Lining for TBM tunnels

Johannes Gollegger, 10. June 2021

Temamøte om vanntette elementløsninger i TBM-tunneler

What we don’t want

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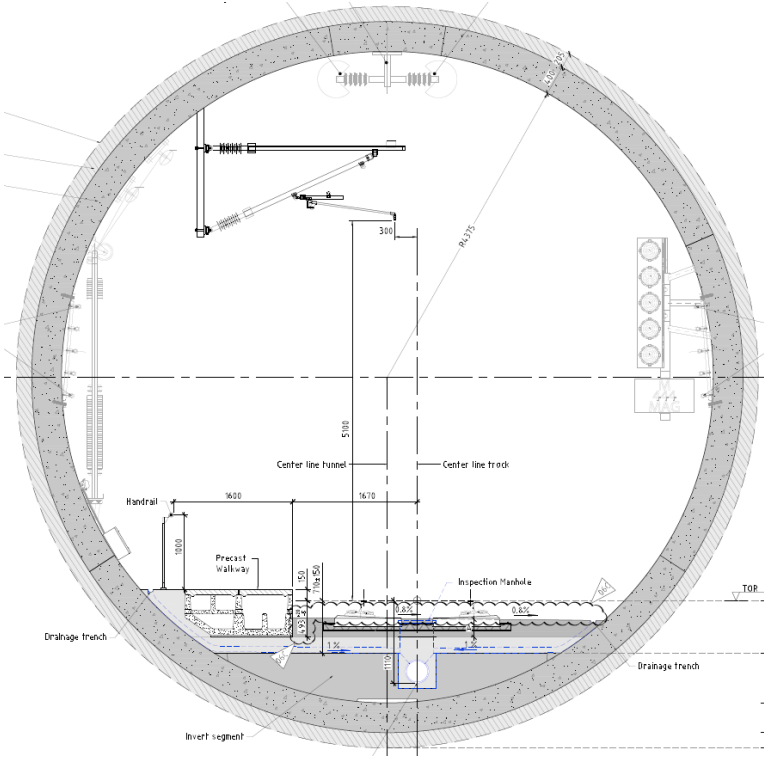
Follobanen – single shell lining



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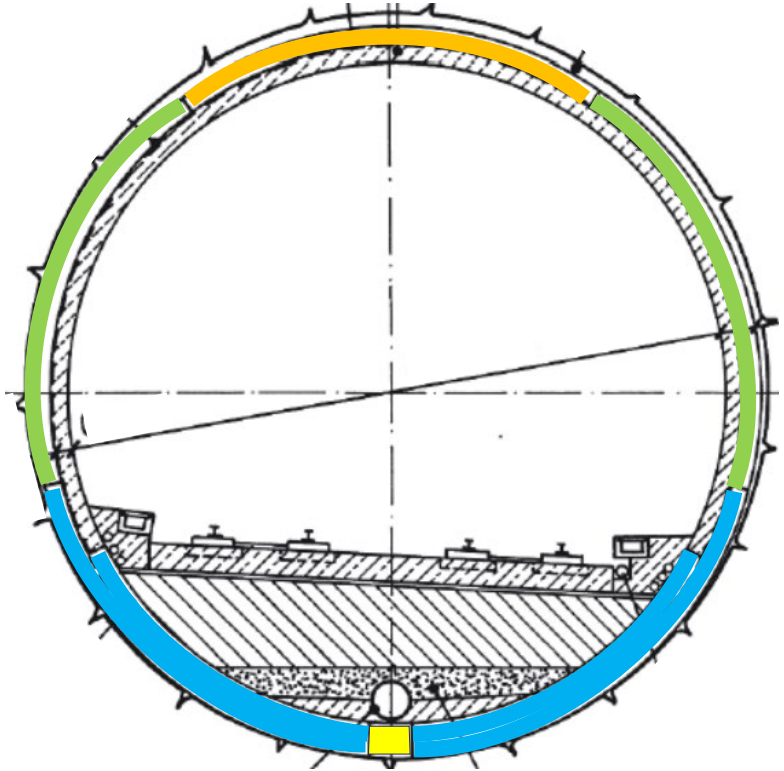
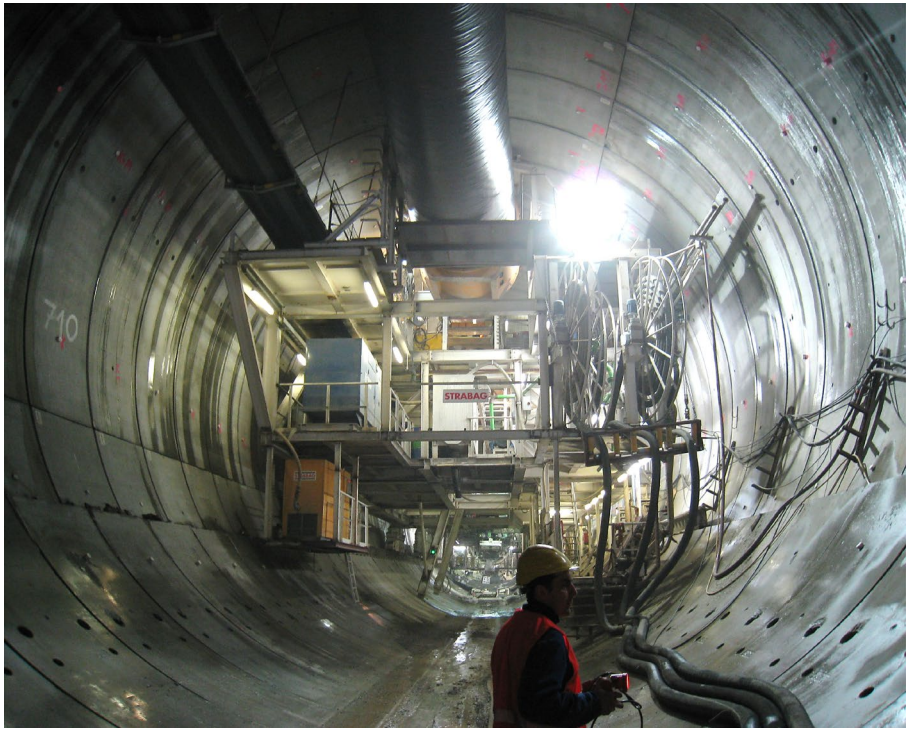
Tunnelkette Perschling – segmental lining + final lining





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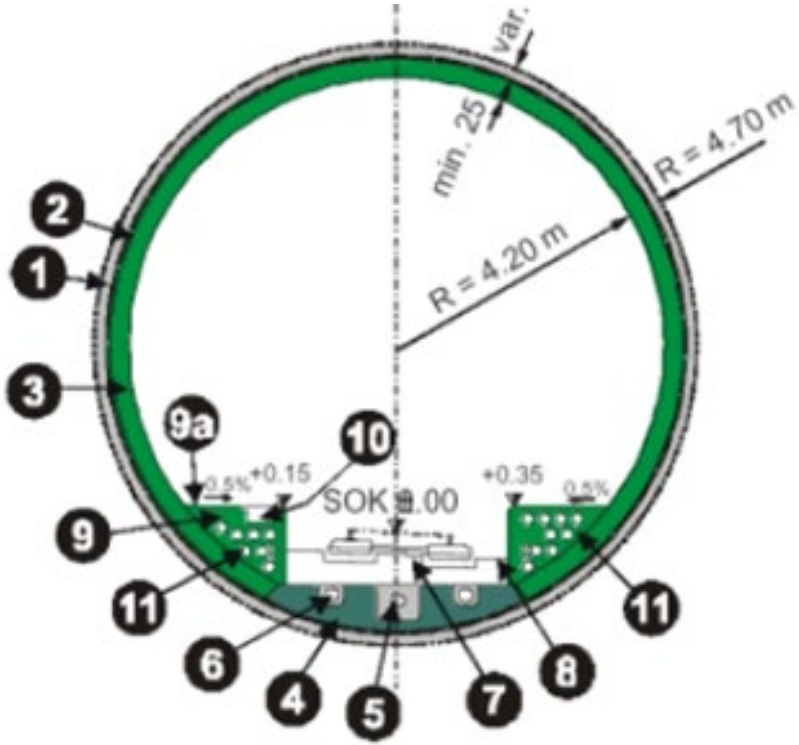
Lötschberg base tunnel – rock support + final lining



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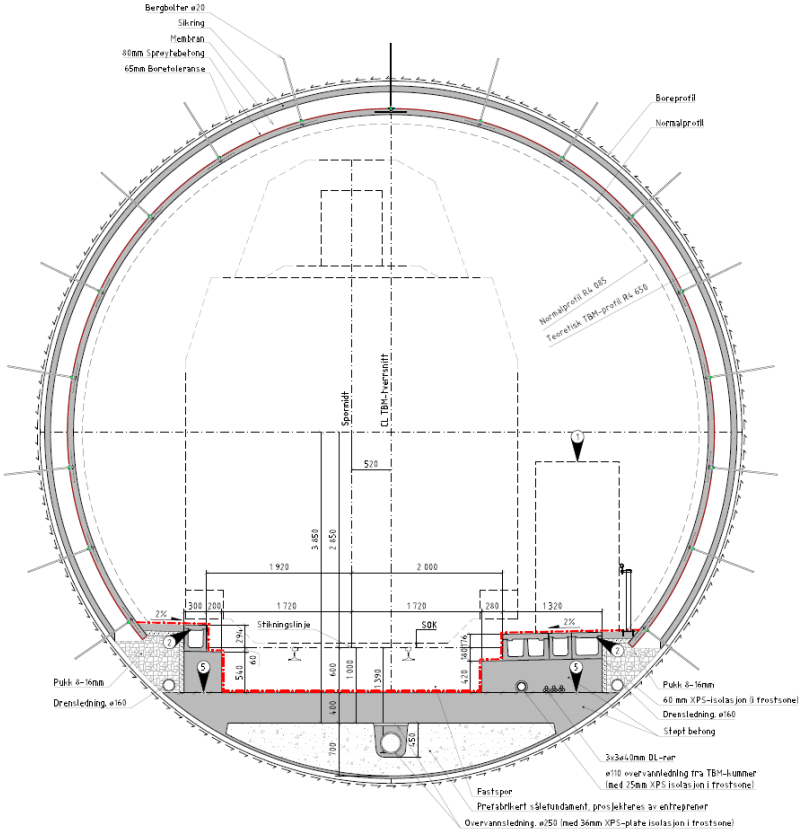
Ulriken Tunnel

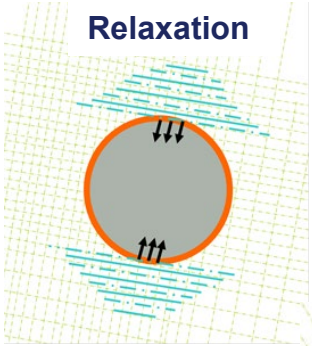


Main requirements for tunnel lining

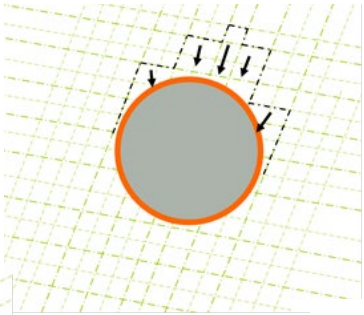
- Take all acting loads – from the ground and operation
- Water tightness
- Frost protection
- Limit environmental footprint
- Competitive in terms of cost and schedule

