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POSSIBILITIES OF AN INCREASED LOAD-CARRYING CAPACITY OF A STEEL ARCH SUPPORT BY MEANS OF ANCHORAGE

Summary: This submitted paper describes the methods of an increased load-carrying capacity of a steel arch support by means of anchorage. Proposed solutions are based on the assumption of an interaction of both a steel arch support and roof bolts. The main aim of all the proposed solutions is to activate rock mass in the vicinity of a working, to prevent the degradation of rock mass stability and to reach a maximum utilization of rock mass self-supporting abilities.

MOŻLIWOŚCI ZWIĘKSZENIA PODPORNOŚCI STALOWEJ OBUDOWY ŁUKOWEJ ZA POMOCĄ KOTWIENIA

Streszczenie: W pracy omówiono metody zwiększenia podporności stalowej obudowy łukowej za pomocą kotwienia. Zaproponowane rozwiązania oparte są na założeniu współpracy stalowej obudowy łukowej i kotwi stropowych. Głównym celem wszystkich przedstawionych metod jest uaktywnienie górotworu w sąsiedztwie wyrobiska, maksymalne wykorzystanie samonośności górotworu i zapobieżenie utraty stateczności.

ВОЗМОЖНОСТИ ПОВЫШЕНИЯ ОПОРНОСТИ СТАЛЬНОЙ АРОЧНОЙ КРЕПИ ПРИ ПОМОЩИ АНКЕРОВАНИЯ

Резюме: В работе представлены методы повышения опасности стальной арочной крепи при помощи анкерования. Предложенные решения осcновываются на предпосылке совместной работы стальной арочной крепи и кровельных анкеров. Главной целью всех представленных методов яблается активизация горного массива, окружающего горные выработки, максимальное использование несущей способности горного массива и предотвращение потери устойчивости.

1. INTRODUCTION

The needs of working experience, associated with such a fact that the underground workings use to be situated in greater and greater depths, do require the support structures with a higher load-carrying capacity.

Load-carrying capacity of a steel support - similar like in the case of all the types of supporting structures - is given by the final number of their parameters, i.e. static(al) parameters of a cross section, deformational and strength properties of materials, geometric shape of a structure, structural solution (joints, yielding, non-yielding, etc.).

The range of true values of the above-mentioned parameters is in a certain limited interval, and from this such a fact follows that load-carrying capacity of a supporting structure can reach a certain limit only, which cannot be considerable exceeded.

The situation, in which load-carrying capacity of a support does not correspond with expected loading, has to be got-over by a changed access to the solution of a given problem. It is convenient to start from the NATM-principles and rules, nevertheless, to concentrate on perfect utilization of strength properties of rock mass and to eliminate factors, which lead to a groundless loss of rock mass stability. Suppost design should be aimed at a creation of an autostabile structure of rock mass. In accordance with this above-mentioned access, a real increase of own support load-carrying capacity cannot be reached at all, as it is given by selected technical parameters, neverthelesss, due to the autostability of rock mass, there are changes inside it, the outside phenomenon of which is a partial decrease of loading, which acts on a support. In accordance with this fact, supports can be used under such conditions,under which they could not be theoretically used at all without including all the influences of autostability of rock mass.

2. ACTIVITIES OF STEEL ARCH SUPPORTS

The proper practical realization is based first of all on usage of a combined types of supports, the main type of which is a steel arch support, being lagged by means of a steel netting, with roof bolts and gunite. Many variants of various types of supports can be created, which are able to react to very specific geotechnic conditions of supporting.

According to their character, both gunite and roof bolts have their own extraordinary abilities to contribute to the autostability of rock mass.

Desing of particular shapes and forms of the individual structures of combined supports has to be based on the analysis of the activities of their parts, extent of their mutual interaction, and the definition of their influences upon rock mass, incl. their quantification.

From the view-points of their forms and extent of their interaction, combined supports can be subdivided into these four below-mentioned groups:

1. Supporting steel support is underspun/upbolted by means of roof bolts, which play the same function like the traditional supports would fulfilled. As a matter of fact, it is a new structure, which can be solved by means of the present methods without any problem. Working realization of this type of a combined support has not been satisfying solved at present regarding its structure, as standard steel parts and roof bolts are used, which are

interconnected in a way, being characterized with a considerable degree of improvization from the reason of mutual non-compatibility of both types of supports. A new shape of a section of this support has to be developed, which would keep its present properties and which, at the same, would enable a simple anchorage by means of one roof bolt in any point. A structure of roof bolts has to be changed as well, i.e. first of all, its ending part, which outgoes from a borehole in that way so that it would enable both prestressing of a roof bolt and a reliable gripping of a support. Static solution of a support structure has to be completed with the determination of an expected area of faulted rock mass in directions of roof bolts so that their length could be set. Other parameters of roof bolts are set on the basis of the intensity of their reaction.

