Development of design solution for mine workings support repair and recovery in case of local massif deformations

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Abstract. The article describes the causes of occurrence and forms of geomechanical processes manifestation in surrounding coal-rock massif of mine workings supported by anchor support. Based on long-term field observations, six forms of typical deformations of the surrounding massif have been established. Design solutions to strengthen the anchor support or complete reinforcement of damaged sections of mine workings during geomechanical processes of local felling have been developed. They include: installation scheme, substantiation of parameters and list of used reinforcement elements; technology of work, a list of equipment used.

1 Introduction

The most important problem of safe long-term maintenance of underground mine workings is the assessment of technogenic impact on the coal massif and support elements (flooding of mine workings, the impact of seismic and shock air waves from massive industrial and uncontrolled explosions). Over the past 20 years, 13 accidents with group fatalities have occurred at the mines of Kuzbass. Most of the episodes are associated with explosions of a gases and coal dust, accompanied by the propagation of seismic and shock waves, as well as a sharp short-term increase in temperature in the explosion zone. When eliminating the consequences of man-made accidents that cause the formation of underground fires, as well as during the conservation or liquidation of coal mines by the "wet" method, water fills the network of mine workings to a full section. The joint development of coal seams by open and underground methods in the long term leads to deformations of the coal massif and disruption of the roof bolting stability [1]. At the same time, in the current normative and literary sources, there is no differentiated approach to determining the characteristic deformations of surrounding massif.

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The object of the study was the area of the coal massif around the mine workings in the conditions of the enterprises of PJSC "Raspadskaya" (mine "Raspadskaya"), OJSC MC "Yuzhny Kuzbass" ("V. I. Lenin" mine), AO" SUEK-Kuzbass "("V. D. Yalevsky" mine, Taldinskoe-Zapadnoe mine union), JSC HC SDS-Ugol (mine Yuzhnaya).

2 The results

Based on the results of long-term observations of the state of surrounding rock mass and elements of anchorage [2-4], it has been established that geomechanical processes in the near-contour layers of workings occur in the following sequence. The process of bridging is caused primarily by the decompaction of rocks. Decompaction consists in the formation of a zone of increased fracturing along the mine working contour as a result of the opening of natural cracks and the creation of new cracks. Deconsolidation cracks develop parallel to the exposed rock surface, forming zones of weakening. As a result of decompaction, the rocks are stratified. The delamination process is determined by two factors - fracturing and layering [5]. There is a separation of rocks into parts, which, under the action of gravitational forces, are displaced towards the working. During the stratification of rocks, individual layers, mainly underlying ones, peel off from the upper layers, that is, there is a process of detachment of separates from the massif and their displacement to the contour of the excavation. Delaminated rock builds up on the lattice, loading the lattice and anchors. As a result of deformations of the lattice tightening, and pick-ups, the exfoliated rocks collapse into the working. Layering of rocks in the roof of the workings extends beyond the boundaries of the workings in width. As a result, the stress in the sides of the workings and the deformation of the coal increase. Spins take place, coal falls out of the mine working walls.

Six main typical forms of deformation of surrounding coal-rock mass has been identified:
   - accumulation of exfoliated roof rocks on mesh wire without it deformation;
   - accumulation of exfoliated roof rocks with deformation of mesh wire and the formation of collapses and domes;
   - accumulation of collapsed rocks with deformation of mesh wire and the formation of a dome along the entire width of the mine;
   - squeezing of rocks in the walls of workings in the form of a sliding prism;
   - squeezing coal and rocks in the walls of the workings in the form of dumps;
   - plastic extrusion of rocks in the walls of the workings.

In case of *accumulation of exfoliated roof rocks on mesh wire without it deformation* (fig. 1), the boundary layers of the roof are gradually deformed, the process develops from bottom to top, deep into the roof rocks. With the stratification of rocks, the lower layers, losing their connection with the overlying ones, shift and fall on the lattice tie. The loading of mesh wire, bearing elements and bolts occurs. The height of the collapsed rocks mainly varies from 0.1 to 0.5 m. Depending on the thickness of the layer of exfoliated rocks, the state of mesh wire and bearing elements depends. When sagging, the load-bearing capacity of mesh wire is reduced Thus, the actual load-bearing capacity of mesh wire is determined by the wire diameter, cell dimensions and the sagging boom. When the mesh wire SS-4, SS-5, SS-6 sags by 0.4 m, it is advisable to carry out repairs in such areas. The repair consists in the release of destroyed rocks in such an area, fixing the roof and filling the void after the release of rocks.

