Numerical Studies for the Development of Design Loads of Ground Pressure for Tunnelling Machines with Shield

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1 Introduction

In the loose to friable rock tunnelling machines with shield (shield-TBM) are used. The to time usual design loads of ground pressure for shield drivings was developed for drivings in loose rock with isotropic material behaviour of the rock. On the other hand, no special design loads of ground pressure exist for shield-TBM in the rock with anisotropic material behaviour.

In range of the research activities of the Institute of foundation engineering and soil mechanics of the technical University of Braunschweig (IGB·TUBS) accomplishes numeric studies for the simulation of shield drivings. For the development of design loads of ground pressure for tunnelling machines with shield were implemented numeric computations at a three-dimensional model with the finite difference method (FDM).

2 Construction progress and technique with a shield-TBM

2.1 Construction progress

The shield-TBM is a machine type, which is equipped with an open shield (fig. 1). Tunnelling machines, which do not have a closed system to compensate for the pressure at the working face, are referred to as open shields. This means that no extraction chamber has been defined. In the protection of the shield, the tunnel is largely automated driven and supported. The support of the ground usually takes place by a shield-TBM with reinforced concrete lining segments, which is built in the shield tail by an erector. In order to drill, the shield-TBM supports itself by presses with the tunnelling jacks at the lining segment inserted last.

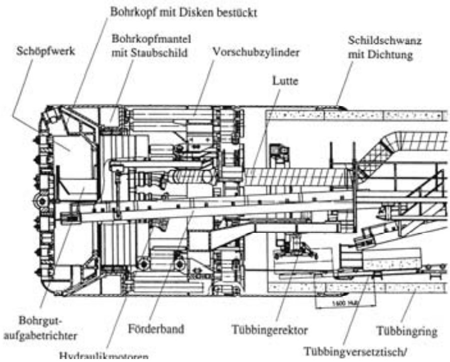

Fig. 1 Shield-TBM from Herrenknecht (Girmscheid 2000)

The cutting wheel is fitted with hard rock discs, which rotate on the working face and notch into it (fig. 2). The notching effect causes large sections of rock to break off. Buckets, located behind the discs transport the rock behind the cutting wheel. Conveyor equipment then transports the excavated material out of the tunnel.

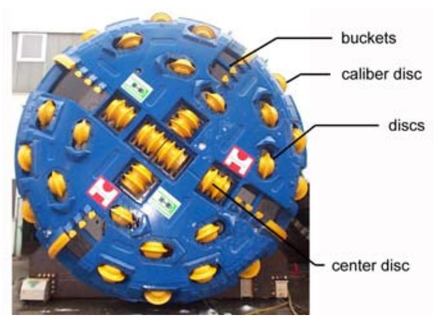

Fig. 2 Cutting head of a shield-TBM from Herrenknecht

2.1 Over cut

With the shield, driving results by the cutting tools and with driving along curves from the shield skin temporary an outbreak cross section, which is larger than the cross-section area of the shield. This difference as over cut is designated. By a reduction of the driving forces overlapped is reached, in order to facilitate the driving and preserve the lining. Likewise by overlapped the controlling of the shield supported.

Over cut more according to plan can by the cutting tools be produced, as longer cutting tools at the drilling head are arranged. Beyond that can overlapped more according to plan by a conical, i.e. to the shield tail tapering shield tail to develop oneself. With driving along curves can by tillable cutting wheel or with disman-tling mechanics built in the shield with angle of rotation-dependent steered and extendable cuttings tools overlapped more according to plan firmly to be reached.

2.2 Annular gap

Due to the over cut and the smaller diameter of the lining segments a free space to the ground, which called annular gap or annular space, results. This annular gap must be filled, in order to reduce and to ensure around the necessary bedding the lining segments loosenings and with it load relocating of the surrounding soil. For the backfilling of the annular gap two possibilities are available.

Usually the annular gap is filled when TBM pushing forward in the rock above the groundwater with fine-grained and narrow-gradated gravel, which is blown e.g. with a drying spraying machine. In addition at the lining segments corre-sponding openings are planned, in order hose lines to attach to be able (fig. 3).

In the rocks with small stability and within ranges in those groundwater is pre-sent, the annular gap with grout is injected (fig. 4). The grout can be brought in either by check valves into the individual lining segments or at the seal past by the shield tail. To make certain with bringing in grout is thereby that the pipes, by which the injecting property is brought in with a stop of the machine not to clog, as the injecting property is accordingly fluid and/or contains a special tying delay. This however difficult by the demand that the grout is to exhibit a large rigidity in a fast confirmation procedure, in order to minimize redistributions of stress.

