Review paper
UDC: 556.332.52(497.6)
DOI: 10.7251/afts.2015.0712.037F
COBISS. 556.332.52(497.6)

FILLING THE EXCAVATED EMPTY AREA IN UNDERGROUND EXPLOITATION OF THE MINE "KREKA" AIMED AT REDUCING DEFORMATIONS OF THE SURFACE CAUSED BY EXCAVATION

Fazlić Edin[1], Fejzić Semir[2]

[1]*PC Elektroprivreda ZD Mines "Kreka" Tuzla Ltd. E.mail: fazlic.s_edin@hotmail.com*
[2]*BCC Tuzla Canton, Tuzla, E-mail: semirf@yahoo.com*

ABSTRACT

Taking into consideration the current situation in the field of energy, the specific conditions of our mining and contemporary achievements in the field of underground exploitation, it can be stated that new circumstances in terms of techno-economic and security parameters of exploitation in the whole system of the exploitation of the coal deposits are present. The aim of this paper is to contribute to solving the problem of the subsidence of ground surface caused by excavation and utilization of the reserves of deposits that are nonrenewable and important economic resource. It is oriented towards solving this problem in order to avoid deformations of ground surface caused by the excavated empty underground area. By solving this problem, the empty excavated area is filled and the problem of the deformations of ground surface is reduced or permanently solved. The paper proposes the potential composition of backfill for filling the excavated empty area. This paper presents a solution based on filling the excavated empty area.

Key words: *filling, excavated empty area, underground exploitation, deformation of surface*

INTRODUCTION

The cause of deformations of the ground surface is the occurrence of the empty area caused by the exploitation of raw materials. The process of its effect on the ground surface is gradual, and it depends on the surface of the deposits under exploitation. The first signs of subsidence occurring in the massif of a cave are the formation of deflection, subsidence or caving-in of a roof of the excavation. Subsidence manifests itself in the increase of roof and board side pressure, and deformations of the support. The shape, size and course of deformations of the ground surface depend on a number of mining and geologic factors that are basic factors that determine the character and parameters of the process of the ground deformation and can be classified in the following groups:

- structural characteristics of rock massif (stratification, fissuring)
- physico-mechanical properties of rock that build the supporting layers
- angles of depositing ore bodies and the supporting layers,
- shape and dimensions of ore bodies, thickness, the relation between dimensions of the excavated area and its depth

- system of excavation
- degree of damage
- appearance of the ground surface

Nowadays, there are contemporary methods for the prediction of the activation and movement of the ground surface, as well as predicting the effect of mining works on the ground surface and objects found on the surface.

Due to the underground excavation of raw minerals, caving-in of roof layers above the excavated ground occurs. Manifestations of the caving-in appear on the ground surface, too. The level of the zone of the caving-in is usually several times higher than the level of the excavated area. The rock mass above this zone does not cave-in, but it is exposed to turning obstructs, and due to its strength cracks appear. This zone is called the crack zone and its level is approximately the same as the level of the caving-in zone. The rock mass above the crack zone bends down when under the weight pressure of the adjacent layers. The strains to which the rock mass in this zone is exposed are not strong enough to cause the occurrence of cracks, and therefore, this zone is called the strain zone. If certain deformations appear on the ground surface, under an influence of the underground works, then, the part of the ground affected by these deformations is called a subsidence through.

ROCK CLASSIFICATION

A simplified scheme of rock classification, the basis of physico-mechanical properties is offered in the tables 1 and 2, [1,2],

Table 1 Rock classification

Compressive strength бр(KN/cm²)	Classification	Rock types
0,5-2	Very weak	Weathered and weakly-compacted sedimentary rocks
2-4	Weak	Weakly-cemented sedimentary rocks, schists
4-8	Medium	Competent sedimentary rocks, some coarse-grained igneous rocks
8-16	Strong	Competent igneous and metamorphic rocks, fine-grained sandstones
16-32	Very strong	Quartzites, dense fine-grained igneous rocks

