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Extension of excavation damaged zone due to longwall working effect

H. Mohammadi[1], M.A. Ebrahimi Farsangi[1*], H. Jalalifar[1], A.R. Ahmadi[2] and A. Javaheri[3]

1. Mining Engineering Department, Shahid Bahonar University of Kerman, Kerman, Iran
2. Mechanical Engineering Department, Graduate University of Advanced Technology, Kerman, Iran
3. Negin Coal Company of Tabas, Tabas, Iran

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**Corresponding author: maebrahimi@uk.ac.ir (M. A. Ebrahimi Farsangi).*

Abstract
In advance longwall mining, the safety of mine network, production rate, and consequently, economic conditions of a mine are dependent on the stability conditions of gate roadways. The gate roadway stability is a function of two important factors: 1) characteristics of the excavation damaged zone (EDZ) above the gate roadway and 2) loading effect due to the caving zone (CZ) above the longwall working, which can extend the EDZ size. Generally, due to the coal seam dip, the failure possibility of main gate roadway is more severe than tail gate roadway. The aim of this work is to determine the longwall working effect on the EDZ extension above main gate roadway. To achieve this purpose, considering three factors involved in the CZ characteristics, the coal seam properties (dip and thickness) and the geomechanical properties of hangingwall, a new geometrical model is developed. Then, based on the geometrical calculations, a new relationship is presented to determine the working influence coeffiecint. Furthermore, taking into account the new geometrical model, an algorithm is suggested for the stability analysis of main gate roadways. Validation of the new geometrical model is carried out by the instrumentation and monitoring results of a longwall working carried out in the Parvade-2 coal mine of Tabas, Tabas, Iran. The results obtained show that there is a good agreement between the values obtained by the new model and the actual measured values. Finally, a sensitivity analysis is carried out on the effects of pillar width, bearing capacity of support system, and coal seam dip.

Keywords: *Maingate Roadway, Excavation Damaged Zone (EDZ), Longwall Working, Caving Zone (CZ), New Geometrical Model.*

1. Introduction

One of the important factors involved in the success of longwall mining is the stability of the gate roadways [1-5]. During the construction of a gate roadway, the redistribution of in situ stresses causes a damage within the rock mass and consequently a non-elastic zone is created surrounding the gate roadway, named as the excavation damaged zone (EDZ) [6,7]. Within EDZ, the changes in strength properties and rock mass behavior are permanent and significant and the stability condition of the gate roadway is dependent on the EDZ characteristics [8-12]. A wide range of methods have been developed to assess the EDZ characteristics such as the instrumentation and monitoring, laboratory physical simulation, numerical modeling, and empirical methods [13-15].

It should be mentioned that the situation of EDZ surrounding the gate roadways of a longwall working differs from the other underground openings, which is due to reloading related to the coal extraction within the longwall working. In this case, EDZ can be extended and the stability condition of gate roadway is extremely threatened. In reality, after advancing the support system of longwall working, a null space is created behind the support system and the immediate roof, which is an unsupported part of the working roof between the goaf and support systems. Under this condition, the immediate roof is collapsed and caved. Due to downward movements of the roof strata, a caving zone (CZ) with the height of H_c above the longwall working is created. Therefore, the overburden pressure above CZ is redirected towards ahead of face and both sides, where the gate roadways are located. In fact, the overburden pressure above CZ produces an additional loading on the gate roadways, which causes an extension in EDZ and its instability [1,3,15,16]. It should be noted that, in the dip coal seams or inclined longwall working, the loading due to CZ creation on the main gate roadway is greater than the tail gate roadway, and thus the damage of the main gate roadway is greater than the tail gate roadway.

Different methods such as numerical modeling, physical modeling, analytical solution, and empirical relationships have been presented to analyze the longwall working effect on the gate roadway stability [17-18]. Recently, by studying the instrumentation and monitoring results of some coal mines, it has been concluded that the loading effect due to CZ creation (longwall working effect) on the main gate roadway can be deduced from a schematic concept of longwall mining mechanism [15] (Figure 1). Taking into account a horizontal longwall working, it has been proved that due to the working effect, a triangular damaged zone above the main gate roadway is created and consequently, the EDZ size extends. Afterwards, using this concept and considering a horizontal longwall working, as in Figure 2, some researchers have presented a simplified mathematical model for calculating the characteristics of the extended EDZ. According to this figure, the extended part of EDZ is equal to the difference between the triangular damaged zone area and the area of EDZ [16].

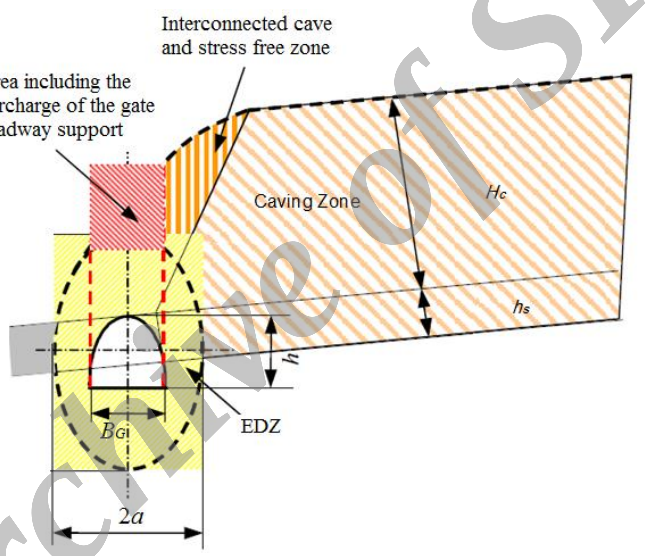

Figure 1. Schematic concept of longwall working effect on main gate roadway [15].

