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ORIGINAL PAPER

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USAGE OF CABLE BOLTS FOR GATEROAD MAINTENANCE IN SOFT ROCKS

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ABSTRACT

Purpose	This paper analyses the effectiveness of gateroad reinforcing by means of cable bolts under weak rock conditions. In the worldwide mining industry the method of gateroad support reinforcement using cable bolts is considered to be effective. The experimental application of cable bolts was performed in gateroad #165 of the "Stepova" mine, Western Donbass, Ukraine, and required instrumental control of "support-rock mass" system conditions.
Methods	Obtaining absolute displacement of "support-rock mass" system elements and extensometer anchors by means of levelling in order to improve the method of observation.
Results	The peculiarities of geomechanical behaviour of rock mass in the roof of gateroads is investigated. It has been established that the application of cable bolts allows for a reduction in the vertical convergence of the gateroad, both in front of and behind the longwall face.
Practical implications	Advantages of cable bolts instead of end-face support and props in case of a high advance rate of the longwall face are shown.
Originality/ value	1. There are no regulations and state standards in regard to cable bolt installation parameters in the mines of Ukraine, consequently the usage of cable bolts for gateroad maintenance required preliminary testing under geological conditions at the Western Donbass mines with soft enclosing rocks. 2. Combining levelling with observations using extensometers allowed for the detection of the rock layers' uniform sagging zone in the roof of the gateroad.

Keywords
gateroad, soft rock, cable bolt, vertical convergency, abutment pressure, levelling, multiple-position borehole extensometers

1. INTRODUCTION

The current economic environment which the coal industry of Ukraine is experiencing requires increasing volumes of production whilst reducing the operating costs of mines.

Issues arise in the gateroad contour longwall which provides ventilation and transportation of rock mass and materials. The excessive impact of abutment pressure manifestations on the support of gateroads leads to cross-section losses and to further reduction of coal mining efficiency. This is particularly evident in conditions of weak strata.

One example of the aforementioned condition is the geological condition of the Western Donbass coal mines. The mines are characterized by soft enclosing rocks (with a uniaxial compressive strength of less than 30 MPa), thin (0,6–1,2 m) lightly pitching coal ($\alpha < 5°$), and a depth of 200 m to 600 m. Coal extraction is carried out by longwall mining with caving.

According to Standart (2007), in soft rocks (UCS < 30 MPa), it is not recommended to maintain gateroads behind the longwall face. Nevertheless research was carried out for these conditions and technology for gateroad maintenance was developed under advance rates of the longwall face of up to 100 m/month (Instruktsiya, 1994, p. 2). Thus there is a plan that support of gateroad should be reinforced in the area of abutment pressure ahead of the longwall (area 1, Fig. 1), at the T-junction (area 2, Fig. 1) and behind the longwall face (area 3, Fig. 1).

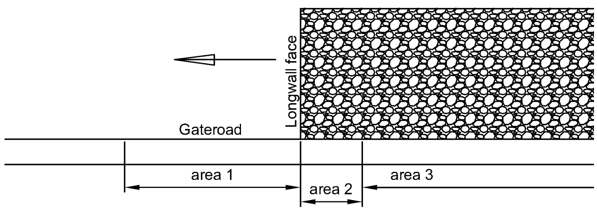

Fig. 1. Areas of longwall influence on the gateroad

The reinforcement of the gateroad support ahead of the longwall face (area 1) by means of props (wooden, hydraulic or friction) is recommended. The usage of face-end support is believed to mechanize the process of intersectional supporting (area 2), improve safety and productivity (Shirokov, Lider, & Petrov, 1987, pp. 4, 15). This type of "classic" system of gateroad support reinforcement in areas 1–2 is characteristic for the longwall mines of Ukraine (Fig. 2).