Examples for possible ground loads

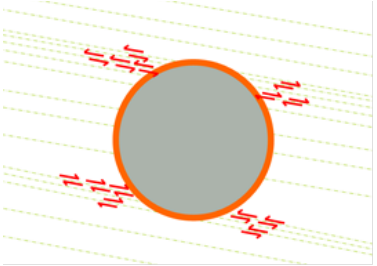
Relaxation



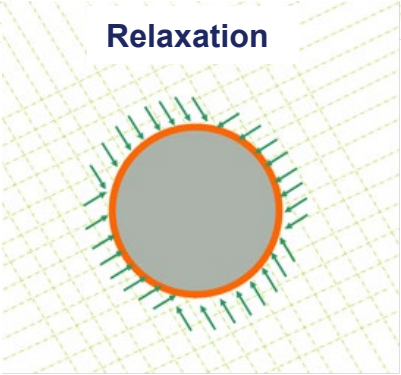
Wedge failure



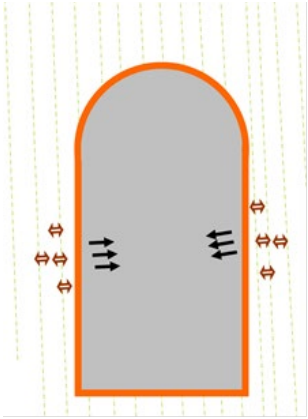
Shear failure



Relaxation



Buckling failure



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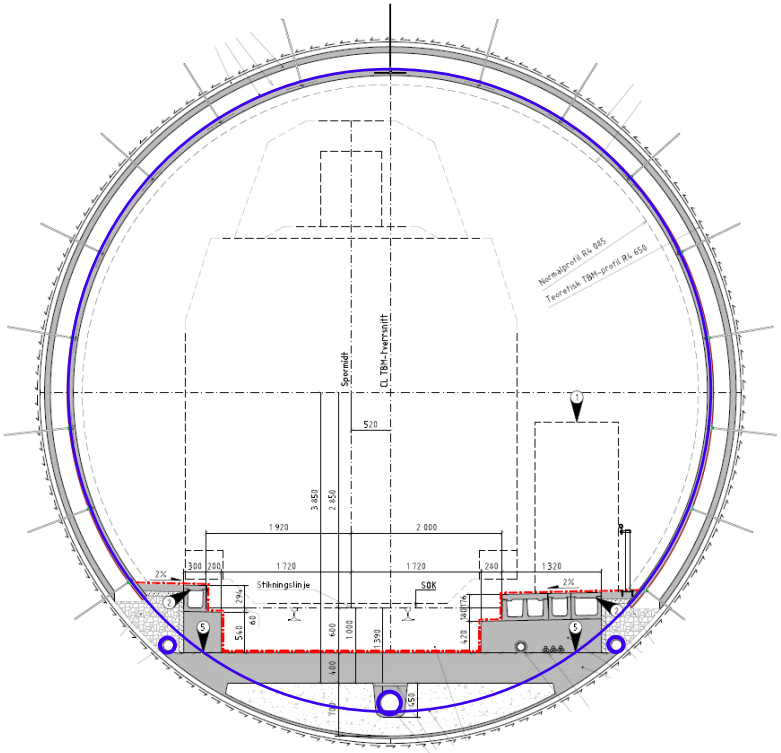
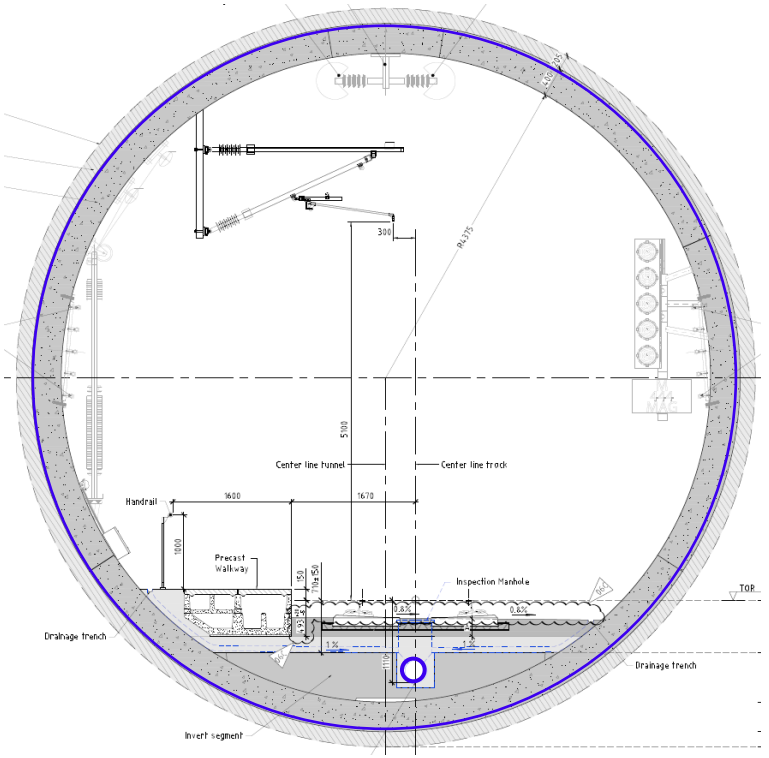
Water tightness: drained versus undrained





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Limits for undrained solutions

The maximum manageable pressure

- Gaskets can theoretically hold pressure > 20 bar

Example Follobanen:

D_G=	9,45 m
C_G=	29,7 m
L_G=	84,6 m
L_{Gtot}=	1 693 026 m

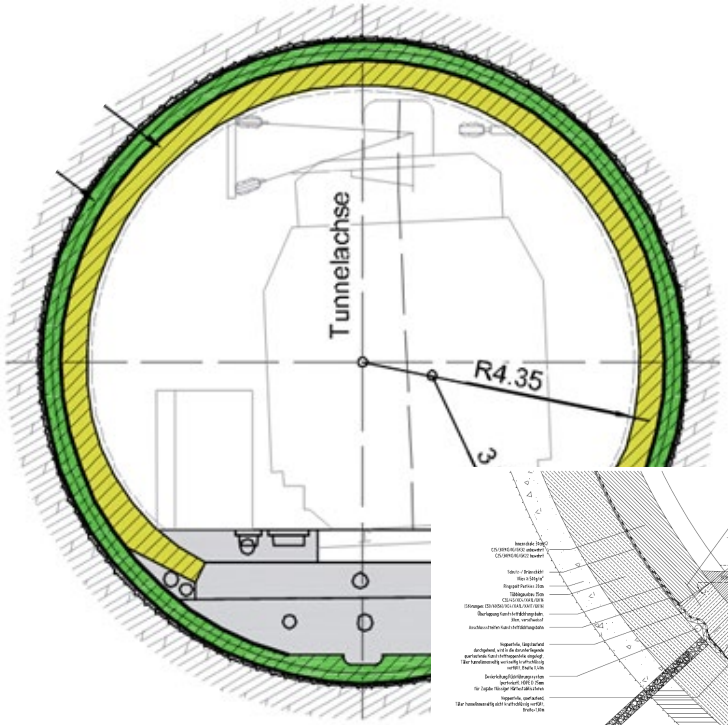
- Adjacent structures like cross passages, exit tunnels, technical rooms,..

