Proceedings of the 16th International Conference on Soil Mechanics and Geotechnical Engineering

doi:10.3233/978-1-61499-656-9-1651

Tunnelling in top cover technique combined with compressed air for a highspeed railway line in Germany

Creusement d'un tunnel en tranchée couverte sous conditions de surpression pour une ligne ferroviaire à grande vitesse en Allemagne

H. Quick
H. Quick · Ingenieure und Geologen GmbH, Darmstadt, Germany
S. Meissner
H. Quick · Ingenieure und Geologen GmbH, Darmstadt, Germany

ABSTRACT
The Tunnel Offenbau is part of the new highspeed railway line from Nuremberg to Ingolstadt. The Tunnel is constructed in difficult soil and groundwater conditions. The bordering village Offenbau was a further challenge of designing the tunnel. As a result the tunnel was constructed in top cover technique combined with compressed air in order to guarantee the serviceability of the neighbouring buildings of the village at all times. The construction of the tunnel was accompanied by an extensive monitoring programme, which included the monitoring of tunnel and the neighbouring buildings. Moreover, the monitoring is required for the conservation of evidence of the buildings and all structural objects.

RÉSUMÉ
Le tunnel Offenbau fait partie de la nouvelle ligne ferroviaire à haute vitesse entre Nuremberg et Ingolstadt. Il fût construit en conditions de sol et d'eaux souterraines difficiles. Le fait que le village Offenbau soit en toute proximité du chantier apporte un défi additionnel à la conception du tunnel. En conséquence le tunnel a été construit en tranchée couverte sous conditions de surpression afin de garantir à tout moment l'aptitude des bâtiments du village avoisinant. La construction du tunnel fût accompagnée d'un programme de contrôle étendu concernant la surveillance du tunnel et des bâtiments voisins, celle ci étant exigée pour la conservation des preuves.

1 INTRODUCTION

The Tunnel Offenbau undercrosses a small mountain hill and is located between the existing highway A9 and the village Offenbau. The Tunnel was formerly planned in open cut technique (Phase 1) with temporary slopes during the of construction and accompanying lowering of the groundwater level.

Figure 1. Overall situation of the Tunnel Offenbau

Due to the difficult soft soil and groundwater conditions and the nearby village the tunnel had to be re-planned and was constructed by means of the top cover technique combined with compressed air as well as additional groundwater lowering in order to reduce the required air pressure (phase 2).

2 SOIL AND GROUNDWATER CONDITIONS (PHASE 1)

Prior to the construction of phase 1 a ground investigation was carried out. Quaternary fills and soft weathered claystone respectively claystone was encountered during the investigation in phase 1. The groundwater condition were characterized by one unconfined groundwater level in the quaternary fills.

3 TUNNELLING TECHNIQUE (PHASE 1)

In the phase 1 the tunnel had been planned in open cut technique with temporary slopes. The unconfined groundwater level was lowered with wells. The soil conditions lead to slope stability problems, large settlements of the first tunnel segments and settlements of the surface due to the groundwater lowering. A supplementary ground investigation (phase 2) was initiated.

4 SOIL AND GROUNDWATER CONDITIONS (PHASE 2)

After the supplementary ground investigation the ground conditions were characterized by quaternary fills (sands and clay/silt) and soft weathered claystone with very little stiffness. Within the quaternary fills planes with reduced shear parameter were found. Besides, the weathered claystone and the claystone tends to swell.
A second groundwater level in the claystone was found. This groundwater level is confined (subartesian and artesian) underneath the weathered soft clay. (Fig. 2, indicated by the red dotted line).

