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# Stress environment around head entries with pillarless gobside entry retaining through numerical simulation incorporating the two type of filling wall

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**Abstract.** Longwall mining is the most productive system for underground extraction of coal. Many coal mines use a pillarless mining. Reserving a gateroad for the usage of next panel mining is a popular gob-side entry retaining. Thus, the conventional entry retaining method requires an installation of filling walls. The mechanical properties of filling materials largely determine the quality of job-side entry retaining. Stress field evolution study around head entries when main roof console length increase with two variants of filling wall. Ansys code was used to analyze the stress evolution law under different mining conditions. As a result of numerical simulation, it was found that in the case of gob-side entry retaining, the localization of maximum stresses in surrounding rock is determined by the length console of the main roof, which hanging on the border with the gob, and the filling walls deformation module. Potential location of roof cutting, stress gradient and extremum stress in the main roof define the stability of entries. Main roof console length and filling material parameters control can help to the formation of a stable structure around the entry to meet the requirements of the next working face.

## 1. Introduction

Active mining of mineral resources was carried out during last century by many countries. This has led to a significant increase in the depths at which minerals are mined. Coal mining in USSR, Poland, Germany, Britain and France had reached deeper than 1000 m as early as the XX. At present the depth of coal mines has reached 1500 m, the average depth of metal mines has reached 2000 m, the depth of non-ferrous metal mines has reached around 4500 m [1]. An increase of the mining depth leads to a number of negative phenomena in mines: rockbursts, large-scale caving, large inrush of mixed coal, etc. One of the typical phenomena observed at great depths is damage to and failure of the surrounding rock masses of mine roadways.

Mine roadways are a very important element of a coal mine. Their condition largely determines the safety and rhythm of the mine, the stability of ventilation, total cost of extracted mineral resources.

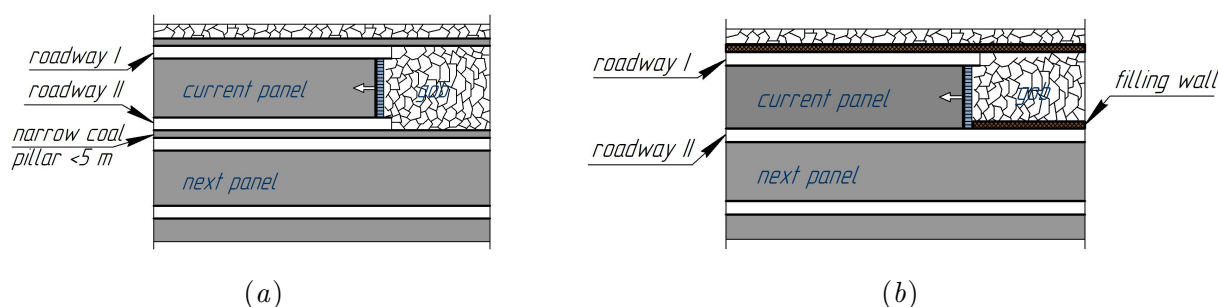
A common underground coal mining technique used in the United States, China, Poland, Russia, Ukraine is the longwall method. Longwall mining, a safe and highly productive coal mining method, has become more frequently used for extracting coal seams. In the longwall



method, the overlying strata are allowed to cave behind the working face after the coal is extracted, creating a gob.

Most commonly, U.S. and Australia longwalls use three- or four-entry gate roads for panel mining. Two-entry gates are often used under deeper cover to achieve better pillar stability. Wide pillars in coal mines of Europe and Asia were replaced to narrow ones back in the 80s.

Size of the narrow coal pillar in Ukraine is generally 1.5-3 m, as shown in figure 1a. In recent years the pillarless technology was vigorously developed, as shown in figure 1b. In this technique, the former entry is artificially retained as the tailgate for the next mining panel by using pigsties, concrete blocks, paste-like backfill material, high-water packing material, and other fill materials [2]. Many coal mines of China, Poland, Russia, Ukraine use a pillarless mining [3], [4], [5], [6]. Many scientists believe that it is necessary urgent to implement and popularize the pillarless mining technology with reasonable economy and high safety (figure 1).



**Figure 1.** Typical coal mining modes: (a) mining with a narrow coal pillar; (b) gob-side entry retaining by filling artificial material.

As can be seen on figure 1b the gob-side entry retaining method requires an installation of artificial filling walls. The mechanical properties of filling materials largely determine the gob-side gate road stability. Many scholars researched in fields for improved efficiency filling wall, optimizing the entry-in support parameters. The varieties of wall types have been tried, such as timber cribs, dense pillar, gangue piling, and masonry walls [7], [8], [9], [10]. However, due to low support force and large deformation most conventional construction have been greatly affected.

Bai et al. [11] developed high-water quick-setting materials and pasty materials as new filling wall materials. The advantages of them include high-support force, quick force-increase speed, good gob-side gate road maintenance performance, mechanized creation, and good isolation of the gob.

Li and Hua [12] by taking Xieyi coal mine in Huainan as project background, established a mechanical model of key blocks and immediate roof, and analyzed the interaction mechanism between key blocks and surrounding rock around the gob-side entry retaining. As a result, determined reasonable width of roadside backfill, calculated stability coefficients of key blocks, and obtains sensitive coefficients of influencing factors on the stability of key blocks.

Chen et al. [13] researched method combining entry-in basic support with reinforced support, which is successful in gob-side entry retaining method practice for easy caving and medium caving roofs. Jiang et al. [14] presented a case study of the failure mechanisms and support design for deep composite soft rock roadway in the Yangcheng Coal Mine of China. Based on the failure mechanism, a new combine support was proposed that consisted of bolting, cable, metal mesh, shotcrete, and grouting.

