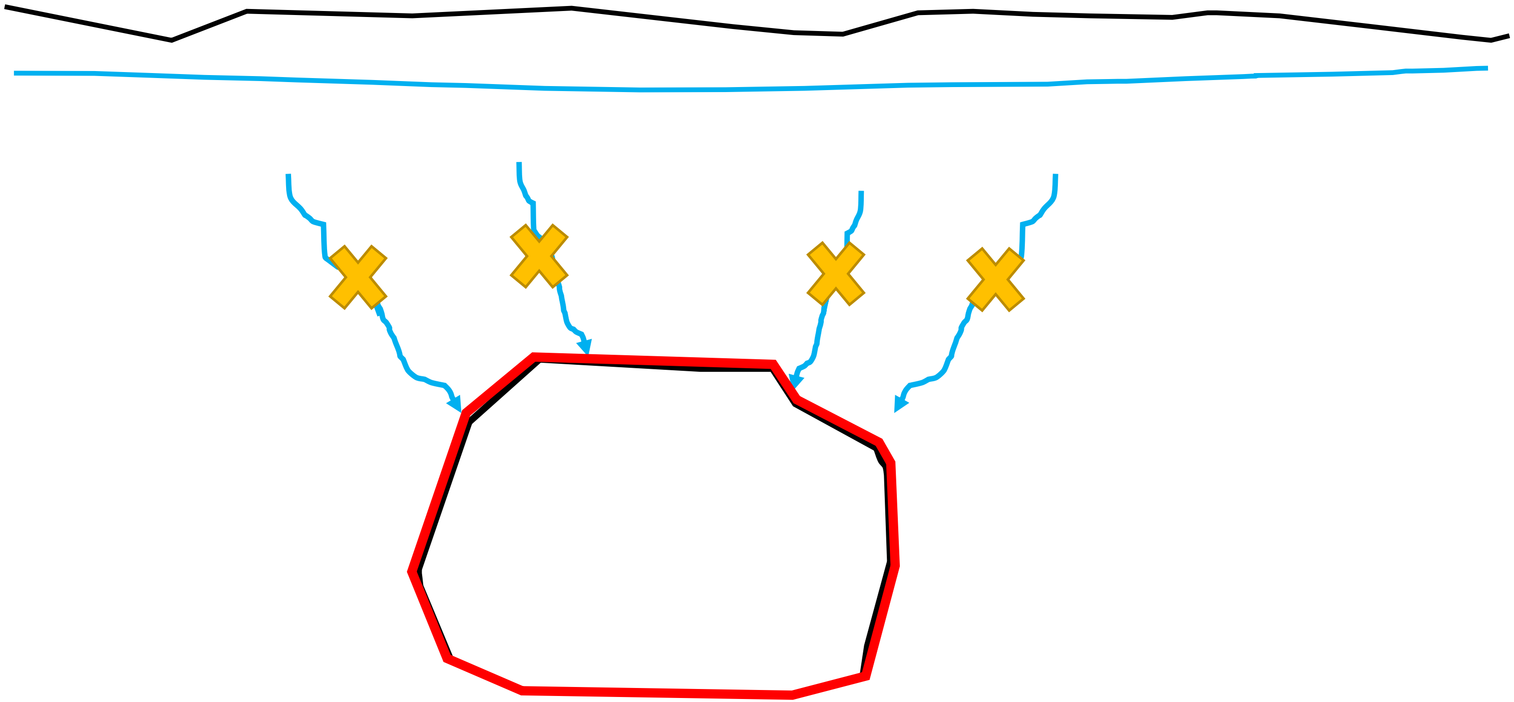
- Lowering of ground water table should not be allowed in urban areas
- Reduced life-time
- Higher maintainance costs
- Environmental issues – water chemistry in drainage water affected by NRD and ARD
- Damage to third part

Drained solution – moving water



Structor

Undrained solution



Structor

Principles design open construction sites

No drained solutions –

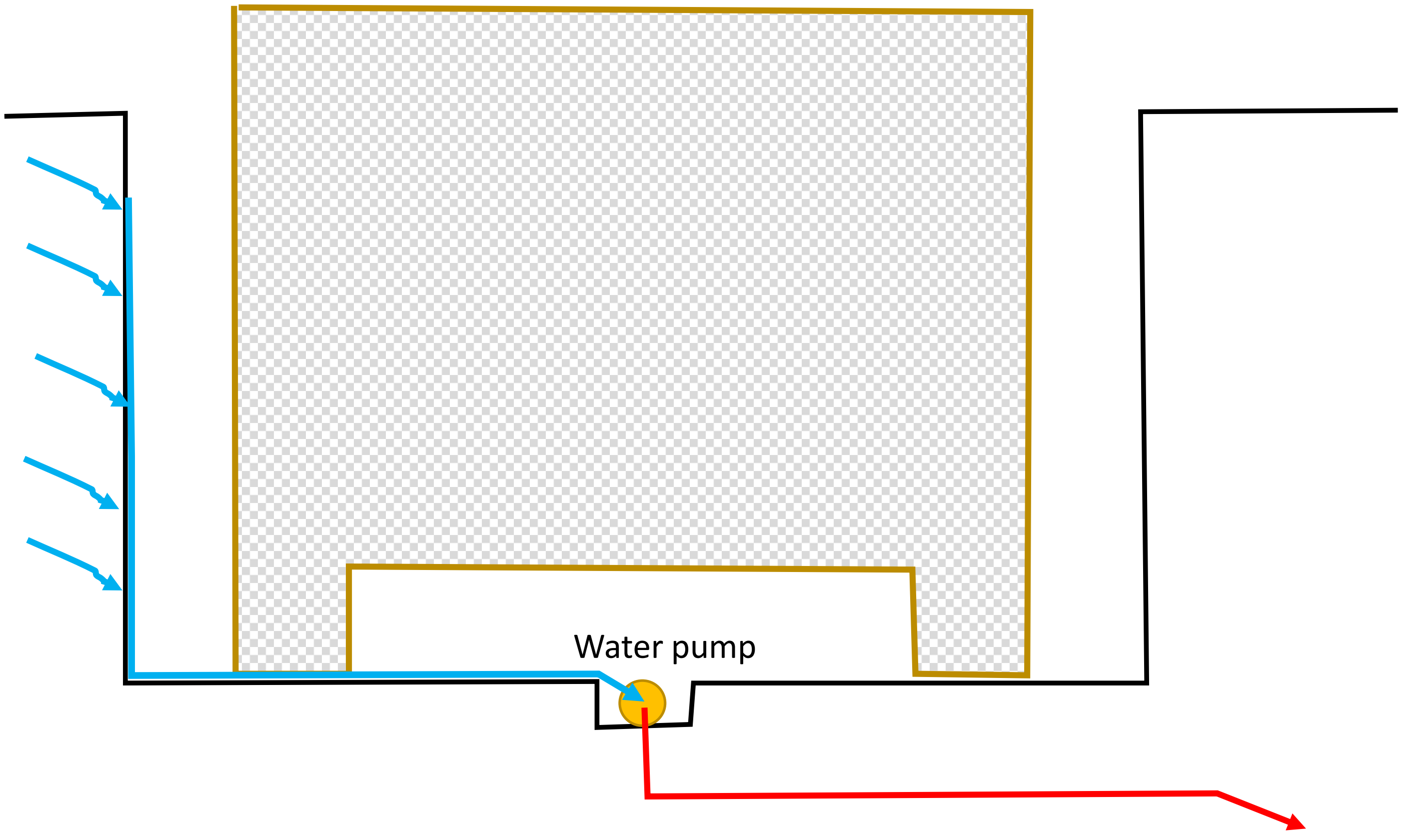
- no moving water in contact with black shale

No infiltration og surface water into black shale ground

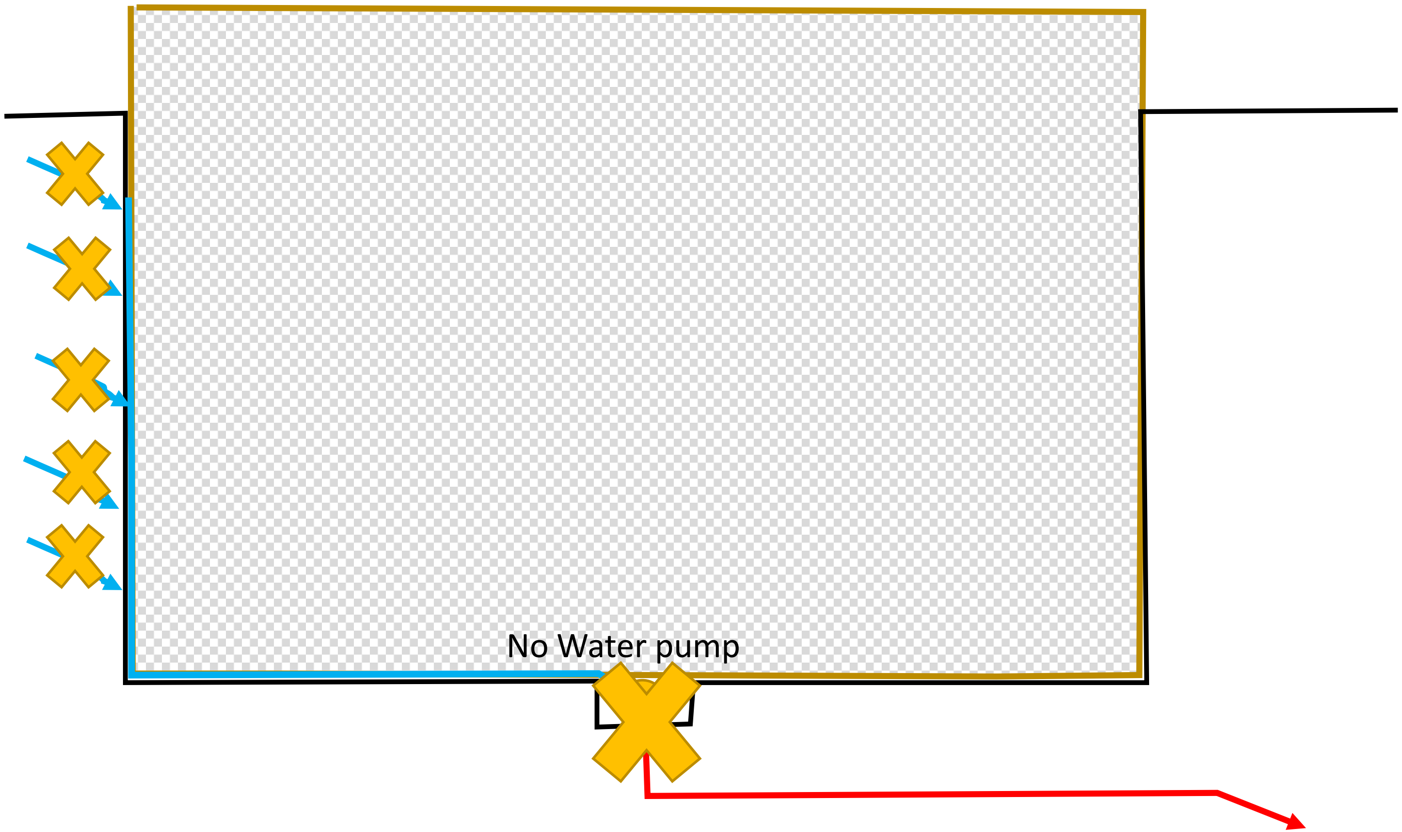
Risk of swelling pressure on constructions

  - Swelling pressure can be neglected og minimized if you can handle the physical and chemical prerequisites for the chemical reactions causing swelling pressure

Drained solution – moving water



Undrained solution



Principles foundations

Point foundations

- Two factors
  - Surface area > 0,5 m2
  - Load from building surface load should not exceed 5-6 MPa
  - Swelling pressure may be controlled by controlling the chemical and physical environment to eliminate risk of mineral reactions
- Line foundations (walls)
- Cast concrete reinforced plate/sole basement
- Tunnel lining – non-drained solution

Structor

Principles rock cuts

- Any height leap is prone to develop a drained solution over time
- Drilled holes for rock bolts may establish drainage through the holes – risk of deterioration Cement grout (both sulfate and pH will weaken the cement grout over time)
- The weakest layer in the construction is the two-three centimeters of shale in the contact zone under the shotcrete
- Rock bolts must keep the shotcrete in place
- Sandwich construction
  - To ensure bond strength between shotcrete and EVA-based membrane, dry conditions is necessary
  - Sandwich (shotcrete-membrane-shotcrete) construction should be performed quickly after excavation

Structor

Drained solution water seepage along rock bolt.
Rock grout will dissolve over time……. false security
Can be solved by pregrouting hole before grouting

Structor

Drained solution–

Cracks in star pattern indicates volum changes (swelling) under sprayed concrete layer

Principles station areas

- Station areas goes from expected water saturation below ground water table to the «vadose zone» up on the surface
- Successful solutions must involve black shale expertice, construction expertice, architects and land scape architects and other expert groups designing solutions in the ground

Structor

Shielding indicates water/drained solutions

Structor

Shielding indicates water/drained solutions

Structor

possibly water/drained solutions

Structor

Principles street level to station plattforms

- This crosses vadose sone and continues under the ground water table
- Main topic in the vadose zone is to avoid moving water and avoid development of swelling pressure caused by moist chemical/physical environment surrounding the construction
- Surface water should not enter (infiltrate) the ground
- Chemical grouting/impregnation may reduce degree of fissile behaviour

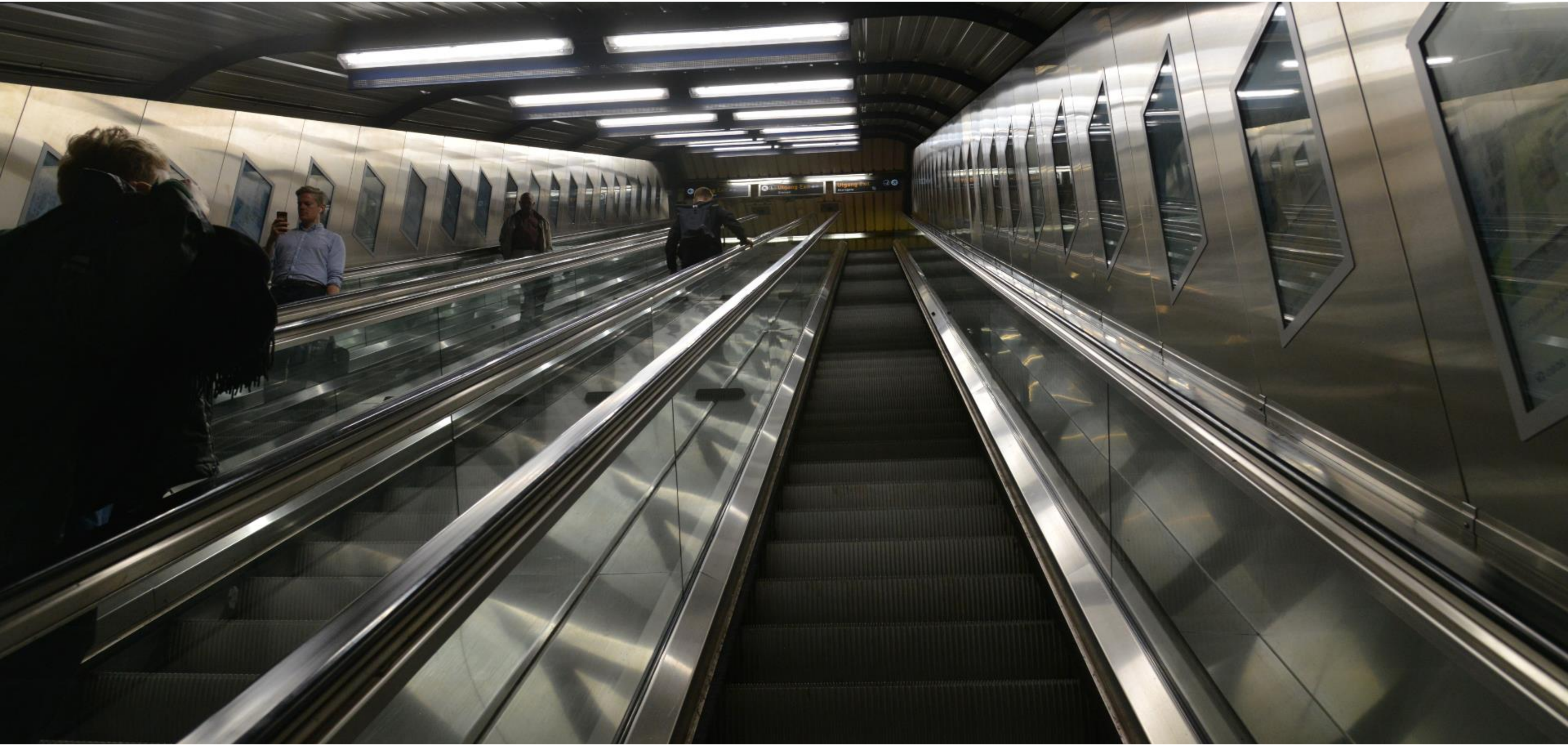
Structor

Cracking due to swelling pressure

Structor

water/drained solutions and improper sealing

Structor



Possibly water/drained solutions - Shielding necessary?

Structor

Polyurethane

Structor

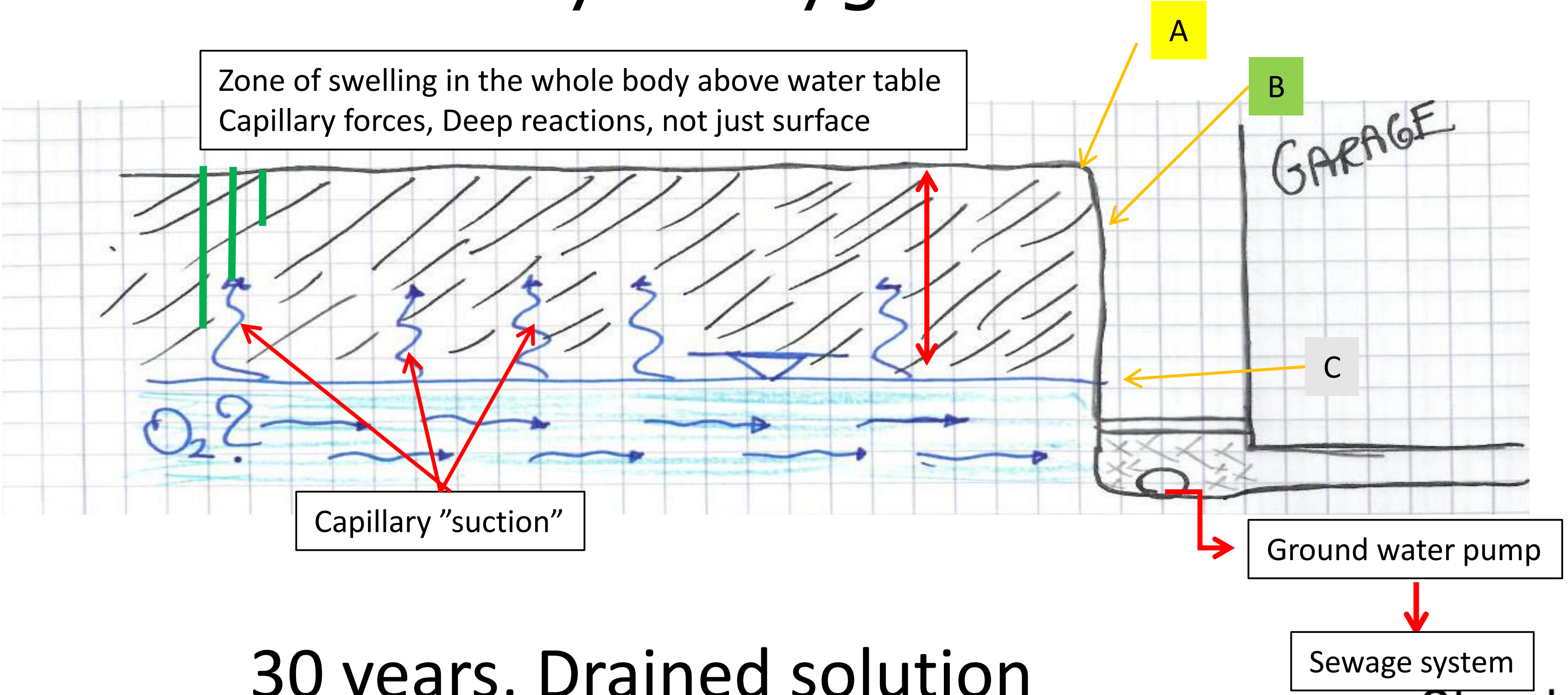

T-bane
Metro
Stortinget 11:51
T-bane
Metro
Utgang Exit
Lille Grensen

Structor

Additional examples drained solutions

Drained solutions urban areas

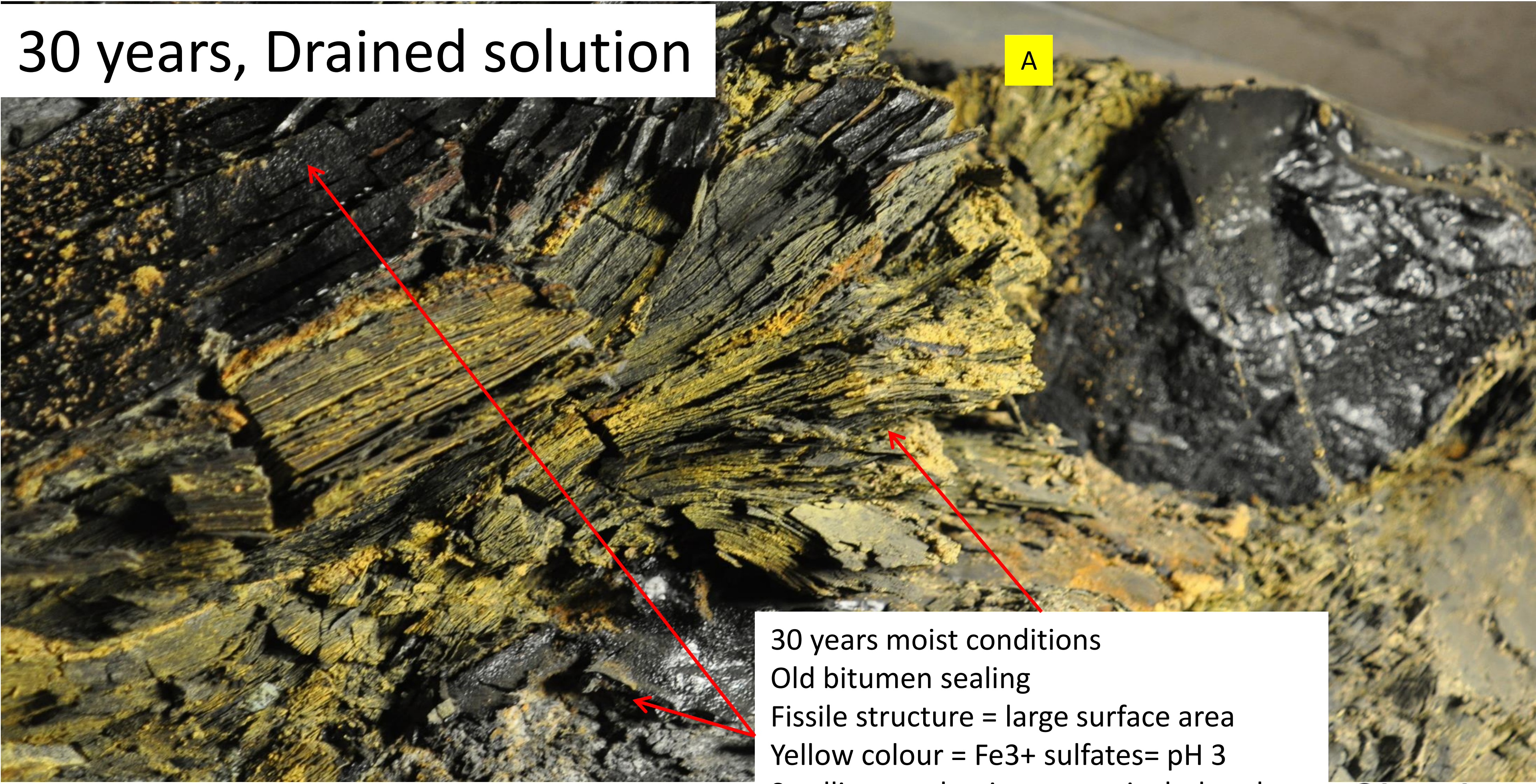
Groundwater table
Water chemistry – oxygen content?