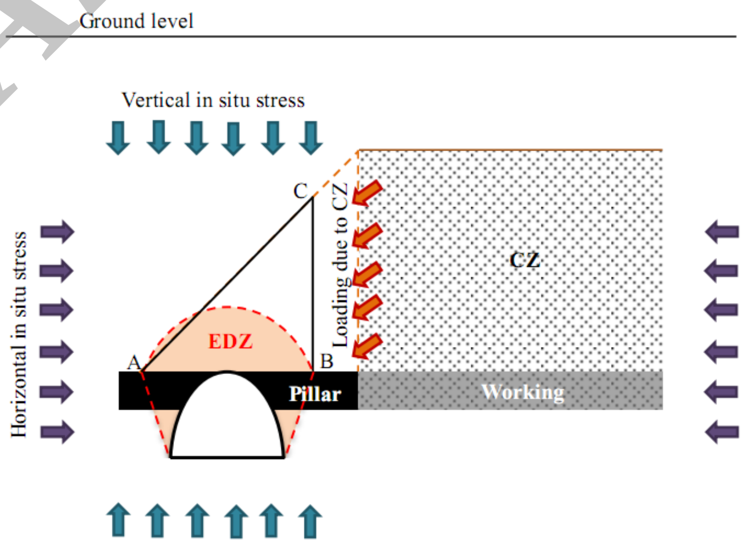

Figure 2. A geometrical concept of horizontal longwall working effect on EDZ [16].

However, investigations carried out on the previous geometry models have shown that there are some major shortcomings in determining the working effect on the stability conditions of the main gate roadway. In the previous models, although the EDZ characteristics have been calculated using the simple empirical relationships, but no attention has been paid to the ratio of the in situ stress and the uniaxial strength of rock mass. Moreover, the previous models have been obtained only based on the horizontal longwall working, whereas the majority of longwall workings are inclined. It should be noted that the value of working dip (coal seam dip) plays an important role in the transmission of the additional loading to the main gate roadway. Finally, in the previous models, all the mathematical relationships related to the working effect on EDZ have been obtained approximately and the accuracy of calculations is low.

The main purpose of this research is to develop a new geometrical model for calculating the working effect on the EDZ characteristics without the mentioned shortcomings. To achieve this aim, firstly, a new empirical relation for calculating the EDZ characteristics is presented. Then, based on the new geometrical model and using the integration operation, the new mathematical equations are presented. Moreover, a new formulation is obtained to calculate the working influence coefficient and finally an algorithm is suggested to carry out the stability analysis of main gate roadway, considering the effect of pillar width.

2. Calculation of EDZ characteristics without working effect

The EDZ characteristics depend on the geomechanical properties of rock mass, depth, and shape of gate roadway. The factors of shape and size of gate roadway play an important role in achieving a long-term stability. In spite of the use of rectangular and circular cross sections, a large number of coal mining gate roadways are still arch-shaped, supported with steel girders, predominantly as an arch profile [10,19,20]. One of the estimating methods of the EDZ characteristics is the arch theory [15,18]. Based on this theory, due to the excavation of gate roadway, EDZ may be produced as a natural arch form. Due to the redistribution of stresses surrounding gate roadway, the resistance properties of rock mass within EDZ is decreased, and therefore, the rocks may loosen and separate from the above part of overburden along the arch [14]. Figure 3 shows a schematic view of EDZ above the main gate roadway, whereas the coal seam extraction within the longwall working has not yet been started. In this figure, H is the main gate roadway depth from the ground level, B_G is the main gate roadway width, h is the main gate roadway height, B_n is the EDZ height, a is a half of the EDZ width, α is the coal seam dip angle, and φ_p is the peak internal friction angle of rock mass.

Considering the arch theory, and based on instrumentation and monitoring results of some gate roadways in Ostrava-Karviná coalfield (OKR), an empirical relationship has been suggested for calculating the EDZ height, as follows [15,21,22]:

$$B_n = K_n {B_G}^{0.4} u^{0.6} \quad (1)$$

Also, the following relationship has been suggested to calculate the EDZ displacements [21].

$$u = 0.1 B_G \left(e^{\frac{1.5H - q}{45\sigma_{cm}}} - 1 \right) \quad (2)$$

where, u is the EDZ displacement (m), σ_{cm} is the rock mass compressive strength above gate roadway (MPa), q is the bearing capacity of the support system at the gate roadway (kPa), and K_n is a constant coefficient.

Also, the maximum EDZ height has been calculated using the following relation [15,22].

$$B_n = 2B_G \left(e^{0.03\frac{H}{\sigma_{cm}}} - 1 \right)^{0.6} \quad (3)$$

Based on the results obtained from the previous parametric studies, if the rock mass strength falls below 20% of the in situ stress in no-support condition, the EDZ size will increase rapidly. In this case, it is very difficult to control the stability of the tunnel and the collapse of the tunnel is likely to occur [23]. However, in Eqs. (2) and (3), a constant value of unit weight has been considered for rock mass (about 0.03) and these equations could not consider an actual in situ stress for different case studies.

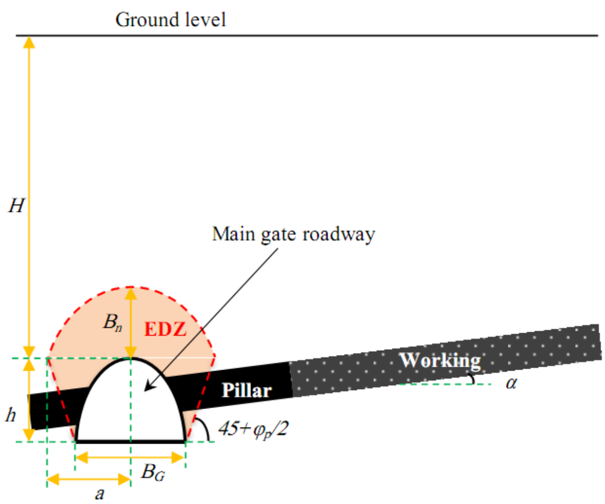

Figure 3. EDZ characteristics of main gate roadway before coal mining.

