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Investigating Effect of Induced Stresses due to Coal Panel Extraction on Next Panel Strata behavior during Mechanized Longwall Mining: a Case Study

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Abstract

Due to longwall mining, a large space without any support is created, and the in-situ stress regimes change. The change of the in-situ stress regimes affects the roof and face of the adjacent panel. In other words, the strata behavior would be different from the intact condition during the previous panel mining. In this study, two adjacent panels are simulated in the FLAC3D software to study the effect of panel extraction on its adjacent panel strata behavior during longwall mining. The available data of the Tabas Parvadeh Coal Mine panels is used for this purpose. According to the numerical modeling results, the length of the first roof's weighting effect (FRWE) in the gob of the first and second panels is calculated, respectively, as 26 and 21 meters. In other words, the gob dimension in the second panel is reduced by about 19.2%, and the vertical displacement value is increased by about 18.5%. In addition, the chance of roof collapse and face spalling during the first-panel mining is more than the second-panel. It means that roof and face instability in the (FRWE) during the first-panel mining is confirmed, while in the second-panel extraction is just very likely.

1. Introduction

By drilling a rock mass or soil, the condition of the in-situ stresses around the drilled space changes, depending on the underground space size and shape. Accordingly, the behavior of the rock mass or soil changes. The strata deformation will continue until the induced stresses reach an equilibrium. In other words, the rocks around the structure are deformed until they can bear the induced stresses caused by underground space extraction. This deformation does not always have an elastic behavior, and sometimes a plastic deformation or rock failure might occur on the mass of surrounding rocks. The surrounding rocks' failure and deformation and the strata displacement have a direct impact on underground space stability, and cause roof collapse and walls spalling.

In the longwall mining method, a large space without any support is created, named "gob" or "goaf". The coal extraction disturbs the equilibrium of in-situ stresses, and redistributes the in-situ stresses. By extracting the coal seam, the weight of the above layers is applied to the face and pillars. The larger the size of the gob, the intensity of the loads on the face and pillars (barrier and chain pillars) increases more. In addition to panel strata deformation, the surrounding layers will also deform [1,2].

These changes in the extraction area also affect the in-situ stresses distribution around the un-extracted adjacent panel. Thus, the strata behavior will be unexpected, which risks continuing the mining operation in new panels. Therefore, investigating the effect of panel extraction on the adjacent panel is very important. In general, mine engineers always face various challenges in underground methods because of the complexity of

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geological structures and strata behavior during mining. Therefore, understanding the strata and sub-surface structure behavior will help to apply these methods safely and economically.

An essential issue in the drilling of underground spaces is the stability of the roof and walls. Coal mines, due to the low resistance of coal, have a high sensitivity from the stability point of view. Accordingly, another major issue in the longwall method is the stability of the face based on the gob-induced stresses. Therefore, in the longwall method, the assessment of face stability and caving behavior of the roof strata in the gob due to the induction of in-situ stresses is important.

Recently, many researchers have studied strata behavior in underground mining. Kwaśniewski studied the coal panel's roof seam behavior by using a discrete element method in the UDEC software [3]. Hosseini *et al.*, by studying the roof properties and using numerical modeling, calculated the first roof weighting effect interval (FRWEI) and periodic roof weighting effect interval (PRWEI) value in the longwall method [4]. Bai *et al.* modeled the rock mass and support system using the FLAC2D software, and investigated the face spalling [5].

Ptáček *et al.* comprises stress monitoring, primarily of the changes induced by longwall mining or destress blasting, which was realized in a mine of the Ostrava-Karviná Coalfields [6]. Rezaei *et al.* (2015) determined the longwall mining-induced stress using the strain energy method [7]. Barbato *et al*. provided predictive equations for bay length difference based on a two-step process. The focus of this research work was to extend these predictive equations based on wider ranges of the mining geometry and overburden lithology [8]. Li *et al*., by using physical simulation and beam theory analysis, found that the roof seam near the tailgate would fall by undercutting while the upper seam of the main gate moves slowly and never falls [9]. Kang *et al.* created a large-scale physical model based on a real case, and a numerical model was introduced based on the configuration of the physical model to simulate massive roof collapse during longwall coal retreating mining [10]. Tulu *et al.* developed a numerical-model-based approach, were for estimating the changes in loading conditions induced by an approaching longwall face [11]. Ozdogan *et al.* presented a method to determine the optimal set spacing for support system applying in section A of the Omerler underground coal mine [12]. Rezaei (2018) analyzed the long-term stability of the goaf area in longwall mining using the minimum potential energy theory [13]. Sinha *et al.* used an extensive suite of borehole pressure cell data to advancing the knowledge of the stress redistribution process in longwall chain pillars [14]. Boothukuri *et al*. elucidated that the main roof weighting interval decreases with an increase in face width and attains a constant value with further increases in face width under the same geo-mining conditions [15].

Rezaei (2019) revealed a new coefficient for forecasting stress concentration around the mined panel using a soft computing methodology [16]. Ansari Ardehjani *et al.* calculated and predicted the first and periodic roof weighting effect interval at one of the panels in the Tabas Parvade Coal mine, using numerical modeling [17]. Islavath *et al.* described a methodology for the estimation of roof-to-floor convergence using numerical modeling during the web cut [18]. Le *et al.* studied the roof strata behavior during underground coal mining. They confirmed that an increase in the value of the mechanical property of the immediate roof, and coal bedding spacing, improves the stability of top coal before its first fall [19]. Fei *et al*., using numerical modeling to studied the roof strata behavior and failure, during underground mining. They studied the first and periodic roof fall by a mechanical model [20]. Ansari Ardehjani *et al.* investigated the effect of seam slope in the mechanized longwall operation and its impact on the roof strata behavior [21].

Investigating the literature of longwall mining and the assessment of strata behavior due to induction of in-situ stresses are very important in longwall mining methods, and there are only a few studies that have investigated the effect of coal panel extraction on the adjacent panel in longwall methods. Thus in this study, a panel under intact condition is simulated, and its extraction effect on the adjacent panel extraction in the mechanized longwall method is investigated. For this purpose, the Tabas Parvadeh Coal Mine's geological, geo-technical, and engineering data are used for model validation. First, a coal panel (panel A) is simulated in the FLAC3D software, and the effect of coal extraction on the face stability and roof caving under intact conditions is investigated. Then another panel (panel B) is developed, which is adjacent to pPanel A, and the strata behavior is assessed under the new condition of stresses.

2. Case Study

The Tabas Central Coal Mine (TCM) is located in the Tabas coal region in the South Khorasan Province of Iran. Tabas Parvadeh Coal Mine is the only fully mechanized longwall mine in Iran and the Middle East. This research work has been done by simulating the E3 panel.

The E3 panel is located at a depth of 440 meters in the eastern part of Parvadeh, inside the coal seam C1. The barrier pillars with 30 meters thickness are designed to provide stability for the maingate and tailgate. The boundary between the two adjacent panels is 30 meters. Face advance is made retreating along the seam C1 at a 10-degree slope [22]. The geological column of panels and the seam thickness are given in Table 1.

Table 1. The layer thickness around the coal panel.

Rock type	Thickness (m)	Layer location
Sandstone	7	Roof
Silty-Sandstone	18	Roof
Argillite	2	Roof
Coal C2	1	Roof
Silty-Sandston	16	Roof
Coal C1	2	panel
Silty-Sandston	5	Floor
Siltstone	3	Floor
Sandston	6	Floor

3. Numerical Modeling

To study the strata behavior during longwall mining and investigate the effect of panel extraction on its adjacent panel strata behavior, a block model is constructed in the FLAC3D software. The block size is 530 × 200 × 92 m^3 to be able to develop two coal panels with 210 × 170 × 2 m^3 dimensions in the model.

The mesh size of the exact and accurate study is considered 1 x 1 x 1. This mesh size is applied 25 meters above and 20 meters beneath the extracted coal seam. In the boundary conditions, the model is fixed at the floor to prevent movement in the x, y, and z directions. The walls of the model are fixed only in the x and y directions to simulate the subsidence of the strata. By considering these boundary conditions, the model remains stable, and the software can effectively solve it. The model boundary conditions in Figure 1 are depicted.

