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A New method for stability analysis of chain pillar in longwall mining by using Coulmann graphical method

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Abstract

The stability analysis of chain pillars is crucial, especially as coal extraction rates increase, making it essential to reduce the size of these pillars. Therefore, a new method for estimating the load on chain pillars holds significant importance. This research introduces a novel solution for estimating side abutment load and analyzing the stability of chain pillars using the dynamic mode of the Coulmann Graphical (CG) method. The solution is implemented using Visual Studio software and is named Coulmann Chain Pillar Stability Analysis (CCPSA). The CG method is widely recognized in civil engineering as a highly efficient technique for determining soil side abutment pressure in both static and dynamic conditions. This method involves calculating the top-rupture wedge of chain pillars using the CG method. The CCPSA software functions share significant similarities with those of the Analysis Longwall Pillar Stability (ALPS) method. However, the main point of departure between the proposed method and the ALPS empirical method lies in their respective approaches to calculating side abutment load on chain pillars and evaluating subsidence conditions. The effectiveness of this method has been validated using a database of chain pillars from various mines worldwide and has been compared with the ALPS method. The results of the comparison demonstrate that the CCPSA is highly effective in evaluating chain pillar stability. This underscores the potential of the CG method and CCPSA software in providing valuable insights for assessing and ensuring the stability of chain pillars in mining operations.

1. Introduction

A pillar is a segment of rock mass located between two or more underground spaces [1], serving the crucial function of supporting tunnels, shafts, and other large underground structures. Pillars must possess sufficient stability to bear the overburden load [2]. The strength of pillars is influenced by various factors, including their geometry, width-to-height ratio, joint structure, stress conditions, the ratio of horizontal to vertical stress, roof pillar conditions, ore dip, creep, and time [2]. In longwall mining, chain pillars are utilized to prevent roof collapses and safeguard longwall entries. These pillars, found in multiple longwall corridors, are exposed to varying stress fields, necessitating consideration of different loading stages in their design [3]. According to the two-dimensional subsidence method, calculations for pillar loads must accommodate both critical and sub-critical subsidence conditions.

Accurate dimensioning of pillars between two panels in longwall mining is imperative, as mining-induced stresses can lead to damage near the longwall face and the lower entry of the subsequent zone. Various experimental, numerical, and analytical methods are currently employed for chain pillar design. Wilson [4] developed an analytical equation focusing on the confined core and its width-to-height ratio's impact on strength. This method simulates stress distribution within the pillar and identifies failure conditions at the corners. Wilson's research aimed

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to optimize chain pillar dimensions while considering safety and economic factors. Hsiung and Peng [5] used a two-dimensional finite element numerical method to design chain pillar width, simulating front and side abutment loads through the finite element method. Their application revealed that surrounding environmental parameters significantly influence chain pillar dimensioning.

Extensive research has been carried out in the field of calculating stresses around mined environments, offering the potential to predict the stability of any type of underground structure.

Rezaei [6] presents three innovative methods, namely the radial basis function neural network (RBFNN), fuzzy inference system (FIS), and statistical analysis (SA) models. These methods have been specifically designed to accurately predict the stress concentration coefficient (SCC) around a mined longwall panel. Notably, these models incorporate the assessment of transferred stress induced by longwall mining when estimating the SCC. Majdi and Rezaei [7] introduce two predictive models, based on artificial neural network (ANN) and statistical analysis, for forecasting the height of the destressed zone. A well-suited dataset comprising the geometrical characteristics and mechanical properties of the panel and roof strata was compiled from literature sources and subsequently divided into training and testing sets. The performance of the models was evaluated using various metrics such as the coefficient of determination (R2), variance accounted for (VAF), mean absolute error (Ea), and mean relative error (Er), which was calculated based on the testing data. Rezaei [8] focuses on the height of the caving-fracturing zone above the mined panel, which is considered the destressed zone (HDZ). Accurately estimating this height over the long term is crucial for determining maximum ground surface subsidence and transferred loads to neighboring solid sections. He introduces a novel stability analysis model for the caved material system in the goaf area. To achieve this, a theoretical energy-based model for determining HDZ in long-term conditions is developed. Subsequently, the stability of the caved material system is examined using the principle of minimum potential energy. Rezaei et al. [9] introduces an analytical model based on the strain energy balance in longwall coal mining, with the goal of determining the mining-induced stress over gates and pillars. The proposed model analytically determines key parameters including the height of the destressed zone above the mined panel, total induced stress, abutment angle, vertical component of induced stress, and coefficient of stress concentration over gates and pillars.

Choi McCain's [3] research focused on U.S. longwall chain pillar design, combining the two-dimensional subsidence method with empirical relationships to develop a formulation for panel width calculation, which in turn determines chain pillar width. Mark and Beniawski [10] conducted research on rigid pillar design using the ALPS method, utilizing the two-dimensional subsidence method to calculate side abutment loads and empirical relationships to assess pillar strength. Whittaker and Frith [11] applied field measurements and calibrated their concept of side abutment loads to chain pillar stability analysis. Molinda et al. [12] developed a new relationship for calculating the safety factor and analyzing chain pillar stability using the longwall roof and floor quality index. Yang et al. [13] combined numerical modeling and field results, finding that increasing the chain pillar width led to maximum stress transfer around the pillar, aiding in proper design. Ghosh et al. [14] conducted their analysis on chain pillars in various panels in India, obtaining favorable results for chain pillar design. Yu et al. [15] monitored the Shanxi mine in China and evaluated chain pillar performance under weak roof conditions altered with igneous rocks. Xu et al. [16] used numerical modeling to calculate chain pillar stress under weak roof conditions. Past roof collapses caused by inadequate pillar design have led to the closure of many mines [17, 18]. Properly designing chain pillars is important to ensure underground space stability. Hashikawa et al. [19], considering the weak geology of Indonesia's mining areas, completed studies on the effect of pillar dimensions on underground space stability. Oraee et al. [20] compared analytical, numerical, and experimental methods for chain pillar design, highlighting their positives and negatives. Najafi et al. [21] performed a probabilistic method for chain pillar stability using Monte Carlo simulation and compared their results to numerical modeling. Zhu and Li [22] studied the effect of longwall entry size and chain pillar width on entries' stability, comparing results to numerical modeling and sensitivity analysis. Furthermore, many researchers have investigated the impact of chain pillar dimensions on underground space stability in various geological conditions using numerical and probabilistic modeling [23-43].