Therefore, to investigate the accuracy of Eqs. (2) and (3), they were checked against the results obtained from the instrumentation and monitoring of some gate roadways at Parvade-2 coal mine in Tabas, Iran. Parvade-2 coal mine, with an area of about 40 km^2 and a total reserve of about 5 million tones, is one of the five coal areas in Tabas. This mine includes three coal seams B_1, B_2, and C_1, from which, the coal seams C_1 and B_2 have a high ability in coal extraction [24]. The studies have shown that since the actual ratio of the in situ stress to the rock mass compressive strength was not considered, the accuracy of Eqs. (2) and (3) is not high.

According to the previous studies, the height and displacement of EDZ are functions of two parameters (σ_0/σ_{cm}) and (q/σ_{cm}) [23]. Therefore, to modify Eqs. (2) and (3), in the first step, the height and displacement of EDZ at different gate roadways were measured by the instrumentation and monitoring method. Then, by taking into account Eqs. (2) and (3) and using multivariate regression method, the relations between the measured values and parameters (σ_0/σ_{cm}) and (q/σ_{cm}) were investigated and finally, Eqs. (4) and (5) were obtained as follows:

$$u = 0.1B_G\left(e^{\frac{\sigma_0-\gamma q}{\sigma_{cm}}}-1\right) \quad (4)$$

$$B_n = 2.08B_G\left(e^{\frac{\sigma_0}{\sigma_{cm}}}-1\right)^{0.6} \quad (5)$$

where, σ_0 is the vertical in situ stress (MPa) and γ is the unit weight of rock mass (MN/m^3).

Also, in order to prevent the loosening phenomena within EDZ, the minimum required support pressure (P_{min}) is obtained using Eq. (6). It should be noted that in EDZ, the strength properties of damaged rock mass, particularly cohesion, are decreased extremely, even to the zero value [16].

$$P_{\min} = \frac{\frac{\gamma B_G}{2} - c_r}{K\tan\varphi_r}\left(1-e^{-K\tan\varphi_r \frac{2B_n}{B_G}}\right) \quad (6)$$

where, c_r and φ_r are the residual cohesion and internal friction angle of rock mass respectively within EDZ, and K is the stress ratio between the horizontal and vertical stresses.

3. Calculation of EDZ characteristics, considering working effect

Due to the coalface advance, creating a CZ above the longwall workings and the redistribution of stress field, an additional load is applied to the coal pillars and main gate roadway, which causes an extension in EDZ. To study the longwall working effect on EDZ of the main gate roadway at a cross-section of the face behind the advance longwall mining, a new geometrical model is presented, as in Figure 4. As shown in this model, contrary to the previous models, two important factors have been considered: the coal seam dip and the vertical distance between the coal pillar and crown of the main gate roadway (it determines the coal seam location at the sidewall of the gate roadway). It should be noted that in thin coal seam, generally, the seam dip and working slope are the same. According to this model, the damaged area due to the longwall working effect is the triangle ABC and the additional loading relates to the part of the triangle, which is located outside the parabolic area of EDZ.

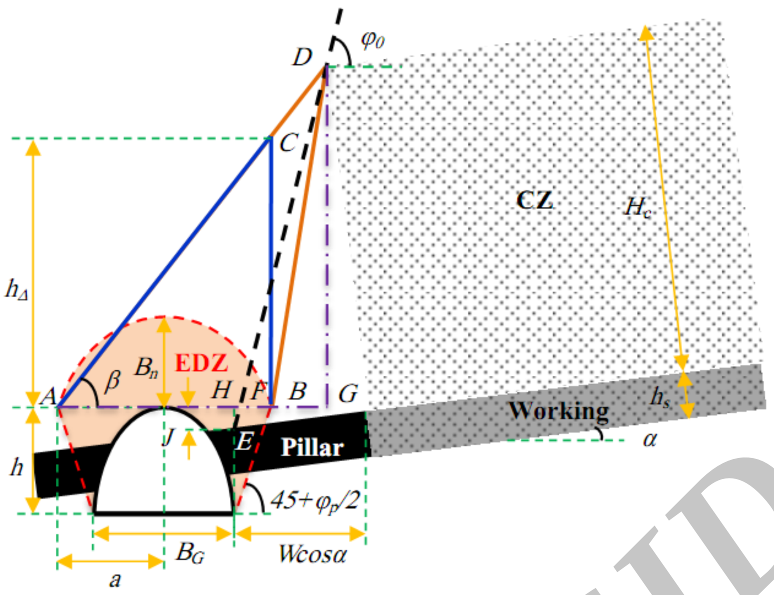

Figure 4. New geometrical model to determine the working effect on the main gate roadway.