2. Steel support is not connected to roof bolts by means of its own structural bond. Roof bolts are situated in the middle of two frames of steel support. Both types of supports work separately. Their mutual interaction is realized by means of rock mass. Parameter design of both types of supports can be carried-out individually for each support separately. Roof bolts length is set in accordance with expected thickness of the faulted area in the vicinity of a working, roof bolts pitch is set according to the pitch of crack structures, which weaken rock mass in a tangential direction towards the working s outline, and furthermore, in accordance with roof bolts load-carrying capacity. The distance of two adjacent rows of roof bolts, i.e. two adjacent frames of a steel support as well, is set in correspondence with load-carrying capacity of steel arch support in that way so that balance between loading and load-carrying capacities of a roof bolt and a steel frame support would be kept. By means of a changed density of an- chorage, loading on a support can be well influenced in a certain extent.

3. Roof bolts in rock mass intersect the crack systems, surfaces of stratification, characteristic with a zero tensile strength, low shear strength being dependent upon the state of stress, which are a potential danger for both the occurrence and development of open cracks and free spaces being characteristic for zones of a total instability. Their early mutual interconnection prevents from degradation of strrength properties in these places; artificial longer lasting interactions are created. From the view-point of rock blocks interconnection, the new structures are formed, having either a ring-shape, or a roof bolt shape, going along the stope shape. These new structures can be not only self-supporting, but they can be able to carry certain out- side loading as well.

Ability of roof bolts also intervene in the development of the state of stress and deformation in the vicinity of a working outline in these two ways:

a) In an active way, it can bring a part of a stabilization stress into rock mass by means of prestress of roof bolts,

b) In a passive way, due to roof bolts rigidity, it can prevent from decrease of state of stress in rock mass, which accompanies loss of its stability.

Loading of steel arch support will be lower and more equable due to a higher rigidity, and there will be smaller deformations of an artificial created ring-shaped structure, or roof bolts structure.

Quantification of the above-mentioned factors is too difficult, nevertheless, at the same time, it is the basis for the expression of a contribution of roof bolts to the autostability of rock mass. Quantification of the autostabilization influences of roof bolts within the activities of combined supports have to be considered to be the basis of a possibility of increased load carrying capacity of a combined support.

4. Combined supports are not used at the same time (it is their characteristic sign, at which the autostabilization processes of rock mass are fully applied), i.e. their usage and applications are subdivided into several phases in that way so that a support, within a given time, would transferred a minimum of a stabilization reaction only, being needed for preservation of a stability of rock mass.

Gunit is a mean, which can flexibly react to an instantaneous situation, and step by step, it can increase the load-carrying capacity of a combined support with successive spraying of further layers of a gunit.

It is impossible to cover all the factors mentioned in points 1. - 4., as phenomena, which are their real cause, can be neither caught, expressed nor quantified by means of forms being adequate with forms in analytical methods.

Such steps have to be used and applied, which will be based on:

Monitoring, facts, which can be unambiguous determined (real deformation and a working plot of a steel frame, parameters of roof bolts, etc.), and their retrospective evaluation by means of the methods of an back analysis, to quantify the influences of anchorage and phase supporting, e.g. in form of reduction coefficients of loading, or coefficients improving the strength and deformational properties in those parts of rock mass, which are situated within the influence of roof bolts.

The increase of load-carrying capacity of steel arch supports under such consitions, provided that a underground working, supported with steel arch supports, is situated within the influences of mining works, can be carried-out by the usage of roof bolts.Nevertheless, the situation seems to be too complicated due to considerable influences of acting loading on a support, which will be dependent upon changes of a stress field in the vicinity of a working, which are associated with face advance and mining works continuation.

Steps of the determination of load-cyrrying capacity of combined supports under the conditions of the influences of mining works have to be based on a detailed analysis of both time and space of the changes of state of stress within rock mass, which can be given by the methods of mathematical modelling and research on physical models only.