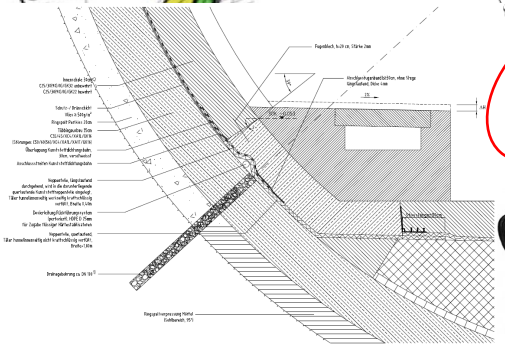
- Connections between main tunnels

→ Limit of approx. 10 bar are for main tunnels with adjacent structures

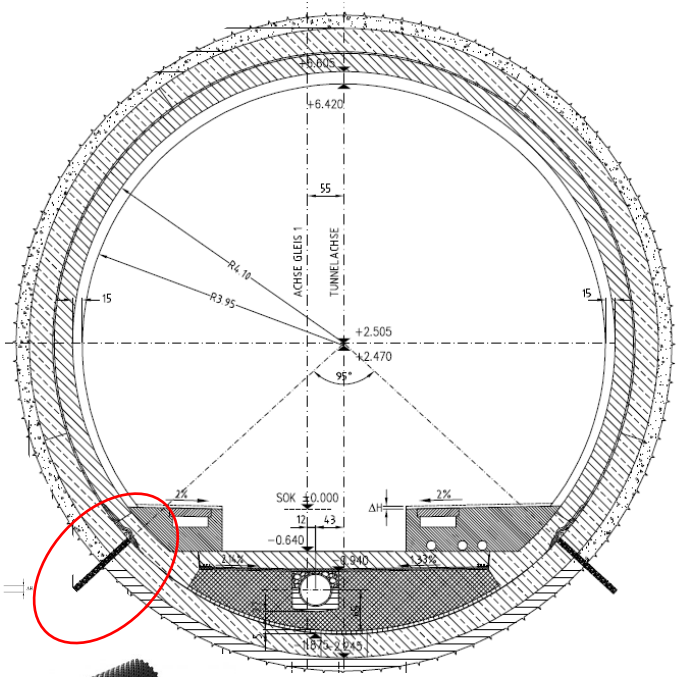
Segmental lining as drained solution

Segmental lining without gaskets





Segmental lining with gaskets



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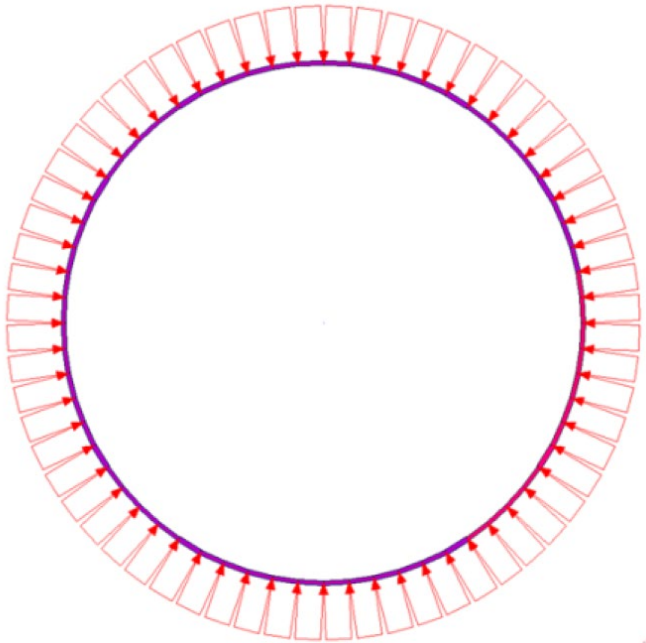
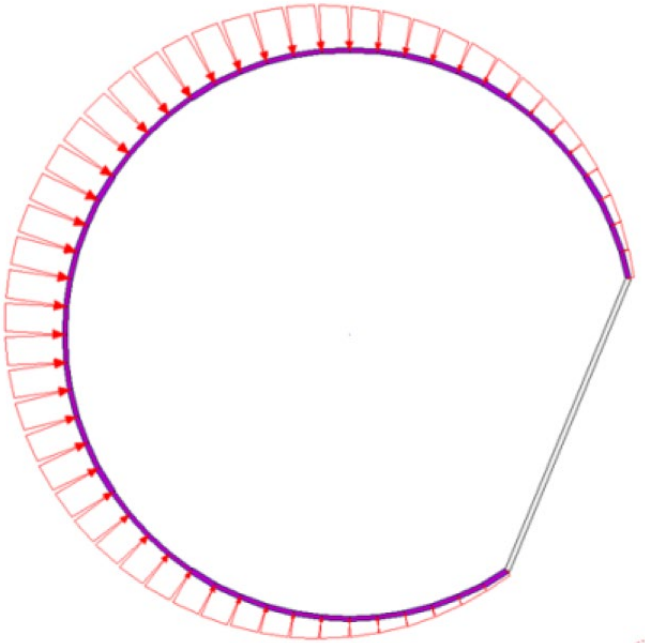
Water load





Frost – ice building

How much water ingress can be tolerated?

Table 3-8, Classification of Watertightness by Deutsche Bahn AG (German Rail) for their Underground Facilities, (AITES 2001)

Tightness Class	Moisture Characteristics	Use of Tunnel	Definition	Acceptable leakage rate (l/day/sq.m) at the reference length	
				10m	100m
1	Completely dry	Stores, workrooms, rest rooms	The wall of the lining must be tight so that no moist patches are detected on the intrados	Nil	Nil
2	Substantially dry	Frost-endangered underground sections	The wall of the lining must be tight so that only slight, isolated patches of moisture can be detected on the intrados, e.g. result of discolouration. After touching such slight moist patches with a dry hand, no traces of water should be detected. A sheet of blotting paper placed on a patch, should not discolour as a result of absorbed moisture.	0.2	0.05
3	Capillary moisture penetration	Underground sections and rooms which do not require class 1 or class 2.	The wall of the lining must be tight so that only isolated, locally restricted patches of moisture are to be seen. Restricted patches of moisture are areas at which a penetration of moisture could be registered. A sheet of blotting paper will discolour as it is soaked with water, but no trickling water is to penetrate the intrados.	0.4	0.1

Table 2. Permissible daily leakage water rates, depending upon the use of subsurface facilities, according to findings of the Otto-Graf-Institute. Note: The leakage water rate present at particularly noticeable leakage points must not exceed ten times the average leakage water rate value.

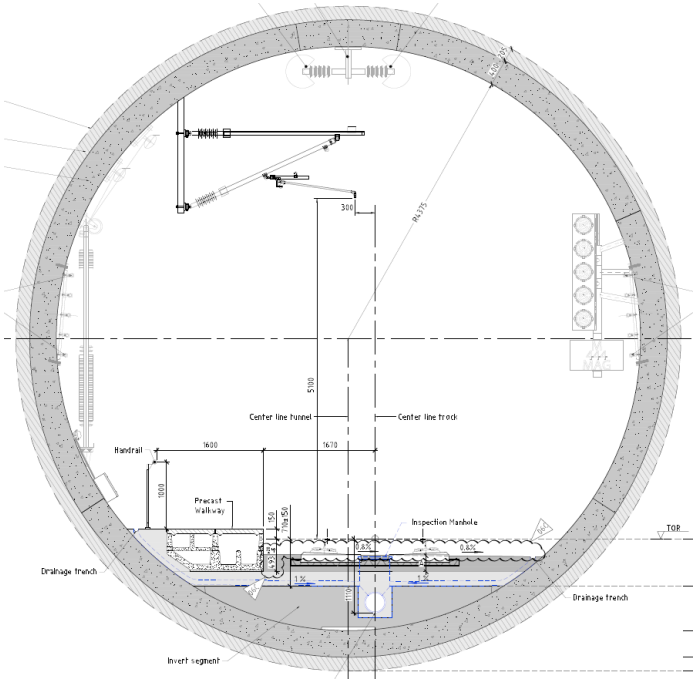
Line	Moisture Characteristics	Purpose	Permissible Daily Leakage Water Rate (l/sq. m)
0	1	2	3
1	Completely dry	Storerooms, restrooms	0.001
2	Substantially dry	Underground/tramway tunnels	0.01
3	Capillary penetration of moisture	Road, pedestrian tunnels	0.1
4	Weak trickling water	Rail tunnels	0.5
5	Trickling water	Sewage tunnels	1.0

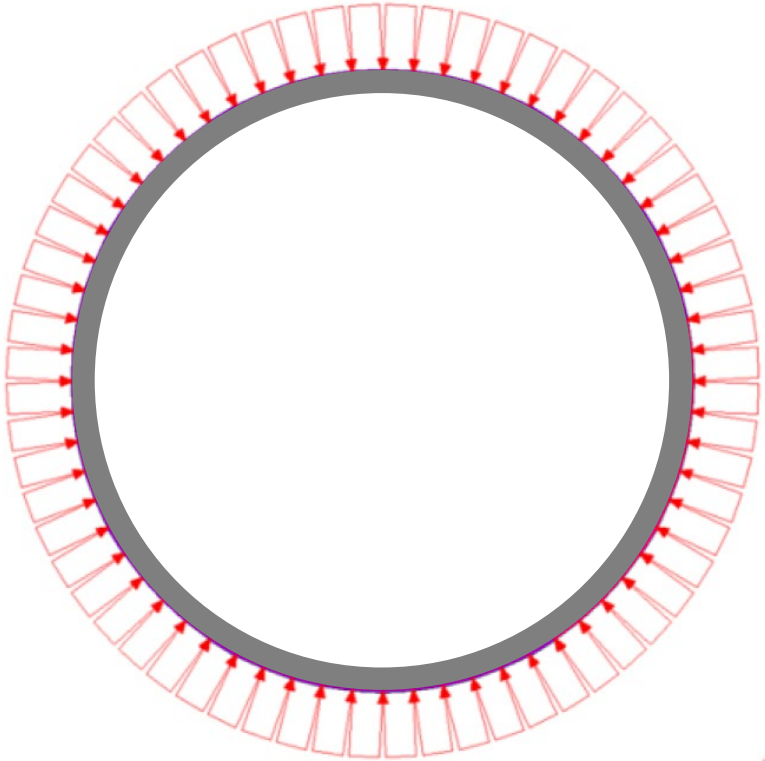
How to measure these low values?

Follo Line: No dripping/visible flow of water is permitted whatsoever, damp spots are.

If absolute leakage values shall be defined, need they be adjusted to Norwegian circumstances.

Pressure on segmental lining from freezing backfill grout





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Freezing test of small backfill grout samples

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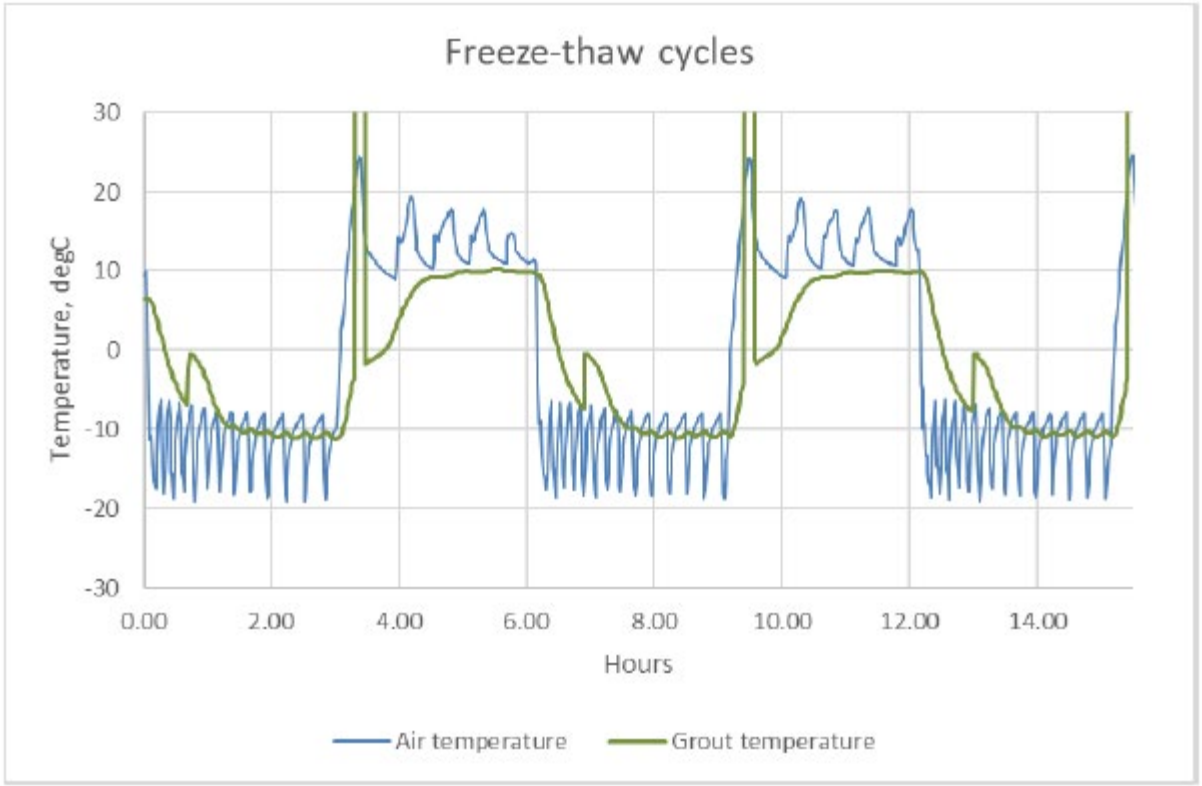
Freeze-thaw cycles