A barrier pillar with a 30 m width is considered between the panels (Figure 2). The panel opening and panel dimensions are considered according to the panel's dimensions of Tabas coal mine. The panel opening dimensions are presented in Table 2. The amount of roof displacement, face stresses and, shear strain in the gob, face, and its roof was investigated in two panels; then the results were compared together. First, the linear Mohr-Coulomb model was applied to rock mass, and then after observing the first roof weighting effect on panel A, the double-yield model was applied to the caving zone. The geo-mechanical properties of rock mass used for the block models are presented in Table 3. All numerical modeling steps have been done according to the FLAC3D manual.

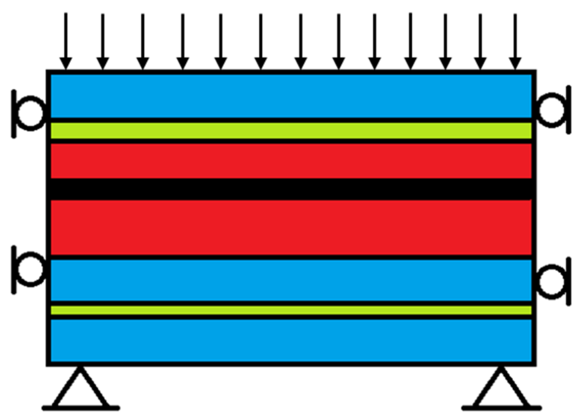


Figure 1. The boundary conditions in the constructed model.

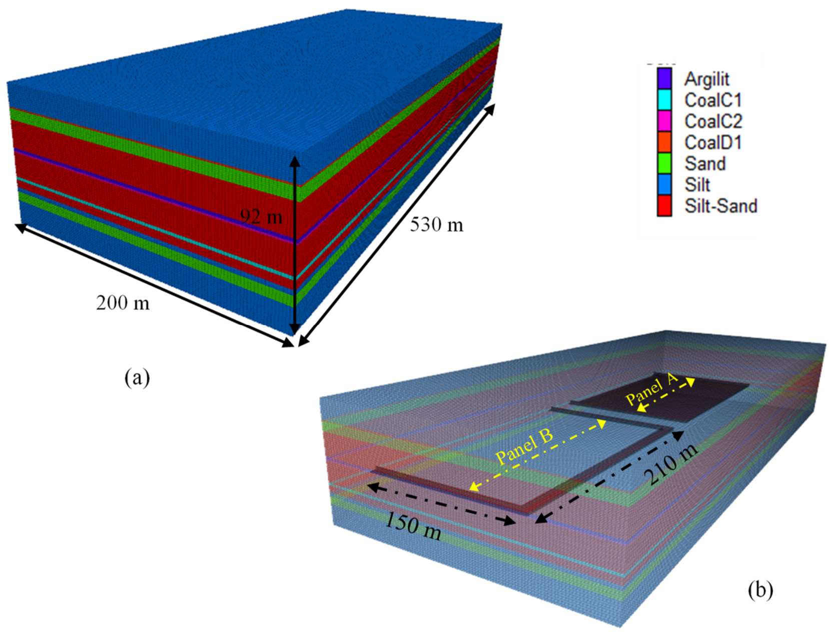


Figure 2. a) The constructed model in FLAC3D; b) The panels A and B located in the block model.

Table 2. The dimensions of the panels in the numerical model.

Opening	Length (m)	Width (m)	Height (m)
Main gate	150	5	3
Tailgate	150	5.5	3
Bleeder	210	7	3

Table 3. Rock mass properties in E3 panel [17-19].

Rock type	Cohesion (MPa)	Friction angle (φ)	Tensile strength (MPa)	Poisson (ϑ)	Deformation modulus (GPa)
Siltstone	1.8	30	0.08	0.26	2.4
Silty-sandstone	4.26	50	0.09	0.25	2.34
Coal	**0.33**	**34**	**0.009**	**0.25**	**0.09**
Mudstone	0.18	26	0.017	0.31	1.86
Sandstone	4.25	35	0.1	0.25	2.72

After constructing the model and applying the boundary conditions and constitutive models, the model is solved. When the model reaches equilibrium, the panel opening is drilled. Then the rock bolts and steel frames are installed as a support system. The model is then solved again to achieve balance. The sequence of drilling is similar to the patterns of Tabas Parvadeh Coal Mine's panel development. To model the rock bolts and steel frames in FLAC3D, the cable and beam elements are used, respectively. The powered support system is applied as an extensive load. To apply this load on the panel face and roof, the shell element is used to simulate the support system, then the load is applied to these shells. The properties of the support system are presented in Tables 4 and 5.

Table 4. The properties of the steel and fiberglass rock bolt [22].

Rock bolt type	Cross-section A (m^2)	Elasticity modulus E (GPa)
Steel	0.0005	200
Fiberglas	0.0005	40

Table 5. The properties of the steel frame [22].

Young modulus (M/L^3)	Poisson ratio	Cross-section (L^2)	Horizontal axis second moment (L^4)	Vertical axis second moment (L^4)	Polar moment of inertia (L^4)
2×10^{11}	0.3	23.9×10^{-4}	101×10^{-8}	101×10^{-8}	123×10^{-7}

After developing panel A, the coal layer is extracted in 2-meter cuts until the first roof fall occurs. The amount of roof displacement, face stress, and shear strain in the gob roof, face, and roof above the face is calculated in this panel. After the first roof fall occurrence on panel A, it is extracted until the 30th cut. When the first roof fall occurs, the double-yield constitutive model is applied to the caving zone behind the supported system. During the panel A extraction, panel B was developed. When panel A extraction is finished, panel B is extracted, and the required data was collected. Then the results were compared together.

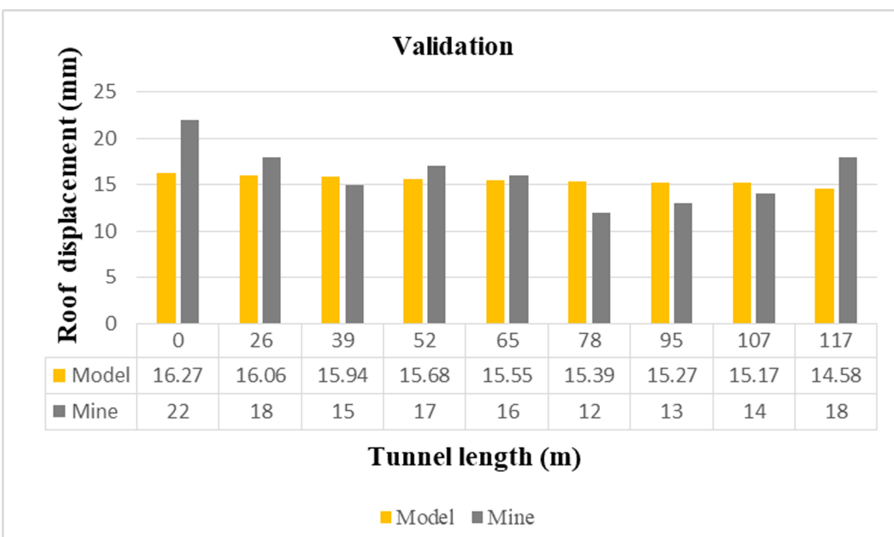
3.1. Model validation

For model validation, the vertical roof displacement data is extracted from the model before the coal extraction and compared with the data from the Telltale. The comparison graph of the extracted data from the Telltales and the data obtained from the numerical modeling is shown in Figure 3. The relationship between the Telltale data and numerical modeling data has been investigated by Root Mean Square Deviation (RMSD). The value of RMSD is calculated according to Equation 1.

$$RMSD = \sqrt{\frac{\sum_{i=1}^{n}(x_{1,i} - x_{2,i})^2}{n}} \quad (1)$$

In this equation, ($x_{1,i}$) represents the first set of data, ($x_{2,i}$) the second set of data, and (n) is the number of entries in each set. After comparing these two sets of data, the RMSD was calculated as 3.9 mm. This deviation in calculations due to human mistakes in noting the Telltale data and simplifying numerical modeling is acceptable.

To monitor the roof displacement for model validation, some history points were defined on the roof of the main gate and tailgate. The history points were put exactly at the same place as the Telltale in the gate road of Tabas Mine. These points monitored the vertical roof displacement after E3 panel development. In Figure 4, the location of history points in panels A and B is shown. Using these history points, the vertical roof displacement in the gob of panels after each coal cut was also monitored.



