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THREE-DIMENSIONAL FINITE ELEMENT ANALYSIS OF OPENING INTERACTION IN SQUEEZING GROUND

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ABSTRACT

This paper presents a numerical study of the interaction of twin, horizontally aligned openings, deeply embedded in salt rock. Complex three-dimensional (3D) creep analyses were carried out using the Finite Element (FE) method. Findings show that opening interaction appears to develop with time, whilst increasing the time period between excavations causes a slight reduction in interaction. The FE model was then used to back analyse openings at Boulby Mine, North Yorkshire.

1 INTRODUCTION

Removal of rock during the formation of an underground opening induces changes in the local stress state of the rock surrounding the excavation, thus causing a disturbance in the stability of the rock mass. This can lead to significant time-dependent closure, or ground squeezing, in openings driven in salt rock and potash, when located in a mining environment. The deformation of these weak rocks is dominated by creep, which can be defined as continued deformation under an applied stress. It is of importance for the mining engineer to obtain an understanding of this time-dependent behaviour in order to gain knowledge of the long term stability of service excavations and to enable the successful design of mine workings.

Excessive ground squeezing has been observed at Boulby Mine, North Yorkshire (Figure 1) [1]. This behaviour is difficult to predict and is affected by factors such as the proximity of openings, in-situ stresses, depth and temperature.

The object of this paper is to simulate the creep behaviour and interactions of deeply embedded openings in salt rock through a series of three-dimensional (3D) Finite Element (FE) analyses. The FE model is then used to back analyse openings at Boulby Mine.

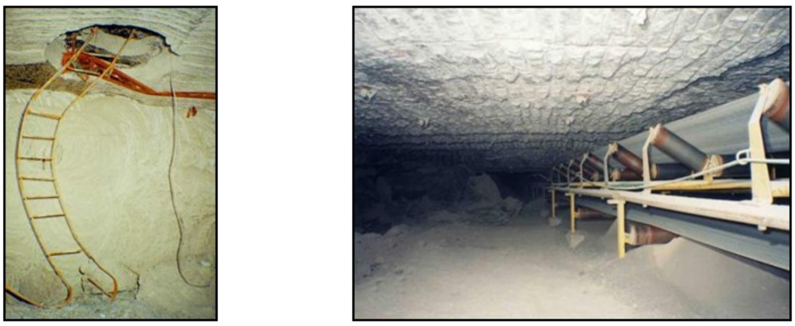

Figure 1: Ground squeezing observed at Boulby Mine [1].

2 INTERACTIONS OF OPENINGS

This investigation involved unsupported circular openings, each with a diameter, D of 2 m, with centre to centre spacing, S, of 8D, 4D and 2D. The geometric arrangement is shown below in Figure 2.

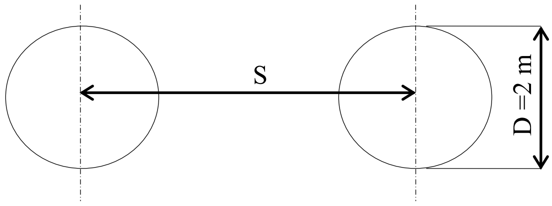

Figure 2: Geometric arrangement of openings.

FE analyses were carried out using ABAQUS/Standard version 6.8 software. Power law creep model was used in the analyses as it has shown good prediction for the creep of rock salts in the laboratory (Obert, 1965 [3]; Le Comte, 1965 [4]; United States Army Corps of Engineers, 1963 [5]) and has successfully been used to predict the closure of Saskatchewan potash mines (Yu, 1988) [6]. This model is available in ABAQUS. The relation between the strain rate $\dot{\varepsilon}$, the deviator stress σ and the time t is given by:

$$\dot{\varepsilon} = A\sigma^n t^m \tag{1}$$

where A, n and m are creep model parameters obtained from laboratory experiments. The material parameters selected for the analyses were taken from Aiyer, 1969 [7]. The stresses are given in MPa and the creep time is in hrs.

Young's modulus,E [MPa]	Poisson's ratio, υ	A	n	m
6895	0.25	$1.86x10^{-7}$	2.98	-0.64

Table 1: Material parameters used in the analyses (Aiyer, 1969 [7]).

The 3D FE mesh for the geometry of S=2D is shown in Figure 3. Each mesh comprises of ten-noded tetrahedral elements and is sized so that negligible displacements occur at the boundaries. The vertical boundaries and base of the mesh are constrained in the normal direction. The initial stress condition of the ground was taken as hydrostatic and the overburden stresses simulated by applying a distributed pressure of 20 MPa to the top of the mesh.