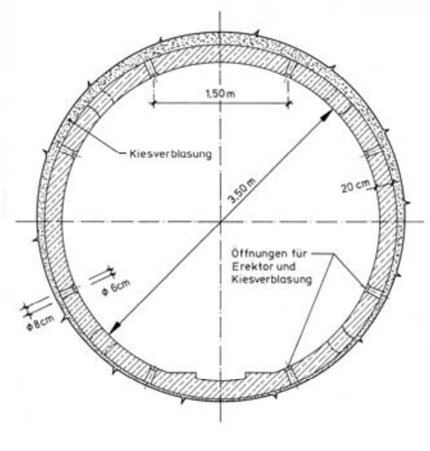

Fig. 3 Backfilling with gravel (Maidl et al. 2001)

In the case of injection with grout for different projects in the rock problems resulted (Girmscheid 2000). It observed that behind the tunnelling jacks within the ranges, within which the fresh grout of the annular gap was not yet confirmed the lining segments swims itself. The moreover one with the shield skin and the lining segments a rolling, due to the insufficient friction for the reaction resistance of the very high drilling head drive moment in the rock, was determined.

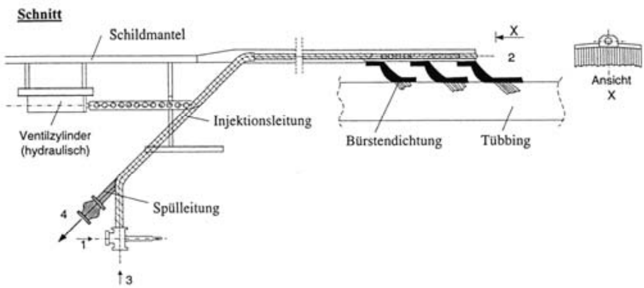

Fig. 4 Backfilling with grout and brushing seal (Girmscheid 2000)

3 Influences on the stress-strain behaviour of the ground by a shield-TBM

By drilling with a tunnelling machine, the shield tail transfers the supporting of the cavity as relatively rigid body in the range of the shield. Behind the shield, the supporting of the cavity takes place by lining segments, which already possesses its ultimate strength with the installation. By this rigid construction, the acceptance exists that in the ground no significant deformations and rearrangement of the stresses takes place.

The observations with implemented projects show however that it comes to a rearrangement of the stresses. For it the following causes can recapitulate be designated:

- Over cut more according to plan the cutting wheel
- Over cut more according to plan by a conical shield tail
- Over cut unscheduled and more according to plan by driving along curves
- Annular gap backfilling/incorrect annular gap backfilling
- To small working face supporting
- Irregular supporting at the working face

4 Numerical model

For drivings in loose rock numerical computations with a three-dimensional FE model was already simulated by IGB·TUBS (Schmitt et al. 2003). It showed up that for the simulation of a shield driving by a simple numerical model are not to be modelling the rearrangement of the stresses of the ground. To form a ground-arch with a two-dimensional FE model, a reduction factor was necessary within the range of 10 % to 15 %. The moreover one the investigations showed that the beginning of an annular gap grouting and the consideration of the construction progress do not have an influence which can be neglected on the determination of internal forces and moments in a spatial numeric computation (Stahlmann et al. 2004).

For the development of design loads of ground pressure for tunnelling machines with shield are accomplished to time numeric investigations to IGB·TUBS. In addition a three-dimensional numeric model with the assistance of the finite difference method (FDM) of a shield-TBM was developed, with which the realizations specified before were considered during the modelling (fig. 5). In order to examine the effects of the over cut and the influence from the annular gap backfilling on the rearrangement of the stresses of the ground, the following geometrical variations were simulated with the developed numerical model (fig. 5):

- Model a: no consideration of an over cut or an incorrect annular gap backfilling
- Model b: consideration of an over cut
- Model c: incorrect annular gap backfilling
- Model d: combination of model b and model c

