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Retraction

Retracted: Optimisation of Working Line Length during the Period of Gently Inclined Slope in Tilted Coal Seam Open-Pit Mine

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This article has been retracted by Hindawi, as publisher, following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of systematic manipulation of the publication and peer-review process. We cannot, therefore, vouch for the reliability or integrity of this article.

Please note that this notice is intended solely to alert readers that the peer-review process of this article has been compromised.

Wiley and Hindawi regret that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] B. Cao, B. Zhao, S. Wang, M. Lv, Q. Li, and G. Liu, "Optimisation of Working Line Length during the Period of Gently Inclined Slope in Tilted Coal Seam Open-Pit Mine," *International Transactions on Electrical Energy Systems*, vol. 2022, Article ID 2886565, 14 pages, 2022.

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Research Article

Optimisation of Working Line Length during the Period of Gently Inclined Slope in Tilted Coal Seam Open-Pit Mine

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In the initial production phase of an inclined seam opencast mine, due to initial investment and production capacity constraints, zoning or phasing is usually used, resulting in changes in the length of the working line during the transition of the mining area. To simplify the process, this article analyses the changes in the length of the working line during the period of slow gang steering in inclined seam opencast mines. In order to simplify the process, this article analyses the changes in the length of the working line in each period. The relationship between the length of the working line and the realm stripping ratio in the overlapping area of the two mining areas is discussed, and the variation in the realm stripping ratio and the economically reasonable stripping ratio under different working line lengths is illustrated. The advantages and disadvantages of the different optimization options are described. The optimization method was applied to the Zhundong opencast coal mine to calculate the working line lengths for the two stages. The optimized stripping ratio for the second-stage south gang location is equal to the economically reasonable stripping ratio of 3.50 m^3/t, which reduces coal compression and improves economic efficiency, and is a guideline for the study of the working line lengths in each stage of the open-pit mine slow gang turning.

1. Introduction

In China's near-level coal seam and inclined coal seam opencast mines, due to factors such as initial investment and production capacity, the location with a small stripping ratio is usually selected for trenching, and zoning or phased mining is used to divide the entire mine area into multiple mining areas, which are mined in sequence until the entire mine area is fully mined. As an important indicator of open-pit production, the length of the working line runs through the entire process of normal mining and steering, and has a significant impact on production succession. In combination with the existing open-pit production in China, most of which is suitable for slow gang steering, it is important to determine the length of the working line for each period, taking slow gang steering in open-pit mines as an example. In the process of slow gang steering, there are problems such as fluctuations in the length of the working line and coal pressure in the overlapping areas of adjacent mining areas, leading to increased stripping costs and a complex production process, resulting in a certain waste of resources.

Domestic scholars analyse the steering problem by analysing the right-angle slow gang of opencast coal in near-level coal seam and the adjacent mining area. Zhiguo et al. [1] determined the direct relationship between the total benefit of leaving the trench and the depth of leaving the trench by establishing the model of the best economic benefit of leaving the trench with slow help; Ziguang et al. [2] established a mathematical model to determine the best height of pressure help by calculating the amount of pressure help in the first mining area and the secondary stripping of pressure help in the third mining area, according to the end help level leaving trench scheme; In a study Ding et al. [3], the key parameters for the height of leaving ditch between the mining areas of the two mines were calculated; Guangwei et al. [4] established a mathematical model for the height of internal discharge pressed gang and repeated stripping depth to derive the internal discharge transport distance under different pressed gang methods; Runcai [5–7] et al. successively determined the final steering method as well as the mining realm by establishing the adjacent mining area first pressed gang and then left ditch, and analysed the coordinated mining of open-pit mines; Fuping [8] established a mathematical model in order to solve the problem of unbalanced internal drainage caused by the single-loop transportation and internal drainage bridging under the condition of internal drainage; Weishi et al. [9] proposed to solve the problem of unbalanced internal drainage caused during the steering of the retention ditch in Haidaigou open-pit coal mine under the conditions of the bucket shovel reverse stacking process. Mao et al. [10] analysed the mining as well as coordination problems between adjacent open-pit mines, compared the relationship between stay ditch and complete mining, and determined the optimal stay ditch height; Yanhe et al. [11] established a calculation model for the optimal mining depth of delta coal from the perspective of resource recovery and economy by analysing the characteristics of pressure gang internal drainage under the zoning mining conditions in open-pit mines. Guo et al. [12] analysed the stripping ratio during the transition period of open-pit mine turning by equalizing the stripping ratio during the transition period to ensure the safe, smooth, and orderly production organization during the transition period; Changsheng [13] analysed three steering methods and their characteristics, such as right-angle slow gang, fan, and re-drawing trench, between adjacent strips during the zoning mining of large open-pit coal mines with flat terrain, near horizontal, and gently inclined assignments. The analysis of secondary stripping, internal drainage space, and infrastructure volume of different steering methods was carried out.