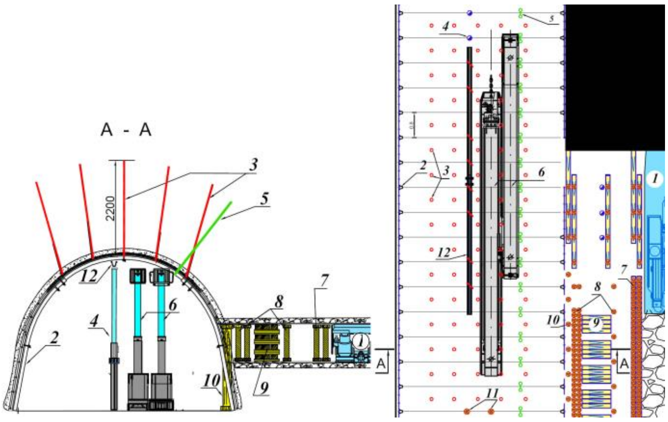

Fig. 2. The "classic" support and reinforcement pattern of the gateroad #163 at intersection with #161 longwall: 1 – longwall set of equipment; 2 – steel arch support KShPU-17,7; 3 – rock bolts; 4 – hydraulic props installed 20 m in front of the longwall face and under the horsehead; 5 – rock bolts connected to the top section of arch support; 6 – face-end supports; elements of roadside pack: 7 – breaker row; 8 – breaker props; 9 – chock; 10 – wooden prop between the roof of the seam and the floor of the gateroad; 11 – wooden props installed under each arch; 12 – steel horsehead

However, it is ineffective in cases of high advance rate of the longwall face (more than 100 m/month) because of the high labor input of the works, time spent on operations near the face-end, and the cluttering of the gateroad.

A system of gateroad support reinforcement by means of cable bolts installed before the beginning of abutment pressure influence in areas 1–2 is considered to be effective. This system excludes the usage of props in area 1 and face-end support at the intersection (area 2). Experience of cable bolts application has been accumulated abroad (Razumov, Grechishkin, Samok, & Pozolotin, 2011; Tadolini & McDonnell, 2010). There are no regulations and state standards with regard to the cable bolt installation parameters in Ukrainian mines. That is why, the usage of cable bolts required preliminary testing and geomechanical substantiation under the geological conditions that exist in the Western Donbass mines with rocks with a UCS of less than 25 MPa (Khalymendyk, 2011).

This article is dedicated to the effectiveness of the experimental method of gateroad #165 reinforcing at T-junction and in front of #163 longwall face at the "Stepova" mine, which included the application of cable bolts instead of face-end support and props.

2. GEOLOGICAL AND TECHNICAL CONDITIONS

The gateroad was driven from the roadways at a level of 300 m down the dip of the coal seam C_6 to a level of 490 m, with an average inclination of 4° (Fig. 3). Coal seam C_6 is fractured, simply structured and has no cohesion with the enclosing rocks. The extracting seam thickness is 1.04 m. Enclosing rocks are interstratified siltstones and mudstones with a UCS of up to 25 MPa and weak cohesion.

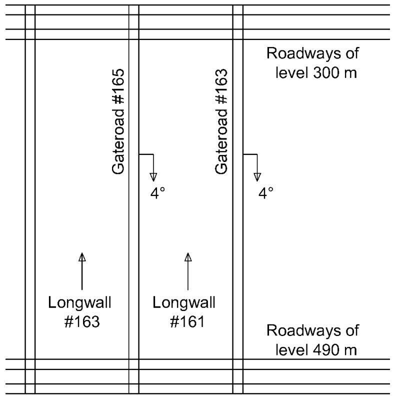

Fig. 3. Principle scheme of mine workings at C_6 seam

Gateroad #165 was arched with KShPU-17,7, with spacing 0,7 m (Fig. 4). The roof of the gateroad was bolted on the depth of 2.2 m with 5 bolts in a row. Load-bearing capacity of bolts was 275 kN, untensioned, resin-grouted using resin-cartridges of a total length of 1.5 m.

Maintenance of the gateroad #165 in the area of abutment pressure and at the intersection with the longwall (areas 1, 2, Fig. 1) was performed by two rows of cable bolts with a load bearing capacity of 210 kN (Fig. 4, No 4). The density of the cable bolt setup was 0.3 pcs/m^2.

Two wooden props were installed under each steel arch and a roadside pack was erected behind the face of the longwall (Fig. 4, No 7–11).