The results indicate that when using empirical methods, side abutment loads on chain pillars are estimated more conservatively. In the ALPS method, the side abutment loads are calculated geometrically and with significant conservatism. To improve the efficiency of this method, this research presents a new method for calculating side abutment loads on chain pillars using the dynamic mode of the CG method, a powerful graphical method to calculate the side abutment load.

2. Coulmann Graphical Method

In 1776, Coulomb [44] proposed a theory on active and passive soil pressure against retaining walls. He assumed that the rupture surface was planar and took into account the soil friction with the wall. Figure 1 illustrates the method, including the basic equation for calculating side abutment pressure on the retaining wall.

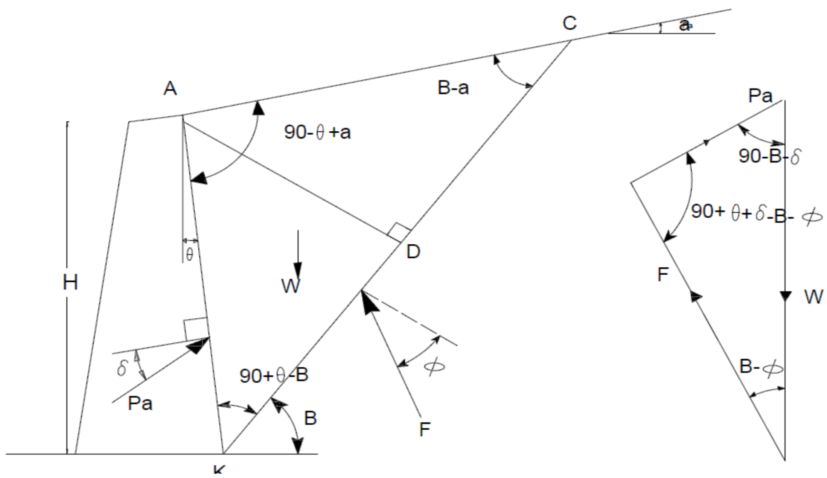


Figure 1. Coulomb active pressure calculation (H: Height of overburden, W: Weight of optimum wedge, a: ground slope, φ: Internal friction angle, B: Corner wedge angle, θ: Front retaining wall slope, δ: Angle of earth pressure direction)

From the law of Sines, the forces triangle to balance the rupture wedge is as follows:

$$\frac{W}{Sin\ (90+\theta+\delta-\beta+\varphi)}=\frac{Pa}{Sin\ (\beta-\varphi)}$$
$$Pa=\frac{Sin\ (\beta-\emptyset)}{Sin\ (90+\theta+\delta-\beta+\varphi)}.W \tag{1}$$

According to the Figure 1, the wedge weight is equal to:

$$W=\frac{1}{2}\ (AD)(BC).\gamma$$
$$AD=ABsin\ (90+\theta-\beta)$$
$$AD\ =\frac{H}{Cos\theta}.\sin(90+\theta-\beta) \tag{2}$$
$$AD=H\frac{Cos\ (\theta-\beta)}{Cos\theta}$$

From the law of Sines, we have:

$$\frac{AB}{Sin(\beta-\alpha)}=\frac{BC}{Sin\ (90-\theta+\alpha)} \tag{3}$$

$$BC=\frac{Cos\ (\theta-\alpha)}{Sin\ (\beta-\alpha)}\ .AB=\frac{Cos\ (\theta-\alpha)}{Cos\ \theta.Sin\ (\beta-\alpha)}.H$$

By placing the Eq (3) in Eq (1) and (2), the following relationship is obtained:

$$W=\frac{1}{2}\gamma H^2\frac{Cos\ (\theta-\beta).Cos\ (\theta-\alpha)}{Cos^2\theta.Sin\ (\beta-\alpha)} \tag{4}$$

In 1875, Coulmann [44] introduced a graphical method to solve Coulomb's pressure theory and calculate the W parameter with greater precision. The CG method is suitable for any level of overburden friction, regardless of the soil type or variations in overburden properties. This makes CG method an ideal method to estimate the side abutment pressure of the soil. By using CG method, this research aims to calculate the side abutment load on the chain pillar, which is the weight of the rupture wedge. The step-by-step process of CG solution for determining side abutment pressure is outlined in Figure 2.

The CG method involves the following steps to estimate the side abutment load on a chain pillar:

1. Draw the geometry with an appropriate scale, including the chain pillar dimensions, panel width, entry width, and overburden height.
2. Calculate the value of ∂ by subtracting the overburden internal friction angle (φ) from 90 degrees.
3. Draw line BD making an angle φ with the horizon.
4. Draw line BE making an angle ∂ with line BD.
5. Draw lines BC1, BC2, BC3, and BCn to create test rupture wedges.
6. Determine the areas of triangles ABC1, ABC2, ABC3, ... ABCn
7. Determine the soil weight W for each test wedge by using the areas calculated in the previous step as follows:

W_1= (Area of ABC_1) × (γ)

W_2= (Area of ABC_2) × (γ)

W_3= (Area of ABC_3) × (γ)

W_n= (Area of ABC_n) × (γ)

8. Choose an appropriate scale for the forces and plot the weights W1, W2, W3... Wn calculated in step 7 on the line BD (Note: BC1 corresponds to W1, BC2 to W2, BC3 to W3, and so on up to BCn to Wn).
9. Draw lines c1c'1, c2c'2, c3c'3... cnc'n, parallel to line BE, intersecting their respective rupture lines (note: c'1, c'2, c'3... c'n are located on the break lines BC1, BC2, BC3... BCn respectively).
10. Connect the points c'1, c'2, c'3... c'n with a smooth curve, called the Coulmann line.
11. Draw a tangent B'D' parallel to BD on the curve obtained in step 10 and note the point of contact with C'a.
12. Draw the line Bc'a to Ca. The triangle ABCa represents the preferred rupture wedge.