In [15] the load-bearing capacity of mine roadway supports with flexible concrete formwork is studied to create a new integrated supporting control system. This approach is combined a

flexible concrete formwork, bolt and anchor cable support with a wire mesh for retaining the surrounding rock of a roadway. As a result, retained roadways are formed in the surrounding rock.

Mentioned technologies that came out in recent years has been applied in gob-side entry retaining engineering in which roofs are managed using the caving method, but the high cost limits its wide application.

In [9], [16], [17] proposed the using of gangues as a filling wall material, that can help remove gangues on the ground. This reduces the cost a filling wall and solves the problem of rock wastes. It [18] have studied the performance of gangue concrete for its application as material of filling walls. Coal gangue is a concrete material utilizing gangues as a coarse aggregate and cement as a cementing material, mixed with a certain amount of additives. Through laboratory tests, Gong et al. [18] focused on the study of the influence of the water-cement ratio, aggregate content on the compressive strength, and the post peak carrying capacity of gangue concrete. An economical filling walls gangue concrete material is provided for the development with fully mechanized gangue backfilling mining.

Scientists for different application fields have recently researched the properties of gangue concrete. These concrete materials are gaining popularity when applied in farmland drainage ditches [19], in building [20], [21], as road base material [22].

The use of gangue concrete in China mining as filling walls material is mainly associated with the application on backfilling working faces [23], [24], [25], but similar technologies applied in mining in which roofs are managed using the caving method are of interest. Such an experience is of interest in full-mechanized mining of coal seams with a thickness of 0.8-2.0 m. Such seams are mainly mined in Ukraine. The use of conventional gangue piling is impossible on longwalls with a high advance rate due to the poor mechanization of the process and the low bearing capacity of filling walls, which does not allow reusing gateroad for the next panel mining. At the same time, filling walls from new high-water quick-setting materials and pasty materials are limited in their application due to their high cost.

Thus, the analysis carried out indicates that the opportunity of job-side entry retaining by longwall mining is primarily determined by the material and parameters of the filling wall. At the same time, combined fastening technologies are becoming increasingly popular. Usage of one or another filling wall design option is determined by mining and geological conditions and technological parameters of seam excavation, because they will determine the stress field around entry gate roads, which form the loading of the surrounding rocks and support system.

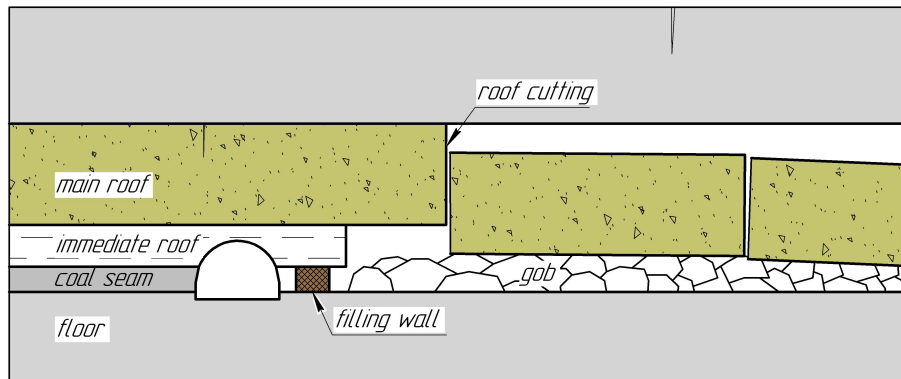
In this paper, based on the geological conditions typical for the Ukrainian Donbass, through numerical simulation stress field evolution around head entries when main roof console length increase with two variants of filling wall: high-support cemented filling and gangue concrete wall, was controlled. This study provides a reference on which filling wall design to choose in the gob-side entry retaining for coalmines that have similar geological conditions.

## 2. Methods

We used methods of computer simulation to investigate stress field evolution around head entries. The general scheme of the model is shown in figure 2. Finite element analysis software system Ansys was used. The modeling was carried out in a volume setting on a natural scale. The solution used a standard method for simulating the stress-strain state of an array near various mining structures using the principle of forces superposition.

The geometric and physical nonlinearities typical for the problems of mining geomechanics were taken into account. Therefore, the numerical analysis was carried out by the iterative Newton-Raphson method.

The model simulated geological conditions typical for the Ukrainian Donbass. In the numerical simulation model, the thickness of coal seam is 1.5 m. The immediate roof was



**Figure 2.** The gob-side entry retaining method of gob roof managed by caving method.

represented by siltstone with a thickness of 2.5 m and a uniaxial compressive strength of 40 MPa. The main roof is sandstone with a thickness of 6.0 m and a strength of 70 MPa. The floor rocks are mudstone with a uniaxial compressive strength of 40 MPa.