	0	26	39	52	65	78	95	107	117
Model	16.27	16.06	15.94	15.68	15.55	15.39	15.27	15.17	14.58
Mine	22	18	15	17	16	12	13	14	18

Figure 3. Comparison between Telltale and numerical values.

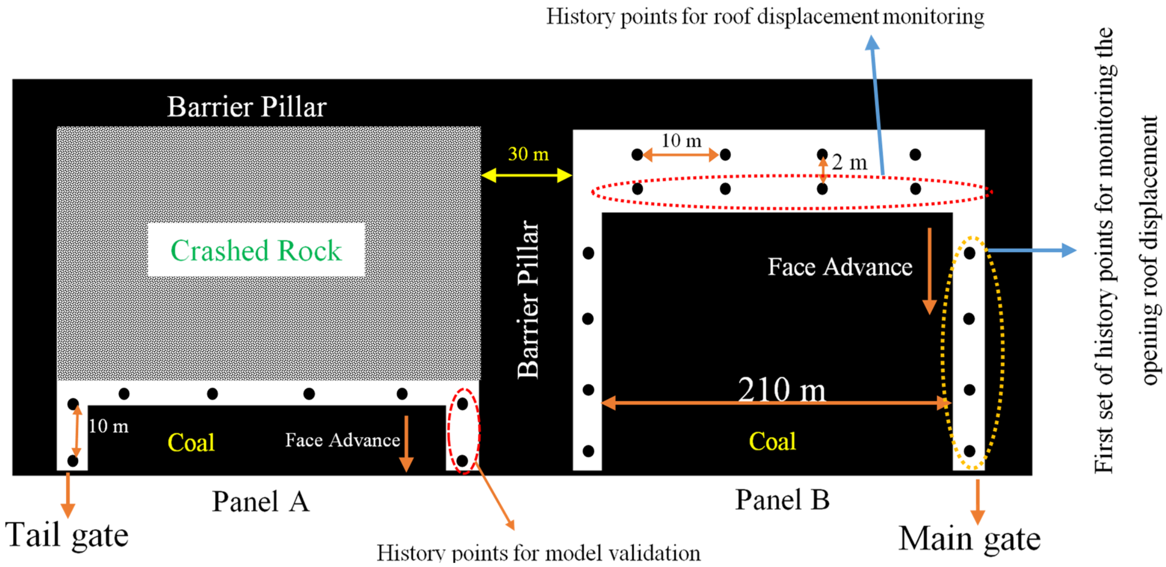


Figure 4. The location of history points and panels in numerical modeling.

3.2. Behavior investigation of roof strata of panel A

The failure extension process form is shown in Figure 5. Based on numerical modeling, failure start and shear cracks maiextension happen at the floor of the earliest extracted cuts in panel A. It means that failure begins on the floor seams on the gob with upward floor movement (Figure 5.a). By advance of the face, shear cracks gradually expand to the roof. Because of the installation of rock bolts to support the bleeder's roof, the roof failure starts developing from the top of the powered support system and newly extracted area. With the advance of the face, failure extends through the gob roof and floor (Figure 5 (a to d)). Shear and tension are two components of the failure mechanism, and shear-n and tension-n show that the plastic and failure condition is active. Shear-n and tension-n also mean that the mesh is in the shear and tension condition. However, shear-p and tension-p mean that the mesh was before in the shear and tension condition but not now. In other words, plastic and failure conditions are passive [23].

The stress changing after coal extraction in panels A and B is shown in Figure 6. Based on numerical modeling, the stress concentration occurred at a 7- or 8-meters distance from the face and barrier pillar (Figure 6.a). The changes in vertical stresses after panel A development and coal extraction are shown in Figure 5.b. According to these figures, the main stress concentration happens in the vicinity of the panel A opening and its face corners, where the possibility of instability is very high. Thus, to continue coal extraction, the cuttable rock bolts should be installed to support these areas during the coal extraction. By assessing the contour of vertical stresses on the face of panel A and drawing the diagram of stress changing, it is concluded that after the ninth cut extraction, the trend of vertical stress curve changes to descending, and the concentration of stress on the face is reduced. Thus, the first roof failure happened after the ninth cut extraction, and the value of the first roof weighting effect interval (FRWEI) was calculated as 26 meters. The graph of vertical stresses changes after each coal cut, and the time of first roof weighting effect (FRWE) is shown in Figure 7.

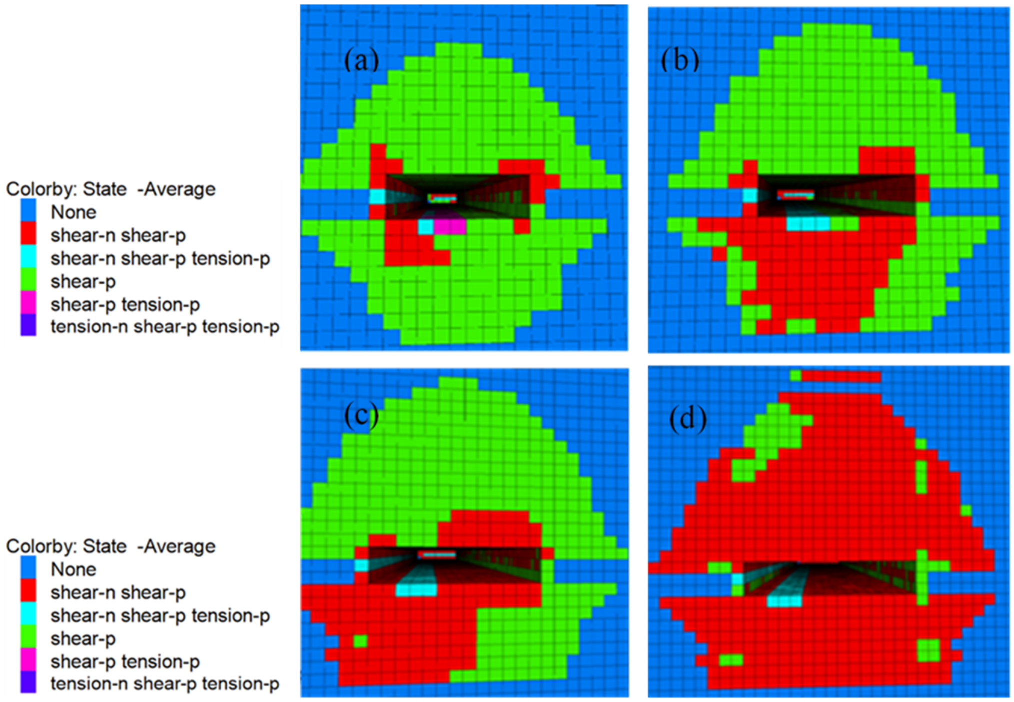


Figure 5. Failure extension process form (a to d).