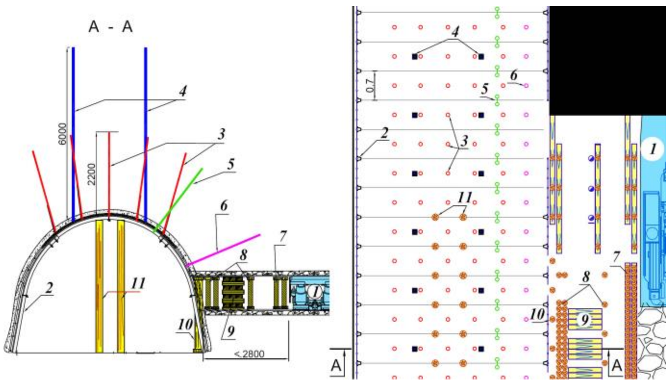

Fig. 4. Support and reinforcement pattern of the gateroad #165 at intersection with #163 longwall: 1 – longwall set of equipment; 2 – steel arch support KShPU-17,7; 3 – rock bolts; 4 – cable bolts, length 6.0 m, paired installation, spacing 1.4 m; 5 – rock bolts connected to the top section of arch support; 6 – rock bolt for strengthening of the roof above the roadside pack; elements of roadside pack: 7 – breaker row; 8 – breaker props; 9 – chock; 10 – wooden prop between roof of the seam and floor of the gateroad; 11 – wooden props installed under each steel arch

3. RESEARCH TECHNIQUE

The measurement of the deformation of the support elements and rock mass ("support-rock mass" system) i.e. roof, floor, rock layers in the roof, elements of arch support, are possible with the use of wall-embedded marks (Fig. 5) (Prusek, 2010; Metodicheskiye ukazaniya, 1973; Novikov & Shestopalov, 2012).

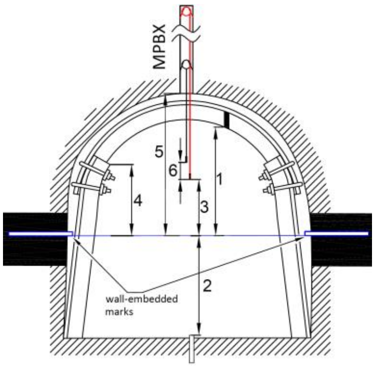

Fig. 5. Typical observations of the displacement of support elements and rock mass: 1–5 – linear measurements from the level of wall-embedded marks to: 1 – top section of steel arch; 2 – gateroad floor; 3 – the deepest placed anchor of the extensometer; 4 – end of steel arch rack; 5 – collar of the borehole of extensometer; 6 – displacement of the anchors of extensometer with respect to the deepest (highest) placed anchor

This method is substantiated when the wall-embedded marks are immovable. In soft rock conditions and in abutment pressure zones the phenomenon of rib bending often occurs (Fig. 6). It inevitably leads to the displacement of the marks and to a decrease in reliability of the results gained.

Fig. 6. Condition of rock mass around the gateroad at the "Stepova" mine – phenomenon of rib bending

To improve the method of observation the use of levelling in order to obtain absolute displacement of "support – rock mass" system elements and extensometer anchors, was proposed (Fig. 7). Thus the benchmarks are placed outside of the zone of longwall influence therefore ensuring their immovability, while the usage of accurate level provides sufficient accuracy of the elements position determination at the observation station.

Such an improved method was used during the experiment in the #165 gateroad. To monitor the deformation of the rock mass, multiple-position borehole extensometers (MPBX) were used. Boreholes were drilled vertically in the roof of the gateroad. The depth of the boreholes was 8–9 m, anchors were placed with a spacing of 1.0 m (some anchors were lost during the observations due to mechanical damage to the ropes).

The strain of the rock mass ε was calculated for the midpoints between MPBX anchors from the equation:

$$\varepsilon = \frac{l_{i'-(i+1)'} - l_{i-(i+1)}}{l_{i-(i+1)}} \cdot 10^3, \text{ mm/m} \quad (1)$$

where:

$l_{i-(i+1)}$ – is the initial length between #*i* and #*i*+1 anchors placed in the borehole, m;

$l_{i'-(i+1)'}$ – is the changed length between #*i* and #(*i*+1) anchors after longwall face advanced, m;

i – is the sequential number of the anchor (corresponding to the depth of the anchor placing from the collar of the borehole).