The ultimate breaking wedge of the CG method can be used to calculate the side abutment load on the chain pillar by determining the specific weight of the overburden and calculating the wedge area (represented by the green triangle in Figure 2).

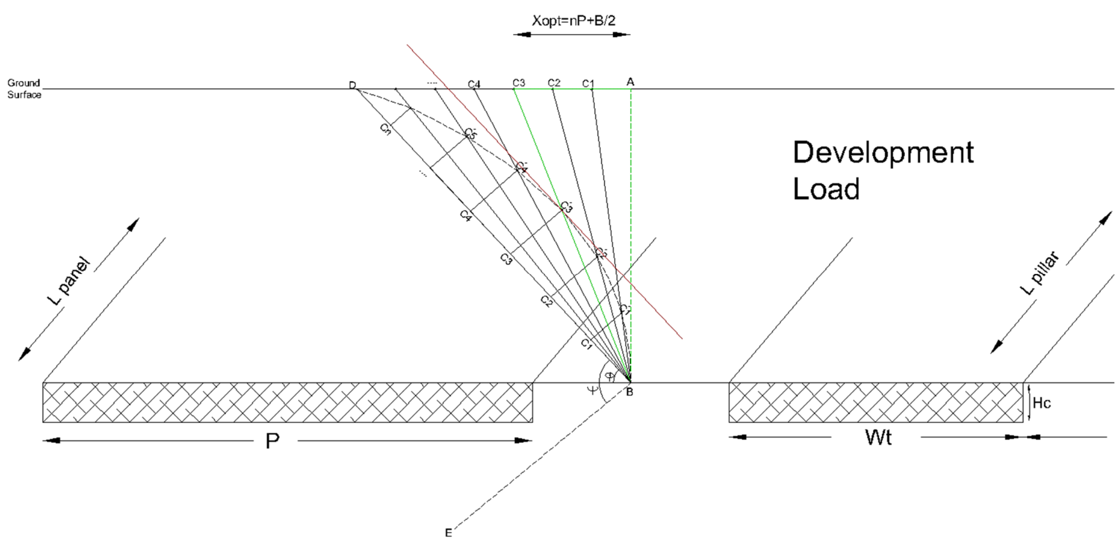


Figure 2. Coulmann Graphical method (which L_{panel}: Panel length, P: Panel width, W_t: Total chain pillar width, L_{Pillar}: Pillar length, H_c; Coal height)

3. Chain Pillar Stability Analysis by using Coulmann Graphical Method

The CCPSA program and CG method are robust analytical tools used to evaluate the stability of chain pillars, determine pillar loads, and assess subsidence status. These methods employ accurate calculations of side abutment loads through the use of the Coulmann graphical method. Coulmann's method, also known as the 'determination of active soil pressure by the graphical method', builds upon the foundational work of Coulomb and Rankin on earth pressure.

In this research, the dynamic mode of the CG method was employed for a more comprehensive analysis of civil and mining structures. This approach involves calculating the optimal rupture wedge in the overburden panel to ascertain the side abutment load. The research methodology aligns with the ALPS method, with the exception that the CCPSA program utilizes the CG method to evaluate side abutment loads. To calculate pillar strength, Mark and Beniawski's equations [45] were employed, and the development load was determined using the tributary area theory and front abutment load equations from the ALPS method. The CPSA program flowchart is illustrated in Figure 3. By calculating the optimal rupture wedge in the overburden panel, the method effectively determined the side abutment load. This research closely adhered to the ALPS method, with the notable deviation of utilizing the CG method within the CCPSA program to assess side abutment loads. To compute pillar strength, Mark and Beniawski's equations [45] were employed, while the development load was determined using the tributary area theory and front abutment load equations from the ALPS method. Furthermore, the CPSA program flowchart is depicted in Figure 3.

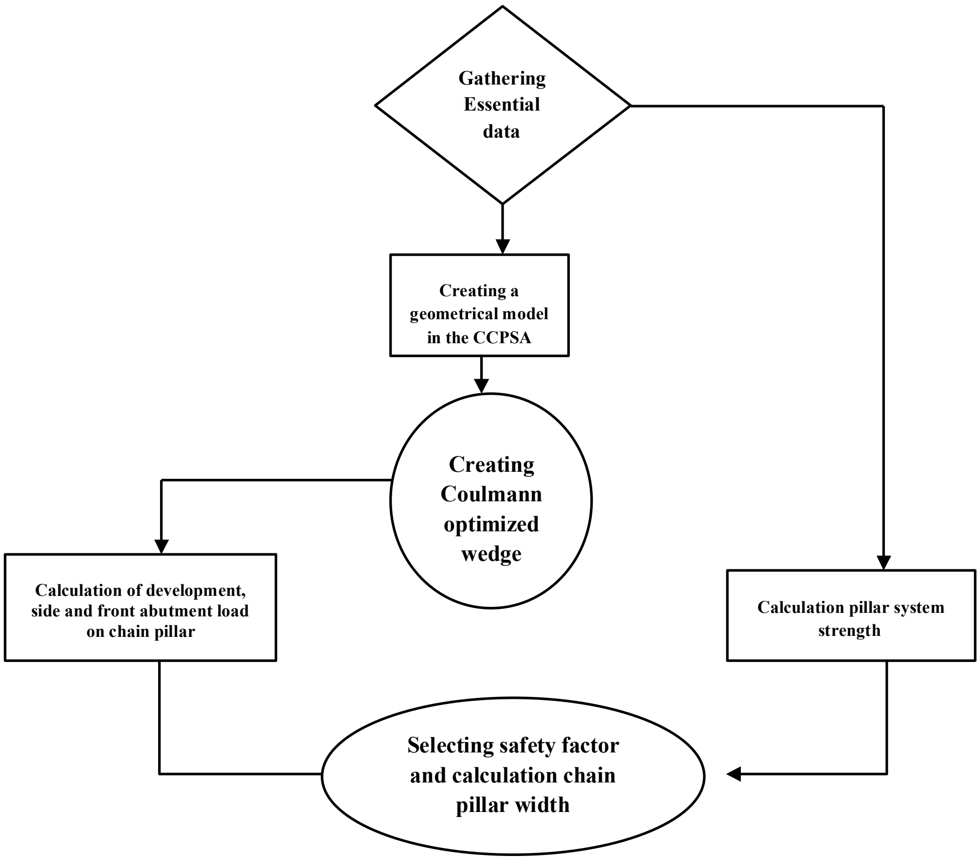


Figure 3. CCPSA program performance flowchart

The calculation of the loads in this method is done as follows:

- The calculation of the development load represents the weight on the pillar system prior to mining operations and is determined using the tributary area theory. The development load per foot of pillar length is obtained from the following equation:

$$L_t = H \times w_t \times \gamma \tag{5}$$

Where, γ is the specific weight of the overburden (in pcf), w_t is the total width of the chain pillar system (in ft), and H is the height of the overburden (in ft). The total loads are determined by adding the development loads and side abutment loads.

