Snowmelt Water Breakthrough into Coal Mine in Sub-Arctic Region

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Abstract

The paper addresses the mechanism of floodwater inrush from a ground sinkhole into underground excavation. As demonstrated by computed simulation, a natural hydrofracture of the rock mass may develop from the sinkhole into the mine opening under the effect of low stresses in the rock mass and water hydrostatic pressure. On approaching the mine opening the fracture may stop growing due to local rock compression near the mine opening. A strong infiltration water flow may occur from the fracture into the opening that may lead to water erosion of roof and dynamical water inrush into the opening.

Keywords: underground mining, ground surface, sinkhole, floodwater, technogenic rock stresses, natural hydrofracture, filtration, water inrush

Introduction

Emergency situations caused by spontaneous hydrological events show a continuous trend towards increasing frequency and scale of consequences (Guidelines 2000). Major economic damage from floods due to snow melting is inflicted to engineering constructions on the earth surface. However, under certain conditions meltwater may affect safety of underground mining. There are a variety of mechanisms of this effect. As a rule, they are associated with general increase in the rock mass water saturation and intensification of infiltration.

Underground mining of solid mineral resources at small depth is sometimes accompanied by local sinking of the earth surface with rupture of rock continuity referred to as technogenic ground fall-through. The fall-through is caused by a shift of the undermined rock into the opening. In Russia design and construction of buildings in such cases are done in accordance with appropriate codes of practice to avoid adverse effects (The Building Codes 2011).

The surface sinkholes are often filled with water. In this case, besides the dangerous geomechanical effect on mining safety, the sinkhole becomes a source of hydrogeological hazard as a reservoir of water that can breakthrough into the underground mine opening. The water breakthrough into the underground opening may proceed by various mechanisms depending upon rock mass geological structure, features of its stress state and water pressure. Water inflow into the underground opening from a surface reservoir in a homogeneous and well-penetrable rock mass may proceed by a water infiltration mechanism (Mironenko & Strelsky 1993, Luckner & Shestakov 1991). Another mechanism of water penetration into the underground opening may take place in the rock mass with horizontal layers. In this case rock undermining is associated with generation of vertical rock mass tension, bending and disclosing of layer contacts, water filling of the layer contacts, rupture of some layers due to critical bending deformation, which results in water penetration into the opening (Iophis & Maltseva 2002, Baryakh & Samodelkina 2012, Liu et al. 2014).

If vertical pressure of the overlying rock is about twice as high as natural horizontal stress (this situation is characteristic of sedimentary rock in regions with rather calm geodynamical environment), fields of tensile horizontal technogenic stress may be generated in the undermined rock. Tensile cracks may develop and become filled with water in such regions. This water as a factor of force may play an active role in the crack development due to pressure on the crack sides. Such fracture cracks may become major canals for water breakthrough into openings both from surface and underground reservoirs (Odintsev and Miletenko 2015).

In subarctic regions water breakthrough may also be caused by generation of so called frost cracks due to extremely low negative temperature. The generation of the frost cracks descending into depth up to ten meters is characteristic of subarctic regions and is not associated with mining activities. These cracks may be considered natural objects affecting subsequent technogenic geomechanical and hydrogeological processes in the rock (Grechishchev et al. 1984).

Another mechanism for water breakthrough from the sinkhole to the opening related to both to crack generation and infiltration flow is considered below on the example of the Yun-Yaga coal mine. As known, study of practical experience is the best way to understand the specific mechanism of an event and to develop adequate methods for prediction of similar cases in future.

Water breakthrough from a sinkhole into a ventilation gallery at the Yun-Yaga mine

The now closed Yun-Yaga mine was used to extract coal from the Yun-Yaga coal deposit located in the north-eastern part of the Pechora coal basin (Gorbachevskij 2007). The climate of this region is subarctic with sharp temperature and pressure variations. Average temperature for a many-year period of observation is minus 6.3°C with absolute minimums of -42 to -52°C and maximums of +30 to +32oC.

The Yun-Yaga deposit is located in a region involving a zone of permafrost. The zone is 50-60% of the whole area, and there are multiple through taliks in the remaining portion, the zone maximum thickness is 180-200 m (average 50-70 m, predominant values up to 20-30 m), temperature ranges from -0.5 to -3.0°C. The through many-year taliks are as a rule located under large undrained lakes, the Yun-Yaga river, some streams and in a region of sinkholes.

