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Influence of block size and shape on the deformation behavior and stress development around tunnels

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ABSTRACT: 2 D discontinuum analyses were performed with UDEC to investigate the influence of block sizes and shapes on the deformation behaviour and stress development around tunnels. As the block shape changes different failure modes around the tunnel are observed. The block size and joint residual friction angle are other factors determining the failure mode. Within the same failure mode a decrease in the block size and slenderness of the block result in an increase in the displacements. A decrease in the residual friction angle of the joints increases displacements considerably. At high joint friction angles block wedging determines the displacement vector orientations. As the joint friction angle decreases the influence of shearing along the joints become more dominant. The effect of the block size on the displacement orientation is not significant for the same block shape up to a certain limit. Tangential stresses close to the sidewall generally are lower than those determined with the closed form solution. Tangential stresses at the crown are generally higher compared to the closed form solution due to a wedging effect between the blocks.

1 INTRODUCTION

ÖGG (2001) described a recommended procedure for the geotechnical design and construction of underground structures. At the design phase, the rock mass types, which are determined based on the rock mass specific parameters, are evaluated with initial stress conditions, discontinuity orientations and ground water to assign the rock mass behaviour types. The System behaviour is predicted considering the excavation and support measures. At this phase numerical simulations are helpful tools to analyze rock mass behaviour types and system behaviour.

Jing and Hudson (2001) stated that the choice of the continuum or discrete methods in rock mechanics depends on many problem specific factors and mainly on the problem scale and fracture system geometry. The discrete approach is most suitable for moderately fractured rock masses where the behaviour is governed by the discontinuities or where large scale displacements of individual blocks are expected.

Sellner (1996) carried out numerical analysis with UDEC considering geological and geotechnical data from the Semmering tunnel and showed that the anisotropic behaviour in jointed rock can be realistically modelled by discontinuum approach.

There are efforts by Wittke (1990), Sitharam and Madhavi (2002), Tonon and Amedei (2002)for the representation of discontinuous medium around the tunnels by continuum approach. But they are not efficient because sliding, block rotation, complete detachment and large displacements can not be considered.

The influence of geological structure on deformation phenomena around the tunnels was illustrated by Schubert (1993), Krassnig (1997) and Steindorfer (1998) by analyzing data from Austrian Tunnels.

To evaluate the influence of the geological structure on the deformation behaviour and stress development around a tunnel in blocky rock mass, numerical simulations of the tunnel excavation in a rock mass with two joint sets were performed with the two dimensional Distinct Element code UDEC. The deformation and stress development phenomena around the tunnel were investigated for the models with different block sizes, block shapes and joint properties.

2 NUMERICAL ANALYSIS

2.1 *Model Properties*

A circular tunnel with a diameter of 10 m and 600 m overburden is considered. To decrease the boundary effect on the results of the analysis, the model boundaries are chosen at a distance of five tunnel diameters from the tunnel in both directions. To model the overburden, stress is applied at the top boundary considering overburden height and density of the blocks. The lateral pressure coefficient (Ko) is set to 0.5 and variation of in situ stresses with the depth is considered in the model. The remaining boundaries are chosen as velocity boundaries. At both sides the model is restricted to move in x direction and at the bottom in y direction (Figure 1).

Two joint sets dipping to the left hand side are modelled. The dip angle (angle from horizontal in ccw direction) of the first joint set is kept constant as 80°. The dip angle of the second joint set is varied from 70° to 0° in 10° steps. As the dip angle of the second joint set varies the block shape and size change simultaneously. For high joint angles slender blocks are formed and as the dip angle decreases blocks with more uniform dimensions are formed. The joint spacing for both sets are chosen as 2m, 1m, and 0.5m.

