Grout pressure distribution during TBM tunnelling

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We have been able to control the occurrence of settlements around TBM’s

- Face pressure, tail-void grouting

But we still struggle to predict these settlements accurately

Numerical models will never be accurate if their boundary conditions do not reflect the real stresses around a TBM

\[ \{\sigma\} = \lambda \cdot \{\sigma\}_0 \]

\[ \{\sigma\} = f(TBM) \]
Introduction

Soil – deformable
Fluid (bentonite, grout) – viscous
Structure (shield, lining) – rigid?

Pieces of the TBM Puzzle
Grout Injection

The injected grout pressure dissipates as the grout flows between the lining and the soil.

\[ p = f (\text{soil-lining gap}) \]

\[ p_B = p_A - \frac{\tau_g}{\text{gap}} . dl - \gamma_g . dh \]
How can we model that realistically?

- Traditional approach = The imposed pressure is constant
- Iterative calculation = The pressures depend on the ground deformations
Grout Consolidation

∅ Water pressure gradient (outflow)
∅ Boundary pressure = f (convergence)

\[ k \cdot \frac{(GP(dr) - U_w)}{x} \cdot dt = dx \frac{(n_i - n_f)}{(1 - n_i)} \]
Grout Consolidation

Think of a balloon....

volume

Local water outflow

Variation in

Local reaction $x$

Closed system

As we add water, the total deformation is monitored so that the

deformation
Simulation Routine (Python)

Ø FEA Calculation: Creates a phase with the new grout pressures.

The displacements around the tunnel are imported from the Output software.

Ø Iterative Grout Pressure: Uses the 1st routine iteratively until equilibrium between grout pressures and tunnel contraction is achieved.

q (Fixed grout pressure at the tunnel roof, and an initial soil lining gap)

Ø Grout Consolidation: Calculate average contraction due to consolidation.

q Root finding scheme (using 2nd routine) for the grout pressure at the tunnel roof to cause an average boundary contraction that is equivalent to the consolidation contraction.
Example Calculation

Ø Empirical correlations with RD

q Grout Properties

Yield stress of 0.5 kPa

; \( \gamma = 20 \text{ kN} \)

\( q_{ni} = 0.4, \quad q_{nf} = 0.3; \quad \gamma = 20 \text{ kN/m}^3 \)

q 400 kPa at the Roof x 560 kPa

q Injection Strategy

kPa at the Roof x 560 kPa at the Invert
Example Calculation

Grout Injection \( \times \) Grout Pressure \( \times \) Soil Deformability
Example Calculation

Ø Grout Consolidation  Pressure drop x Gap variation

![Diagram showing Grout Consolidation](image)

**Graph 1:**
- Height above invert / diameter vs. Grout Pressures (kPa)
- Lines represent 0 min, 30 min, and UW
- Grout pressures: 0 min = 15 kPa/m, 16 kPa/m

**Graph 2:**
- Grout Pressure (kPa) vs. Time (min)
- Lines represent Roof, Mid-Height, Invert, and dGap
- Time intervals: 0 to 30 min
- Grout pressures: 0 min = 600 kPa, decreasing over time

**Legend:**
- Roof
- Mid-Height
- Invert
- dGap
Example Calculation

Grout Consolidation - Soil deformations

Soil-lining gap (cm)

Distance from the tunnel centre (m)

Settlements (mm)

0 min
15 min
30 min
Conclusion

associated with a finite element model to calculate the processes in interaction with the induced soil displacements

ø Injection The position of the s around the tunnel can have a major influence on the final pressure distribution and the displacements very fast dissipation, causing a distribution of grout pressures violating Continuity for the tunnel boundary as a whole
ø The reaction of the tunnel invert is very stiff. A local model would predict a

Output = f (input) but the point here is that within an objective and
THANK YOU FOR YOUR ATTENTION

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9th IS - Underground Constructions in Soft Ground
São Paulo, April, 2017