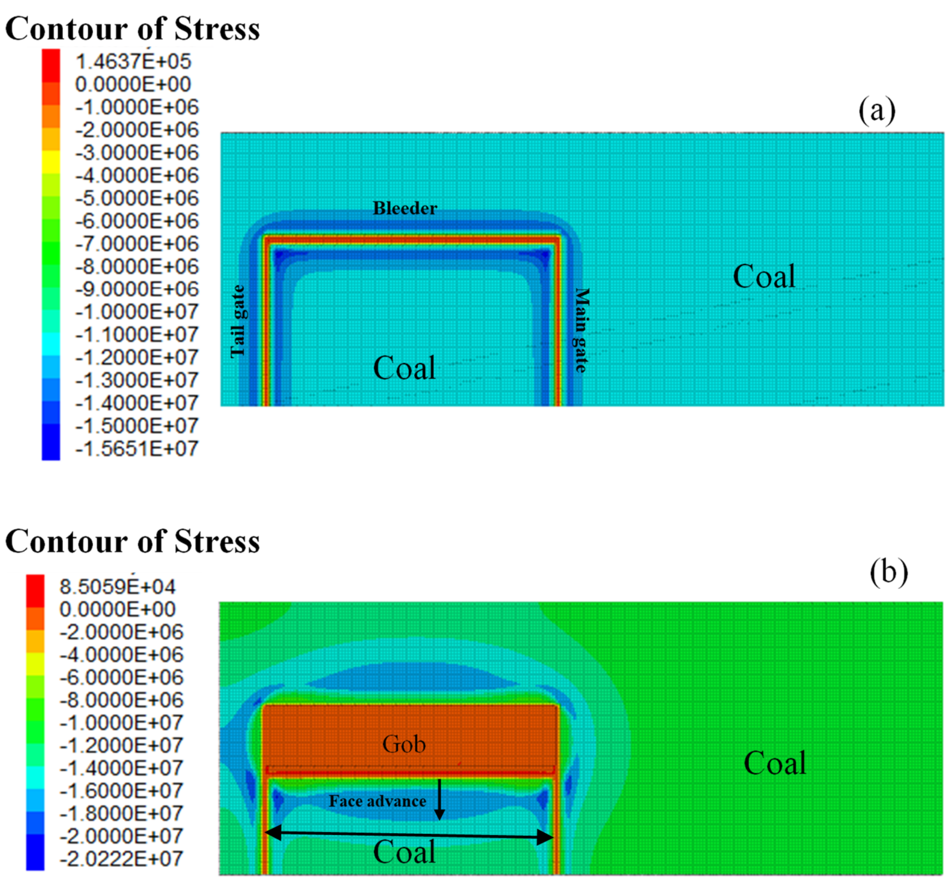


Figure 6. a) Stress condition after panel A development; b) Stress condition after coal extraction.

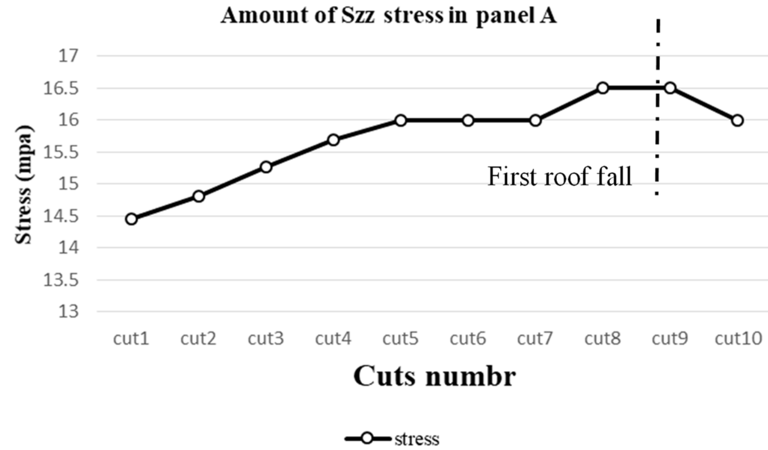


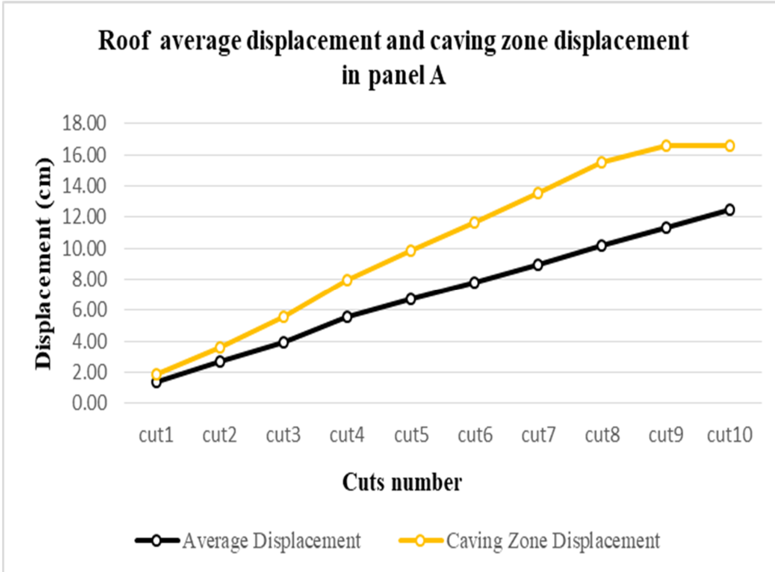
Figure 7. The vertical stress variation diagram on the face for each coal cut extraction in panel A.

Changes in vertical roof displacement are shown in Figure 8. In the longwall mining method, the roof of the gob moves downward. By face and supported system advance, the vertical roof displacement increases. Based on numerical modeling, the first roof fall happened approximately at 9 meters distance from the barrier pillar at the roof of the first extracted coal cut because the highest displacement for the roof was recorded here. The diagram of roof average vertical displacement and caving zone vertical displacement after ten coal cut extractions is shown in Figure 8.a, and the diagram of roof average vertical displacement and caving zone, vertical displacement for stress variations in each coal cut extraction is shown in Figure 8.b.

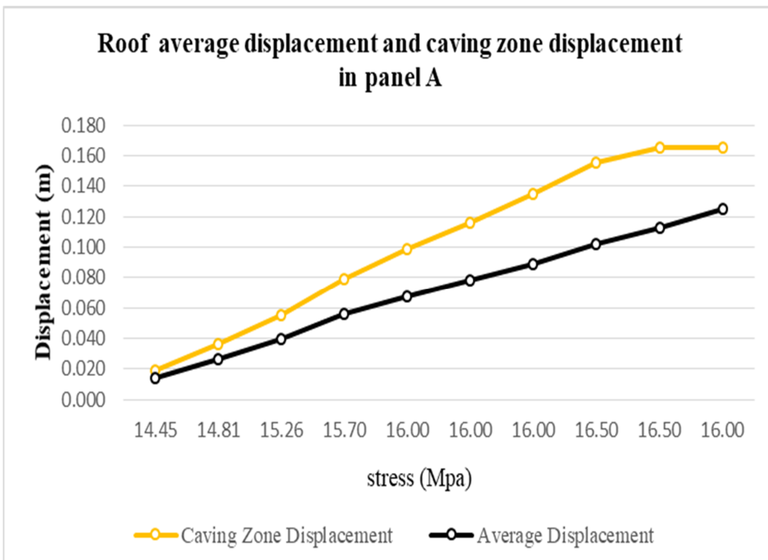
3.3. Investigating effect of panel A extraction on strata behavior of panel B

After the calculation of the FRWEI in panel A, the panel is extracted completely. It should be noted, after coal extracting by longwall mining method, the strata will be moved at the top of the gob, and the in-situ stresses are change. This phenomenon is continued until the strata do not move, and it's taken time until the strata stopped movement. If, the next panel develop and extract immediately, after finishing of the first-panel extraction, the extracting data from numerical modeling will be wrong. To avoid resulting the wrong results from numerical modeling and, doing a correct simulation of coal extraction, strata movement and, their effect on the adjacent strata movement, and inducted stresses at longwall mining, the model solved thousands time using cycle command code, until the inducted stresses around caving zone and drilling space did not change. It is mean the strata will not move and, the model is at the equilibrium. After all of this, panel B is developed, and the openings of the panel are drilled. Also, by monitoring the changes of the trend of unbalanced forces chart, this aim is possible. When the trend of changes of the unbalanced forces chart gets constant, developing of the second-panel is possible.

After the first roof fall, the double-yield model is applied to the caving zones according to the instructions given in Section 3.2. The applied stresses on the face and pillars, vertical roof displacement, the shear strain of the face, and all other necessary information after every coal cut is recorded. The corresponding charts are plotted. The changes of in-situ stresses after the development of panel B (Figure 9.a) and coal extraction on panel B (Figure 9.b) are shown in Figure 9.



(a)



(b)

Figure 8. a) Roof average vertical displacement and caving zone vertical displacement after ten coal cut extractions in panel A; b) Roof average vertical displacement and caving zone vertical displacement for stress variations in each coal cut extraction in panel A.