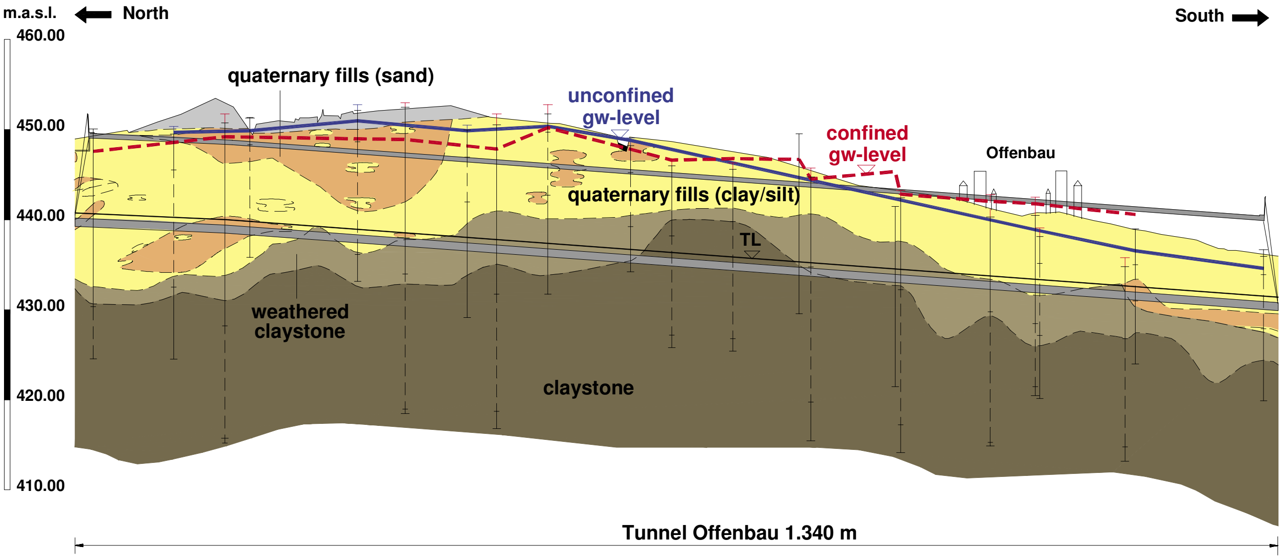

Figure 2. Geotechnical longitudinal section (phase 2)

5 RE-PLANNUNG OF THE TUNNEL

The re-planned tunnelling technique had to take into account the new conclusion from the supplementary ground investigation (phase 2). In particular the very soft soil condition of the weathered claystone as well as the second groundwater level underneath the weathered claystone. Besides the limitation of groundwater withdrawal by authorities had to be observed. The proof of the serviceability was carried out with numerical analysis. Fig. 3 shows settlements due to a groundwater lowering of the unconfined and the confined groundwater level for the tunnelling in open cut technique (phase 1). Therefore, a groundwater lowering as planned (up to 16 m) was not possible.

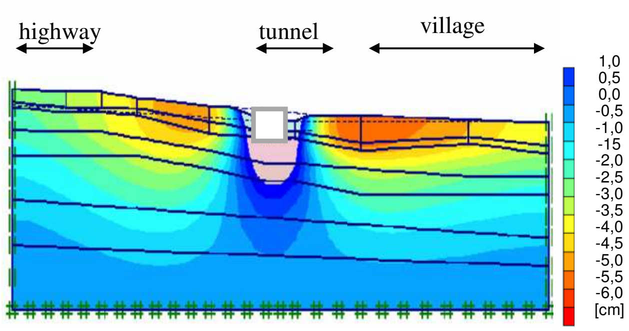

Figure 3. Analysis of the settlements

The tunnel was re-planned in top cover technique with pile walls combined with compressed air pressure and if necessary additional groundwater lowering to reduce the maximum air pressure. The piles were supposed to carry the load of the tunnel into the deeper ground layer with higher bearing capacity.

6 PILE LOADING TEST

To determine the pile capacity parameters pile loading tests were carried out. Two static and dynamic loading tests with pile length of 22 m and 27 m were carried out. An monitoring programme with pressure cells and strain gages in diiferent levels in the piles were installed to determine the end bearing capacity as well as the skin friction in different soil layers (Fig. 4). The tip of two piles (PN) end in the layer of the weathered claystone, the other two piles (PS) end in the claystone. This made a determination of the end bearing capacity in these two layers possible.