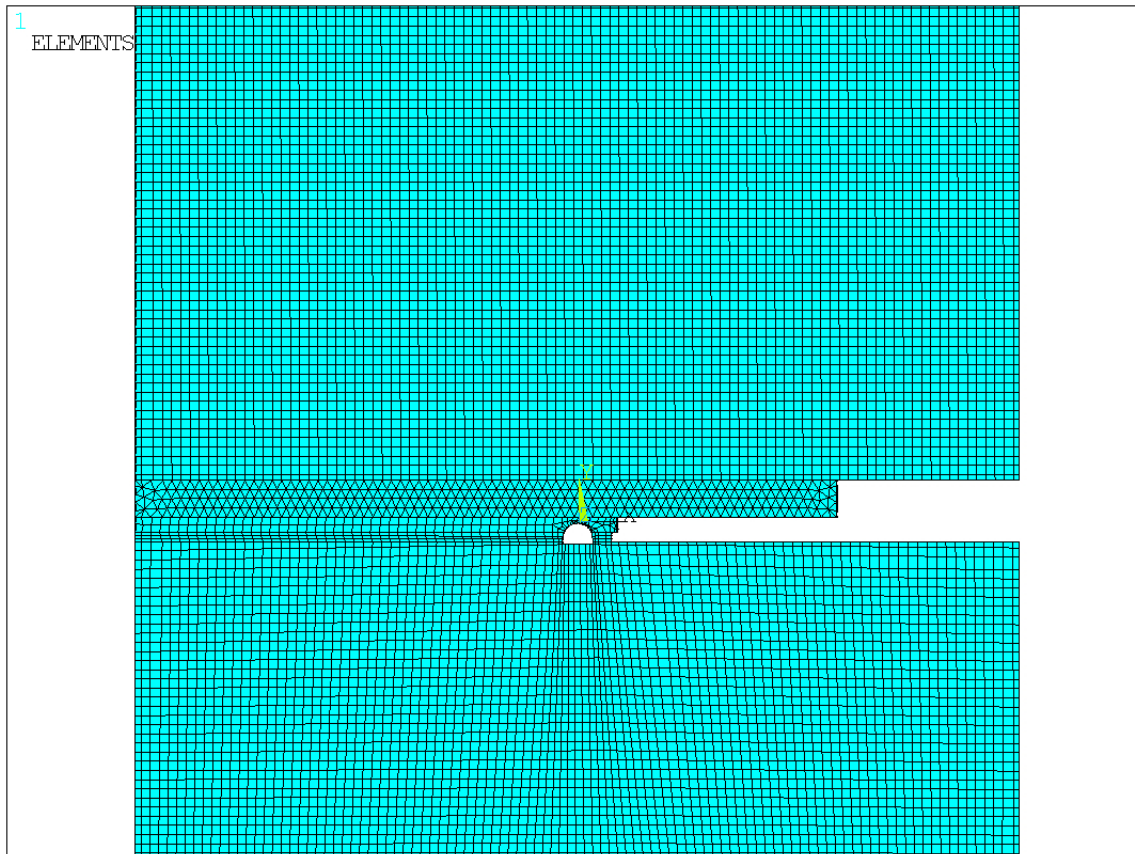
To simulate the behavior of rocks, a Drucker-Prager deformation model was used. The adequacy of the deformation model was established by simulation experiments [26]. According to the described structure, each layer was assigned a deformation modulus, Poisson’s ratio, an angle of internal friction, an adhesion coefficient, and a dilatancy angle (table 1).

**Table 1.** Initial data for numerical modeling.

Nº	Density, kg/m <sup>3</sup>	Elastic modulus, GPa	Poisson’s ratio	Angle of internal friction, deg	Dilatancy angle,deg	Cohesion value, kPa
1	2500	27.5	Mine roof 0.25	27	25	135
2	2400	22	Immediate roof 0.25	32	30	106
3	1350	3	Coal seam 0.3	30	27	96
4	2400	22	Floor 0.25	32	30	106
5	2300	32	High-support cemented filling 0.25	-	-	-
6	2000	5.2	Gangue concrete filling 0.22	-	-	-
7	1200	1	Cribs 0.25	-	-	-

The dimension of the model is length x width x height = 256 m x 145 m x 10 m. The load at the upper boundary is calculated with the assumption that the mining depth is 800 m. The bottom boundary is vertically fixed. The left and right boundary is horizontally fixed. Arched entry gates were modeled. The dimension of the roadway is width x height = 5 m x 3.5 m. The bearing capacity of the lining arches was assumed to be 600 kN and was simulated by a distributed rebound over the area of the roof and sides.

The geomechanical situation corresponded to the state of the massif behind the longwall after coal seam was excavated and the immediate roof collapsed. The finite element model is shown in figure 3.



**Figure 3.** General view of the finite element model.

The properties of two variants of filling wall: high-support cemented filling and gangue concrete wall are given in table 1. The parameters of filling wall are taken from studies by Gong [18] for gangue concrete. The reported modulus of the HD C-S-H phase in the pure cement paste varied from  $29.1 \pm 4.0$  GPa to  $36.1 \pm 3.4$  GPa [27], [28], [29]. For comparison, a simulation was also carried out using wooden cribs.