Based on the above comprehensive analysis, experts and scholars mostly analyse the stay ditch and inner row during slow gang steering in near-level opencast coal mines, and there is less research on the length of working line in each stage of slow gang steering in inclined coal seam. In view of the above problems, through the analysis of the width of the retention ditch and the reserved coal pillar during the steering of the slow gang of inclined coal seam, the way of partial pressure on the gang in the unmined area between adjacent mining areas and the reserved coal pillar in the inner row is proposed to reduce the secondary stripping cost. And through the economic and reasonable stripping ratio for control, the economy of the scheme was confirmed, and the location of each stage of the project was determined.

2. Slow Help Steering Process

According to the different stripping positions in the open-pit steering process, considering the relationship between the working gang mining position and the coal seam inclination, based on the mining area where the working gang is located, the adjacent mining area open-pit slow gang steering is divided into two stages, namely, the stay ditch slow gang stage and the second slow gang stage, with the operation mode of cross mining to longitudinal mining to cross mining. Due to the instability of the mine development, the overall in-row stripping transport distance of the open-pit mine varies greatly. In order to further optimize the working line length, a simulated mining model of slow gang steering is established for the two stages separately for the problem of slow gang steering in inclined coal seams, and the relationship between the working line length and stripping ratio in each stage and the relationship between the working line length in each stage is analysed, and the example of the Zhundong open-pit coal mine is used. The results of the analysis can be of some significance to the calculation of the working line length during slow gang steering in opencast mines with inclined coal seams.

2.1. Determination of the Slow Gang Steering Method. The way in which open-pit mines are steered can be divided into two types of steering: no ditch steering and ditch steering, depending on whether the steering process leaves a ditch or not. No trench steering refers to the normal workflow in open-pit production; when the uppermost step reaches the boundary, the mining equipment and transportation tools of the flat pan are gradually moved to the corresponding position in the next mining area for steering operation, and there are problems of crossover of the production and discharge positions of the two mining areas and a large amount of secondary stripping; leave trench steering refers to the position of the inner discharge field near the next mining area in open-pit production. When the uppermost step reaches the boundary, the mining equipment and transport tools of the flat pan are gradually moved to the corresponding position in the next mining area and the steering operation is carried out, which has the problem of incomplete disposal of the internal drainage space. In this article, we propose to analyse the length of the working line in the period of slow gang steering.

2.2. Slow Gang Steering Workflow. For inclined seam opencast mines, if the I mining area starts with cross mining, the flow of the trench retention and slow gang steering is as follows.

A schematic diagram of the open-pit mine retention trench slow gang turning process is shown in Figure 1. The study is now carried out with the adjacent mining area inclined coal seam open-pit mine cross mining to the north with slow gang steering.

(1) Open-pit mine ditching and slow gang steering refers to the use of a location close to the II mining area for ditching during normal production in open-pit mines, as the upper working flat is coming to the boundary, in order to reduce secondary stripping.

(2) When the uppermost step of the I mining area reaches the boundary, due to the reduction of the production stripping ratio in the I mining area, the slow gang steering begins, and the mining equipment and transport system of the flat plate to the boundary are gradually moved to the northern part of the I mining area where the ditch is left, and the slow gang steering of the ditch is started.

(3) When the open-pit I mining area gradually reaches the boundary, the work line gradually shifted to the north