Table 2 Classification of rocks in relation to their strength

Rock types	Compressive strength бр (KN/cm²)	Shear strength бs (KN/cm²)	Bulk density P (t/m³)	Porosity N (%)
Granite	10-20	1,4-5,0	2,6-2,9	0,5-1,5
Gabbro	15-30	-	2,8-3,1	0,1-0,2
Basalt	15-30	2,0-6,0	2,8-2,9	0,1-1,0
Sandstone	2-17	0,4-2,5	2,0-2,6	5-25
Limestone	3-25	1,0-5,0	2,2-2,6	5-20
Dolomite	3-25	-	2,5-2,6	1-5
Quartzite	15-30	2,0-6,0	2,6-2,7	0,1-0,5
Gneiss	5-20	-	2,8-3,0	0,5-1,5
Marble	10-25	-	2,6-2,7	0,5-2
Marlstone	2-6	0,5-2,0	2,0-2,3	4-16
Coal	0,5-2	0.2-1,2	1,3-1,5	1- 8

DEFORMATIONS OF THE SURFACE AS A CONSEQUENCE OF EXCAVATIONS

By opening the underground area, especially the excavations, after a certain time, the roof above the excavation gets deformed, it delaminates, cracks, and finally caves-in in the excavated area. Caving-in of the roof has the tendency of decreasing the height until a balanced roof is formed. One side of the roof relies on the solid, front part of the excavation, while the other side relies on the bottom part, backfill or the ruins in the old working. Within the roof occurs the rearrangement of the stress, and zones with pressure and tangent load, without sharp borders between the zones.

The load mass above the roof is rearranged on the board sides, so the high pressure in the remaining parts is called bracing cave pressure. The pressure is higher in the front because the bracing surface is smaller, and the pressure is lower in the old working because the bracing surface is expanded. The differences in the pressure in the excavation are greater in the case of solid deposits, and smaller in the case of softer rocks. The disrupted zone is wider in softer, and narrower in solid deposits. The purpose of operating the roof is to lower the pressure on the excavated support. [1] The process of caving-in follows the process of advancing of the front.

The roof caving can be divided into:

- first caving
- current caving
- primary caving

The first caving is performed immediately after forming the excavation. By spreading the excavation, the support is either removed or moved, and the roof is forcedly caved. If the roof is not naturally caved-in, then mining is applied. The current caving is a continuous process which is performed cyclicly by self-caving, depending on the progress of the front working.The immediate roof fills the area, and its filling affects the looseness coefficient. The primary caving of the roof covers the caving of the basic roof, and then it is more difficult to cave-in. This caving is followed by sound effects, and cannot be controlled efficiently. If the immediate roof has a great looseness coefficient (after compaction), the basic roof completely overlaps it, so the primary caving is not necessary.
From the standpoint of stability, the roof can be divided into:

- the completely unstable roof, it cannot even be maintained with special construction support; usually protection boards made of raw materials are put, so, in this case, the economic justifiability has to be proved,
- the roof that is easy to cave-in is an unstable roof, and requires the presence of protection boards and reinforced bearing of the support,
- the roof that is easy to cave-in which can be opened and supported by individual abutments, or complex support,
- the medium caving roof keeps the compactness during the opening of greater free surfaces; individual abutments or complex support can be used as a support,
- the hard caving roofand the very hard caving roof are favorable for locating and operating the equipment. In the case of this type of roof, due to its compactness, just before caving, there is an increased stress and load of the support, which has to be strengthened by protection boards in specific cases.

During the underground excavation of raw materials, the roof deposits above the excavated opening cave-in. Depending on the depth of underground working, manifestations of their effect on the ground surface can be different. According to the scope of the surface ground deformations, due to the underground working, deformations can be in the shape of: chasm, cracks and balanced deformations, figure 1, [2].

SECURING THE EXCAVATED EMPTY AREA BY FILLING

Cave pressures are created by disturbing the natural balance using the technological processes of excavation. By using the process of excavation, free areas are created, which are exposed to cave pressures during the excavation process. Uncontrolled closure, caving of these rooms, would cause huge material expenses and endanger lives. Due to that, in the case of excavation (excavation method), the aim is to build technological procedure and security measures in the technology in order to deal with the cave pressure [3,4,5].