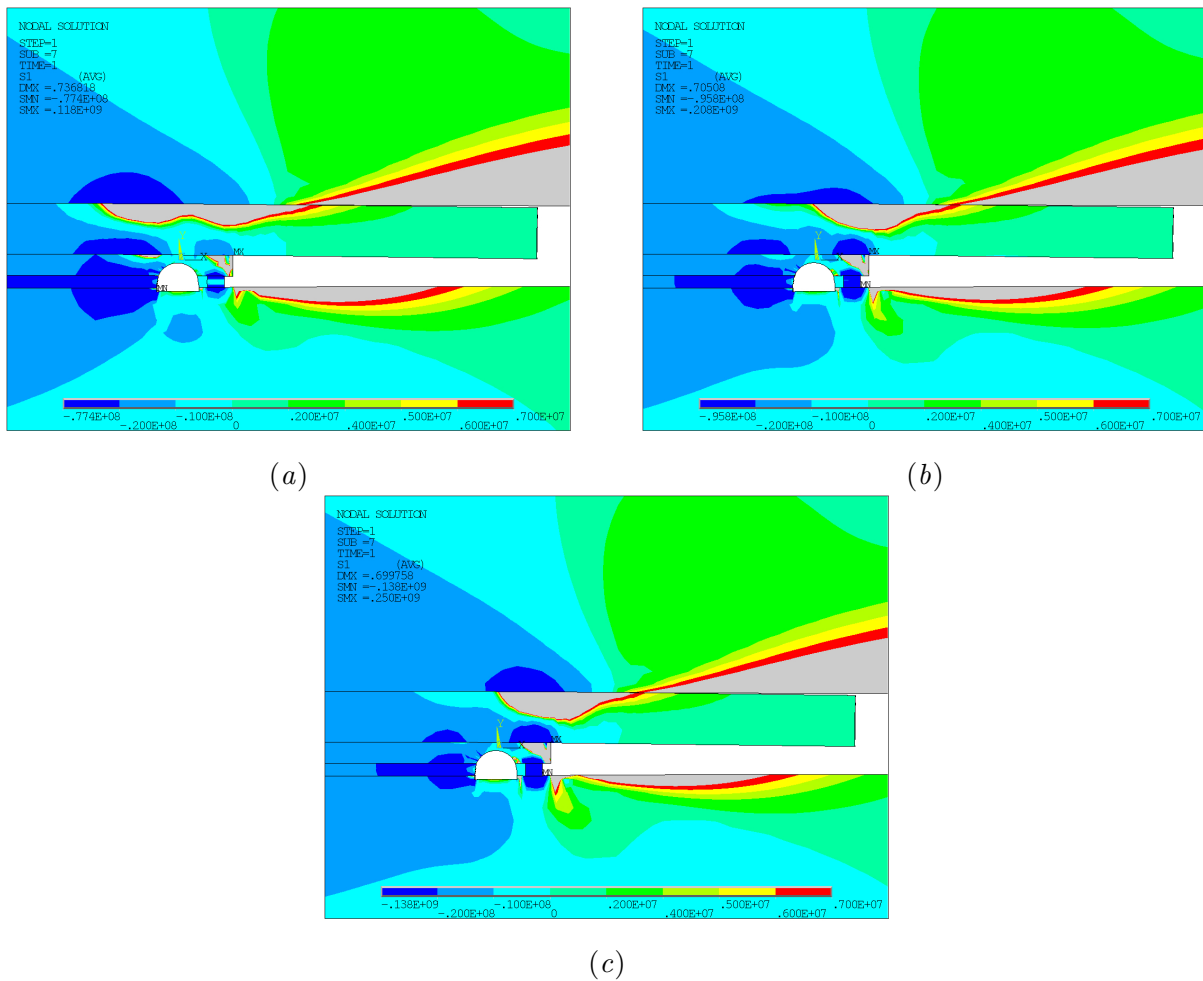
### 3. Results and discussion

To study the stress environment around head entries, simulation modeling of the deformation process was carried out. Main roof console length was varied from 18.5 to 57.5 m. At the same time, three tasks were successively solved:

- analysis of the massif stress-strain state (SSS) with a wooden cribs;
- analysis of the massif SSS with a gangue concrete filling wall;
- analysis of the massif SSS with a high-support cemented filling wall.

Distributions of the maximum principal stresses around the head entries, with 42.5 m main roof console length are shown in figure 4.

Gray color in figure 4 highlights the areas in which the resulting stresses exceed the tensile strength of the rocks. It can be seen from the figures that areas of maximum stresses are formed in the main roof near the entry, which are higher than the ultimate strength of rocks. These



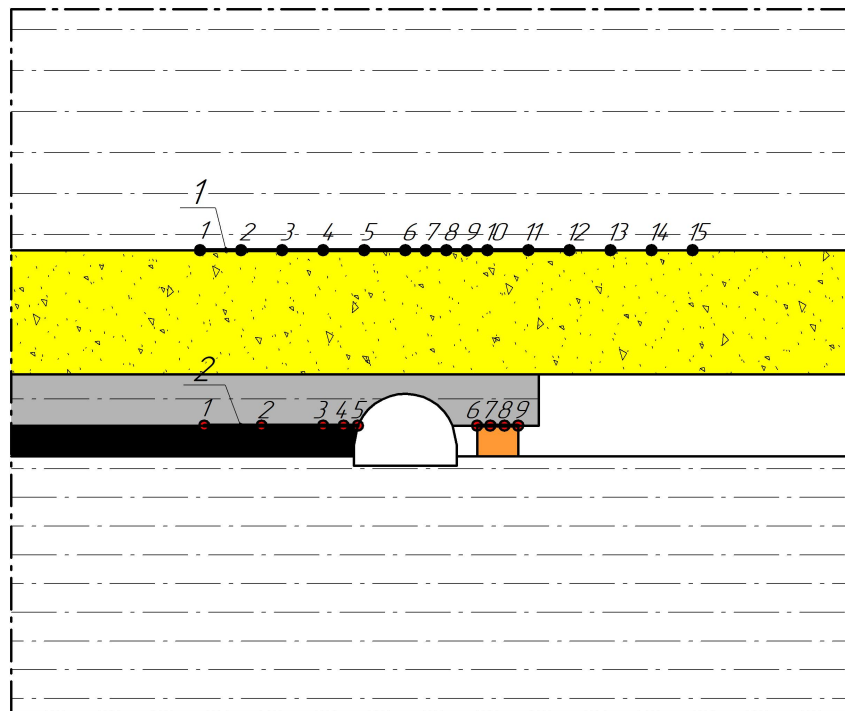
**Figure 4.** Distribution patterns of the maximum of the principal stresses  $\sigma_1$  around the head entries with a wooden cribs (a), a gangue concrete filling wall (b), high-support cemented filling wall (c).

areas are large, which may indicate a high probability of cutting the main roof console there. The localization of the mentioned zones is different when using wooden cribs (figure 4a) and filling walls (figure 4b, c). In the case of using cribs, the maximum of the principal stresses  $\sigma_1$  in the main roof is on the coal seam side. Here is probably the cutting of the main roof. When using filling walls, the maximum stress is above ones, which contributes to the cutting of the main roof above the wall and is more favorable for the stability of the head entries.