30 years, Drained solution

Structor

30 years, Drained solution



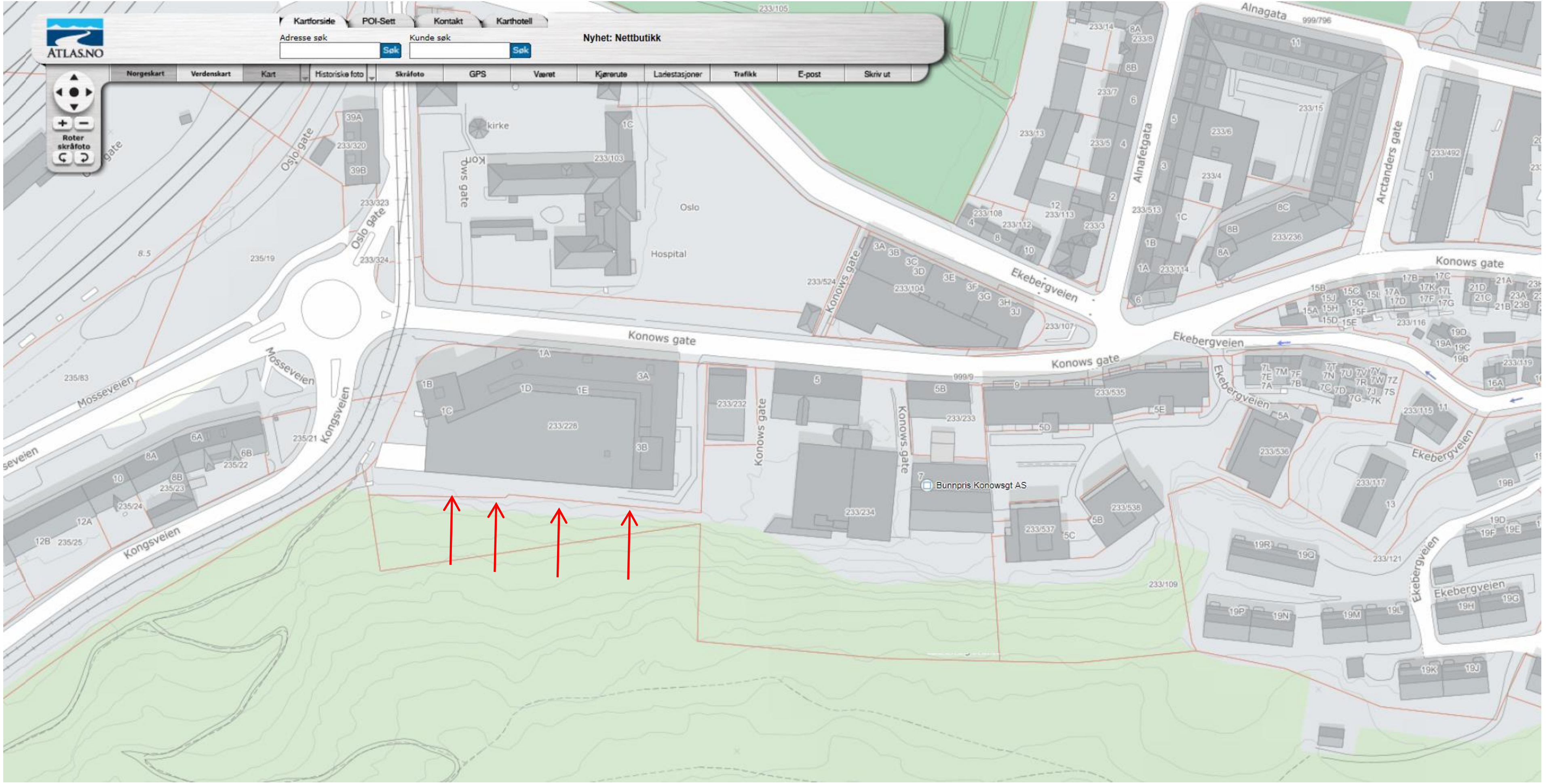
30 years moist conditions
Old bitumen sealing
Fissile structure = large surface area
Yellow colour = Fe^{3+} sulfates= pH 3
Swelling mechanisms must include other reactions than gypsum formation

30 years, Drained solution

30 years moist conditions
Fissile structure = large surface area
Blue-green colour = Fe2+ sulfates= pH 4-7
Open cracks… complicated mechanism swelling
Directional growth fibrous blue-green mineral

30 years, Drained solution

Mineral growth in «wet zone, possibly jarosite



ATLAS.NO
Kartforside
POI-Sett
Kontakt
Karthotell
Adresse søk
Søk
Kunde søk
Søk
Nyhet: Nettbutikk
Norgeskart
Verdenskart
Kart
Historiske foto
Skråfoto
GPS
Været
Kjørerute
Ladestasjoner
Trafikk
E-post
Skriv ut
Roter skråfoto
kirke
Oslo
Hospital
Konows gate
Ekebergveien
Alnagata
Alnafetgata
Arctanders gate
Oslo gate
Mosseveien
Kongsveien
Bunnpris Konowsgt AS

Drained solution
Surface net corroding
in very short time
Ekeberg main fault Oslo

Structor

Drained solution
Height leap on border between properties
Colour says: Fe-O-OH and not sulfates
Colour indicates pH > 4

Ground water pumps belongs to «future past»

DSC_3927

Choice of
correct design
and solutions
A prerequisite for
sustainable and
environmentally
sound solutions

Structor

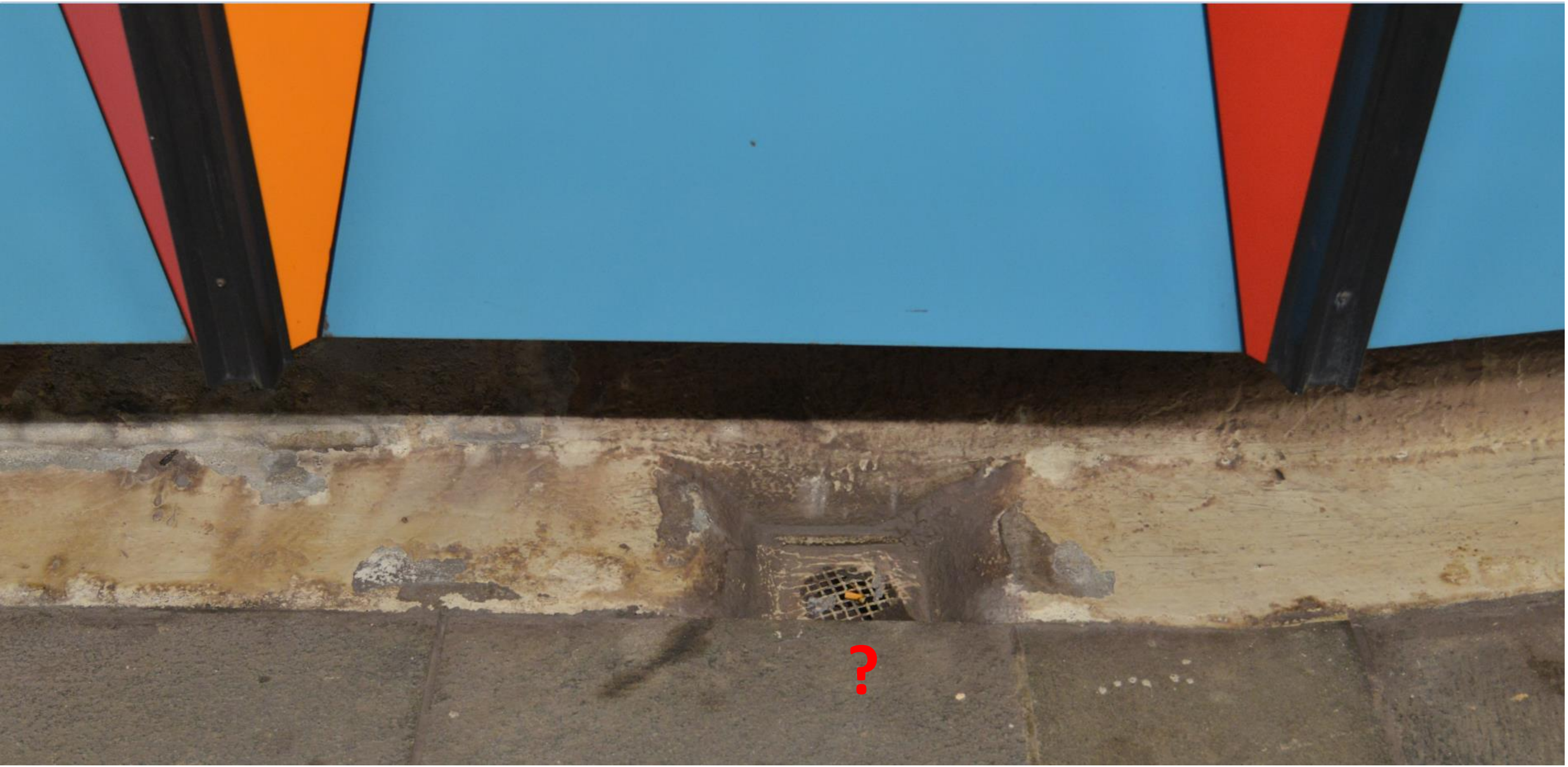
Black shale (alum shale) in rock cut behind buildings.
Water seepage (red arrows) from rock cut goes under building, causing swelling (blue circle) and an unwanted environmental situation downstram

Structor

Structor

Drained solution
Building on point foundations will here neglect risk of swelling
Environmental issues are not taken care of

Structor



Very high humidity

What can be solved with cast in-place concrete lining with membrane?

Andreas Finstad, Project Manager
The Follo line Project, Drill and Blast

29.8.2019, Oslo

Content

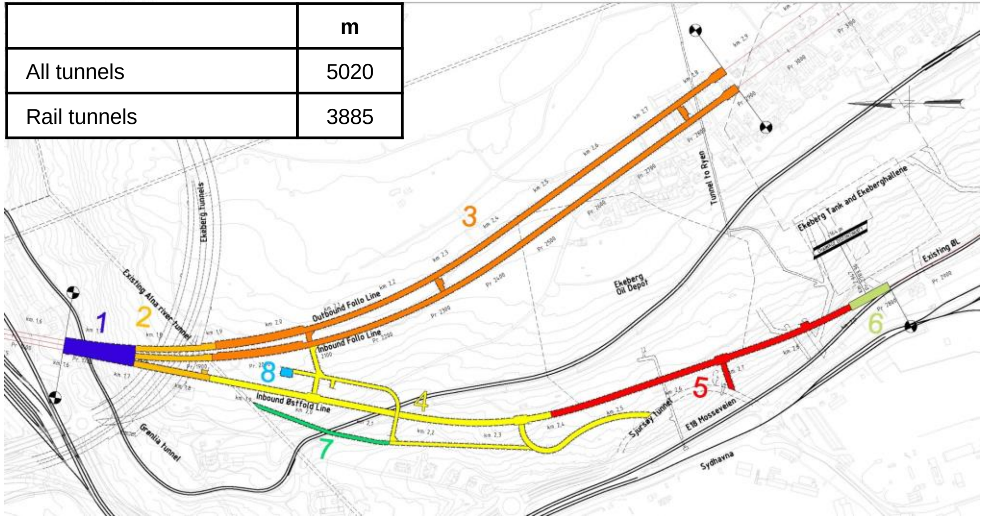
- Project overview
- Background
- Construction execution
- Experience
- Summary

Project Overview

- Excavation method
  - Drill and blast
- Rock support
  - Fibre reinforced shotcrete, CT bolts
  - Crossing of oil caverns, E6, E18, Alna river: Heavy rock support incl. pre-bolting, prefabricated lattice girders
- Water and frost protection
  - Cast in-situ concrete lining with membrane
  - <u>Not part of the rock support in drill and blast project</u>

1 - Three track tunnel
2 - Crossings of the existing E6 road tunnels
3 - Follo Line tunnels
4 - Inbound Østfold line, part 1
5 - Inbound Østfold line, part 2
6 - South portal
7 - Alna river crossing
8 - Pumping station

	m
All tunnels	5020
Rail tunnels	3885



Background

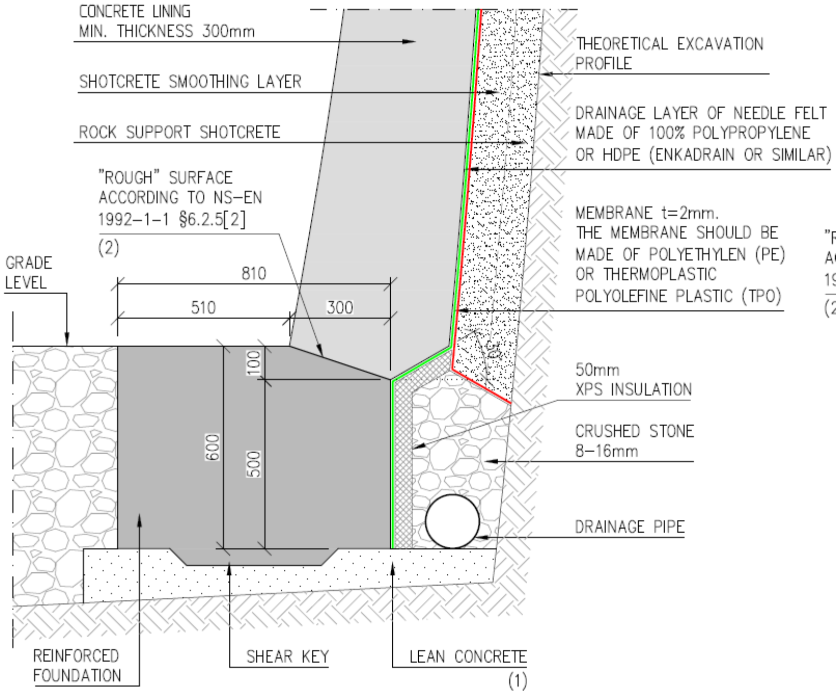
- The lining concept is based on a LCC assessment (2012)
  - Alternatives (Teknisk regelverk, 2012)
    - Segment lining (betongelementhvelv)
    - Cast in-situ concrete lining with membrane (kontaktstøp)
  - Design Life: *80* years
  - RAMS methodology with main criteria's:
    - Low frequency of generic maintenance
    - High system availability for train traffic

⇒ Cast in-situ concrete lining with membrane

BANE NOR

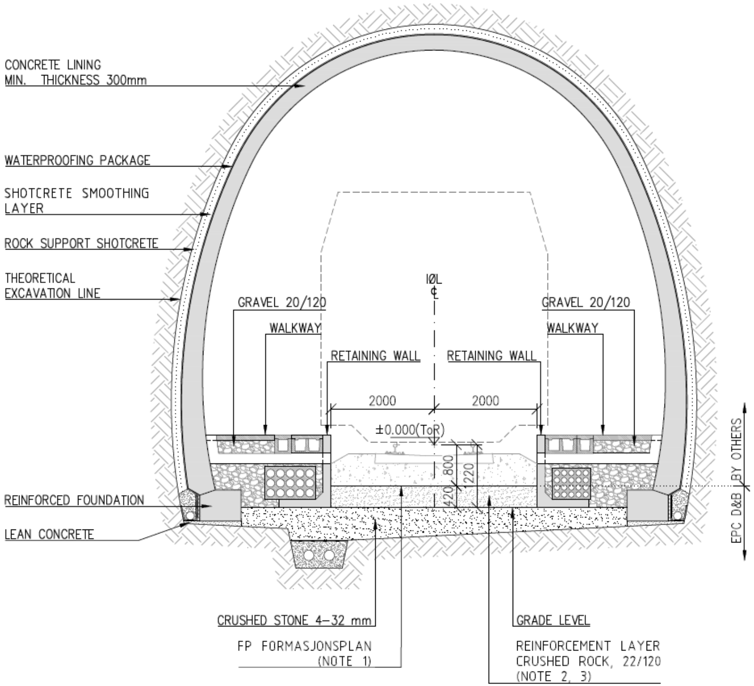
Construction execution (1/2)

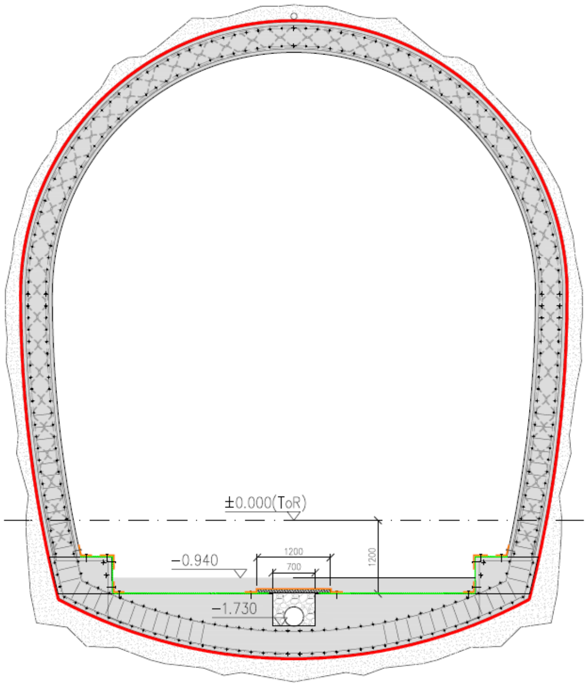
- Pre-concrete works:
  - Smoothing layer (shotcrete)
  - Lean concrete and reinforced foundation - «kicker»
  - Drainage behind foundation
    - Un-drained solution in gas or water-tight area
- Membrane works:
  - Applying drainage layer on the rock surface (needle felt)
  - Installation of membrane
  - Welding works
- Concrete lining works
  - Unreinforced
    - Reinforced in special areas
  - Min. 300 mm thickness
- Post-concrete works
  - Post-grouting through installed hoses in the top crown (autogenous shrinkage)



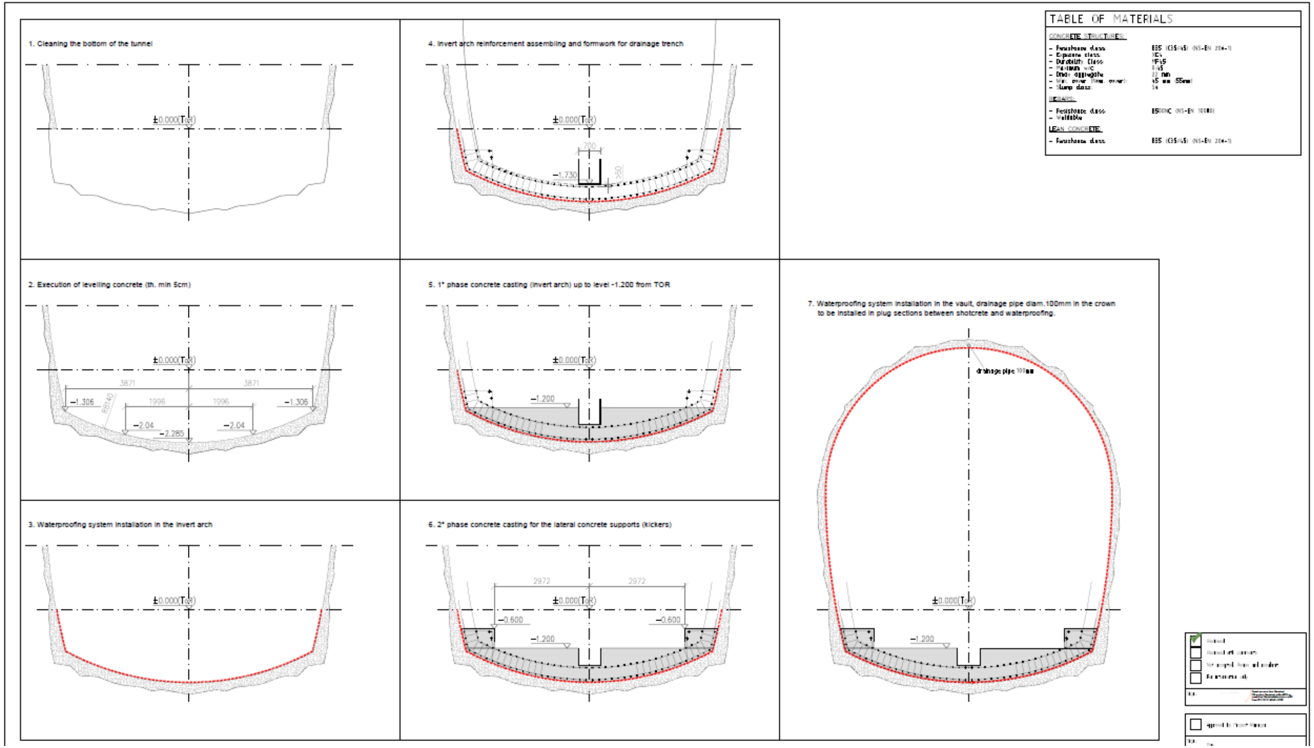
Construction execution (2/2)

Drained vs Undrained (1/2)





Drained vs Undrained (2/2)



Crossings of:

- Alna river
- Oil storage caverns (gas tight)

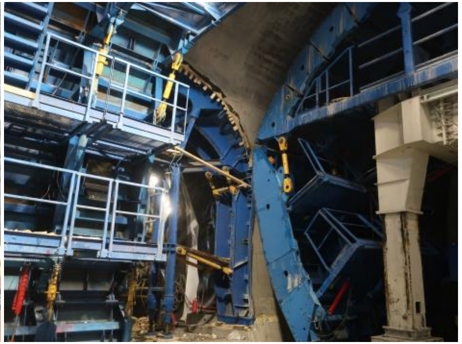
BANE NOR

Formwork (1/2)

- Formwork system
  - Normal cross section: CIFA
  - Widening cross section: Euroform
    - Hydraudralic system to adapt to the different cross section
  - To enable achievement of important milestone dates in the project: DOKA

Cross sections	Number
Railway tunnels	6
Niches, teqnical rooms	8



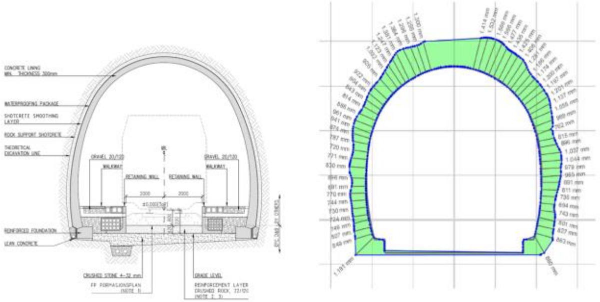
BANE NOR

Formwork (2/2)

Experience

- In general a safe execution method
- In general the final product quality is good
- Progress
  - 12 meter/section, 72 meter/week (normal cross section)
  - Lower progress on wider cross sections with reinforcement
- Construction cost:
  - Concrete theoretical versus actual: 90m3 vs. 180m3
    - Sensitive to actual blasting profile
  - Not efficient with many different cross sections
    - time consuming
  - High acceleration cost with lost progress
    - not very flexible

Theoretical versus actual constructed



Summary

- Pros (operation phase):
  - Dry tunnel
  - Low maintenance requirements
  - Long lifetime
- Cons (construction phase):
  - High cost
  - Not very flexible
  - Environmental issue

Bane NOR is having an on-going optimization process of the concept

Freezing

Anne-Lise Berggren

Geofrost AS

Waterproofing - Stabilization - Environmental impact

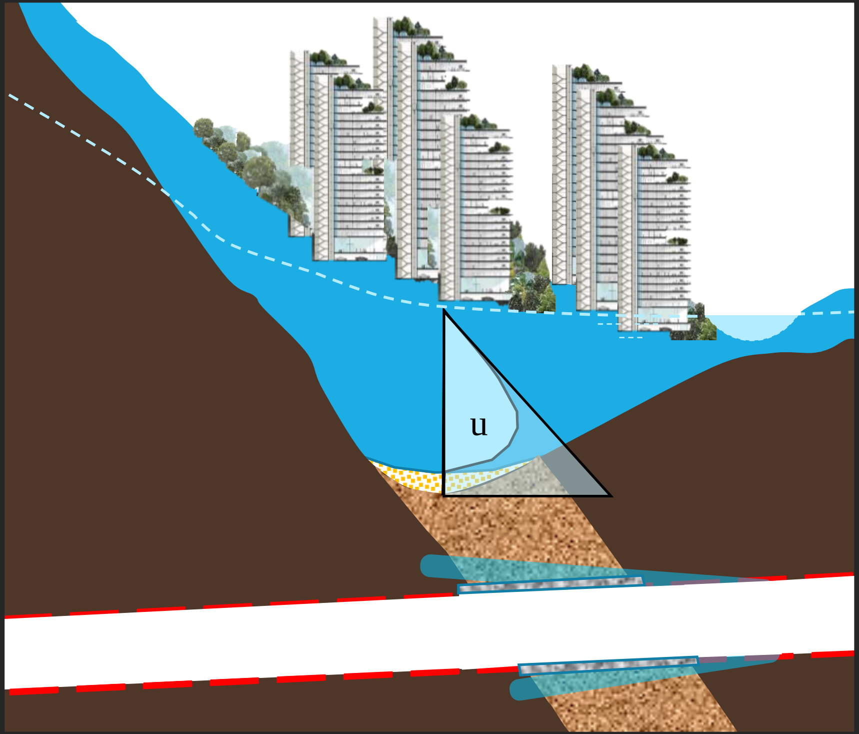
GEOFROST

Waterproofing

- When the ground freezes
  it becomes 100 % water proof.

Waterproofing

- When the ground freezes
  it becomes 100 % water proof.
- Pore pressure reduction and settlements can be avoided by sealing with ground freezing.

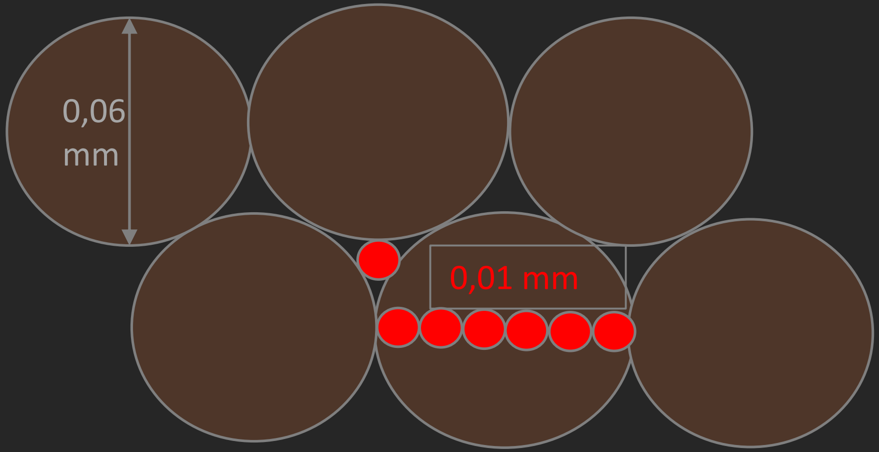


Waterproofing

- When the ground freezes it becomes 100 % water proof.
- Pore pressure reduction and settlements can be avoided by sealing with ground freezing.
- Grouting in soil may reduce permeability, but not avoid pore pressure reduction, although it works well in rock. (Byggeindustrien 9/2017)

  Ground freezing works in all kinds of ground conditions because it is not dependent on permeability.

- Silt:
  D = 0,060-0,002 mm



- Ultrafine cement:
  D95 < 10 mikron = 0,010 mm

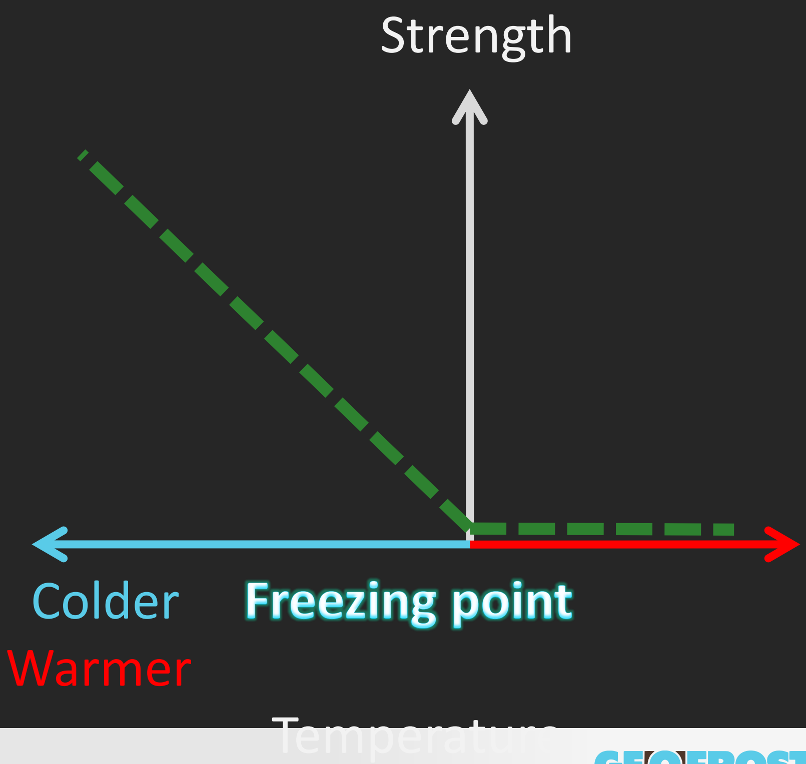
Undisturbed sampling

Find out what is down under,
where you normally don't get any samples,
by Geofrost Coring.