In case of *accumulation of exfoliated roof rocks with deformation of mesh wire and the formation of collapses and domes* in areas with a broken mesh wire, rock breakthroughs occur into the working. The formed collapses have different shapes and different parameters. The mesh wire fractures related to with rock falls are most often observed in

local areas where the rocks are weakened, there is increased fracturing, high moisture content of the rocks, near zones with disjunctive disturbance. It has been established that ruptures of mesh wire occur with the accumulation of exfoliated rocks with a height of 0.5 m and more. Areas with a broken mesh wire and the presence of exfoliated rocks in the adjacent areas adjacent to the fall are subject to urgent repair. The repair consists in reinforcing the adjacent sections with supporting lining, releasing rocks near the fallout, securing the fallout with anchor support and filling the resulting void. Filling can be done with wood, foaming resins, foam concrete, followed by the construction of mesh wire puff. In case of ruptures of mesh wire in the areas where the processes of continuous bridging take place, the collapses further develop into long and high domes.
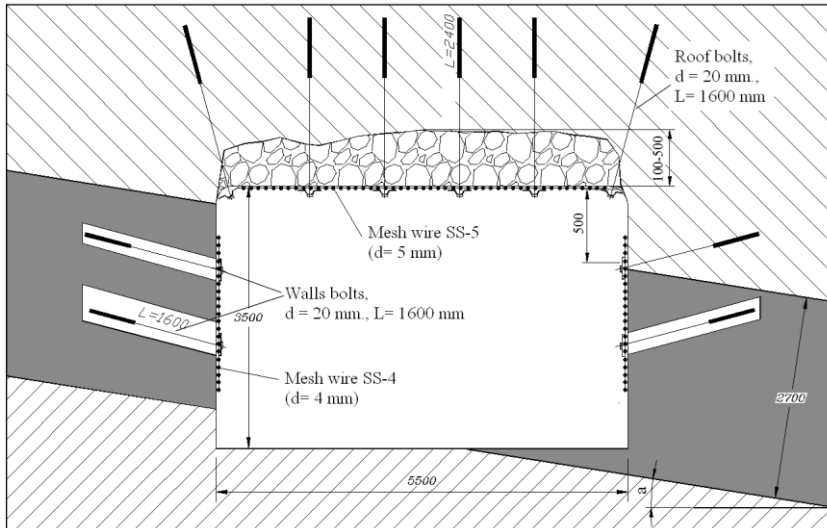

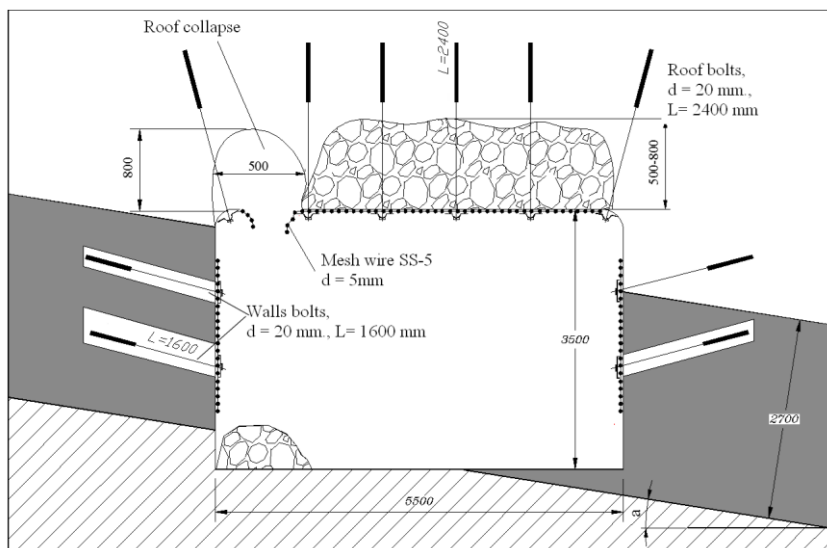**Fig. 1.** The accumulation of exfoliated roof rocks on mesh wire without it deformation

Fig. 2. The accumulation of exfoliated roof rocks with deformation of mesh wire and the formation of collapses and domes

In case of *accumulation of collapsed rocks with deformation of mesh wire and the formation of a dome along the entire width of the mine* (fig. 3), the height of the domes, as a rule, is up to 2.5 - 3.0 m, the width is equal to the width of the working, and the length can reach 10 m With this type of deformation of the rock mass in the emergency sections, a complete re-strengthening of the working is carried out. Re-fastening works are carried out from a special shelf. Collapsed rocks are released from under mesh wire into free area, the deformed parts of mesh wire are removed, then the walls and roof are trimmed. Either a new anchor support or a metal frame support is installed along the section of the mine working. The voids in the walls and roof are filled with either a wooden fire support or foam concrete.