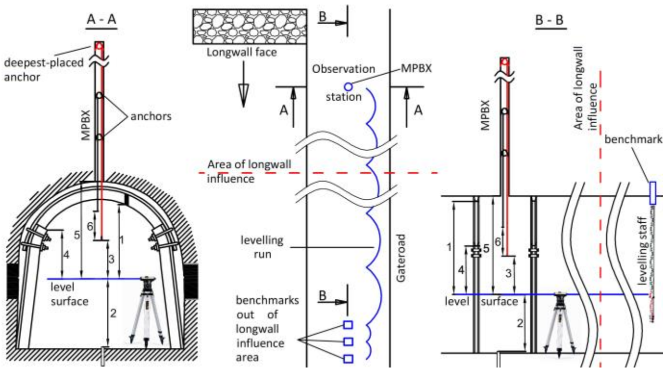

Fig. 7. Levelling of "support-rock mass" system elements and anchors of extensometer: 1–5 readings from staff placed on: 1 – top section of steel arch; 2 – gateroad floor; 3 – the deepest placed anchor of the extensometer; 4 – end of steel arch rack; 5 – collar of the borehole of extensometer; 6 – displacements of the anchors of extensometer with respect to the deepest (highest) placed anchor

The displacement of the roof, floor, top section of the steel arch, ends of the steel arch racks, collar of the borehole ("#0 anchor") and the deepest-placed anchor of extensometer were obtained by levelling.

4. RESULTS OF THE RESEARCH

The combination of levelling with observations of extensometers has been applied in the course of the observations in gateroad #165. Graphs of the displacement of extensometer anchors at three observation stations are presented in figures 8, 10, 12. Graphs of the vertical strain of rock mass in the roof of the gateroad are presented in figures 9, 11, 13. Distance to the longwall face with a "minus" sign, for example "–40" means that it is 40 m behind the longwall face.

