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Support design for permanent mine roadways in tectonically active areas

PV Deev*, MA Petruhin and AA Tzukanov

Tula State University, Tula, Russia

E-mail: *dodysya@yandex.ru

Abstract. The authors propose an analytical method of support design for arbitrary cross-section mine roadways subjected to the action of tectonic forces and seismic loads of earthquakes. As distinguished from the existing methods, the new technique allows taking into account influence of a close interface of different rocks. The seismic analysis includes the action of the waves reflected from the interface and the waves refracted through it. The method is based on an analytical solution of 2D elastic problem on stress state of an elastic ring supporting an arbitrary hole in one of two half-infinite media with the common boundary. The solution of the problem has been obtained using the theory of analytical functions of complex variables, Cauchy type integrals, conformal mapping and complex series. The examples of the support design are given.

1. Introduction

Many minerals occur in the zones of active neotectnics. Nonuniform rate movements of tectonic blocks induce additional stresses in rocks, which should be taken into account in mine planning and design.

At the present time, parameters of a tectonic stress field can be found to a sufficient accuracy using geomechanical and geophysical methods of stress measurement [1, 2]. Estimates of stress state of underground structures are obtained from analytical solutions of problems in continuum mechanics [3, 4] and by numerical modeling [5]. The analytical methods of solving elastic problems are advantageous over the numerical techniques though restrained by the limited number of the available analytical solutions.

The method proposed in [6] for the support design for noncircular mine roadways under the action of tectonic forces is based on the analytical solution of 2D elasticity problem on stress state of a ring supporting an arbitrary shape hole in an infinite uniform medium under conditions of initial stress state. The problem is solved using the theory of analytical functions of complex variable. The approach put forward in [7] enables taking into account technological nonuniformity of rocks in the support design under the action of tectonic forces. The technological nonuniformity is understood by the authors as one or a number of zones having different characteristics from the surrounding rock mass around a roadway. Such zones appear as a result of rock failure under drilling and blasting, or when injection reinforcement is applied. A feature of the elasticity problem set and solved in [7] is modeling of the nonuniform rock mass zone and support as variable thickness rings, which allows considering nonuniform domains of arbitrary configuration. Inclusion of many domains–layers in the analytical models makes it possible to image smooth variation in deformability of rocks with distance from the roadway boundary.

2. A new method of support design for a mine roadway

This study offers the method of support design for a mine roadway located in the tectonically active rock mass near an interface of rocks of different deformability. The analytical model of the support is depicted in Figure 1.

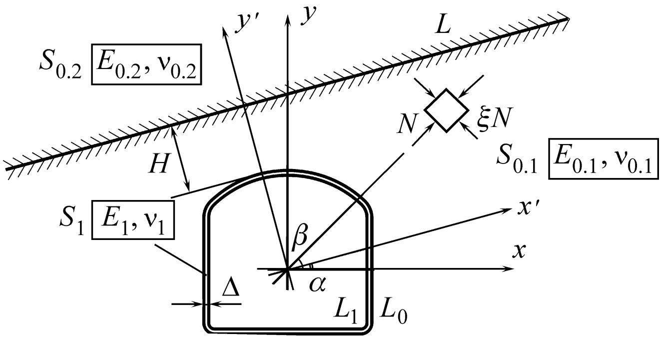

Figure 1. Analytical model of support for roadway located near interface in tectonically active rock mass.

In the figure, the deformable media $S_{0,1}$ and $S_{0,2}$, deformability of which is characterized by the deformation moduli $E_{0,1}$, $E_{0,2}$ and Poisson's ratios $\nu_{0,1}$, $\nu_{0,2}$, simulate rock mass composed of two types of rocks. At the distance H from the interface L occurring at the α relative to horizontal line, there are a hole supported by the ring S_1 made of a material with the deformability characteristics E_1 and ν_1. The medium $S_{0,1}$ experiences uniform initial field of the principal stresses N and ξN such the the principal stress N is oriented at the angle β relative to horizontal line. At the lines L and L_0, the vectors of stresses and displacements are continuous; the internal boundary L_1 of the ring is free from the external forces.