In case of *squeezing of rocks in the walls of workings in the form of a sliding prism* (fig. 4) the creep prism angles θ vary over a wide range, from 50 ° to 65 °, and the creep prism width C is from 1.0 to 1.8 m. Pressing in the form of creep prisms causes significant outcrops of roof rocks and their collapses into the working. The width of the workings, as a result of this, increases sharply at the contact with the rocks. In the absence of rock falls from the roof in the sections of workings with squeezing the lining is reinforced based on the width of the sliding prism. Anchor support is used as a reinforcing lining. Initially, the mesh wire is applied, then the reinforcing roof bolting is installed.
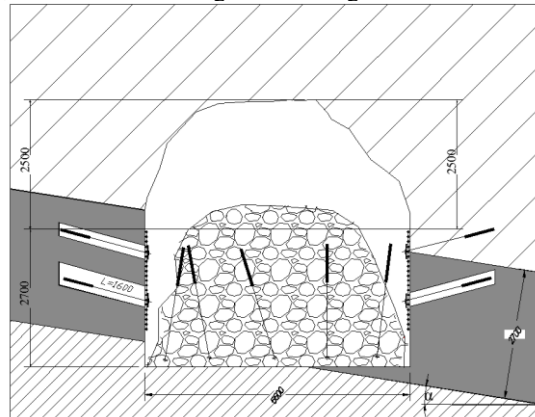

Fig. 3. The accumulation of collapsed rocks with deformation of mesh wire and the formation of a dome along the entire width of the mine in conditions of seam 9 of «Raspadskaya» mine
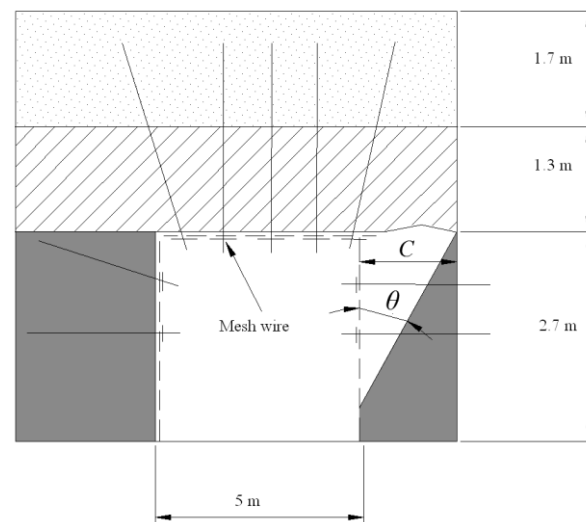
Fig. 4. The squeezing of rocks in the walls of air roadway 4-9-25 of «Raspadskaya» mine in the form of a sliding prism

The squeezing of coal and rocks in the walls of workings in the form of dumps (fig. 5) is observed in areas where the roof is difficult to break. The depth of the extraction h_B reaches 1 m or more, the height B is different, sometimes it reaches the working height. Most often observed from lying wall side. In case of minor collapses in the walls, repair work is carried out by installing and securing a mesh wire or polymer mesh using one or two steel-polymer bolts. With deep and high falls, the site is re-strengthened. Exfoliated coal and rock are removed, the surface of the dump is leveled, mesh wire and bolts are installed. In some cases, the dumps are filled with bonding compounds such as Carbofil, Geofom, Tekfom.
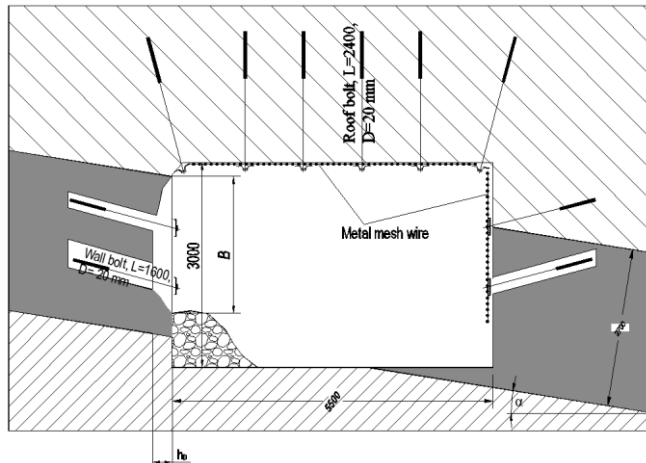