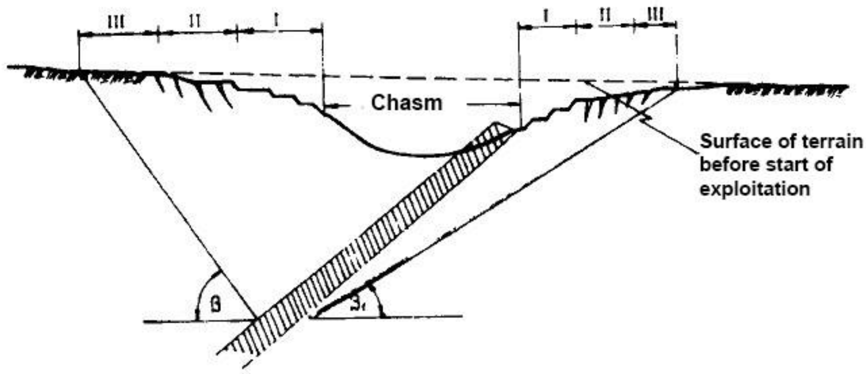

Figure 1 The shapes of the surface ground deformations : I – zone terrace,
II – zone cracks , III – zone of balanced deformations

For purposes of confronting the forces which affect empty areas, the following steps are undertaken: substructure

- security, using protection abutments,
- security, using the backfill,
- caving-in

Excavation methods for filling the excavated areas are considered to be one of the safest excavation methods. Advantages of securing the empty excavated areas using filling are:

- increased security during excavations
- the effect of pressure in an excavation (an excavation site) is reduced
- demand for setting is reduced
- chance of self-combustion is reduced
- weather conditions are improved
- chance of subsidence of ground is reduced or ruled out
- occupational safety is increased
- loss of raw minerals is reduced
- chances of cave fires are prevented.

Methods with filling empty excavated areas

Concerning the methods with filling, the integral part of technology is the backfill which prevents the subsidence of the surface above the excavated areas. The backfill is a permanent means for securing the board sides of excavations. Excavations are additionally secured by substructure on their weak parts. It is applied in deposits with weaker board sides and solid ore. The excavated empty area is also secured by filling and different types of substructure. Substructure is mainly filled. It is applied to all types of deposits, with proper and improper contours. For deposits with greater depth of subsidence and increased pressure, applying the method with filling is almost excluded.

- The thickness of coal layers in the "Kreka" basin is between 5 and 20 m, but in the bigger part of deposit, it is from 8 (m) to 10 (m). It is impossible to excavate the layers of that thickness in a single procedure without huge loss and reduced occupational security. Exploitation of those layers requires their division on an adequate number of interventions (zones). Depending on conditions, excavations of different interventions can be with caving the roof from above to below, or with filling from below to above [6].

- The slope of layers of the "Kreka" basin is changeable, ranging from horizontal to steep, and in some parts vertical. However, in the largest area of the basin, the layers have from light to medium slope, i.e. from 5 to 20°. That slope offers great possibilities for the choice of different excavation systems between wide-front, short-front, chambered, etc. The slope is favourable for applying the excavation with filling, especially from the standpoint of building and percolation of filling.

- The physico-mechanical characteristics of coal affect the way of digging, dimensions of excavation and the way of substructing excavations. The immediate roof of all four coal layers consists of clay or sand, marly clay, while the high roof consists of sand. Based on the classification of GIG Katowice, both types of rocks, concerning their proneness to subsidence, belong to class I, i.e. they are easy to break, easily form the subsided old working, and subside themselves in the old working when the excavation reaches 5 (m). The recommended maximum opening of a roof here, without substructure, is around 1 (m). By excavating in layers from below to above with filling, the remaining part of a layer, together with roof deposits, would gradually bend and, without significant demolitions, lower on the backfill, so it would serve as a stable roof during the excavation of the next layer [3].

- The way of digging depends on physic-mechanical composition of raw material, especially strength, hardness, tenacity, cracked condition. These characteristics of all of the coal in "Kreka" make mechanized excavation impossible without the equipment of larger mass and installed capacity. The indicators of this are the previous experiences on applying mechanized excavations in this mine [6].

- The depth of exploitation is the factor which affects the size of underground pressure in cave areas and excavations, and thus affects the scope and way of substructure. In the same way, the depth affects processes of caving of roof rock after the excavation of ore. Concerning the filling, depth has an effect on the size of hydraulic pressure in a pipeline, and it decides on the maximum length of transport of filling, the need for construction of so called resistant loops, etc.

