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CONTRIBUTION ON POTENTIAL PREDICTION OF ROCK FAILURE IN THE SURROUNDINGS OF LONG MINE ROADWAY IN STRATIFIED ROCK MASS

Summary. A computer program has been developed for approximated determination of the rock failure zone in the vicinity of a dog heading, executed in a rock mass made up of five different rock strata, arbitrarily situated in the cross-section of the excavation. Use was made in the program of Kolosov-Muskhelishvili algorithm for the calculation of the state of stress round a hole of any shape. The criterion of the limit state of rocks in each stratum was expressed by Mohr's envelope in the form of a broken line, composd of three straight segments. By the way of an example are presented the results of calculations for a heading executed at the depth of 700 m, in the cross-section of which there are two rock strata, characterized by different values of Poisson's ratio and different values. of cohesion, and angle of internal friction.

PRZYCZYNEK DO PROGNOZOWANIA ZNISZCZENIA SKAŁ W OTOCZENIU WYROBISKA KORYTARZOWEGO W GÓROTWORZE O BUDOWIE WARSTWOWEJ

Streszczenie. Opracowano program komputerowy do przybliżonego określania strefy zniszczenia skał w sąsiedztwie wyrobiska chodnikowego wykonanego w górotworze zbudowanym z max pięciu różnych warstw skalnych dowolnie usytuowanych w przekroju poprzecznym wyrobiska. W programie wykorzystano algorytm Kołosowa-Muscheliszwilego do obliczania stanu naprężenia wokół otworu o dowolnym kształcie. Warunek stanu granicznego skał w każdej warstwie wyrażono obwiednią Mohra w postaci linii łamanej składającej się z trzech odcinków prostych. W charakterze przykładu przedstawiono wyniki obliczeń dla wyrobiska wykonanego na głębokości 700 m, w którego przekoju poprzecznym występują dwie warstwy skalne charakteryzujące się różnymi wartościami współczynnika Poissona i różnymi wartościami spójności i kąta tarcia wewnętrznego.

К ВОПРОСУ О ПРОГНОЗИРОВАНИИ РАЗРУШЕНИЯ ГОРНЫХПОРОД В РАЙОНЕ УЗКОЙ ВЫРАБОТКИ В ГОРНОМ МАССИВЕ СЛОИСТОГО СТРОЕНИЯ

Резюме. В статье представлена компьтерная программа, разработанная для приблизительного определения зоны разрушения пород в районе узкой выработки, проведенной в горном массиве, состоящем из самое большое пяти слоев разных пород, расположенных любым образом в поперечном сечении выработки. В программе был использован алгоритм Колосова-Мусхелишвили для расчёта напряженного состояния вокруг отверстия любой формы. Условие предельного состояния горных пород было выражено огибающей Мора, в виде ломаной линии, состоящей из трёх прямых отрезков. В качестве примера были представлены результаты расчётов для выработки, проведенной на глубине 700м, в поперечном сечении которой выступают два слоя пород, характеризующися разными значениями коэффициента Пуассона, а также разными значениями сцепления и углами внутреннего трения.

Mechanical processes occurring in rock strata of mine roadway surroundings after roadway drivage may have infavourable consequences as cavings, excessively excavation dislocations or even dynamic phenomena.

For selection of measures and means preventing such infavourable events an estimation of stage and development of mechanical processes in the given geologic situation is necessary. For an adequate choice of support type, support construction and loading capacity of support a knowledge of mechanical condition on the contact of rock strata with roadway support is indispensable. The condition of rock stability in the drivage face can be described as

$$\sigma_{tmax} - \sigma_d = 0$$

where:

σ_{tmax} - maximum tress affecting the drivage face of unsupported roadway,

σ_d - compressive strength of rock.

By fulfilment and compliance with the above-mentioned stability condition the rocks are classified as stable, in a contrary case they are classified as unstable. Based on this a number of criteria have been created by which an unsupported roadway could be classiied according to its stability degree. Most frequently the following criterium is applied:

$$k = \frac{\gamma \cdot H}{\sigma_d}$$

where $\gamma \cdot H$ - vertical component of geostatic stress.