- The calculation of side abutment loads applied to the chain pillar is conducted using the CG method as described in section 2. This load is determined by drawing the final rupture wedge at the top of the chain pillar in the overburden, represented by the green triangle in Figure 2.

$$Ls = \frac{ɣ(H \times ((n - Project) \times P + \frac{B}{2})}{2} \quad (6)$$

In this equation, ɣ represents the specific weight of the overburden (pcf), H denotes the height of the overburden (ft), 'n-Project' corresponds to the output of the CG method, P indicates the width of the panel (ft), and B signifies the width of the entry.

Therefore, predicting the subsidence status (super-critical, critical, and sub-critical) is crucial in calculating the load on the chain pillar. The subsidence state after coal seam extraction can be determined by utilizing the CCPSA output [46, 47].

$$\begin{aligned} &IF \ \frac{P}{H} < 1.4 && Condition = Sub\ Critical \\ &IF \ \frac{P}{H} = 1.4 && Condition = Critical \\ &IF \ \frac{P}{H} > 1.4 && Condition = Super\ Critical \end{aligned} \quad (7)$$

By using the Equation 7 and the horizontal distance resulting from the effect of Coulomb wedge rupture on the surface (Xopt = ((n-Project) × P) + B/2) (as shown in Figure 2), the subsidence condition can be determined through trigonometric relations.

$$Tan\ (45 - \varphi) = \frac{((n - Benchmark) \times P) + \frac{B}{2}}{H} \quad (8)$$

Where, φ represents the equivalent overburden internal friction angle (in degrees), B is entry width (in ft), n is the Coulmann number, P is panel width (in ft), and H is over burden height (in ft). Based on the condition specified in Equation 7, we can deduce the following:

$$(n - Benchmark) = \frac{HTan\ (45 - \varphi) - \frac{B}{2}}{1.4H} \quad (9)$$

By utilizing the Coulmann number (n-Project) from the CCPSA output, the subsidence condition can be determined by comparing it with the benchmark number (n-Benchmark) using Equation.

$IF \ \ n - Benchmark = n - Project$	$Condition = Critical$	
$IF \ \ n - Benchmark > n - Project$	$Condition = Super\ Critical$	(10)
$IF \ \ n - Benchmark < n - Project$	$Condition = Sub\ Critical$	

The side abutment load percentage applied to the chain pillar is equal to the fraction of the influence zone where the side abutment loads have expanded, which is calculated using the following equation.

$$R = 1 - (\frac{D - W_t}{D})^3 \quad (11)$$

Where, D is the extent of side abutment influence zone, which represents the expansion of side abutment loads and is equal to $9.3\sqrt{H}$ [46].

- Headgate loading can be determined by combining the development loads and the initial front abutment loads. The result of the headgate load calculation can be found in [46, 48].

$$L_H = L_t + L_s F_h R \quad (12)$$

The calculation of the headgate load requires two front load factors: 1) the load that acts during the extraction of the first panel with a value of 0.5, and 2) the load that acts during the extraction of the second panel with a value of 0.7 [31, 33].

- Tailgate loading is the maximum load that enters the pillars and is obtained from the sum of the other specified [45, 47].

$$L_T = L_t + L_s(1 + F_t) \quad (13)$$

The next step is to determine the load bearing capacity (LB) of the pillar system. The load bearing capacity of the pillar system per ft is determined by summing the strength of each pillar, as calculated by equation 15 [46, 48].

$$LB = \sum[\sigma_P \times W \times L] \times \left[\frac{144}{(L+B)}\right] \quad (14)$$

The strength of each individual pillar is calculated using the Beniawski equations. [46, 48].

$$\sigma_p = S_1\left(0.64+0.36\frac{W_p}{h}\right)$$

$$\sigma_P = S_1\left(0.64+0.54\frac{W_p}{h}-0.18\frac{W_P{}^2}{L\times h}\right) \tag{15}$$

The safety factor is determined by dividing the bearing capacity of the pillar system (LB) by the total loads on the pillar system [46, 48].

$$SF = \frac{LB}{L_{\max}} \tag{16}$$

4. Introduction of CCPSA program in the Visual Studio software

The software Visual Studio, developed by Microsoft, is an integrated development environment that supports a variety of programming languages [49]. Leveraging its graphical capabilities, it stands out as optimal software for designing and implementing stability analysis, including the method outlined in this research. The equations for calculating development loads and side abutment loads were implemented using the C-sharp programming language. Figure 4 illustrates the input data of the CG method along with the final rupture wedge (green wedge).