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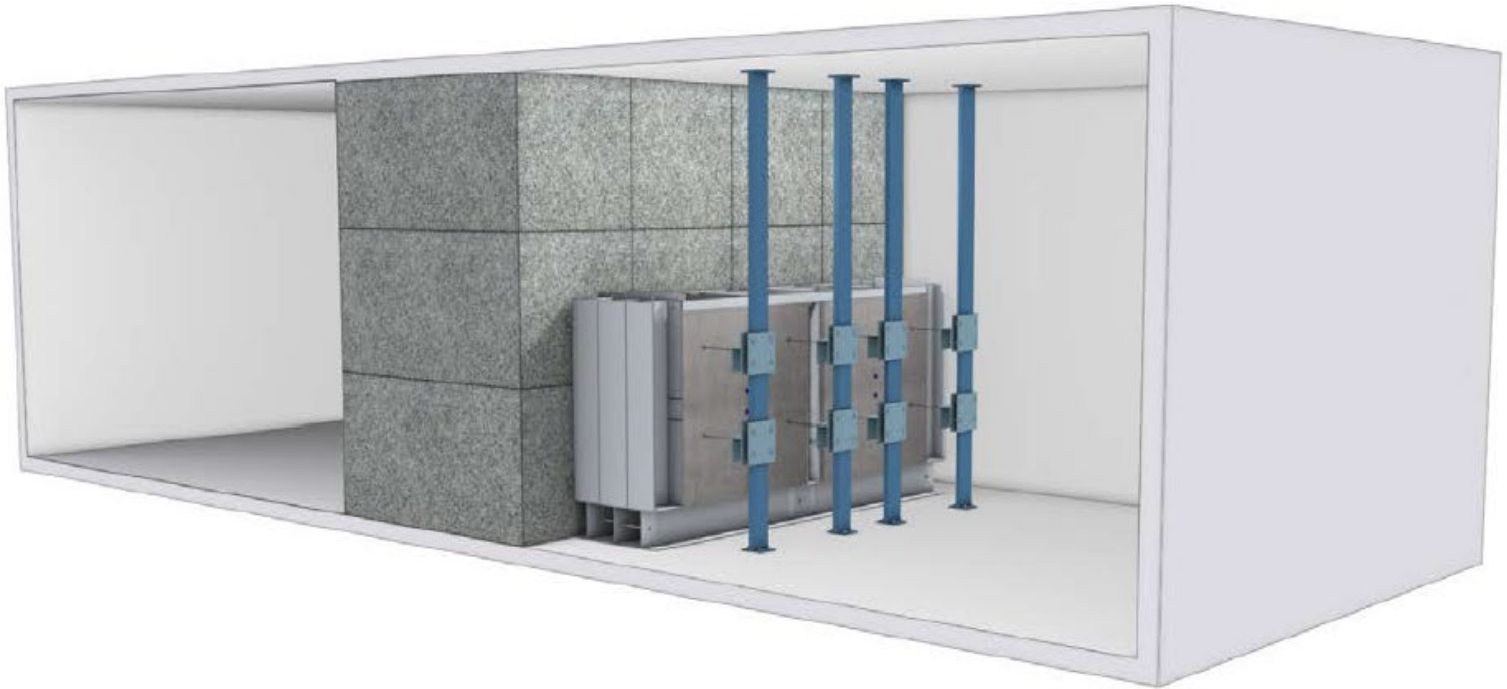
Results from backfill grout sample testing

Results from backfill grout sample testing

after 4 cycles

after 24 cycles

Freezing chamber at Sintef



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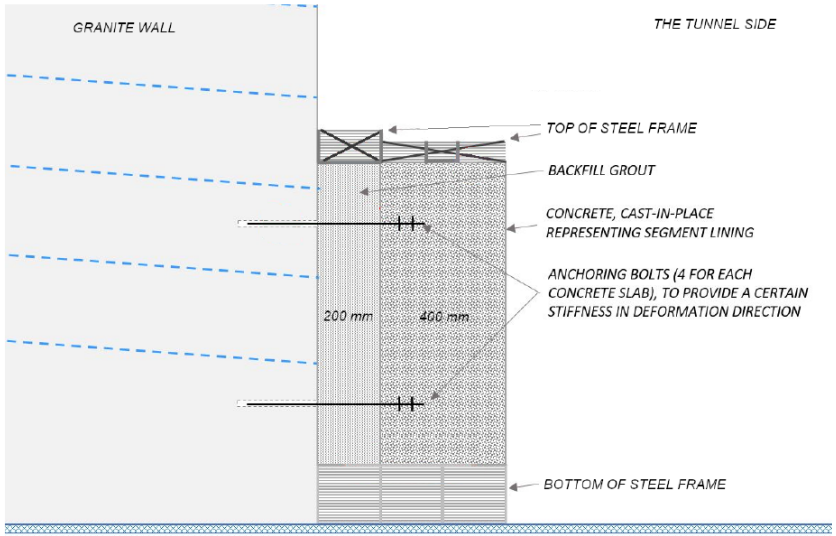
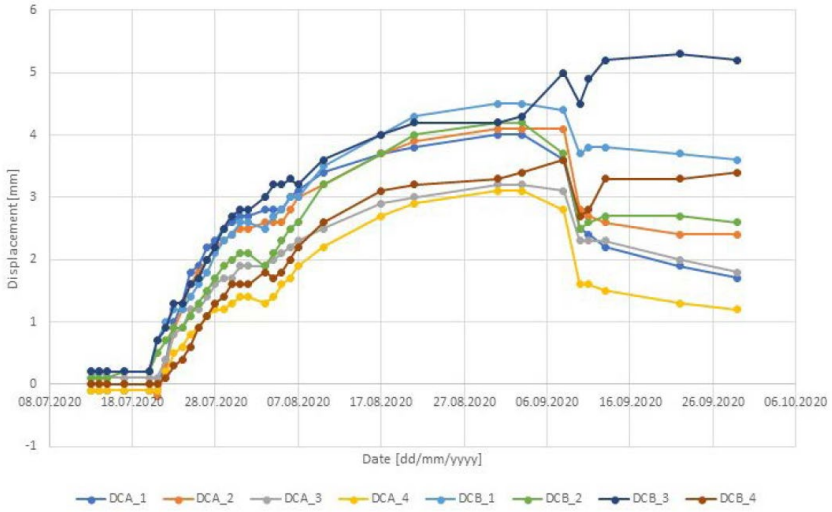
Displacements of concrete lining





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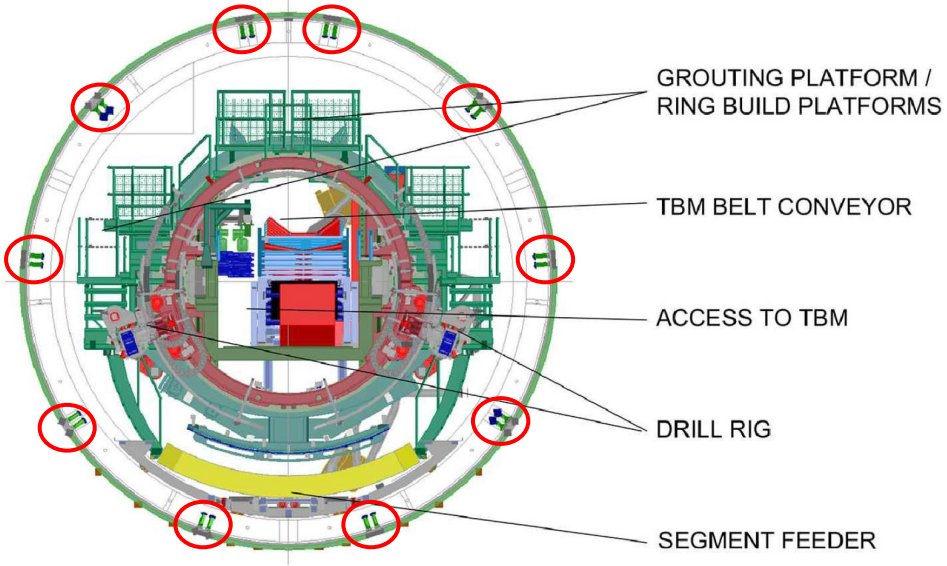
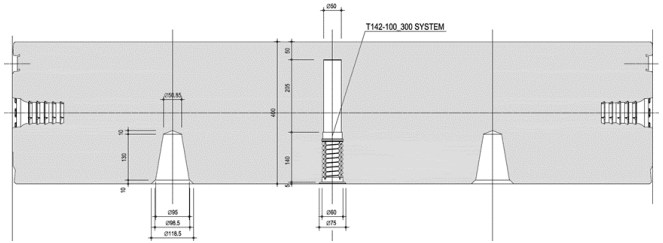
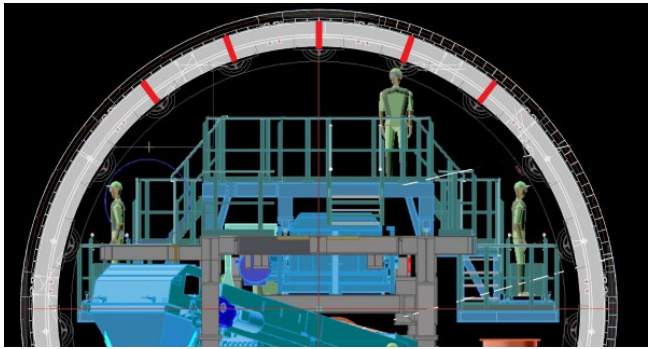
Backfilling process

Grout ports through tail shield



Grout ports through the segments





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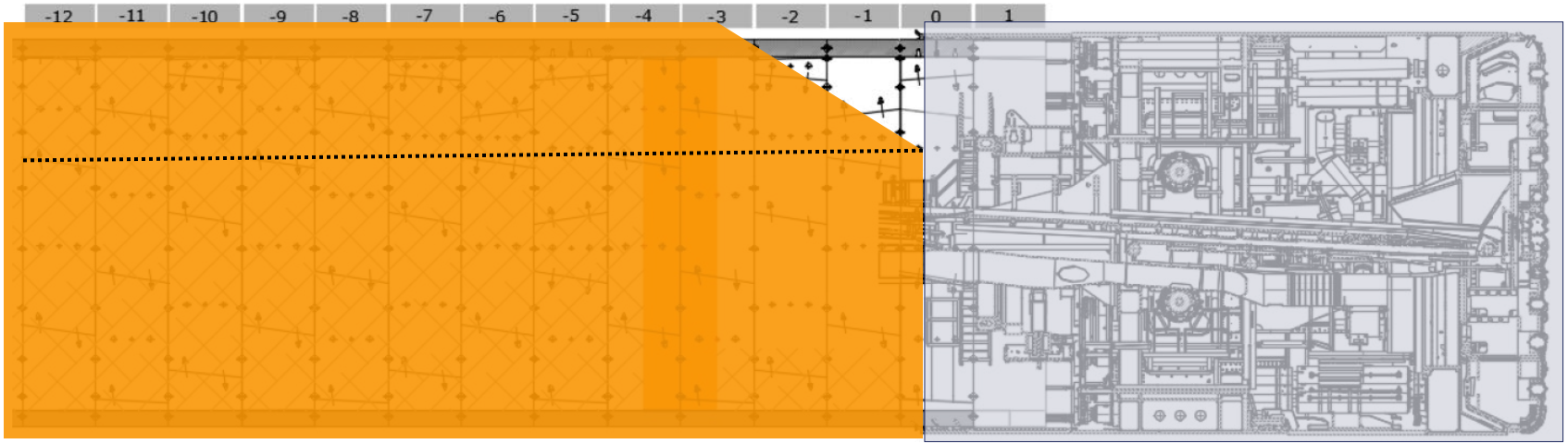
Backfilling in two steps