3.CALCULATION DRAFT OF A COMBINED SUPPORT - STEEL ARCH SUPPORT SUPPORTED WITH ROOF BOLTS

Combined support (in accordance with the activity 2.) and its interaction with rock mass - from the view-point of statics - seems to be a too complicated system, the solution of which has to be based on some static simplifications and assumptions as well. Supporting and stabilizing function of roof bolts is combined with a supporting (passive) function of a steel frame, which - with its character, load-carrying capacity and deformation rigidity - creates a possibility of an occurrence of a faulted area in the vicinity of a underground working. These two static imaginations have to be well combined on a calculation model. To express the influence of roof bolts upon state of stress and fracture of rock vicinity of a working, an implicite access - consisting in the determination of additional parameters of strength of anchored rocks - has been selected. This step is advantageous as it allows to use standard algorithms for the determination of the intensity and shape of faulted area in the vicinity of a working /1/ both for the parameter determination of roof bolts, and for loading determination of the individual arches of steel support. Calculation and desing of a support can be characterized with these below-mentioned steps:

(a) Determination of a shape and a size of the faulted area in the vicinity of a working reflecting mechanical properties of rocks, a geologic section, rocks faults, working s shape and size, etc.
(b) Parameters proposal of an intermediate roof bolt in accordance with the theory of a "suspension" (of an arch), i.e. determination of the roof bolts length, their load-carrying capacity, anchorage density, etc.
(c) Monitoring/checking of rock mass state after anchorage has been carried-out, i.e. implicite expression of stabilizing influence of roof bolts and determination of the faulted area of an anchored environment.
(d) Determination of loading of a complete steel arch in accordance with the arch theory with the consideration of the influence of intermediate anchorage and static calculation of an arch.
(e) Checking of load-carrying capacity of grating lagging

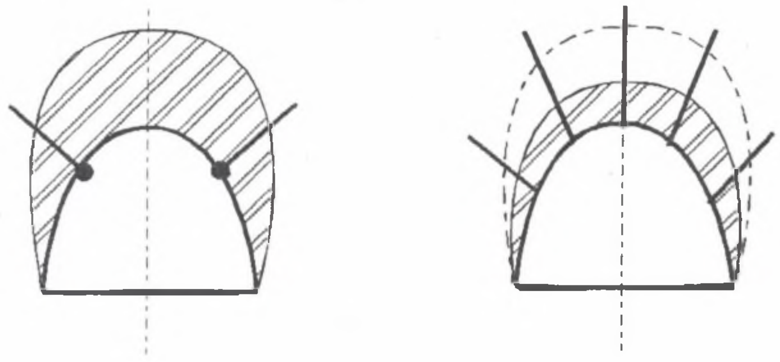

Fig. 1 . The working schemata of rock bolts endorsing the steel arch support
Rys. 1 . Schematy robocze kotwi współpracujących ze stalową obudową kotwiową

Given static schemes are in Fig. 1

3.1. Determination of the area of faulted rocks in the vicinity of a underground working

To carry-out this basic calculation, the MUSCH calculation system has been used, the basic algorithm of which is described in [1]. Program enables to determine the basic parameters of faulted area, and, the main influences, determing this area, remain to be respected. Fig. 4 shows the result calculation example. The size of a faulted area forms the basic information for further step of a calculation (see Fig. 1).

The area of faulted rocks in the vicinity of a working can also be determined on the basis

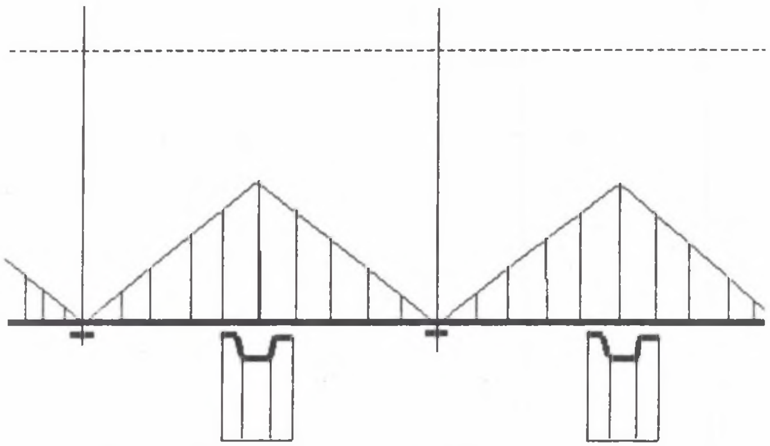

Fig. 2.The decrease of vertical loading of a steel arch due to intermediate anchorage
Rys.2. Spadek obciążenia pionowego łuków stalowych w wyniku zastosowania kotwienia górotworu pomiędzy odrzwiami obudowy