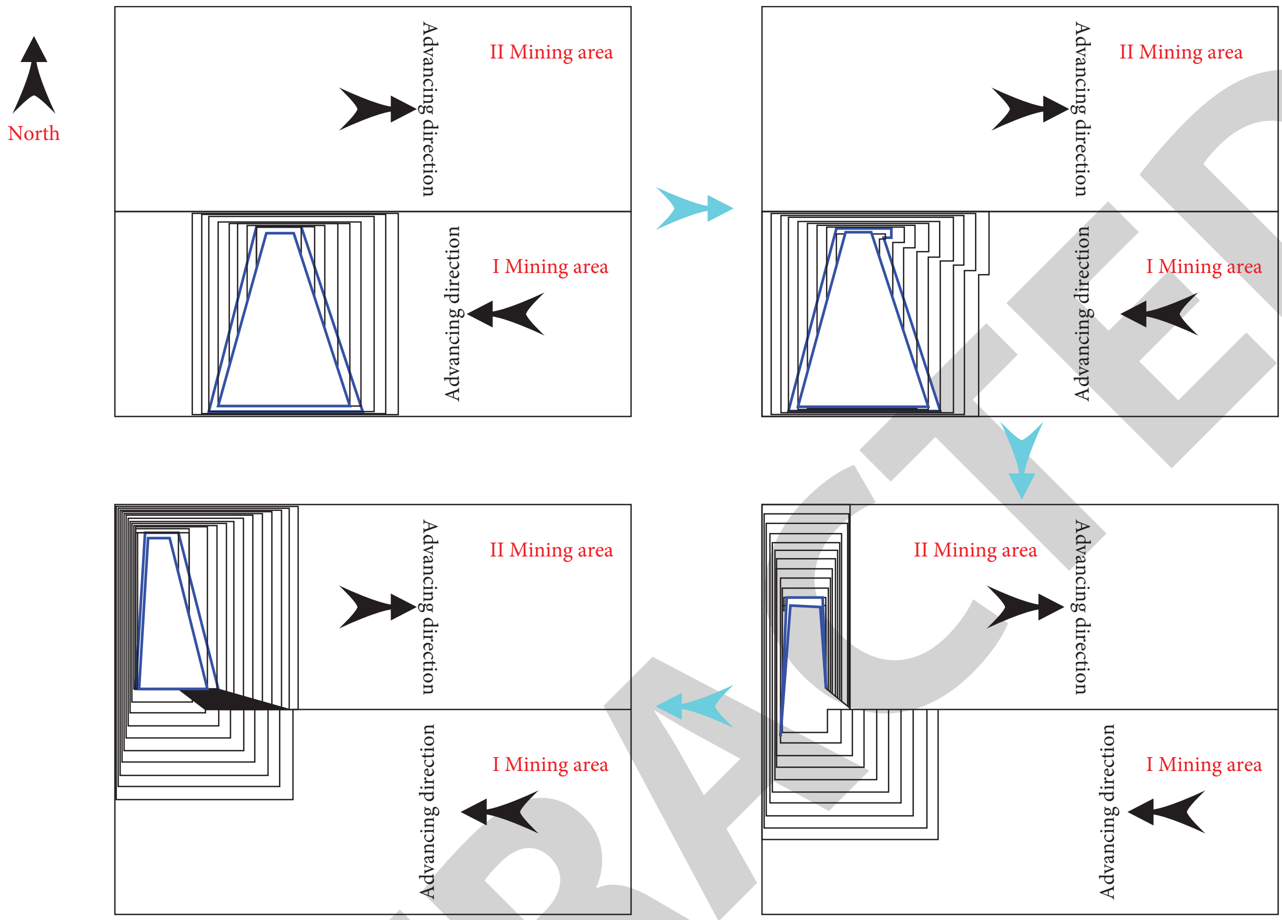

Figure 1: Schematic diagram of the open-pit mine retention trench slow gang turning process.

gang to pull away; open-pit mining operations shift from horizontal mining to vertical mining, and while the work line continues to advance, the mining depth gradually increased; when the uppermost flat plate of the north gang of II mining area reaches the boundary, the minimum flat plate width at the bottom of the pit should meet the minimum working flat plate width requirement, at which time the second slow gang steering is mined.

(4) When the north gang of the II mining area gradually reaches the boundary, the work line is shifted from the north gang to the east gang, and the operation mode of the open pit is shifted from horizontal mining to vertical mining.

2.3. Simulated Mining Model for Inclined Coal Seam Opencast Mines. For slow gang steering of inclined coal seams in a surface mine, the working line is arranged perpendicular to the coal seam strike and advances along the coal seam strike when mining in the I mining area. In order to analyse the relationship between the length of the working line and various factors in each stage of slow gang steering, a simulation mining model of an inclined coal seam opencast mine with one recoverable coal seam is established for two stages. Let the thickness of the coal seam be m, m; the inclination angle of the coal seam be θ; the working edge slope angle of the I and II mining areas be α; the edge slope angle of the inner drainage field be β; the gang slope angles of the east, south, west, and north gangs of the I mining area be β_1, β_2, β_3, and β_4 in order; and the gang slope angles of the east, south, west, and north gangs of the II mining area be β_1', β_2', β_3', and β_4'. Figure 2 shows the schematic diagram of the realm after the slow gang turn of the stay ditch, and Figure 3 shows the schematic diagram of the realm after the end of the second slow gang turn.

3. Analysis of the Morphology and Parameters of the Overlap Zone in Adjacent Mining Areas

3.1. Formation and Morphology of the Overlap Zone. For inclined coal seam opencast mines, the original mining plan was to mine the coal seams within the opencast mine boundary to achieve the objective of not wasting resources; in the actual production process, the adjacent mining area part due to the coal seam part of the resources have been mined, making its production stripping relatively large. If mining is carried out in accordance with the mining area boundary line, the coal resources are fully mined, which will result in the mining of a large amount of the original internal drainage stripping within the I mining area, resulting in an increase in secondary stripping and wasted funds.

The formation of the overlap zone is mainly related to the angle of the end gang of the two mining areas and the dip

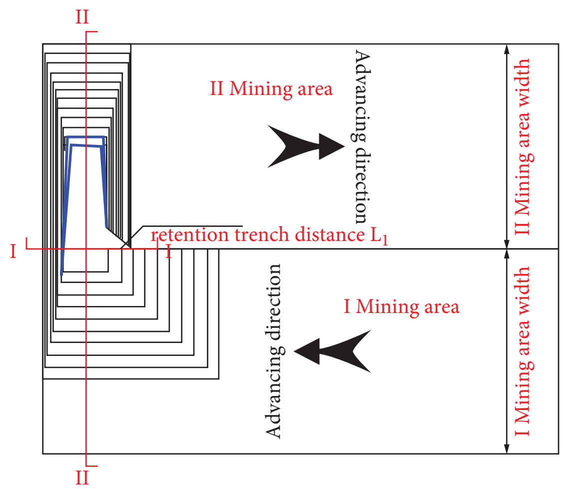

FIGURE 2: Diagram of the realm after the turning of the slow gang in the retention ditch.

