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Modelling of the influence of salt creeping on shaft lining

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1 INTRODUCTION

The development of the Ust-Jaiwa potash mine, located in the Perm Region of the Russian Federation, commenced early 2012. It involves the construction of two vertical shafts with a final diameter of 8.0 m and a depth of approximately 500 m each. Both shafts are constructed through the application of the freeze shaft method with a freeze depth of approx. 280 m. At a depth of approx. 280 m, the shafts reach the rock salt horizon.

This article describes the numerical modelling of the shaft lining in the rock salt using *FLAC3D* (Itasca 2009). The numerical calculations in the section of the freeze shaft are described in Franz et al. 2015.

Above the wedge ring (289.5 m depth), the shafts are being built using steel tubing with concrete backfilling. Underneath the wedge ring, the shaft is removed using reinforced concrete to the final depth. Shaft 1 reaches to a depth of 465 m and has 3 onsets (386 m, 436.5 m, 465 m). Shaft 2 extends to a depth of 422 m and also has 3 onsets (381.5 m, 392 m, 422 m). For the shaft lining below the wedge ring, the time-dependent rock mechanical loads as well as the accompanying deformation due to creep of the existing salt must be taken into account. Rock mechanical calculations are performed to determine the deformation behavior.

2 NUMERICAL CALCULATIONS

The shaft area to be considered here ranges from the wedge ring to the shaft bottom. The shaft lining in this section is made of reinforced concrete. Above the wedge ring (depth at approx. 289.5 m), the shafts are constructed using steel tubbings with concrete backfill.

A gap between the reinforced concrete and the rock salt is provided so that no loads as a result of salt creeping run onto the shaft lining. This gap is closed with a foamed concrete. The onsets are equipped with a reinforced concrete lining on the first 5.0 m from the shaft. The base only receives a sub-concrete layer and remains unfinished. The remaining 30 m will not be removed. The filling site extension is separated from the shaft extension by the gap described above, so that there is no forcelocked connection. To absorb the load from the salt creep, a backfill material is placed between the reinforced concrete lining of the filling site and the rock salt. This material is able to endure very large deformations as a kind of soft layer until the load is passed on.

Figure 1 shows the shaft geometry and the geometry of mine. The onsets are connected to the mine network except for the lowest filling location, which represents the sump chamber. These sections significantly increase the degree of penetration of the mine. The perspective illustration on the right in Figure 1 gives an insight into the route network of the mine.

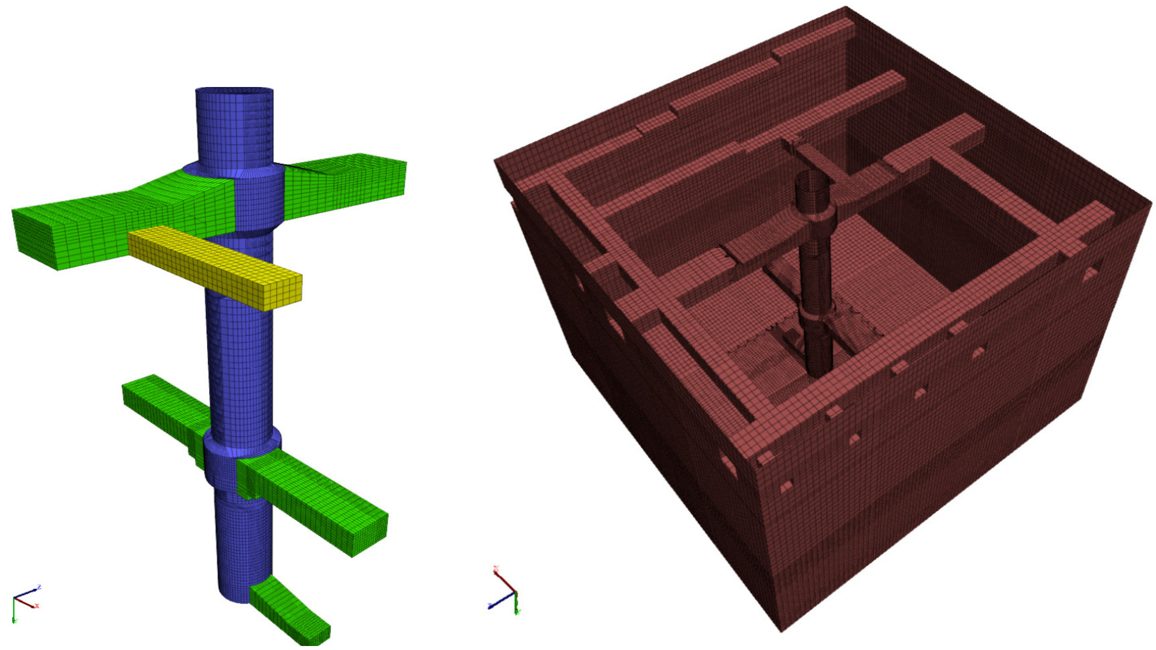

Figure 1. Model of the Shaft 1 with onsets (left) and Model with Shaft 1 and additional mine gallery (right).