GEOFROST

Stabilization

- Strong as concrete
- Strength increase
  with decreasing temperature
- For drill and blast excavation:
  blasting may take place adjacent to the freezing pipes
- For TBM drives:
  start and end blocks,
  mixed face conditions



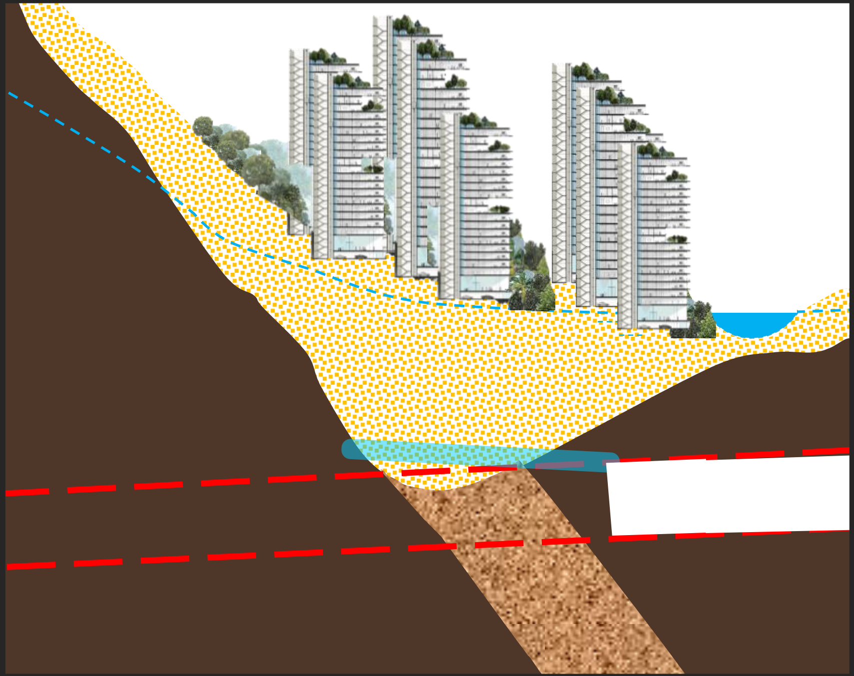
Stabilization

WHY:

- Avoid washout, sinkhole and collapse

WHEN:

- Little or no rock overburden
  - Stabilize from tunnel



GEOFROST

Stabilization

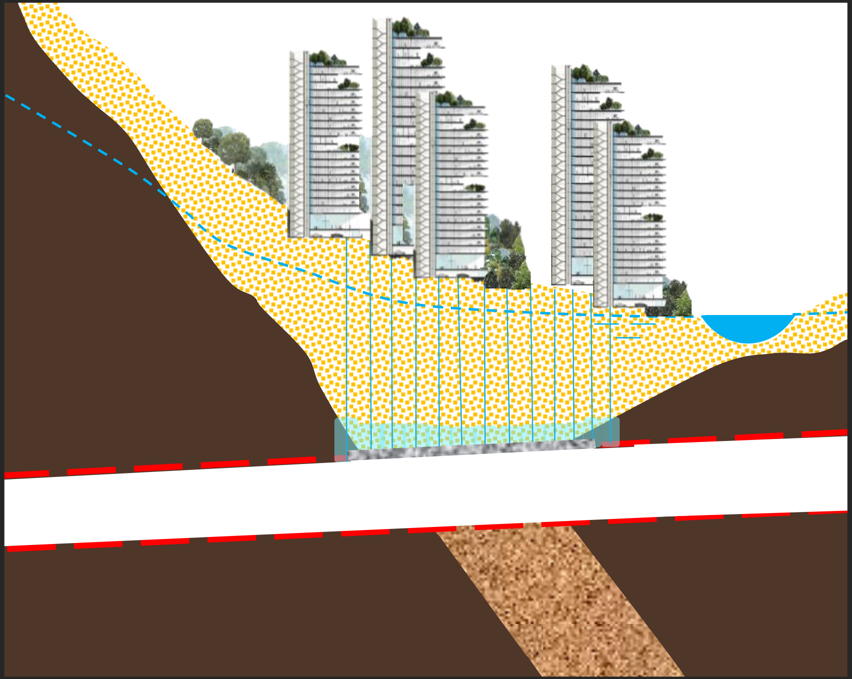
WHY:

- Avoid washout, sinkhole and collapse

WHEN:

- Little or no rock overburden
    - Stabilize from tunnel
    - or from surface,

  => ready when tunnel face arrives



Stabilization

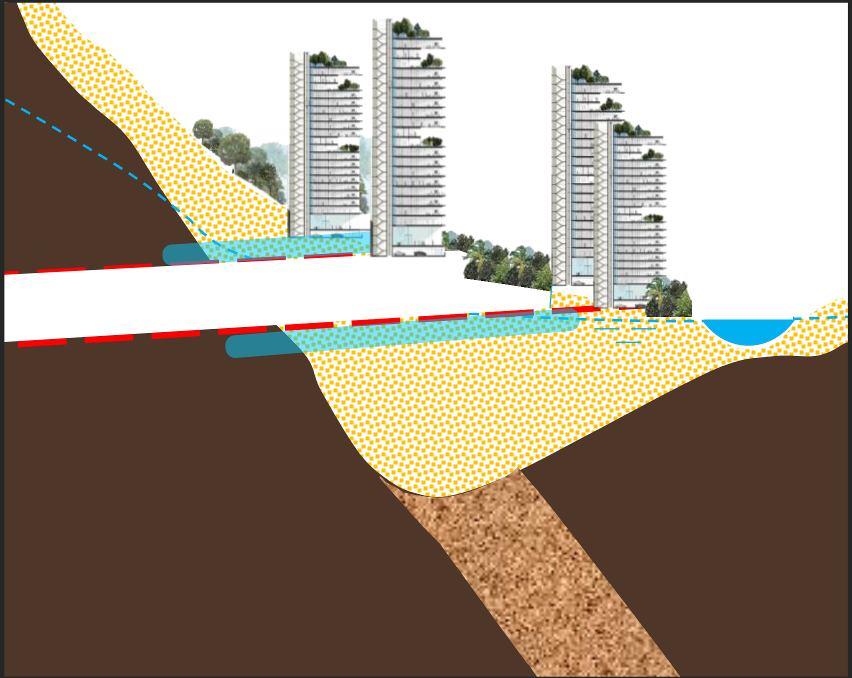
WHY:

- Avoid washout, sinkhole and collapse

WHEN:

- Little or no rock overburden
  - Stabilize from tunnel
  - or from surface,

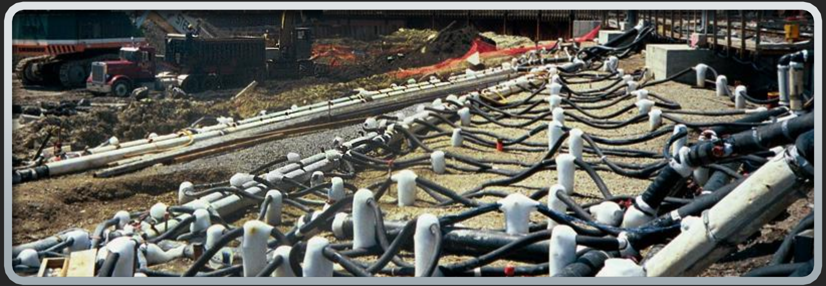
  => ready when tunnel arrives
- Mixed face or
  tunnel completely in soil:
  - Move the tunnel entrance
    to minimize excavation
    and save the environment



Environmental impact

Electric energy is transported => Construction material is made at site

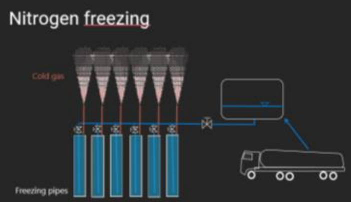


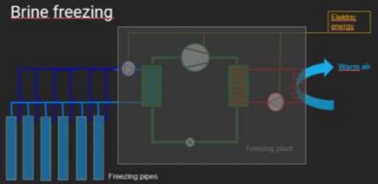


GEOFROST

Environmental impact

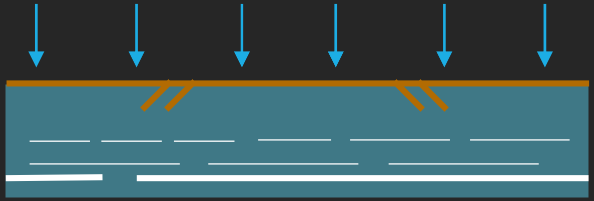
- Contributes to fossile and emission free construction sites
  - Electric energy
  - No emission, closed circuits
  - Minimal transportation, material already at site
  - Minimal CO_2-equivalent footprint
- Little noise, vibrations and dust
  - Drilling rig
  - Freezing plant
  - Ventilation fans

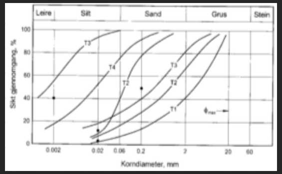




Environmental impact

- Seasonal frost





- Slow freezing
- Low overburden
- Icelenses may form in frost suceptible ground and lift the surface.

- Artificial ground freezing

- Rapid freezing
- Fine grained soil:

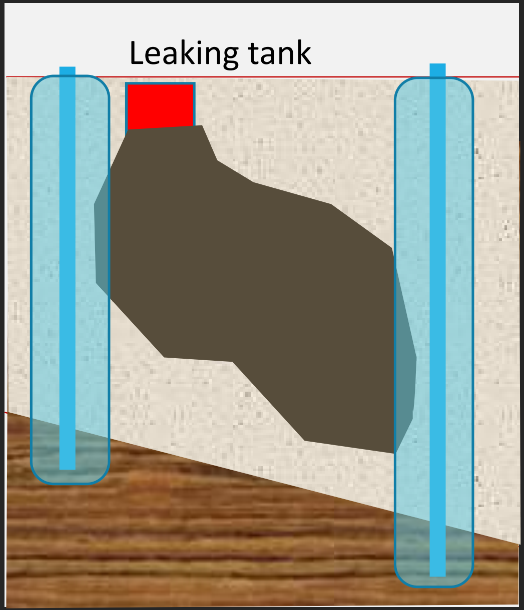
  Permeability prevents ice lense building.
- Coarser material:

  Pore ice growth displace water.

  No heave or expansion.

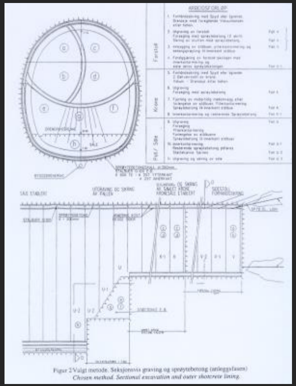
Environmental impact

Contamination may be insulated, and removed



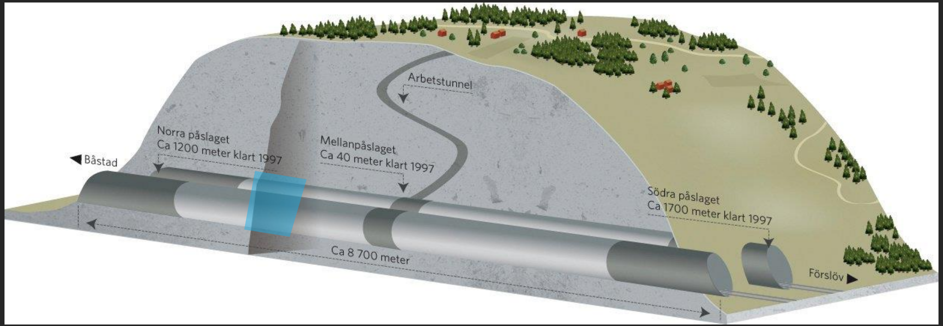
The Eidsvoll tunnel through clay and silt

- NATM with steel arches and sprayed concrete, through clay and silt. Excavation through silt below ground water needs stabilization!
- Ground freezing stabilizes and makes the ground impermeable (right).



The Hallandsås tunnels through disintegrated rock

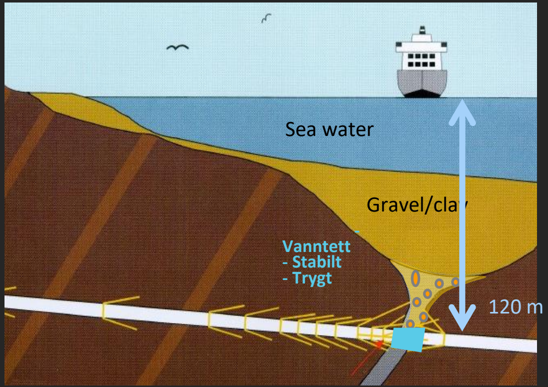
Ground freezing stabilized the dificult Möllebäck zone before TBM drilled through. The zone (300 m) consisted partly of deeply physical and chemical weathered rock (residual soil) and partly of rock with highly permeable fissures.



The Oslofjord tunnel, permeable soil 120 m below sea

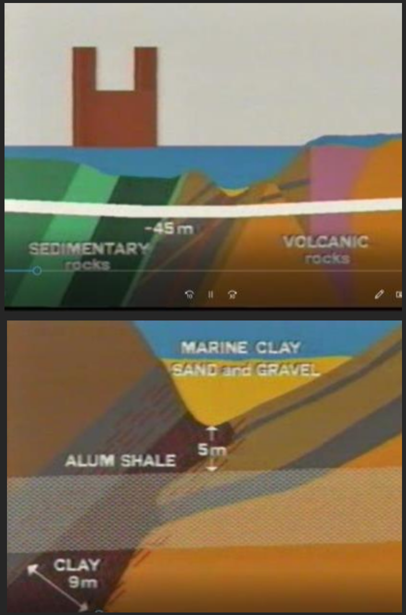
Glaciofluvial material of sand, gravel and blocks, was impossible to grout to achive impermeability and sufficient stability.

Ground freezing stabilized and sealed the zone before drill and blast 120 m below the fjord.



http://www.geofrost.no/article/Oslofjordtunnel/

Festningstunnelen (Fjellinjen) under Oslo 1988



- marine soft clay
- sand and gravel
- permeable moraine
- alum shale
- weakness zones
- mixed face

Freezing

Waterproofing - Stabilization - Positive environmental impact

Different TBMs For different ground conditions

Sindre Log, The Robbins Company
Under Oslo, 29.08.2019

Who is this guy?

Sindre Log

M.Sc. Civil engineering, NTNU

Specializations in Tunneling, geology and Project management

Worked for Robbins last 9 years

Product manager – Cutters, Tools and Geology and troubleshooting worldwide

Working out of Trondheim, Norway

Outline

Introduction

Hard Rock TBMs

Soft ground TBMS

Crossover TBMs

Case studies

What is a TBM?

In principle two different TBM types:

In principle two different TBM types:

- Hard rock TBMs
- Soft ground TBMs
- (Multi Mode/Crossover etc.)

TBM Types

Hard Rock

– Main beam TBM

– Double shield TBM

– Single shield TBM

Mixed/Soft Ground

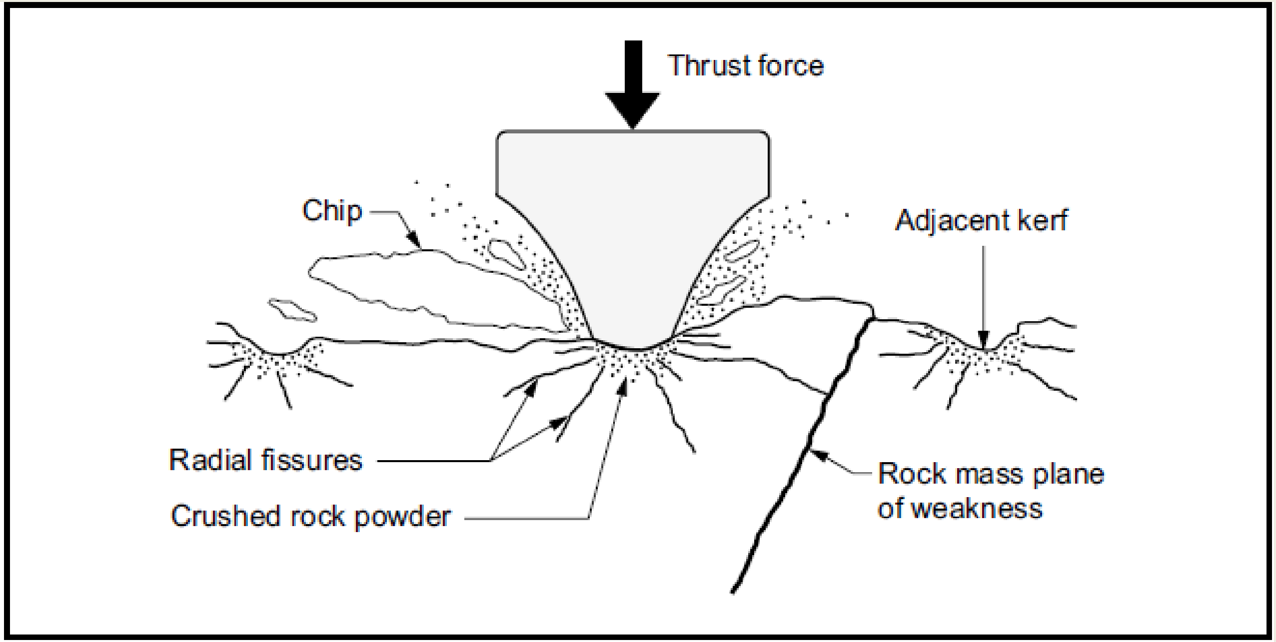
– Earth pressure balance (EPB) machine

– Slurry machine

Crossover machines

Hard Rock TBMs

Basic rock breaking



Hard Rock TBM Types

Røssåga HEPP
NORWAY
MB236-308-1
Robbins
LNS

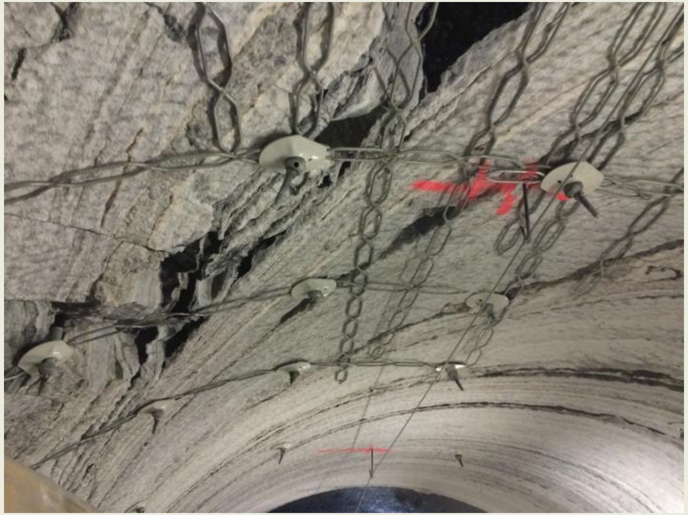
Rock Support

- Probing and pregrouting
- Rock bolting
- Shotcrete
- Slat systems
- Concrete segments
- Other lining

Water control

- Probe drilling and pregrouting

- Relatively good access for drilling and some access through cutterhead



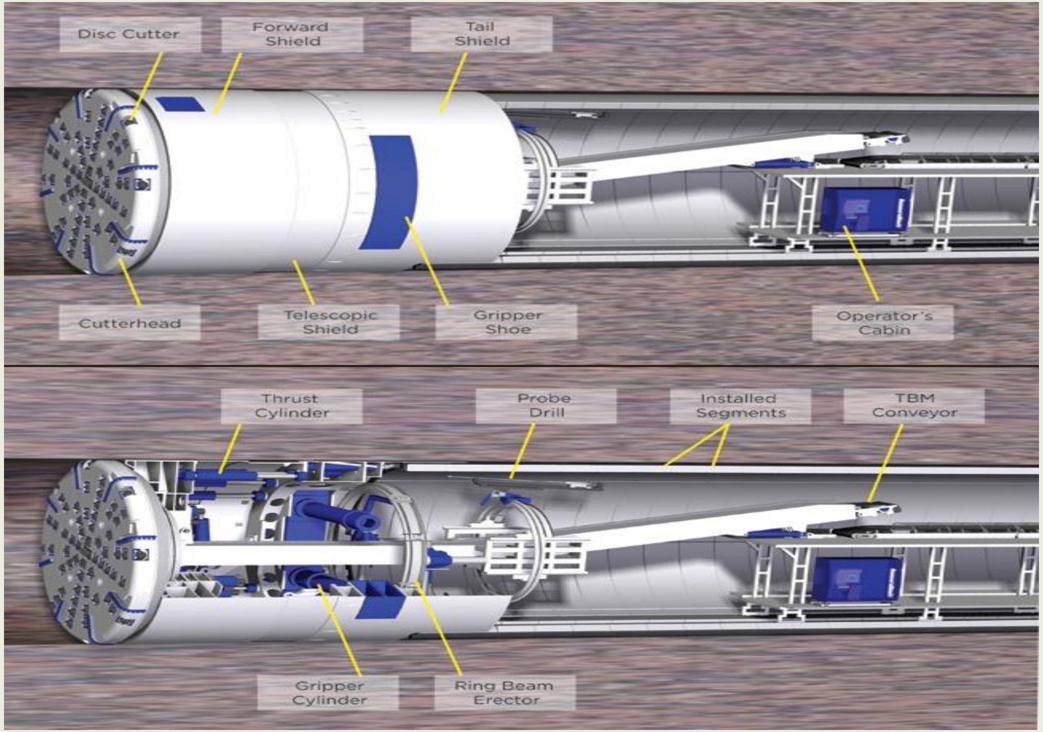
Shielded TBMs

Shielded TBMs
Same rock breaking mechanism

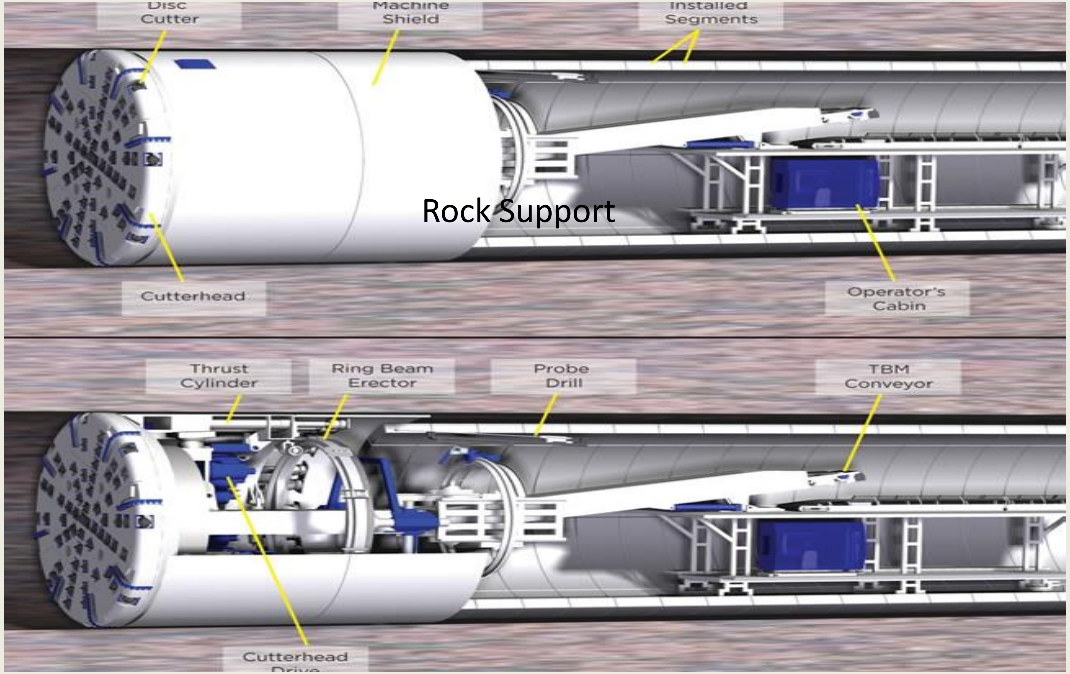
Shields for work safety and rock support

- Singel shield TBMs
- Double Shield TBMs

Double shield TBMs



Single Shield TBMs



Rock Support

+ Concrete lining
+ Forepoling

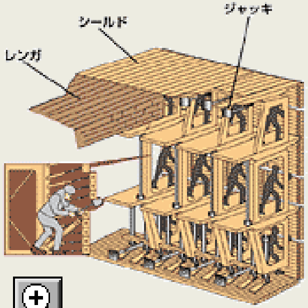
Water control

+ Probe drilling and pregrouting

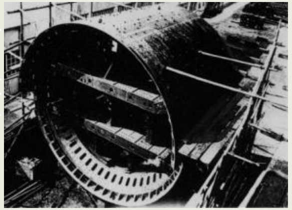
+ Possibility to use TBM as a static plug

Soft Ground TBMs

History



ブルネルのシールドマシン



first shield
In England
(manual)
1825

first shield
under the sea
(manual)
1914

mechanical shield
1950s

slurry shield
1960s

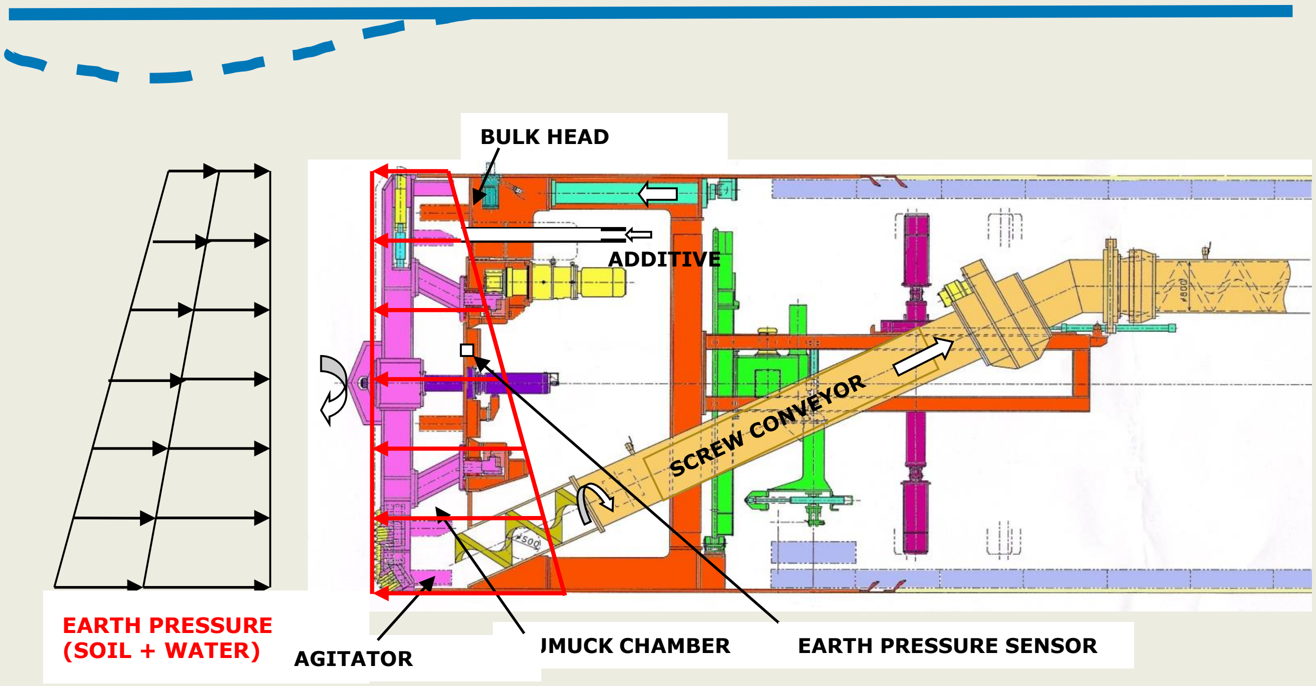
EPB shield
1970s

EPB with foam
1980s

year

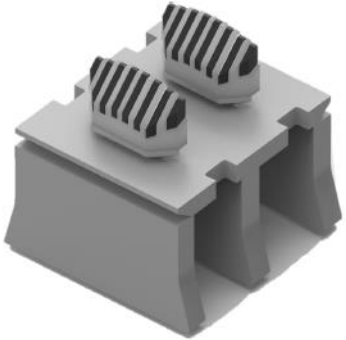
MARKET

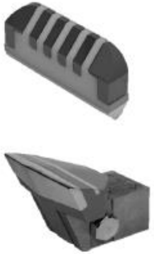
OUTLINE OF EPB METHOD
Earth pressure control by soil

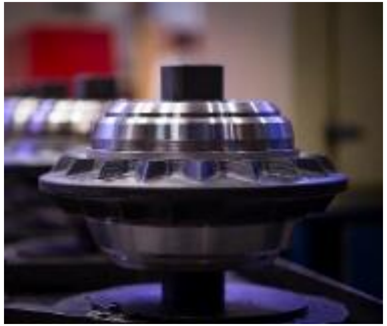


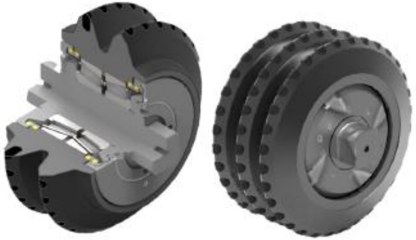
Soft Ground tools

Cutting Tools



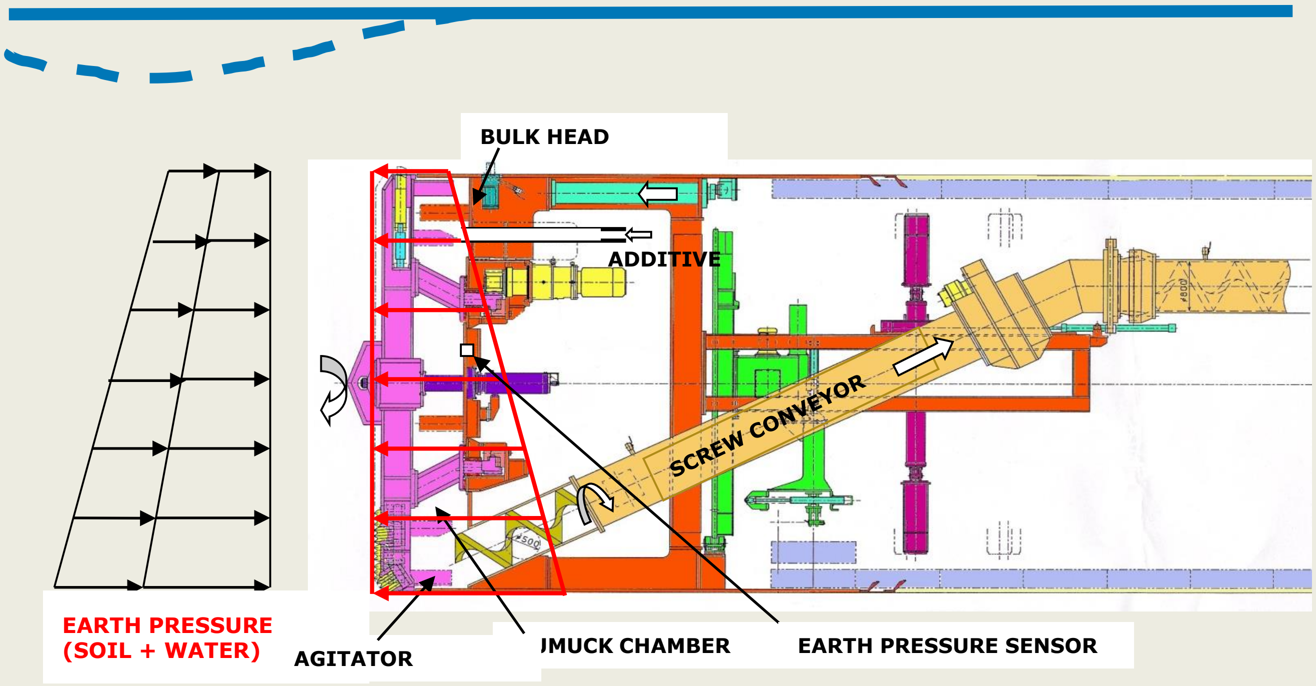






Earth Pressure Balance Machines (EPBs)

OUTLINE OF EPB METHOD
Earth pressure control by soil



Essential parts of EPB Operation

- Withhold earth pressure to avoid ground settlement

- The muck need an plastic consistency to be able to hold sufficent pressure in the screw.