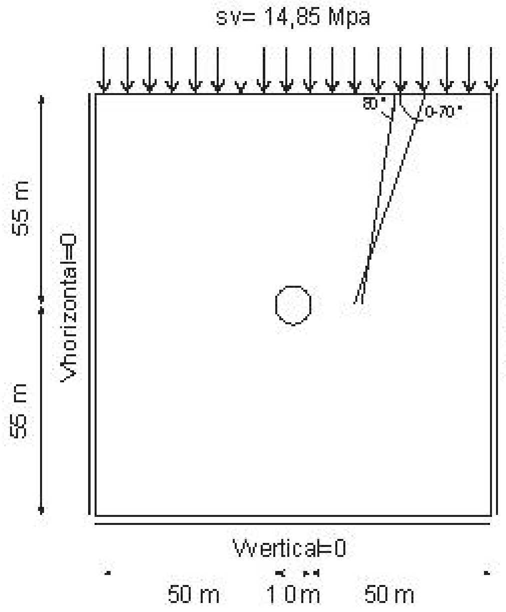

Figure 1. Numerical model for the analysis

2.2 *Material Properties*

The discontinuous medium around the tunnel is. modelled by rigid blocks and discontinuities. The rigid blocks are chosen to ignore the unrealistic deformation of the blocks under high stresses. The input parameters for the rigid blocks are: mass density=0.0027 kg/cm3, E=20000 MPa, K=16000 MPa, G=8000 MPa, ν=0.3.

For the joints a Coulomb criterion with a drop in strenth after the peak was chosen. The input parameters for this joint model are: jkn=5000 MPa/m, jks=2500 MPa/m, jc=0.1MPa, jresc=0, jfric=25°, jrfric =16-22°, i=7°. The residual friction angle of the joint is varied from 22° to 16°. The other parameters for the blocks and joint sets are kept constant.

3 RESULTS OF NUMERICAL ANALYSIS

3.1 *Displacements and Vector Orientation*

As the block shape changes different failure modes around the tunnel are observed. The block size and joint residual friction angles are other factors determining the failure mode. Changing failure modes according to the block shape, size and joint residual friction angle are given in the Table 1.

																
	a=10°		a=20°		a=30°		a=40°		a=50°		a=60°		a=70°		a=80°	
	H	L	H	L	H	L	H	L	H	L	H	L	H	L	H	L
js=2 m	Mode A		Mode A		Mode A		Mode A	Mode B	Mode B		Mode C		Mode C		Mode C	
js=1 m	Mode A		Mode A		Mode A		Mode A	Mode B	Mode B		Mode B		Mode C		Mode C	
js=0.5m	Mode A		Mode A		Mode A		Mode A	Mode B	Mode B		Mode B		Mode B	Mode C	Mode C	

js=joint spacing a=apex angle H: high joint strength L: low joint strength

Table 1. The failure mechanisms acc. to the block shape, size and joint strength

In Mode A, the tunnel stabilizes pretty quickly. With a decrease in the block size and slenderness of the blocks, displacements increase. A decrease in the residual friction angle of the joints increases displacements considerably. The smaller the block size, the more pronounced is the effect of the residual friction angle (Figure 2).

At high joint friction angles block wedging determines the displacement vector orientations. As the joint friction angle decreases the influence of shearing along the joints become more dominant (Figure 3). The effect of the block size on the displacement orientation is not significant for the same block shape up to a certain limit.

In Mode B, failure wedges are formed around the tunnel (Figure 4). The size and extent of these wedges and their effect on failure process around the tunnel depend on the block size and joint strength beside the block shape. As the block size and joint residual friction angle are decreased for the same block shape, displacements and extent of the wedges around the tunnel increases and failure proceeds with increased shearing along joints.

