Determination of stresses in concrete lining with rock-bolt in case of exhaustion of rock-bolt supporting strength

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Abstract. The article deals with the solution of analytical problem of flat axisymmetric elasticity theory, when rock-bolt supporting strength is exhausted. Expression for determination of stresses in concrete lining is deduced, where pressure increasing at exploitation have regarded. This methodology can be used at blueprint stage and preliminary calculation during mining operations. Further evaluation of concrete lining strength and geophysical probe of rock is needed for the preliminary calculation.

1 Introduction

Lining of the mining shaft must have an adequate load-carrying capacity and imperviousity for overall life of shaft. Different factors exercise the influence on durability, which can make operating parameters of lining worse.

At shaft excavation, support setting is in arrears of excavation by 20 - 25 m. Borehole zone is fixed by rock-bolt. During these operations forms a bilayer lining, which includes outer layer of hardened rock mass and inner layer of concrete lining.

The inner layer of concrete lining is contacts with atmospheric environment of mine shaft, which corrosive properties are defined by: amplitude attributes, air-flow resistance of frames, temperature and etc. Analysis of these factors can be examined in researches [1-5].

The water can affect a concrete lining outer layer and rock-bolt. Analysis of corrosion processes, defects and damages in lining, examination of influence on lining load-capacity can be found in researches [6-10]. Exploration and empirical research illustrates that service life of rock-bolt is three-four time lower than service life concrete lining. On operational phase at one point rock-bolt loses its functionality, which leads to an increase in the load on the concrete lining and a change in the stress-strain state. Methodology of analysis this process must be refined.

2 Computational model

Let's consider interaction between concrete lining and rock mass, which is fixed by rock-bolt on operational phase.

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This study is based on universality accepted analytical calculation of lining in plane method [11-16].
After lining setting and shaft bottom removal, the system "concrete lining – rock-bolt support – rock mass" is setting up and can be submit in computational model (fig. 1).

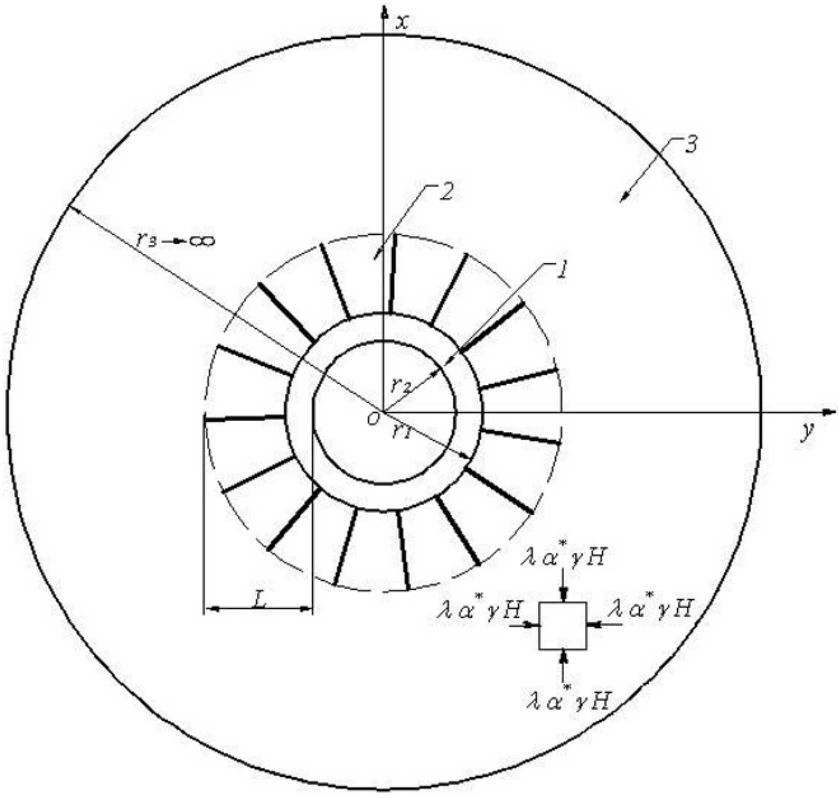

Fig. 1. Computational model. 1 – Concrete lining; 2 – Rock mass fixed by rock-bolt; 3 – rock mass

Circle of rock mass that fixed by rock-bolt is certain layer. It is aquasihemogeneous layer with E_{str} and R_{str} parameters (where E_{str} is elasticity modulus and R_{str} is rock mass strength fixed by rock-bolt). The axisymmetric problem of stress-deformed state of infinite plane, that relaxed by circular perforation in equal parameters of stress pattern is considered.

