

Passage under Lövstävågen at Bypass Stockholm - From Design to Realization

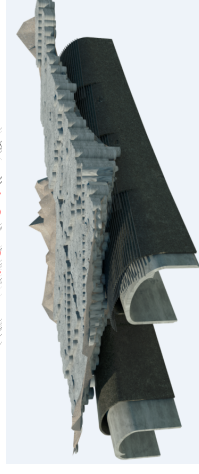
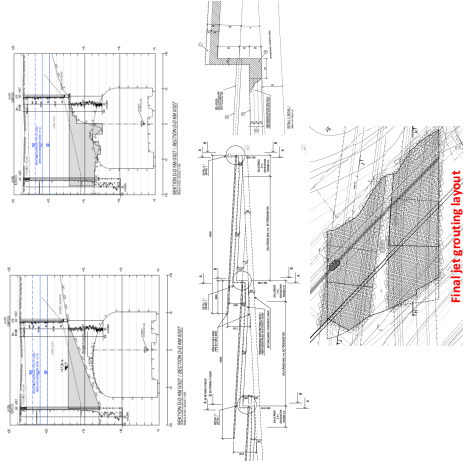
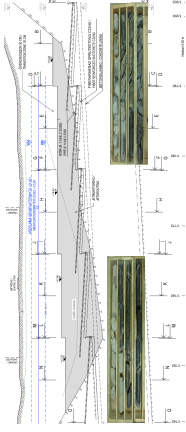
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Construction Phase – Jet Grouting and pipe umbrella

Jet grouting operation started in December 2015 and asked for some adjustments to the original designed solution to better fit with real situation:

- Extension of jet grouting area due to lower rock cover;
- No fixed stop level for the JG but variation based on the tunnel crown level;
- No jet grouting column between two ramps.

Back analysis of the data from jet grouting provided more information about the situation that will be met during excavation



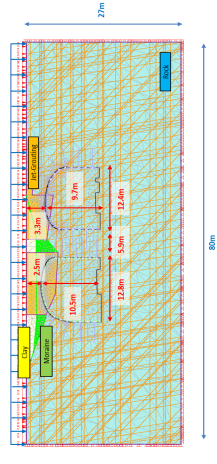
Design optimization

Based on the real data collected during the jet grouting operation and to meet some additional request from client and contractor a re-design of the temporary support was necessary with focus on:

- Worse rock mass condition than previously assumed;
- More extended low rock cover area;
- Better jet grouting parameters than assumed in original design;
- Longer excavation round up to 4m (instead of 1m) is allowed;
- Pipe umbrella geometry adjusted in order to reduce risk of pipes to invade tunnel profile

For pipe umbrella verification has been based on a model consisting of a beam with one end simply supported and the other fixed. Sensitivity analysis based on different rock mass properties and jet grouting influence.
Result: Ø114 / 6-3 3355 tubes, c/c 50 cm, length 15m, inclination 6° offset from axis

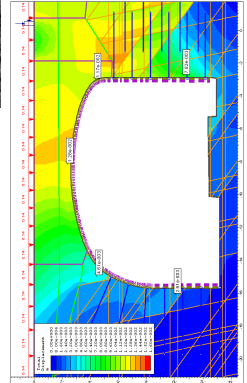
For temporary rock support in tunnel the verification has been based on numerical analysis (discontinuum model), a sensitivity analysis based on different rock mass properties has been carried out.
Result: shotcrete 300 mm, rock bolts length variable (3 or 4m) with spacing variable (1.3 to 2.0m)



Jet grouting	Rock mass properties		Verified excavation length [m]
	Thickness c [Pa]	Thickness φ [°]	
Case# 1	1 1000, 35	1 1000, 45	4 [m]
Case# 2	0.5 1000, 35	2 40, 17	3 [m]
Case# 3	0.5 1000, 35	2 150, 21	2 [m]
Case# 4	0.5 1000, 35	2 150, 21	2 [m]



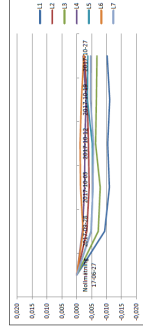
C _{min}	Bolts		Shotcrete
	Spacing s [m]	Thickness h [mm]	
> 4	2.0	3	300
1 < C _{min} ≤ 4	1.5	4	
0.1 < C _{min} ≤ 1	1.3		



Monitoring

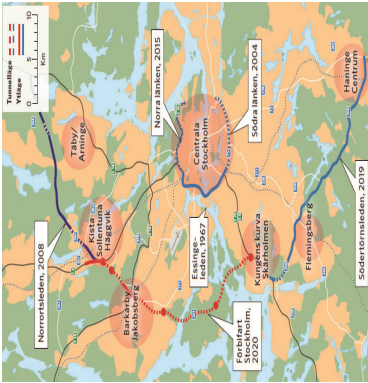
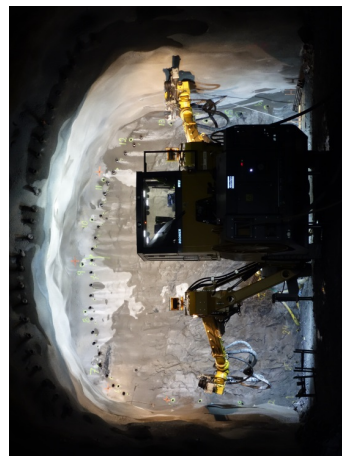
During the construction of the Lövstävågen passage the following monitoring system has been installed in the area:

- Extensometer from surface down to the jet-grouting body
- Convergence measurement in the tunnel
- Inclinometers in the pipe umbrella

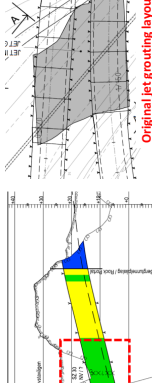
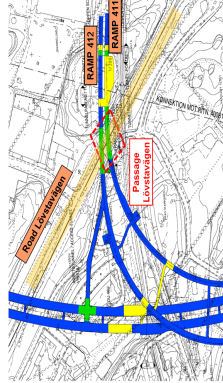


CONCLUSION

- Data coming from the jet grouting operation played a crucial role in identifying deviations from the design scenario and helped to better calibrate the numerical and analytical models
- Higher jet grouting quality opens the possibility to reach a longer excavation round length, even in poor rock mass conditions
- Optimization of design allows to speed up works compared to the original design without reducing the safety margin and with advantages for both the owner and the contractor
- The both ramp tunnels have been excavated without any major issues and the monitoring confirms good match between numerical simulations and real data



Geological conditions
 Zone with little or no rock cover directly under the road Lövstävågen
 Above rock surface are present: 10 m overburden consisting of:
 - Main-made ground
 - Soft clay layer
 - Water-bearing moraine layer
 Below the rock surface has been predicted a competent granite rock



Original design
 During the first phase of the design (2013) main concerns were regarding the rock stability and the hydrogeological consequences related to a low rock cover passage and the following procedure was defined:
 - Prior the tunnel excavation: Jet Grouting
 - During the tunnel excavation: Additional grouting, pipe umbrella, fibre reinforced shotcrete and bolts
 - After the tunnel excavation: cast-in-place concrete lining, sealing system