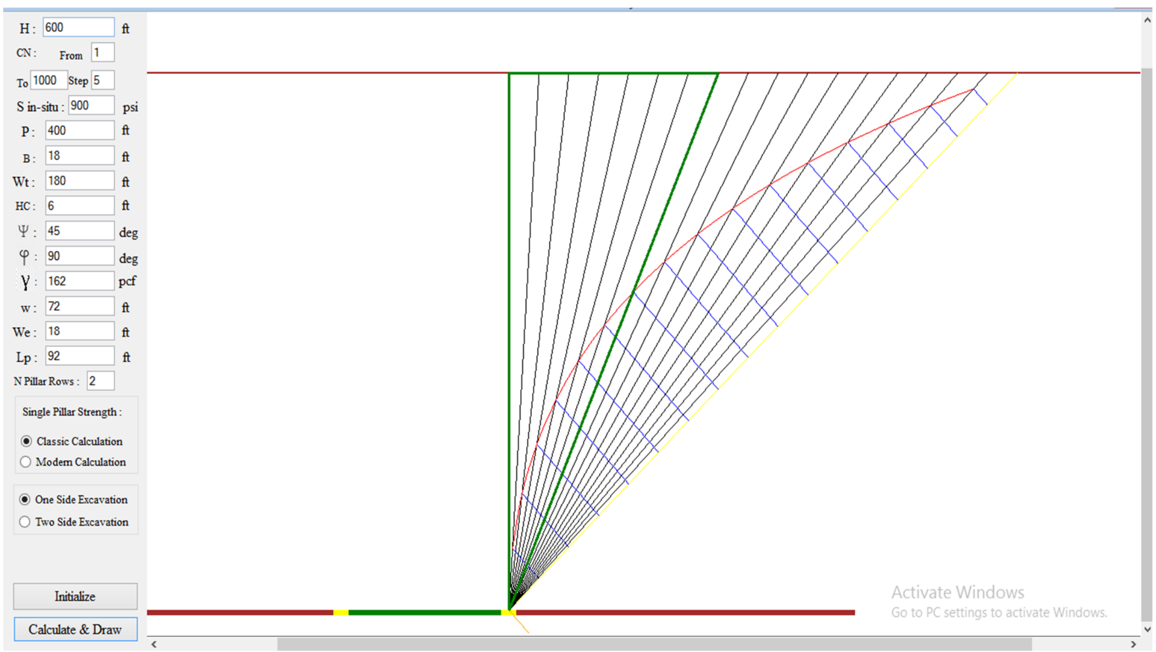


Figure 4. CCPSA program inputs with the final rupture wedge in green

According to Figure 3, all inputs are as follows:

H: Overburden height (ft)

C_N: Division of surface for wedge production

P: Panel width (ft)

B: Entry width (ft)

W_t: Total chain pillar width (ft)

Hc: Pillar height (ft)

Ψ: Overburden internal friction angle (degrees)

φ: CG method angle (degrees)

ɣ: Overburden specific weight (pounds per cubic foot)

W: Chain pillar width (ft)

LP: Chain pillar length (ft)

N Pillar rows: The number of pillar rows

Select icon: The number of panel

After the calculations, the CCPSA outputs will include the following, as depicted in Figure 5:

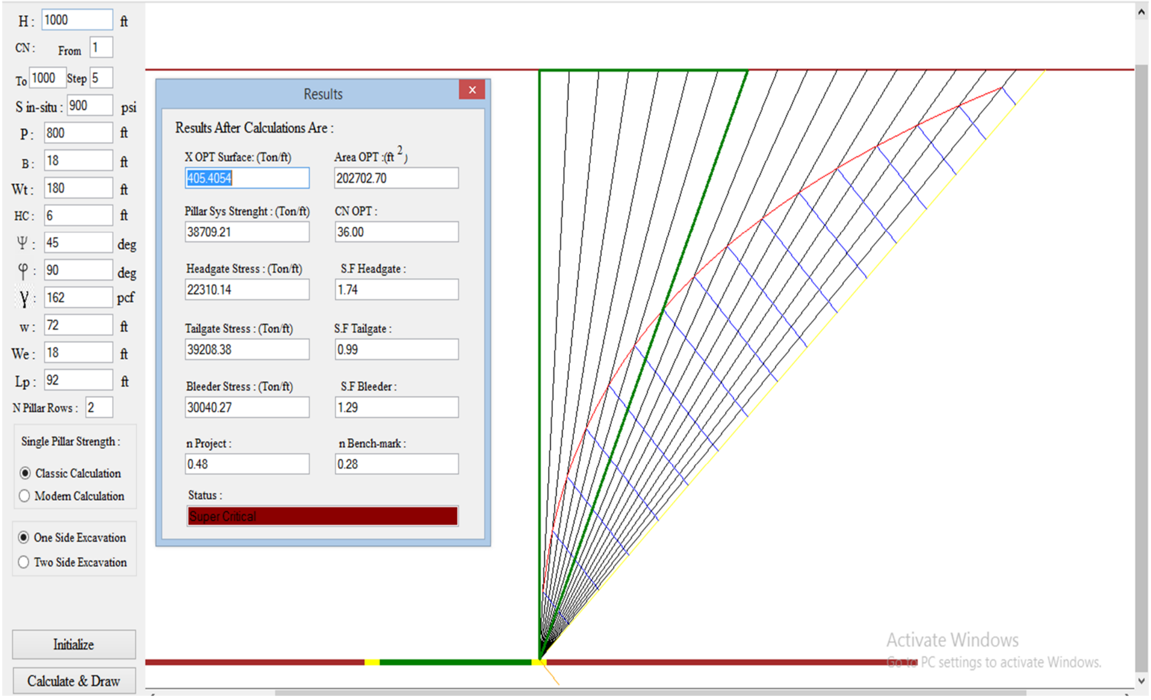


Figure 5. CCPSA program outputs

According to Figure 4, most important outputs are as follows:

Xopt: Optimal horizontal distance of the rupture wedge on the surface (ft)

Area OPT: Optimal wedge rupture area (ft^2)

CN OPT: Optimal division of the surface in order to make a rupture wedge

Pillar System Strength: Chain pillar system strength (tons per ft)

n. Project, n. Benchmark: Subsidence condition

5. CCPSA method validation

The CCPSA method was validated through the examination of 100 chain pillar datasets from various mines worldwide. In assessing its accuracy, the outputs of the CCPSA program were compared with those of the ALPS method. The results, presented in Table 1, reveal that the CCPSA method consistently yields a higher safety factor than the ALPS method under similar conditions. This characteristic renders it a valuable tool for optimizing chain pillar dimensions and maximizing coal extraction. Furthermore, the versatility of the CCPSA method is evident as it can be applied to two, three, and four-entry systems, as well as pillars with varying widths, making it useful across a range of scenarios. The stability analysis was conducted using Visual Studio software and the C-sharp programming language, harnessing the graphical capabilities of the software to define the equations for stability analysis. Table 1 shows Safety factor and side abutment load calculation with ALPS and CCPSA methods for 20 case studies [50, 51].