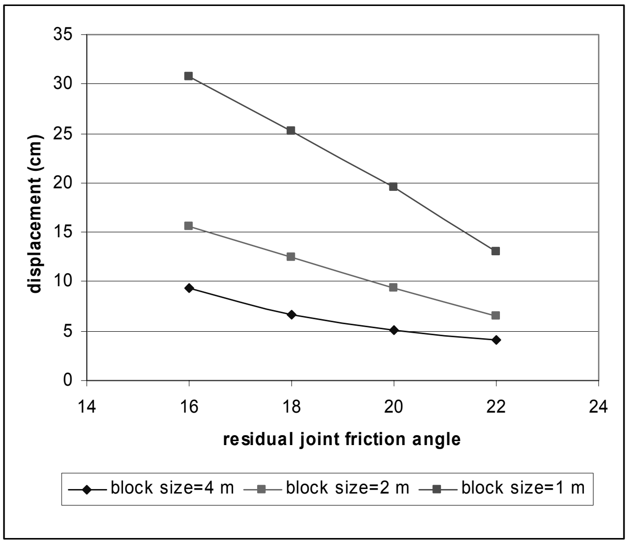

Figure 2. Displacement vs residual joint friction angle for different block sizes (Mode A)

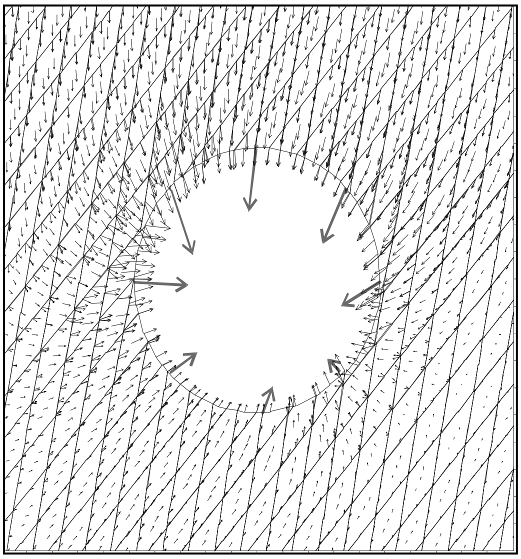

Figure 3. Displacement vectors for low joint strength (Mode A)

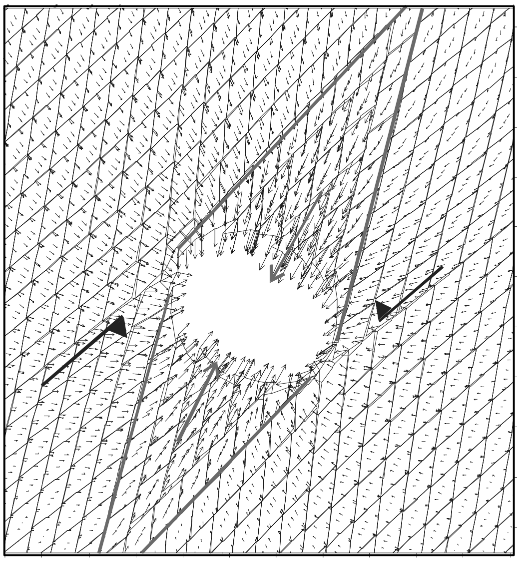

Figure 4. Displacement vectors and deformed shape of the tunnel for Mode B

In Mode C, several blocks in the roof detached, otherwise the tunnel is stable (Figure 5). Some shearing along the joints tangent to the tunnel can be observed. The displacements are considerably lower compared to the block shapes with lower apex angles. For the same block shape a decrease in joint strength and block size results in an increase of the displacements.

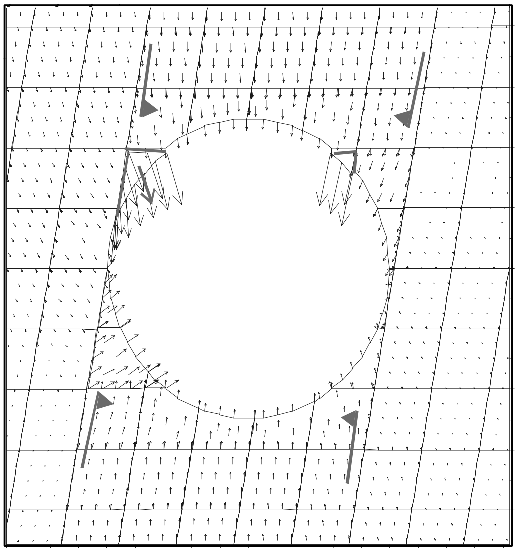

Figure 5. Displacement vectors and deformed shape of the tunnel for Mode

3.2 *Tangential stresses around the tunnel*

Tangential stresses close to the sidewall generally are lower than those from the closed form solution. The decrease is more pronounced with a decrease in joint friction angle (Figure 6).