- Can operate in «open» mode if the face is stable

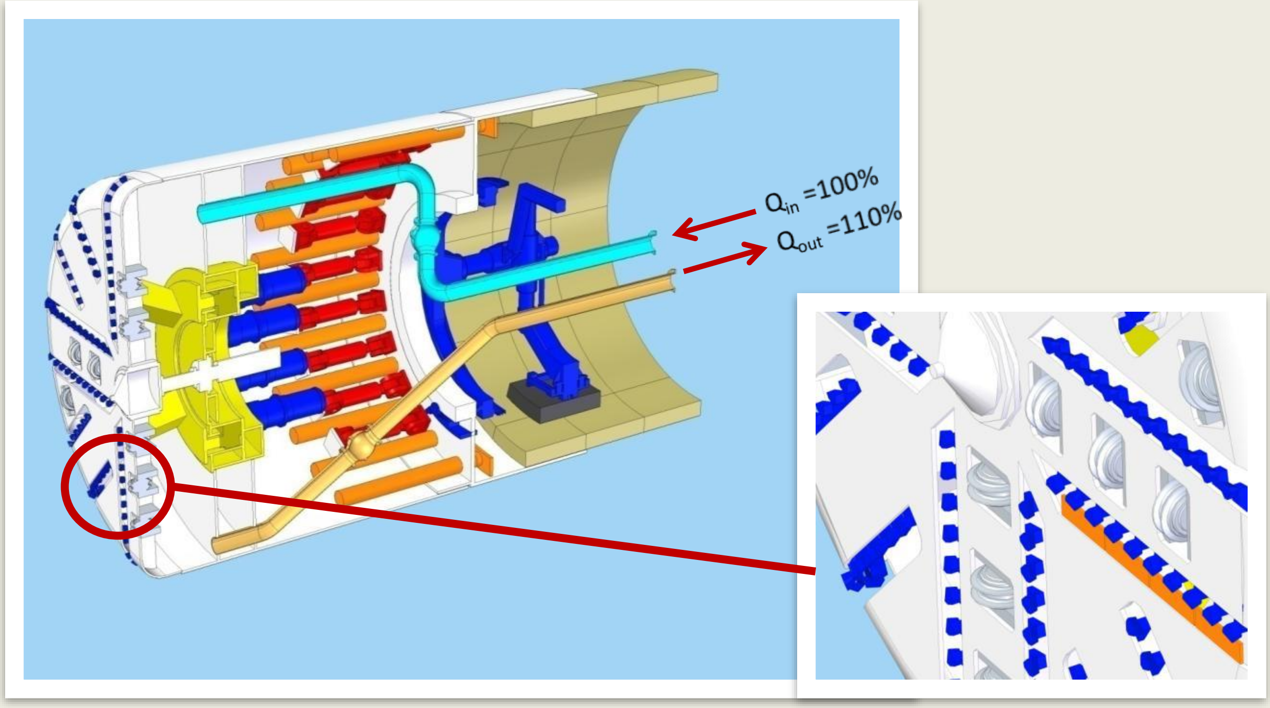

SFMTA
central
subway
"MOM CHUNG"
Robbins

Slurry TBMs

Face Support

Control of flow in & flow out

$(Q_{out} > Q_{in})$



Essential parts of slurry Operation

- Withhold earth pressure to avoid ground settlement
- Can be prone to abrasivty in the slurry system
- Requires a more area on the surface (slurry seperation plant)

Crossover / Multi–mode TBMS

Why Crossover Machines?

Today, Crossover Machines are required to excavate different types of ground efficiently with one machine.

A Crossover machine may be considered if your tunnel includes a combination of these elements:

- You want to excavate self supporting ground → Open Mode (hard rock)
- You want to excavate self supporting ground but want to mitigate underground water ingress → Closed Mode (Compressed air, Slurry, EPB, etc.)
- You want to excavate unstable ground → Closed Mode (Compressed air, Slurry, EPB, etc.)

Cr

Considerations for Crossover Machines

- **Safety**
  Conversion work should be carried out in a confined space
- **Schedule**
  Conversion works can be time-consuming, so a detailed plan must be in place
- **Geological information**
  - To decide when and where to convert, reliable geological information will be required
  - Adequate probe drilling is essential to determine the ground conditions ahead of a Crossover TBM
- **Cost**
  - Up-front costs may be high, but significant savings in the long-run
  - Durability: savings in repair costs
  - Dual-Mode: multiple project usage

How to chose a TBM?

How to choose a TBM

- Geology
- Requirements from the owner
- Expectations from external environment
- Cost
- Risk
- Competence

Design Considerations

- Weakness zone /Weak rock
  - Rock mass quality
  - Material flow
  - Water flow/ingress
  - Face stability
  - Cutter rotation
  - Thrust reaction (grippers)

- Stability
  - Rock support system
  - Rock mass quality

- Water ingress(pressure)
  - Detection
  - Water system
  - Pressure
  - Amount
  - Groutable?

- Weakness zone /Weak rock
  - Type of machine
  - Lining?
  - Rock support methodology
  - Grouting capabilities
  - Torque
  - Invert thrust systems
  - Cutters?

- Stability
  - Rock support methodology
  - Type of TBM

- Water ingress(pressure)
  - Probe drilling
  - Pregrouting
  - Pumping
  - Watertight design?

Design Considerations

- Muck Removal
  - Clogging
  - Capacity
- Squeezing
  - Rock stresses
  - Rock types
  - Clays (Montmorllionite)
- Rock bursting
  - Overburden
  - Rock stresses
  - Rock types
- Karst
- Blocky ground
  - Fracturing / RQD
  - Descriptions
- Extremely hard and abrasive rock
  - UCS
  - Fracturing
  - Abrasivity

- Muck removal
  - Foam system
  - CHD design
  - Muck buckets
- Squeezing
  - Shield length
  - Shield lubrication
  - Stepped shield
  - Overbore
- Rock bursting
  - McNally?
  - Shield?
  - Shotcrete
- Karst
  - Probe drill
  - Geophysics
- Blocky ground
  - CHD design
  - Wear plates
  - Cutter protection
  - Wider tip widths
  - Shield dimensions
- Extremely hard rock
  - CHD Design
  - Cutter protection


Thank you!

TBMs FOR MIXED GROUND CONDITIONS, NEW POSSIBILITIES

Werner Burger, Herrenknecht AG

Under Oslo – Part 2, August 29th 2019

Ground Conditions

- **Soft Ground**
  - Cobbles and boulders (soft ground and rock cutting tools)
    - Stable or unstable face (positive face support)
      - Waterbearing ground below water table (face support pressure)
        - Coarse or fine grained ground (TBM type EPB, Slurry or VD)
- **Hard Rock**
  - Fault zones, fractured rock
    - Stable or unstable face and tunnel wall, overbreaks (gripper or shielded TBM, ground improvement)
      - Waterbearing rock below watertable (pre-excavation grouting, freezing, closeable shield)

Mixed Ground Conditions

No common understanding in the industry about mixed ground conditions

- Variant 1, based on required cutter head tool dress

  ➔ TBM cutter head needs dual tool dress options of soft ground tools (scrapers) and rock cutting tools (disc cutters)

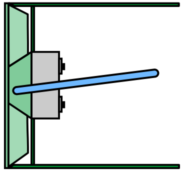
  - Soft ground containing cobbles and boulders of a size too large for the downstream mucking system (cutting at the face required)

- Variant 2, based on anticipated face conditions

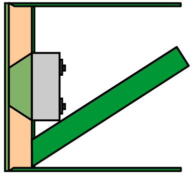
  ➔ TBM cutter head needs dual tool dress options of soft ground tools (scrapers) and rock cutting tools (disc cutters)

  - Full face rock, full face softground and rock - softground transitions along the alignment
  - Potential to change between closed mode and open mode operation along the tunnel alignment (Multi Mode TBMs)

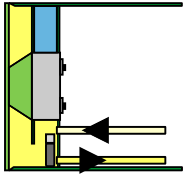
Existing Types of Shielded TBMs



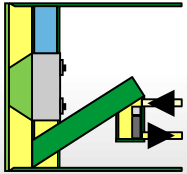
Open Shield TBM (Single or Double Shield)
Predominately stable face conditions, non pressurized excavation chamber, dry primary mucking system



EPB TBM
Unstable face conditions, pressurized excavation chamber, fine grained material, screw conveyor as primary mucking system



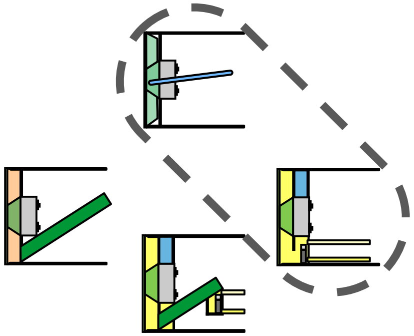
Slurry TBM (Mixshield)
Unstable face conditions, pressurized excavation chamber, coarse grained material, slurry circuit as primary mucking system



Variable Density TBM
Unstable face conditions, pressurized excavation chamber, fine to coarse grained material, screw conveyor and slurry circuit as primary mucking system

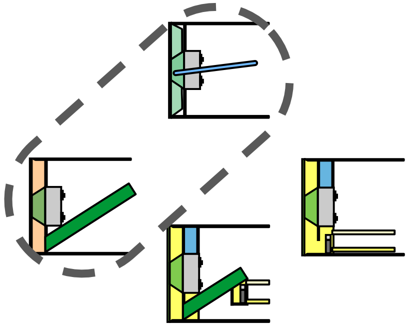
Convertible Machines, Multi-Mode Options

Open Shield ↔ Slurry



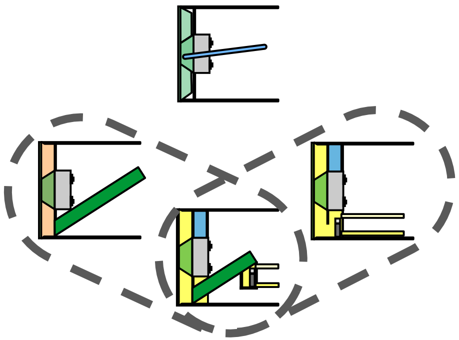
- State of the Art Technology
- First Application for Grauholz Tunnel in 1989
- Retractable muckring
- Two tunnel mucking systems (wet – dry)

Open Shield ↔ EPB



- State of the Art Technology
- First Application for Glattstollen in 1991
- EPB open mode or retractable muckring

Slurry ↔ EPB



- Variable Density TBM
- First Application for Klang Valley KL in 2012
- Seamless transition from EPB to HD-slurry to LD-slurry

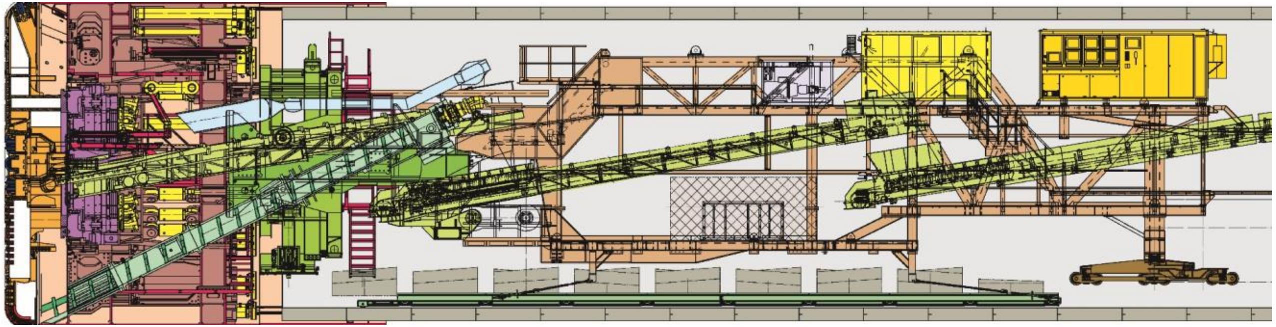
Saverne TGV Rail Tunnel

Saverne, France

- Multi Mode TBM (EPB – open mode) Ø 10,01 m
- Tunnel length 2 x 4 km
- Water pressure max. 3 bar in soft ground section

Saverne - Change Between Open Single Shield and EPB

Center Belt Conveyor And Screw Conveyor As Primary Mucking System



Closed Mode - Earth Pressure Balance
- Screw conveyor in forward position for full capacity
- Center belt and muck hopper retracted, rotary installed
- Cutterhead muck transport channels partially removed

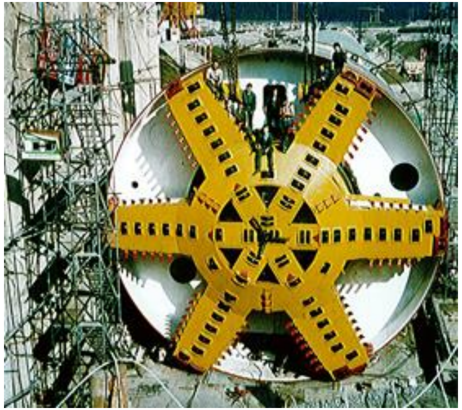
Open Mode
- Screw conveyor in retracted position (limited capacity)
- Center belt and muck hopper in forward position, rotary removed
- Cutterhead muck transport channels installed

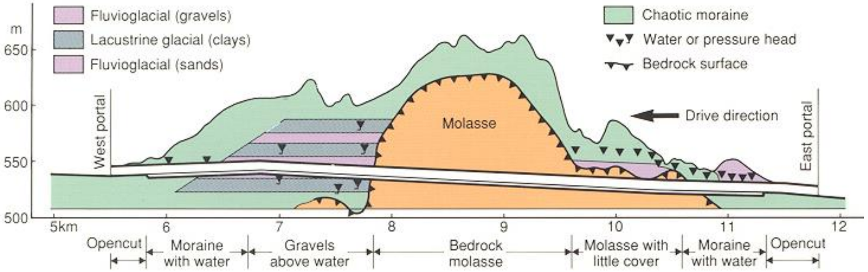
Saverne - Change Between Open Single Shield and EPB

- Screw conveyor and center belt / muck hopper for primary mucking system
- Approx. four days required for open – closed mode change
- Two short closed mode sections along the alignment (approx. 5%)
- Very high rock/soil abrasivity

Grauholz Tunnel 1989

Bern, Switzerland

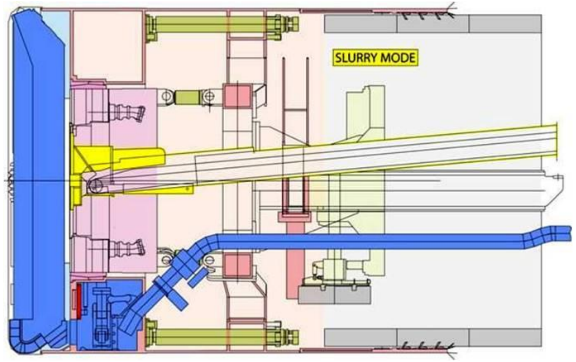


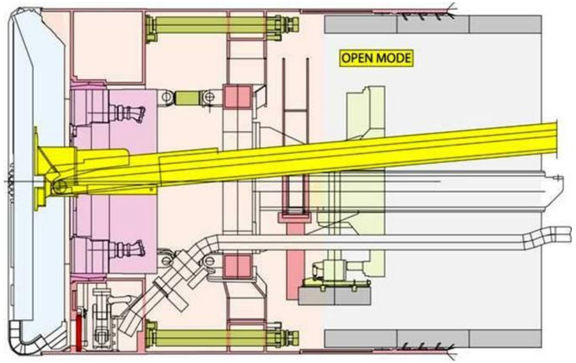


- Multi Mode TBM (slurry – open mode) Ø 11,6 m
- Tunnel length 5,6 km
- Water pressure max. 4 bar

Change Between Open Single Shield and Slurry

Center Belt Conveyor And Slurry Circuit As Primary Mucking System





Closed Mode – Slurry machine
- Submerged wall gate open
- Center belt and muck hopper retracted and sealed
- Slurry circuit and treatment plant in operation

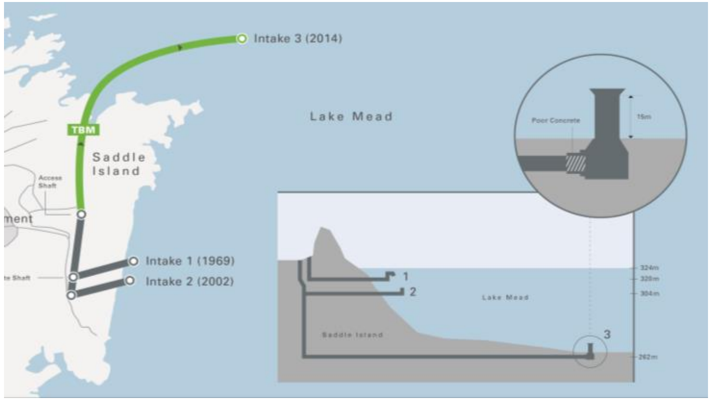
Open Mode
- Submerged wall gate closed
- Center belt and muck hopper in forward position
- Closing / Mode change within 2 - 4 hours

Weinberg Tunnel
Zürich, Switzerland

- Slurry circuit and center belt / muck hopper for primary mucking system
- Approx. one week required for open – closed mode change
- 10% of the tunnel length in closed slurry mode at the end of the drive for Limmat river crossing (transition from molasse rock in gravely material)

Lake Mead Intake #3

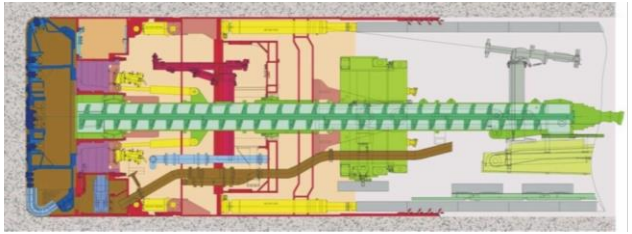
Las Vegas, NV

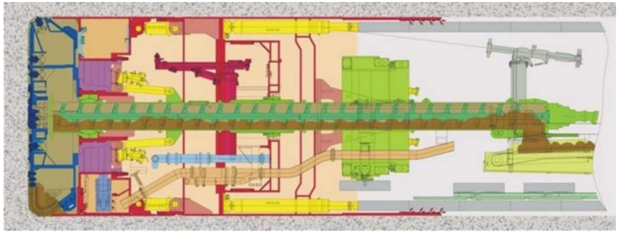


- Multi Mode TBM (slurry – open mode) Ø 7,18 m
- Tunnel length 4,8 km
- Water pressure max. 15 bar

Change Between Open Single Shield and Slurry

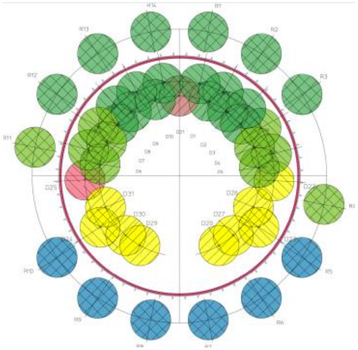
Center Screw Conveyor and Slurry Circuit as Primary Mucking System
(Special Version for Lake Mead Intake No. 3 Tunnel)

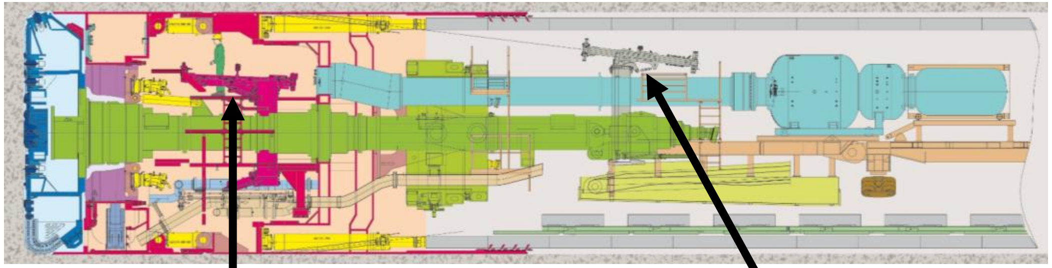




- Open mode with dry primary muck discharge system (screw conveyor)
- Open mode with cyclic pre excavation grouting
- Open mode with cyclic per excavation grouting in closed static conditions
- Closed mode with hydraulic muck discharge system under reduced face pressure and atmospheric chamber access
- Closed mode with full face pressure, potential for positive face support and pressurized chamber access

Lake Mead Intake No. 3 – Pre Excavation Grouting Drill Pattern

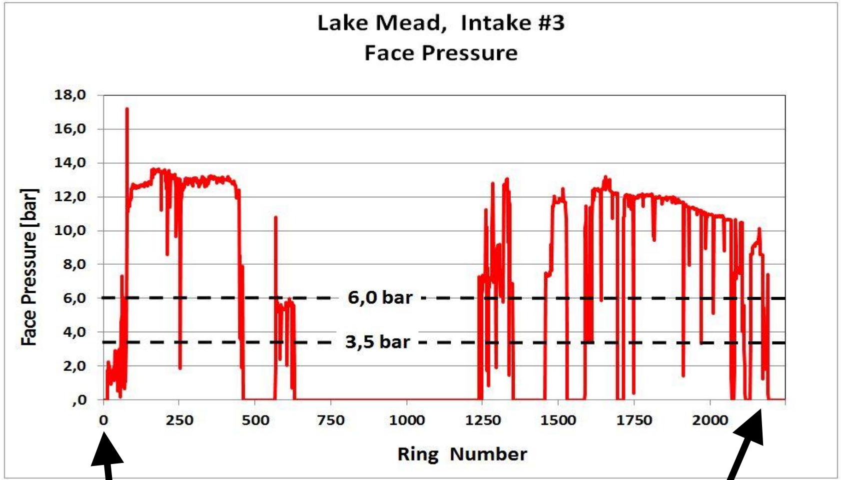




Two permanent installed front drills for face drill pattern

One permanent installed rear drill for periphery drill pattern

Lake Mead Intake No. 3 – Closed Mode vs. Open Mode



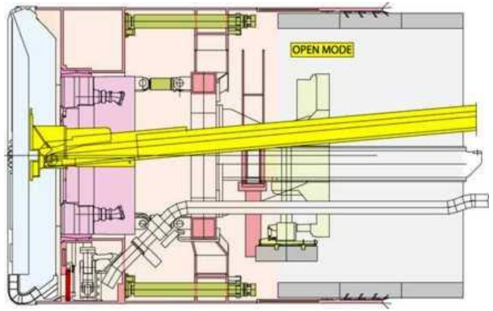
Real site experience:

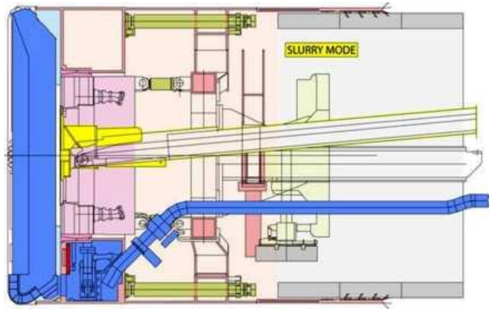
- Several attempts for pre-excavation grouting with limited success
- Closed mode at full water pressure of 10 – 13bar as preferred mode of operation along high water inflow sections

Hallandsås Tunnel
Båstad, Sweden

- Multi Mode TBM (slurry – open mode) Ø 10,53 m
- Tunnel length 2 x 5,6 km
- Water pressure max. 13 bar

Hallandsås Tunnel – The Multi Mode TBM concept

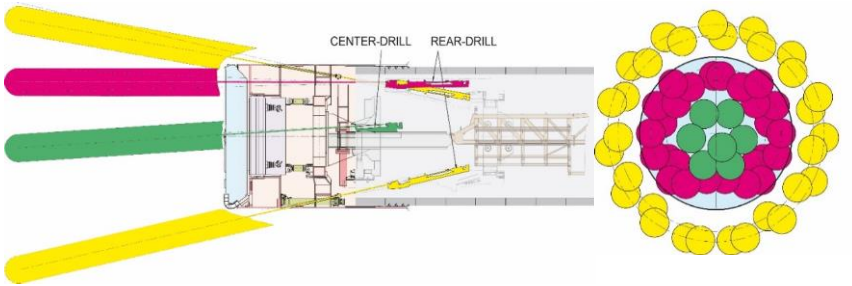




- Open mode with dry primary muck discharge system (belt conveyor)
- Open mode with cyclic pre excavation grouting
- Open mode with cyclic per excavation grouting in closed static conditions
- Closed mode with hydraulic muck discharge system under reduced face pressure and atmospheric chamber access
- Closed mode with full face pressure, potential for positive face support and pressurized chamber access

Hallandsås Tunnel – Probing And Pre-Excavation Grouting

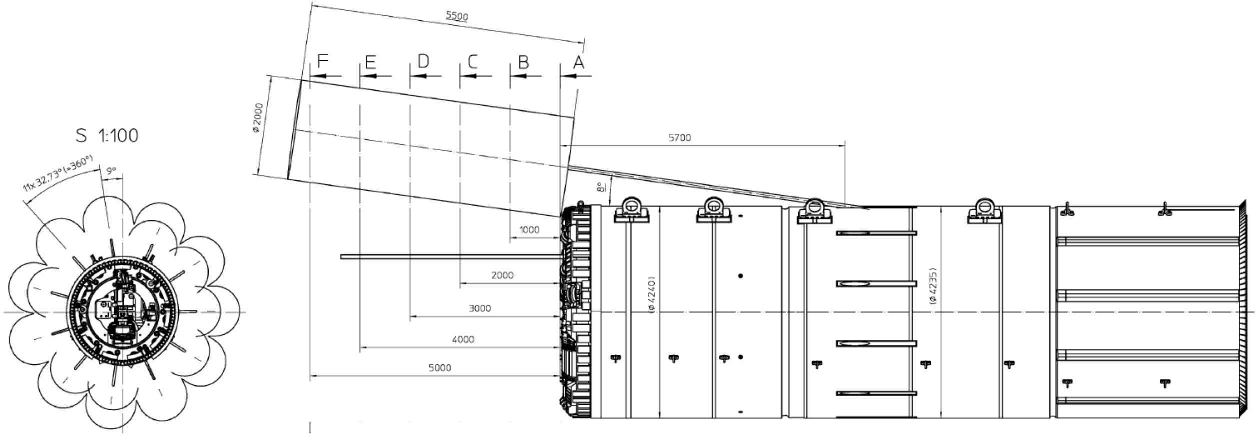
- Three permanent drills behind shield for periphery and outer face coverage
- Two temporary drills in shield
- Temporary mounted drill in center area and erector



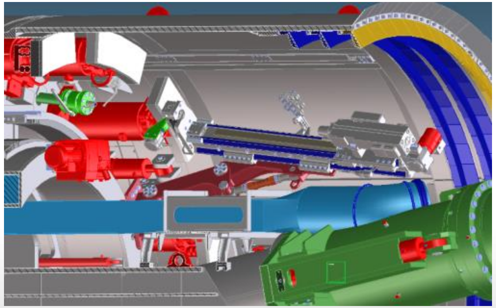
Real site experience:

- Predominately open mode operation with frequent pre-excavation grouting
- Very limited use of closed mode option due to severe blocky face conditions
- Closeable TBM concept beneficial in order to provide static water conditions for pre excavation grouting, rear barrier construction and inflow reduction during standstill periods

Pre-Excavation Grouting for Small Diameter TBM



- 360° periphery drill pattern with approx. 8° lock-out angle feasible for a 4m TBM
- Drill rig temporary erector mounted for periphery drill pattern
- Permanent mounted drill in shield for 1 or two face positions feasible