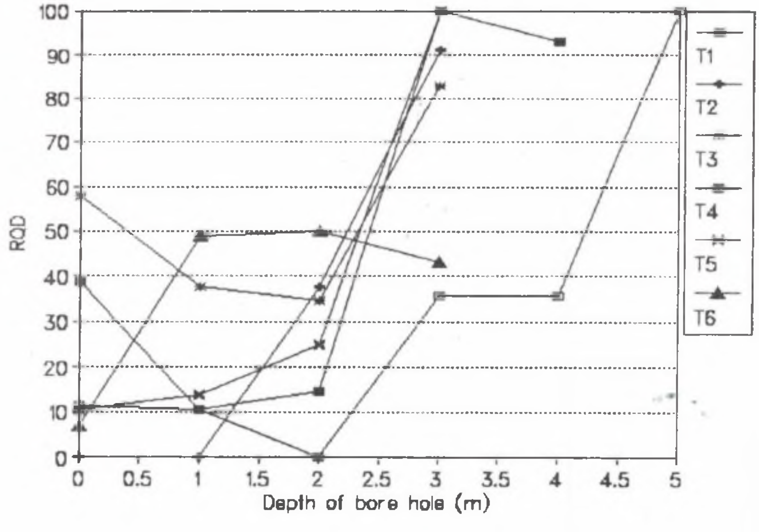

Fig.3. The display of RQD index in rock mass bore holes around the opening
Rys.3. Rozkład wartości wskaźnika RQD górotworu (wyniki oznaczeń dla sześciu otworów wiertniczych wykonanych wokół wyrobiska)

of measurements of quantitative characteristics of faults (e.g. RQD) of rocks. An example of such a step is given in Fig. 3, showing the RQD evaluations of six fan-shaped bore

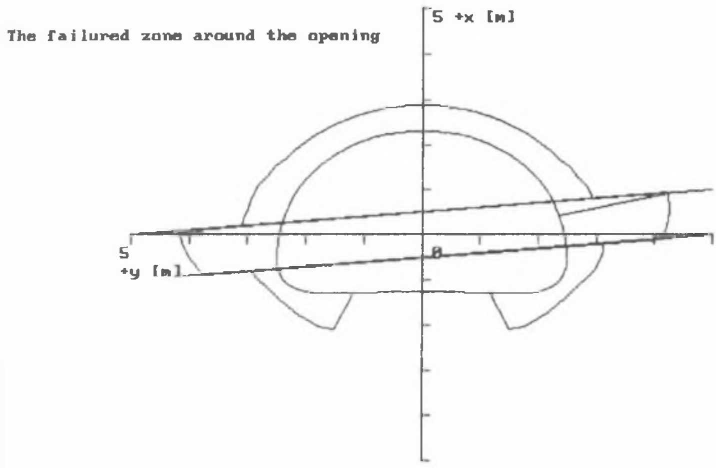

Fig.4.The failure zone around the opening without anchorage
Rys.4.Strefa spękania wokół wyrobiska bez obudowy kotwiowej

holes. From the curves course it is obvious that the faulted area is situated between 1.5 - 2.0 meters.

3.2. Parameters draft of roof bolts

Within the first phase, roof bolts have been designed in accordance with arch theory (theory of suspension) - Fig. 1 - in that way that its basic parameters are set:-

- Length of a roof bolt l_s

$$l_s = b + l_k$$

l_k - Length of a anchorage part of a roof bolt

b - Size of a faulted area

$$l_k = \frac{N_S}{\tau \pi d}$$

- Load-carrying capacity of a roof bolt N_s

$$N_S = \frac{1}{3} \pi b^3 \, tg \, \varphi \, \gamma + \frac{a \gamma}{2 \, tg \, \varphi} + \frac{l_a \gamma}{2 \, tg \, \varphi}$$

b - Size of a faulted area
γ - Volume gravity of a rock
φ - Angle of inside friction of a faulted rock
a - Distance between roof bolts in one row
l_a - Distance of arches of a steel support

- Distance of roof bolts in a row (a) is checked for a load-carrying capacity of grating lagging N_p according to a relation:-

$$a = \sqrt[3]{\frac{64\, N_p\ tg\,\varphi\, y_{max}}{\gamma}}$$

N_p - Load-carrying capacity in the "a" direction ($N_p = f_a . R_{sd}$)
y_{max} - Permissible deflection of lagging (m)