According to this criterion unsupported roadways are classified into:

- stable ($k < 0,1$),
- medium stable ($0,1 \le k \le 0,24$),
- unstable ($k > 0,24$).

An assessment of mechanical rock condition in the surroundings of a mine roadway requires a determination of rock failure in the roadway surroundings and to perform estimates of processes occurring after rock failure. It is therefore necessary to specify dimensions of arising failure zones and to determine methods and means for stability control.

Mutual effects between the support and rock strata are linked with mechanical processes which are manifested by rock cavings (local, continuated) or rock deformations. In the former case the loading condition is known, in the latter case the roadway deformation condition is known. Among the existing methods for determination of local cavings the method of elastic superposition appears as the most adequate. The principle of this method lies in comparison of stresses derived from elastic rock strata model solution for rock strata weakened by the roadway with the strength of surrounding rocks. Where reliability conditions are not fulfilled, disturbance areas occur.

Two potential solution approaches should be mentioned. The former one is based on simplification when determining actual stress condition and it compares strength characteristics with actual stress characteristics. It does not require an application of special algorithms or of computer equipment. The basic input parameters are roadway dimensions, compressive strength and tensile strength of rocks and the stress on roadway periphery.

The relevant procedure is as follows:

- the roadway contour is drawn and within it a coordinate system (x,y) is located. Along the contour 8 points are designated and they are numbered in compliance with fig. 1. The location of points 2 and 4 will be defined by the angle $\theta = \pm \operatorname{arctg} \frac{h}{a}$,
- stress in contour points will be determined for a "substitute" roadway of elliptic shape and equivalent cross section.

  The half-axes of the ellipse will be calculated:

$$a_e = \sqrt{\frac{S \cdot a}{\pi \cdot h}} \quad i \quad h_e = \sqrt{\frac{S \cdot h}{\pi \cdot a}}$$

S = cross section area of investigated roadway

- for each point radius of ellipse curvature will be determined

- for points 1,5 $R_e = \frac{h_e^2}{a_e}$

- for points 3,7 $R_e = \frac{a_e}{h_e}$

- for points 2,4,6,8 $R_e = \frac{1}{a_e \cdot h_e}\sqrt{\frac{(a_e^2 + h_e^2)}{2}}^{\,3}$

- in a graphic way contour curvature radii in each point will be determined (R_i^k).

  The correlation of radii in i-point is given by parameter κ

  $$\kappa = \left(\frac{R_i^e}{R_i^k}\right)^{2/3} \qquad \begin{array}{l} \kappa = 6, \text{ for points 6 and 8} \\ \\ \kappa = 0, \text{ for straight contour sections} \end{array}$$

- for $p_{max} = p_{min} = p$ a tangential stress in the contour will be determined according to corelations:

  $$\sigma_i^{1;5} = p[0,35(1 - \kappa_i) + (0,3 + 1,7\,\kappa_i)\frac{a}{h}]$$

  $$\sigma_i^{3;7} = p[0,35(1 - \kappa_i) + (0,3 + 1,7\,\kappa_i)\frac{h}{a}]$$

  $$\sigma_i^{2;4;6;8} = p[1,2(\kappa_i - 1) + \frac{h^2 + a^2}{a \cdot h}]$$

- for a development of contour at axes (σ_i; θ) a stress pattern and a strength pattern of rocks will be drawn. Zones in which the stresses exceed rock strength are disturbed and with caving risk. A caving length 1 will be derived from adiagram (see fig. 1),
- height of distrubance or failure area is given by correlation:

  $$h_c = \frac{a'}{2f} \qquad \text{(f = coefficient of Protodyakonov)}$$

- width of disturbance zone a' : $a' = 2R_d \sin\left(\frac{180 \cdot 1}{2\pi \cdot R_d}\right)$

  (R_d = arch radius in zone 1)