A 50 cm thick foam layer was applied in the area of the onsets. Based on previous investigations regarding the deformations, this dimension is considered sufficiently thick to absorb the deformation from the salt creep. The soft padding material does not exhibit any appreciable compressive stresses up to a deformation of approx. 60% and the failure of this cushion layer does not begin until 80%. This means that at least 25 cm of deformation from salt creep can be absorbed over the applied cushion layer without the reinforced concrete lining experiencing an increase in load. Furthermore, it can be assumed that up to a deformation of the foam layer of 80 to 85% no significant load increase results from the compression of the foam layer. A modulus of elasticity of 3 MPa is assumed for the elastic material behavior. The value thus amounts to 1/10,000 of the applied modulus of elasticity of rock salt.

The material model Norton (also known as BGRa) is used to describe the creep behavior of the rock salt:

$$\varepsilon_s = A \cdot \left(\frac{\sigma_v}{\sigma^*}\right)^m \qquad (1)$$

The model can be used to determine the stationary creep of the salt. This material law is used in rock mechanical calculations to describe the load-deformation behavior of intact rock salt. Comparisons with other material laws show the model to be deformation-friendly (Hunsche & Schulze 1994). On the basis of laboratory tests and the evaluations of the shaft pre-drilling, it was possible to derive the material parameters listed in Table 1 for the Norton material model.

Table 1. Parameters for the Norton material model.

	K [GPa]	G [GPa]	A [1/d]	n [-]
rock salt	20.00	12.00	1.0E-10	5
carnallite	12.50	7.14	9.0E-09	5

3 RESULTS

Due to the high modulus of elasticity of rock salt, no significant displacements are caused as a result of the shaft sinking. Only the general degree of penetration has an effect on the displacements. Much more important is the deformation caused by salt creeping.

The radial displacements at the shaft contour for the two shafts show pronounced deformations for the carnallite layers. Using the material parameters given in Table 1, maximum deformations of a few decimeters in the carnallite layers over the 65 years under consideration are obtained. In the salt rock layers, the displacements are in the range of less than 10 cm. Notable elastic deformations due to the shaft depth cannot be taken from the calculations.

The result plot in Figure 2 show that the displacements in the area of the onsets are in the lower decimeter range (< 25 cm) and can therefore be completely absorbed by the buffer layer (d = 0.5 m).

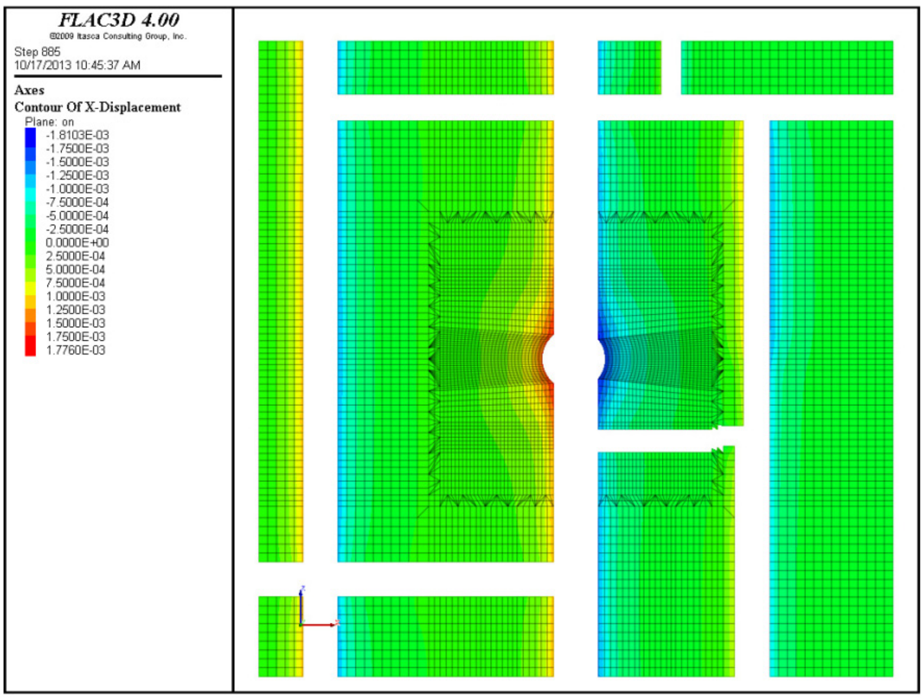

Figure 2. Horizontal deformation [m].

The influence of the high excavation ratio was also investigated. Variations with different excavation scenarios were calculated. The influence of the high excavation ratio is clearly shown. The greater the excavations, the greater the impact on the other levels. At the same time, however, it can also be seen that the displacements are essentially in the vicinity of the excavations and thus of the area at the onsets. The excavations on one level influence the displacements on the other levels only to a small amount.

4 CONCLUSIONS

The numerical deformation calculations show that the radial displacements in the shaft area and in the onsets to be extended (5.0 m from shaft edge) are in the lower decimeter range. With the 40 cm gap between the salt and the shaft lining required for the sliding formwork, there is thus sufficient width of the constructive joint to separate the rock from the shaft lining over the 65 years to be considered.

The dimensioning of the shaft lining was carried out on the basis of the structural separation from the salt by applying vertical loads. The deformations in the area of the outlined onsets are absorbed by the padding layer, so that here the liner only had to be dimensioned for its own weight.

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