Multiscale 3D stress field modelling for the URL 'Reiche Zeche' using a discontinuum model approach

MSc. Sebastian Rehde, Prof. Dr.-Ing. habil. Heinzi Konietzky

Background and motivation

As part of the STIMTEC project we investigated the in situ stress field at the Reiche Zeche Underground Research Lab (URL) in Freiberg, Saxony. A multiscale 3D numerical analysis was performed using a discontinuous, anisotropic plastic approach incorporating stress data from literature. The model results were validated by hydrofracture stress measurements at the project test site. Stress data from a recent study gave reason to investigate the effect of an EDZ around the mine drifts.

Materials

The numerical analysis is based on 3D geological models developed on the basis of maps and digital data. These GIS-models were created with GOCAD.

Methods and results

For the numerical analysis we used the distinct element code 3DEC (Itasca). It allows representation of discontinuities among the numerous faults in the investigation area.

Stress boundary conditions corresponding to the regional stress field were applied to the large model, which then was validated by stress data from [4]. Because M2 is centred in M1, the boundary stress for M2 was taken directly from the results of M1. M2 was validated using the stress measurements performed in the injection borehole BH10 (slightly dipping north) and validated borehole BH17 (vertical) of the STIMTEC project. Parameters and boundary conditions of M1 & M2 were varied to investigate their influence on the model results.

Large scale model M1

The regional stress fields describe a strike-slip regime with a ratio of 1.2 : 2 : 0.7. The vertical stress is equal to the overburden and 
\( \sigma_z \) is striking in NNW direction. Local stress field data from overburrowing measurements [5] near the investigation area of the STIMTEC project used for validation of M1 are listed in Table 1.

Table 1: Stress data from [5]

<table>
<thead>
<tr>
<th>( \sigma_x )</th>
<th>( \sigma_y )</th>
<th>( \sigma_z )</th>
<th>( \sigma_2 )</th>
<th>( \sigma_3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 MPa</td>
<td>3.6 MPa</td>
<td>2.8 MPa</td>
<td>1.2 MPa</td>
<td>0.7 MPa</td>
</tr>
</tbody>
</table>

Mechanical parameters for the anisotropic, faulted, crystalline rock (Freiberger Graupenitz) taken from cores and corrected for a geological strength index \( GI=80 \) after [6] are listed in Table 2. We used a transversely isotropic, elastic constitutive law for a plane of isotropy dipping with 15° in southern direction. Faults were assigned the Mohr-Coulomb failure criterion and are able to undergo slip or tensile failure.

Table 2: Mechanical properties of rock and fault data from [5]

<table>
<thead>
<tr>
<th>Material</th>
<th>( E )</th>
<th>( \nu )</th>
<th>( \phi )</th>
<th>( c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>rock</td>
<td>30 GPa</td>
<td>0.25</td>
<td>28°</td>
<td>5 kPa</td>
</tr>
<tr>
<td>fault</td>
<td>2 GPa</td>
<td>0.35</td>
<td>38°</td>
<td>50 kPa</td>
</tr>
</tbody>
</table>

Slice model M3 – EDZ

To investigate the local perturbation of the stress field measured in BH17, we introduced an excavation damage zone (EDZ), an excavation disturbance zone (EDZ), and a thickness to the prominent 'Wilhelm Stehender' ore vein within the slice model M3 (see Fig. 1). Assumptions led to EDZ, and EDZ, where \( \delta_{EDZ} = 2.5 \text{m} \) and \( \delta_{EDZ} = 5.5 \text{m} \). With \( \delta_{EDZ} = 2 \text{m} \) assumed fault zone thickness \( \delta_{ EDZ} = 2 \text{m} \). BH17 is centred in M3. We developed five different scenarios (Tab. 3) to study the effect of changes in formation moduli \( E_i \) or geometrical features (Fig. 5).

Small scale model M2 – BH10 & BH17

The simulation procedure for model M2 contained several steps: (1) primary equilibrium for the virgin rock mass, (2) excavation of the drifts and (3) finally calculating the secondary stress field. The model results were verified by the data from BH10. Different boundary stress fields resulting from M1 were tested for model M2 (Fig. 3).

The data from validation borehole BH17 could not be reproduced with M2. The measurements showed a change in stress regime (SS to TF) with raised stress magnitudes for \( \sigma_x \) and \( \sigma_y \).

Interpretation of M3 results

For the chosen Young's moduli, model M3 did not provide satisfying results. It was only possible to obtain a change in stress regime from strike slip to thrust fault for extremely low Young's moduli, which are not realistic. However, the results would still not show the strong increase of \( \delta_{EDZ} \). This suggests that the chosen model approach is not suitable to elucidate the observations from BH17 numerically. The damages from drift excavation are well represented by the proposed approach. Thus, local stress field perturbations cannot be duplicated by this model, but the overall stress field is well reproduced.

Outlook

Future work should include additional measurements in-situ and other modelling approaches, for instance, considering other constitutive models. The EDZ may be better represented by a DFN or complex elastico-plastic constitutive models with strain softening. Another approach could consider local inhomogeneities of the rock mass by assuming statistical distribution of properties. Finally, also the assumption of local stress variations (locked-in stresses) created during the geological process should be considered. Best would be to lay emphasis on the influence of the bedding plane as a discontinuity. As shown in Fig. 6, the bedding plane has a provable influence on the displacements in the rock after excavation of the tunnels. Yet, model M3, scenario B only can show the function of the method as there are only two bedding planes in the model, with much larger spacing than in reality.

References:
8. Software used: 3DEC, GREEN3D by ITASCA, RHINO 5, SKYJAC3D by Pasigord, Matlab

MSc. Sebastian Rehde, Prof. Dr.-Ing. habil. Heinzi Konietzky
TUG Bergakademie Freiberg | Institut f"{u}r Geotechnik | Professur f"{u}r Felsmechanik | Gustav-Geuter-Str. 1 | 09599 Freiberg | Telefonnummer: 03731 / 39-5545 | sebastian.rehde@ffg.tu-freiberg.de