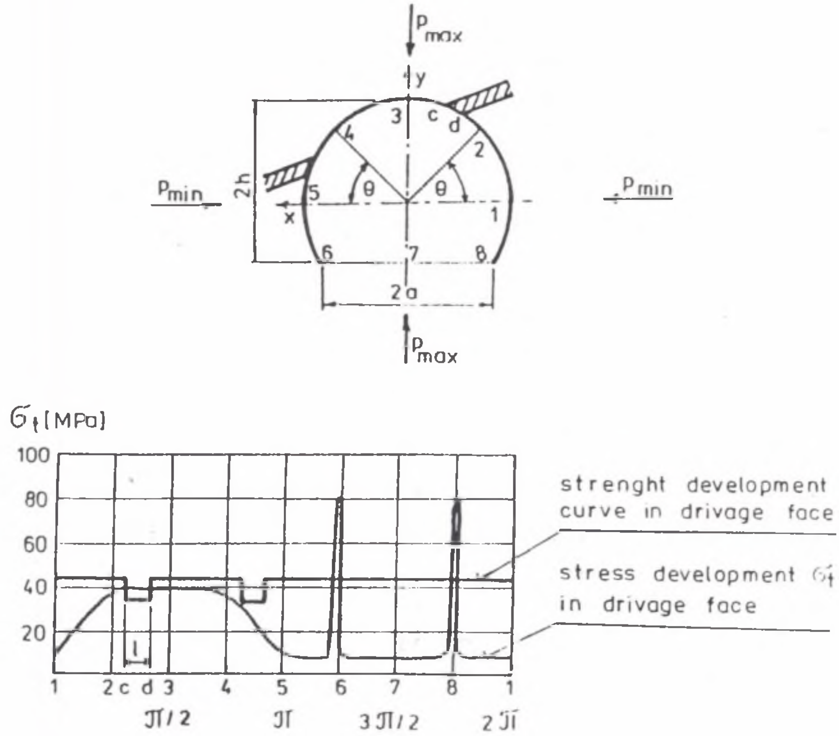

Fig. 1

- caving area: $S = \frac{R_d^2}{6}\left[8\left(1 + \frac{1}{2R_d\cdot f}\right)\sin\alpha - \frac{3\cdot 1}{R_d} - \sin 2\alpha\right]$

$$\alpha = \frac{180\cdot 1}{2\pi\cdot R_d} \quad i \quad 2\alpha = \frac{180\cdot 1}{\pi\cdot R_d} \qquad (1 = 1)$$

- loading by disturbed rock weight: $q = \gamma \cdot S$.

As mentioned above this procedure is an approximative solution, especially in view of stress condition solution in the roadway surroudings. The authors of this paper have therefore elaborated a MUSCH calculation system based on Kolossov-Muskhelishvili algorithm for stress condition determination in the surroundings of roadway of a given shape and also based on Mohr stregnth condition for rocks in dimensionless formula as follows:

$$V = \frac{1}{\gamma\cdot H}\left[(\sigma_r - \sigma_t)^2 + 4\tau_{rt}^2 - (\sigma_r + \sigma_t + 2\,c_i\cdot\mathrm{cotg}\varphi_i)^2\sin^2\varphi_i\right]$$

(for $V \geq 0$ disturbance-failure occurs; at $V < 0$ disturbance does not occur).

The calculation procedure is based on stress determination: σ_t; σ_r; τ in each required point (on selected radial beams for a roadway whose conform representation is considered as:

$$z = w\ (\xi) = \sum_{1}^{5} A_n \cdot \xi^{1-n}$$

where A_n are real numbers, which are determend for actually used cross sections 00-0-XX or OP-0-XX, see (1).

A general form of Mohr strength envelope is approximated for each type of rock by a broken line consisting of three straight sections. Their proportions are determind by the values φ_i; c_i ($i = 1,2,3$). By calculation a stress condition in sections positioned radially towards roadway is gradually determined and evaluated. In every section the point representing a boundary between disturbed and intact zones is sought for iteration. At the same time rock features of individual layers defined are respected.