Through grout ports

From tail shield

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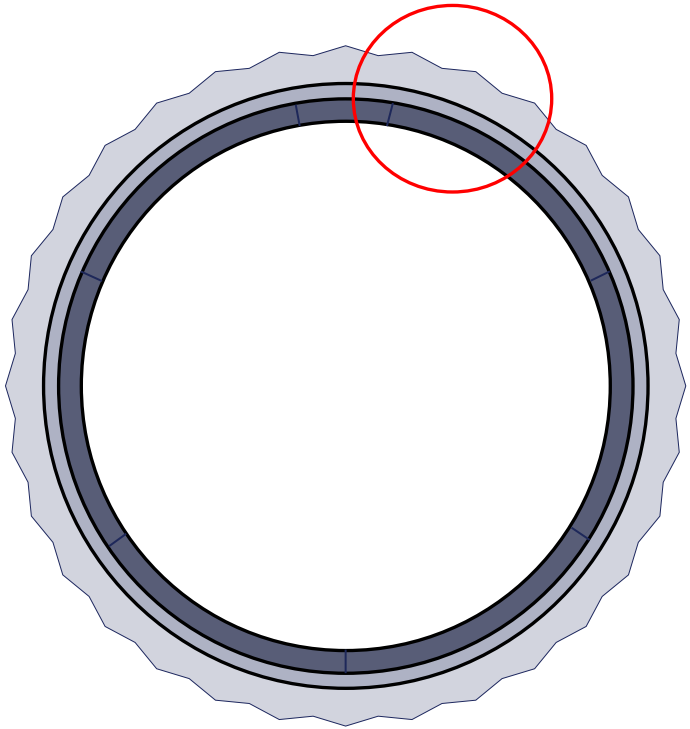
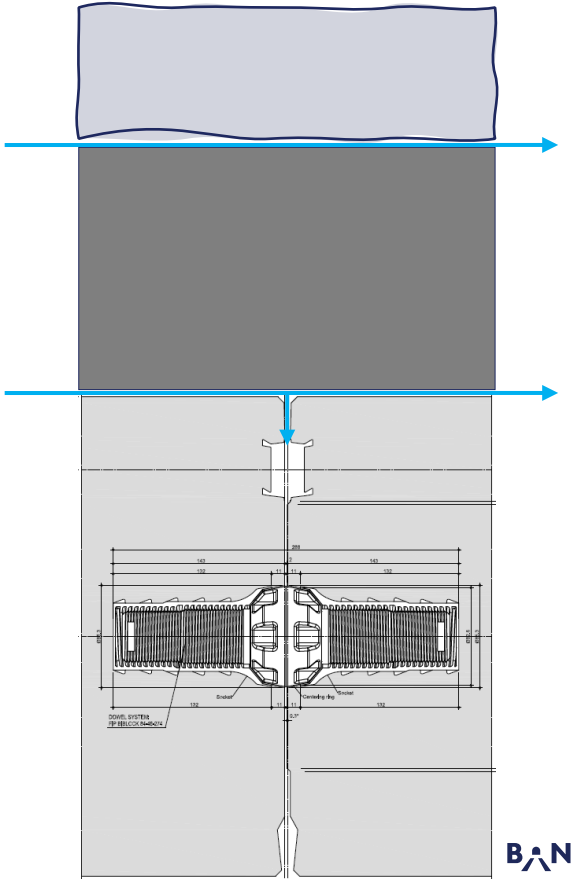
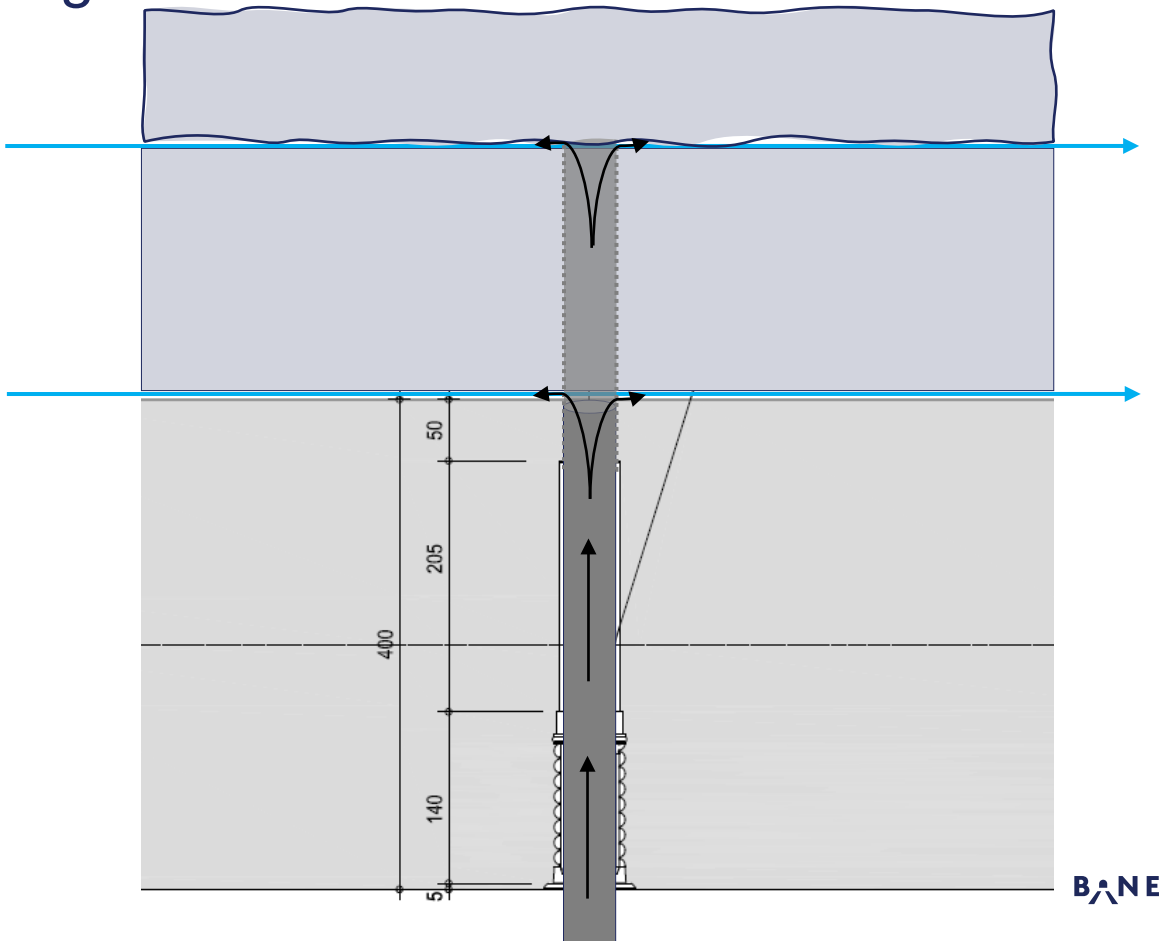
Detail of segmental lining with backfill grout





Contact grouting



Water ingress with and without high pressure

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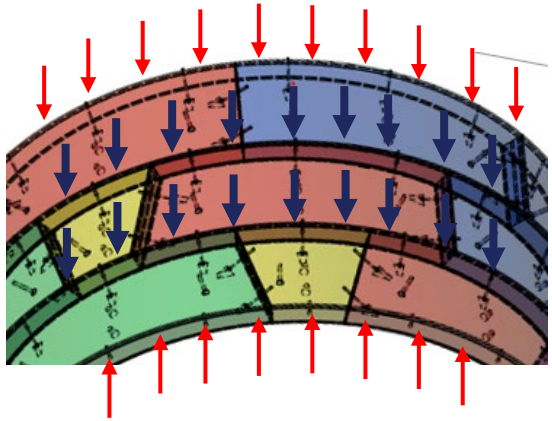
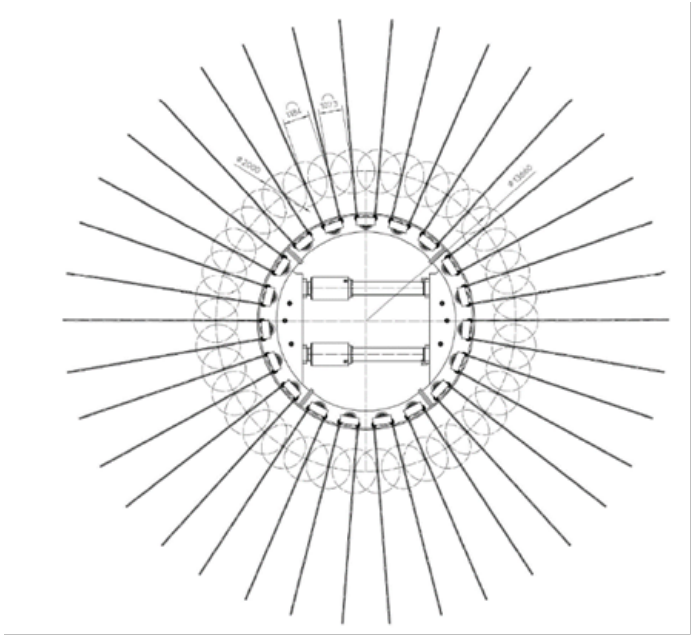
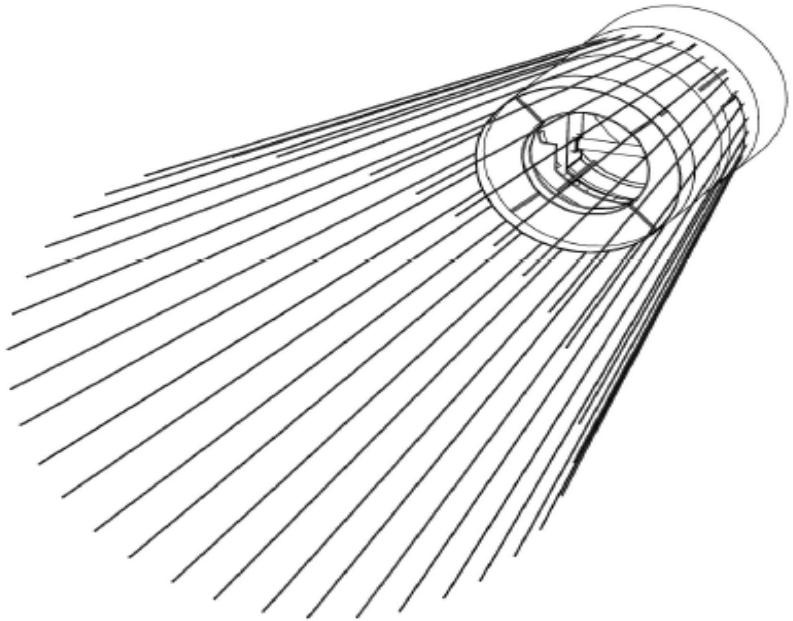
Recommendations for single shell lining