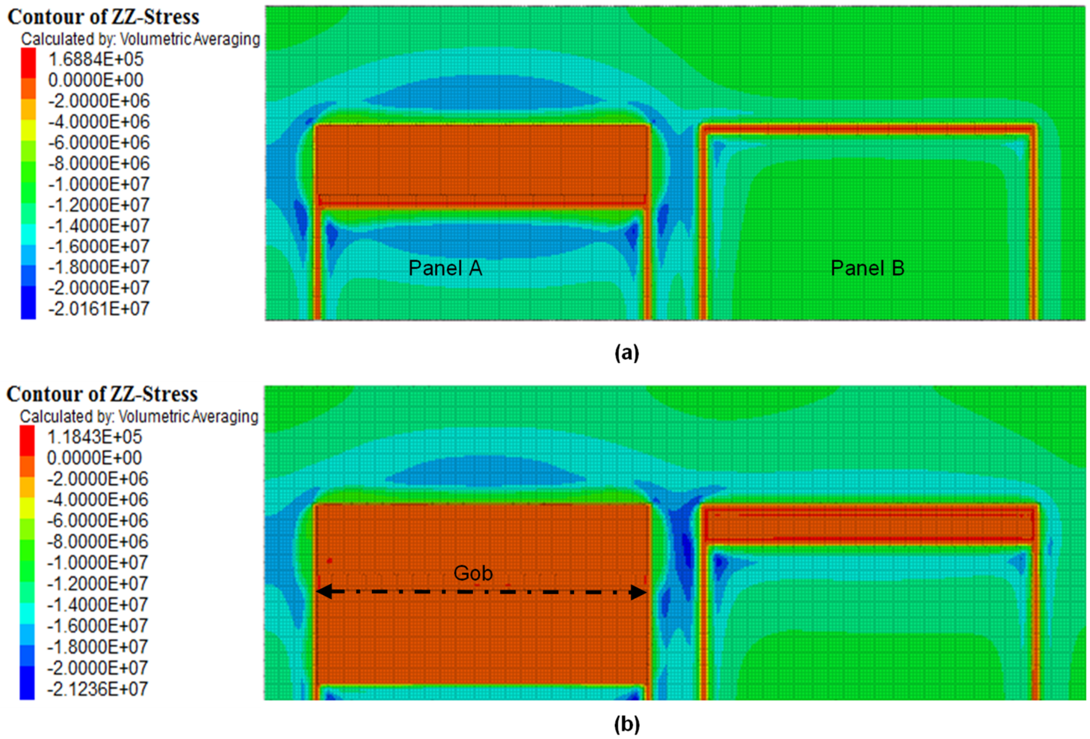


Figure 9. Change of in-situ and induced stresses after panel B development (a), and coal extraction in panel B (b).

The comparison of stresses applied to the face during coal extraction at panel A and panel B is provided in Figure 10. Based on this figure, the average applied stress on the face in panel B is less than in panel A. The maximum applied stress on the face of panel B in the 7th cut is about 16.4 MPa, and after that, stress is reduced. However, the maximum applied stress on the face of panel A is about 16.5 MPa and occurred in the 8th and 9th cuts, and then after the first roof fall, the stress reduced. Based on the trend of stress changes, FRWEI in panel B is about 21 m, which is less than the FRWEI of panel A (26 m). Furthermore, after the 9th cut extraction, there a rise, and this stress increase at the 10th cut (15.8 MPa) is less than the maximum calculated value at the 9th cut (16.4 MPa); it happened because of the beginning of the periodic roof weighting.

The contour of vertical stress after panel A extraction and before panel B extraction is shown in Figure 11. Two factors have contributed to stress reduction in panel B. First, because of the upward movement of stress concentration, by face advancing in panel A, the stress concentration moved upward on the roof strata. As a result, the applied stress on the separating barrier pillar (pillar between panel A and panel B) is concentrated in the upper location, compared to the intact condition. Less stress is applied to the face and barrier pillars. Thus, the average stress is reduced. The second reason is the strata deformation due to the roof collapse and roof failure in the gob of panel A. When the roof moves downward in the gob of panel A, the horizontal position of the roof layers is changed and deformed. Strata deformation depends on layer type, layer thickness, coal thickness, rate of face advance, and other factors. Before collapsing, roof strata act as a bridge and transmit the induced stresses on the face and barrier pillars. However, with the deformation of the layers, this bridge will be out of horizontal shape, and its ability of load transmission is reduced. In this case, the slope of the layers is towards the extraction space (gob space), and as the distance from the gob is increased, the layers become horizontal and can transmit the load very well. Thus, by face advance in panel A, the stress concentration is transmitted to the end of the deformed strata, and by increasing the vertical displacement, the stress concentration moves upward.

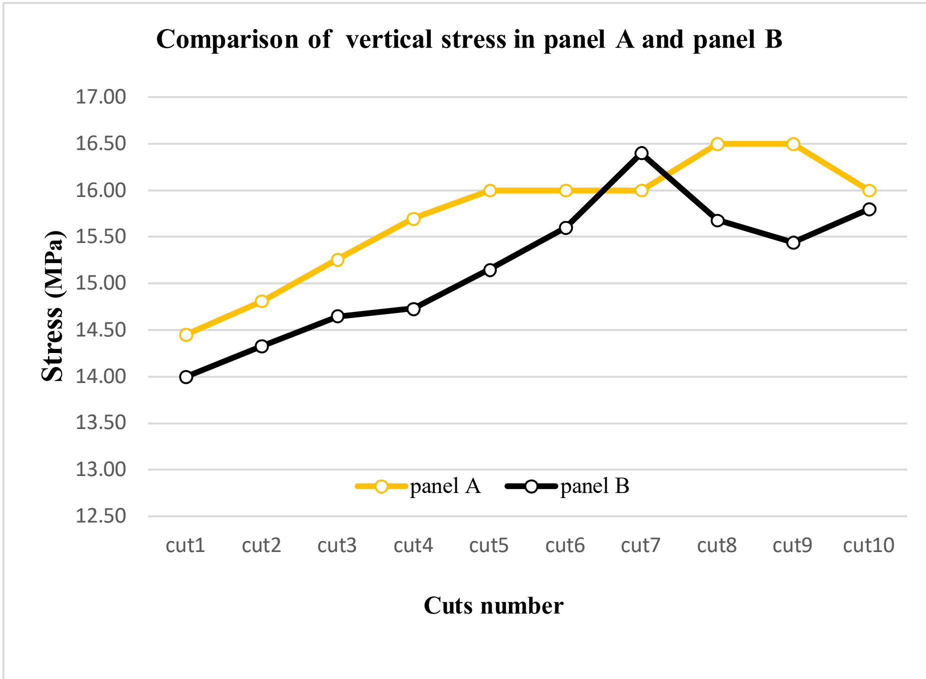
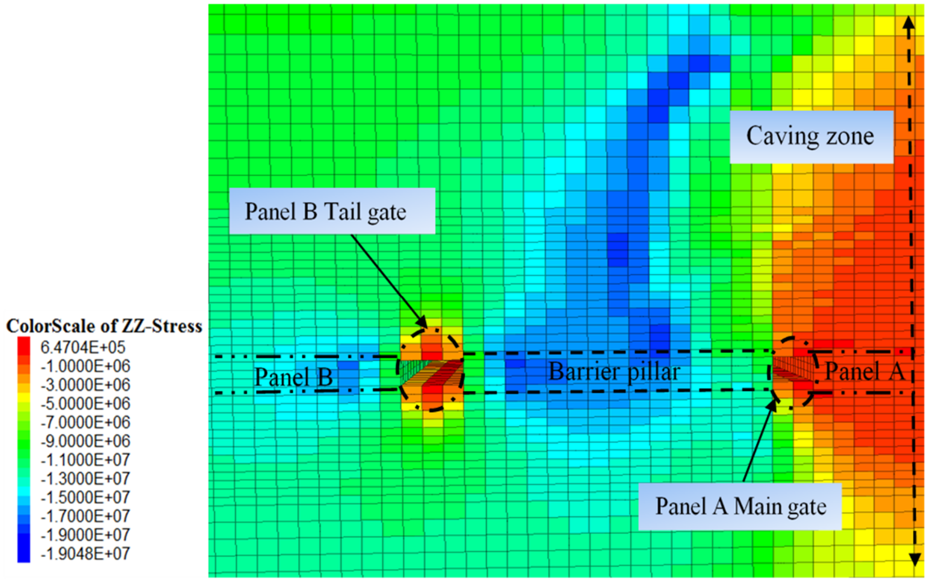


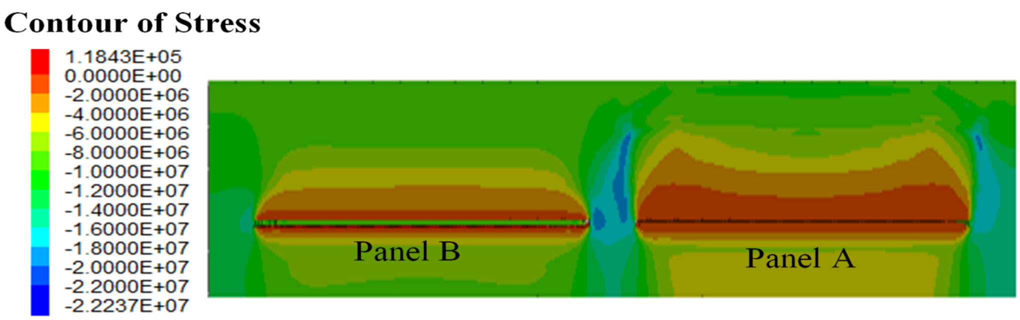
Figure 10. Comparison of vertical stress in panel A and panel B.