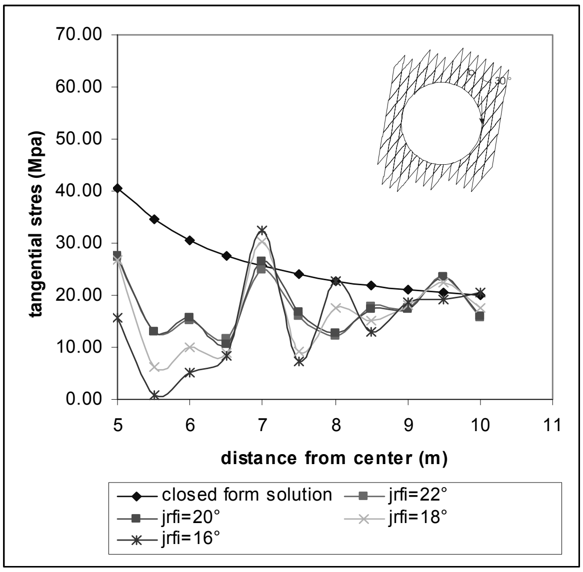

Figure 6. Variation of the tangential stress at the sidewall acc. to the joint block shape and size

Decrease in tangential stress at the side wall is considerable in cases where failure wedges are developed near the crown and invert (Mode B). For failure Mode C, tangential stresses at the boundary of the side wall are higher than those calculated with a closed form solution but follow the closed form solution in a bigger from some distance from the tunnel. The block size does not have a significant influence on the tangential stress at the side wall.

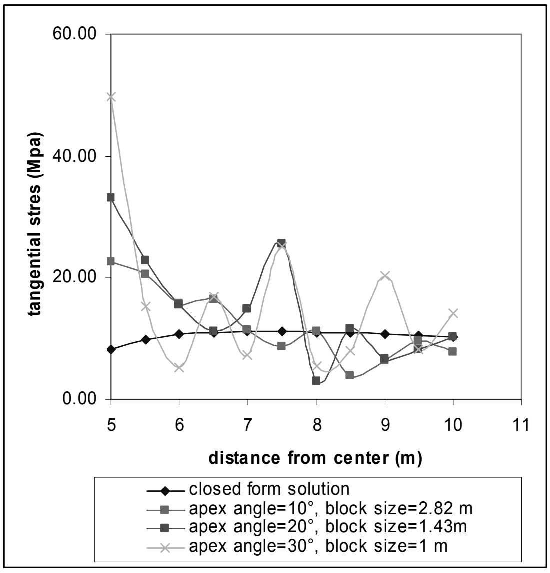

Figure 7. Variation of the tangential stress at the crown acc. to the joint residual friction angle

For Mode A, tangential stresses at the crown are generally higher compared to the closed form solution due to a wedging effect between the blocks (Figure 7). Both at the side walls and the crown the stresses vary close to the tunnel due to different block contacts.

For Mode B, where failure wedges are formed tangential stress at the crown decreases considerable compared to the Mode A. For Mode C, the tangential stress curve at the crown approaches the closed form solution.

4 CONCLUSION

The investigation shows that a variation of block sizes and shapes not only changes the failure mode, but also leads to considerable changes in the stress distribution around the tunnel. The stress distribution around a tunnel obtained with the discontinuum dramatically deviate from the results of the closed form solution, especially for rock masses with elongated blocks. The smaller the blocks, and the higher the apex angle of the blocks is, the closer the results of the discontinuum model are to those of the continuum model.

The limits of applicability of continuum models could be clearly shown, and it is hoped that with further investigations a guideline indicating under which conditions which model is to be preferred can be established.

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