- Study carefully type and location of the gaskets
- High focus on ring gap filling
- Various injection rounds (contact grouting)
- Avoid water running along the tunnel
- Establish water barriers
- Minimize water in tunnel vicinity



Pre-excavation grouting





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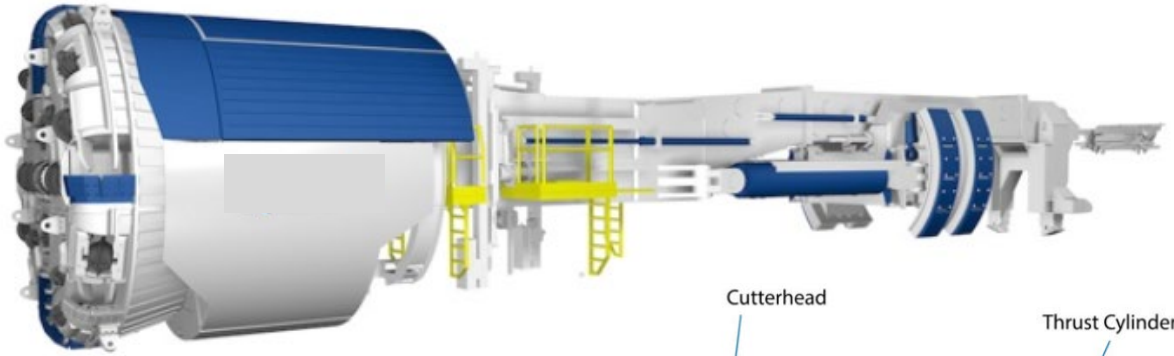
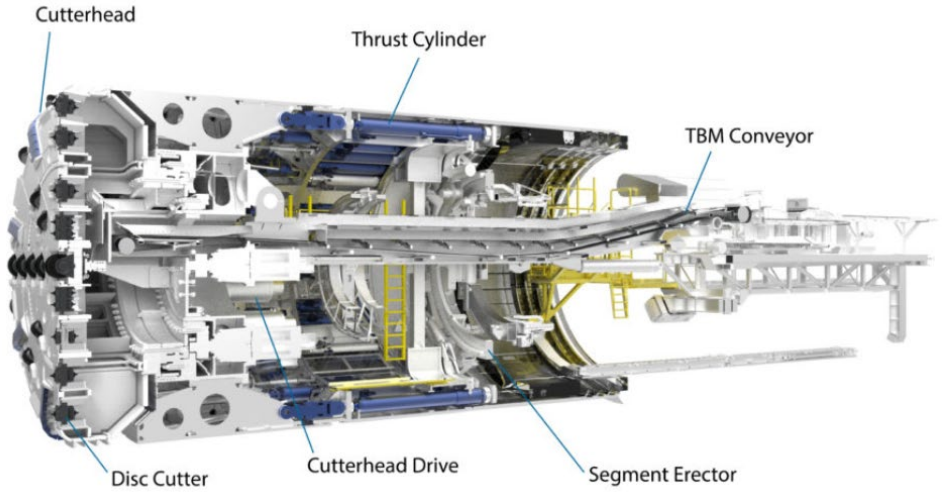
Gripper TBM



Shield TBM



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Excavation of open Gripper TBM and rock support

Ulriken Tunnel

Vereina Tunnel

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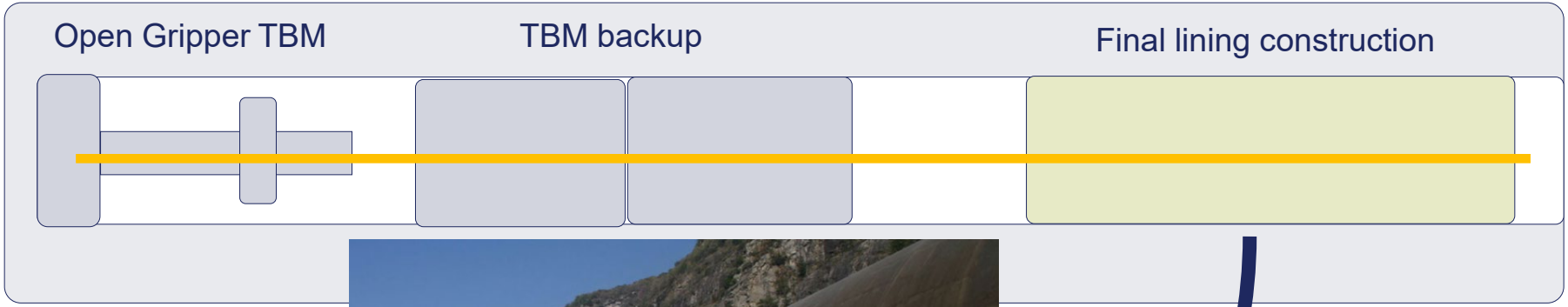
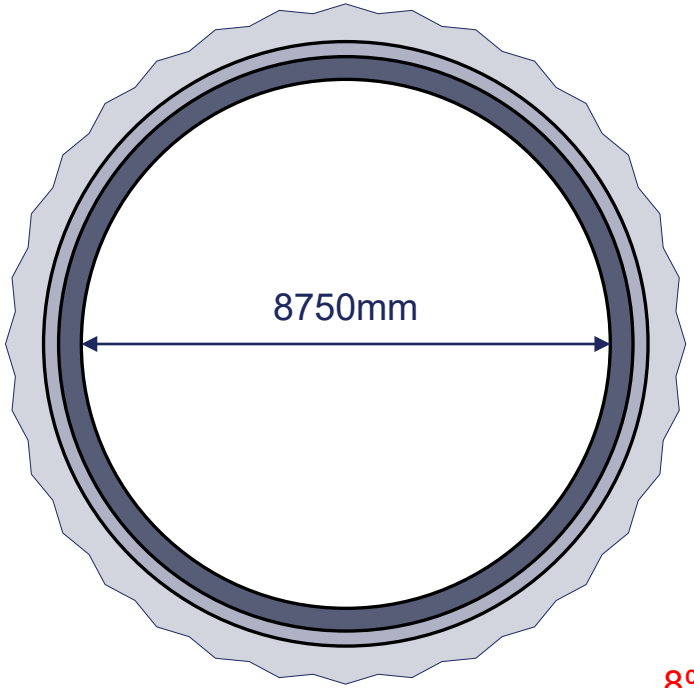
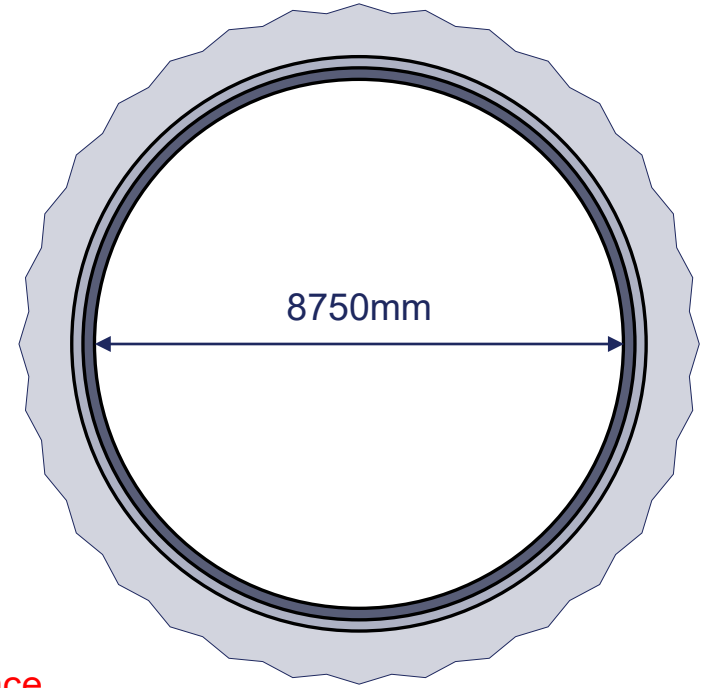
Final lining construction right behind the TBM



Excavation diameter single shell lining versus double shell





8% Difference

D_{exc}= 8750 + 2*400 + 2*205 = 9960 mm

D_{exc}= 8750 + 2*250 + 2*150 = 9550 mm

Follobanen
220 000 m^3

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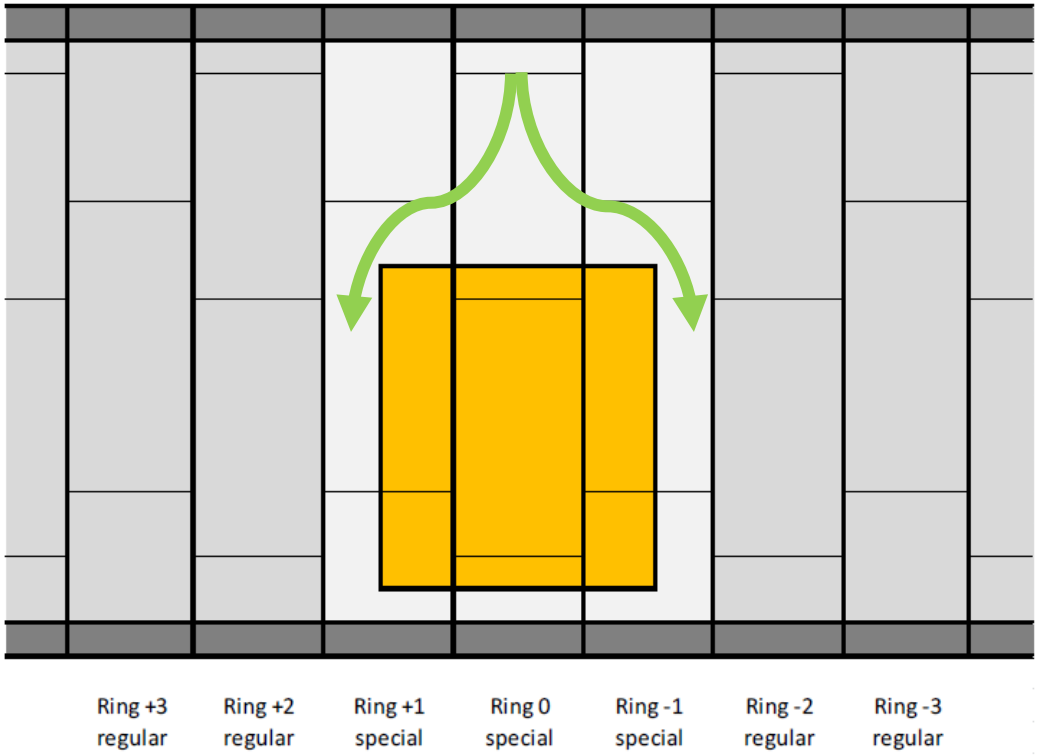
Segment openings for cross passages



