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Calculating arched supports with blocking

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Abstract

Relevance. *Improving the stability of driftways and inclined mine workings is an essential task in underground mining. Support efficiency largely depends on the conditions of its contact with the host rocks. When building steel arch supports, much attention is therefore paid to set blocking and contact grouting. Evidence shows that the blocking is important for support stability. Whenever due attention is not paid to this problem, load from shifting rocks transfers to the middle part of capping and causes bending before the support ever reaches the yielding mode.*

Research objective *is to increase the stability of driftways and inclined mine workings by controlling the stress-strain state of frame supports.*

Research object *is steel arch support of driftways and inclined mine workings.*

Research subject *is the calculation and design of steel arch support with control forces.*

Research task *is to develop the methods for calculating frame support using the most rational types of control forces.*

Methods of research *include an integrated research method with scientific generalization of theoretical and experimental works by domestic and foreign researchers, theoretical studies based on the methods of structural mechanics, field observations and experiments, results processing based on the methods of mathematical statistics.*

Results. *It was established by calculations that under symmetrical load, the use of blockings with a given force value of 20 kN increases the bearing capacity of the support by 1.5 times, and under asymmetric load – by 2.3 times. The given calculation data make it possible to determine the rational parameters of support with blocking to ensure stable support for mine workings.*

Keywords: *support; mineral resource; rock bolt; mine working; mine; deformation; analytic model; stability.*

Introduction. Steel support provides support of mine workings at coal mines. In the Russian Federation more than 80–90% of all extended workings are now supported with steel support. There is a further upward trend towards using steel support for extended workings both in Russia and abroad (Germany, China, Great Britain, etc.) [1–10]. Steel support is widely used at both coal and ore deposits that mine at great depths [11–13], as well as at the deposits with soft host rock and ore (manganese ore mines, emerald mines, etc.). There are some problems at mines related to mine working protection in the stoping influence zone (on drilling horizons and when transporting by scraper winches). Drive towards the increased mass of special profiles under a significant scope of repair in mine workings supported by steel support, under these conditions, will be the same as for sheet deposits.

“Specialized Guidance for the Use of Frame Support and Rock Bolts in Development Workings of Coal and Shale Mines” noted that when installing any type of frame support, set blocking is required.

Steel pliable support of arched profile is blocked by placing wooden wedges in the gap between the arch and the rock contour. Blocking secures the arch in its design position, enables correct operation of flexible joints, and creates conditions for soil passive resistance under the influence of active load in zones of maximum displacement of cavity contour in the rock mass [1, 12, 14–16].

Body. When calculating the schemes of frame support and frame-anchor support with blocking elements, efficient places for their installation should be carefully chosen. The authors of scientific studies on frame support calculation state that the indicated factor is key in optimizing the values of internal forces in the support itself [1, 17]. They also replaced the impact of blocking on the support frame with the impact of a local force of a specified value, which is not always legitimate.