Table 1. Safety factor and side abutment load Comparison of 20 longwall chain pillar in different regions with ALPS and CCPSA methods

Zone name	Depth of cover (ft)	Pillar width (t)	Chain pillar length (ft)	Panel width (ft)	One Side Abutment load (ALPS) (Ton/ft)	S.F tailgate (ALPS)	One Side Abutment load (CCPSA) (Ton/ft)	S.F tailgate (CCPSA)
Crinume	443	114	410	902	2666.4	2.57	2457.2	2.75
Dartbrook	820	114	311	656	9326.8	0.86	7463.0	1.09
Elouera	1148	147	410	508	14896.7	1.02	13840.1	1.1
Elouera	1100	147	410	508	14688.3	1.0	13212.5	1.12
Gordon Stone	754	131	311	656	7453.2	1.49	6920.5	1.61
Wyee	721	104	334	534	7137.0	1.43	7382.4	1.38
Kenmare	564	98	393	656	4321.3	1.46	3811.3	1.68
Kenmare	524	82	393	656	3704.3	1.17	2963.5	1.45
Kenmare	426	82	393	656	2448.1	1.65	2561.2	1.58
Kenmare	590	101	318	426	4900.4	1.39	4623.7	1.47
Goonyella	590	98	311	836	4596.6	1.26	3880.1	1.52
Oakey Creek	590	98	310	656	4695.8	1.32	4112.4	1.52
Oakey Creek	590	98	310	656	4365.1	1.32	3710.6	1.60
Southem	524	98	311	820	3756.1	1.8	2912.5	2.34
Springvale	1066	147	312	820	15851.2	1.22	16310.6	1.18
Ulan	475	98	311	836	3000.8	1.65	2560.5	1.97
West Wallsend	787	114	318	475	7874.9	1.24	7930.5	1.23
West Wallsend	836	114	318	764	9228.9	1.11	8617.5	1.20
West Wallsend	820	104	360	460	8484.1	0.99	7721.2	1.09
West Wallsend	820	114	360	460	8423.9	1.08	7480.9	1.22

To provide a clearer understanding of the significance of the results, Figure 6 and Figure 7 present graphs depicting the safety factor and abutment loads calculated by both the CCPSA and ALPS methods. These graphs demonstrate the effectiveness of the CCPSA method, as it consistently produces favorable outcomes.

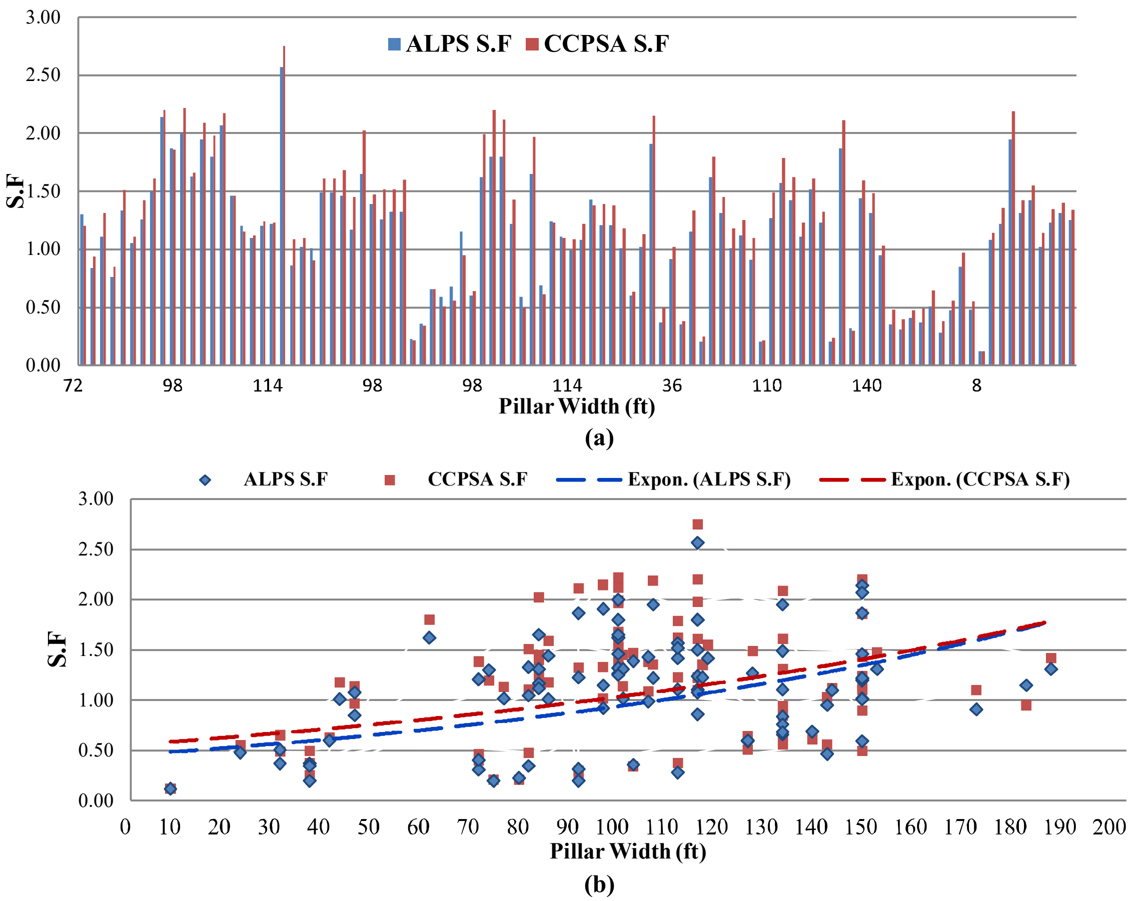
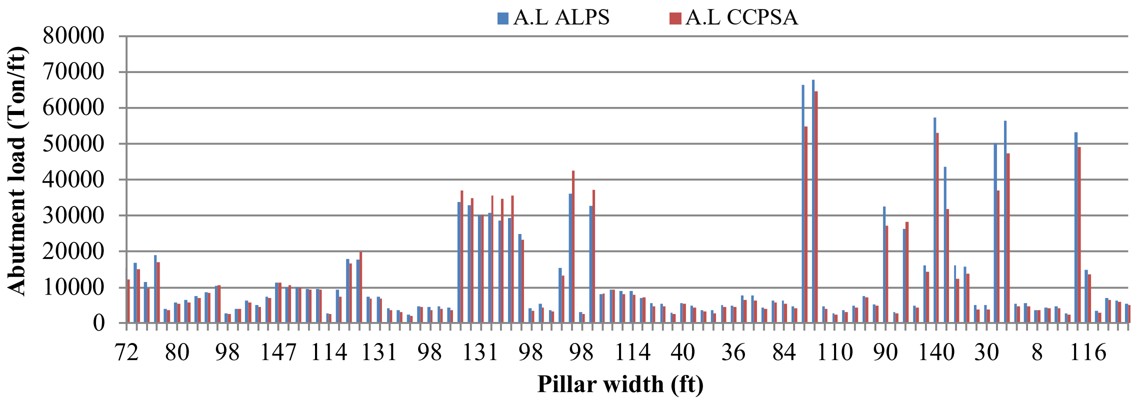
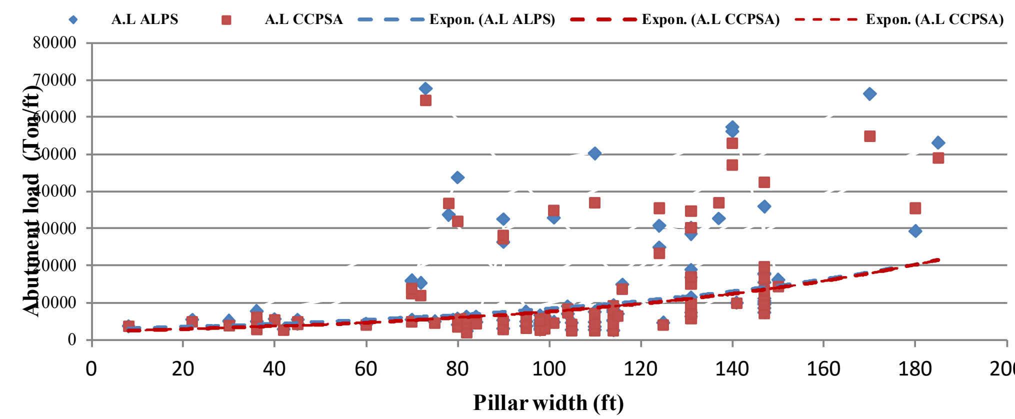