3 Results

In case of loss of rock-bolt functionality, parameters of layer 2 (fig. 1) lead to rock mass loading-out and stress parameters change. These may be written as:

$$\sigma_x = \alpha_{rb} \lambda \gamma H \,, \tag{1}$$

Where λ – lateral earth pressure coefficient;
γ – weight of incumbent rock mass;
H – depth of mine shaft;
α_{rb} – loading-out coefficient of support, based on the fact that shaft excavation is in arrears of excavation and fixed rock-bolt influence on rock mass.

For determination parameter α_{rb} let's analyze the dynamic of movement in contour line of mine shaft.

Summary fractional rock mass contour line movement before concrete lining setting may be written as [12]:

$$\tilde{u}_0 + \tilde{u}_{rb} = \frac{u_0}{u_\infty} + \frac{u_{rb}}{u_\infty}, \tag{2}$$

where u_0 – Initial displacements before fixing rock-bolt;
u_{rb} – mine shaft contour line displacement after fixing rock-bolt and before concrete lining setting;
u_∞ – total displacements of relaxed mine.
Thus

$$\alpha^* = 1 - \tilde{u}_0 - \tilde{u} = \alpha^* - k , \tag{3}$$

where α^* – coefficient in accordance with [1].
Value parameter k_{rb} determined with numerical model study of bottom shaft zone, which has fixed rock mass layer, width equal rock-bolt length l_{rb} and instantiated of elasticity model $K_{rb} \cdot E_0$.
As a result of data handling, will have correlation connection for determinating parameter k_{rb}:

$$k_{rb} = \frac{0.6 \exp\left(-0.152 \frac{D}{l_0}\right)}{l_{rb}^{0.136} K_{rb}^{0.942}}, \tag{4}$$

where D – outside of shaft timber diameter, m;
l_0 – Concrete lining arrearage from bottom shaft, m.
Equivalent stresses applied at infinite, is given as

$$P_{eq}^{'} = \sigma_x \frac{2}{\chi_0 + 1}, \tag{5}$$

where χ_0 – coefficient equals at plane deformation:

$$\chi_0 = 3 - 4\nu_0, \tag{6}$$

ν_0 – coefficient equals at plane deformation.
Radial stresses on outline section of mine shaft (with rock mass contact) equal

$$p = P_{eq}^{'} \cdot K_0^{'} \cdot K_2^{'} - P_{eq}^{'} \cdot K_0 \cdot K_2, \tag{7}$$

Where K_0 – stress transfer coefficient through infinite layer of rock mass until rock-bolt strength loss:

$$K_0 = \frac{\chi_0 + 1}{2 + \frac{G_0}{G_2} \frac{1}{c_2^2 - 1}\left(d_{1(2)}^{'} - K_2 \cdot d_{2(2)}^{'}\right)}; \tag{8}$$

$K_0^{'}$ – stress transfer coefficient through infinite layer of rock mass after rock-bolt strength loss:

$$K_0^{'} = \frac{\chi_0 + 1}{2 + \frac{G_0}{G_2^{'}} \frac{1}{c_2^2 - 1}\left(d_{1(2)}^{'} - K_2^{'} \cdot d_{2(2)}^{'}\right)}; \tag{9}$$

where G_0 – rock mass shear modulus;
G_2 – layer 2 shear modulus fixed by rock-bolt;
$G_2^{'}$ – layer 2 shear modulus after rock-bolt strength loss;
$c_2 = (r_1 + l)/r_1$;
$d_{1(2)}^{'} = c_2^2(\chi_0 - 1) + 2$;