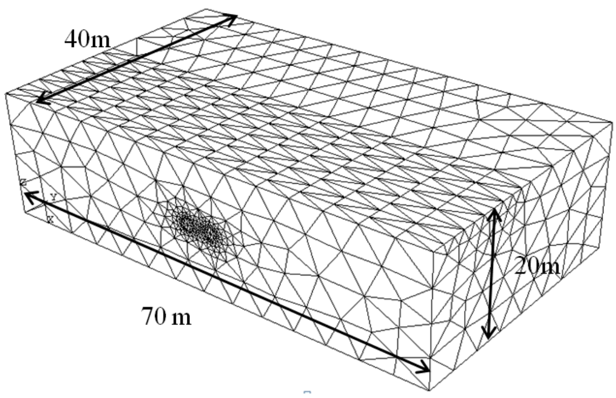

Figure 3: Three-dimensional FE mesh (S=2D). 38465 elements, 53023 nodes.

Each opening is 20 m in length in order to investigate ground behaviour at a significant distance behind the face. A single opening was driven in 20 hours, followed by a 10 hour break in construction after which the second opening was excavated. The opening excavation procedure was simulated in steps during which element zones of 1 m in length were successively deactivated in front of the opening face. Creep deformation was introduced during each excavation step. Analyses were run for over 100 years after the completion of both excavations in order to discover interaction at different time periods. The time period between excavations was also varied to see the effect on opening deformation.

The investigation focuses on the deformation of the first excavated opening, therefore the effect of the second opening on the first can be established. Figure 4 shows the crown displacement along the opening length for each of the opening geometries. It can be seen that for these particular material parameters there is negligible interaction at S=8D and significant interaction at S=2D. It was shown that the influence of interaction appeared to develop with time. Increasing the time between excavations caused a reduction in opening interaction.

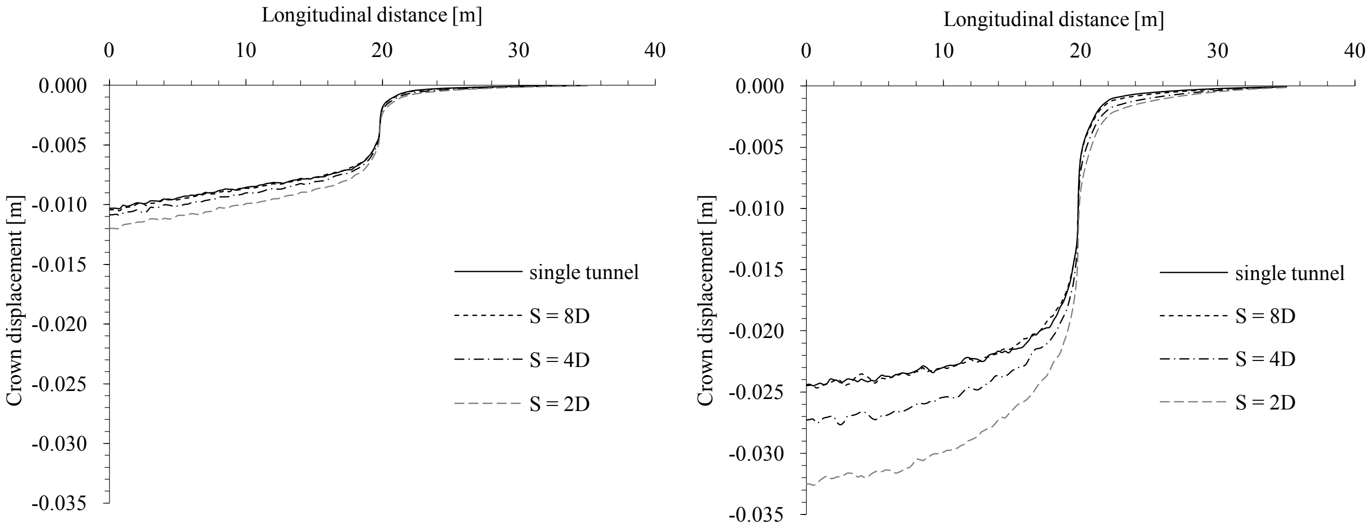

Figure 4: Crown displacement profiles along the opening length: (a) at end of excavation; (b) approximately 40 days after excavation.

3 MODELLING A SECTION OF BOULBY MINE

A simplified section of a salt panel at Boulby Mine was modelled. The geometry is shown in Figure 5. The creep parameters shown in Table 1 were used and the elastic material parameters were obtained from laboratory testing carried out by other investigators (E=4000MPa, υ=0.25). The FE mesh is shown in Figure 6. A surface pressure of 28 MPa was applied to the top of the mesh (assuming ground unit weight of 25 kN/m^3) to represent the overburden corresponding to 1120 m depth. Hydrostatic stress conditions were assumed. The excavation procedure is shown in Figure 5. A 10 m length section of the first opening was excavated in two passes followed by a 10 m length section of the second opening in two passes. This process was repeated until the total excavated length was 60 m. The procedure was the same as used earlier, but with element zones of 2.5 m in length, rather than 1 m.