In Figure 4, h_s is the coal seam thickness, φ_0 is the caving angle, β is the influence angle of CZ, W is the pillar width, J is the vertical distance between the pillar and crown of the main gate roadway and h_Δ is the height of the triangle ABC. To influence the coal extraction operation within longwall working on the main gate roadway, the level of the upper interface between CZ and the overburden must be located above the level of the main gate roadway crown. Therefore, the following condition must be satisfied.

$$H_C \cos\alpha + W \sin\alpha > J \quad (7)$$

The parabolic area of EDZ is obtained using the following equations [16].

$$S_{par} = \frac{4}{3} B_n (AB/2) \quad (8)$$

$$AB = 2a = B_G + (2h \tan(45 - \varphi_p/2) \quad (9)$$

The height of the triangle ABC is a function of the CZ height. Therefore, to calculate the area of the triangle, firstly, the CZ height must be calculated. Many researchers have investigated the CZ characteristics [25-29]. There are several methods used to determine the CZ height such as the in situ measurement, laboratory physical simulation, numerical modeling, and mathematical modeling. Recently, a study has been carried out on the relation between CZ shape and height [30]. In the current work, using the mathematical modeling, it was shown that there are two general models for CZ: 1) geometry-independent roof fracture and 2) geometry-dependent roof fracture, and finally, considering these general models and based on the results obtained for the in situ measurements, five mathematical models were presented to calculate the CZ height. One of these models is an arithmetic one, which is a sub-model of the geometry-independent roof fracture model. Based on this model, a tensile failure occurs at two extreme ends of the panel perpendicular to the advancing direction. Hence, the CZ width is equal to the extracted panel width (working length). Moreover, it was shown that in this model, the CZ height is a nonlinear function of the two parameters coal seam thickness and expansion factor of broken rock within CZ (d), and it includes the Peng model [30]. In this work, the CZ height is determined based on the arithmetic model as [30]:

$$H_C = \frac{h_s(h_s + 3d)}{2d} \quad (10)$$

The height of the triangle ABC is calculated as follows:

$$h_\Delta = AB \tan(\beta) \quad (11)$$

Moreover, according to Figure 4, the influence angle is calculated as follows:

$$\beta = \tan^{-1}(DG/AG) \quad (12)$$

where,

$$DG = \left(\frac{H_c \sin(\varphi_0) - J \sin(\varphi_0 - \alpha)}{\sin(\varphi_0)\sin(\varphi_0 - \alpha)} \right) \sin(\varphi_0) \quad (13)$$

$$AG = AH + FH + FG = B_G + (h \tan(45 - \phi_p / 2) + J / \tan(\phi_0) + \left(\frac{H_c \sin(\phi_0) - J \sin(\phi_0 - \alpha)}{\sin(\phi_0)\sin(\phi_0 - \alpha)} \right) \cos(\phi_0) \quad (14)$$

The above mentioned equations show that the height of triangle depends on the caving angle, which is determined using the following equation:

$$\varphi_0 = \tan^{-1}(H_c / W) + \alpha \quad (15)$$

The area of triangle is calculated as follows:

$$S_\Delta = (AB/2)h_\Delta \quad (16)$$

Within the triangle ABC, due to the rock mass damage, the resistance properties as well as EDZ are decreased. The area of non-subscription part between the parabolic area of EDZ and the triangle ABC is related to the additional loading on the main gate roadway due to the working effect (the area of extended part of EDZ). According to Figure 5, the area of extended part of EDZ can be calculated by integration operation. The functions $f_1(x)$ and $f_2(x)$ are as follows:

$$f_1(x) = \frac{h_\Delta}{2a} x \quad (17)$$

$$f_2(x) = -\frac{B_n}{a^2} x^2 + \frac{2B_n}{a} x \quad (18)$$

Therefore, the integral form for the area of extended part of EDZ is written as follows;

$$S_{add} = \int_{x_1}^{x_2} [f_1(x) - f_2(x)]dx = \int_{x_1}^{x_2} [\frac{h_\Delta}{2a} x - \frac{B_n}{a^2} x^2 + \frac{2B_n}{a} x]dx \quad (19)$$

where, x_2 is equal to $2a$, and x_1 is obtained as follows:

$$f_1(x_1) = f_2(x_1) \Rightarrow \frac{h_\Delta}{2a} x_1 = -\frac{B_n}{a^2} x_1^2 + \frac{2B_n}{a} x_1 \Rightarrow x_1 = \frac{(4B_n - h_\Delta)a}{2B_n} \quad (20)$$

Therefore, the area of extended part of EDZ is obtained using Eq. (21):

$$S_{add} = \frac{1}{48} \frac{a h_\Delta^2 (12B_n - h_\Delta)}{B_n^2} \quad (21)$$

Moreover, the area of extended EDZ (total area of EDZ) is calculated as follows:

$$S_{ext} = S_{par} + S_{add} \quad (22)$$

Due to the extension of EDZ area, the minimum required support pressure is increased. According to Eq. (6), it is a function of the EDZ height. Therefore, in the first step, the height of extended EDZ ($B_{n,ext}$) must be determined. Considering the area of extended EDZ and Eq. (8), $B_{n,ext}$ is calculated using the following equation:

$$B_{n,ext} = \frac{3S_{ext}}{2AB} \quad (23)$$

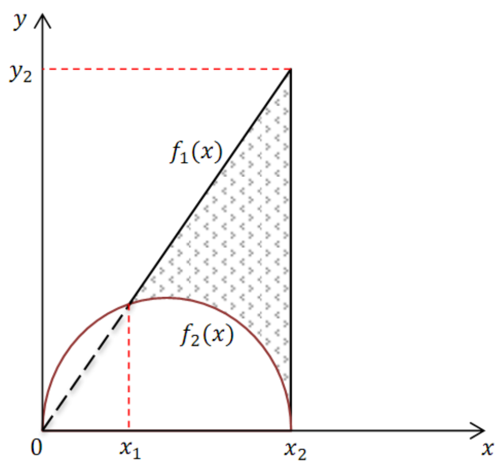

Figure 5. The area of extended part of EDZ due to the longwall working effect.