Using the theory of analytical functions of complex variables, in particular, complex potentials proposed by Kolosv–Muskhelishviliy, Cauchy type integrals, conformal mapping and complex series, the set problem was solved as iteration of step-by-step refinements of influence exerted by the interface of two media on the stress state of the ring simulating support of a mine roadway.

Aiming to take into account the support–rock interaction, an adjusting factor α^* is introduced in the calculations; this factor can be found using the procedure described in [8].

The calculations are performed for a solid concrete lining in a roadway having cross-section illustrated in Figure 2.

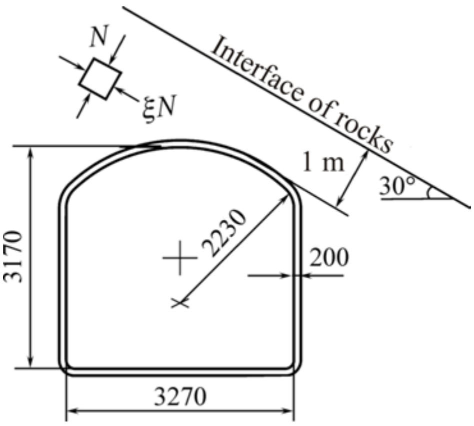

Figure 2. Cross-section of roadway under analysis.

The deformation characteristics of the support and surrounding rocks are: E_1 = 20 000 MPa, ν_1 = 0.2, $E_{0,1}$ = 50 000 MPa, $\nu_{0,1}$ = 0.25, $E_{0,2}$ = 1000 MPa, $\nu_{0,2}$ = 0.35. The initial stress field in rocks includes the major compressive stress oriented in perpendicular to the interface (β = 60°), and the ratio of the principal stresses is ξ = 0.5.

Figure 3 depicts the calculated results for the support for the described roadway as the distribution diagrams of normal shear stresses at the internal and external boundaries of the lining—$\sigma_\theta^{(in)}$ and $\sigma_\theta^{(ex)}$, respectively. The values of the stresses are given as fractions of of the product α^*N. The dashed lines show the calculation without regard for the influence of the rock interface.

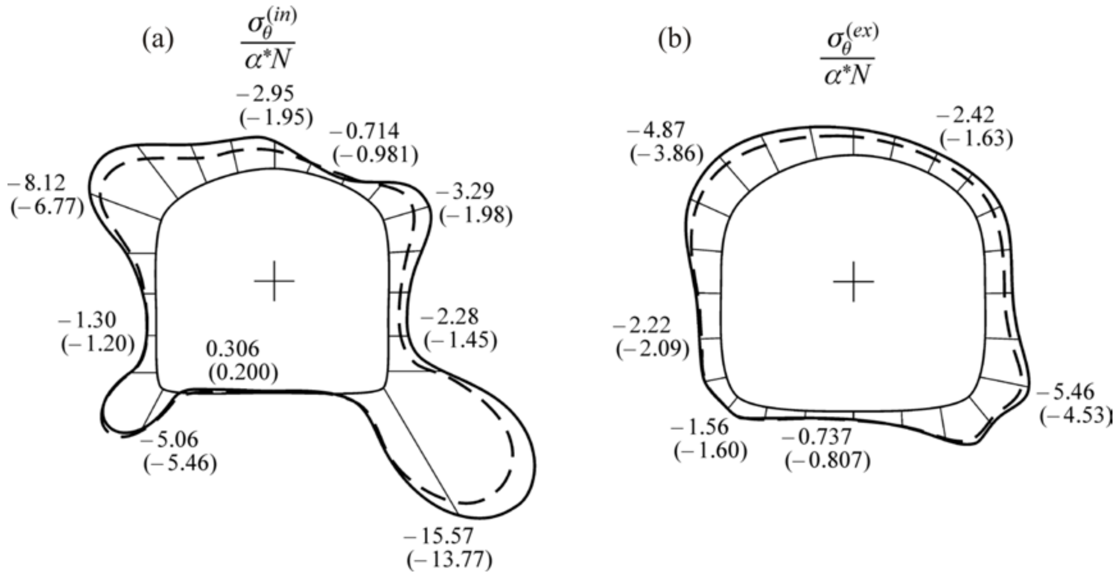

Figure 3. Normal shear stresses at (a) internal and (b) external boundaries of the support cross-section under the action of tectonic forces.