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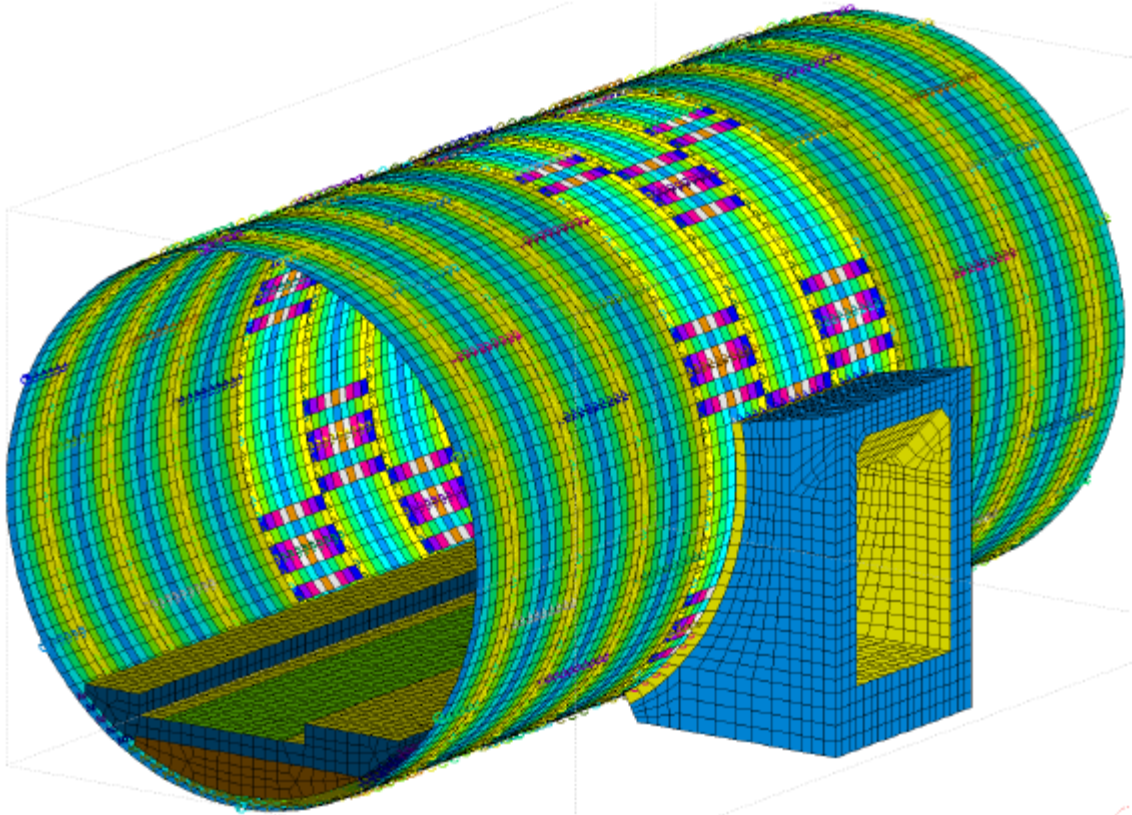
Segment openings for cross passages – numerical model



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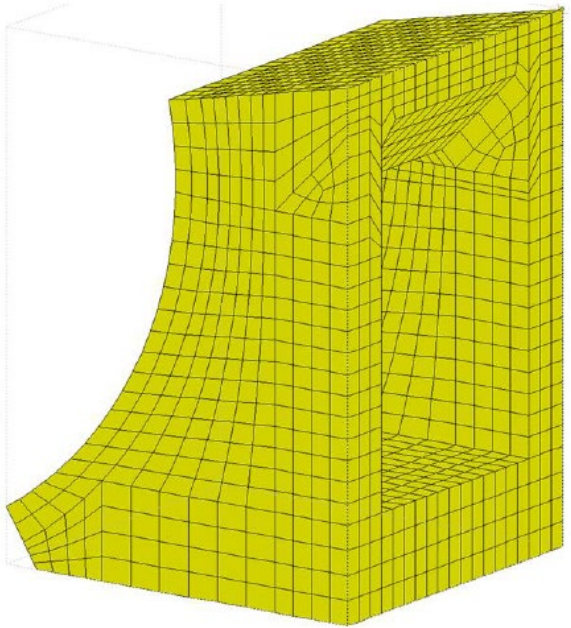
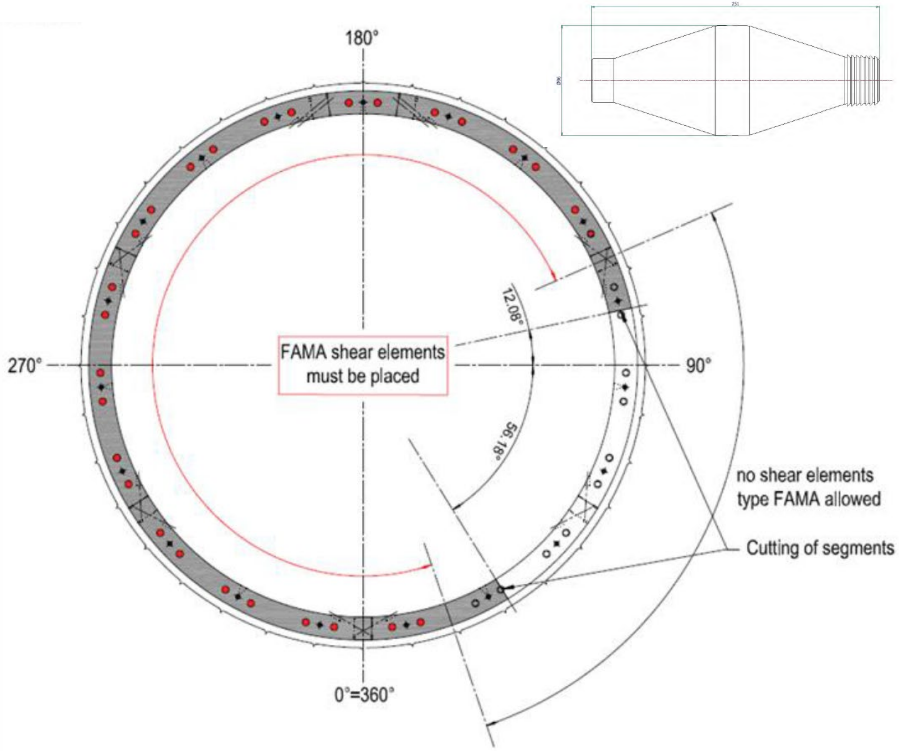
Collar and segment special shear cone





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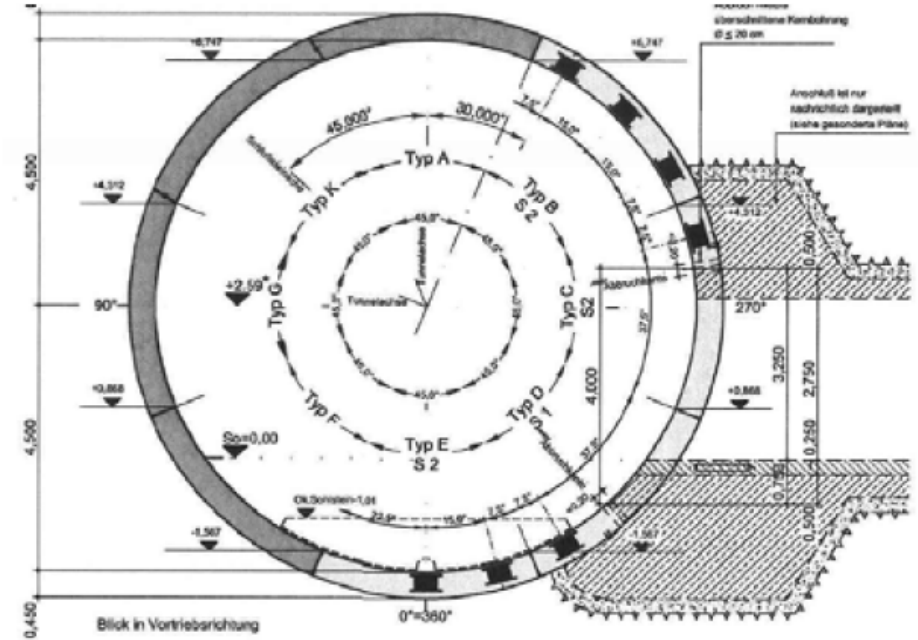
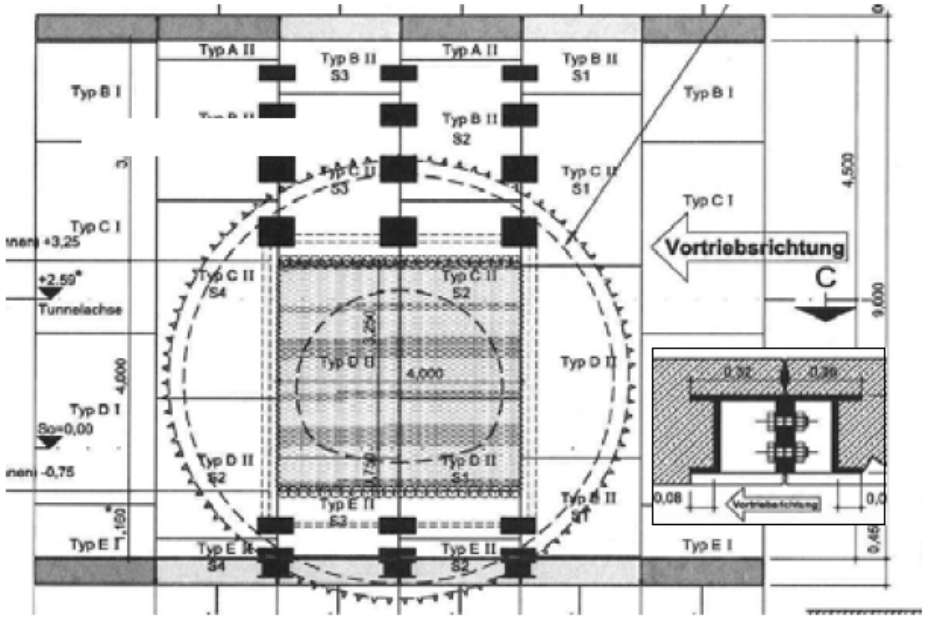
Segments with screw connections