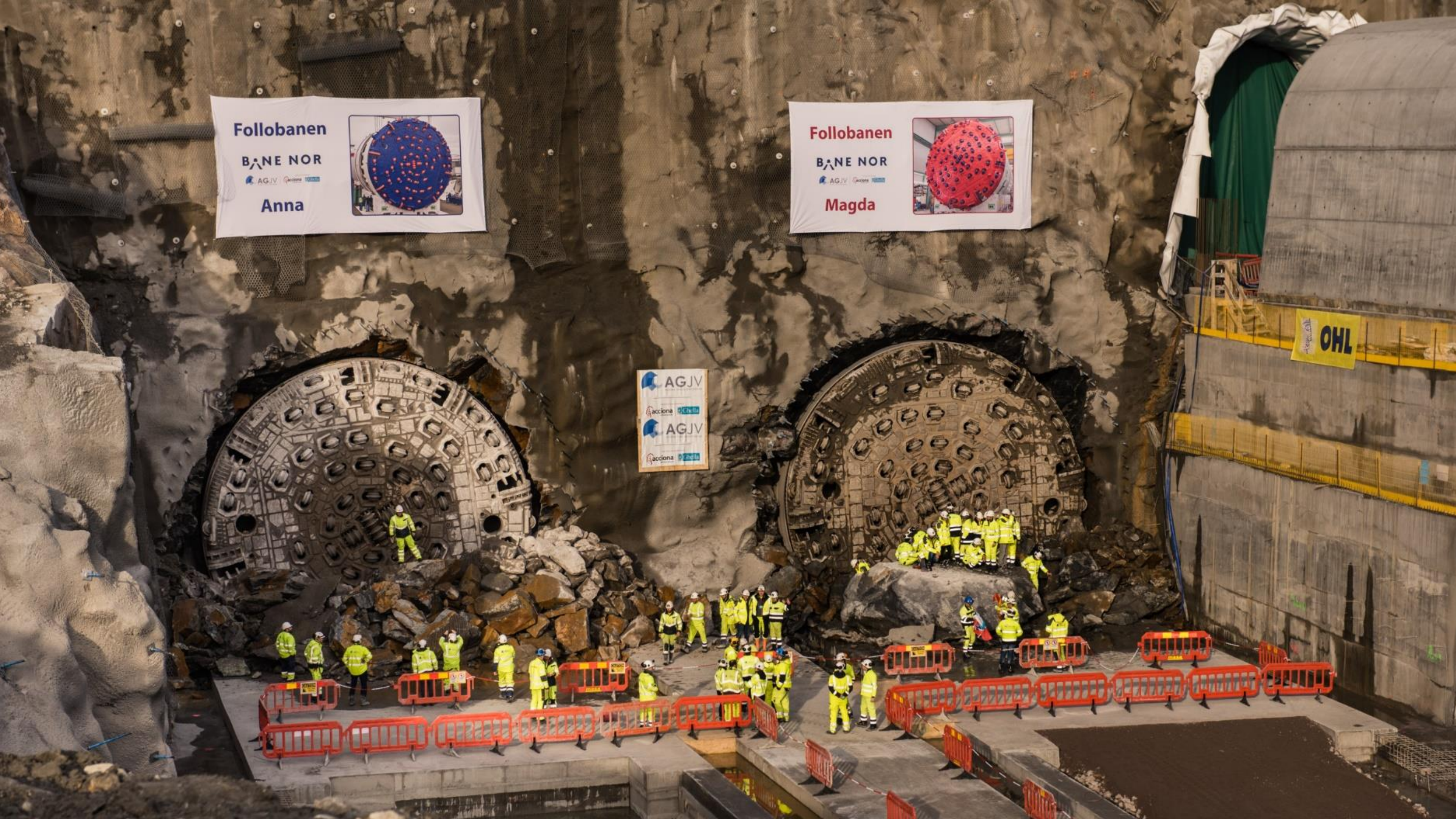


TBMs For Mixed Ground Conditions

- Four basic shielded TBM types for different ground conditions are available
- Mixed ground conditions may force into compromises or be addressed with a combination of the different TBM types ➔ Multi Mode TBM
- Pre-excavation grouting for ground improvement or inflow water control may be an alternate solution or additional “on - board” tool
- For difficult mixed ground conditions the provision of a variety of different “on-board tools” can be the key to success (Multi-Mode concept, pre-excavation grouting, closeability, different backfill systems, excess water handling systems…)







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OHL

NTNU

Norwegian University of Science and Technology

Special requirements for the TBMs for use under Oslo

Amund Bruland

Under Oslo 29.08.2019

Content

- The ground conditions of Oslo
- The future tunnels of Oslo
- The TBM requirements, part 1
- Some specific topics/requirements
- Project design
- Conclusive remarks

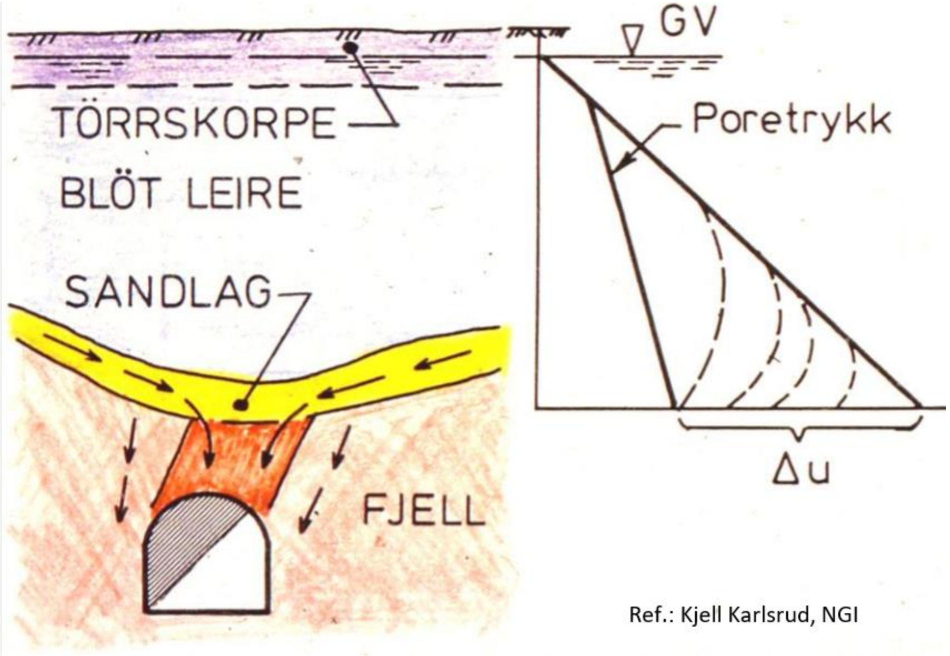
The rocks of Oslo

From Boge and Johansen, Under Oslo 1

- Precambrian gneisses and granites
- Cambrian-Ordovician-Silurian – sedimentary rocks, limestone, sandstone, shist, black shale (alum), …
- Permian eruptions and intrusions – basalt, syenite, diabase, granite, ….

The soils of Oslo

- Marine deposits
  - Quick clay
  - Soft clay
  - Dry and hard clay
  - Sand and gravel
- Man-made deposits
- Buried valleys



The ground conditions of Oslo

- Strong and weak rocks, abrasive and non-abrasive rocks, low fractured to highly fractured rock mass, “aggressive” minerals (alum), from almost dry to quite wet rock masses, …
- Soil of many qualities, soft clay an quick clay in focus
- In general, the ground conditions of the Oslo area are quite well investigated to a quite detailed level, there is a lot of experience available, and a large amount of knowledge is published and available

The Oslo ground challenges

- In a Norwegian perspective, the Oslo underground is considered challenging.
- In a world scale, tunnels have been excavated in more difficult ground conditions than Oslo provides.

The prospective tunnels of Oslo

- Small to large diameters
- At shallow depth in Oslo City
- Up to several hundred metres overburden in suburban Oslo
- In the long perspective – any thinkable purpose
- In the short perspective
  - Railway, subway, roads
  - Water supply
  - Utility tunnels

TBM requirements

My general answer to the given title of my presentation is:

- All available TBM types and features should be evaluated and will probably be needed to excavate future tunnels under Oslo.
- A specific tunnel may be suited for different TBM types and designs, as well as Drill & Blast or other excavation methods
- Hence, there is need for reliable models for estimation of time, cost, risk etc. in the project design phase
- And, there is need for good processes and open minds in the early phases of these complex projects.

Some specific topics

Quick and/or soft clay

- The main approach is lime/cement stabilisation
- Salt stabilisation reported from research projects
- Stabilisation is a slow process and should be done before tunnel excavation starts
- Stabilisation should be done regardless of tunnel or cut and cover excavation
- I.e., the excavation method has low impact on the need to pre-treat difficult ground conditions.

Quick and/or soft clay

A TBM to be used to e.g. cross a buried valley containing quick clay, should at least have the following features:

- Shielded TBM with closed or closeable cutterhead
- Able to withstand a high static ground pressure
- Good possibilities to probedrill and pre-treat the ground ahead of the tunnel face, e.g. through BOPs

Pore pressure reduction

- Usually handled by pregrouting the ground ahead of the tunnel face (in rock)
- A safe and efficient method
- All TBM projects in rock in Oslo, will most likely require an efficient pregrouting system

Mixed face

- Rock – soil
  - Slurry type TBMs are well experienced to handle such conditions
  - Other TBM types may be used, depending on soil quality
- A slurry TBM requires a separation plant, may restrict the starting point of the tunnel
- Rock – rock (typically intrusions in limestones)
  - Shielded or open hard rock TBM

Segmental lining

- Gaskets/seals in alum shale?
- Inflatable gaskets between the segments and the ground to reduce water flow along the lining annulus (stop the water).

Environmental impact

- Oslo City has been leading in setting environmental impact requirements to public construction projects
- E.g.
  - Noise
  - Working hours
  - Fossil free and zero emission construction sites
- Very likely, Oslo will also be in front regarding new environmental impact requirements
- In the long run, this will be beneficial for the industry

Beyond the TBM technology

- Meeting the requirements discussed above may be seen as the responsibility of the TBM suppliers (mainly) and the tunnel contractors (partly).
- However, the clients and consultants, as well as research institutions, have a significant share of the responsibility to meet the future challenges.
- Looking at the development in the TBM technology since 1980, it is a different world today.
- As an example, we will look at a project presented at Under Oslo 1

The new railway tunnel through Oslo

Ref. Elin Bustnes Amundsen

Is there a knowledge gap?

- I was not present at Under Oslo 1, my interpretation is based on the slides from the presentation (available at nff.no)
- The tunnel is intended to be opened in 2035
- It is not clear which options that have been investigated
- The excavation method seems to be decided already 16 years ahead
- The excavation technology to be used in critical parts of the tunnel alignment, seems to be the same as the technology applied roughly 40 years ago.

Conclusive remarks

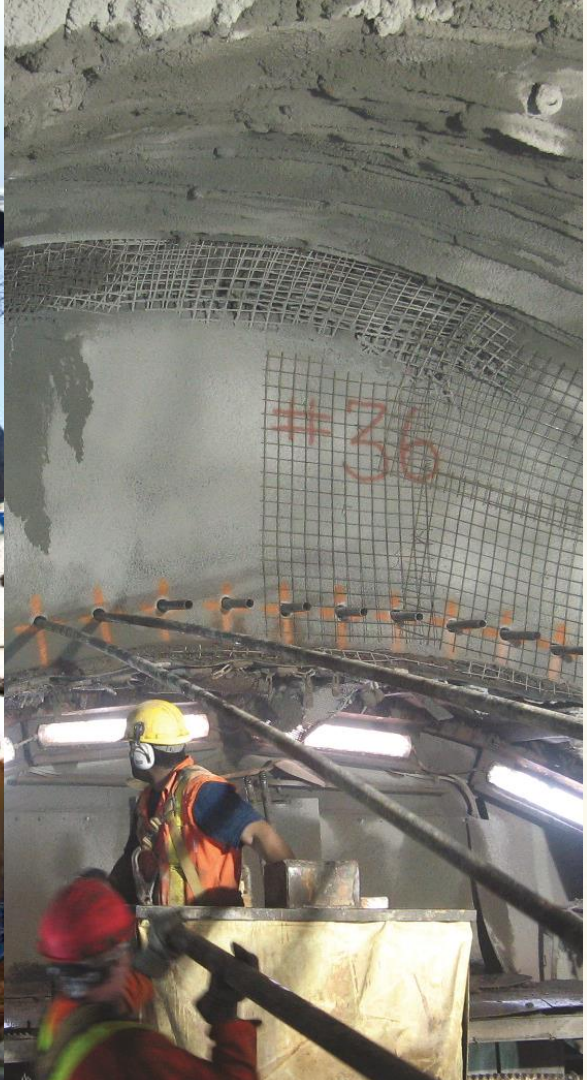
- The «state of the art» in TBM technology is able to handle the ground conditions to be met under Oslo, also for the New Oslo Tunnel.
- The TBM technology has made large steps forward over the last 40 years, i.e. since the last significant TBM project in Oslo.
- There is high quality knowledge and experience available from the TBM suppliers and TBM projects in many places around the world.

Takk for oppmerksomheten!

Case Studies

USE OF A DUAL MODE, CROSSOVER TBM TO EXCAVATE CHALLENGING GEOLOGY

MEXICO'S EMISOR PONIENTE II WASTEWATER TUNNEL



PRESENTATION OUTLINE

MANAGING RISK ON TEP II

OVERVIEW

- Project Overview for Túnel Emisor Poniente (TEP) II
- Primary Challenges
- Risk Mitigation Methods
- Excavation and Solutions

Conclusions

Q & A

PROJECT OVERVIEW

TEP II

Wastewater Tunnel

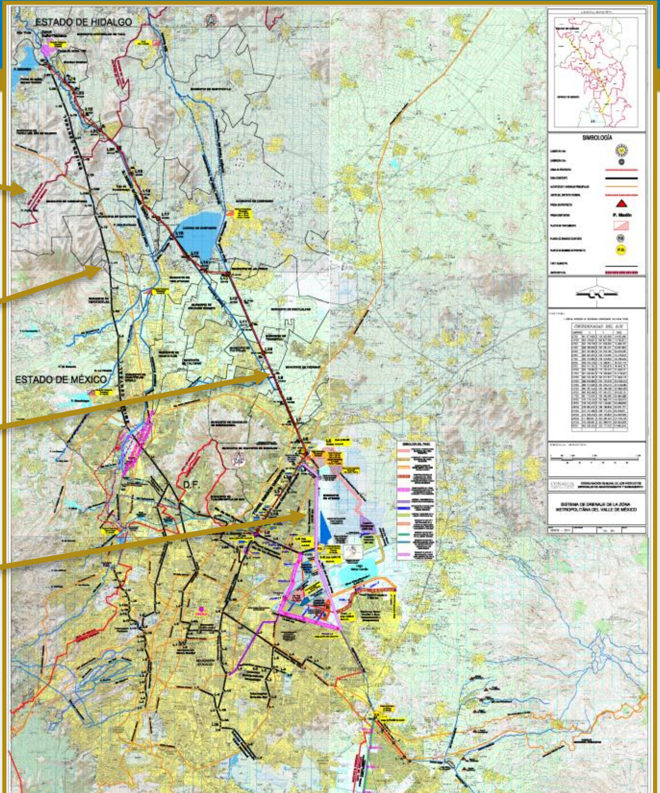
- Location: West of Mexico City
- Excavation Diameter: 8.7 m
- Final Diameter: 7.0 m
- Max Flow: 150 m^3/min
- Mechanized Tunnel Boring

Emisor Poniente II

Tunnel Emisor Central

Emisor Oriente

Dren General

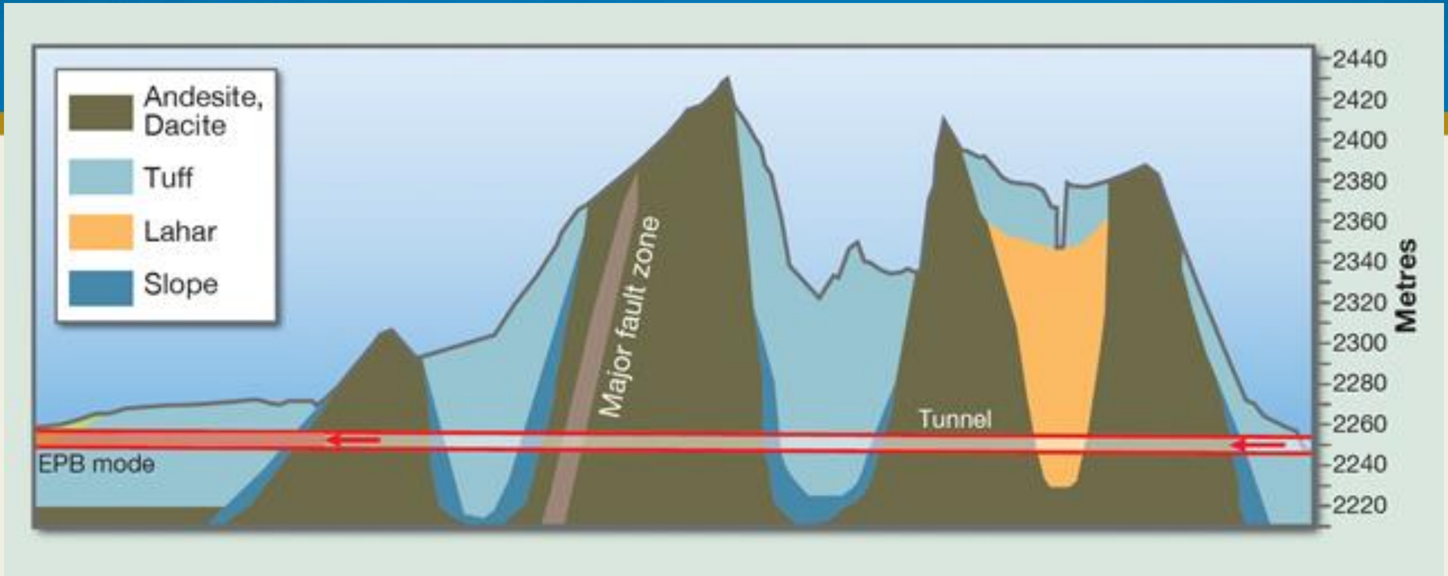



Robbins

PRIMARY CHALLENGES

Challenges

Geological Risks



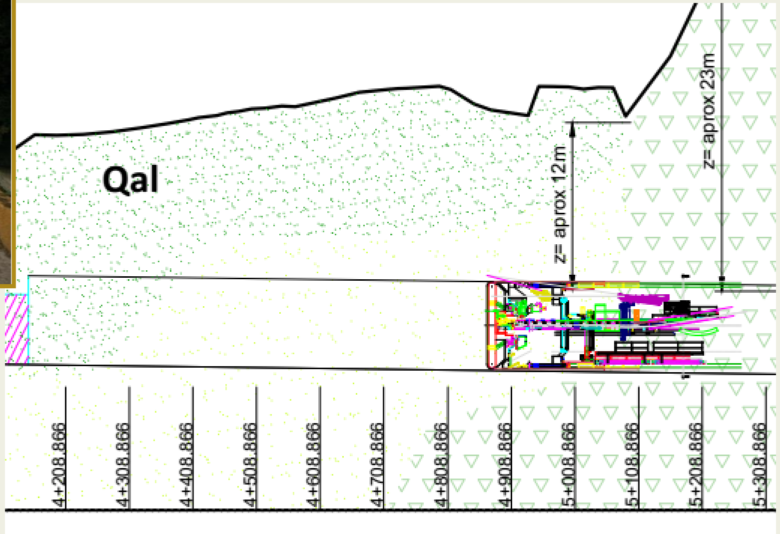
Expected Geological Concerns:

- Estimated Water Inflow: 180 liters/min
- Fault (silty clay): 69 m @ Chainage 5 + 718 to 5 + 649
- Hard rock
- Soft ground (Sand, Clay, Soil)
- Flowing Ground

Challenges

Low Cover

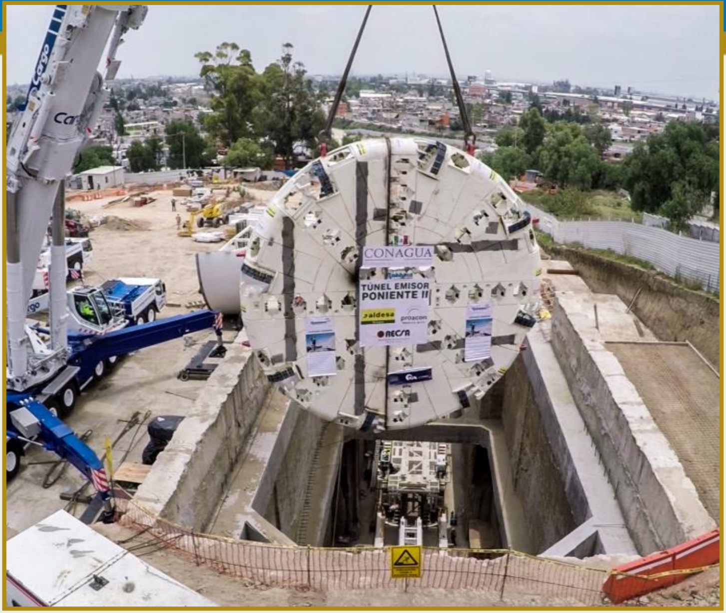
Coverage above TBM as little as
4m from structure foundations



Machine Design

GENERAL SPECIFICATIONS

- Hard Rock conversion to EPB
- Bore Diameter: 8.72 m
- Cutterhead Power: 3,630 kW (VFD)
- Cutterhead Max Torque: 14,875 kNm
- Cutterhead Speed: 0 - 6.5 RPM
- Thrust Max: 72,000 kN
- Active Articulation
- TBM Weight: 1,000 tons



Purpose built TBM: Crossover XRE

Special Design Features:

