Numerical calculation of NATM-tunneling with staged-construction

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Summary

In the course of a large infrastructure project the construction of an underground station was planned. The station with a maximum depth of approx. 32 m is located close to sensitive buildings. The station comprises either a main box and one shaft (clients' proposal) or two shafts (alternative proposal). Depending on the chosen alternative, a NATM-tunnel will be constructed prior or after the excavation of the main box pit.

The aim of the presented calculations was the estimation of settlements at a settlement sensitive church due to the excavation of the pit and the tunnel construction considering different construction procedures. Settlements caused by the installation of the retaining walls were not included in the calculated settlements.

Basically, the construction of tunnels is a full 3D problem. Since a 3D-calculation of the tunneling is very time consuming, 2D plane strain calculations have been carried out. In order to consider the 3D effects in the 2D model, the so called stress reduction method (β-method) has been used. The stress relaxation of the ground due to the delayed installation of the shotcrete lining and the load sharing between ground and lining are addressed by this method. Soil, rock, frozen soils and grouting were simulated using an elastic-ideal plastic material behavior with tension cut-off. In the present case, the Mohr-Coulomb criterion has been used.

The subsoil consists of Limestone, overlain by fill, late/post glacial sediments, upper till, lower till, middle meltwater sand and gravel. Most of the soils, except the post glacial deposits, are over-consolidated. The upper part of the Limestone is glacially disturbed. The calculations have been carried out assuming drained conditions.

Showed calculations were carried out as an employee of Bilfinger Construction GmbH.
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Project „NATM-tunneling with staged-construction“

Description

- Tender phase.
- Estimation of settlements due to the excavation of a pit and tunnel construction immediately next to a settlement sensitive church.
- Foundation loads of approx. 300 kN/m².
- Complex sequence of construction phases.
- Groundwater close to the groundlevel.
- Analysis of different cross sections.
- Study to find an alternative construction procedure.
- Investigation of the necessity of temporary props below the foot of the retaining wall.

Source: www.marmorkirken.dk
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Numerical simulation

• Plane-strain FEM-model.
• Altogether 17 FEM-construction steps have been considered starting from the initial stresses prior to the construction.
• Simulation of retaining walls, ground freezing, dewatering phases, excavation in several levels, NATM-tunneling with head and bench, shotcrete lining (SCL), permanent tunnel lining.
• Parameter study to identify factors that have relevant effect on the results.
• Investigation of an alternative construction sequence.
• Interface elements between concrete members and soil.
• Tunneling simulated by the stress reduction method ($\beta$-method).
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Numerical simulation: cross section

Source: http://www.m.dk/#!/stations/byggepladser/marmorkirken/om+marmorkirken/byens+hegn+mmk
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Numerical model after excavation to concourse level
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Numerical model of excavation of NATM-head

RT-walls

2nd strut

shotcrete lining

RT-walls

micropiles
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Numerical model of excavation of NATM-bench
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Numerical model in the final construction stage after installation of final lining and excavation of staircase
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Results of the calculation in the final construction stage: vertical displacements [m]
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Results of the numerical calculation

settlements at the ground level

![Graph showing settlements at the ground level with various GL steps.]

evolution of settlements at a sensitive point

Monitoring Point Church FL