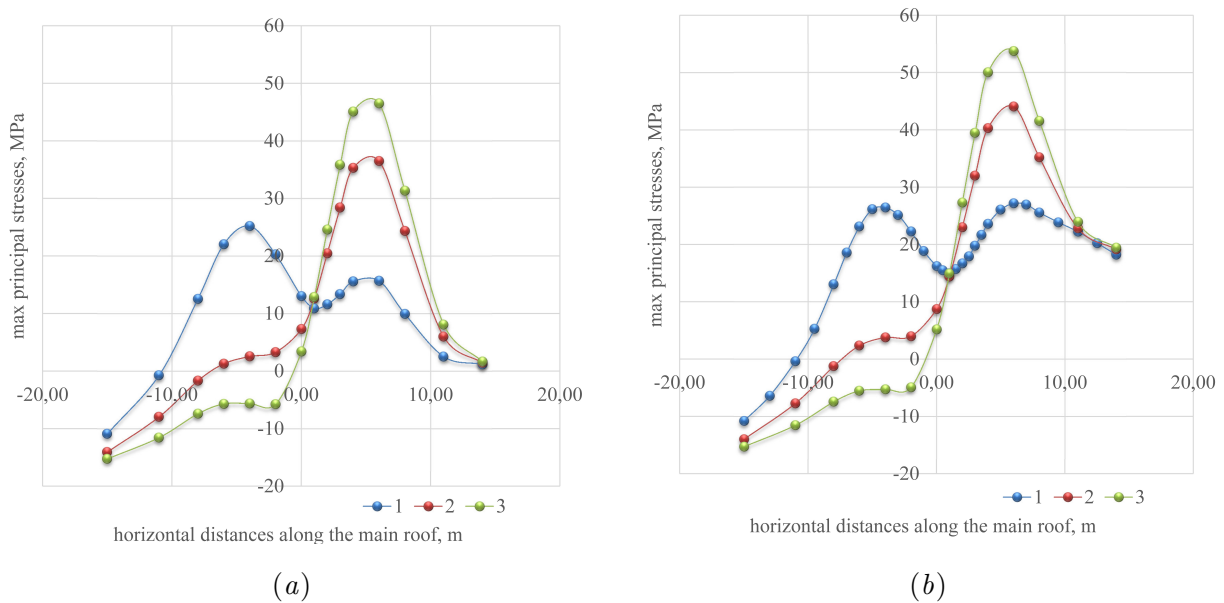
To quantify the influence of the type of filling wall and main roof console length on the localization of the area of maximum stresses in the main roof and, accordingly, the probable place of main roof cutting, the stresses that form in the upper part of the hanging console of the main roof were analyzed. The stress control points are shown in figure 5.

Figure 6, figure 7 shows graphs of changes in the maximum of the principal stresses  $\sigma_1$  in the model along line 1 of the main roof. The Y-axis on the graphs corresponds to the cross-sectional axis of the reusing entry. The positive direction of the X-axis coincides with the direction from the entry to the goaf.

Figure 6 shows that a decrease in the rigidity of the filling wall (case cribs) leads to a shift of the stress extremum in the main roof relative to gateroad towards the untouched massif. This

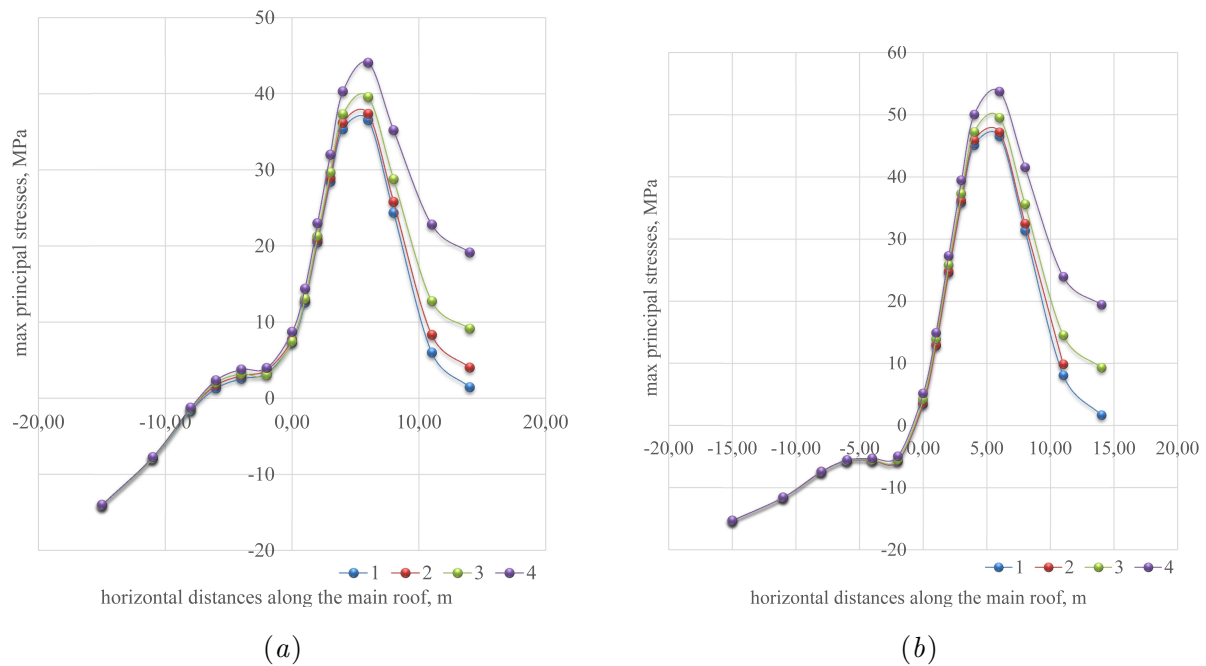


**Figure 5.** Scheme of the model with stress control points: 1 – line in the upper part of the hanging console of the main roof; 2 – line along the contact surface of the filling wall with the immediate roof.