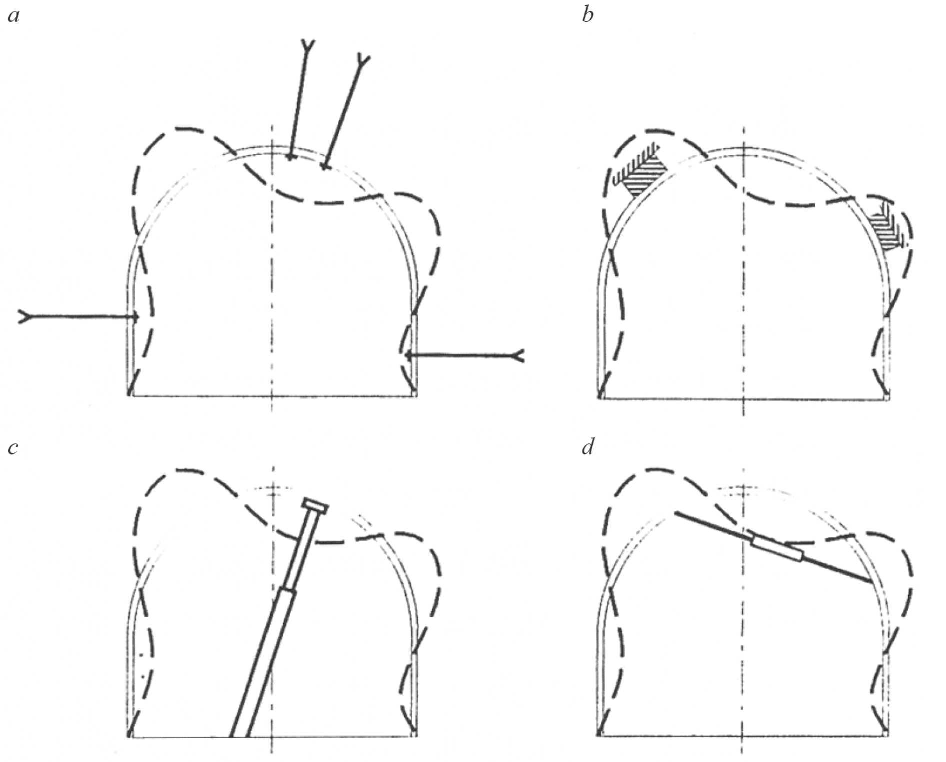

Figure 1. The main methods of controlling the stress-strain state of the arch support:
a – frame-anchor support; *b* – set blocking; *c* – anchor posts; *d* – metal ties of controlled stress
Рисунок 1. Основные способы управления напряженно-деформированным состоянием арочной крепи:
а – рамно-анкерная крепь; *b* – расклинка крепежной рамы; *c* – распорные стойки; *d* – металлическая стяжка регулируемого напряжения

Blocking elements and anchors in frame-anchor supports impact the arch from one side along the entire contour of the support. And interreaction between blocking and arch will occur only in zones where bending moments M_2 and M_4 crumple the support towards the rock mass (Figure 1).

The structures of timber blocking elements have a sufficiently high ability to resist deformation. It is therefore proposed to represent them as rigid connections in analytic models (Figure 2, *a*), as in frame-anchor support analytical models (first stage). The proposed analytical model greatly resembles the alternatives with the creation of a preliminary stressed state of the arch, since the rock mass will first of all impact