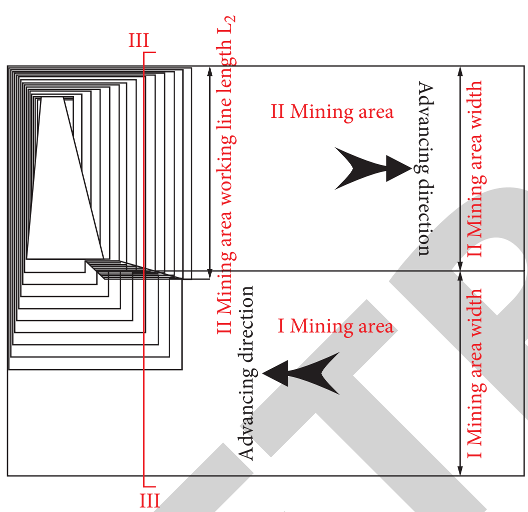

FIGURE 3: Diagram of the final realm after the second slow gang turn.

angle of the coal seam, which runs through the entire length of the intersection of the two mining areas. To reduce the amount of coal pressed in the intersection zone, the south gang of the II mining area needs to be pushed southwards to exchange the amount of coal with the amount of secondary stripping, and the limit mining position exists to maximize the economic benefits of the open pit.

3.2. Relationship between the Overlap Zone and the Length of the Working Line. Figure 4 shows a schematic diagram of sections III-III, where the overlap between the two mining areas is analysed, and the north gang of the I mining area and the south gang of the II mining area are simplified to derive the relationship between the overlap area and the length of the working line.

When the south gang of II mining area is located in position 1, all coal seams mined north of the south gang are all coal seams; when the south gang of II mining area is located in position 2, all coal resources can be fully mined, but the secondary stripping volume is larger. It is necessary to determine the mining position of the south gang to achieve the maximum economic benefits of the open pit. To simplify the calculation, the end gang, working gang, and the inner drainage field slope are calculated according to the slope angle, and the distance L_{12} between the two positions is

$$L_{12}=\frac{m}{\tan\beta_4+\tan\theta}+\frac{m\tan\beta_4}{\tan\beta_2'(\tan\beta_4+\tan\theta)}. \tag{1}$$

Let the south gang slope of mining area II be at any position x; the amount of stripping ΔS1 per unit advance to the east as it advances dx to the south isΔS_1 is

$$\Delta S_1=h_f+\frac{L_{12}\tan\theta}{1-\cot\beta_2'\tan\theta}+\frac{x}{\cot\beta_4+\cot\beta_2'}dx+\frac{dx^2}{2\cot\beta_4+2\cot\beta_2'}, \tag{2}$$

where h_f is the thickness of the overburden at the northern coal outcrop of the first mining area, m.

Advancing degree of coal mining to the east unit ΔS_2 is

$$\Delta S_2=\begin{pmatrix} m-\dfrac{x}{\cot\beta_4+\cot\beta_2'}+\dfrac{L_{12}-2x}{\cot\theta-\tan\beta_2'} \\ +\dfrac{x\tan\theta}{1-\cot\beta_2'\tan\theta}\end{pmatrix}dx-\begin{pmatrix}\dfrac{1}{2\cot\beta_4+2\cot\beta_2'}+\dfrac{1}{\cot\theta-\tan\beta_2'} \\ -\dfrac{\tan\theta}{2-2\cot\beta_2'\tan\theta}\end{pmatrix}dx^2. \tag{3}$$

Boundary stripping ratio n is the ratio of stripping to coal mined per unit depth increase in surface mining:

$$n=\frac{\Delta S_1 vp}{\Delta S_2 vp\gamma\eta}, \tag{4}$$

where v is the annual advance, m/a. P is the service life of the mining area, γ is the capacity of the coal, t/m^3, and η is the coal seam recovery rate, %.

Summarizing the above three equations gives

$$n=f(x)=\frac{h_f+(L_{12}\tan\theta/1-\cot\beta_2'\tan\theta)+(x/\cot\beta_4+\cot\beta_2')}{(m-(x/\cot\beta_4+\cot\beta_2')+(L_{12}-2x/\cot\theta-\tan\beta_2')+(x\tan\theta/1-\cot\beta_2'\tan\theta))\gamma\eta}\le n_j. \tag{5}$$

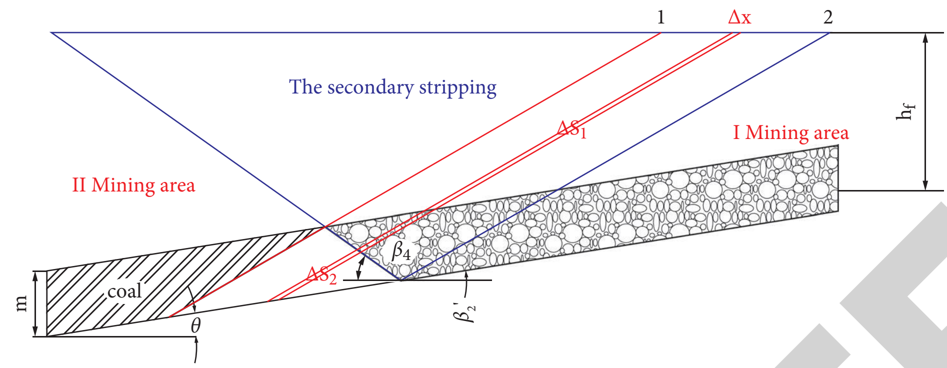

Figure 4: Schematic diagram of the location and morphology of sections III-III of the overlap zone of adjacent mining areas.