By geotechnical situation existence of bedded structures is presumed (max. 5) which can be absolutely arbitrarily situated in the roadway cross section (see fig. 2). The job is made by interactive method with potential

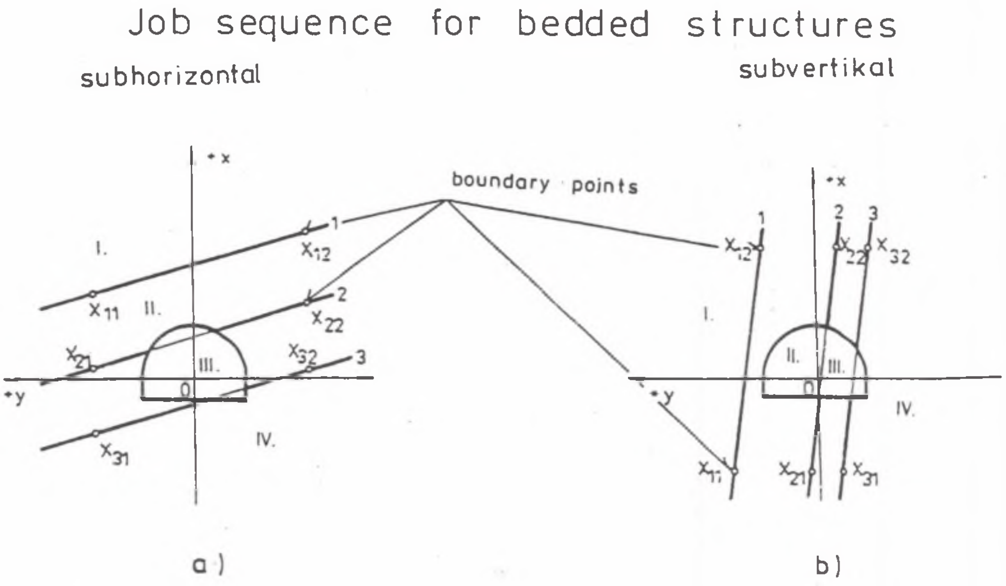
Job sequence for bedded structures

Fig. 2

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C O M P U T E R   P R I N T O U T

Input data

Roadway shape                                       OO-O-12
Roadway depth                                        700  m
Roof weight loading                                  .026  MN/m3

Table of strength parameters
------------------------------------------------------------
  nr. of    mi   fi1      c1     fi2      c2     fi3     c3
  layer         [st.]  [MPa]   [st.]  [MPa]   [st.]  [MPa]
------------------------------------------------------------
       1  0.30  55.0     3.0    45.0     5.0    25.0    6.0
------------------------------------------------------------
       2  0.25  50.0     2.0    40.0     4.0    20.0    5.0
------------------------------------------------------------

mi - Poisson's ratio
Parametric input of Mohr strength envelope
fi1,fi2,fi3 - angle of int. friction
c1,c2,c3 - cohesion
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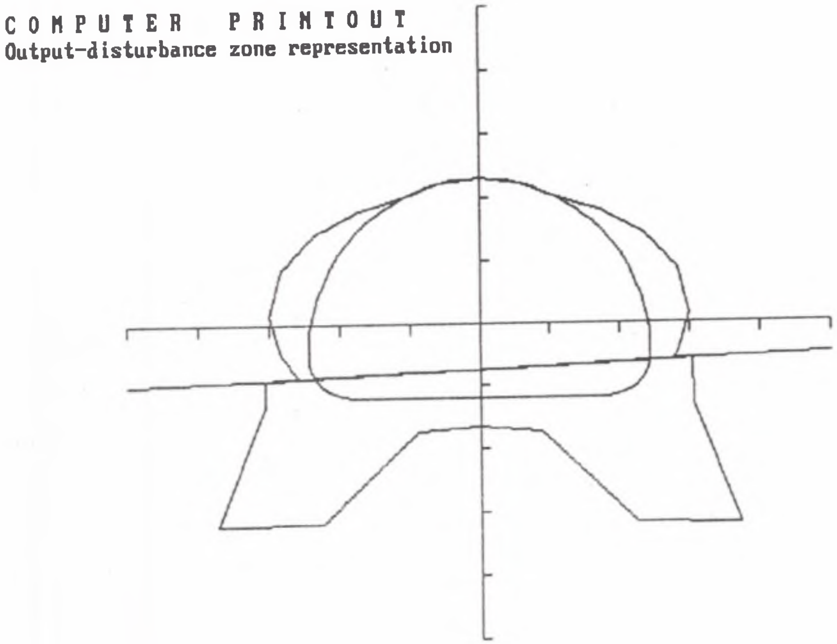