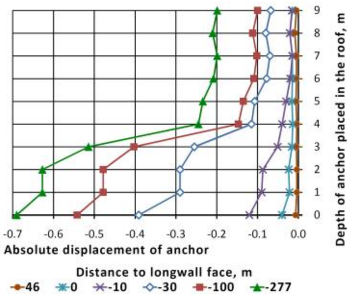

Fig. 8. Absolute displacement of extensometer anchors at observation station #1

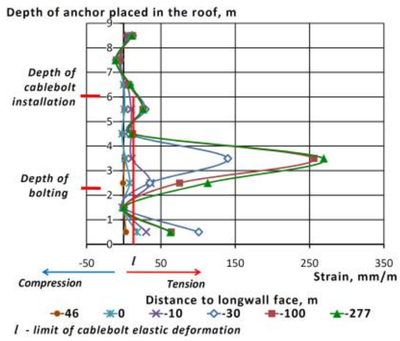

Fig. 9. Vertical strain of rock mass at observation station #1

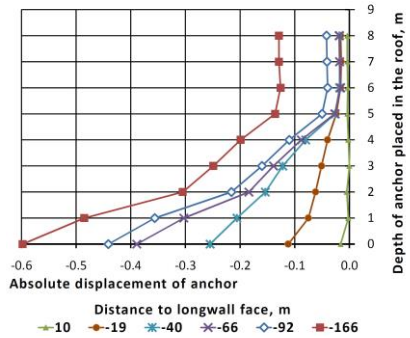

Fig. 10. Absolute displacement of extensometer anchors at observation station #2

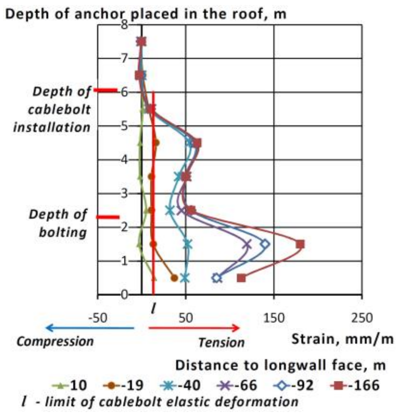

Fig. 11. Vertical strain of rock mass at observation station #2

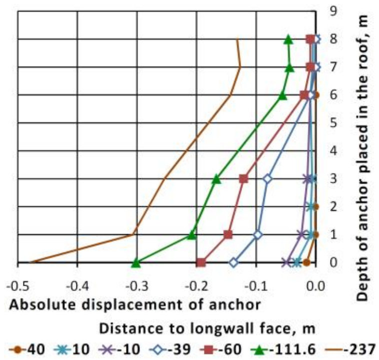

Fig. 12. Absolute displacement of extensometer anchors at observation station #3

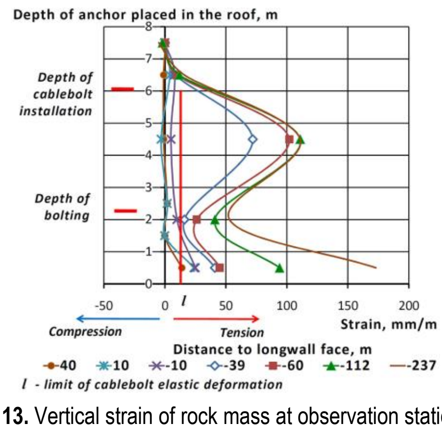

Fig. 13. Vertical strain of rock mass at observation station #3

The reaction of the rock mass on the abutment pressure was detected at a distance of about 40–60 m in front of the longwall face. In front of the longwall the maximum displacement of the rock mass in the roof of the gateroad was up to 40 mm (Fig. 8). At a distance from 0 to 20 m behind the longwall face, the lamination of rock layers develops to a depth of 7 m in the roof at stations #1, and #3, and to a depth of 6.5 m at station #2, when the maximum displacements of the anchors are 110 mm. With further longwall face advancement, a rock layer of about 4 m in thickness is detached from the overlying strata while uniform sagging of strata above 7.0 m is taking place.

The vertical strain of rock mass in the bolted zone does not exceed the limit of elastic deformation of bolts in front of the longwall face (Fig. 9, 11, 13). The maximum value of tension strain in cable bolted rock layers varied from 150 to 270 mm/m behind the longwall face.

Installation density and load-bearing capacity of the cable bolts was sufficient to maintain the gateroad in the area of abutment pressure in front of the longwall face and at the T-junction. However, behind the longwall face the weight of the rocks in the disintegration zone exceeded the load-bearing capacity of the cable bolts, which led to elastic deformation of the cable bolts and to the breaking away of the cable bolt locks and bearing plates (Fig. 14).

Fig. 14. Breaking away of the locks and bearing plates as a result of an excessive load on the cable bolt

The intensive development of the disintegration zone in the roof of the gateroad behind the longwall face is explained by the fact that the actual resistance of the roadside pack, built up on the "gateroad – goaf" border, varied. Consequently, the sagging of the roof over the roadside pack was allowed. According to the results of the research, conducted by scientists of the Central Mining Institute, the load on the gateroad steel arch support behind the longwall face does not exceed its load bearing capacity, in the case of building an effective roadside pack and roof bolting (Prusek & Lubosik, 2006). Functional connection between the sagging of the roof over the roadside pack and the value of the vertical convergence at the gateroad was highlighted in a research paper (Khalymendyk, 2011). In such a manner the sagging of the roof over the roadside pack led to greater displacement of the rocks in gateroad #165. The results of the investigations, conducted in gateroad #165 behind the longwall face, showed that the dependence of vertical convergence in the gateroad (Δh) on the sagging of the roof over the roadside pack at the "gateroad-goaf" border (Δc) is described by the equation (Fig. 15):

$$\Delta h = 0.598\ln(\Delta c) + 1.308 \quad (2)$$
$$R^2 = 0.828$$

The degree of correlation between Δh and Δc is 0.880.

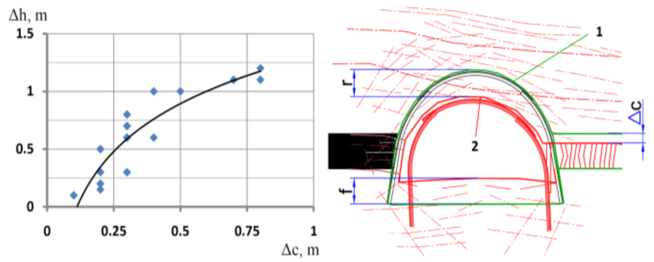

Fig. 15. Dependence of vertical convergence in gateroad (Δh) on the sagging of the roof over the roadside pack at the border "gateroad-goaf" (Δc): 1 – contour of the gateroad before deformation; 2 – deformed contour of the gateroad behind the longwall face; r – roof sag; f – floor heave; $\Delta h = r + f$

An analogue of gateroad #165 was gateroad #163, which was driven for the purpose of extracting the neighboring 161 longwall and was under similar geological conditions (Fig. 3). Maintenance of gateroad #163 was carried out in accordance with the regulatory document (Instruktsiya, 1994) using the "classic" scheme with props and face-end support (Fig. 2). The advance rate of longwall face 161 was up to 120 m/month when operating the same plow system as in longwall 163.