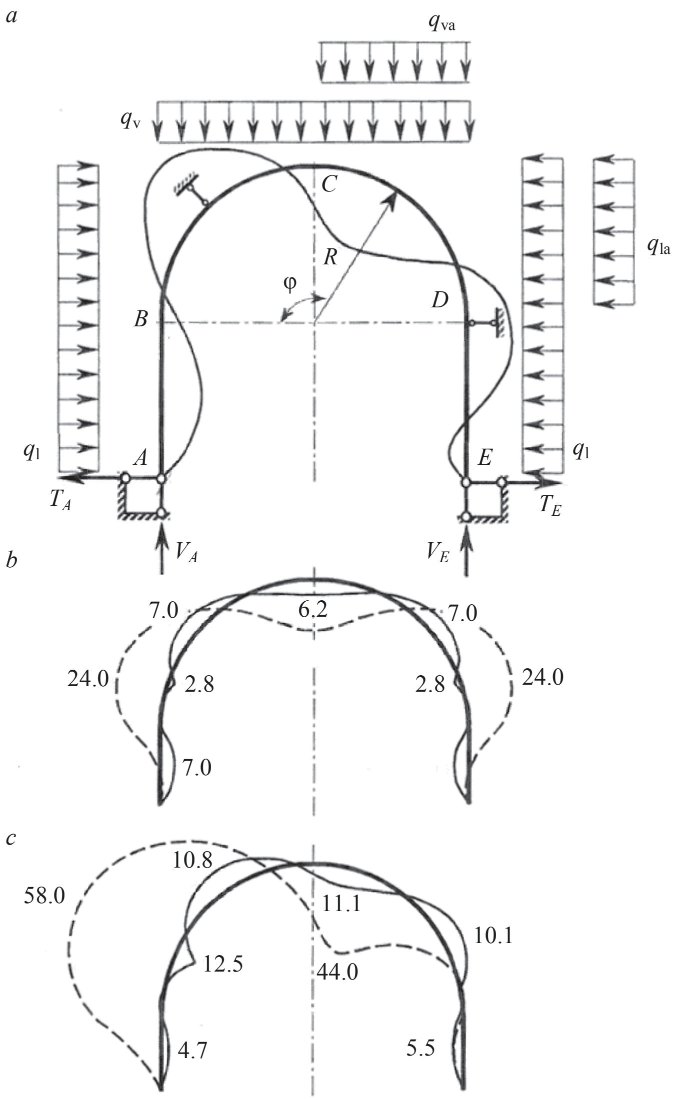

Figure 2. Analytical model of an arch support with a blocking, represented by rigid connections – *a*; bending moment diagram, kN · m, under symmetrical load (two blocking points $\varphi_1 = 20°$, $\varphi_2 = 160°$) – *b*; under asymmetrical load (two points of the wedge $\varphi_1 = 25°$, $\varphi_2 = 170°$) – *c*; *T* – moment of inertia in points *A* and *B*, N · m; *V* – balance force in points *A* and *B*, N · m; q_v – vertical support load, N/m; q_{va} – additional vertical load on the support, N/m; q_l – lateral support load, N/m; q_{la} – additional lateral support load, N/m

Рисунок 2. Расчетная схема арочной крепи с расклинкой, представленной жесткими связями – *а*; эпюры изгибающих моментов, Кн · м, при симметричной нагрузке (две точки расклинки $\varphi_1 = 20°$, $\varphi_2 = 160°$) – *b*; при асимметричной нагрузке (две точки расклинки $\varphi_1 = 25°$,$\varphi_2 = 170°$) – *c*; *T* – момент инерции в точках *A* и *B*, Н · м; *V* – уравновешивающая сила, в точках *A* и *B*, Н · м; q_v – вертикальная нагрузка на крепь, Н/м; q_{va} – дополнительная вертикальная нагрузка на крепь, Н/м; q_l – боковая нагрузка на крепь, Н/м; q_{la} – дополнительная боковая нагрузка на крепь, Н/м the support through the blocking until the moment of rock stratification, which will form a uniform load along the entire perimeter of the frame.

Figure 2, *b*, *c* shows the analytical models of bending moment diagrams that occur in the arch support where blockings (under symmetrical load at points $\varphi_1 = 20°$, $\varphi_2 = 160°$, and under asymmetric load of $\varphi_1 = 25°$, $\varphi_2 = 170°$) are replaced by rigid connections. The sizes of loads on the support are taken the same as in the calculation of the arched support [1]. The dotted line in the figures indicates bending moment diagrams in the arch support with no blocking element. Bending moment diagrams analysis revealed that the use of rigid blockings will reduce the value of bending moments in the support under symmetrical load by 3.4 times, and under asymmetric load by 4.4 times.

When using blocking elements [17] with high deformation properties (polymer resins, low-modulus mortars) the blockings should be replaced with elastic connections in analytical models of arch supports, with restrictions on the maximum response (Figure 3, *a*).