Therefore, the minimum support pressure due to the extended EDZ ($P_{min,ext}$) is obtained, considering B_n=$B_{n,ext}$ within Eq. (4). Moreover, considering B_n=$B_{n,ext}$ and Eq. (5), the equivalent height of overburden (H_E) is determined as Eq (24). Hence, considering H_E, the total displacement due to the extended EDZ (u_{ext}) is calculated using Eq. (4).

$$H_E = \frac{\sigma_{cm}}{0.03}\ln\left(\left(\frac{3S_{total}}{8B_G a}\right)^{1.67}+1\right) \tag{24}$$

Eq. (23) shows the height of extended EDZ above a main gate roadway at a depth of H, which is under the working effect. The characteristics of the extended EDZ could be the same as those for EDZ of a main gate roadway at a depth of H_E without any working effect on the main gate roadway. Therefore, the concept of difference between H and H_E is used for calculating the working influence coefficient (G) in Eq. (25). According to this equation, G can be used to determine the value of longwall working effect on the main gate roadway. It should be noted that when there is no influence from the longwall working on the main gate roadway, G is equal to 1.

$$G = \frac{H_E}{H} \tag{25}$$

4. Algorithm of stability analysis

As it has been already mentioned, in the process of stability analysis of the main gate roadway, two important factors must be considered: a) loading effect, due to EDZ without the working effect and b) additional loading effect, due to the extended EDZ, considering the working effect. The pillar width has an important role in the transmission of loading on the main gate roadway due to the working effect. In reality, from the technical point of view, a greater pillar width decreases the longwall working effect, but it is very important that the size of the pillar width is controlled from the economical point of view. Therefore, to achieve an optimum design, an algorithm is presented for analyzing the main gate roadway stability and designing the optimum size for the pillar width based on the new geometrical model, shown in Figure 6. This algorithm includes five main stages as follows:

Stage1: Without considering the working effect, the stability condition of the main gate roadway is analyzed and the support system is designed.

Stage 2: After calculating the CZ height, the possibility of the working effect on the main gate roadway is investigated. If there is no effect, the design is finished; otherwise, proceed to the next stage.

Stage 3: Considering the working effect, all characteristics of the extended EDZ and the working influence coefficient are calculated.

Stage 4: Considering the characteristics of the extended EDZ, the stability condition of the main gate roadway is investigated. If the main gate roadway is stable, the design is finished; otherwise, proceed to the next stage.

Stage 5: Three solution methods are suggested to stabilize the main gate roadway: 1) increasing the pillar width, 2) increasing the bearing capacity of the support system, and 3) increasing the pillar width and bearing capacity of the support system, simultaneously. It should be noted that for selecting each solution method, and also to achieve an optimum design, two important technical and economic factors must be considered.

5. Validation of the new geometrical model

In order to validate the performance of the proposed geometrical model, one of the longwall workings of the Parvade-2 coal mine of Tabas was considered. In this longwall working, B_2 coal seam is mined by advance longwall method. The thickness of B_2 coal seam including 37% of the mine reserve (1500000 ton) is changed from 0.4 m to 1.75 m, as the B_2 thickness is 1.6 m. The hangingwall of B_2 consists of siltstone, sandy siltstone, and sandstone; and the footwall of B_2 consists of argillite and sandstone [24]. The working length is 88 m, and to protect the main gate roadway, a pillar (width of 15 m) was considered. The depth of main gate roadway is equal to 120 m, and the width and height of the main gate roadway is 3.60 and 2.60 m, respectively. Due to the high convergence in the supported main gate roadway, the displacements were investigated by the instrumentation and monitoring operation. The results obtained showed that the working effect on the main gate roadway is very high, and a maximum convergence of 45 cm at the crown gate roadway was occurred [24]. Based on Eq. (10), the CZ height above the mentioned longwall working is equal to 15.2 m. The required characteristics of the longwall working in the Parvade-2 coal mine for modeling, based on the proposed geometrical model, are shown in Table 1. The main gate roadway of longwall working was analyzed based on the suggested algorithm, and the results obtained are presented in Table 2.