Figure 6. Safety factors Comparison of the CCPSA and ALPS methods



(a)



(b)

Figure 7. Side abutment load Comparison of the CCPSA and ALPS methods

Given the importance of designing chain pillars in underground mines and the direct impact of loads on these pillars, the effect of the new approach has been investigated in this research. Based on the fundamental equations and the CCPSA graphical method, input data from 20 different mines were examined. In this study, the obtained outputs, including the safety factor and side abutment loads, indicate a noticeable reduction in the calculation of side abutment loads. According to Figures 6-a and 7-a, it is clear that the safety factor and side abutment load values improve in the CCPSA method in most cases. This improvement will help in the optimal design of chain pillars and the estimation of side abutment loads. Moreover, according to Figures 6-b and 7-b, the exponential trend line of 100 chain pillars indicates that the CCPSA method produces suitable results when compared to other methods. These results demonstrate that the CCPSA method includes individual design aspects that can calculate side abutment loads and chain pillar width more accurately than the ALPS method.

6. Case study

Tabas coal mine No. 1, situated in eastern Iran within the Parvardeh region. The thickness of the overburden in this mine ranges from 100 to 700 meters and the C1 coal seam is extracted using the mechanized longwall mining method. According to the design specifications, the width of the initial panel is 200 meters, while in the subsequent panels it reaches a maximum of 220 meters. The extraction panels measure approximately one kilometer in length, sometimes even more, and are mined using the retreat mining technique. Essentially, the final mine layout has been developed based on technical and economic principles, taking into account the interplay between the ore deposit conditions and the mechanical environment, with a focus on operational mechanization and practical constraints. For the stability analysis of the chain pillar in Tabas coal mine using the CCPSA method, the necessary information has been listed in Table 2.

Table2. Input parameters for stability analysis of pillar in Tabas coal mine

Pillar height (m)	Overburden Density (ton/m^3)	Number of pillar rows	Panel width (m)	Entry width (m)	Overburden height (m)
3.2	2.65	1	200	5	600

Based on the CCPSA model inputs (Table 2) and the fundamental equations governing the load and equivalent strength of chain pillars system calculation, the results shown in Figure 8 indicate that with the tailegate safety factor controlling (S.F=1.1), the chain pillar width in the mentioned area is approximately 72 meters, and the subsidence condition under these circumstances is determined to be supercritical. This is achieved by applying similar conditions to the CCPSA method in the ALPS software, with the same safety factor in both methods, a pillar width of 78 meters is obtained. The results underscore the superior performance of the CCPSA method over the empirical ALPS approach and emphasize the distinctive features of the CCPSA methodology. In addition to the mentioned items, other outputs of the model have been presented in Table 3.

Table 3. CCPSA output parameters for stability analysis of pillar in Tabas coal mine

X_{OPT} (m)	Final wedge area (m^2)	Tailgate S.F	Head-gate S.F	Bleeder S.F	Subsidence status
3499	105109.7	1.09	2.43	1.84	Super critical