With such analytical model, at the first stage, the arch support should be calculated with the determination of the deformation value in the area of arch displacement in the zones of blocking elements mounting. Then, response values in blockings should be calculated and the place of the local forces on the diagram should be marked in the selected arch perimeter. At the next stage, the deformation in the zone of the blocking element is determined using the Mohr integral [18, 19]:

$$\Delta_{\text{bloc}} = \int_0^{H-R} M_2^{AB} M_{Px}^{AB} (EL)^{-1} d_y + \int_0^{\pi/2} M_2^{BC} M_{Px}^{BC} (EL)^{-1} R d_\varphi + \Delta_{\text{bloc}} =$$
$$= \int_{\pi/2}^{\pi} M_2^{AB} M_{Px}^{AB} (EL)^{-1} d_y + \int_0^{H-R} M_2^{DE} M_{Px}^{DE} (EL)^{-1} R d_y, \quad (1)$$

where M_2 is the bending moment from the action of a single force applied at the displacement determination point (the blocking point), kN · m; M_{Px} is the bending moment in the main computational system, considering X_1 force (blocking), kN · m; H is the height of the mine working, m; R is the arch radius, m; E is the moment of inertia of a component, kN · m; L is the width of the mine working, m; d_y is the differential along the y axis; d_φ is the differential from the degree of curvature of the mine working.

The amount of force in the blocking is calculated by the formula:

$$P_{\text{bloc}} = G\Delta_{\text{bloc}},$$

where G is the rigidity of the blocking element, kN/m; Δ_{bloc} is deformation in the area of the blocking element, m.

Since there are both rectilinear and curvilinear sections in the arch support, the integration according to formula (1) is carried out over individual sections *AB*, *BC*, *CD* and *DE* (Figures 2 and 3).

Bending moment diagrams shown in Figure 3, *b*, *c*, are obtained by analyzing the analytic models of the arch support, where the blocking elements are replaced by an elastic connection with a limitation on the maximum response $P_{\text{bloc}} = 20$ kN. It should also be noted that under asymmetric loading, it is not advisable to place the blocking in the right half of the arch, because the blocking is a unilateral constraint and will not allow creating a response when interacting with the arch (under given support geometry