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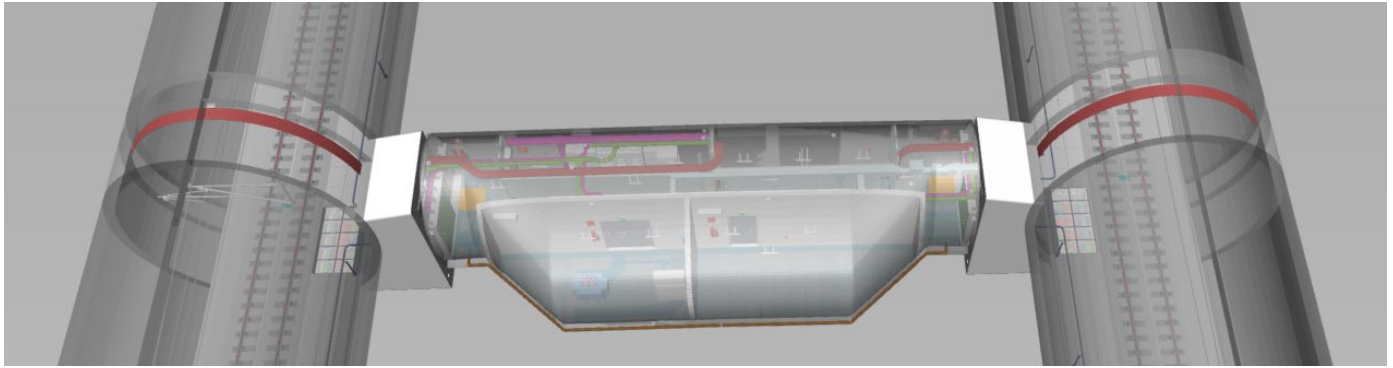
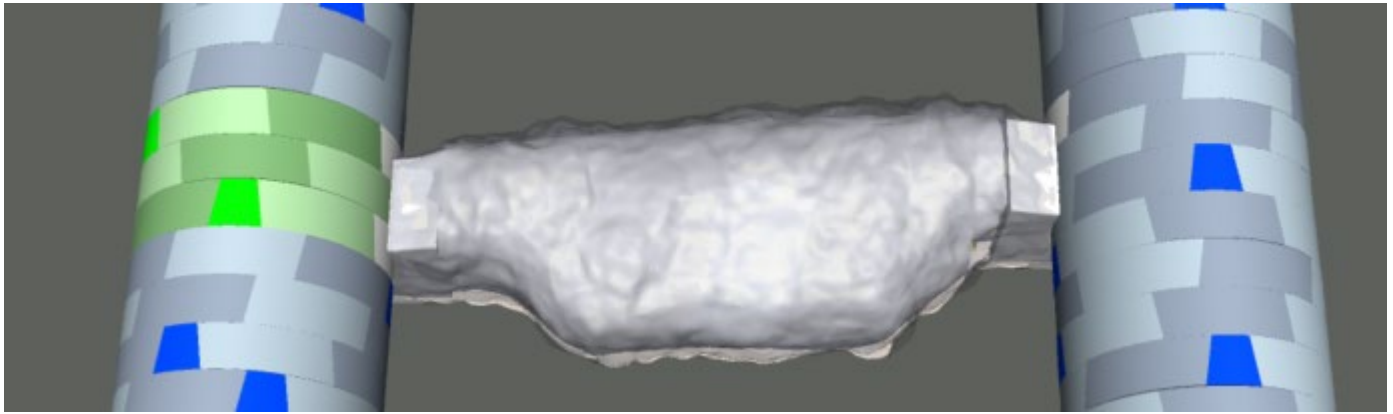
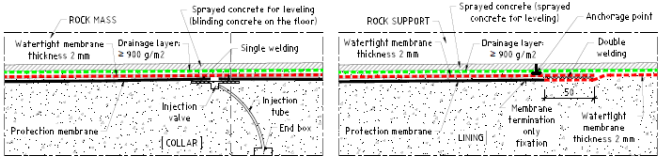
Water tightness of connections with adjacent structures



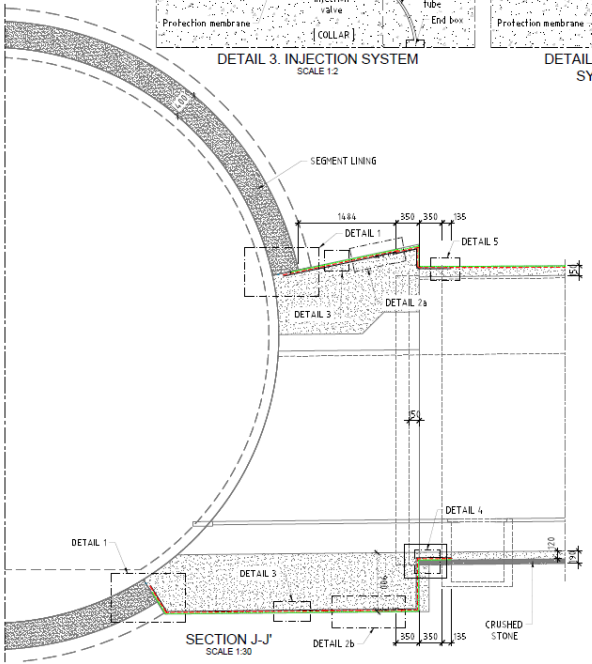


Connection details

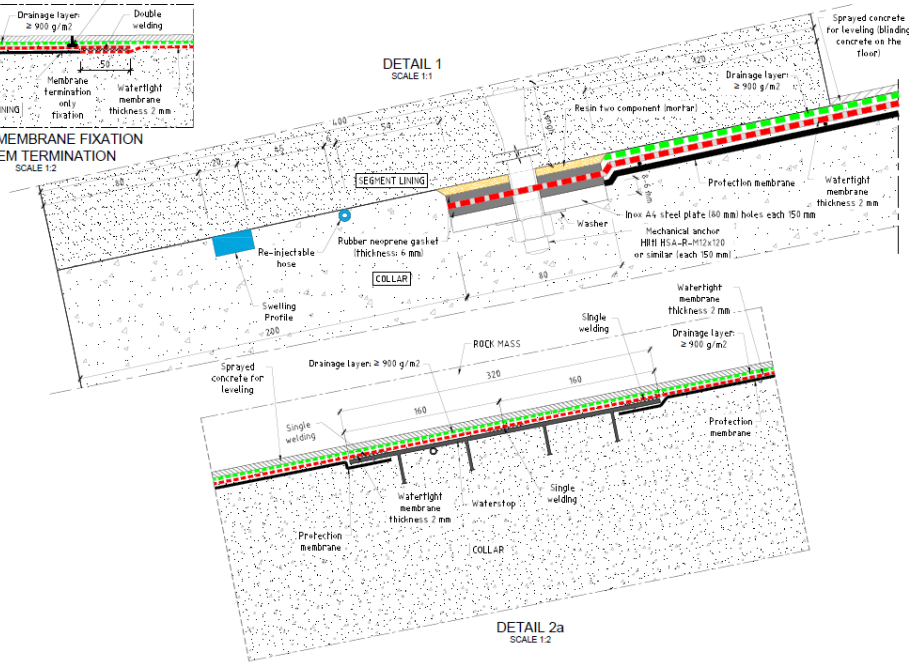


DETAIL 3. INJECTION SYSTEM
SCALE 1:2

DETAIL 5. MEMBRANE FIXATION SYSTEM TERMINATION
SCALE 1:2



SECTION J-J'
SCALE 1:30



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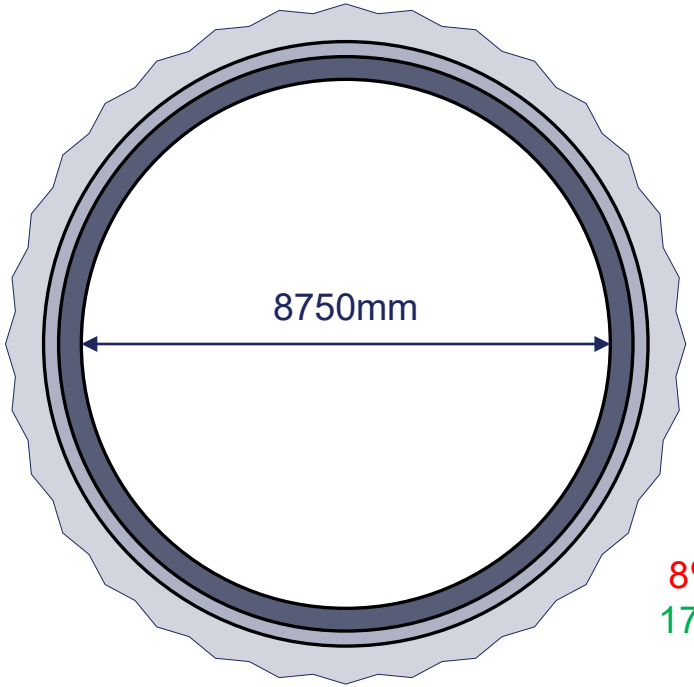
Recommendations for linings in TBM tunnels

- If complete water tightness is required, a double shell lining including a water membrane is recommended
- If double shell, study if the final lining can be built in parallel to TBM excavation

- If a single shell lining is chosen, high focus on the backfill grouting is mandatory
- Make sure all voids of the ring gap are filled
- Consider space for intervention

Excavation diameter single shell lining versus double shell



D_{exc}= 8750 + 2*400 + 2*205 = 9960 mm

Intervention room + 2*250 = 10460mm

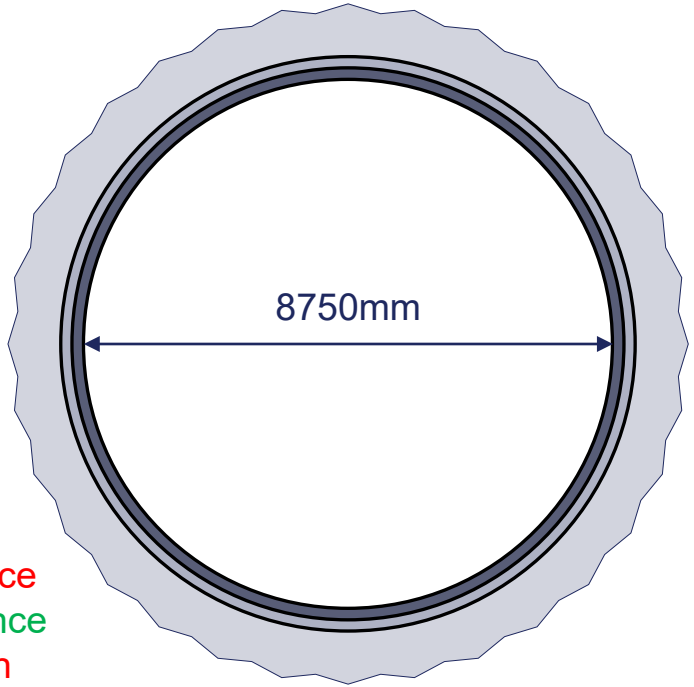
8% Difference

17% Difference

Follobanen

220 000 m^3

515 000 m^3



D_{exc}= 8750 + 2*250 + 2*150 = 9550 mm

BANE NOR

Recommendations for linings in TBM tunnels

- To achieve water tightness with high water pressure, two water barriers are recommended
- Reduce water coming to the tunnel - demand for pre-excavation grouting depends on water appearance and chosen concept
- Have focus on adjacent structures like cross passages and D&B or cut&cover tunnels
- Evaluate the various concepts not only based on ground conditions with water appearance. Consider also other construction constrains, like logistics, and last but not least RAMS perspective including environmental footprint for the entire life time

Thanks for your attention!

BANE NOR