By analysing the stripping ratio per unit of advance, a reasonable location for the southern part of the working gang in the II mining area was determined to ensure that its realm stripping ratio meets the requirements of an economically reasonable stripping ratio [14].

4. Optimization of Working Line Length

4.1. Optimization of Retention Trench Width. For the slow gang turning stage of inclined coal seam opencast mines, the width of the retention trench is mainly related to the level of the retention trench, production capacity, and other factors.

The analysis was carried out for inclined seam opencast mines to retain the minimum working distance b at the bottom of the pit when the end gang is formed in the north gang of the II mining area, leaving the trench level at the base of the coal seam at the bottom of the pit.

When the uppermost step of the I mining area reaches the boundary, the mining equipment and the transport system of the flat pan to the boundary are gradually moved towards the northern part of the I mining area where the trench is left and the mining area is started to leave the trench to slow the help. A diagram of the I-I section is shown in Figure 5 to analyse the trenching distance.

For the tilted coal seam open cast mine slow gang steering period, when the work line to the north gradually develops, the coal seam depth gradually deepens; the II mining area north gang boundary needs to meet the minimum working distance of the pit bottom b. The I mining area north gang needs to stay ditch, the rest of the internal row, so as to slow gang steering stay ditch work; II mining area north gang mining coal seam floor height from the surface is H, and the uppermost flat plate minimum stay ditch width L_1 is

$$L_1 = H \cot \beta_3' + b + H \cot \beta. \tag{6}$$

For inclined coal seams, when the mine is steered to slow help, the width of the uppermost flat pan trench needs to be greater than L_1 to reduce the amount of secondary stripping in the open pit during the slow help steering from the I to the II mining area. Figure 6 shows a diagram of the II-II section, analysing the height of the bottom plate from the bottom of the coal seam in the north gang of the II mining area.

When the minimum working distance from the bottom of the final boundary pit in the north gang of the II mining area is b, the height of the bottom of the coal seam in the north gang of the II mining area from the surface, H, is

$$H = \frac{h_f + m + L \tan \theta}{1 + \cot \beta_4' \tan \theta}, \tag{7}$$

where L is the width of the mining area in mining zone II, m.

Combining the above two equations, the width L_1 of the retention trench is

$$L_1 = \frac{\left(h_f + m + L \tan \theta\right)\left(\cot \beta_3' + \cot \beta\right)}{1 + \cot \beta_4' \tan \theta} + b. \tag{8}$$

The length of the uppermost flat pan working line is analyzed for slow gang steering for inclined coal seam surface mine production capacity. In the actual production of opencast mines, due to the limitations of the mining process, mining equipment and production procedures, there is a maximum annual advance, but in the stage of staying in the ditch and slowing down the gang, it is necessary to minimize the number of years of steering, so the maximum advance $v_{\max}$ is used to calculate the length of the uppermost flat pan working line during slow gang steering.

The total advance in the steering phase of a tilted coal seam opencast mine with slow help $v_{\max}$ is calculated by the following formula:

$$v' = L + \left(h_f + m\right)\cot \beta_4 - \frac{h_f + m + L \tan \theta}{1 + \cot \beta_4' \tan \theta} \cot \beta_4'. \tag{9}$$

For inclined coal seam opencast mines in the slow gang steering phase of the retention ditch, the lowermost working flat working line length increases linearly with progressive northward, and its lowermost working flat working line length per unit advance at any position a, L', is

$$L' = \frac{-L\tan\theta\cot\beta_4' - L\tan\theta\cot\beta_4}{L + \left(h_f + m\right)\cot\beta_4 - \left(h_f + m + L\tan\theta/1 + \cot\beta_4'\tan\theta\right)\cot\beta_4'}a + L\tan\theta\cot\beta_4' + b + L\tan\theta\cot\beta_4. \quad (10)$$

The amount of coal per unit of advance in the steering phase of a tilted coal seam opencast mine with slow help S' is calculated by the following formula:

$$S' = \frac{m}{2}\left(mcot\beta_3' + mcot\beta_1' + 2L'\right). \quad (11)$$

The production capacity of the steering stage of the tilting coal seam opencast mine with slow help A_p is calculated by the following formula:

$$A_p = v\gamma\mu S'. \quad (12)$$

Based on the annual production capacity of the open-pit already determined, the length of the uppermost flat pan working line is derived L_1 and the annual advance v. The relational function between this and its reduction to the simplest form gives

$$v = \frac{A_p}{\gamma\mu\left(A_1 L_2 + B_1\right)}, \quad (13)$$

where $A_1 = m$,

$$B_1 = \frac{m^2}{2}\cot\beta_3' + \frac{m^2}{2}\cot\beta_1' - \frac{mL\tan\theta\cot\beta_4' + mL\tan\theta\cot\beta_4}{\left[L + \left(h_f + m\right)\cot\beta_4 - \left(h_f + m + L\tan\theta/1 + \cot\beta_4'\tan\theta\right)\cot\beta_4'\right]}a + mL\tan\theta\cot\beta_4' - m\frac{\left(h_f + m + L\tan\theta\right)\left(\cot\beta_3' + \cot\beta\right)}{1 + \cot\beta_4'\tan\theta} + mL\tan\theta\cot\beta_4. \quad (14)$$

where v is the annual advance, m/a; p is the service life of the mining area, a; γ is the capacity weight of coal, t/m3; and η is the coal seam recovery rate, %.