**Figure 6.** Maximum of the principal stresses  $\sigma_1$ , with console length 18.5 m (a), 57.5 m (b) and using: 1 – cribs, 2 – gauge concrete filling wall, 3 – high-support cemented filling wall.

increases the probability of cutting of the main roof from the side of the massif. In this case, the weight of the roof rocks rests on the lining of the entry and leads to its deformation, which does

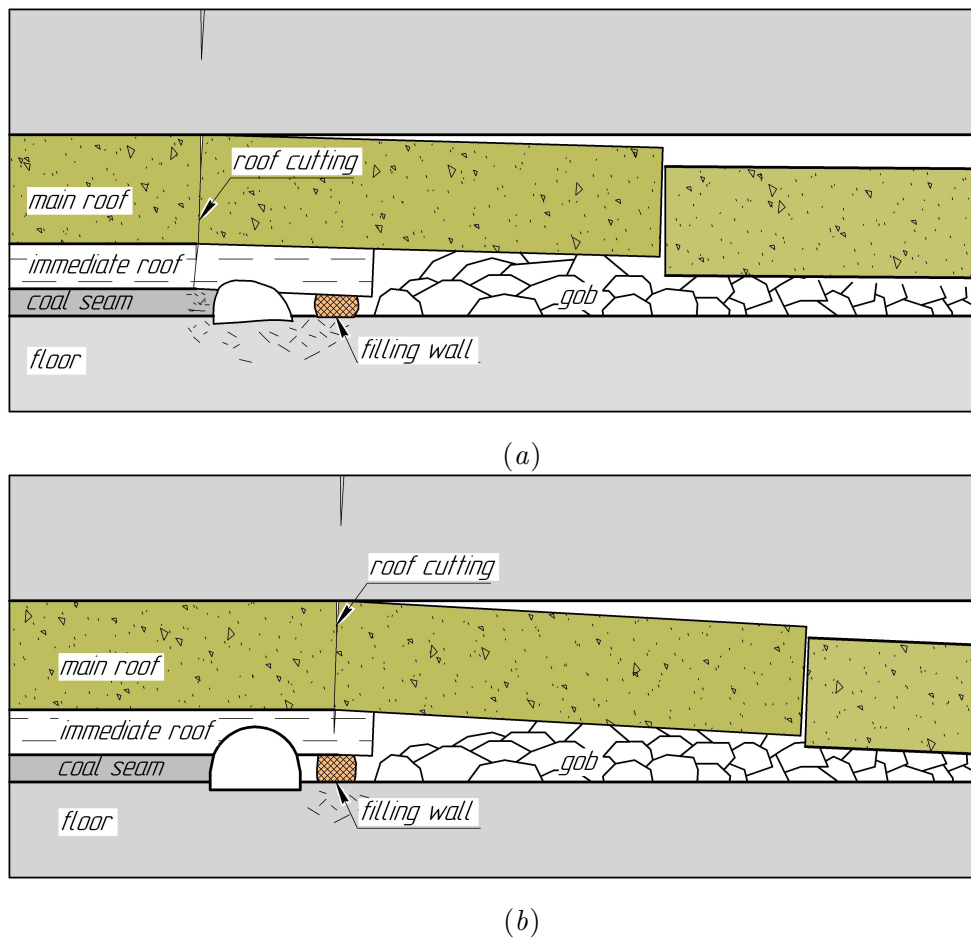


**Figure 7.** Maximum of the principal stresses  $\sigma_1$ , when using gangue concrete filling wall (a), high-support cemented filling wall (b) and console length: 1 – 18.5m, 2 – 30.5, 3 – 42.5, 4 – 57.5m.

not allow saving the gateroads for reuse. In the case of using both types of filling wall (figure 6), the maximum stresses are located above the wall, which contributes to the cutting of the roof and its fall to the goaf. The described process is shown in figure 8. Thus, the fact that gangue concrete can replace high-support cement when creating a filling wall is confirmed. However, it is also seen that filling wall with a higher modulus contributes to the formation of higher principal stresses in the main roof. Therefore, with a console length of 18.5 and 57.5 m, the stress extremes for gangue concrete filling wall are 36.5 MPa and 46.5 MPa, and for high-support cemented filling wall – 44.0 MPa and 53.7 MPa. That is, an increase in the length of the console of the main roof from 18.5 to 57.5 MPa causes an increase in stresses by 22-27percent. Figure 7 shows that an increase in the length of the main roof console leads to an increase in stresses in the main roof, which is generally logical. The maximum influence of the console length on the principal stresses  $\sigma_1$  is observed in the section between points 6-15 along line 1 (Figure 5), that is, above the entry and the filling wall, where the maximum stresses are formed. This influence naturally grows in the direction from entry to gob. An increase in the length of the console also causes an increase in min principal stresses  $\sigma_3$ . It leads to rock and coal disintegration around the entry and also determine the deformation of one. Thus, the reserve for increasing the stability of the entry is to reduce the length of the hanging roof console. At the same time, it should be taken into account that the filling wall must withstand the load from the bending and the weight of the roof rocks without destruction.