K_2 – stress transfer coefficient through layer 2 that fixed by rock-bolt:

$$K_2 = \frac{d_{1(2)}}{d_{2(2)} + \frac{G_2}{G_1}\frac{c_2^2 - 1}{c_1^2 - 1} \cdot d'_{1(1)}};\tag{10}$$

$$K'_2 = \frac{d_{1(2)}}{d_{2(2)} + \frac{G'_2}{G_1}\frac{c_2^2 - 1}{c_1^2 - 1} \cdot d'_{1(1)}},\tag{11}$$

where $d'_{2(2)} = \chi_0 + 1$;

$d_{1(2)} = c_2^2(\chi_0 + 1)$;

$d_{2(2)} = 2c_2^2 + \chi_0 - 1$;

$d'_{1(1)} = c_1^2(\chi_1 - 1) + 2$;

$c_1 = r_1 / r_2$;

$\chi_0 = 3 - 4\nu_1$;

G_1 – concrete shear modulus;

ν_1 – transverse deformation coefficient.

Average normal tangential stresses in lining of mine determined from the formula

$$\sigma_m = p\left(m_{1(1)} - 0.5\right),\tag{12}$$

where $m_{1(1)} = 2c_1^2 / \left(c_1^2 - 1\right)$.

Strength condition for lining

$$\sigma_m \le R_b,\tag{13}$$

where R_b – estimated concrete compressive resistance.

4 Conclusions

In connection with the problem solution of flat axisymmetric elasticity theory we generated a method of determining stresses in lining during rock-bolt support strength loss. This method can be used at a blueprint stage and preliminary calculation during operation of mining venture. Further evaluation of concrete lining strength and geophysical probe of rock is needed for the preliminary calculation. This equates to implementation of advanced lining enforcement measures.

References

1. A.N. Vulfson, Izvestia. Atmos. Oceanic Phys, **37(3)** (2001)
2. A.N. Vulfson, Russ. Meteorol. Hydrol, **1** (2001)
3. A.N. Vulfson, Journal of Engineering Physics and Thermophysics, **3** (2001)
4. A.N. Vulfson, I.A. Volodin, O.O. Borodin, Russ. Meteorol. Hydrol, **10** (2004)
5. A.N. Vulfson, O.O. Borodin, Russ. Meteorol. Hydrol, **34(8)** (2009)
6. F.I. Yagodkin, A.Y. Prokopov, M.S. Pleshko, A.N. Pankratenko, IOP Conference Series: Earth and Environmental Science, **87(6),** 062014 (2017)
7. F. Yagodkin, M. Pleshko, A. Prokopov, Procedia Engineering, **206,** 293–298 (2017)

8. M.S. Pleshko, Y.V. Vcherashnyaya, A.A. Nasonov, Gornyi Zhurnal, 10 (2016)
9. M.S. Pleshko, S.G. Stradanchenko, S.A. Maslennikov, O.V. Pashkov, ARPN Journal of Engineering and Applied Sciences, **10(1)** (2015)
10. M.S. Pleshko, O.V. Pashkova, A.A. Nasonov, Gornyi Zhurnal, **3** (2015)
11. M. Pleshko, B. Meskhi, M. Pleshko, MATEC Web of Conferences, **170,** 03023 (2018)
12. A. Pankratenko, M. Pleshko and A. Isaev, MATEC Web of Conferences, **7,** 02026 (2018)
13. B. Meskhi, M. Pleshko, Y. Buligin, L. Alexeenko, M. Molev, IOP Conference Series: Earth and Environmental Science, **90(1),** 012217 (2017)
14. M. Pleshko, A. Pankratenko, A. Revyakin, E. Shchekina, S. Kholodova, E3S Web of Conferences, **33,** 02036 (2018)
15. G. Romanova, M. Pleshko, M. Rossinskaya, N. Saveleva, A. Pankratenko, Advances in Intelligent Systems and Computing, **692** (2018)
16. M. Pleshko, I. Voinov, A. Revyakin, MATEC Web of Conferences, **106,** 05004 (2017)