Numerical simulation in machinised tunnelling

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3D Simulations in TBM tunnelling

- Reliable prognoses of settlements (in particular in sensitive urban areas), stresses in tunnel lining etc.
- Insight into interacting mechanisms between individual components
- Sensitivity studies: Evaluation of influence of selected parameters
- Investigation of difficult soil conditions, identification of critical situations, failure of tunnel face
- Basis for optimization of design of tunnel excavation

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European Research Initiative TUNCONSTRUCT

SP 1
Design

SP 2
Innovative Technologies

SP 3
Innovative Processes

SP 4
Maintenance & Repair

UNDERGROUND CONSTRUCTION

INFORMATION

Automated steering

New cementitious materials

Product model Life Cycle Cost model

(UCIS)
European Research Initiative TUNCONSTRUCT

Subproject 1: Design of Underground Construction

SP1
Design of underground structures

Günther Meschke (RUB-ISM)

16 partners
3 Companies
6 SME
7 HE

WP 1.1: Virtual underground construction
George Exadaktylos (TUC)

WP 1.2: Expert knowledge basis
Felix Amberg (Amberg)

WP 1.3: Design support system
Wulf Schubert (TUG-IRMT)

WP 1.4: Integrated Optimization Platform
Dietrich Hartmann (RUB-ICE)

- Amberg (CH)
- Bouygues (F)
- C3M (SL)
- CIMNE (ES)
- Geodata (A)
- Maidl & Maidl (Ger)
- NCC (S)
- Univ. Bochum (Ger)
- TNO (NL)
- TU Crete (GR)
- TU Graz (A)
- TU Vienna (A)
- Univ. Barcelona (ES)
- Züblin (Ger)
Integrated Concept for Numerical Simulation in Tunnelling
Construction process

Simulation

Model components

Numerical model

Motivation

Fully & partially saturated soil
Tail void grouting
Face support
TBM steering
Simulation procedure

Tail void grouting
Lining
Cutting face
Tail void grouting
Hydraulic jacks

Back-up trailer
hydraulic jacks
TBM
Soil
Lining
TBM considering conicity and overcut
Construction process

Simulation

Model components

- Fully & partially saturated soil
- Tail void grouting
- Face support
- TBM steering
- Simulation procedure

Construction process:
- Tail void grouting
- Lining
- Cutting face
- Tail void grouting
- Hydraulic jacks

Simulation:
- Tail void grouting
- Hydraulic jacks

Model components:
- Back-up trailer
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- TBM
- Soil
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Simulation

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Numerical model
Modelling of partially saturated soils

Balance of momentum
\[ \text{div}\sigma + \rho b = 0 \]

Balance of mass of gaseous phase
\[ \frac{\partial \phi^g \rho^g}{\partial t} + \phi^g \rho^g \text{div} \mathbf{w}^g = 0 \]

Balance of mass of liquid phase
\[ \frac{\partial \phi^l}{\partial t} + \phi^l \text{div} \mathbf{w}^l = 0 \]

DARCY – law for fluid phases
\[ q^\beta = \frac{k^\beta}{\mu^\beta} (-\nabla p^\beta + \rho^\beta g) \]

Relative permeabilities \( k^g \) and \( k^l \) according to VAN GENCHTEN (1985)

Displacements \( \mathbf{u}_s \)

Gaseous & liquid pressure \( p^l, p^g \)

Degree of air saturation \( S^a \) [%]

Degree of water saturation \( S^w \) [%]

Motivation | Numerical model | Numerical Analyses | Aspects of optimization | Ongoing research
Numerical model

Modelling of tail void grouting

2-phase material with hydration-dependent stiffness and permeability

$t = 0, \nu_s \sim 0$

$t > 0, \nu_s > 0$

Accounts for interactions between grout and soil
Construction

Simulation

\[ k_r = \frac{EA}{L} \]

\[ k_t = \frac{EA}{L} \]
Construction

- Lining
- Hydraulic jacks
- TBM

Simulation

\[ k_r = \frac{EA}{L} \]

\[ k_t = \frac{EA}{L} \]

- Desired TBM driving path
- TBM reference point (control node)
- \( \beta \) - steering angle for the jack thrusts
- \( \Delta \) - steering angle for the jack thrusts
- \( \Delta \) - steering angle for the jack thrusts
## Integration of geological, geotechnical and simulation model

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- Model components
- Fully & partially saturated soil
- Tail void grouting
- Face support
- TBM steering

### Simulation procedure

**Motivation**

**Numerical model**

**Numerical Analyses**

**Aspects of optimization**

**Ongoing research**
Prognosis of settlements

![Graph showing vertical displacements over time for points A, B, and C during tunnel advance and consolidation.](image)

- **Tunnel advance**
- **Consolidation**

Vertical displacements (cm)

- **Point A**
- **Point B**
- **Point C**

**Passing of face** 0.5 days

**Passing of tail** 0.19 days

**days (log.)**

**FE-model**
**Settlements**
**Pore pressure**
**Lining**
**Sensitivities**

**Motivation**
**Numerical model**
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**Research perspectives**
Computed excess pore pressures during the tunnel advance

Excess pore pressure (kN/m²)

TBM with taper

TBM without taper
Computed excess pore pressures during tunnel advance – Influence of filter cake

End of stopping phase

End of advancement phase

Motivation
Numerical model
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Computed lining pressure in the monitoring section

Measured lining pressure on a tunnel in Japan [HASHIMOTO 2002]

Motivation

Numerical model

Numerical Analyses

Aspects of optimization

Ongoing research
Geometry-related parameters: Influence of length of TBM

Influence on surface settlements
European Research Initiative TUNCONSTRUCT

Decision Support System for steering of TBM’s

- Support of tunnel excavation by means of information and process management system
- Integration of numerical simulation and Methods of Computational Intelligence in real time

Current state

Mid-term perspective

Engineer

Steering of TBM

Tunnel Drive

Measurements

Suggestions for driving parameters

Simulation

Knowledge-Basis

Steering data

Tunnel advance

Measured data

Steering data

IF... THEN...

Adjustment

Ongoing research