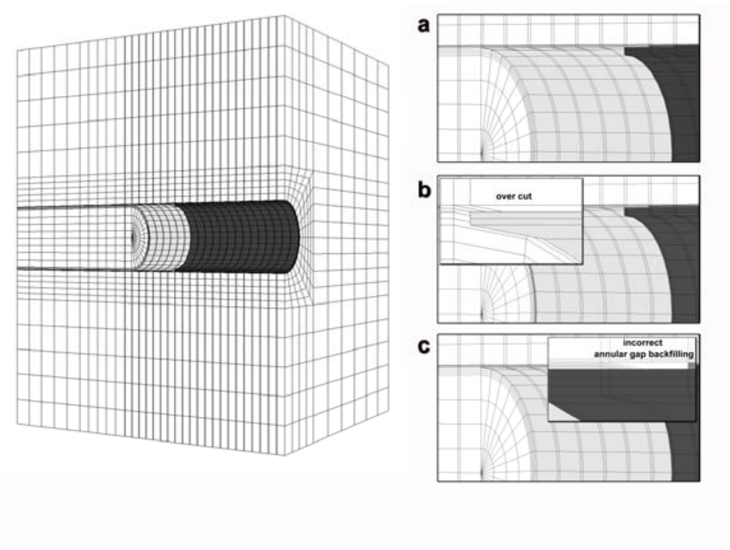

Fig. 5 Numerical model, geometrical variations a) without over cut b) with over cut c) incorrect annular gap backfilling

With a diameter of the tunnel cross section of D = 11.60 m the dimensions of the computation model were specified to the German society of geotechnique according to the recommendations of the working group 1.6 "Numerik in der Geotechnik" (Meißner, 1996). Afterwards a lateral distance to the edge of 45 m according to 4d to 5d and a distance from the lower edge of 30 m were selected according to 2d to 3d. The thickness of the lining segments was specified by a preliminary design for an overburden by 30 m with d = 40 cm. For the width of the lining segments 1.5 m was selected.

	Ground	Steel (St37)	Lining segments (B35)	Gravel
E-modulus E [MN/m^2]	1,000	210,000	33,500	100
Poisson's ratio ν [-]	0.25	0.3	0.2	0.35
Unit weight γ [kN/m^3]	26.0	75.0	24.0	16.0
Angle of friction φ' [°]	25	-	-	-
Angle of dilatancy ψ' [°]	0	-	-	-
Cohesion c' [MN/m^2]	0.5	-	-	-

Table 1 Used material parameters

The surrounding ground is simulated with a linear elastic ideal plastic material law according to Mohr-Coulomb and a not associated flow rule. Table 1 shows the used ground parameters.

For the simplification of the modelling, only the shield tail in the model was modelling. The Shield, the lining segments and the gravel backfilling for the annular gap were set with linear material behaviour (Table 1).

For the simulation of the supporting pressure at the working face, an evenly distributed load per unit area was set. This was measured from the earth pressure at rest with 300 kN/m^2, working in the depth situation, in which the tunnel comes to lying.

The computations took place as step by step analysis. In addition, 20 load cases and/or states during construction were modelled. After the computation of the primary state of stress, the driving of the shield machine with a length of 10.5 m was simulated. State during construction #7 simulates the activated first ring of lining segments near the shield tail of the tunnel machine. State #8 activates the following ring of lining segments and replaces the material of the shield tail with the grout. For illustration are represented the states during construction 6 to 9 in fig. 6.

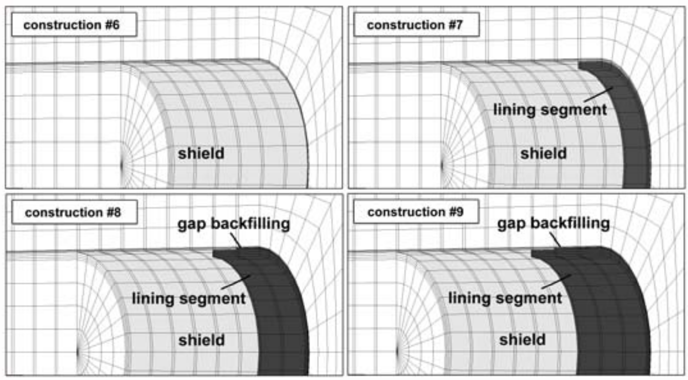

Fig. 6 Allocation of material properties for states during construction #6 to #9

5 Computation results parameter studies

For the analysis of the rearrangement of the stresses of the ground with the different geometrical model variations, the radial and tangential stresses within the range of the sidewall of the tunnel were regarded.