By extracting panel B, for the layers on the roof, one side of them is in the caving zone resulting from the extraction of panel A and the other side is in the intact area. Thus, the roof layers in panel B collapse in low-stress conditions compared with the roof layers of panel A. Therefore, lower abutment pressure is applied to the face and pillars of panel B. This factor causes a difference in the average amount of applied stress on the face and the vertical roof displacement in panels A and B. The comparison of average displacement and caving zone displacement in panels A and B are, respectively, shown in Figures 12.a and 12.b. In other words, integrated horizontal layers prevent excessive vertical roof displacement during panel extraction. Still, after extraction of panel A and roof failure, roof strata are deformed, and their ability to prevent the downward movement is reduced. This is the reason for the vertical displacement increase on panel B relative to panel A. Thus, the first failure point in panel B is located at 6 meters distance from the barrier pillar, and for panel A, it is about 9 meters. Based on numerical modeling the roof displacement in panel B (121.6 cm) is also more than in panel A (102.6 cm), and the first roof weighting effect interval in panel A (26 m) is more than that panel B (21 m). Note that the phrase of average displacement in the text means the average of whole vertical roof displacement after ten coal cut extractions.

To better understand the impact of a panel extraction on the adjacent panel layers behavior and applied stresses, the changes of the abutment pressure chart in each panel must be compared together. The difference between abutment pressure in panel A and panel B is shown in Figure 13. These profiles show a width section of panel A and panel B. Obviously, after panel A complete extraction and strata deformation at above of the extracted zones, the most value of abutment pressure in the barrier pillar and face in panel B is about 2 MPa lesser than this values in panel A. It refers to strata deformation at the top of the crash zone. This deformation is revealed in Figure 11.

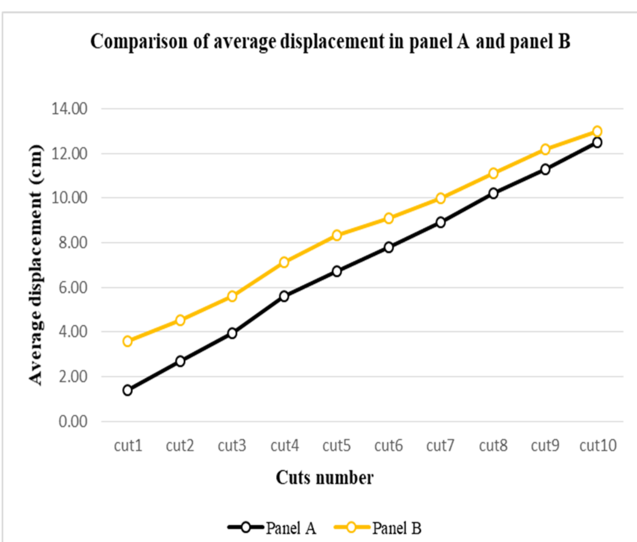


(a)

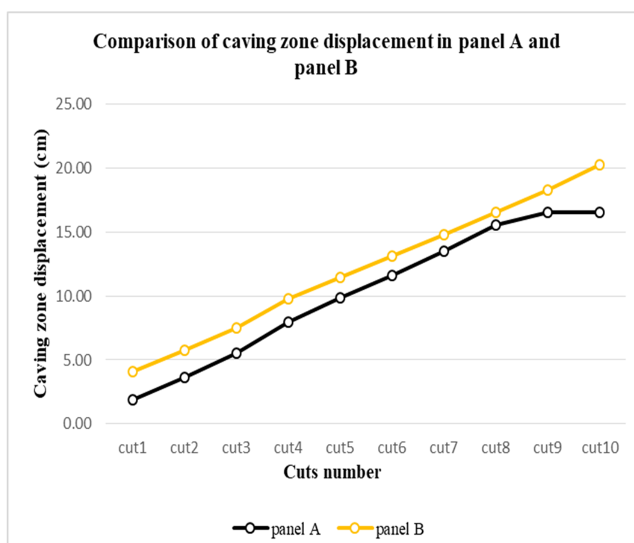


(b)

Figure 11. The Contour of vertical stress after panel A extraction and before panel B extraction. a) Applied stress on the barrier pillar located between panel A and panel B; b) Front view of both panels.

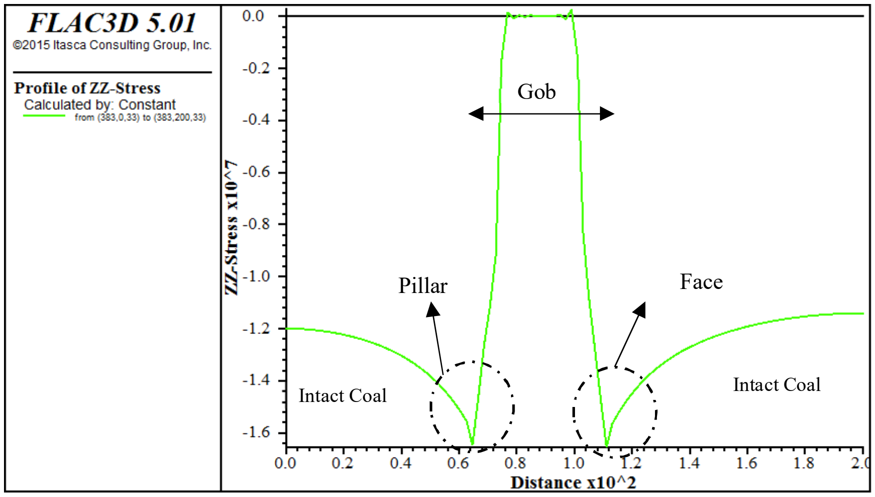


(a)

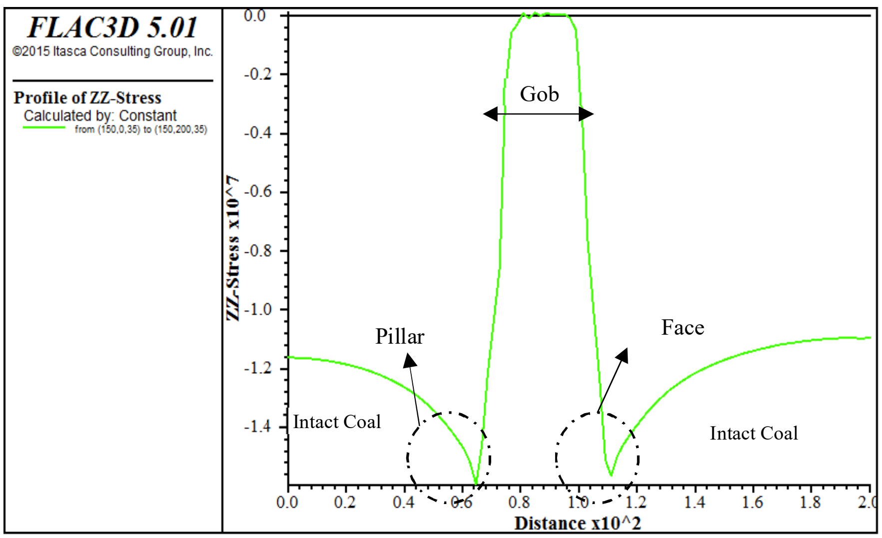


(b)

Figure 12. a) Comparison of average displacement in panel A and B; b) Comparison of caving zone displacement in panel A and B.



(a)



(b)

Figure 13. a) Panel A abutment pressure after 10 coal cuts. b) Panel B abutment pressure after 10 coal cut.