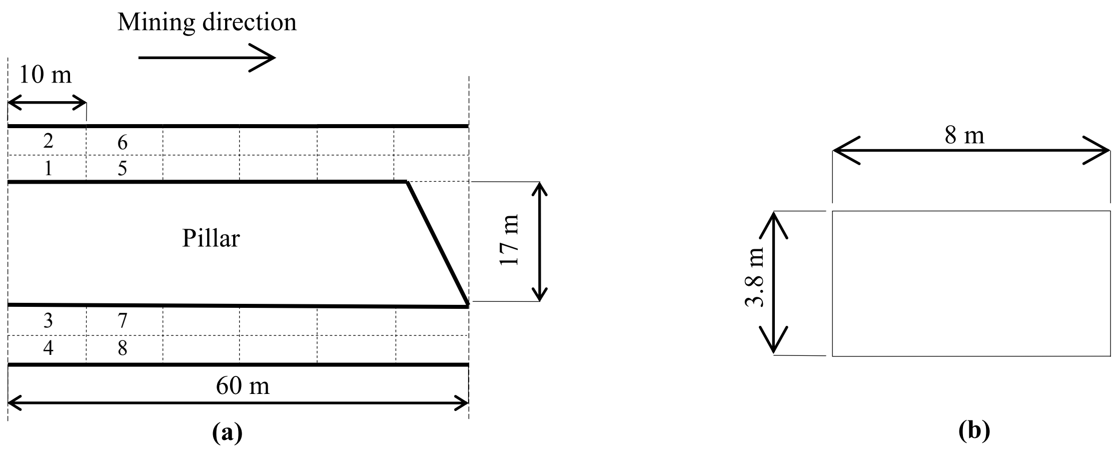

Figure 5: Geometrical model: (a) Simplified plan view of mine section showing part of excavation sequence; (b) Opening cross-section.

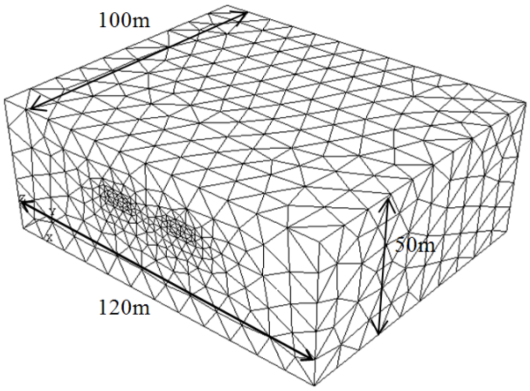

Figure 6: 3D FE mesh of section of Boulby Mine. 47444 elements, 64733 nodes.

Figure 7 shows the predicted relative displacement between the roof and floor for a cross-section located at 30 m along the left-hand opening of the model. The displacement values are taken along the centre line of the opening. It was assumed that both openings had advanced 10 m ahead of this cross-section before displacement measurements were recorded.

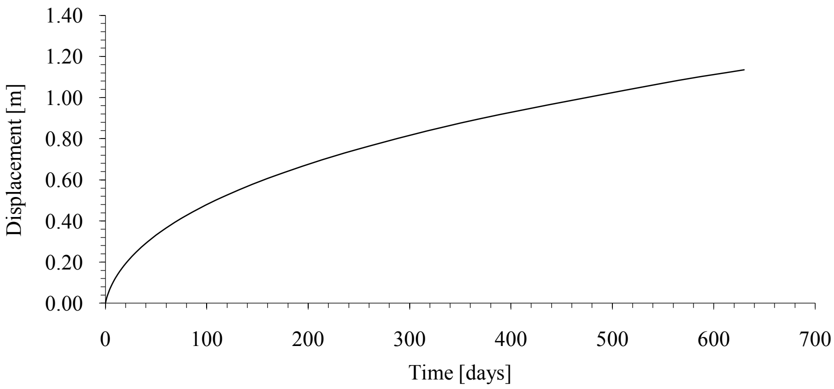

Figure 7: Predicted relative displacement between the roof and floor of an opening for a 30m cross-section.

4 CONCLUSIONS

The interaction between twin, horizontally aligned openings, deeply embedded in salt rock appears to be dependent on time. Findings show that opening interaction appears to develop with time, whilst increasing the time period between excavations causes a reduction in interaction. Significant creep deformation has been predicted for the modelled section of Boulby Mine. The authors aim to carry out further simulations of this section, incorporating rock bolts, in order to make accurate comparisons with field measurements.

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