The distribution of vertical compressive stresses surround of the entry with different types of filling wall with a console length of 18.5 m are shown in figure 9.

Figure 9 shows that an increase in the deformation modulus of the filling wall leads to an increase in compressive vertical stresses in the roof above the wall and in the floor below it. Accordingly, the loads on the filling wall also grow. Cutting of the roof from the goaf side will only occur if the compressive strength of the filling wall is higher than that of the main roof.



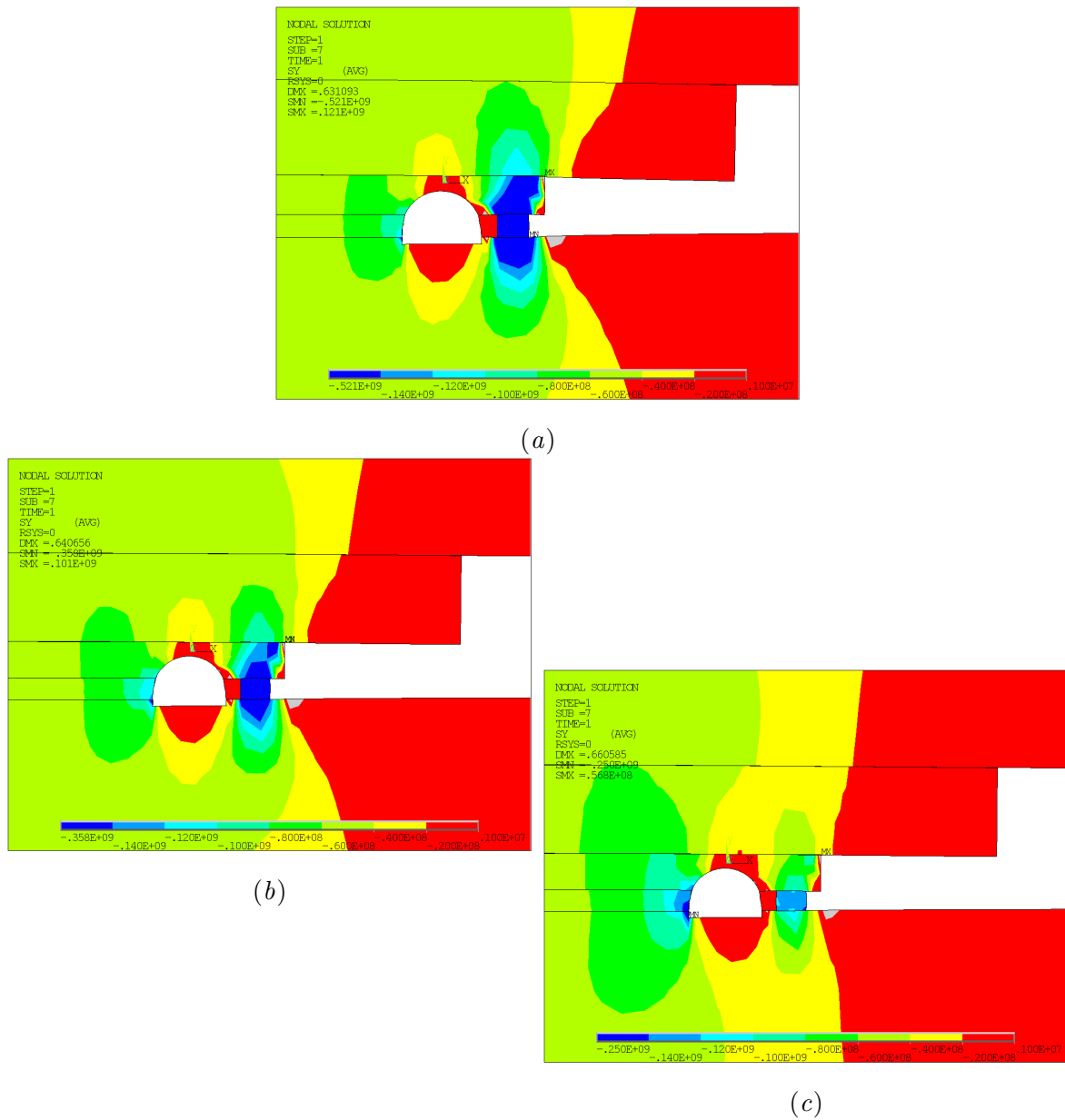
**Figure 8.** Maximum of the principal stresses  $\sigma_1$ , when using gangue concrete filling wall (a), high-support cemented filling wall (b) and console length: 1 – 18.5m, 2 – 30.5, 3 – 42.5, 4 – 57.5m.

The compressive stresses from the coal seam side decrease with an increase in the filling wall deformation modulus. They are greatest when using wooden cribs, as can be seen from figure 9a. In this case, the destruction zone around the gateroad from the side of the formation is much larger, respectively, the convergence in the entry is also. The lowest formation stresses are observed when using high-support cemented filling wall figure 9c.

To estimate of compressive stresses around of the entry and the dependence of the pressure on the filling wall on its type and the length of the console, the vertical stresses in the model were analyzed along the contact surface with the immediate roof (line 2 in figure. 5) presented in figure 10.

Figure 10 shows that the stresses from the coal seam side are maximum at a lower value of the deformation modulus and decrease with an increase in the filling wall deformation modulus. It can also be concluded that the filling wall is loaded unevenly. The pressure from the gob side is much greater than the pressure from the working side. This unevenness is the greater, the greater the modulus of deformation of the filling wall material. It is maximum for high-support cemented filling wall. In this case, the pressure difference across the width of the wall is 123 MPa between 308 and 185 MPa at the edges of the wall.