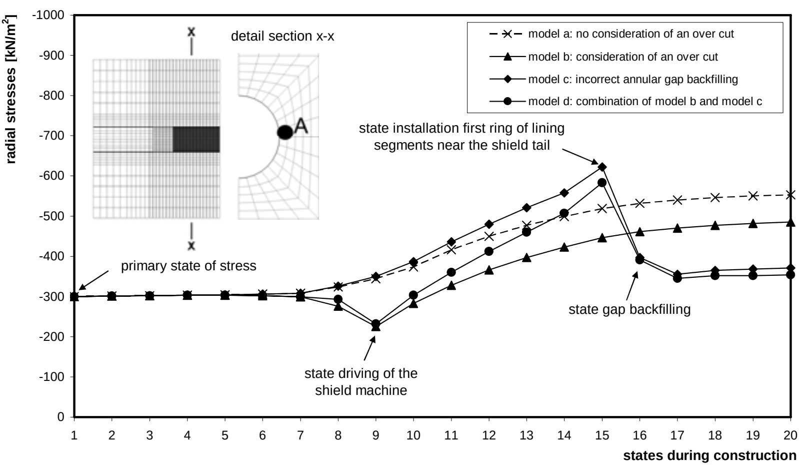

Fig. 7 Radial stresses dependent on construction progress

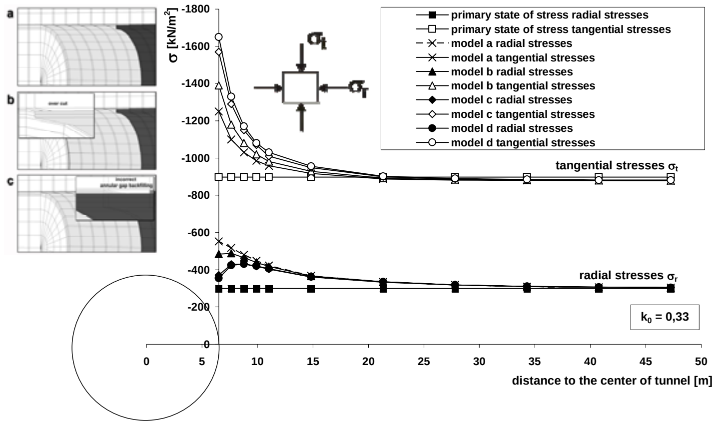

Fig. 8 Distribution of tangential and radial in the surrounding of the excavation near the wall

In fig. 7 are represented the radial stresses dependent on construction progress in the range of the sidewall of the tunnel for the different geometrical models a to d. To recognize clearly it is that the consideration of the over cut leads and incorrect annular gap backfilling in the computation models to a substantial reduction of the radial stresses within the range of the elm tree. The incorrect annular gap grouting seems to have a larger influence on the reduction of the radial stresses than the consideration of the over cut. Likewise it is to be stated with the analysis of the radial and tangential stresses within the range of the sidewall of the tunnel transverse to the tunnel that the modelling of the over cut and incorrect annular gap backfilling have a substantial influence on the rearrangement of the stresses of the ground (fig. 8).

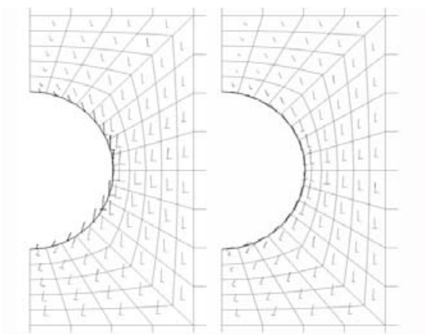

Fig. 9 Stress trajectories model a / model d

Consideration the stress trajectories on average x-x, then shows up that with consideration of the over cut and an incorrect annular gap backfilling a ground arch is formed (fig. 9).

6 Conclusions

The numeric investigations accomplished up to now show that the modelling of the over cut and the annular gap backfilling have a substantial influence on the rearrangement of stresses. Likewise the analyses show that the material parameters have a substantial influence on the form of the ground-arch.

In further computations the influences are examined, which result from the variation of the geometrical parameters e.g. size of the over cut, thickness of the ring gap, tunnel diameter, overburden and from the variation of the material parameters for the description of the underground e.g. elastic modulus, poisson's ratio, shear strengths.

In the next stage numerical simulations are to be accomplished, with which the anisotropic material behaviour is considered by rock by the application of appropriate material laws.

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