Fig. 5. The squeezing of coal and rocks in the walls of workings in the form of dumps

An *episode of plastic extrusion of coal and rocks from the walls of workings* (fig. 6) occurs in workings with a hard-to-break roof in areas with weakened strength properties of coal. Weakened coal layers at high horizontal stresses are squeezed out towards the workings. The squeezed out part of the coal into the working is destroyed, the fastening of the sides is broken. More often, coal squeezing is observed in the workings from the side of the hanging side. The amount of coal squeezing d into the working is 0.5 - 0.6 m, sometimes more. When coal is squeezed out, overhanging cornices are formed in the workings. At high yields, they are dangerous. Therefore, in such areas, the walls are reinforced. The destroyed coal collapses, the walls is leveled, overlapped with a mesh wire or polymer mesh, bolts installed into coal massif, sometimes the coal mass is strengthened with bonding chemical compounds.
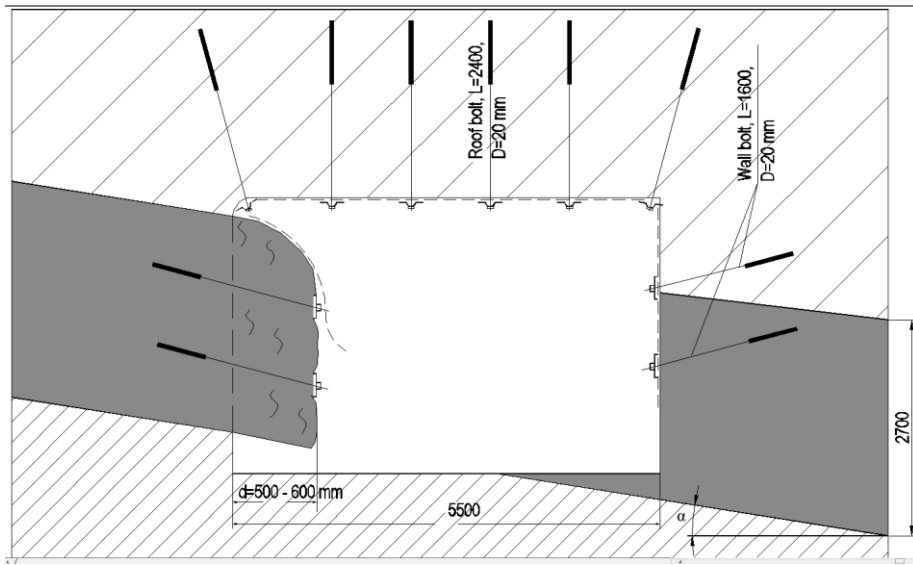
Fig. 6. The plastic extrusion of coal and rocks from the wall of working

3 Discussion

It should be noted that the current regulatory documentation on the calculation of parameters and the use of roof bolting at coal mines in Russia does not cover the issues of repairing damaged sections of mine workings. Therefore, on the basis of the identified typical forms of deformations of surrounding coal-rock mass, design solutions has been developed to strengthen the fastening or complete re-strengthening of damaged sections of mine workings. They include: installation scheme, substantiation of parameters and the list of used reinforcement elements; technology of work, a list of equipment used. The calculation of the required parameters of reinforcement support were carried out using the basic provisions of the theory of the balance arch [6].