The mine field geological structure has several water bearing sandstone layers located in roofs of coal seams under operation. The deposit natural hydrogeological conditions are impaired due to mine construction. The mine construction was accompanied by large water inflow (reaching 720m^3/h). The underground water state underwent considerable change by the end of the construction. A large drawndown cone was generated that reached and even went beyond the deposit outline involving the Yun-Yaga river-valley. The total decrease in the underground water level in main water-bearing horizons was 65 to 130 m.

A water breakthrough occurred from a rather small surface sinkhole into the ventilation gallery located at about 30m below the sinkhole. The sinkhole was formed in the area of influence of the excavation. However, the sinkhole had no hydrological connection with the ventilation gallery, which was explained by sufficiently plastic properties of the overlying rocks and rapid closing of induced cracks (Kostarev & Mitishova 2000).

Water from the ventilation gallery penetrated further into the lava and the conveyor drift. The water-resistant doors did not give effect due to water infiltration through the surrounding rock mass and concrete partitions. Lack of power and flooding of the pumping stations led to flooding of the coal mine (Miletenko 2007).

The breakthrough occurred during the period of high level of melt water (above 0.5 m) due to complete thawing of the overlying rock strata after their partial freezing in winter. The causes of the flood included limited water runoff and insufficient conveyance capacity of the hydrotechnical construction (bridge). The water breakthrough into the ventilation gallery began with weak dripping of water from the roof of the gallery, which turned into strong dripping with erosion and fall of loose roof rock and intense flow of water from the roof.

The coal seam thickness was 1.9 m and inclination was 10o (fig.1). The immediate roof was a 1 m siltstone layer of 40M Pa strength; the main roof was a sandstone layer about 14 m thick and 70-90 MPa strong. The overlying rock mass in the weathering area was weakened by oxidation process and individual frost cracks.

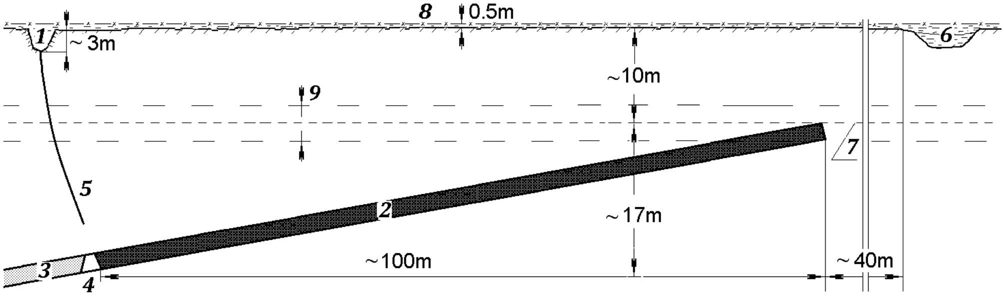

Figure 1 Scheme of water breakthrough in the Yun-Yaga mine: 1– sinkhole, 2– coal pillar, 3 – worked-out seam, 4 – ventilation gallery, 5 – water-conducting crack, 6 – river, 7 – coal seam egress under the bedrock, 8 – flood level at the event occurrence, 9 – natural talik.

Check-up at the mine reported the following main geomechanical cause of the event – development of a frost crack. But this conclusion was not supported by any calculations. Frost cracks cannot be deeper than ten meters. The season-associated temperature variance has no effect at such a depth due to the talik effect. Development of the major crack should occur in another manner. Therefore, this event was considered abnormal and requiring a special examination.

Modeling of water breakthrough

An attempt was made to model the geomechanical and hydrogeological situation using the approach described in (Odintsev and Miletenko 2015). This approach is based on the assumption that the occurrence of a large water-supply crack is associated with the combined effect of technogenic pressure reduction of rocks and hydrostatic effect of water in the crack. The growing crack is actually a hydrofracture of the rock.

Since the initial geometric and geomechanical situation was not known in detail, different calculation schemes existed for the formulation of modeling problems. Each of the patterns included a rock mass up to 100 m deep and a 50-meter part of the excavations. On the part of the excavated seam (50 m in length) the resistance of the support to the movement of the overlying rocks was set by back pressure of 0.5 MPa. There was no back pressure in a small part of the excavation, including the ventilation gallery.

In the calculation the sinkhole was assumed to be an ellipsoid earth surface depression of about 3m in depth, water pressure near the sinkhole bottom was 0.03 MPa. Since the sinkhole had no hydraulic connection with the mine opening and permafrost was absent in the considered area, the rock mass was assumed to be homogeneous elastic solid medium with 103 МПа modulus of elasticity and Poisson’s ratio of 0.3.