Due to the need to reduce the time of the stay trench slow helper phase, it is necessary to mine at the maximum annual advance $v_{\max}$, when the uppermost working flat is the smallest and the annual capacity requirements need to be met near the north helper in the II mining area, namely,

$$v_{\max} = \frac{A_p}{\gamma\mu S_{\min}'} = \frac{2A_p}{\gamma\mu\left(m^2\cot\beta_1' + m^2\cot\beta_3' + 2b\right)}. \quad (15)$$

When mining is carried out near the north gang of the II mining area, if the uppermost working flat working line length L_1 meets the annual advance requirements, L_1 meets the actual demand; if the uppermost working flat working line length L_1 does not meet the annual advance requirements, then the working line length needs to be increased to ensure the lowermost working flat width B in the subsequent advance:

$$B = \frac{A_p}{m\gamma\mu v_{\max}} - \frac{m\cot\beta_1'}{2} - \frac{m\cot\beta_3'}{2}. \quad (16)$$

The formula for calculating the rock volume S_y' per unit advance degree at the turning stage of slow help in the open-pit mine of inclined coal seam is

$$S_y' = \frac{H'}{2}\left(m\cot\beta_3' + m\cot\beta_1' + B_{\min} + L_1\right). \quad (17)$$

The production stripping ratio n is

$$n = \frac{S_y' vp}{S' vp\gamma\eta} \le n_j, \quad (18)$$

For inclined seam opencast mines, it is assumed that the minimum working distance at the bottom of pit b can meet the capacity requirements of the opencast mine. The optimization of the width of the trench at the opencast mine of the inclined coal seam is mainly related to the internal drainage space and can be classified by the time of trenching into two categories: (1) trenching after a period of advancement and (2) trenching with the status quo. This corresponds to optimization option 1 and optimization option 2, respectively.

4.1.1. Optimization Option 1. If the width of the lowermost working pan during the transition period of the mining area is taken as the minimum working distance $B_{\min}$ at the bottom of the pit (if the uppermost working pan working line length L_1 does not meet the annual advance degree requirement, the lowermost working pan width is guaranteed to be B), as the coal seam continues to deepen, its uppermost working flat pan working line length gradually increases, and at this time, the inner drainage space in mining area I is the largest under the condition of the minimum secondary stripping. The width of the ditch is mainly related to the end slope angle, the minimum working flat width and the inner waste dump slope angle. There are:

$$L_1' = \left(h_f + m\right)\cot\beta_3 + b + \left(h_f + m\right)\cot\beta. \quad (19)$$

The morphology is shown in Figure 7.

$$\Delta L = L_1 - L_1' = \frac{\left(L \tan\theta - h_f \cot\beta_4' \tan\theta - m \cot\beta_4' \tan\theta\right)\left(\cot\beta_3' + \cot\beta\right)}{1 + \cot\beta_4' \tan\theta}. \tag{20}$$

The uppermost flat disc working line pattern after optimizing the distance of leaving grooves is shown in Figure 8.

As the workings of the inclined open pit gradually advance northwards in the slow steering of the retention ditch, the length of the workings grows linearly until it increases to L_1, at which point the uppermost step of the workings is pushed to the II mining area boundary.

Optimized internal row capacity is

$$\Delta V = \frac{1}{2}\cot\beta_4\left(m + h_f\right)^2 \Delta L + \left(m + h_f\right) b \Delta L + \frac{1}{2}\cot\beta\left(m + h_f\right)^2 \Delta L. \tag{21}$$

Depending on the relationship between the actual internal drainage space and the required internal drainage space for trench turning, the initial trench width L_1 and the optimized trench width L_1' are required for the inner row space. The need for internal space can be classified as surplus, oversized, or undersized.

Internal drainage space required for initial trench width V_1 is

$$V_1 = L_1\left(m + h_f\right)b + \frac{L_1\left(m + h_f\right)^2}{2\tan\beta_4} + \frac{L_1\left(m + h_f\right)^2}{2\tan\beta}. \tag{22}$$

Optimization of the internal drainage space required after leaving the width of the trench V_2 is

$$V_2 = \left(m + h_f\right)b^2 + \frac{b\left(m + h_f\right)^2}{2\tan\beta_4} + \frac{b\left(m + h_f\right)^2}{2\tan\beta}. \tag{23}$$

(1) If there is space available in the inner row, $V_P \geq V_1$.