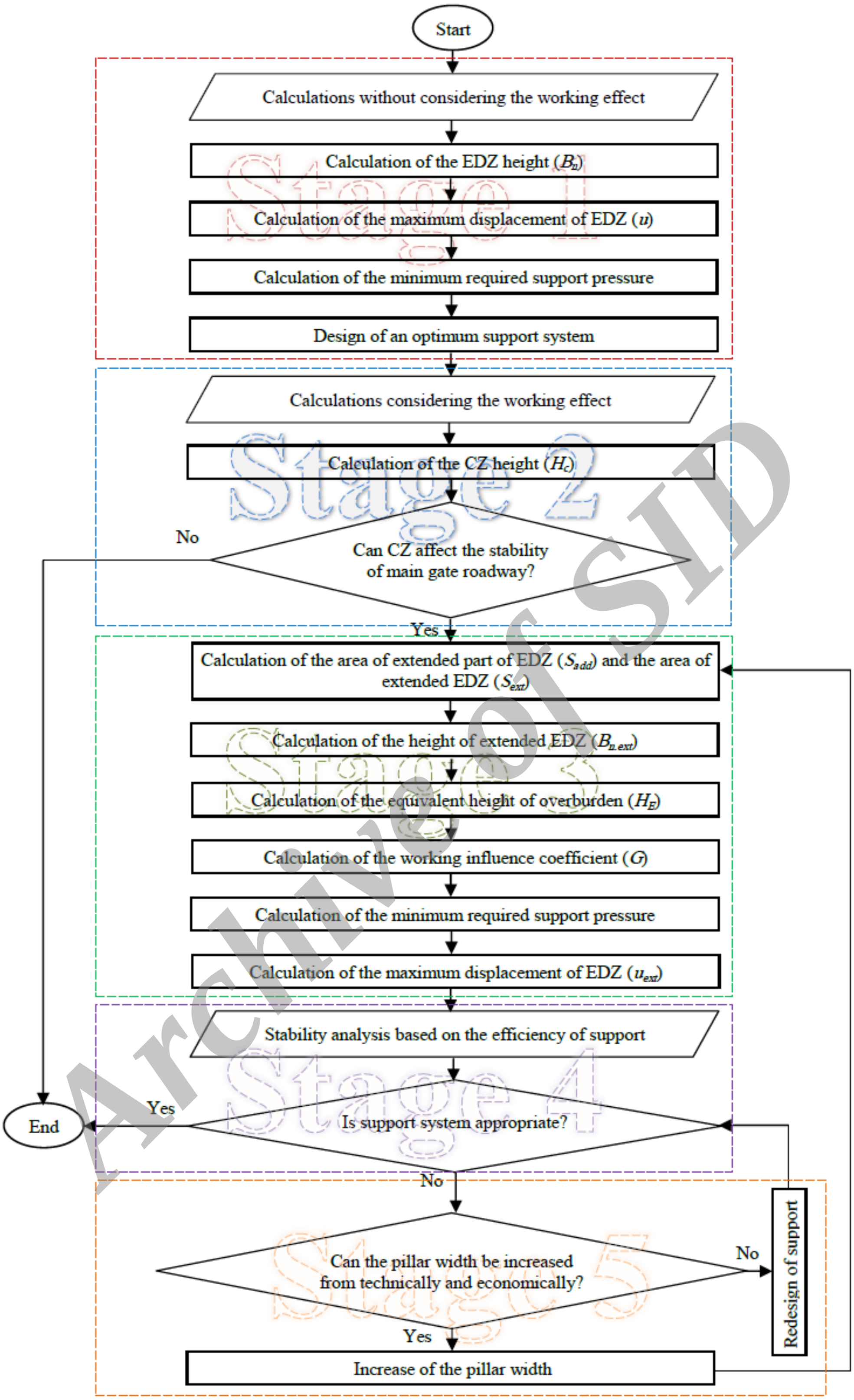

Figure 6. The design algorithm of gate roadway based on the new geometrical model.

Table 1. Characteristics of a longwall working in the Parvade-2 coal mine [24].

γ (t/m^3)	α (deg.)	φ_p (deg.)	σ_{cm} (MPa)	q (kPa)	φ_r (deg.)	c_r (MPa)	K	d	h_s (m)	W (m)	J (m)
2.3	28	28	15	60	15	0.05	1.1	0.12	1.60	15	0

Table 2. Modeling results for main gate roadway obtained by the new geometrical model.

S_{par} (m^2)	B_n (m)	u (cm)	φ_0 (deg.)	S_Δ (m^2)	S_{add} (m^2)	S_{ext} (m^2)	$B_{n,ext}$ (m)	H_E (m)	u_{ext} (cm)	G
12.86	2.87	3.47	73.38	4.05	28.19	41.05	9.16	570.72	42.78	4.76

As shown in Table 2, the working influence coefficient of 4.76 is obtained, and EDZ is extended about 219%. Moreover, the EDZ displacement at q=60 kPa, without considering the working effect, is 3.47 cm. However, by considering the working effect, this displacement is increased about 1133% (42.78 cm). Based on the calculated displacement (42.78 mm) and the measured displacement (45 mm), and using Eq. (26), an error of about 5% for the new geometrical model is obtained, which shows the capability of the new geometrical model.

$$error = \frac{u_{measured} - u_{calculated}}{u_{measured}} \times 100 \qquad (26)$$

where, $u_{measured}$ is the measured displacement obtained by the instrumentation and monitoring method, and $u_{calculated}$ is the calculated displacement obtained by the geometrical model.

6. Discussion

The sensitivity analyses were carried out to investigate the effects of the pillar width, bearing capacity of the support system, simultaneous effects of the pillar width and bearing capacity of the support system, and the effect of coal seam dip on the EDZ displacement and the working influence coefficient.

6.1. Effect of pillar width

Eqs. 11-16 show that the working effect on the main gate roadway is a function of the caving angle. Based on Eq. (15), the caving angle depends on three factors: the CZ height, pillar width, and coal seam dip; and the only changeable factor is the pillar width. The caving angle affects the EDZ displacement and the working influence coefficient, which they are dependent on the pillar width indirectly. To investigate the effect of pillar width in transferring the longwall working effect on the main gate roadway, a series of analyses were performed, and the parameters EDZ displacement and working influence coefficient were evaluated, as shown in Figure 7. As it can be seen in this figure, the relationship between the pillar width and the output parameters is nonlinear, and in a small pillar width, the working effect is increased extremely. The reduction in W from 15 m to 10 m (decreasing by about 33%) causes an increase of about 82% in the EDZ displacement and an increase of about 42% in the working influence coefficient. However, increasing W from 15 m to 20 m (increasing by about 30%), the EDZ displacement is decreased from 42.78 cm to 28.62 cm (decreasing by about 33%), and the working influence coefficient is decreased from 4.76 to 3.67 (decreasing by about 23%). Also, with increase of W by about 100% (increasing from 15 m to 30 m), the EDZ displacement is decreased about 58% (from 42.78 cm to 18.11 cm), and the working influence coefficient is decreased about 43% (from 4.76 to 2.71).

