

Numerical simulation study on the influence of the ground stress field on the stability of roadways

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Abstract: We adopt the concept of generalized plane strain to model a roadway in a stress field. This can avoid limitations caused by simplifying the stress analysis as plane strain. FLAC^{3D} was used to investigate the maximum tensile stress and displacement of a roadway in a known stress field for angles, α , between the roadway axial direction and the maximum principal stress of 0°, 30°, 45°, 60° and 90°. This theory was applied to the analysis of an engineering case. The results indicate that stress and displacement of the surrounding rock increase as the angle, α , increases. This provides some significant guidance for a reasonable layout of roadways in a known stress field.

Keywords: roadway; ground stress field; generalized plane strain; numerical simulation

1 Introduction

Mining activities are mainly carried out in the upper strata of the Earth's crust and are subject to ground stress, stope roof-control and surface subsidence and movement. So the layout of roadways and supports is different from the general case^[1-4].

Previous design and construction of roadways rarely took into account ground stress fields, which are an important factor in the stability of rock surrounding the roadway. Gail considered the horizontal stresses around underground mine tunnels to be greater than vertical stresses because of the directionality of the stress field^[5-8]. We report here numerical simulations using FLAC^{3D} to establish a model for investigation of the maximum tensile stress and displacement of a roadway in a known stress field. The model is conditioned on the assumption that the angle between the roadway axial direction and the maximum principal stress is different. This provides a basis for reasonable layout of roadways within a known stress field.

2 Generalized plane problem

An analysis based on classical mechanics vertically cuts the roadway along the axial direction. The problem is then simplified as a plane strain problem re-

quiring that the axial direction of the roadway be aligned with the direction of principal stress. It is difficult to adapt this limited model to the analysis of a complex tectonic stress field^[9-10]. Therefore, a new concept of a generalized plane strain problem is derived from the space problem

If the longitudinal strain, ϵ_z , is constant the problem is one of generalized plane stress. Most underground engineering involves long cavern type space problems where the longitudinal length is much larger than the cross-section. This may be considered a generalized plane strain problem. The stability of surrounding rock and the ground pressure in a shaft, the stress distribution around a borehole, or the slope and drift through a tilted stratum are examples of this problem. Brady first proposed a computational model for a generalized plane strain problem. That model was based on the plane strain problem superimposed with an anti-plane shear and a uniaxial compression stress state, as shown in Fig. 1.

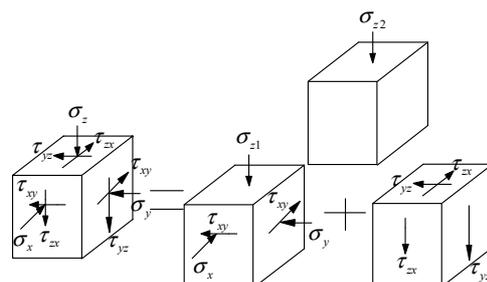


Fig. 1 Decomposition of generalized plane strain

3 Model theory

The principal stress and its direction can typically be obtained by ground stress measurements. Since roadways may be aligned in any direction it is necessary to convert the third order principal stress tensor into a third order stress tensor. Eq.(1) allows a known, third order tensor to be converted into an arbitrary third order tensor aligned in any direction.

$$[A'] = L[A]L^T \quad (1)$$

where A is the third order tensor in the original coordinate system, A' is the tensor in the new coordinate system and L is a transformation matrix consisting of the cosines of the angles between the original axes and the new axes.

Transformation of stresses by Eq.(1) followed by substitution of the transformed tensor into the formula for calculating the stress field was demonstrated by Zheng Yutian to give the stress distribution in rock surrounding a circular roadway.

The ground stress field is dominated by the horizontal stresses, as shown in Fig. 2, and the vertical stress is aligned with one of the principal stress axes. If the vertical axis in the new coordinate system is parallel to the original vertical axis the transition matrix is given by Eq.(2).

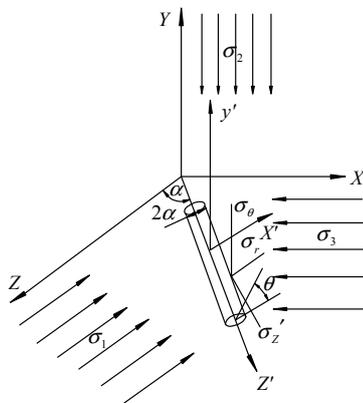


Fig. 2 Numerical model of a roadway aligned in a random direction

In Eq.(2) σ_1 , σ_2 and σ_3 are the known ground stresses, σ_r , σ_θ and σ_z are the normal stresses in the surrounding rock, in polar coordinates and α is the angle between the axial direction of the roadway and the maximum principal stress axis.

$$L = \begin{bmatrix} \cos \alpha & 0 & -\sin \alpha \\ 0 & 1 & 0 \\ \sin \alpha & 0 & \cos \alpha \end{bmatrix} \quad (2)$$

The stress component in the new coordinates can be obtained by combining Eq.(1) with Eq.(2) to give Eq.(3).

$$[p_{ij}] = L[\sigma_{ij}]L^T \quad (3)$$

where P_{ij} is the stress component in the new coordinate system and σ_{ij} is the stress component in the original coordinate system.

After substituting the known ground stress and the transformation matrix into Eq.(3) stresses in the new coordinates are given by Eq.(4).

$$\begin{bmatrix} P_x & P_{xy} & P_{xz} \\ P_{yx} & P_y & P_{yz} \\ P_{zx} & P_{zy} & P_z \end{bmatrix} = \begin{bmatrix} \cos^2 \alpha \sigma_3 + \sin^2 \alpha \sigma_1 & 0 & -0.5 \sin 2\alpha (\alpha_1 - \sigma_3) \\ 0 & \sigma_2 & 0 \\ -0.5 \sin 2\alpha (\alpha_1 - \sigma_3) & 0 & \cos^2 \alpha \sigma_1 + \sin^2 \alpha \sigma_3 \end{bmatrix} \quad (4)$$

4 Numerical simulation

4.1 Model

A Mohr-coulomb model with the dimensions 90 m×100 m×80 m was selected^[11-16]. The lithology and mechanical parameters of the model are shown in Table 1. Actual measurements show the principal stresses as 16.2, 12.6 and 7.5 MPa. The added stresses on each model surface follow Eq.(4) and the model boundaries provide the constraint for horizontal displacement while the bottom is fixed.

Table 1 Mechanical parameters of rock for the numerical model

Rock	Elastic modulus E (GPa)	Compressive strength σ_c (MPa)	Poisson's ratio μ	Density γ (10^{-3} N/mm ³)	Friction angle ϕ (°)
Mudstone	19.3	32.3	0.38	2.60	27.8
Siltstone	26.3	43	0.22	2.65	32.1
Fine sandstone	20	56.3	0.26	2.65	35
Coal	6	10.9	0.35	1.40	16

4.2 Results and discussion

1) The maximum tensile stress in the surrounding rock

The angle, α , between the roadway axial direc-

tion and the direction of maximum principal stress was varied from 0° to 90°. Slices along a plane at $Y=40$, see Fig. 3, were plotted using post-processing software. These predictions are shown in Fig. 4 as the distribution of tensile stress around the roadway.

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