The open-pit mine has ample space for internal drainage. Consider leaving a trench in advance to reduce the amount of secondary stripping between adjacent mining areas, so that the coal resources can be fully developed and ensure that the working line is advanced vertically to the east after the completion of the slow gang transition within the II mining area. When the retention trench width LL ≥ L1, the relationship between V_P and L_L is

$$V_P = L_L\left(m + h_f\right)b + \frac{L_L\left(m + h_f\right)^2}{2\tan\beta_4} + \frac{L_L\left(m + h_f\right)^2}{2\tan\beta}. \tag{24}$$

Open-pit mine retention trench width L_L is

$$L_L = \frac{V_P}{\left(m + h_f\right)b + \left(\left(m + h_f\right)^2/2\tan\beta_4\right) + \left(\left(m + h_f\right)^2/2\tan\beta\right)}. \tag{25}$$

Using the internal drainage space as a constraint, the opencast mine can be steered by leaving a trench and slowing the gang to minimize secondary stripping, increase the amount of coal mined, and improve the overall economic benefits of the opencast mine.

(2) If the inner row space is on the large side, $V_1 \geq V_P \geq V_2$.

If the open pit has a large internal drainage space, but the primary internal drainage space is insufficient, then consider changing the distance between the bottom of the north gang pit in the I mining area in order to increase the internal drainage space, ensure the normal internal drainage of the open pit, and reduce stripping costs. When the relationship between ditch width LL and L1 '、 L1 is L1' ≤ LL ≤ L1, there are:

$$L_L = \frac{V_P}{\left(m + h_f\right)b + \left(\left(m + h_f\right)^2/2\tan\beta_4\right) + \left(\left(m + h_f\right)^2/2\tan\beta\right)}. \tag{26}$$

(3) If there is insufficient space in the inner row, $V_P < V_2$.

If Method 2 is still unable to meet the demand for space for the internal drainage of stripped material generated in the I mining area and in the slow gang transition, a partial flattening of the gang is also carried out first on the basis of Method 2, followed by a secondary stripping. The width of the retention trench is $L_1' = L_L$.

Assume that the internal drainage space requirement is met when the height of the retention trench is H:

$$V_1 = L_1\left(m + h_f\right)b + \frac{L_1\left(m + h_f\right)^2}{2\tan\beta_4} + \frac{L_1\left(m + h_f\right)^2}{2\tan\beta}. \tag{27}$$

After the internal stripping has been drained according to method 2, the remaining stripping volume is

$$V_2 - V_P = L_L H b + \frac{L_L\left(2Hm + 2Hh_f - H^2\right)}{2\tan\beta_4} + \frac{L_L\left(2Hm + 2Hh_f - H^2\right)}{2\tan\beta}. \tag{28}$$

The above equation shows that the remaining stripping is related to the height of the retention trench. However, in the actual production of an open-pit mine, it is necessary to ensure that the economically reasonable stripping ratio is met during the slow gang turning phase.

Assume $H_{\max}$ is the maximum height of trench left when an economically reasonable stripping ratio is met. Stripping volume per unit advance $\triangle S_{\mathrm{b}}$ is

$$\Delta S_b = \frac{1}{2}(H - m)^2 \cot \beta_4 + \frac{1}{2}(H - m)^2 \cot \beta_2'. \tag{29}$$

Coal extraction per unit advance $\triangle S_{\mathrm{m}}$ is

$$\Delta S_m = \frac{\gamma\eta 2xL_{12} - \gamma\eta x^2}{(L_{12} - x)^2}\left(\begin{array}{c} \dfrac{x^2}{2\cot\beta_4 + 2\cot\beta_2'} + mx - \dfrac{x^2}{\cot\beta_4 + \cot\beta_2'} \\ + \dfrac{xL_{12} - x^2}{\cot\theta - \tan\beta_2'} + \dfrac{x^2 \tan\theta}{2 - 2\cot\beta_2' \tan\theta} \end{array}\right). \tag{30}$$

The stripping ratio n is

$$n = \frac{\Delta S_b v p}{\Delta S_m v p \gamma \eta} \leq n_j. \tag{31}$$

① If the pressurized part meets the economically reasonable stripping ratio.

When the stripping ratio is equal to the economically reasonable stripping ratio, the height of the pressed gang is the maximum pressed gang height $H_{\max}$, with

$$H_{\max} = \frac{H_{\max} n_j \Delta S_m}{\Delta S_b \gamma\eta} = m + \sqrt{\frac{\left(4xL_{12}n_j - 2n_j x^2/(L_{12} - x)^2\right)\left(\begin{array}{c}(1/2)x\left(x/\cot\beta_4 + \cot\beta_2'\right) + mx - \left(x^2/\cot\beta_4 + \cot\beta_2'\right) + \left(xL_{12} - x^2/\cot\theta - \tan\beta_2'\right) \\ + (1/2)x\left(x\tan\theta/1 - \cot\beta_2'\tan\theta\right)\end{array}\right)}{(\cot\beta_4 + \cot\beta_2')\gamma\eta}}. \tag{32}$$

The height of the trench is $0 \leq H \leq H_{\max}$, and the width of the trench is $L_{\mathrm{L}} = L_1{}'$.

②If the pressurized part of the helper does not meet the economically reasonable stripping ratio.

When the internal drainage trench height calculated by the above equation is $H > H_{\max}$, if the internal drainage space is greater than the economically reasonable stripping ratio, and if the internal drainage space is still insufficient, the stripped material will be considered for external drainage. In this case, the width of the retention trench is $L_{\mathrm{L}} = L_1{}'$.