When repairing sections of workings with accumulation of exfoliated roof rocks with mesh wire deformation and the formation of collapses and domes (fig. 2), the location of domes and collapses relative to the center of the excavation is determined by the formed stratification of rocks or natural layering and layer-by-layer cracks. The development of the domes along the height occurs along the normal to the layer-by-layer cracks and delamination cracks. When calculating the parameters of the roof bolting for fastening the local formation of collapses and domes formed during mechanical processes, it is recommended to use the following procedure (fig. 7):
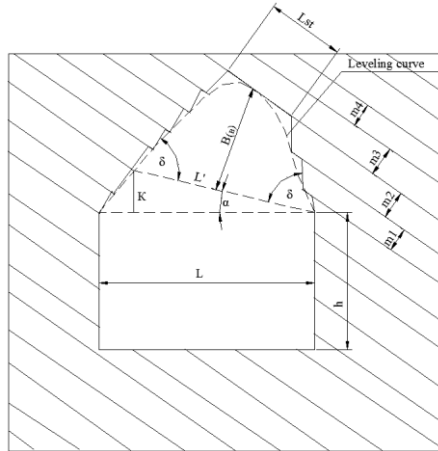
Fig. 7. Scheme for determining the main expected parameters of collapses during mechanical processes of local formation of collapses or domes

The main predictive parameters of collapses include:

B_B – the collapse height;

L_{ST} – the stable collapse span;

δ - the angle of inclination of the fracture line of the rock layers at the supports in walls.

The expected collapse height is taken equal to the height of the collapse vault:

$$B_B = \frac{L}{2 \cdot K \cdot f}, \qquad (1)$$

In the type: L – the mine working span, m; K - the number of layers from the mine working contour to the base of the collapse ($K = \sum m_i$); m_1, m_2, m_3, m_4 - the thickness of the rock layers in the roof, m.

The stable collapse span when seam dip α up to 10° determined by the formula:

$$L_{ST} = L - 2B_B \cdot ctg\delta, \qquad (2)$$

In the type: δ - the angle of inclination of the fracture line of the rock layers at the supports in walls, degrees ($\delta = 60°$-$70°$).

The stable collapse span when seam dip α more than 10° determined by the formula:

$$L_{ST} = L' - 2B_B \cdot ctg\delta, \qquad (3)$$

In the type: L' – the collapse span, m.

$$L' = \frac{K}{\sin\alpha}, \qquad (4)$$

The length of the bolts for collapse supporting o is determined by the formula:

$$l_a = B_B + l_{ex} \text{Equation.3}, \qquad (5)$$

In the type: l_{ex} - the depth of the anchor for the fallout zone, m (not less than 0.3 m).

When supporting the collapses, the bolts installation scheme is: linear, checkerboard-like, arbitrary, depending on the parameters and shape of the collapse. In this case, it is advisable to use the bolts density - P and the distance between the anchors - C_a.

The bolts density is determined by the formula:

$$D = \frac{B_B \cdot \gamma_\kappa \cdot k}{N_a}, \qquad (6)$$

In the type: γ_k - volumetric weight of roof rocks, кН/m³; k – bolts overload factor, taken equal to 1.2; N_a – bolts load-bearing capacity, кН.

The bolts distance is determined by the formula:

$$C_a = \sqrt{\frac{N_a}{B_B \cdot \gamma_K \cdot k}}, \tag{7}$$

The required bolts resistance for collapse support is determined by the formula:

$$P_a = B_B \cdot \gamma_K \, Equation.3 \,, \tag{8}$$

In the type: P_a – the resistance support in the surface of collapse, кН/m².

Using the bolts density installation and the bolts required distance a project for collapse support is being prepared.

Earlier it was found [7] that depending on the sagging of mesh wire and its deformation, the degree of danger in the development is qualified as follows:

- if the mesh wire sagging is not more than 0.3 m, it is necessary to establish mesh wire and mine working control;

- when the mesh wire sags up to 0.4 m, the state of mine working support is unsatisfactory, it is necessary to plan repair work;

- when the mesh wire sagging more than 0.4 m, the state of mine working should be classified as hazardous, repair work is required;

- if the mesh wire sags is 0.5 m or more - the mine working support is in a dangerous state, it is required to immediately carry out repair work.

As an example of the implementation of design solutions for the repair and strengthening of the anchoring of mine workings, the section of the air roadway along seam 9 is presented in the conditions of "Raspadskaya" mine with exfoliated rocks, with a rupture of mesh wire (fig. 8).
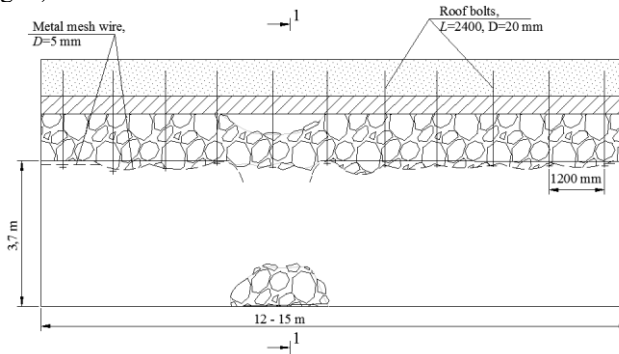