- The amount of remote gases in a cave does not depend only on gaseousness of the excavated cola layer, but also on gaseousness of other layers and rock massif. By excavation using caving of roof rocks, gases can appear in the area of excavation through old workings. In the case of excavations with hydro-backfill, a roof is gradually lowered, demolition of rocks is excluded or minimal, which reduces the extraction of gases [4].

- In the conditions of the mine "Kreka", there are life-long experiences in the field of production of isolation bulkheads, using hydro-filling, which can be of great importance for the implementation of the system of filling, especially in terms of the technology of preparation, transport, building hydro-backfill.

THE CONCEPT OF TECHNOLOGY WITH FILLING THE EXCAVATED EMPTY AREA

Technology is based on a thesis that the effect of excavated empty areas on deformations of the ground surface will be less if conditions closer to working conditions in coal deposits are created. It can be achieved by complete and high-quality filling of the excavated empty areas with material that will, after setting, have physico-mechanical qualities similar to those of coal [7,8,9]. The empty area needs to be filled on time, in order for backfill to have time to solidify.The time needed depends on the composition of the used backfill. In any case, it is better when the time available for solidification is longer, so filling needs to be done when the excavated empty area is no longer necessary. Filling starts from the lower part of the excavated empty area to the higher part, and it consists of the following phases: setting a barrier for the backfill, Figure 2, removing the support from the part of the excavation (sections, steps of filling), filling of a section,removing the support from the following section, and so on, until the last excavated empty area. Installation for filling, from the surface to the empty area, is put through ventilation rooms. During the process of filling, it is necessary, in a transport system of a cave, to ensure the location of the excavated backfill on an appropriate landfill, from where it can again be used for filling the excavated empty area [9]. For achieving the necessary effects for filling, the following is important: a) characteristics of material used for filling, b) characteristics after the mixture in the preparation phase, phase of transport and setting, c) characteristics of the set backfill.

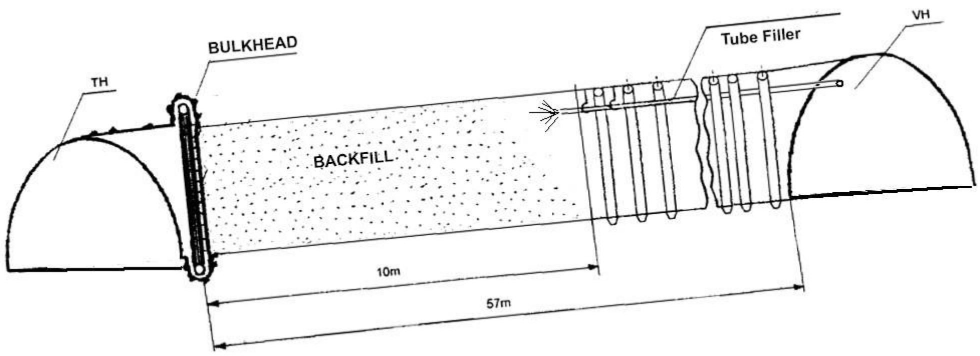

Figure 2 The display of filling

The choice and characteristics of the material for filling

The material for filling the excavated empty area in the underground exploitation of raw minerals can be defined as a set of particles of solid, incombustible, non-toxic material, with adequate physico-mechanical properties that satisfy the conditions of transport and building-in in the excavated empty area in a cave. The demands of transport and setting the backfill are mostly reduced to physical, mechanical, chemical and technical characteristics of the given material. Some characteristics have a smaller, direct or indirect, effect on the choice and realization of the filling process. The backfill material can contain the particles of the same material or the mixture of grains of different material and specific admixture. The basic classification of distribution of material for filling based on a type and source is presented in the following table [8].

Table 3. Distribution of materials for filling

Materials for filling						
Sand	Waste materials					Mixture of sand and waste
	Tailing	Dross	Ash	Granular ash	Other	

The choice of the filling material depends on the following factors:

- the necessary characteristics of the backfill
- the amount and distance of the available material, and
- the price of the material, its transport, preparation and setting
- For filling, along with sand, a variety of materials can be used. This fact is of significant importance because through disposing waste in the excavated empty area their permanent disposal is achieved which contributes the environment protection [7].