The comparative plot of vertical convergence for gateroad #165 reinforced with cable bolts and gateroad #163 without cable bolts is shown in figure 16.

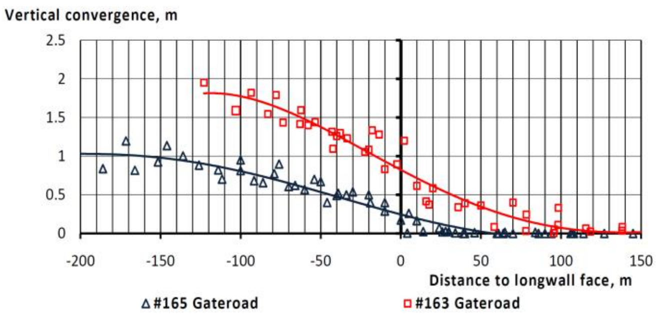

Fig. 16. Comparative plot of vertical convergence in gateroads #165 and #163

Dependence of gateroad #165 and the vertical convergence (Δh^{165}) on the distance (L) to longwall face 163 is described by the equation:

$$\Delta h^{165} = (1.4635997 \cdot 10^{-15})L^6 - (7.6990152 \cdot 10^{-13}) \times$$
$$\times L^5 - (3.0332073 \cdot 10^{-10})L^4 + (1.0193612 \cdot 10^{-7}) \times$$
$$\times L^3 + (1.7435529 \cdot 10^{-5})L^2 - 0.0053231L + 0.2430414 \qquad (3)$$
$$L \in (60; -280)$$
$$R^2 = 0.944$$

The dependence of gateroad #163's vertical convergence (Δh^{163}) on the distance (L) to longwall face 161 is described by the following equation:

$$\Delta h^{163} = -(7.5703126 \cdot 10^{-10})L^4 + (2.5499487 \cdot 10^{-7})L^3 +$$
$$+ (1.7328015 \cdot 10^{-5})L^2 - 0.0111652L + 0.8157256 \qquad (4)$$
$$L \in (120; -120)$$
$$R^2 = 0.914$$

The application of cable bolts led to a reduction in the losses of gateroad height ahead of the face of the longwall and at the intersection by no less than 3 times the original amount (without cable bolts), and behind longwall face – by about 2 times the original amount (without cable bolts).

5. CONCLUSIONS

1. The experimental method of gateroad #165 support the view that reinforcement with cable bolts in the area of abutment pressure ahead of longwall face 163 and at the T-junction has a clear advantage over "classic" methods. In addition, the exclusion of props ahead of the longwall face and face-end support at the intersection allowed for the reduction of labor intensity, the time spent on operations at the face-end, increasing the free space in the gateroad and at the intersection of the gateroad with a longwall. This allowed for the increase of the advance rate of longwall face 163 to 200 m/month.
2. According to the results of the experiment the density of the cable bolts setup of 0.3 pcs/m^2 is enough to effectively maintain the gateroad in the area of abutment pressure and at the T-junction. But to prevent the displacement of the roof behind the longwall face such density is insufficient.
3. Usage of the MPBX and levelling of the MPBX anchors allowed for the establishment of a zone of rock delamination to a depth of 7.0 m in the gateroad roof and a zone of uniform sagging of rock layers above 7.0 m. The maximum value of the sagging is 200 mm. Practical importance of the obtained results consists in their usage for substantiation of installed support parameters. The recommended length of cable bolts for these conditions should be 8.0 m, setup density is determined from the weight of the rocks in the zone of delamination (disintegration) and total bearing capacity of the gateroad steel arch support and the roadside pack. It is impossible to resist the uniform sagging of the rock layers, as it occurs as a result of elastic deflection which takes place because of coal seam extraction. That is why the support of the gateroad and the roadside pack should compensate for the sagging of the rock layers. This is realized due to: the deformation of the rock mass of the disintegration zone; deformation of the roadside pack; presence of clearance between steel arch support and contour rocks of the gateroad.
4. The development of the gateroad's vertical convergence depends not only on the setup density of the cable bolts, but also on the bearing capacity of the roadside pack. Thus, all bearing elements of the support should work as a unified system "steel arch support – cable bolts – protective pack" for the effective maintenance of the gateroad behind the longwall face.

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