Fig. 8. Exfoliation of roof rocks in roadway. Sagging of mesh wire with rupture (position before repair)

Repair work must be carried out using frame support - support frames and temporary support. The support frame is used to prevent deformation of mesh wire and the spread of its sagging to areas adjacent to the emergency one. The support frame is made of two ore racks with a diameter of at least 200 mm with the installation of racks under a wooden plank. A carriage is used as a top stand (timber, a block can be used). The support frame is installed in the spaces between the anchor rows in front of the emergency section. Temporary support serves to fasten the part of the site where the rock is released from the roof and mesh wire will be replaced. The temporary support consists of two VK-7 (VK-8) racks, which are installed under a wooden plank (timber, block). From under the protection of temporary lining, work is carried out directly on the release of destroyed rocks and replacing the mesh wire and strengthening the roof bolting.

Roadway repair works are carried out in the following sequence. Elements of the support frame and temporary support frame and other materials are delivered to the working area - reinforcing support anchors with washers and nuts, lattice lagging, block (bar or carriage), portable shelves, equipment and tools for performing work, one or two wooden ladders, metal peaks at least 3 m long. The base frame is initially installed. The frame is installed with a spacer, wooden wedges are used. After that, it is carried out with the help of metal peak frills of the roof and walls from the hanging pieces of rock and coal. The temporary support frame is installed directly in front of the front boundary of the site where repair work is to be carried out. With scissors for metal, the bars of mesh wire are cut, the deformable tightening section is thrown out, a new lattice tie is installed, fixed on the readway suppoort bolts. From under the protection of temporary lining, boreholes are drilled in the area where the rocks are released, then reinforcing lining bolts are installed and fastened in the boreholes.

The parameters of the reinforcing lining anchors are calculated according to the regulatory method in force in Russia, according to the weighted average resistance of the rocks within the limits of the thickness equal to the width of the working. In this case, the length of the reinforcing anchors in roadway is taken as 2.4 m, the type of anchor is AVR-20 (A20V), fastening in the holes using resin capsules, the length of fastening in the holes is at least 1 m. Installation of anchors is carried out for individual grips in the form of supporting spherical washers with dimensions of 300x300 mm or flat grips with dimensions of 300x300 mm. Density of installation of anchors is not less than 0.5 bolts/m². Thus, repair work is carried out along the length of the section. In this case, the step of releasing rocks and strengthening the lining during repairs is taken no more than 1 - 1.2 m (fig. 9).

An increase in the height of the working after the release of destroyed rock in the repaired section causes a decrease in the resistance of coal in the sides of the drift, increases the relative tension in the sides [8-10]. It is recommended that the increased part of the height of the sides in the workings after the release of the destroyed roof rocks be fixed with anchor support. In this case, one additional anchor is installed in the sides. Installation of anchors is carried out during the period of strengthening the roof lining. After installing reinforcing anchors along the entire length of the cleaning section of the support frame and the temporary support frame, the resulting void is filled with light foam concrete.
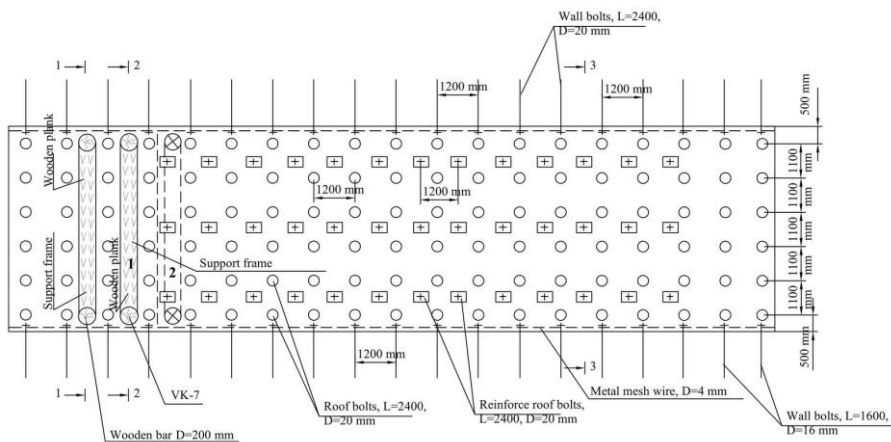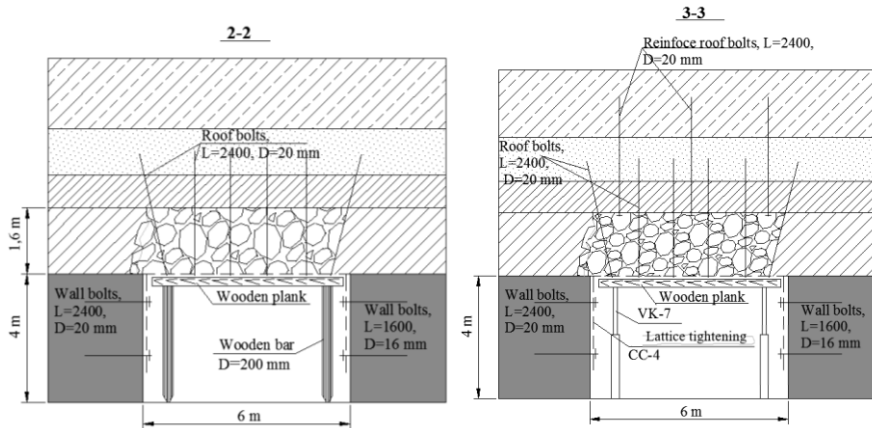
Fig. 9. Condition in the roadway before the start of repair work and after the completion of repair work