The following factors, more or less, affect the preference of the material for filling:

- Granulometrical composition
- Speed of fall of grains in the mixture
- Compressibility
- Weathering through hydrotransport,
- Toxicity

Also, the following characteristics of the material have the effect on the material for filling:

- Specific and bulk weight
- Watertightness
- Porosity
- Water absorption
- The natural angle of the slope of the backfill

The mixture for filling the excavated are should have the following main characteristics:

- the lowest possible compressibility per setting
- simple composition because of the simplicity of the technological preparation process, transportability
- adequate consistency, in order for it to stay in the area of filling, and not to overflow the substruction (the indicator of the tightness of the substructure is used in the same way as for the formwork in the field of construction)
- proneness to emulsification, with the minimum water extraction during the process of solidification, i.e. to contain water that is enough for the binding reaction
- proneness to solidification after a certain time, giving in the end a solid product with the lowest possible compressibility
- the universality of the implementation in a mine, so it can be used for: the construction of insulating barriers in a cave, sanation of potential and active fires, dealing with fire prophilactyc in a cave, dealing with undesirable air movements in a cave, etc.
- economy, i.e. the lowest possible expenses of raw material, as well as preparation and setting the backfill
- non-toxicity, independent as well as when in contact with the surrounding medium (water, air, coal, clay)
- the composition of the mixture has to be selected in a way that, when in the process of condensation and solidification, the water does not separate, because it needs to be completely bound, on a physic-chemical basis

CONCLUSION

The depth of exploitation is a factor which affects the height of the underground pressure in mine openings and excavations. It also affects the range and way of substructure. In the same way, the depth affects the process of caving-in of the roof rocks during the excavation of raw minerals. The complete filling of the excavated empty area at the proper time can ensure the stability of the massif and the area around it during the process of exploitation. It can be concluded from the previous experience that no substructure can ensure that. In this case, the backfill should have the same capacity as coal. The usage of the backfill for filling the excavated area also ensures the greater utilization of raw materials (up to 90 %) which prolongs the life of the mine. Large reserves, low price, and the vicinity of the competent material for filling at this location enable the efficiency of the implementation of filling.

(Received February 2015, accepted March 2015)

REFERENCES

[1] Suljkanović, M. (1989). Analiza metoda prognoze sadejstva jamskog masiva u MHP pri širokočelnom otkopavanju ugljenih slojeva. Tuzla. FSD Rudarskog instituta Tuzla
[2] Stević, M. (1991). Mehanika tla i stijena. Tuzla. Rudarsko-geološki fakultet.
[3] Osmić, M. (1997). Metodologija ekonomske ocjene eksploatacije rezervi mineralnih sirovina iz zaštitnih stubova. Tuzla. Rudarsko-geološko-građevinski fakultet, doktorska disertacija.
[4] Uljić, H. (1998). Sigurnost i zaštita u rudarstvu. Tuzla. Rudarsko-geološko-građevinski fakultet.
[5] Memić, M., Hadžić, E. (1999). Metodologija projektovanja i izgradnja podzemnih prostorija. Tuzla. Rudarski institut Tuzla.
[6] Osmić, M. (2009). Projektovanje i izvođenje bušačko-minerskih radova kod podzemnog otkopavanja ruda. Rudarsko-geološko-građevinski fakultet.
[7] Duranović, N. (2008). Mogućnost eksploatacije uglja ispod naseljenih mjesta otkopavanjem sa zapunjavanjem praznih prostora. Tuzla. Rudarsko-geološko-građevinski fakultet, magistarski rad.
[8] Brkić, J. (2009). Upotreba pijeskova krekanskog basena za zapunjavanje podzemnoj eksploataciji uglja. Tuzla. Rudarsko-geološko-građevinski fakultet, magistarski rad.
[9] Fazlić, E. (2011). Izbor tehnologije prolaza mehanizovanog širokog čela kroz vezne uskope u Rudniku Mramor. Tuzla. Rudarsko-geološko-građevinski fakultet, magistarski rad.