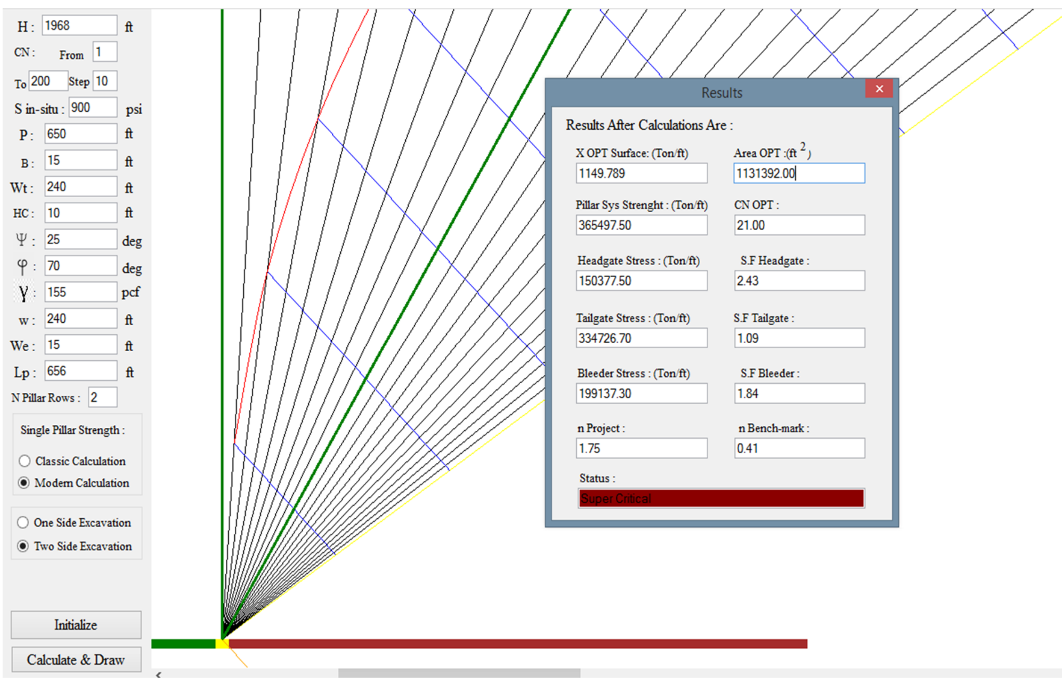


Figure 8. CCPSA results for Tabas coal mine

It should be noted that based on the available database and conducted investigations through Tabas coal mine, the reliability of the CCPSA method in estimating abutment loads as well as calculating the safety factor of chain pillars will greatly assist in the pillar designs. In some mines, when applying the chain pillars design parameters by using the CCPSA method and examining stability, the calculated safety factor tends to be lower compared to the ALPS method. This indicates that the abutment loads calculation by using the ALPS method have been assigned lower numbers which resulted in instability of the pillars in most cases. Therefore, these cases require a reconsideration of the chain pillars design.

7. Conclusions

The introduction of the Coulmann Chain Pillar Stability Analysis (CCPSA) marks a significant advancement in the field of longwall mining stability analysis. By building upon the CG method and leveraging Visual Studio software for program development, CCPSA provides a more precise and comprehensive approach to calculating side abutment loads. This enhanced accuracy translates into tangible benefits such as reduced pillar loads, improved pillar dimensions, and an increased extraction ratio, all of which are critical factors in ensuring the safety and efficiency of mining operations. The validation of CCPSA using data from 100 chain pillars across various mines not only confirms its superiority over the traditional ALPS method but also highlights its potential to revolutionize the industry. The higher safety factor and lower side abutment load demonstrated by CCPSA underscore its practical advantages and position it as a transformative tool for the stability analysis of chain pillars in longwall mining. The findings obtained from the implementation of the proposed method in Tabas coal mine revealed that this approach, when compared to the ALPS method at a depth of 600 meters, yields a significantly reduced width of the pillar by 6 meters. This outcome underscores the effectiveness and efficiency of the proposed method in optimizing the design of the pillars, leading to potential cost savings and improved stability in the mining operations. This research opens up new possibilities for enhancing safety, optimizing resource extraction, and driving cost-effectiveness in mining operations, thereby contributing to the advancement of the industry as a whole. By offering a more reliable and efficient approach to pillar stability analysis, the CCPSA method has the potential to improve safety standards and reduce costs. As a result, the validation of CCPSA and its implications for longwall mining practices represent a significant step forward in advancing the industry and addressing its evolving challenges

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روشی نوین به‌منظور تحلیل پایداری پایه‌های زنجیری در معدن‌کاری جبهه‌کار طولانی با استفاده از روش گرافیکی کولمن

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چکیده:

تحلیل پایداری پایه‌های زنجیری، یکی از موارد مهم در روش استخراج جبهه کار طولانی است. بنابراین، ارایه یک روش جدید برای ارزیابی بار وارد بر پایه‌های زنجیری، اهمیت بالایی دارد. در این تحقیق راه‌حل نوینی را برای ارزیابی بارهای کناری و تحلیل پایداری پایه‌های زنجیری با استفاده از حالت دینامیکی روش گرافیکی کولمن (CG) معرفی شده است. این روش با استفاده از نرم‌افزار ویژوال استودیو پیاده‌سازی شده است و با نام تحلیل پایداری پایه‌های زنجیری به روش کولمن (CCPSA) شناخته می‌شود. روش CG به عنوان یک روش بسیار کارآمد برای تعیین فشار کناری خاک در شرایط استاتیک و دینامیک در مهندسی عمران شناخته شده است. این روش شامل محاسبه گوه گسیختگی بالایی پایه‌های زنجیری با استفاده از روش CG است. عملکردهای نرم‌افزار CCPSA ویژگی‌های مهمی را با روش تحلیل پایداری پایه‌های زنجیری جبهه‌کار بلند (ALPS) به اشتراک می‌گذارد. با این حال، اصلی‌ترین تفاوت بین روش پیشنهادی و روش تجربی ALPS در رویکردهای مختلف آن‌ها در محاسبه بار کناری بر پایه‌های زنجیری و ارزیابی شرایط نشست است. اثربخشی این روش با استفاده از پایگاه داده‌ای از پایه‌های زنجیری از معادن مختلف در سراسر جهان اعتبارسنجی شده است و با روش ALPS مقایسه شده است. نتایج نشان می‌دهد که CCPSA در ارزیابی پایداری پایه‌های زنجیری بسیار مؤثر است. این نکته توانمندی روش CG و نرم‌افزار CCPSA را در ارائه روش مذکور برای ارزیابی و اطمینان از پایداری پایه‌های زنجیری در عملیات معدن‌کاری تأیید می‌کند.

کلمات کلیدی: پایه زنجیری، تحلیل پایداری، جبهه کار بلند طولانی، روش گرافیکی کولمن، بارهای کناری.