4 Conclusions

1. It has been established that during the operation of mine workings supported by anchor support the following geomechanical processes occur in their roof and walls: the process of continuous arch formation, the process of local collapse and walls sliding with different width of the sliding prism.

2. In local geomechanical processes of local deformation, the stratification of rocks, their delamination and collapse does not occur along the entire length of the mine workings, but in separate sections of the workings where there is a decrease in the strength properties of rocks, increased fracturing, increased concentration of stresses, moisture saturation of rocks. In these areas rock falls from the roof, the formation of domes squeezes and dumps of coal from the sides are formed.

3. Six typical forms of deformation of the near-contour coal-rock mass have been identified.

4. It has been established that in normal mining and geological conditions (outside the zones of disturbances, outside the zones of high stresses) pressure cracks are formed within the pressure arch, and the arch development occurs in the direction normal to the created system of cracks.

5. Design solutions are proposed for strengthening the fastening or complete re-strengthening of damaged sections of mine workings, in which processes of local fallout occur. The calculation of the required parameters of the lining was carried out using the basic provisions of the theory of the balance arch as well as on the basis of the regulatory methodology in force in Russia.

References

1. S.S Tsibaev, A.A Renev, A.A Pozolotin, S.N. Mefodiev, MIAB. Mining Inf. Anal. Bull., **2**, 101 (2020)

2. S. Tsibaev, A. Renev, R. Zainulin, A. Kucherenko, E3S Web of Conferences, **174**, 01001 (2020)

3. A. Renev, S. Tsibaev, S. Kalinin, 9th China-Russia Symposium "Coal in the 21st Century: Mining, Intelligent Equipment and Environment Protection", 359 (2018)

4. K. Filimonov, D. Zorkov, S. Tsibaev, A. Kucherenko, E3S Web of Conferences, **174**, 01037 (2020)
5. J. Purcell, D. Vandermaat, M. Callan, P. Craig, Proceedings of the 16th coal operators' conference. Wollongong (NSW): University of Wollongong, 53 (2016)
6. P. T. Tsimbarevich, *Mine rock mechanics* (Ugletehizdat, Moscow, 1948)
7. K.A. Filimonov, A.A. Renev, A.V. Kucherenko, P.V. Grechiskin, MIAB. Mining Inf. Anal. Bull., **5,**133 (2019)
8. W. Zhu, J. Xu, G. Xu, The Journal of the Southern African Institute of Mining and Metallurgy, **117**, 11, 1063 (2017)
9. E. Karampinos, J. Hadjigeorgiou, M. Pierce, The Journal of the Southern African Institute of Mining and Metallurgy, **118**, 12, 1243 (2018)
10. P. Phanthoudeth, T. Sasaoka, H. Shimada, B. Ulaankhuu, J. Oya, S. Dwiki, T. Karian, GSTF Journal of Geological Sciences (JGS), **3,** 1, 15 (2016)