Rock pressure in the virgin rock mass was specified by the academician A.N.Dinnik hypothesis that vertical stresses were determined by weight of overlying rock (about 0.6 MPa at a 30 m depth), while side stresses depended upon Poisson’s ratio of the rock. They were 0.25 MPa in the case considered.

The conditions of the absence of permafrost in the considered area of rock mass were considered. It was due to technogenic influence of mining and the influence of sinkhole. For this reason, the rock mass was considered an elastic medium without internal stress sources.

A variety of situations with initial crack starting from the sinkhole were considered including a small vertical frost crack beginning from the sinkhole bottom and a crack coming out from the sinkhole at an angle (fig.2). As concerns crack growth two factors were considered, i.e. technogenic stress state of the rock mass and water pressure in the crack changing with depth by hydrostatics law.

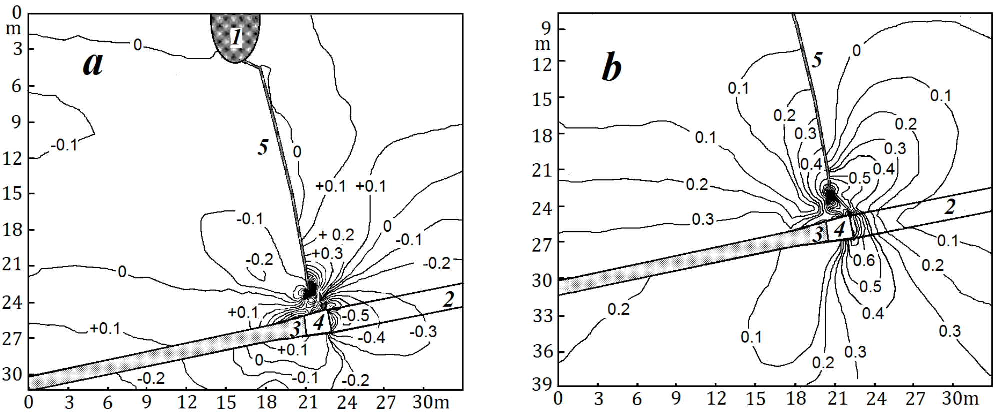

Figure 2 Isolines of main tensile stress (a) (MPa) and von Mises stress (b) (MPa) by the moment of crack approaching the mine opening: 1 – sinkhole, 2 – seam, 3 – worked-out seam, 4 – opening, 5 – crack.

Calculation of crack development was made by sequential steps according to the finite element method. Possibility of rock destruction at the crack end was assessed at each step by the Griffiths-Irwin criterion as described in (Odintsev and Miletenko 2015). The vertical coordinate reflects the change in depth from the earth surface. The horizontal coordinate defines the changes along the coal seam. If the criterion was met, a small length increment was specified along the direction of the highest tensile pressure of the rock. As a result of a sequence of calculation steps a trajectory was found for crack development from the sinkhole to the ventilation gallery due to rock natural hydrofracure.

Figure 2 shows some results of stress calculation for a situation when a water-conducting crack approached the ventilation gallery (the distance from the crack end to the gallery was 2 m with a crack of 24 m in length). Figure 2a shows isolines of main stress which is the highest tensile stress leading to rock fracture. Figure 2b shows isolines of von Mises stress that allows assessment of the rock area of pre-destruction. Rock permeability is known to increase rapidly in this area (Stavrogin & Protosenya 1985).

The analysis of the stress-strain state of the rock mass near the end of the crack and the ventilation gallery shows that the crack can reach the roof of the gallery under some conditions or stop in its development under other conditions (due to the features of the geometry of the opening and the local compression of the rock). The first case is the situation with dynamic break of water into the crack at once, the second case reflects the possibility of water infiltration into the opening.

The problem of infiltration theory is solved to analyze the features of the flow into the ventilation gallery, including the water infiltration directly from the surface and sinkhole together with the water infiltration from the water-conducting crack. The hydraulic conductivity of siltstone 0.001 m/s was used in the calculation

As follows from the calculations, for a crack less than 20 m in length the infiltration water flow from the surface and from the crack to the rock mass is extremely low. The situation changes when the crack approaches the mine opening. In this case interaction between the crack and the opening begins. Figure 3a shows the situation for a 24 m long crack. In the figure the isolines of values of the infiltration rate (m/s) are shown. These values must be multiplied by a correction factor of 10-3. As seen, the infiltration flow of water is strongly limited by the end of the crack. Figure 3b shows isolines in the immediate vicinity of the opening. These isolines are constructed on a different scale for a different finite element mesh to verify the correct calculation and to more accurately estimate the amount of possible water flow into the hole.