C O M P U T E R   P R I N T O U T
Output-disturbance zone representation

```
COMPUTER   PRINTOUT

Table of results
------------------------------------------------------------
 nr. of  XOR     YOR    dis.val.   SIGR     SIGT     TAU
 layer   [m]     [m]      [m]     [MPa]    [MPa]   [MPa]
------------------------------------------------------------
     1    2.22    0.57    0.00     -0.00     7.97    -0.00
     1    1.99    1.11    0.00      0.00    14.57    -0.00
     1    1.78    1.72    0.20      1.69    21.98    -2.48
     1    1.42    2.36    0.47      3.89    26.36    -3.86
     1    0.85    2.83    0.63      5.17    29.75    -3.25
     1    0.14    2.99    0.60      6.24    33.51    -1.62
     1   -0.51    2.82    0.38      8.01    38.98     0.57
     1   -0.51   -2.82    0.38      8.01    38.98    -0.57
     1    0.14   -2.99    0.60      6.24    33.51     1.62
     1    0.85   -2.83    0.63      5.17    29.75     3.25
     1    1.42   -2.36    0.47      3.89    26.36     3.86
     1    1.78   -1.72    0.20      1.69    21.98     2.48
     1    1.99   -1.11    0.00      0.00    14.57     0.00
     1    2.22   -0.57    0.00      0.00     7.97     0.00
     2   -1.30    3.06    0.81     11.70    24.29     8.84
     2   -3.21    3.73    2.56     10.64    14.22     8.75
     2   -3.15    2.25    1.89      8.72    11.23     7.99
     2   -1.73    0.88    0.47      0.61     1.28     1.97
     2   -1.64   -0.00    0.46      0.34    -1.51    -0.00
     2   -1.73   -0.88    0.47      0.61     1.28    -1.97
     2   -3.15   -2.25    1.89      8.72    11.23    -7.99
     2   -3.21   -3.73    2.56     10.64    14.22    -8.75
     2   -1.30   -3.06    0.81     11.70    24.29    -8.84

dis.val. - disturbance values
```

error correction. The geometric location of bedded structures is realized in a graphic mode and disturbance zones in the roadway surroundings are calculated in two steps. In the first step the disturbance zone above roadway floor is defined and an average disturbance value of roadway floor is determined. On the basis of average floor disturbance (disturbance depth) it is possible to approximate a new shape of worked-out section in the floor region (elliptic counter-arch made in rock strata by special blasting method). It is also possible to determine new disturbance zone parameters for eventual projection of further stabilization measures.

The above-mentioned procedure enables creation of criteria for application of measures increasing floor stability.

The output solution set includes:

- representation of roadway and geotechnical situation,
- representation of disturbance (failure) values,

- average (mean) disturbance value,
- table of results with coordinates of points of disturbance zone and stress magnitudes in these points,
- information on maximum sizes of disturbance zones in the roof, sides and floor of roadway.

A specimen of output set of exemplary model is mentioned in Appendix Nr 1. Although the MUSCH system has been created primarily for dealing with stability problems of roadway floor its application for determination of seam disturbance zone in a roadway side is obviously possible and there is a directly applicable programme for such purpose. The reliability of results is directly proportional to input information quality concerning rock features and original geostatic stress.

REFERENCES

[1] *Aldorf J. et al.:* Mechanics of underground structures - exercise instructions. Mining University VŠB.

[2] *Aldorf J., Vojtasik K., Exner K.:* Properties of hydraulically hardened fill material behind roadway support and methodology of floor stability evaluation. HS 284/90, VŠB 1990.

[3] *Baklashov I.V., Kartoziya B.A.:* Mechanics of underground facilities and support structures. Nedra Moscow 1984.

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