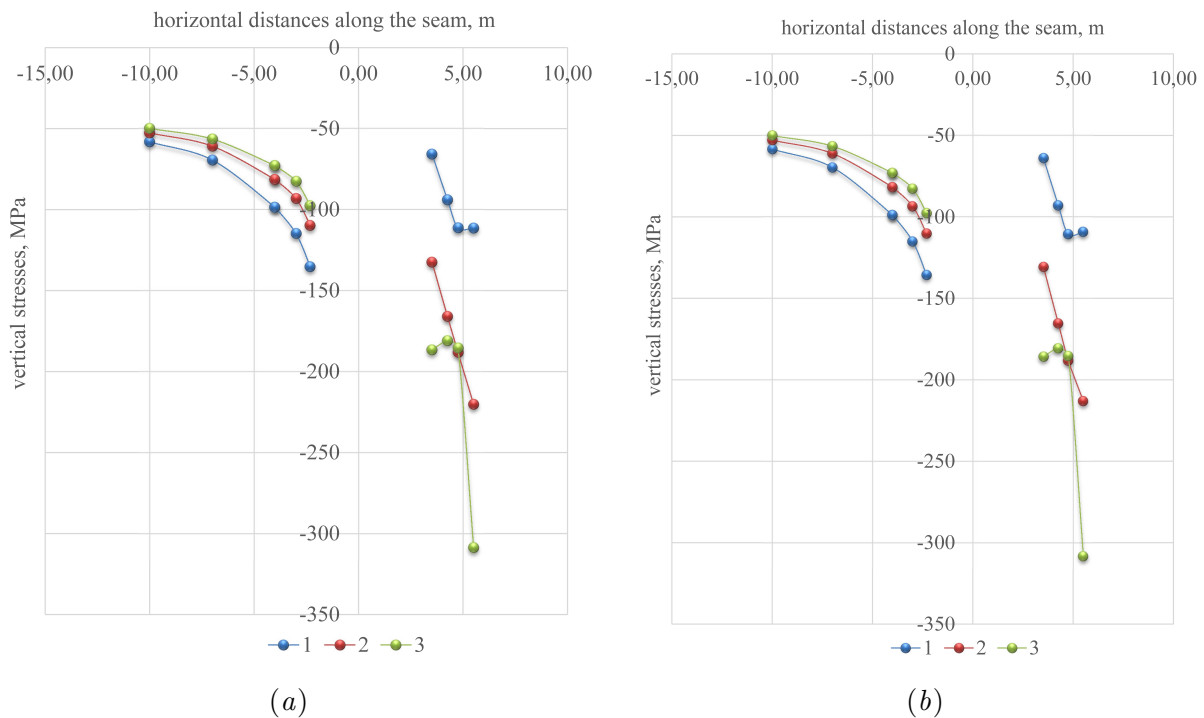
Since the filling wall in the case under consideration works for uniaxial compression, the



**Figure 9.** Distribution patterns of the vertical stresses around the head entries with a wooden cribs (a), a gangue concrete filling wall (b), high-support cemented filling wall (c).

minimum (in the algebraic sense) principal stresses in the wall are close to the values of vertical stresses, which makes it possible to determine the required strength of the filling wall material by comparing the calculated stresses with the limiting ones. In this case, the least stable is the edge part of the protective structure from the gob side.

Since the vertical stresses in the wall significantly exceed the stresses in the roof, the probability of the primary destruction of the wall remains quite high. At the same time, despite the higher bearing capacity of the high-support cemented filling wall, the risk of its destruction is higher than the gangue concrete filling wall, since the excess of the compressive stresses of the corresponding tensile strength is much greater. In the case of filling wall destruction, its



**Figure 10.** Vertical stresses along the contact surface between the massif and the immediate roof, with a console length of 18.5m (a), 57.5m (b) and using: 1 – cribs, 2 – gangue concrete filling wall, 3 – high-support cemented filling wall.

deformation modulus will decrease and the main roof will most likely be cut not above the filling wall, but above the coal seam. It will lead to significant deformation of the entry and make it impossible to reuse it. To avoid the destruction of the filling wall, it is necessary to provide appropriate measures. This may be an increase in the size of the wall, an increase in its bearing capacity, or an artificial cutting of the main roof console.

#### 4. Conclusions

Trends of coal mining are directed to implement and popularize the pillarless mining technology with reasonable economy and high safety. Reserving a gateroad for the use of next panel mining is a popular gob-side entry retaining. At the same time, it is important to improve efficiency filling wall, optimizing the entry-in support parameters. Current research proposes the using both high-support cement and gangue cement as a filling wall material. A study of the stress-strain state of the massif was carried out using the listed types of filling walls in comparison with conventional cribs. Ansys code was used. The influence of the deformation modulus of filling wall and the length main roof console on the localization of maximum stresses in surrounding rocks and respectively area of roof cutting is shown.

It is shown that when using wooden cribs, it is impossible to achieve the reuse of gateroads, since the convergence in the entries is too large. At the same time, gangue concrete can replace high-support cement when creating a filling wall. With gangue concrete filling wall, more favorable conditions are created in terms of stresses in the roof. However, filling walls are only effective if there is a cutting roof over them. If the cutting roof area is localized from the side of the rock massif, then the weight of the rocks falls on the entry and critically deforms it. Cutting of the roof from the gob side will only occur if the compressive strength of the filling

wall is higher than that of the main roof. In case of primary destruction of the filling wall, its deformation modulus will decrease, which will lead to a significant deformation of the entry and make it impossible to reuse it. To avoid the destruction of the filling wall, it is necessary to provide appropriate measures. This may be an increase in the size of the wall, an increase in its bearing capacity, or an artificial cutting of the main roof console.

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