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On the influence of face pressure, grouting pressure and TBM design in soft ground tunnelling

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Abstract

A three-dimensional finite element simulation model, which includes all relevant shield tunnelling components and allows for the modelling of the step-by-step construction process of the tunnel advance is used to analyse the influence of TBM operation parameters and design parameters for a shallow tunnel advance in homogeneous, soft, cohesive soil below the ground water table. The numerical sensitivity studies presented in this paper focus on the face support pressure, the grouting pressure, the trailer weight and the length, weight and taper of the shield machine. The simulation results are evaluated with respect to the settlements of the ground surface, the shield movement and the loading of the tunnel lining. The evaluation of the sensitivity analyses helps to obtain a more detailed insight into the influence of selected parameters relevant for the design and steering of TBM tunnel advances.

Keywords: Shield tunnelling; Numerical simulation; TBM design; Finite element method; Settlements; Parametric studies; Sensitivities; Soft soil

1. Introduction

During the past decades, an increased use of numerical models for the prognosis of the ground behaviour, the surface settlements and the loading and deformation of the lining of shield-driven tunnels can be observed. Starting from two-dimensional approaches, see e.g. Finno and Clough (1985), Bernat and Cambou (1998) and Abu-Farsakh and Voyiadjis (1999), several advanced three-dimensional models have been developed in recent years, e.g. by Mansour (1996), Abu-Krisha (1998), van Dijk and Kaalberg (1998), Komiya et al. (1999), Dias et al. (2000) and Melis et al. (2002). However, relatively few elaborate and systematic parametric studies that evaluate the influence of the various parameters involved in shield tunnelling have been published so far. Finno and Clough (1985) have analysed the effect of the face support pressure of an EPB shield and the influence of the soil stratification on the ground deformations by means of two-dimensional analyses. Using a similar two-dimensional model for tunnel advances in soft soil, Abu-Farsakh and Tumay (1999) have performed parametric studies to determine the effect of the coefficient of earth pressure at rest, the overconsolidation ratio, the face pressure and the cover depth on the ground deformations and the excess pore pressures in the soil. Lee and Rowe (1989) have used a two-dimensional finite element model to study the influence of the anisotropy of natural soils on the ground behaviour. The three-dimensional model developed by Mansour (1996) was used to investigate the effect of the face pressure, the grouting pressure and the constitutive modelling of the soil on the soil stresses and ground deformations. Abu-Krisha (1998) improved this model to take into account the influence of the ground water. He analysed the influence of the soil properties and the cover depth on the ground and lining behaviour by

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means of simplified two-dimensional simulations and the influence of the face and grouting pressure on the excess pore pressures by means of three-dimensional analyses.

A three-dimensional finite element model for shield tunnelling in soft, water saturated soil, which takes into account all relevant components and realistically models the step-by-step construction process, is proposed in Kasper and Meschke (2004). Due to the fact that all components are included in the model, the effect of different parameters can be investigated not only with respect to the stresses, pore pressures and deformations of the soil, but also with respect to the TBM movement and the deformation and loading of the tunnel lining taking the rather complex interactions between the different tunnelling components into account. In this paper, the influence of the face and grouting pressure and the TBM design is evaluated with respect to various important tunnelling design criteria such as the surface settlements, the shield movement and the loading of the tunnel lining. Further details are contained in Kasper (2004).

2. Finite element simulation model

The components of the finite element model and the simulation procedure are described in detail in Kasper and Meschke (2004). Therefore, only a short overview is given here. The water saturated soil, the hydraulic jacks, the tail void grout and the tunnel lining are represented by respective finite elements and the shield machine is modelled as an undeformable contact body with a tapered shield skin (Fig. 1). The segmentation of the tunnel lining is not considered in the model. The back-up trailer is taken into account by point loads on the tunnel lining, which follow the advancing shield machine. According to tunnelling practice, the TBM advance is modelled in each simulation step by length changes of the elements, which represent the jacks between the pressure bulkhead of the TBM and the tunnel lining. Taking into account the face support pressure in the excavation chamber, the weight of the TBM and the frictional contact to the soil along the shield skin, the interaction of the TBM with the soil, the jacks and the tunnel lining is realistically modelled. After each TBM advance, the excavation at the cutting face, the tail void grouting and the erection of a new lining ring during standstill are taken into account by rezoning the finite element mesh at the cutting face, introducing new elements for the grout and the tunnel lining, connecting the jack elements to the new lining elements and computing one or more time steps with updated boundary conditions for the grouting pressure, the face support pressure and updated positions of the trailer loads. The grouting pressure is modelled by pore pressure boundary conditions on the grout element nodes at the shield tail according to the assumed grouting pressure with a variation of 10 kN/m^2/m over the height. Considering the time-dependent stiffness and permeability of the material, the initial pressurised fluid state of the grout and its hardening during hydration are taken into account. The applied coupled two-field finite element formulation for the soil and the grout also takes into account the fluid interaction between the grout and the soil and the dissipation of the grouting pressure behind the TBM.

The automation of the simulation by means of a complementary program TSIM3D, which is linked to the finite element program, forms the basis for user-friendly simulations of arbitrarily long, straight or curved tunnel advances and for extensive parametric studies. Fig. 1 shows the result of a test simulation of a curved tunnel advance with a radius of 200 m. The implemented automatic steering of the individual jack thrusts leads to a deviation from the prescribed driving path of max.

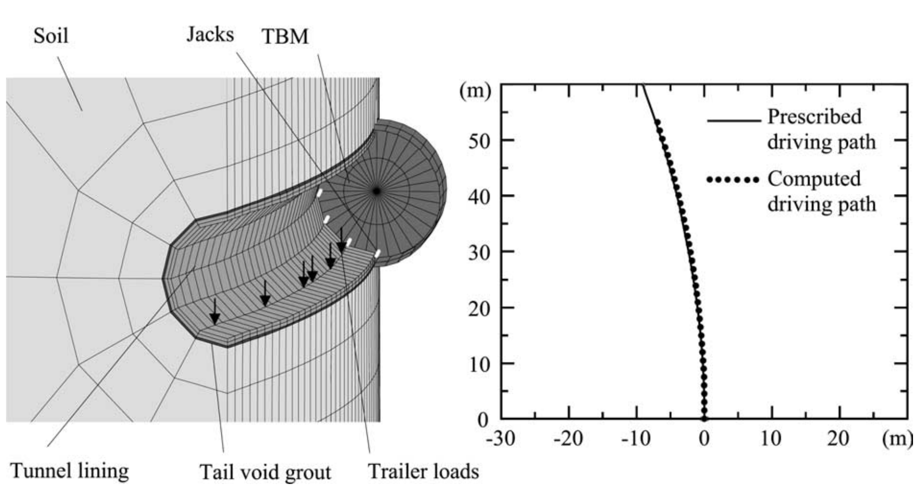

Fig. 1. Test simulation of a curved shield tunnel advance with a radius of 200 m.