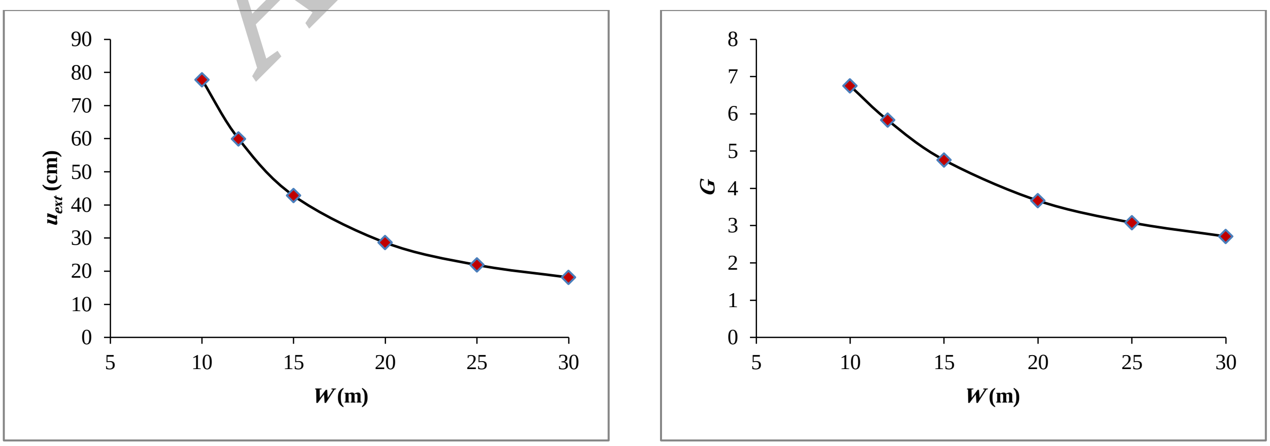

Figure 7. Sensitivity analysis of pillar width effect on the main gate roadway stability at q=60 kPa.

6.2. Effect of bearing capacity of support system

Eq. (4) shows that the EDZ displacement depends on the bearing capacity of the support system. Figure 8 shows a sensitivity analysis of the effect of bearing capacity of the support system on the displacement of the extended EDZ. As shown in this figure, increasing the bearing capacity does not have a high influence on the EDZ displacement. Increase in *q* from 60 kPa to 250 kPa (increasing by about 317%) causes a reduction of about 47% in the displacement (the EDZ displacement decreases from 42.78 cm to 22.87 cm).

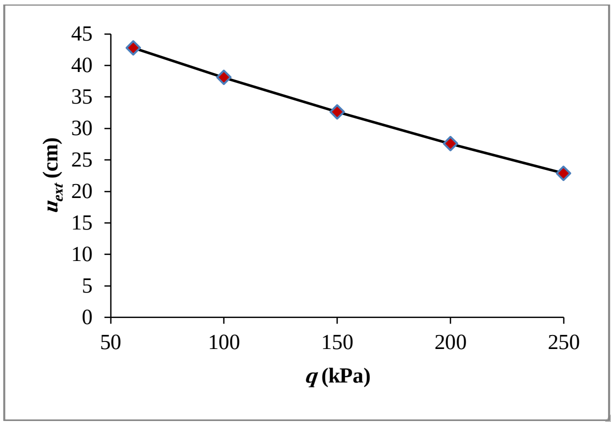

Figure 8. Sensitivity analysis of the effect of bearing capacity of support system on displacement at *W*=15 m.

6.3. Simultaneous effects of pillar width and bearing capacity of support system

As shown in Figures 7 and 8, increasing the width pillar or bearing capacity of the support system alone may not be suitable for reducing the displacement of the extended EDZ. Therefore, a sensitivity analysis was carried out to investigate the simultaneous effects of pillar width and bearing capacity of the support system on the displacements, as shown in Figure 9.

As already explained in section 6.1, at *q*=60 kPa, due to increasing *W* from 15 m to 30 m, the displacements decreased to 18.11 cm (decreasing by about 58%). Also, according to Figure 8, at *W*=15 m, increasing *q* from 60 kPa to 250 kPa causes a reduction of about 47%, and the EDZ displacement is equal to 22.87 cm. However, based on Figure 9, with increasing *q* from 60 kPa to 250 kPa and *W* from 15 m to 30 m simultaneously, this reduction is about 90%, and the displacements are equal to 4.43 cm.

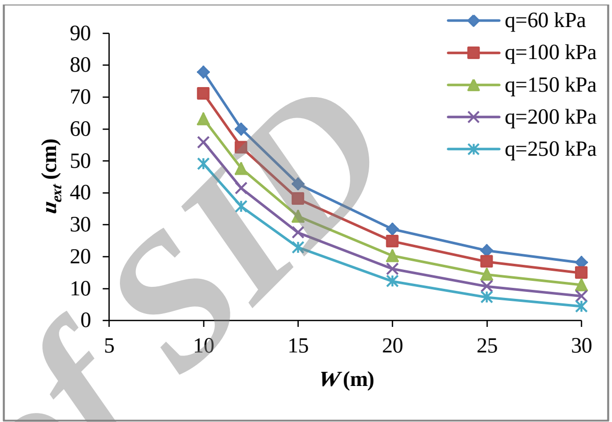

Figure 9. Sensitivity analysis of simultaneous effect of pillar width and bearing capacity of support system on displacements.

6.4. The effect of coal seam dip

To study the effect of coal seam dip on the main gate roadway stability, α=0°, 10°, 20°, and, 28°were taken into account, and the resulting displacement of the extended EDZ and working influence coefficient are shown in Figure 10. Based on the results obtained, the effect of α on the EDZ displacement and working influence coefficient is significant; decreasing α from 28° to 0° causes a reduction of about 77% in u_{ext} and 62% in *G*.