It is seen in the figure that the influence of the interface shows itself as a noticeable increase in the normal shear stresses in the support. The highest increment in the stresses is observed in the roof and at the juncture of the right-hand wall with the floor.

The developed method can be used in support designs under seismic loads of earthquakes. In this case, 2D elasticity problem in Fig. 1 assumes that initial stresses are absent in the medium $S_{0,1}$ which is though subjected to infinite compression along the interface by unequal stresses determined in conformity with the currently customary approach [6, 9] with regard for reflection and refraction of seismic waves at the interface [10]. This problem is solved using the methods applied to to above problem solution.

The calculated results on the support design under the action of vertical seismic waves of tension–compression are shear are presented below. The distribution diagrams of normal shear stresses at the internal $\sigma_\theta^{(in)}$ and external $\sigma_\theta^{(ex)}$ boundaries along the cross-section of the lining are plotted as fractions of the normal P and shear S stresses at the front of P- and S-waves. As before, the dashed lines illustrate calculations regardless of the influence of the interface.

The stresses P and S can be evaluated using the formulas [9]:

$$P = \frac{1}{2\pi} AK_1 \gamma c_1 T_0, \quad S = \frac{1}{2\pi} AK_1 \gamma c_2 T_0,$$

where A is coefficient equal to the earthquake magnitude; K_1 is a coefficient of permissible damage (for underground structures, the product AK_1 is assumed as 0.025, 0.05 and 0.1 in case of seismic activity at magnitudes 7, 8 and 9, respectively); γ is the bulk density of rocks; T_0 is the prevailing PPV period; c_1 and c_2 are the velocities of P- and S-waves, respectively.

According to the distribution diagrams in Fig. 4, the interface near the roadway decrease stresses cause by the tension–compression wave and increase stresses induced by the shear wave.