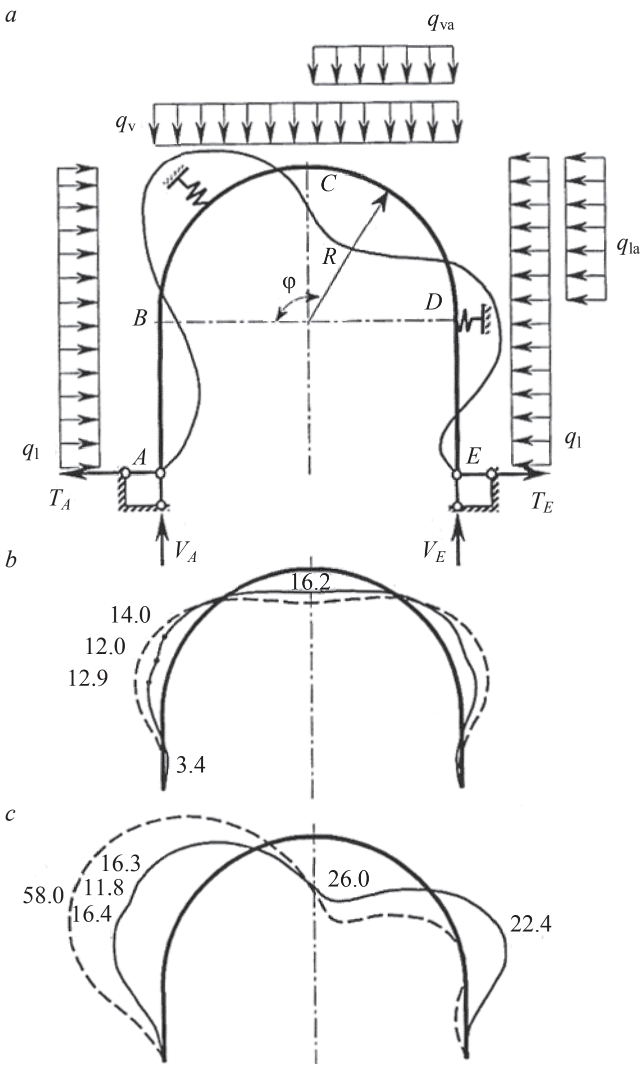

Figure 3. Analytic model of an arch support with blocking, represented by elastic connections – *a*, bending moment diagram *b* – under symmetrical load (two blocking points $\varphi_1 = 20°$, $\varphi_2 = 160°$); *c* – under asymmetrical load (two blocking points $\varphi_1 = 24°$, $\varphi_2 = 26°$)
Рисунок 3. Расчетная схема арочной крепи с расклинкой, представленной упругими связями – *а*; эпюры изгибающих моментов, Кн · м, при симметричной нагрузке (две точки расклинки $\varphi_1 = 20°$, $\varphi_2 = 160°$) – *b*; при асимметричной нагрузке (две точки расклинки $\varphi_1 = 24°$, $\varphi_2 = 26°$) – *c*

and external acting load). According to the scheme in Figure 3, *c*, two blockings are installed at a small distance from each other ($\varphi_1 = 24°$, $\varphi_2 = 26°$).

It has been determined that symmetrical load of blockings with a given force ($P_{bloc} = 20$ kN) increases support bearing capacity by 1.5 times (Figure 3, *b*), while asymmetric load – by 2.3 times (Figure 3, *c*).

Summary. Frame-anchor supports and supports with blocking should be designed as systems with additional unilateral constrains.

Frame-anchor support is calculated in two stages. At the first stage, in the analytic model, anchor connection points are represented as rigid support connections that work only in tension. At the second stage, if the responses in the support connections exceed the bearing capacity of the connection point, their action is replaced by local forces in the analytic model.

Mine supports with blocking can be considered as arched supports with additional unilateral rigid or elastic connections. Very rigid blockings, that can be considered as additional connections, are more effective. With the given support design parameters, the use of two rigid blocking elements increases the bearing capacity of the arched support by 3.4–4.4 times.

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Расчет арочных крепей с расклинкой

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Реферат
Актуальность. *Повышение устойчивости горных (горизонтальных и наклонных) выработок является одной из важнейших задач при подземной разработке месторождений полезных ископаемых. При этом эффективность применения крепи в значительной степени зависит от условий ее контактирования с вмещающими породами. В связи с этим большое внимание при возведении металлических арочных крепей уделяется расклинке рам крепи и забутовке закрепного пространства. Практика показывает, что расклинка имеет весьма важное значение для устойчивости крепи. В случаях, когда этому вопросу не уделяется должного внимания, нагрузка от смещающихся пород передается на среднюю часть верхняка и вызывает его прогиб еще до вступления крепи в работу в податливом режиме.*
Целью работы *является повышение устойчивости горизонтальных и наклонных выработок за счет управления напряженно-деформированным состоянием рамных крепей.*
Объектом исследования *являются металлические арочные крепи горизонтальных и наклонных выработок.*
Предмет исследования *– расчет и конструирование металлических арочных крепей с управляющими силовыми воздействиями.*
Задача исследования: *разработка методов расчета рамных крепей с применением наиболее рациональных видов управляющих силовых воздействий.*
Методы исследования. *В работе использован комплексный метод исследований, включающий научное обобщение теоретических и экспериментальных работ отечественных и зарубежных ученых, теоретические исследования с применением методов строительной механики, натурные наблюдения и эксперименты, обработку результатов с использованием методов математической статистики.*
Результаты. *Расчетами установлено, что при симметричном приложении нагрузки применение расклинок с заданной величиной усилия 20 кН повышает несущую способность крепи в 1,5 раза, при асимметричном приложении нагрузки – в 2,3 раза. Приведенные данные расчетов позволяют определить рациональные параметры крепи с расклинкой для устойчивости поддержания горных выработок.*

Ключевые слова: *крепь; полезное ископаемое; анкер; выработка; шахта; деформация; расчетная схема; устойчивость.*

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