- Anchorage density (sv./m^2)

$$n_s = \frac{1}{a\, l_a}$$

3.3. Monitoring of rock mass state after anchoring

The MUSCH-program system is used again. Mechanical properties of rock anchorage are characterized with a coefficient of consolidation $K_{z,p}$, expressing the influence of roof bolts in an implicite manner.
Anchorage strength of rock mass in pressure R_{dm}^k is given with this relation:- /2/

$$R_{dm}^k = R_{dm}\, K_{z\,p}$$

$$K_{z\,p} = 1 + \frac{2.65\,\sqrt{l}\, n_s^{0.58}}{\sqrt[3]{10\, R_{dm}}}$$

$$l = \frac{l_s}{b}$$

$$b = s\,(0.039\, s\,\lambda\ -\ 0.1144\, s\ -\ 0.83\,\lambda\ +\ 2.7224)$$

s - Working s width in a height of 1.7 m above floor
λ - Coefficient of lateral pressure
n_s - Anchorage density

Example of the solution is given in Fig. 4 and Fig. 5. Figure 4 gives the values of faults without any influence of roof bolts. Figure 5 gives the values with the influence of anchorage (rock consolidation).

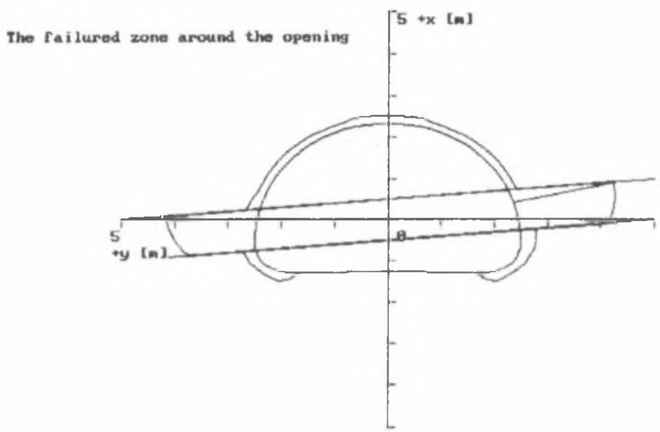

Fig. 5 The failure zone around the opening with anchorage
Rys.5 Strefa spękania wokół wyrobiska zabezpieczonego obudową kotwiową

3.4. Determination of vertical loading of a steel arch of a support

The influence of intermediate anchorage upon vertical loading of a steel arch is shown in Fig. 2. Decrease of a component of vertical loading q_v is realized thanks to "suspension" (consolidation) of a part of anchored rock mass between arches, and it can be determined by means of a coefficient φ :

$$\varphi = 1 - \frac{b}{l_a} tg\, \varphi$$

φ - Angle of influence of roof bolt in faulted area (φ = angle of inside friction of faulted rock)

Arch loading is given with this below-mentioned relation:-

$$q_v = l_a\, b\, \gamma\, \varphi$$

3.5. Static calculation of a steel arch

After arch loading has been determined, static solution is carried-out by means of the REVYZ program system (FEM - straight bars) according to static scheme in Fig. 1.

A steel arch with roof bolts, which form intermediate arch supports, - from the view-point of statics - is solved with the utilization of acting of passive resistances of rocks and result of this solution gives all the necessary inside forces (M, N, Q) for the assessment of both a steel arch and increased roof bolts. Lengths of roof bolts have to be checked in accordance with the height of a faulted area.

3.6. Checking of grating lagging

Loading of grating lagging is in the direction of a longitudinal axis of a working given with this below-mentioned relation:-

$$q_v^{(p)} = \frac{l_a}{4 \operatorname{tg} \varphi} \gamma$$

Longitudinal force in grating is set with this relation:-

$$F_p = \frac{q_v^{(p)} l_a^2}{32 y}$$

y - Permissible deflection of a lag (m)

Stress in longitudinal wires of lags:-

$$\sigma = \frac{F_p}{f_a}$$

f_a - Surface of longitudinal wires of a lag (sq m/m)

4. CONCLUSION

The above-mentioned steps ensure the optimum design of a combined support of the underground workings based on an interaction of roof bolts and steel arches. Software enables a complete automatization of this proposal.

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Wpłynęło do Redakcji w czerwcu 1994 r.