Adaptable Cutterhead

Wide-ranging Drilling Equipment

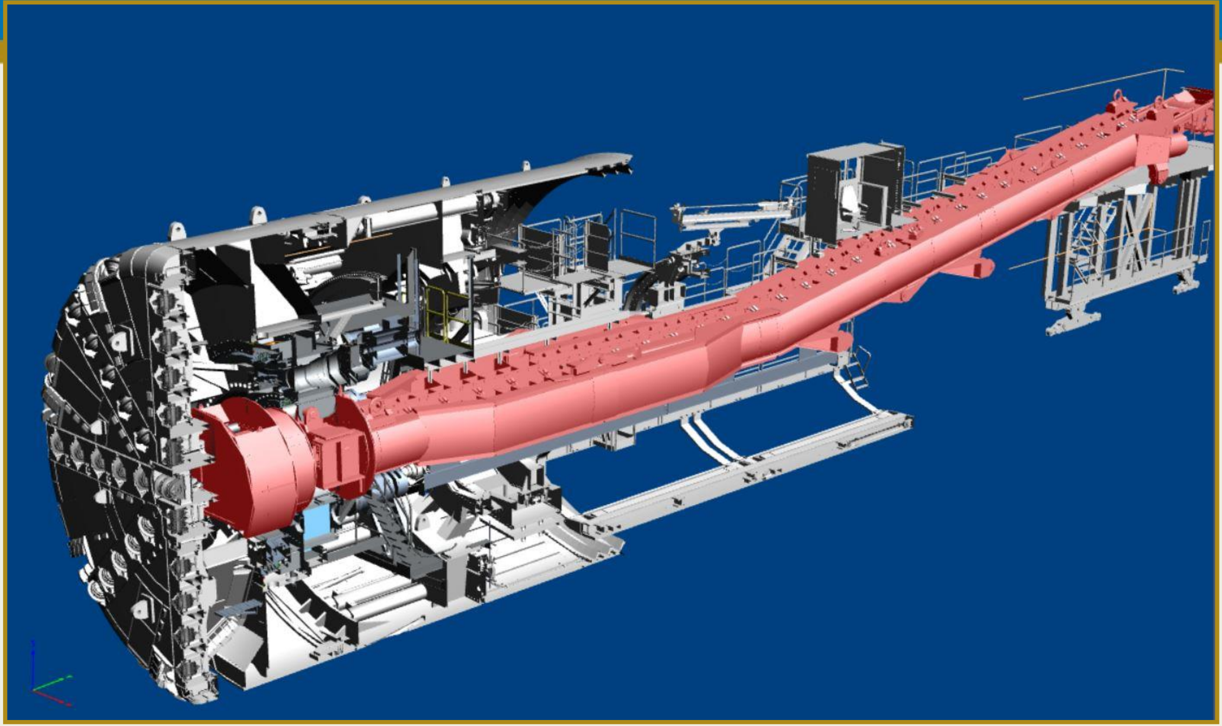
Two-Stage Main Drive Reducers

Bulkhead Closure Gate

Conversion of the de-mucking system

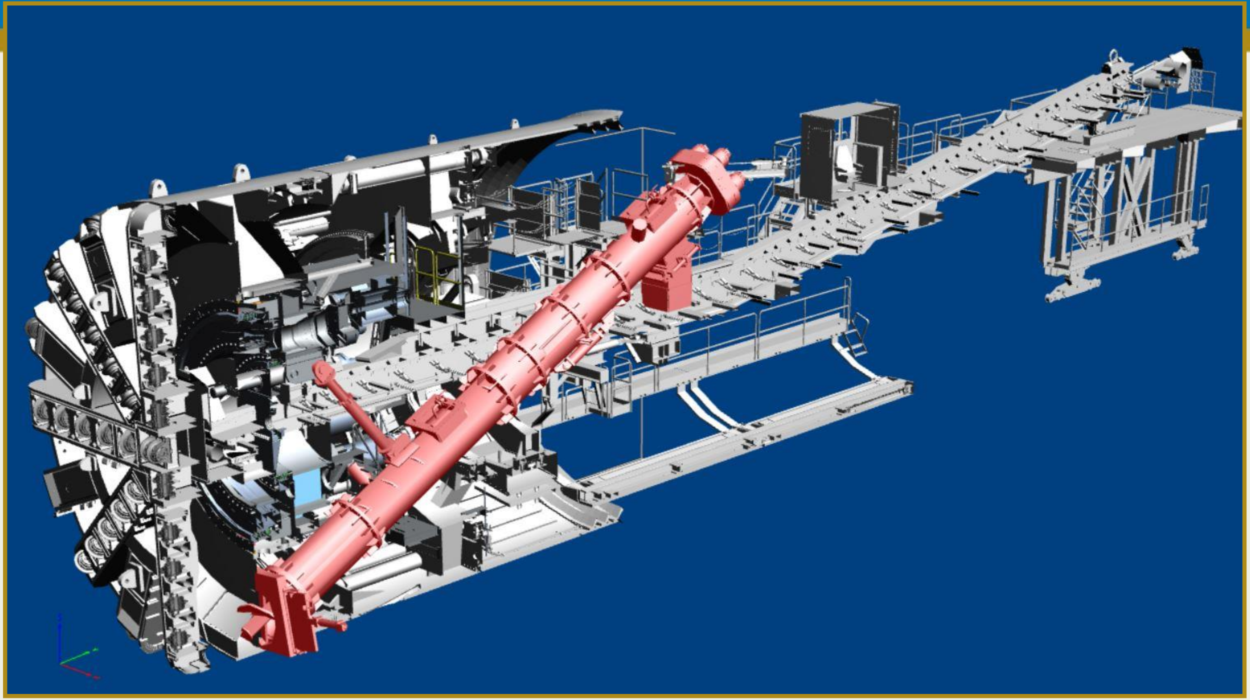
Machine Design

Crossover TBM in Rock Configuration



Machine Design

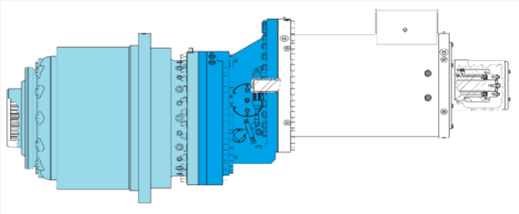
Crossover TBM In EPB Configuration



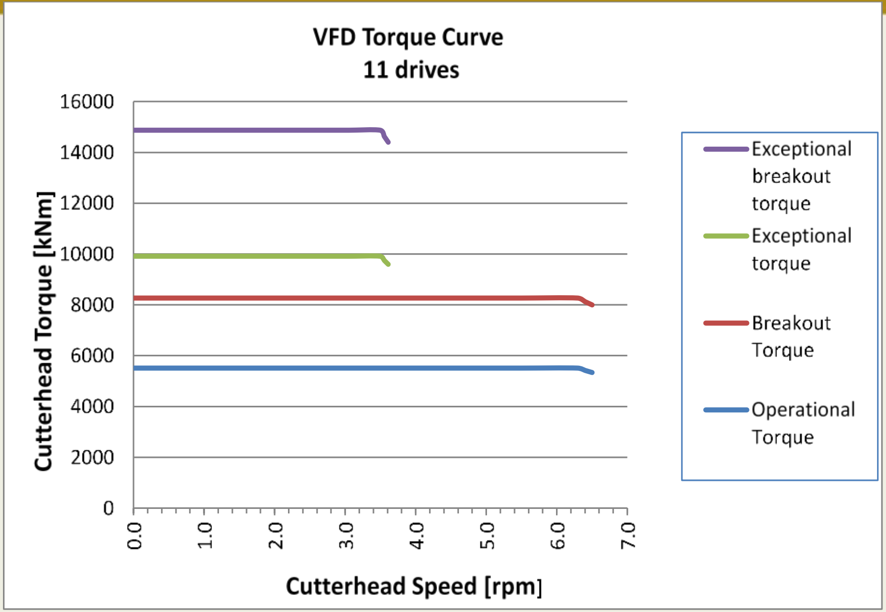
Machine Design

Drives

+ (Ø8.7 m)
+ High Speed/Low Torque
+ Low Speed/High Torque



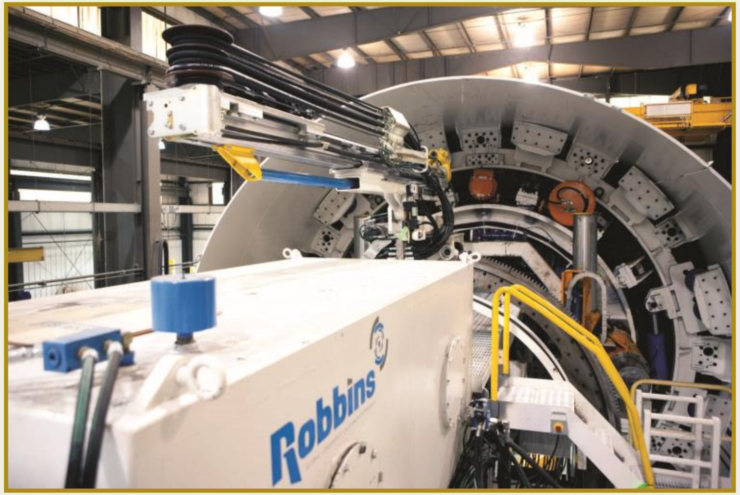
Two-Speed Gear Reducers



Torque Curve

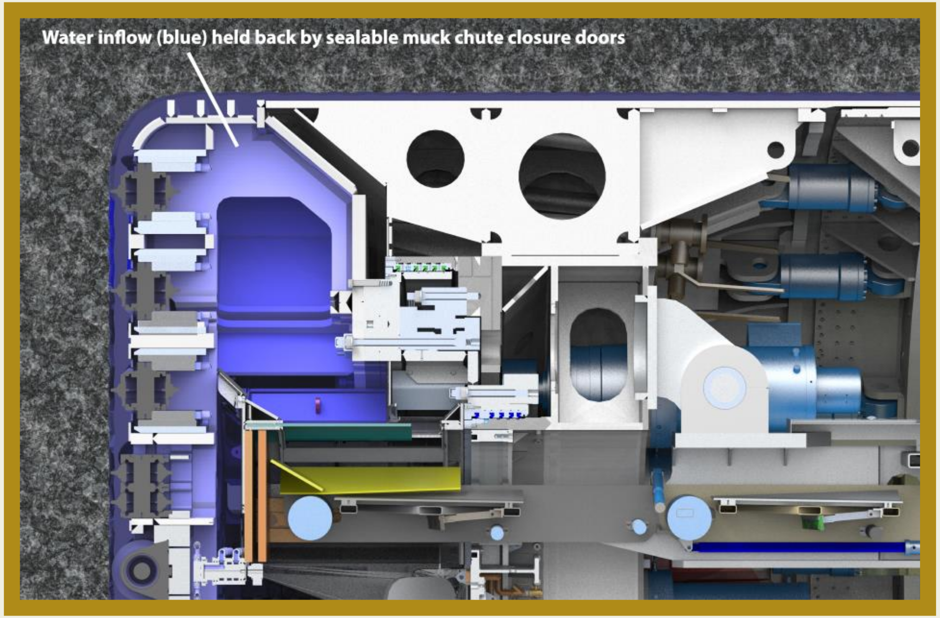
Machine Design

Probe and Canopy Drills



Machine Design

Closure Doors on the Bulkhead



RISK MITIGATION MEASURES

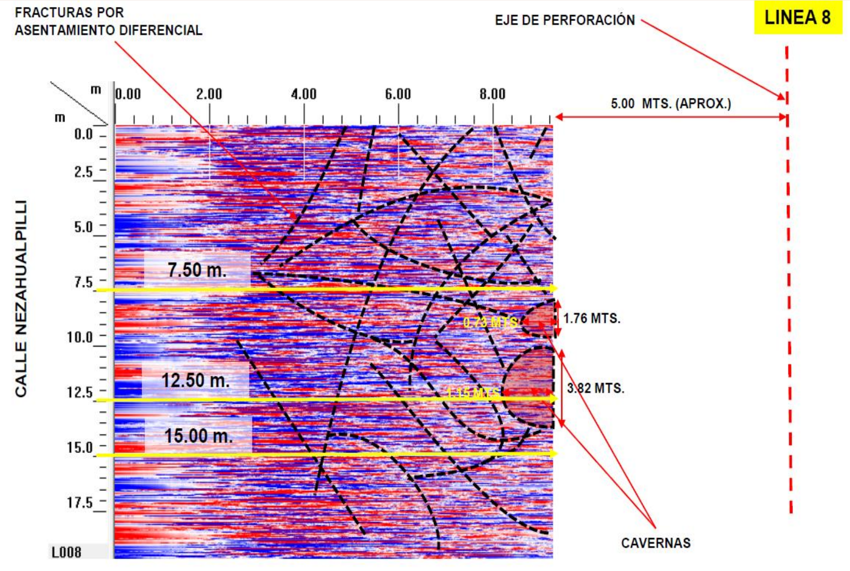
Challenges & Solutions

Water Inflow Video

+ Water inflow in **excess** of 180 l/min!!!
+ Required machine to be "closed"

Challenges & Solutions

Unexpected Geology



Underground Caverns

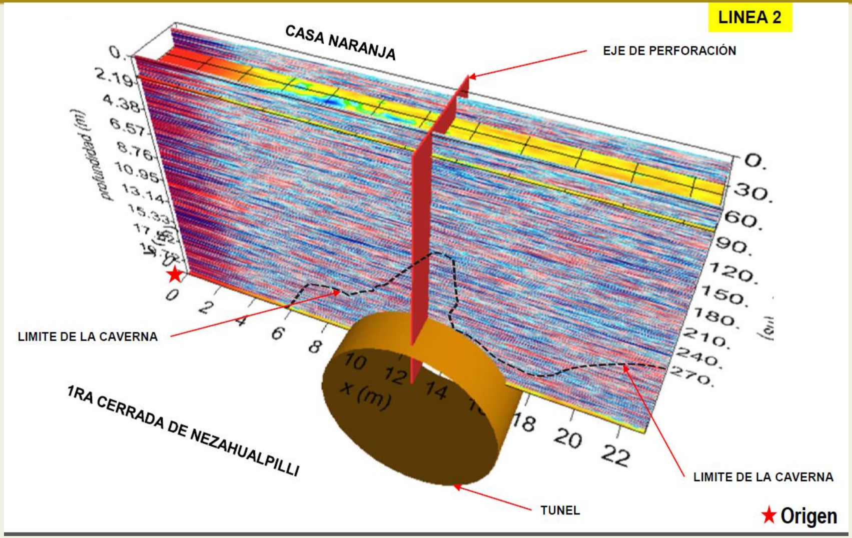
(as detected by Georadar)

Report Disclaimer: "THE RESULTS OBTAINED WITH THE USED SETTINGS INDICATE THE PHYSICAL CHARACTERISTICS OF THE STUDY AREA,

...HOWEVER IT IS NECESSARY TO TAKE INTO ACCOUNT THAT SOME STRUCTURES CANNOT BE CLEARLY DEFINED..."

Challenges & Solutions

Unexpected Geology



Report Disclaimer:

"THE RESULTS OBTAINED WITH THE USED SETTINGS INDICATE THE PHYSICAL CHARACTERISTICS OF THE STUDY AREA,

...HOWEVER IT IS NECESSARY TO TAKE INTO ACCOUNT THAT SOME STRUCTURES MAY NOT BE DEFINED CLEARLY OR DO NOT APPEAR IN THE RESULTS, DUE TO THE LOW CONTRAST OF THE ELECTROMAGNETIC RESPONSES OF DIFFERENT VOLCANIC PRODUCTS PRESENT MATERIALS IN THE AREA OF STUDY."

Challenges & Solutions

Caverns

- Cavern
- Est. size: 90m³
- Urban Zone

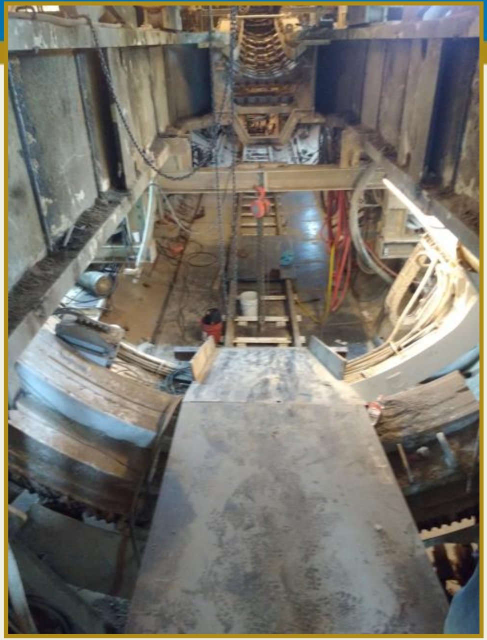
- Injections from cutting chamber

- 38 bore holes from surface
- Bentonite 4 m³
- Pea gravel
- Grout: 26.6 m³

- Foam injected from TBM, 930 liters

Challenges & Solutions

Crossing Over to EPB

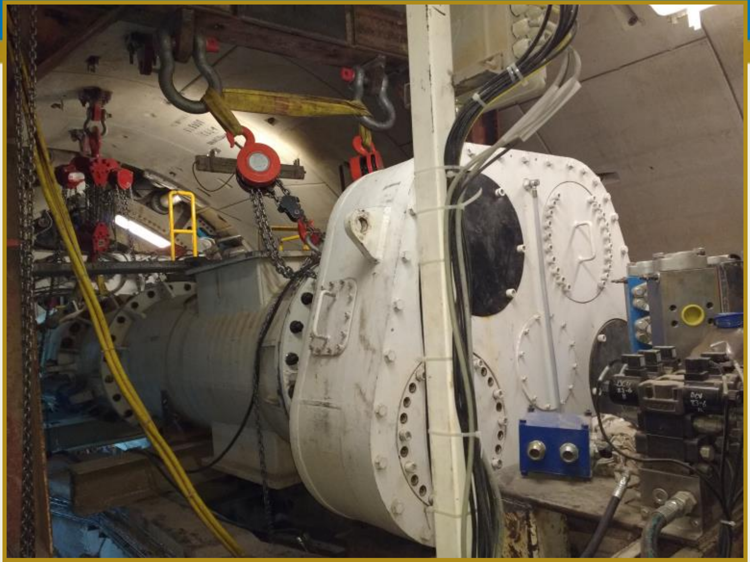


Remove TBM Conveyor

Cut Plates on the Cutterhead

Challenges & Solutions

Conversion to EPB Mode



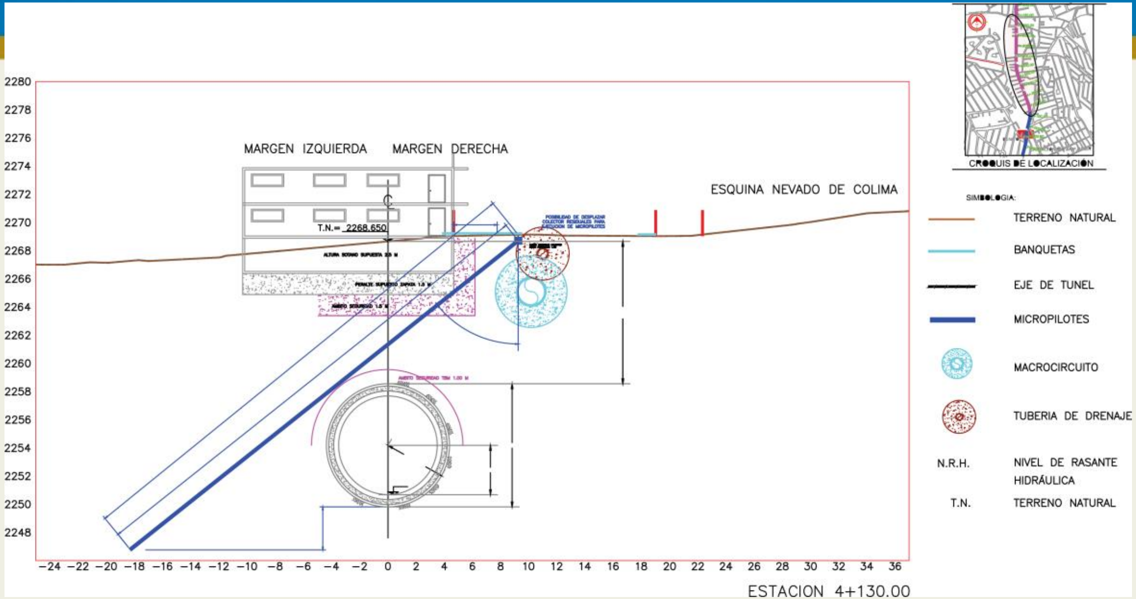
Screw Conveyor Installation in Two Sections

Rotary Union

Conversion started on Oct. 25 and completed on Jan. 15.
Started boring in EPB mode on January 8, 2017

Challenges & Solutions

Low Overhead in Urban Area



+ As low as 4 m of cover between the top of the tunnel and residential foundations
+ Micropiles used at 1 m intervals to successfully stabilize the soils

Challenges & Solutions

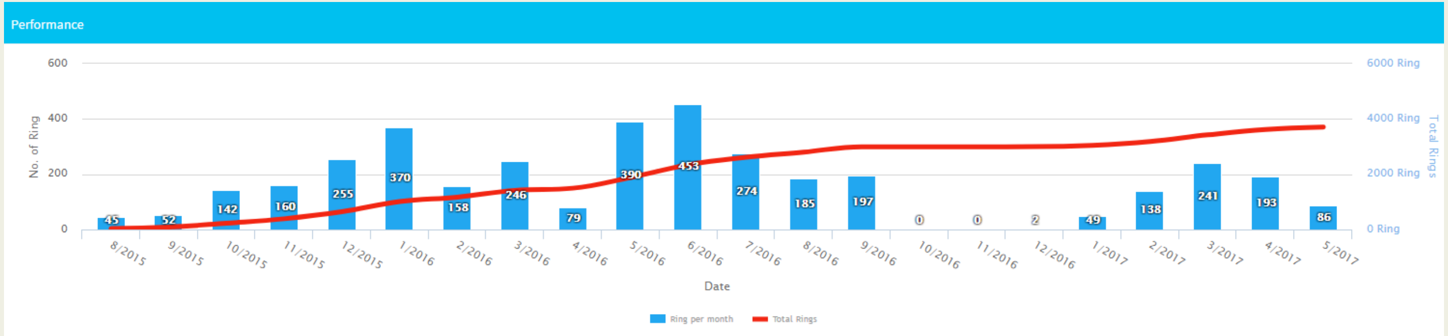
Conditioned Muck

+ In soft ground, watery muck was conditioned with bentonite and controlled well.

Conclusions

Overall Advance Rates

Optimization for Conditions



Three National Records

Swift Advance Rates

+ Final breakthrough occurred on June 8, 2017
+ Best Day: 57 m
+ Best Week: 231 m
+ Best Month: 702 m

Intermediate breakthrough May 2016

Lessons Learned

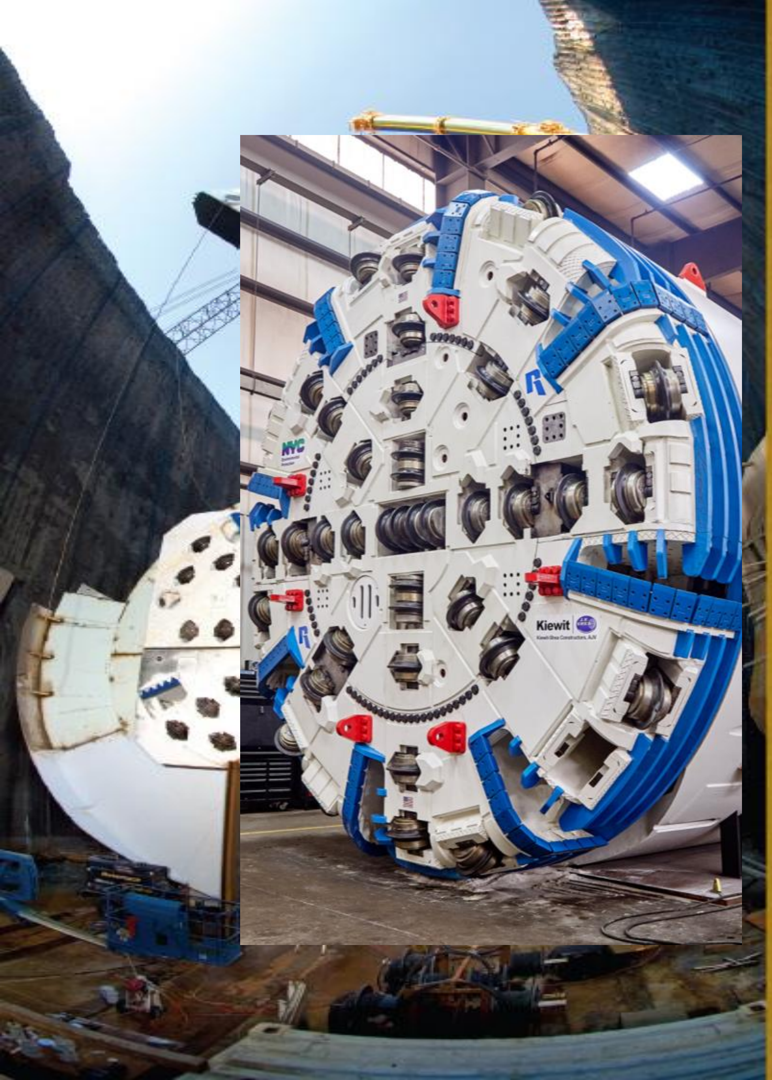
Contingency Plans are Key

+ Having the right geological/geotechnical information is vital.
+ Contingency planning is needed well in advance and incorporated into the design
+ Plans were in place to deal with challenges
+ Probe drilling would be the ideal way to detect fault zones and caverns ahead of the TBM
+ Crossover design maximized advance rates in hard rock sections of ground and kept machine from becoming stuck in the variable geology
+ Crews were able to get through problem areas and make the most of the ground conditions, all while maintaining excellent safety

Delaware Aqueduct Repair

TBM boring in hard rock against high water pressure and high water inflows beneath the Hudson River in New York

Martino Scialpi, P.M.
Project Manager
The Robbins Company



Presentation Outline

- Project Overview
  - Challenges
  - Geology
- TBM Design
- Drilling & Grouting
- Conclusions

Delaware Aqueduct

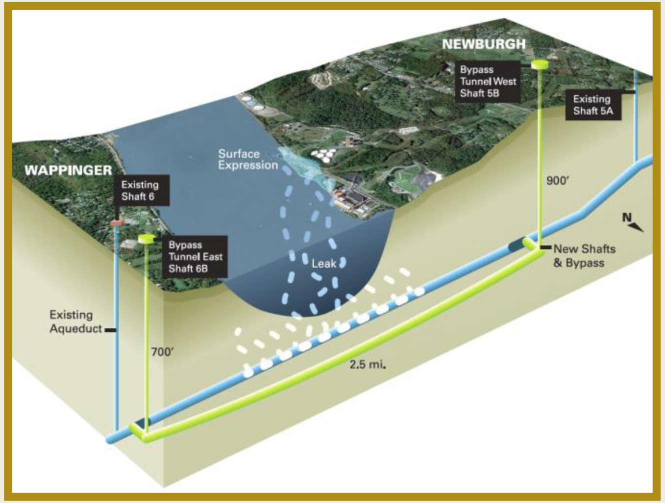
Project Overview

Project Overview

+ Location – Newburgh to Wappinger New York
+ Delaware Aqueduct supplies 50%-60% of the drinking water demand for New York City
+ Placed into service in 1944
+ At 137 km (85 mi) long, the Delaware Aqueduct is cited in the Guinness Book of World Records as the world's longest continuous tunnel

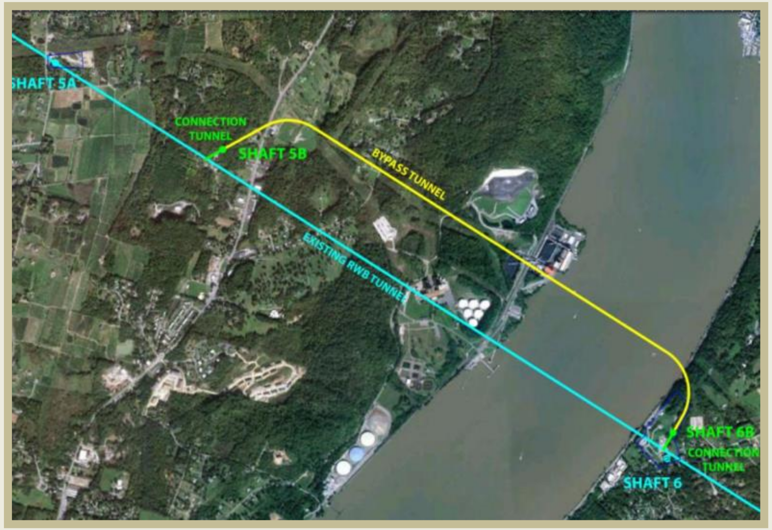
Project Overview - Challenges

+ Existing tunnel - leaking up to 35 million gallons (132 million liters) per day
+ Bored tunnel bypasses around leaking section



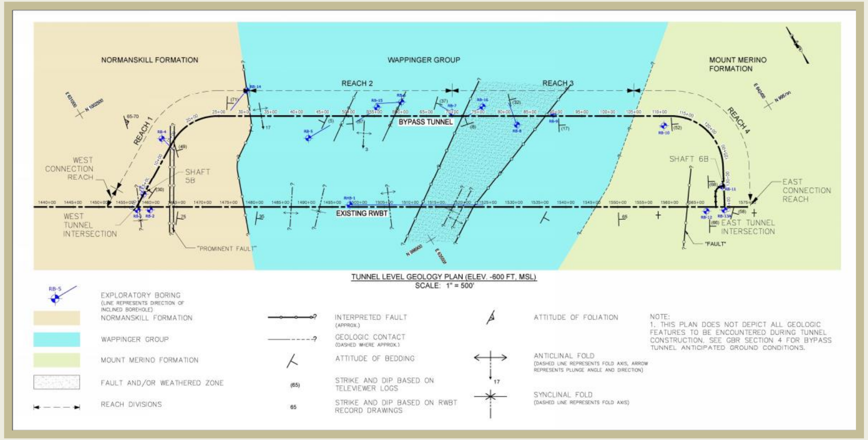
Project Overview – Tunnel Layout

- BT-1 Contract
  - Excavate Shaft 5B and Shaft 6B, with the 5B site able to support tunneling operations
- BT-2 Contract
  - Finish shaft excavation
  - Drill and blast methods for starter, tail, drainage, and connection tunnels
  - 3,800 m (12,500 ft) TBM drive
  - 2,800 m (9,200 ft) of interliner pipe
  - Final reinforce CIP concrete



Project Overview – Geology

- **Reach 1**
  - Normanskill Formation
  - 2,560 lf (780 m)
  - Slatey Shale
- **Reach 2 and 3**
  - Wappinger Group
  - 3,900 lf (1,189 m) & 3,500 lf (1,067 m)
  - Dolomitic Limestone
- **Reach 4**
  - Mont Merino Formation
  - 2,540 lf (774 m)
  - Slatey Shale



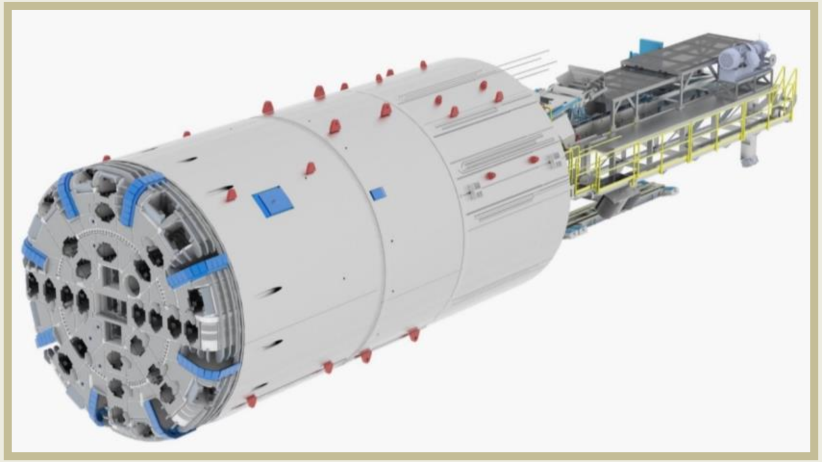
Project Overview – Challenges

+ Water pressure
  - 675 – 875 ft (205 – 267 m) of head
+ Fault zones
+ High water inflows
+ Squeezing ground
+ Maximum UCS of 54 ksi (372 Mpa)
+ Average UCS of 35 ksi (241 Mpa)

TBM Design

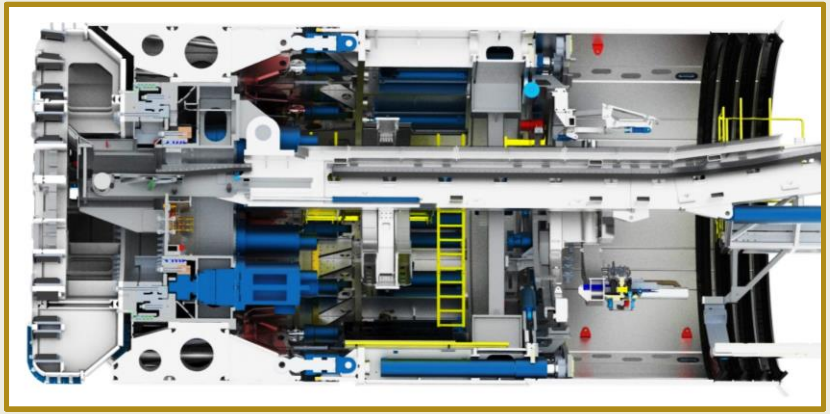
TBM Design - Unique Design Requirements

- Ground water inflows
- Ground water static pressure
- Muck and water handling
- Drilling and grouting systems
- Rock overburden - 2.5 m (8.2 ft) diameter



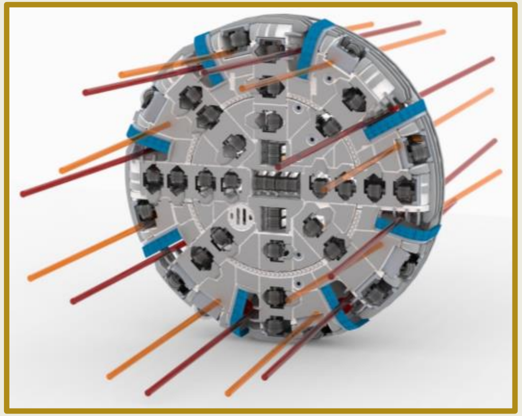
TBM Design – General Information

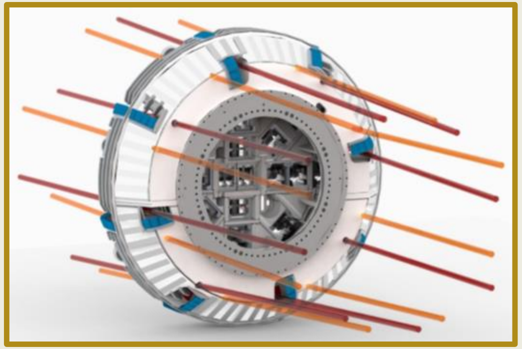
+ Disc cutters
+ Belt conveyor mucking with muck cars
+ Nine VFD motors
+ 32 thrust and 16 articulation cylinders
+ Turn radius - 1000 ft (304.8 m)
+ Skewing ring to correct TBM Roll
+ 4 rows of tail seals
+ Shield stabilizers
+ Gripper shoes



TBM Design – Cutterhead

+ Pressure compensated disc cutters
+ Single direction boring
+ Bolted design - No welding at site on CHD – JV
+ Weight under 100 tons – JV
+ 8 muck buckets with replaceable scrapers
+ Drilling position considerations





Drilling & Grouting

Drilling & Grouting – KSC Approach

- + Groundwater head
  - Ranges from 675 ft to 875 ft (205.7 m to 266.7 m)
- + Max. heading inflows
  - Ungrouted: 250 – 1300 gpm
- + Solution cavities - 3 to 30 lf (1 to 9 m), 5 to 30 Cy of flowing material
  - Reach 2: 3ea
  - Reach 3: 6ea