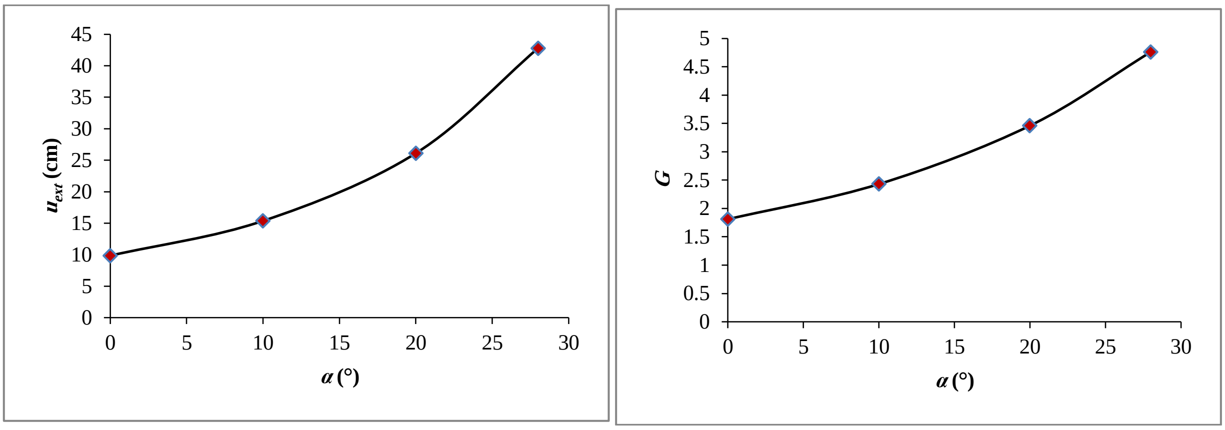

Figure 10. Sensitivity analysis of effect of coal seam dip on main gate roadway stability at W=15 m and q=60 kPa.

7. Conclusions

The purpose of this paper is to determine the characteristics of the extended EDZ above the main gate roadway due to longwall working effect, and the following results were concluded:

1. A new empirical method was presented to calculate the EDZ characteristics such as the EDZ height and displacement.
2. Considering the mechanism of advance longwall mining method, a new geometrical model was developed to determine the longwall working effect on the EDZ of the main gate roadway. This model considers the coal seam dip and the vertical distance between the coal pillar and crown of the main gate roadway to determine the location of the coal seam at the sidewall of the main gate roadway.
3. Based on the new geometrical model, a series of mathematical equations were obtained to calculate the area, height, displacements of the extended EDZ, and the longwall working influence coefficient.
4. An algorithm was presented for the stability analysis, design of the support system, and selection of the optimum pillar width for the main gate roadway.
5. The new geometrical model was validated against the field data obtained from the Parvade-2 coal mine in Tabas, Iran. The results obtained show a good performance of the proposed geometrical model.
6. A sensitivity analysis was carried out, and the results obtained show that the simultaneous effects of the pillar width and bearing capacity of the support system is the best solution method to control the displacements of the extended EDZ. Moreover, it was concluded that the effect of coal seam dip on the main gate roadway stability is very significant.

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تعیین گسترش ناحیه آسیب‌دیده حفاری ناشی از اثر کارگاه استخراج جبهه کار طولانی

حمید محمدی[۱]، محمد علی ابراهیمی فرسنگی[۱*]، حسین جلالی فر[۱]، علیرضا احمدی[۲] و علی جواهری[۳]

۱- بخش مهندسی معدن، دانشگاه شهید باهنر کرمان، ایران

۲- بخش مهندسی مکانیک، دانشگاه تحصیلات تکمیلی صنعتی و فناوری پیشرفته، کرمان، ایران

۳- شرکت زغال‌سنگ نگین طبس ایران، طبس، ایران

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* نویسنده مسئول مکاتبات: maebrahimi@uk.ac.ir

چکیده:

در روش معدنکاری جبهه کار طولانی پیشرو، ایمنی شبکه معدن، نرخ تولید و متعاقباً شرایط اقتصادی معدن وابسته به شرایط پایداری گالری‌ها است. پایداری گالری‌ها تابعی از دو عامل مهم است که عبارت‌اند از: ۱) خصوصیات ناحیه آسیب‌دیده حفاری در بالای گالری و ۲) اثر بارگذاری ناشی از ناحیه تخریب در بالای کارگاه جبهه کار طولانی که می‌تواند ناحیه آسیب‌دیده حفاری را گسترش دهد. عموماً در اثر شیب لایه زغال استخراجی، امکان وقوع شکست در گالری اصلی (گالری حمل‌ونقل) بیشتر از گالری تهویه است؛ بنابراین هدف از انجام این تحقیق، تعیین اثر کارگاه استخراج جبهه کار طولانی بر روی گسترش ناحیه آسیب‌دیده حفاری در بالای گالری اصلی است. برای رسیدن به این هدف، با در نظر گرفتن سه عامل خصوصیات ناحیه تخریب، خصوصیات لایه زغال (شیب و ضخامت) و خصوصیات ژئومکانیکی کمربالا، یک مدل هندسی جدید توسعه داده شد. سپس بر اساس محاسبات هندسی، یک رابطه جدید برای تعیین ضریب تأثیر کارگاه بدست آمد. همچنین با در نظر گرفتن مدل هندسی جدید، یک الگوریتم برای تحلیل پایداری گالری اصلی پیشنهاد شد. اعتبار سنجی مدل ارائه‌شده به‌وسیله نتایج ابزار بندی و رفتار نگاری یکی از کارگاه‌های استخراج جبهه کار طولانی معدن پروده ۲ طبس انجام شد. نتایج نشان دادند که توافق مناسبی بین نتایج مدل توسعه داده‌شده و مقادیر اندازه‌گیری شده وجود دارد. درنهایت، یک تحلیل حساسیت بر روی اثر عرض پایه، ظرفیت باربری سیستم نگهداری و شیب لایه زغال انجام شد.

کلمات کلیدی: گالری اصلی، ناحیه آسیب‌دیده حفاری، کارگاه استخراج جبهه کار طولانی، ناحیه تخریب، مدل هندسی جدید.