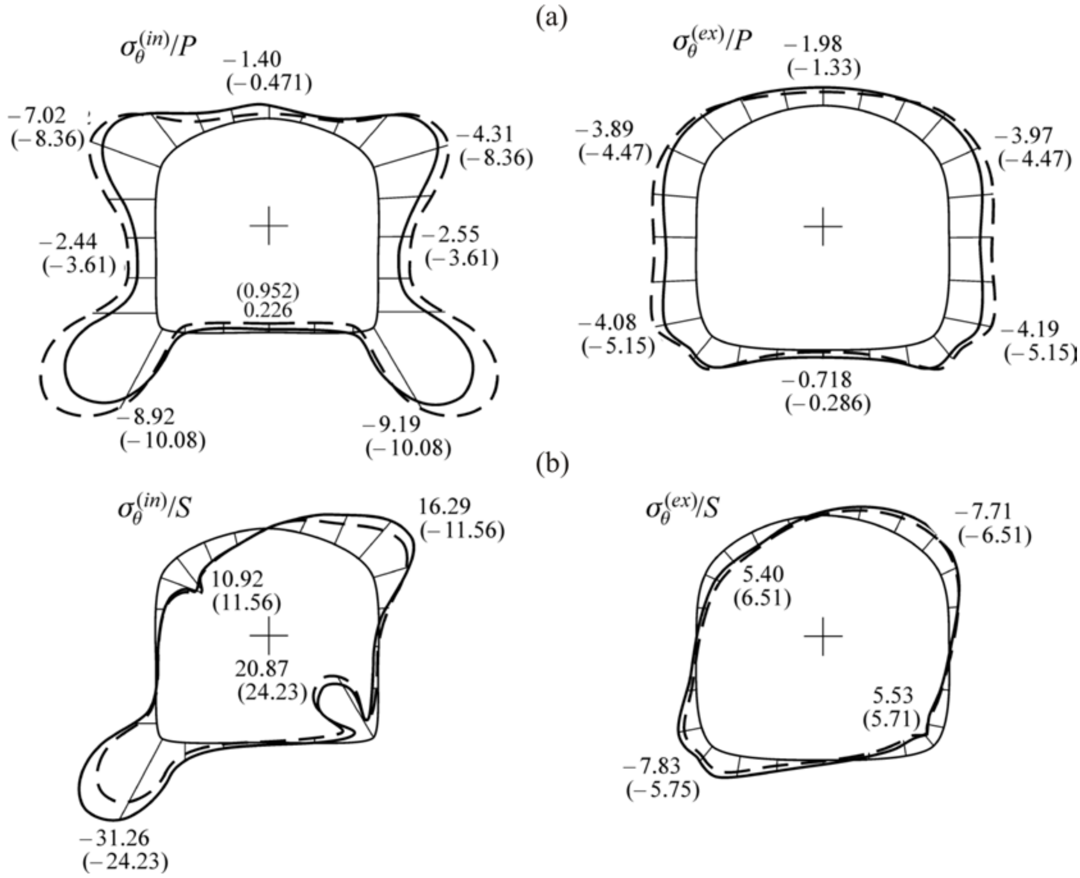

Figure 4. Normal shear stresses in lining in roadway under the action of seismic waves: (a) tension–compression and (b) shear.

It is worthy of mentioning that stress state of rocks near the interface essentially depends on the direction of seismic waves [9], which is impossible to determine before an earthquake. Therefore, in order to get a holistic insight into the seismic load exerted by an earthquake on a roadway located near an interface, it is required to analyze different directions of seismic waves in case of various locations of the roadway relative to the interface. Such research is laborious and complex in terms of interpretation. The present study's authors think that it is wiser to plot envelopes of maximum tensile and compressive stresses arising in support of mine roadways in case of different directions of seismic waves. First proposed in [6], this approach, after little modification, can be applied to the case analyzed in this study.

3. Conclusions

1. The method has been proposed for the support design for underground excavations located near the interface of rocks of different deformability under the action of tectonic forces and seismic loads of earthquakes. The new analytical solutions are obtained for 2D elasticity problems on stress state of a ring supporting an arbitrary configuration hole near a straight interface of two elastic media when the interface is subjected to infinite stresses modeling seismic loads, or one of the media experiences initial stress field.

2. The presence of the interface results in the decrease in the seismic stresses in the support in case of the vertical tension–compression wave and increases the stresses in the conditions of the vertical shear wave.
3. If a thick layer of weaker rocks occurs near the roadway, stresses in the support grow.

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References

[1] Kozyrev AA 1983 Diagnosis and identification of tectonic stress fields in seismically active regions in search of earthquake precursors *Mechanics of Rocks in Underground Construction and Mineral Mining at Great Depths* Leningrad (in Russian)
[2] Rybin VV and Savchenko SN 2017 Reconstruction of effective stresses within the Kovdor group of deposits on the basis of full-scale measurements *Proc. Fersman Scientific Session of the Kola Science Center of the Russian Academy of Sciences* Apatity (In Russian)
[3] Fotieva NN, Bulychev NS, Deev PV and Vladova VV 2008 Design of support of multiple non-circular workings in tectonic areas *Archives of Mining Science. Quarterly. Contribution of Strata Mechanics to Mining Technology and Work Safety* Cracow Vol 53 Issue 3
[4] Muir Wood AM 1975 The circular tunnels in elastic ground *Géotechnique* Vol 25 Issue 1 pp 115–127
[5] Halim IS and Chen WP 2001 The use of numerical method in the design of large underground tunnel and chamber in rock *DC Rocks* American Rock Mechanics Association
[6] Fotieva NN 1980 Support Designs for Underground Structures Seismically Active Regions Moscow: Nedra (in Russian)
[7] Fotieva NN, Bulychev NS and Sammal AS 1997 Designing tunnel linings in tectonic regions with the rock technological heterogeneity to be taken into account *IX International Conference on Computer Methods and Advances in Geomechanics* Wuhan: Balkema pp 1315–1320
[8] Bulychev NS and Fotieva NN 1999 Once more about the modern theory of underground structures design *Proceedings of the World Tunnel Congress 1999* Oslo pp 327–333
[9] RF Construction Code SP 268.1325800.2016. Transport Facilities in Seismic Regions. Design Regulations (in Russian)
[10] Deev PV and Petruhin MA 2017 Seismic analysis of mine support *J. Fundamet. Appl. Min. Sci.* Vol 4 No 2 pp 37–41 (in Russian)