3.4. Investigation of face stability during coal extraction in panel A

The face stability and reduction of the effect of induced stresses due to roof caving in the gob space is another important issue in longwall mining. The wall spalling is one of the most common issues in instability of the coal face. Due to the stress concentration in the intersection between the roof and the face, shear joints are created, and dissimilar blocks are formed in this area. These created blocks may fall before coal extraction, and due to this fall, the distance between the face and the powered support system will increase. This distance is called Tip-to-Face. By increasing the Tip-to-Face distance, the amount of face stress increases, which will raise the risk of coal fall. Roof and face materials in this study are, respectively, silty sandstone and coal.

To determining the stability of face and its roof during longwall mining, the Sakurai Equations (Equation 2 and 3) are used. This criterion is developed for first time to determining the stability of the underground space [24]. After calculating the shear strain values of the walls from numerical modeling after each cut, this amount are compared with the critical shear strain calculated in the Sakurai equations. If the calculated value of the shear strain, which extracted from numerical modeling is greater than the Sakurai amount, the face may be unstable. The calculated values of the critical shear strain of the Sakurai equations are presented in Table 6.

$$\log\varepsilon_c = -0.25\log E - 1.22 \quad (2)$$

$$\gamma_C = (1 + \vartheta) \times \varepsilon_c \quad (3)$$

Table 6. The calculated value of critical shear strain by Sakurai Equation.

Rock type	Poison's ratio (ϑ)	E module (Gpa)	Critical strain $\varepsilon_c \times 10^{-3}$	Critical shear strain $\gamma_c \times 10^{-3}$
Silty sandstone	0.3	2.4	4.82	6.07
coal	0.25	0.09	10.94	13.68
Sandstone	0.3	2.72	5.83	5.83

By investigating the numerical modeling results, after extraction of the first two coal cuts in panel A, the face and roof remained stable. But after the extraction of the third coal cut, the shear strain value of the face and roof is equal to a critical amount of shear strain. This means that the possibility of the face and roof collapse will increase. After extracting the fourth coal cut, the shear strain is more than the critical value in the face and roof, which causes failure and instability. As the longwall mining continues, the roof and face are unstable until the first roof fall in the ninth cut occurs. The change process of the face and roof shear strain after ten coal cut extractions is shown in Figure 13.

3.5. Investigating effect of panel A extraction on the face stability of panel B

The change of face and its roof shear strain is shown in Figure 14. Based on numerical modeling results, by coal extraction in panel B, the face strain and its roof are more than the critical value, so they are unstable. This condition has continued until the third cut. After the third cut extraction, the face and its roof are in rich, stable conditions (Figure 14). This stability is maintained even during the first failure of the roof in the seventh section, where the highest amount of stress has been applied to the face. This happens because of applying new induced stresses on the strata of panel B and relative reduction of average applied stress on the face and roof of panel B due to extraction of panel A. It means that roof caving on panel A causes relative stability on the face of panel B and its roof. Installation of cuttable rock bolt for safe coal extraction in nine first cuts on panel A is necessary, but in panel B, rock bolt installation is probably necessary for the first three cut extractions. A comparison of shear strain changing between panel A and panel B is shown in Figure 14.

3.6. Study of applied stresses on panel B main gate and tailgate

Based on numerical modeling, the most load applied to the tailgate, and the main gate in panel B is applied at a distance of 15 meters from the opening. By increasing the distance along the face, this value is decreased (Figure 15). The maximum applied stresses on the main gate are also occurred at 4 to 6 meters along the coal face, while by approaching the tailgate, the applied stresses are constantly increased. Generally, the average applied stresses on the tailgate are more than on the main gate. It means that the tailgate is under more stress and needs more support than the main gate because it is located in the vicinity of panel A caving zone. In addition, the face in the vicinity of the tailgate is probably unstable. The trend of stress changes around panel B opening during coal extraction is shown in Figure 15.

Changes in the face applied stresses in the tailgate, and main gate vicinity are shown in Figure 16. According to Figure 16.a, roof failure is started near the tailgate after the 6^{th} cut (the complete roof failure happened during the 7^{th} cut extraction, but roof failure started at the vicinity of the tailgate after the 6^{th} cut extraction). The stress increase in the vicinity of the tailgate is visible after the 6^{th} cut, while the stress increase around the main gate happened after the 7^{th} cut extraction (Figure 16.b). Moreover, the average applied stress on the face is increasing after the 7^{th} cut extraction in the vicinity of the tailgate, and after the 10^{th} cut extraction, applied stresses on the face are diminished because of roof failure. It should be noted that the applied stresses on panel A are equal for both the main and tailgates during the longwall mining.

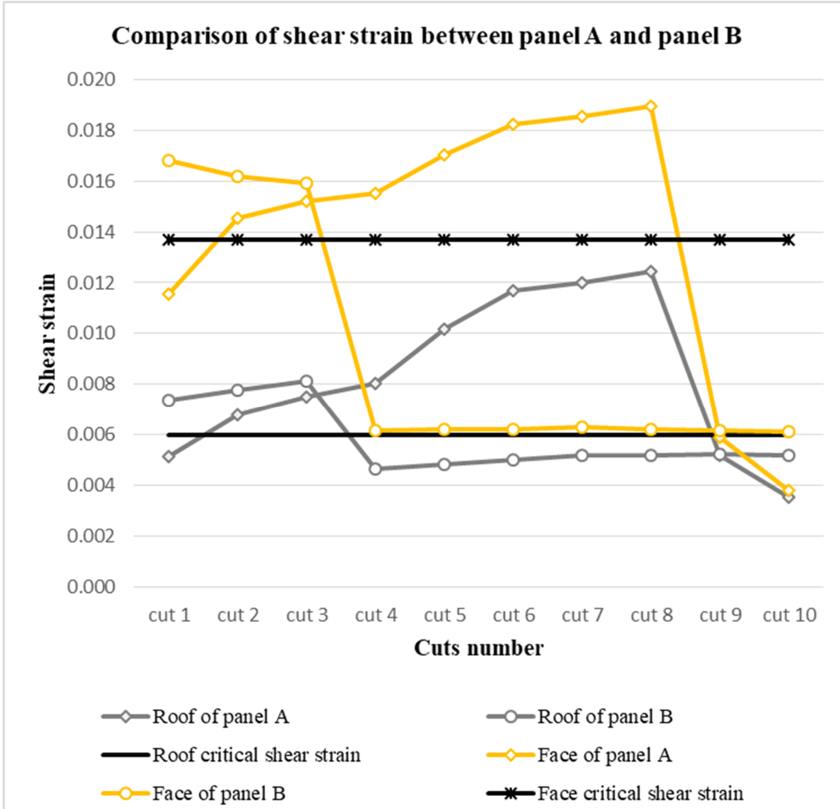


Figure 14. Comparison of shear strain changing between panel A and B.