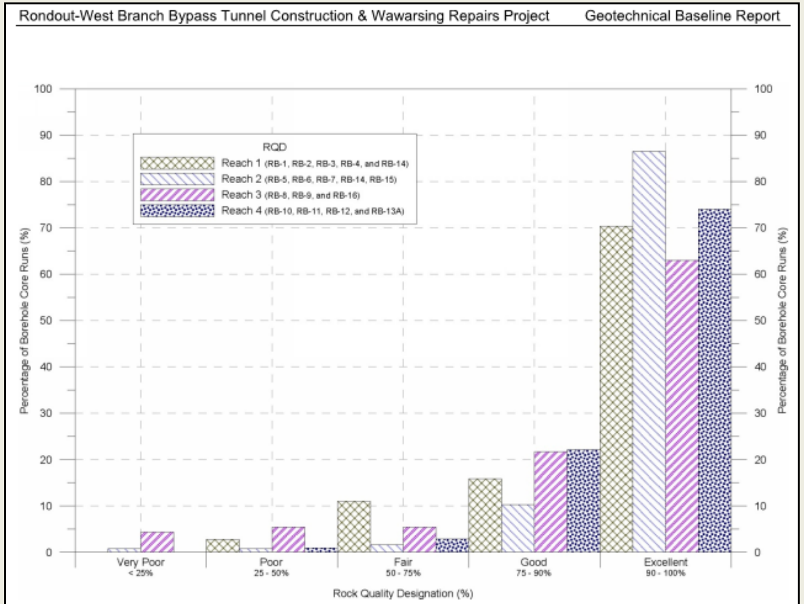
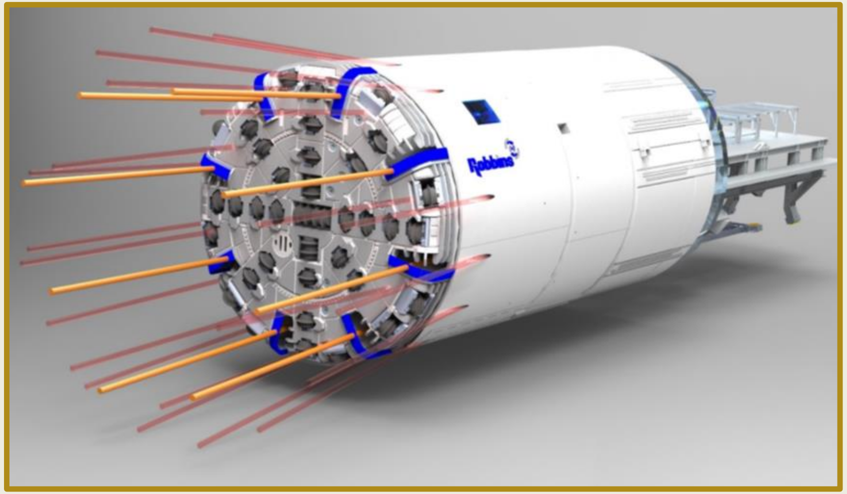


Figure B2-5. Histogram of RQD for Bypass Tunnel Reaches based on core logs

—See Section 4 for baseline conditions—

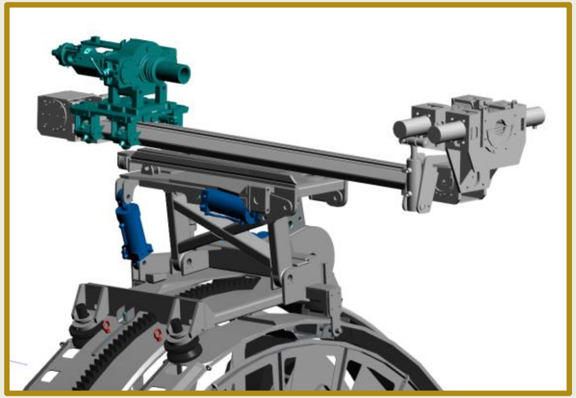
Drilling & Grouting – Drill System Design

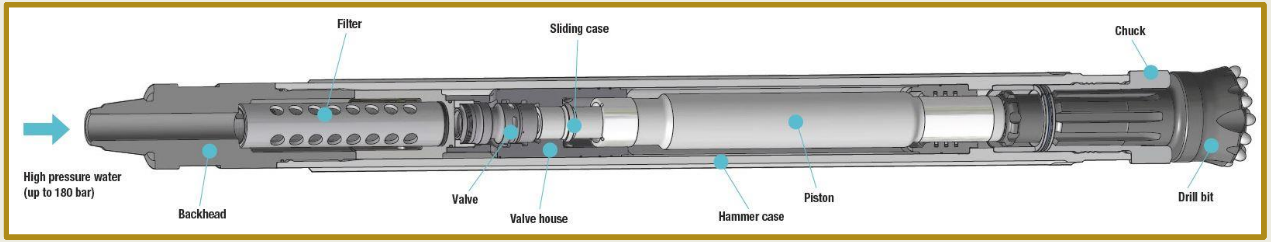
- Pre-excavation Grouting (PEG)
  - Two Forward drills – Cutterhead ports
  - Single Aft drill - Shield ports
- Stage 2 Proof Grouting
  - Mobile drill on bridge for relief holes



Drilling & Grouting – Drilling Equipment

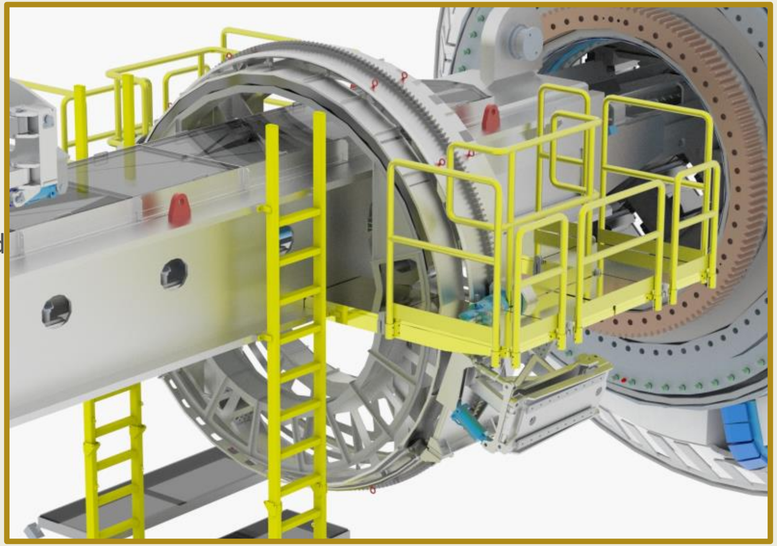
+ DTH water hammers
  - Ideal for drilling in water environment
  - Straighter drilling
  - Drill tests completed near jobsite
+ Drill Feeds
+ Blowout preventers





Drilling & Grouting – Forward Drill System

- Two independent drill positioners
- 360 degree travel each drill
- Moveable platform system
- Drilling through 16 ports
- Two drilling positions through cutterhead



Conclusions

Project Status

Breaktrough

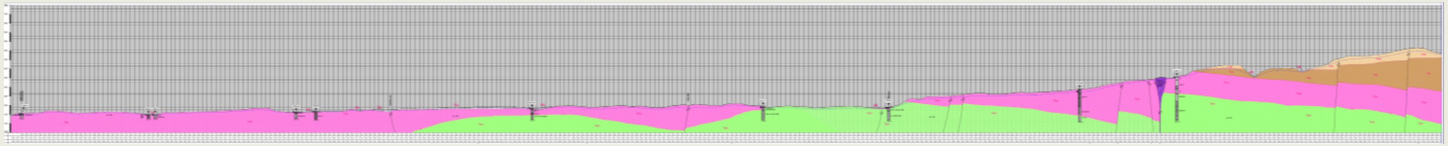

Questions?

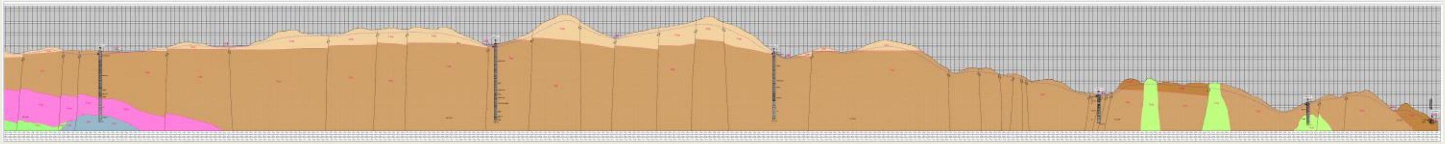
CASE STUDY

GEREDE WATER TUNNEL

GEREDE WATER TUNNEL
OVERVIEW

- 31.6 km water supply tunnel near Ankara, Turkey
- Geology consisting mainly of tuff, basalt, and breccia, giving way to sedimentary formations like sandstone, shale, and limestone
- Nearly 30 fault zones
- JV contractor of Kolin/Limak responsible for tunnel construction





CASE STUDY

GEREDE WATER TUNNEL
ORIGINAL TBM SUPPLY

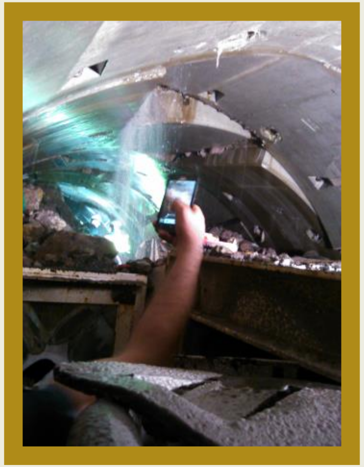
- First attempt: Three standard 5.6 m Double Shield TBMs supplied by another manufacturer
- Each TBM would bore approximately 10 km of the tunnel

TBM 1

- TBM 1 completed 9,588 m of tunnel in relatively homogeneous rock under low cover
- Some water inflows and squeezing ground were encountered that caused delays, but did not trap the machine

TBM 2

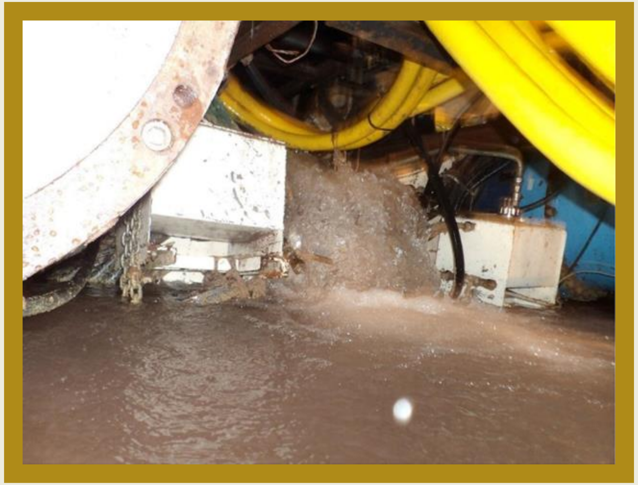
- TBM 2 had bored a significant section of its 10,339 m long tunnel when a massive inrush of water flooded the TBM and tunnel
- The TBM was boring downhill and the water had to be pumped out
- The TBM was deemed a loss. Some parts were salvaged and the rest of the machine was removed



Water ingress at TBM 1.

CASE STUDY

GEREDE WATER TUNNEL
TBM 3



+ TBM 3 was several kilometers into its 11,653 m drive and struggling in karstic aquifer conditions that required polyurethane injection
+ A sudden high inrush of water and mud, about 1,500 liters per second, flowed into the tunnel
+ The pressure was enough to crush the TBM shields and send cylinders catapulting into the back-up
+ Dye tests showed the water had come from a river overhead and was entering the tunnel through a cave system
+ The machine was stuck in place

CASE STUDY

GEREDE WATER TUNNEL
VIDEO

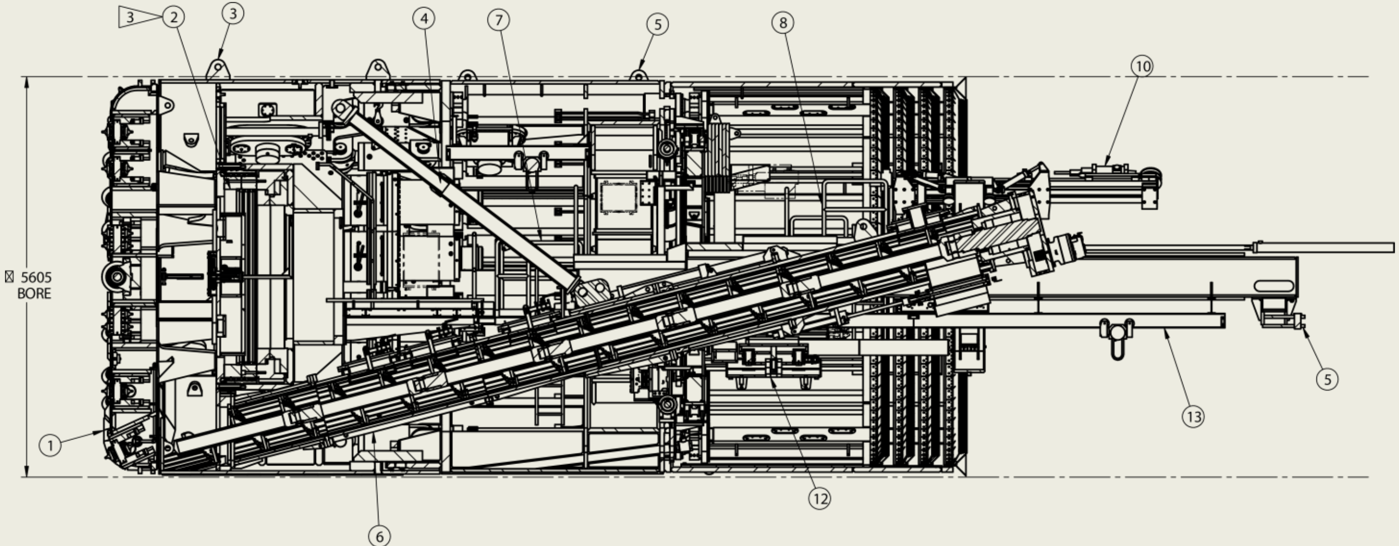
CASE STUDY

GEREDE WATER TUNNEL
ROBBINS SUPPLY

+ Robbins selected to supply a 5.6 m diameter Crossover (XRE) type TBM
+ To excavate 11 km of faulted and fractured rock with pressure up to 20 bar
+ Assembly of the machine onsite in the tunnel
+ Reuse of existing back-up and system components

GEREDE TBM
FEATURES

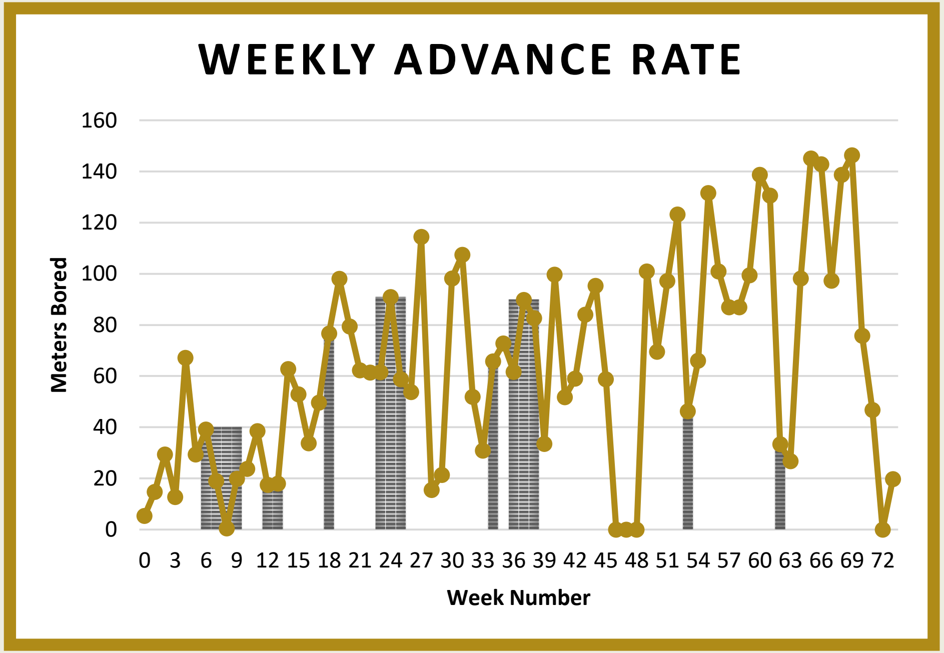
- Crossover (XRE) TBM with Single Shield and EPB TBM characteristics
- Single-direction rock cutterhead
- High strength shield with closed bulkhead to resist water and mud inflows
- Bottom screw conveyor
- Dual ratio transmission for high torque capability
- High-pressure articulation and tail seals
- High thrust capacity
- Multi-position probe drilling



CASE STUDY

GEREDE
TBM ADVANCE

- Machine Launch in Summer 2016
- The geology is variable and the TBM is boring basalt, tuff, medium to hard clay, and sandy clay with excessive groundwater
- Water flow inside tunnel is still 450-570 l/sec and straining logistics including rail transport
- Over 20 bar pressure on the machine

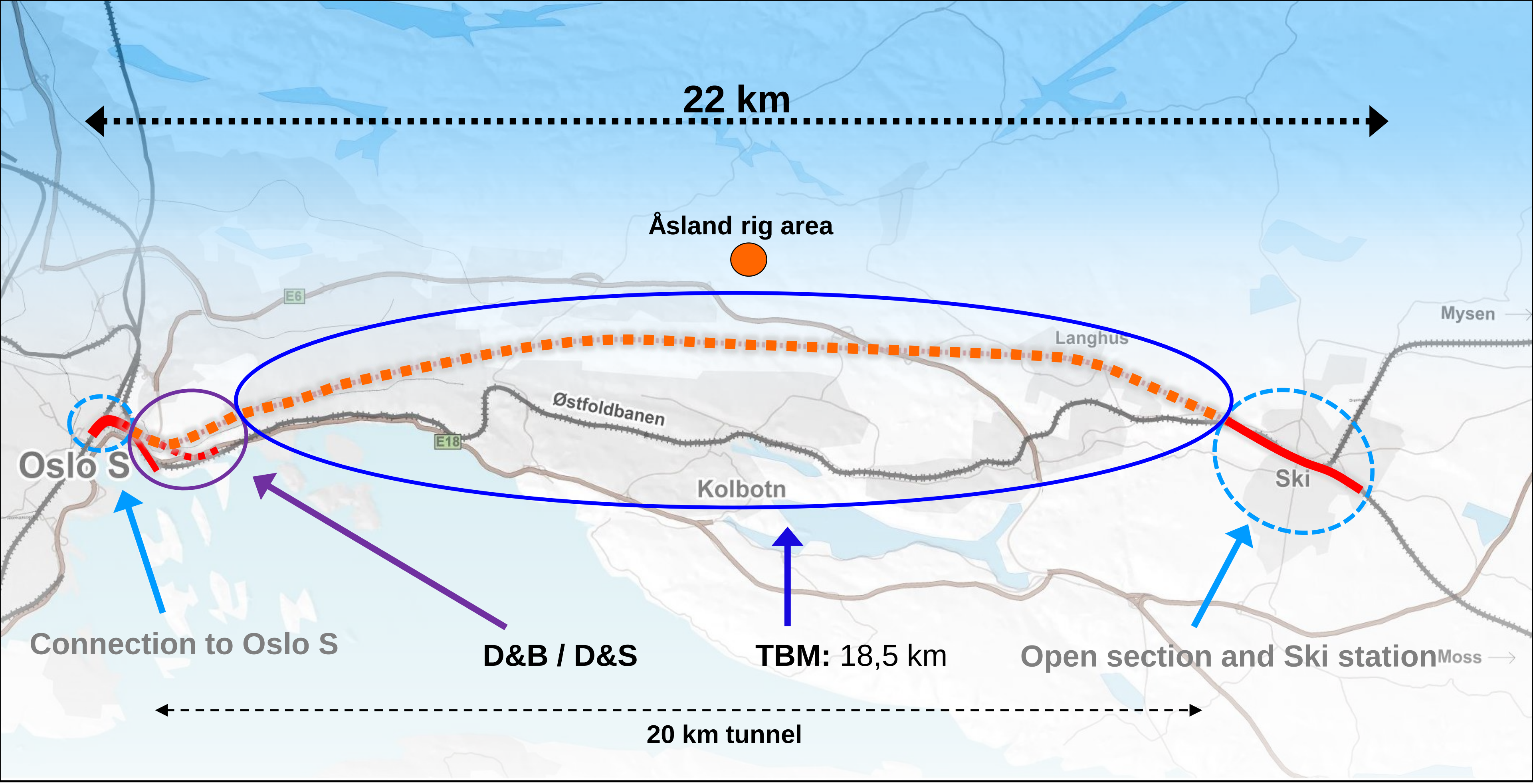


BANE NOR

Complicated crossings

Experiences from The Follo Line project

Anne Kathrine Kalager – Project Manager



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

The tunnel is built with two separate tubes.
Distance between the tubes is approximately 25 meters – CPs every 500 meters

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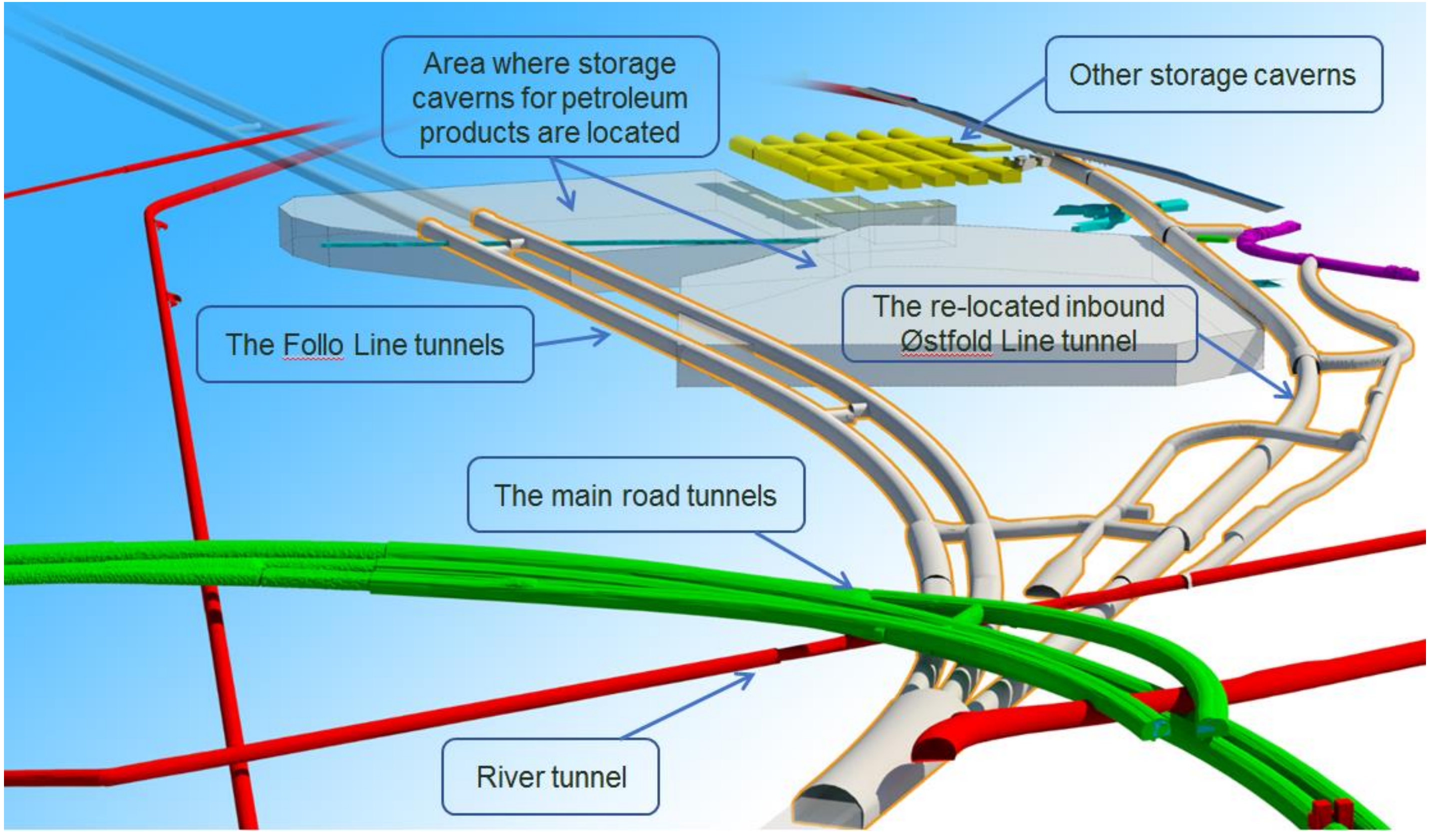
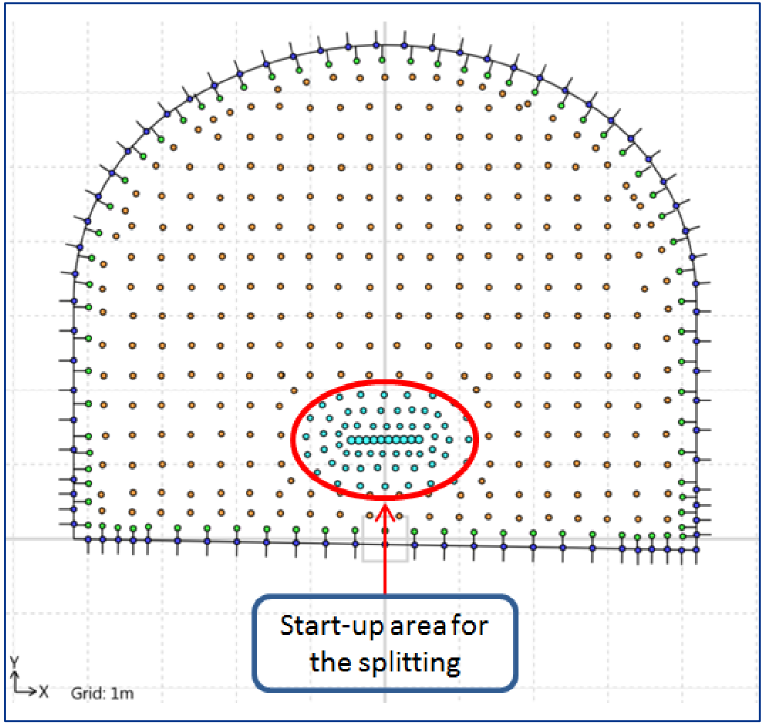
Between the rock tunnel and the connection to Oslo Central station, a 600 meter long concrete tunnel for both the Follo Line and the relocated Østfold Line are under construction

Complicated tunnel system in the northern part of the tunnel section



BANE NOR

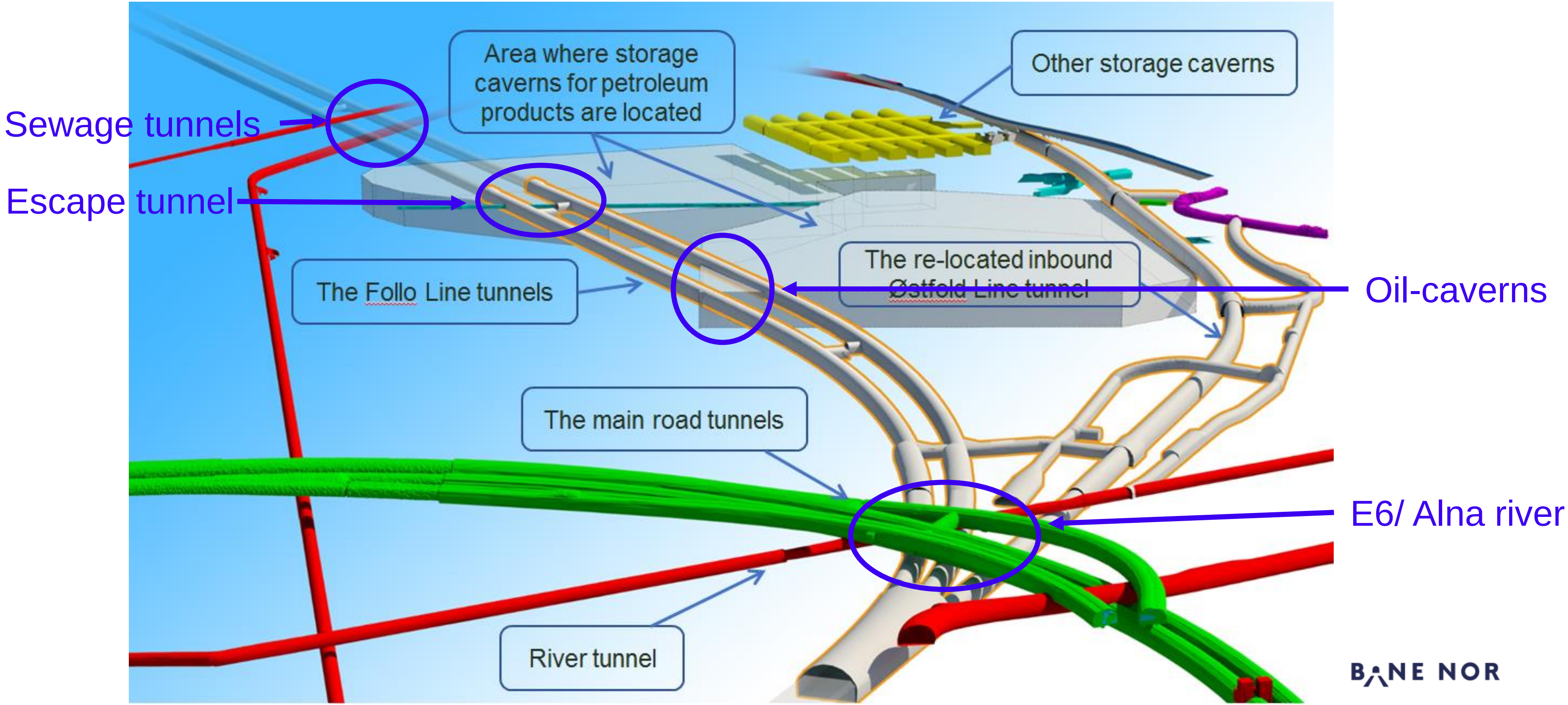


Drill and split methodology

BANE NOR

Drill and split methodology

Crossing close to sensitive infrastructure



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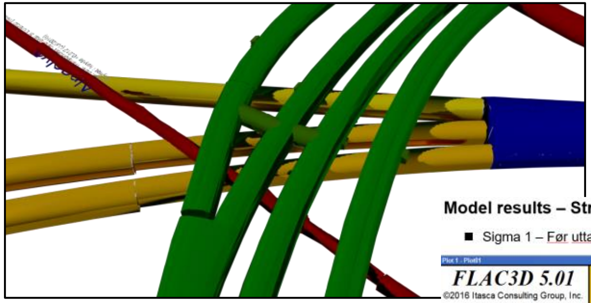
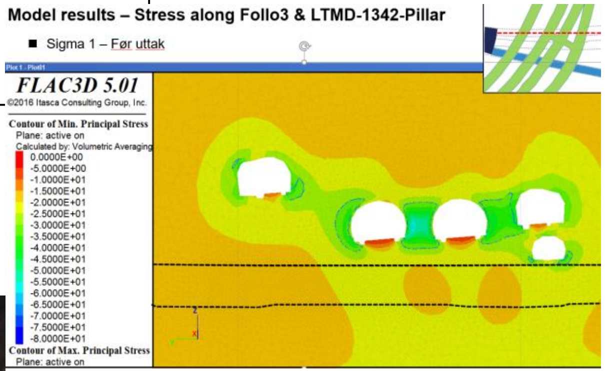
Crossing close under the road tunnels and the river tunnel

Challenges:

- Low overburden:
  - 3,5 m between the Ekeberg tunnel and the Follo Line
  - Follow up the stress-situation around the existing tunnels
- Weakness zone with clay under the road tunnel
  - Strict requirements regarding rock-support
- Zero tolerances regarding vibration:
  - Blasting NOT allowed, only splitting
- Leakages from the Alna-river tunnel
  - Concrete slab
  - Pre-grouting
  - Temporary re-location in steel pipes





Pre-fabricated steel arches, pre-bolting, CT-bolts

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Alna-river

Low overburden; Only 0,7 m between IØL and bottom of the Alna-river tunnel.