Figure 4. measuring systems for the pile loading test

The results of the pile loading test are shortly summarized in Fig. 5. The results of the dynamic loading showed nearly no impact on the pile capacity parameter.

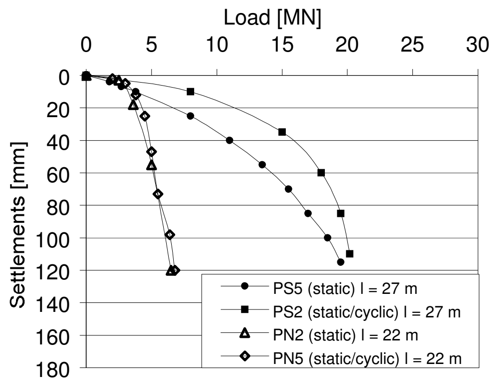

Figure 5. Results of the pile loading test

With the determination of these parameter approx. 10 000 m of piles have been reduced compared to the estimation of the bearing capacity just by the results of the ground investigation.

7 TUNNELLING TECHNIQUE (PHASE 2)

The re-planned tunnel was constructed in 7 stages:

1. Construction of the watertight bored pile walls along both sides of the tunnel (Fig. 6). During construction these piles have the function of a retaining wall. In the final stage the piles are part of the pile foundation to conduct the loads into deeper ground layers. Each pile excavation was geologically documented to draw a comparison with the prognosticated geological situation.

Figure 6. Construction of the watertight bored pile walls

2. Excavation between the walls and construction of the tunnel roof (top cover) and connecting to the pile wall (Fig. 7).

Figure 7. Construction of the tunnel roof (top cover)

3. Earthwork: filling up the ground to the former surface

4. Driving (excavation) of the upper half under compressed air (driving from south to north)

Figure 8. Compressed air driving – air lock

5. Driving (excavation) of the lower half under compressed air (north to south) with additional groundwater lowering to limit a maximum air pressure value to < 1,0 bar.

6. Construction of the invert (temporary).

Figure 9. Construction of the invert (temporary)

7. Construction of the inner lining under atmospheric pressure.

In the construction phases 4 to 5 the loads from the air pressure and the uplift are transferred via the tunnel roof into the bored piles into the ground. The piles receive tension load. In the construction phases 6 and 7 as well as in the final state the loads from uplift and swelling processes as well as the dead and live loads are conducted via the invert / lining into the piles. According to the groundwater level the piles receive tension respectively compression load.

8 TUNNEL DATA

In the following the leading data of the tunnel is presented:

- length of tunnel:	1 340 m
- tunnel width (clearance):	12.30 m
- clear section:	92 m²
- max. overburden:	7.5 m
- secondary piles:	17 m beneath invert
- primary piles:	2 m beneath invert
- piles:	70 000 m *)
- concrete for piles:	56 000 m³
- armour:	8 700 to

*) including the cuts for the tunnel (north and south)

The Tunnel was constructed in the years 2003 and 2004. In May 2003 the driving (excavation) of the upper half under compressed air (driving from south to north) began. The air pressure was increased depending on the confined groundwater level in the tertiary claystone (Fig. 10). In October 2003 the driving was reversed and the lower half of the tunnel was excavated under compressed air and additional groundwater lowering regarding the maximum air pressure of 1.0 bar. In March 2004 the driving was finished and the invert (temporary) was installed and the compressed air shut down.