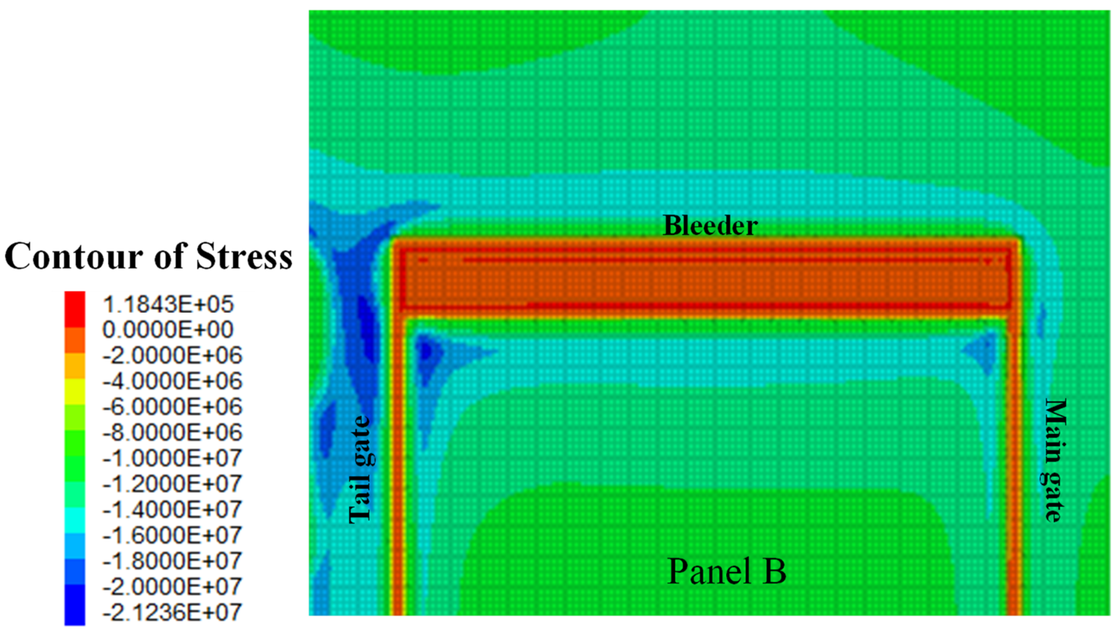
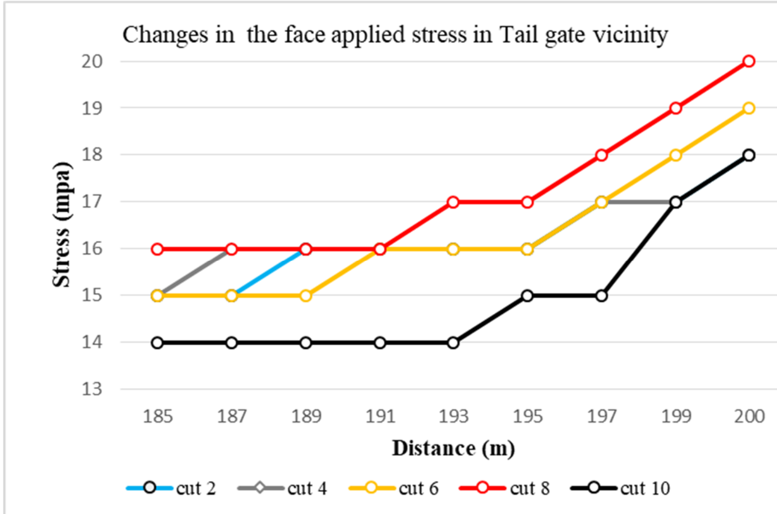
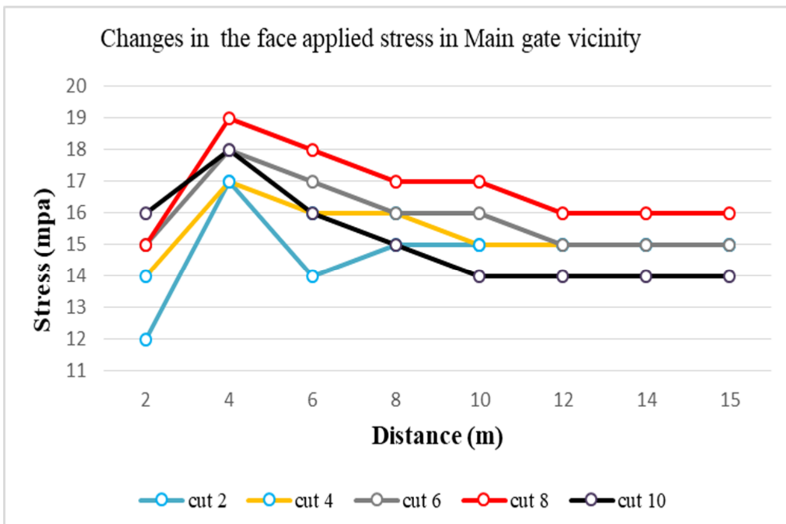


Figure 15. Stress change around panel B opening.



(a)



(b)

Figure 16. a) Changes in the face applied stresses in the tailgate vicinity; b) Changes in the face applied stresses in the main gate vicinity.

4. Conclusions

Due to longwall mining and coal extraction, a large space without any support is created, and in-situ stresses change, and the inductive stresses are applied to the surrounding strata. Changes of in-situ stresses will affect the adjacent panels' strata behavior; i.e. the strata behavior in this condition is different than the intact condition during the previous panel mining. Therefore, investigating the effect of panel extraction under the intact condition on its adjacent panel strata behavior is very important. In this study, a block model by considering two adjacent panels (A and B) is constructed in FLAC3D software to compare the face and roof behavior on panel A extraction (under intact condition) with the face and roof behavior on panel B extraction (under induced condition). The data of Tabas Parvadeh Coal Mine is used for model validation.

- Based on numerical modeling, the value of the first roof weighting effect interval (FRWEI) in panel A and panel B are calculated, respectively, as 26 and 21 meters. The average vertical roof displacement and the caving zone vertical displacement in panels A and B are calculated, respectively, as 71.1, 84.64, 102.59, and 121.59 cm.
- The average abutment stresses on panel A are more than on panel B. The failure in panel A is started at 8 meters distance from the barrier pillar,

and this distance in panel B is 6 meters. Based on numerical modeling, by panel extraction, the stress concentration moved upward. In addition, the applied stress on the panel A opening during extraction is equal, but in panel B, the condition is different, and the applied stresses on the tailgate are more than the main gate.

- Based on numerical modeling, the face on panel A after two cuts is still stable, but after the third cut extraction, the face is unstable and probably will fall. This condition continues until the first roof fall happens in the 9th cut extraction. By starting extraction in panel B, the calculated shear strain of the face and its roof is more than the critical value, so they are unstable. This condition continues until the third cut extraction, and after that, they are stable even during the first roof fall in the 7th cut extraction.

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بررسی تاثیر استخراج پهنه‌ی زغال‌سنگ بر رفتار سقف و جبهه‌کار پهنه‌ی مجاور در روش معدنکاری جبهه‌کار طولانی مکانیزه (مطالعه موردی: معدن زغالسنگ طبس)

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چکیده:

حفر فضای زیرزمینی در لایه‌های سنگی و خاکی وضعیت تنش‌های برجا را در شعاع تاثیر معینی در پیرامون سازه تغییر می‌دهد. دراثر معدنکاری جبهه‌کار طولانی و استخراج لایه زغالسنگ یک فضای بزرگ بدون نگهداری ایجاد می‌شود، حفر این فضا وضعیت تعادل تنش‌های برجای منطقه را برهم زده و موجب باز توزیع تنش‌های برجا در منطقه می‌شود. تغییرات در تنش‌های برجای منطقه موجب تغییر در رفتار لایه‌های سقف و جبهه‌کار در پهنه‌ی مجاورنسبت به حالت بکرخواهد شد. از این رو بررسی تاثیر استخراج یک پهنه بر پهنه‌های مجاورش در معدنکاری جبهه‌کار طولانی امری ضروری است. به همین منظور در این مقاله یک مدل عددی با در نظر گرفتن دو پهنه مجاور (A و B) برای بررسی رفتار سینه‌کار و سقف پهنه‌ی استخراجی طی معدنکاری جبهه‌کار طولانی درپهنه A (حالت تنش‌های برجای و بکر) و سپس پهنه‌ی B (حالت تنشهای برجای القایی ناشی از معدنکاری پهنه B) در نرم‌افزار FLAC3D شبیه‌سازی شده است. بر اساس نتایج مدل‌سازی عددی مقادیر طول تخریب اولیه در پهنه¬های A و B به‌ترتیب برابر ۲۶ و ۲۱ متر محاسبه شده است که نشان می¬دهد با القای تنش‌های برجا طی استخراج پهنه‌ی A ، زمان تخریب سقف ناحیه‌ی تخریب در پهنه‌ی B و ابعاد فضای حفر شده در آن ، در حدود ۱۹/۲ ٪ کاهش یافته و میزان جابه‌جایی سقف در حدود ۱۸/۵ ٪ افزایش یافته است. همچنین احتمال سقوط جبهه‌کار و سقف بالای آن در زمان پیش‌روی پهنه‌ی A و در اولین گام تخریب بیشتر از پهنه‌ی B است. به عبارتی بروز ناپایداری در جبهه‌کار پهنه‌ی اول (A) امری قطعی است در حالی که امکان پایدار ماندن جبهه‌کار پهنه‌ی دوم (B) در اولین شکست سقف امری بسیار محتمل است.

کلمات کلیدی: جبهه‌کار طولانی، تنش القایی، رفتار لایه‌ها، سقوط سقف، پوسته شدن جبهه‌کار.