The assessment showed that the water flow through the free surface of 15 m^2 can reach about 50 m^3 per hour. Such an intense water flow may really cause washout of weak

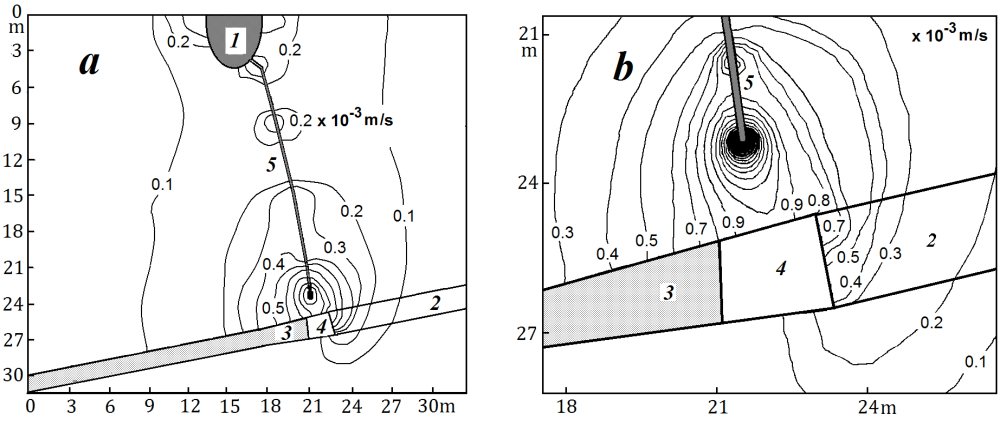

Figure 3 Isolines of filtration flow of water in mine opening when the crack length 24m; 1 – sinkhole, 2 – seam, 3 – worked out seam; 4 – opening, 5 – crack.

rock in the roof of the ventilation gallery and partial roof fall into the opening with the major crack start and water breakthrough in the opening to follow, which was the actual case.

Discussion of results

The modeling has demonstrated that the actual picture of the catastrophic water inflow into the ventilation gallery cannot be explained by infiltration mechanism only. The catastrophic water breakthrough may be caused by development of a major water-conducting crack growing from natural frost crack in the bottom of the sinkhole towards the mine opening.

It follows from the modeling that the major water-conducting crack may be considered as natural hydrofracture of the rock mass in the area of low technogenic stress. Hydrostatic pressure in the crack increases during water flood and the crack may grow to a considerable depth. This factor is of much importance for a case when the sinkhole occurs near the border of projection of the undermined seam portion to earth surface.

It should be noted however that under real conditions of block structure of the rock mass the induced deformations can form a more complex picture as established in (Iophis et al. 2007). Here we used the idea of the rock mass in which the induced water-free cracks were closing over time.

As follows from our modeling, the major rapidly growing crack may stop to develop near the mine opening. In this case a heavy local infiltration inflow into the opening may occur. In practice such a local water inflow in loose rock often leads to washout and fall of the rock from the roof of the opening. In the case considered the rock mass failure area reached the end of the water-conducting crack, which resulted in a powerful stream of water into the opening.

The conclusion may be made that if water penetration into mine openings proceeds by the crack-and-infiltration mechanism, heavy dripping from the opening wall and roof should occur before the catastrophic breakthrough. Therefore, one may predict the critical situation with breakthrough of the major portion of water into the mine opening and take preventive measures beforehand to reduce hazardous consequences of the water breakthrough.

Assessment of the possibility of water breakthrough into underground openings in subarctic regions should involve assessment of possible effect of permafrost, which in general prevents water penetration into underground mine openings. However, one has to take into consideration that taliks may be generated in the rock mass under the effect of mining at small depth. In addition, the presence of natural and artificial water reservoirs on the surface further contributes to the generation of taliks. In this case the poorest conditions for water breakthrough into underground openings at small depth are formed due to spring thawing of subsurface rock.

Conclusion

The meltwater-filled sinkhole changes dramatically rock geomechanical state and makes conditions for generation of a hydrofracture crack to mine opening. Hazardous water inflow into underground mine opening may be associated both with direct hydrofracture crack egress into the opening and with preliminary intense infiltration water inflow from the crack into the opening if the crack development slows down. In loose rock, an intense infiltration inflow of water, which manifests itself by a very intense dripping of water from the roof of the mine, can be an indicator of the approaching washout of the rock and the flood of water from the water-conducting crack. Timely modeling of possible situations with due consideration of geomechanical and hydrogeological factors could help to predict hazardous situations and to prevent water breakthrough in the mine opening.

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