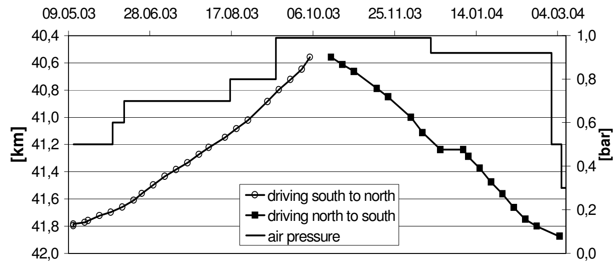

Figure 10. Timetable of the construction

9 MONITORING PROGRAMME

The monitoring programme of the Tunnel Offenbau consisted of geodetical cross sections, geodetical bolts within the tunnel, inclinometer, extensometer and groundwater piezometer standpipes. According to the strict regulation of max. settlements of the neighbouring constructions, the emphasis of the programme was to observe the impact of the air pressure driving in addition with the groundwater lowering in the claystone. The measuring systems of the geodesy and the piezometer standpipes were observed and interpreted weekly.

10 RESULTS OF THE MONITORING PROGRAMME

The largest impact due to the construction of the tunnel was expected for the construction stages 5/6. Fig. 11 shows the lowering of the tertiary groundwater level orthogonal to the tunnel meanwhile construction. The tertiary groundwater was lowered directly next to the tunnel approx. 4 m (29.01.04 – 11.03.04). In March 2004 the lowering was shut off and the groundwater level raised. In a distance to the tunnel axis of 150 m no impact could be observed.

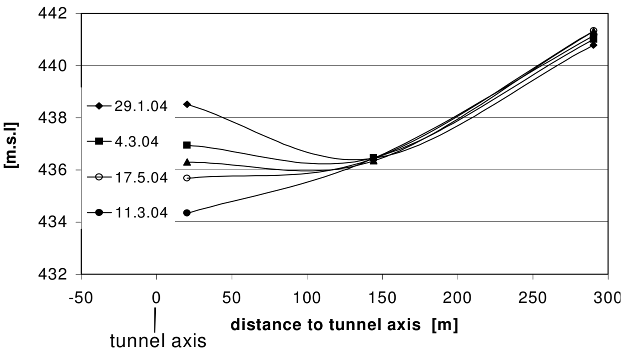

Figure 11. Tertiary groundwater lowering – cross section

The surface settlements due to the construction of the tunnel with additional groundwater lowering are shown in Fig. 12. The settlements reached a maximum of 2 cm. Only in the southern part, where the surface had to be artificially filled up to the tunnel roof, the settlements added up to approx. 9 cm.

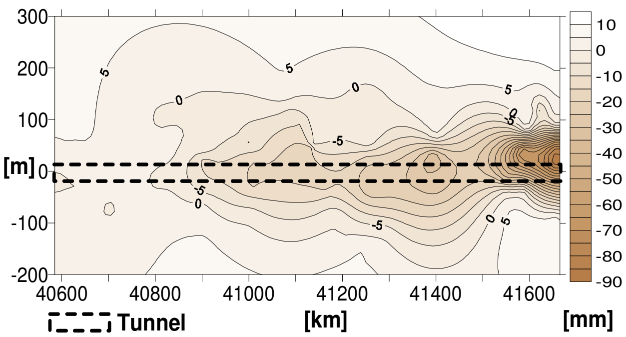

Figure 12. Surface settlements (17.03.04) – plan view

11 CONCLUSION

The Tunnel Offenbau had been planned in open cut technique. Due to the new conclusions of the supplementary ground investigation the tunnel had to be re-planned (phase 2). After all, the tunnel was constructed successfully in top cover technique with compressed air driving and additional groundwater lowering of the confined groundwater level. The groundwater lowering was used to limit the air pressure during construction to a maximum of 1.0 bar. The construction of the tunnel was accompanied by a extensive monitoring programme to observe all impact on all neighbouring constructions. By means of this programme the serviceability of the neighbouring constructions as well as of the tunnel itself was evaluated. Moreover, with the monitoring the conservation of evidence of the housings and all structural objects was possible.
In order to optimise the tunnel construction pile loading tests in consideration of all boundary conditions were carried out.