Solution:

- Install steel-pipes in the tunnel for temporary re-location of the water
- Install a reinforced concrete-slab in the bottom of the tunnel
- Pre-grouting before excavation by D&S
- Excavation by D&S
- Post-grouting to stop the remaining leakages
- Return the water back to the tunnel

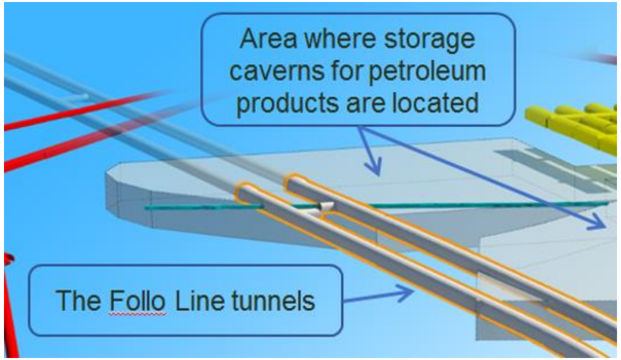
Crossing of the oil-caverns

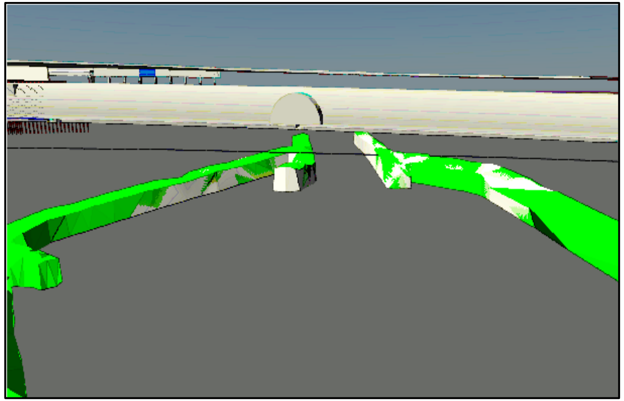
The Hydro-carbon caverns

- Strict requirements regarding vibrations:
  - Initially no blasting, only excavation by D&S
- Strict requirements regarding lowering of the ground water table
  - Keep the Water-curtain stable; Continuous infiltration of water to avoid lowering of the ground water table
- Risk of gas-migration
  - Mitigation
  - Gas- and water tight concrete-lining with membrane

The Escape tunnels

- Strict requirements regarding vibrations due to the ventilation system





The Ryen-tunnel

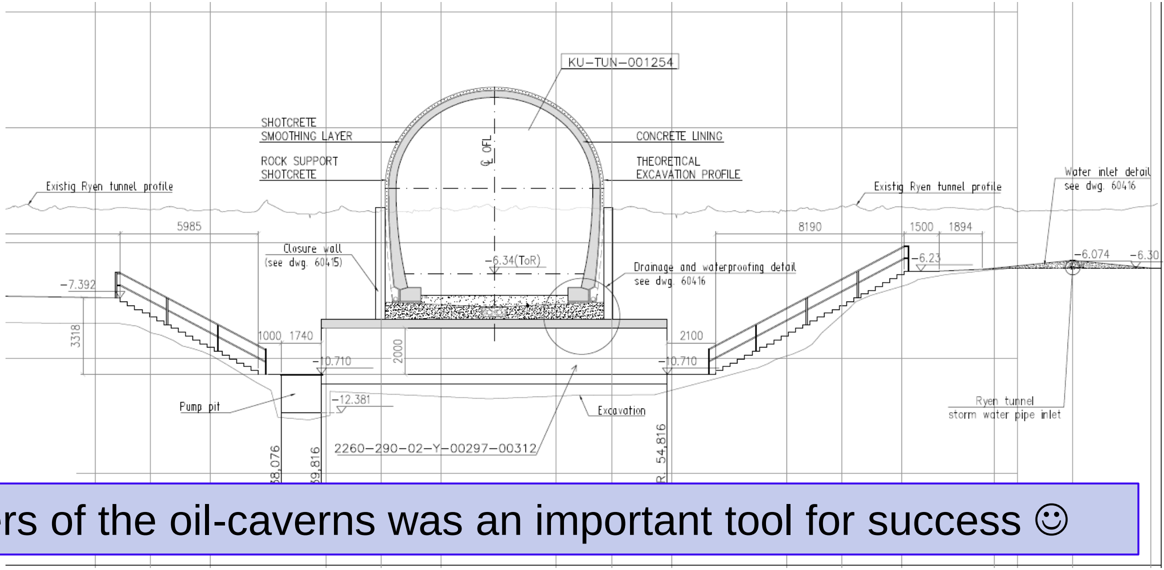
An escape tunnel from the oil-caverns

- 2 km long tunnel from Kongshavnsveien to Ryen
- Crossing right through the profile of the two Follo Line tunnels
- Had to be in operation 24/7

Solution:

– Excavate a by-pass under the two Follo-Line tunnels

– The by-pass was in operation before the excavation of the two Follo Line tunnels



Good communication with the owners of the oil-caverns was an important tool for success ☺

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The rig area at Åsland between Oslo and Ski

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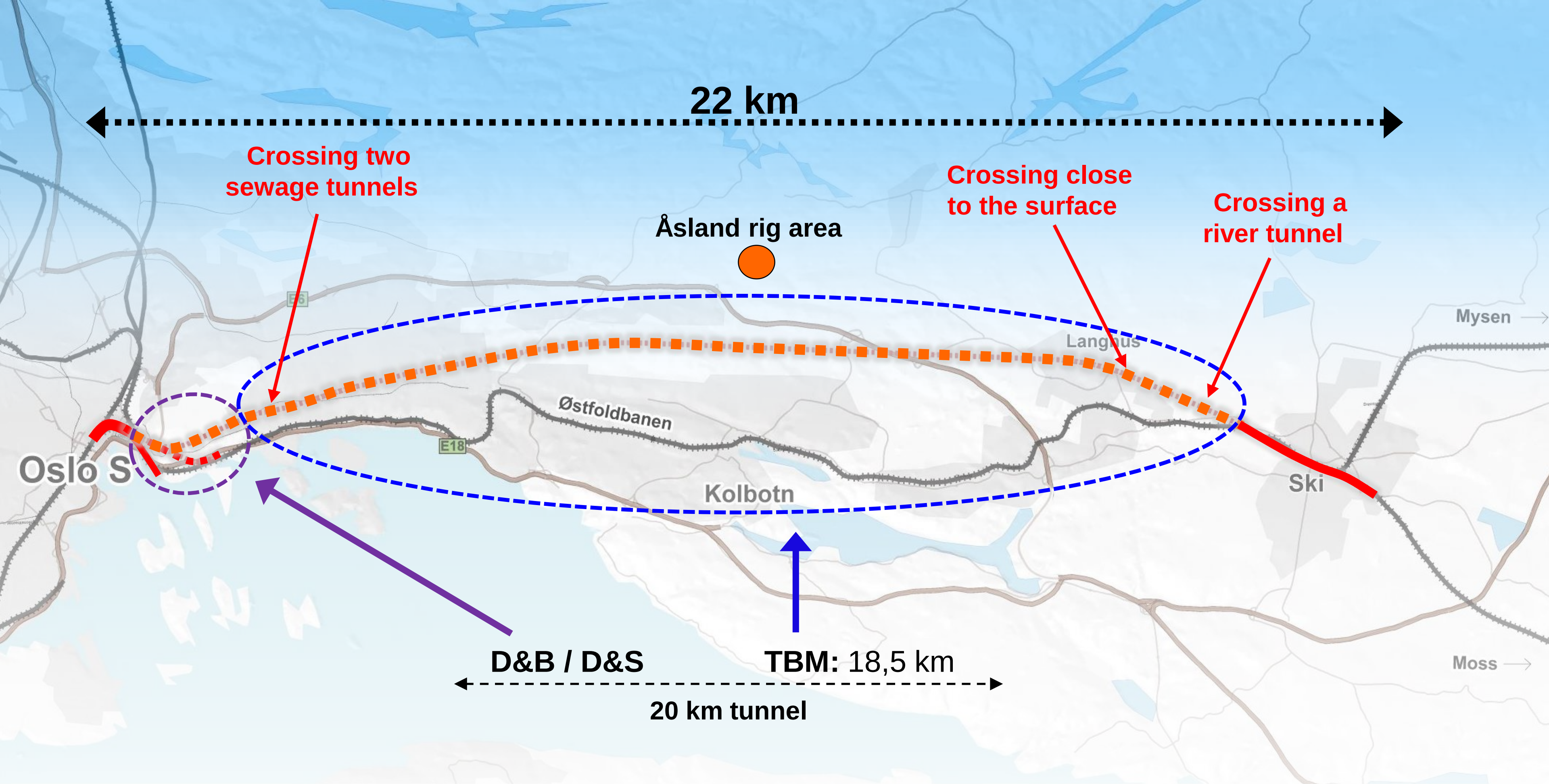
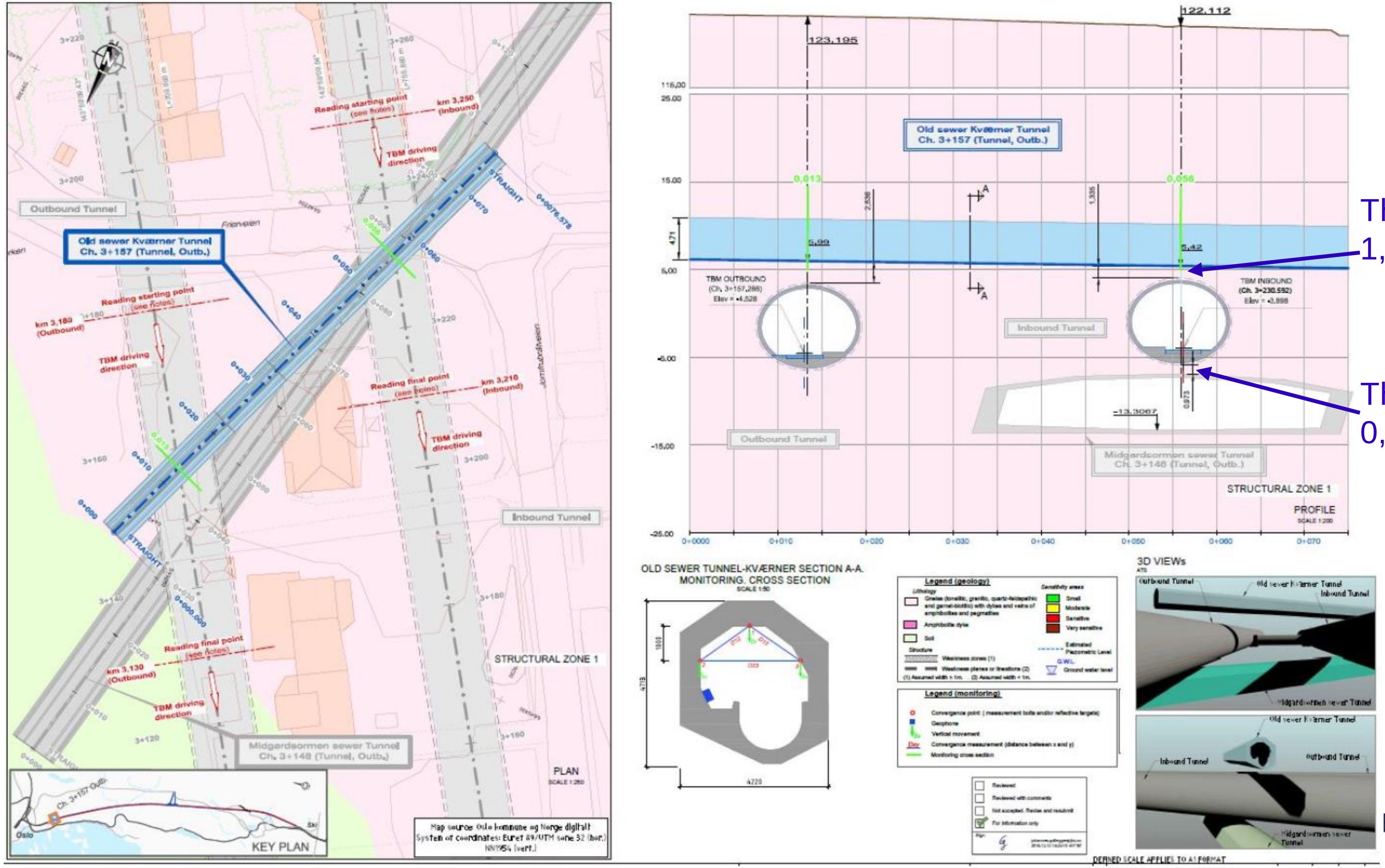


Two tunnel contracts – Different excavation methods

Crossing close between two sewage tunnels



Theoretical distance: 1,35 m

Theoretical distance: 0,5 m

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Crossing above the Midtgardsormen sewage tunnel

Sometimes, we met unexpected conditions as well…..

Concrete missing above the roof of the sewage tunnel;
3,5 m in the direction of the TBM drive and maximum width of 5 m

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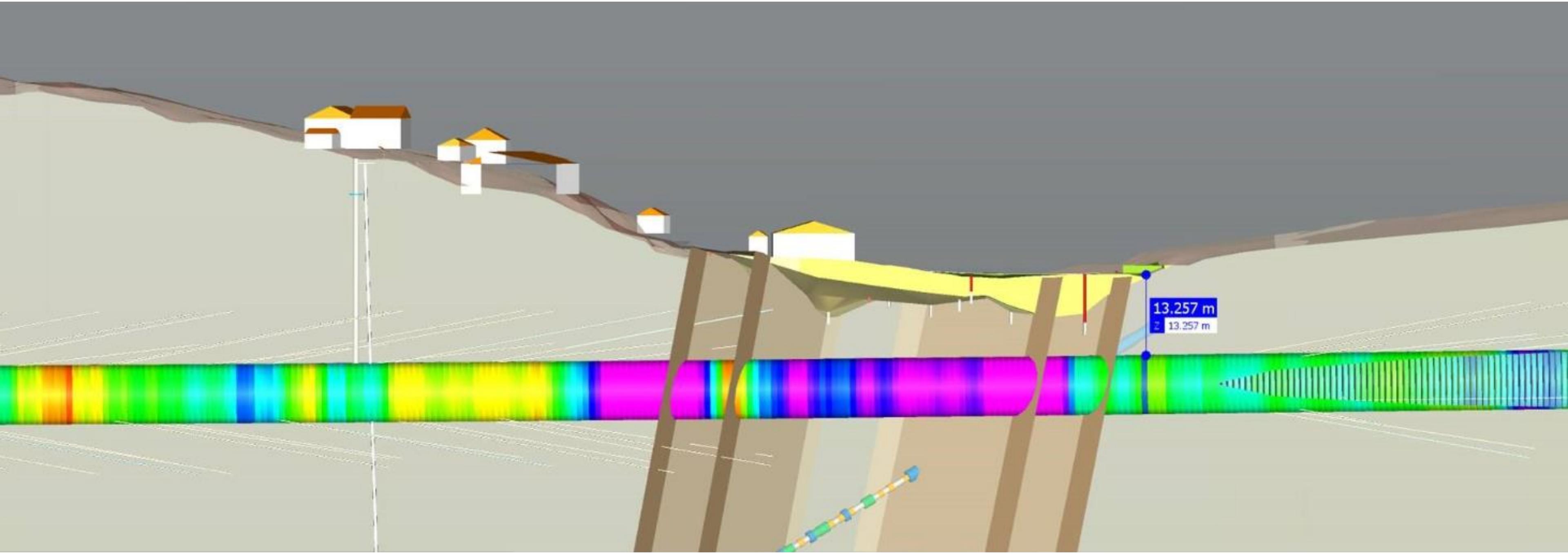
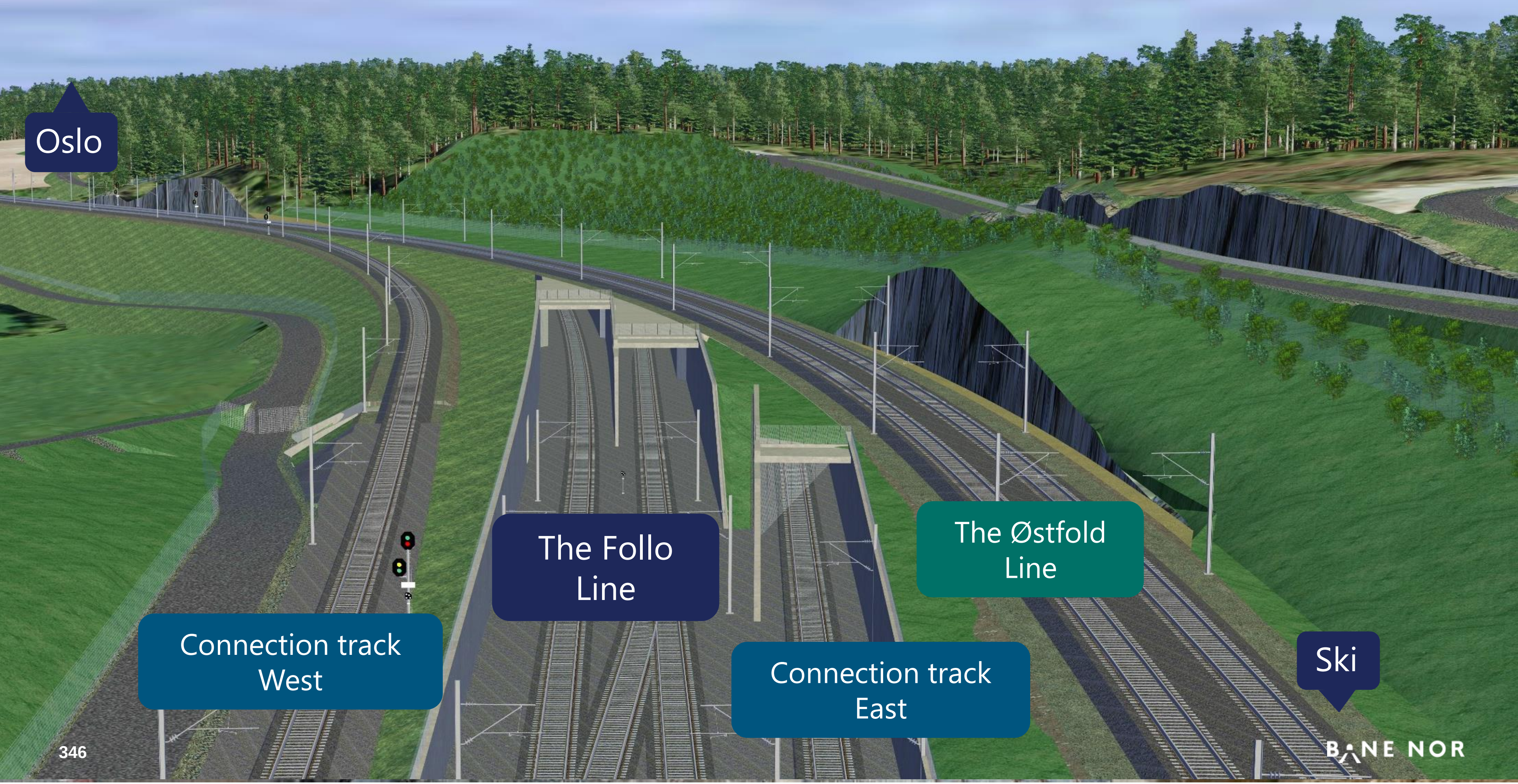
Crossing areas with fracture zones and low overburden

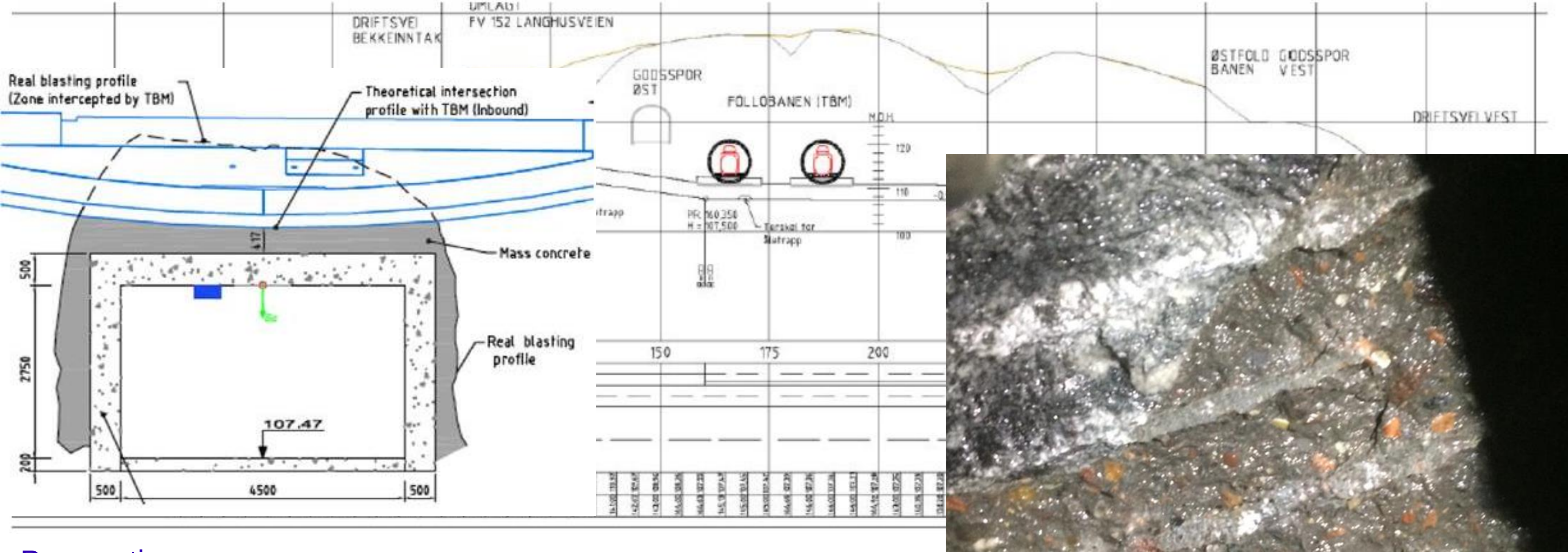


Pre-grouting to avoid leakages and development of settlements on buildings within the influence area



Complicated rail constructions with necessary realignment of the existing rail line

Crossing right over a river tunnel, then right under Connection Track East



Preparations:

- A reinforced concrete slab on top of the river tunnel as a preparation for the excavation of the two TBM-tubes
- A reinforced concrete cradle installed with fiberglass bolts on the bottom of the Connection track east

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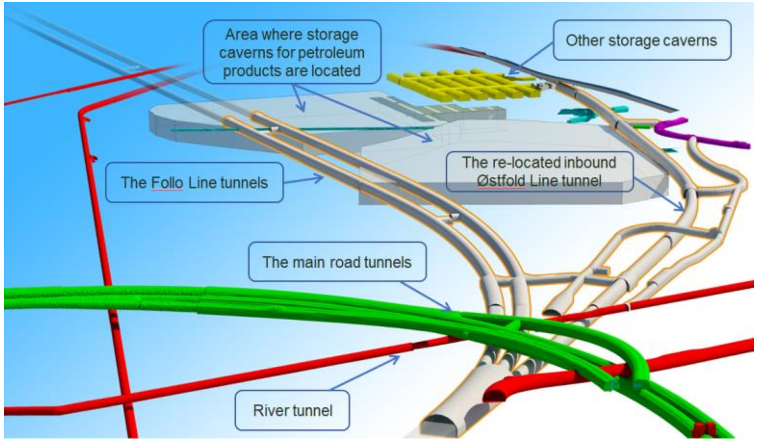
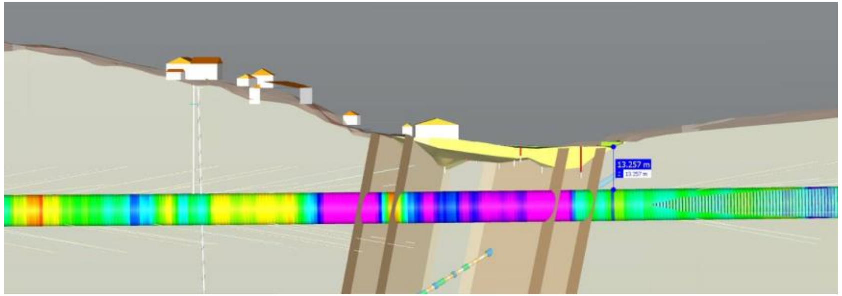
Lessons learned

- Identify all possible crossings
- Identify all energy wells which may have conflict with the future tunnel
- Perform other relevant preparations
  - Good knowledge of the ground conditions
  - Involve relevant stakeholders and establish & maintain good communication
  - Perform necessary reinforcement to avoid conflict or damage of affected infrastructure
- Make a 3D-model/ BIM with detailed information about relevant objects. Update the model during the performance of the project





BANE NOR

BANE NOR

Thank you for your kind attention!

Remember 5th of September

Utilization and planning of the underground

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NFF

NORWEGIAN TUNNELLING SOCIETY