To sum up, the relationship between the space of one moment inner row and the width and level of stay trench by the optimized scheme is shown in Table 1.

4.1.2. Optimization Option Two

(1) If there is sufficient space for internal drainage, the adjacent parts of mining areas I and II are left trenching as they are mined, $L_{\mathrm{L}} = L_0$.

Inside row space V_{P} available is

$$V_p \geq L_0\left(m + h_f\right)b + \frac{L_0\left(m + h_f\right)^2}{2\tan\beta_4} + \frac{L_0\left(m + h_f\right)^2}{2\tan\beta}. \tag{33}$$

(2) If the internal drainage space is partially adequate, increase the internal drainage space by raising the level of the retention trench $H, 0 \leq H \leq H_{\max}$, at this time, $L_{\mathrm{L}} = L_0$.

$$V - V_P = L_0 H b + \frac{L_0\left(2Hm + 2Hh_f - H^2\right)}{2\tan\beta_4} + \frac{L_0\left(2Hm + 2Hh_f - H^2\right)}{2\tan\beta}. \tag{34}$$

The width of the retention trench H can be calculated by the above formula.

(3) If the internal drainage space is still insufficient when the level of the retention trench is $H_{\max}$, there is still insufficient space for internal drainage, then consider advancing eastward for internal drainage to press the gang to the surface and waste some resources by reserving coal pillars in the II mining stage. L_L is given as

$$L_L = L_0 - \frac{V - n_j \Delta S_m}{\left[(1/2)\cot \beta_4 \left(m + h_f\right)^2 + \left(m + h_f\right) b^2 + (1/2)\cot \beta \left(m + h_f\right)^2\right]}. \quad (35)$$

(4) When $L_L = b$, the internal drainage space cannot meet the demand of the open pit, the remaining stripped material is considered for external drainage with a minimum retention trench width of $L_L = b$.

In summary, the relationship between the inner row space and the width and level of the retention trench when optimizing Scheme 2 is shown in Table 2.

4.1.3. Evaluation of Optimization Options

(1) Optimization of Option 1 for the width of the retention trench has the main advantage of maximizing the use of internal drainage space; however, there is a situation where some coal resources cannot be mined from the current situation to the location of the retention trench, resulting in a waste of resources.

(2) Optimization of Scheme 2 for the width of the retention ditch has the main advantage that the existence of the status quo to the location of the retention ditch part of the coal resources can be fully mined, but the amount of secondary stripping is larger, and part of the stripping transport impact, resulting in stripping part of the stripped internal discharge transport distance increased, increasing stripping costs.

4.2. Optimization of the Working Line Length in the II Mining Area. The economically reasonable stripping ratio is the economically reasonable and maximum stripping ratio determined by economic factors and is an important indicator in determining the mining realm of open-pit mines and is linked to the economic principles for determining the mining realm of open-pit mines [15]. The methods for determining an economically reasonable strip ratio fall into two main categories: the raw ore cost comparison method and the price method. From a practical point of view, the price method is used to determine an economically reasonable stripping ratio for deposits that are currently mined only in the shallow part of the open pit and not in the deep part. The calculation formula is

$$n_j = \frac{\left(d_L/1 + \varepsilon\right) - a}{b}, \quad (36)$$

where n_j is the economically reasonable stripping ratio, m^3/t. d_L is the price of raw ore, RMB/m^3; and ε is the coefficient that takes into account production costs, guaranteed contribution, loan interest, profit, etc., deducted from the revenue of the product sold. a is the net mining cost per tonne of open-pit mining, RMB/t. b is the cubic metre stripping cost of open-pit mining, RMB/m^3.

The above equation shows that the economically reasonable stripping ratio is positively proportional to the price of the raw ore and inversely proportional to the cost of coal mining and stripping [16]. The price of raw ore is a value to be determined, while the cost of coal mining and stripping is related to its transportation distance, lifting height, and fuel. Therefore, an economically reasonable stripping ratio is a dynamic value and a reasonable working line length directly affects the overall economic efficiency of the open-pit mining area.

Through the above analysis, the relationship between the economically reasonable stripping ratio and the length of the working line cannot be directly obtained; the directly relevant quantities are transport distance and lifting elevation. Coal mining and stripping lift elevations do not vary significantly and are negligible; a reasonable working line length directly affects stripping and coal mining transport distances, thus affecting stripping costs and coal mining costs.

Assuming that the south gang of mining area II is located at position 1 in Figure 4, its coal mining and stripping transport distances are L_c, L_b. n_j is given as

$$n_j = \frac{\left(d_L/1 + \varepsilon\right) - k_1 L_c + x + (1/2)\mathrm{d}x c_c - b_1 c_c}{k_2 L_b + x + (1/2)\mathrm{d}x c_b + b_2 c_b}, \quad (37)$$

where k_1 and b_1 are the correction factors for the unit price of coal mining. c_c is the unit price of coal mining, RMB/(m^3·km). k_2 and b_2 are the stripping unit price correction factors. c_b is the stripping unit price instead of coal stripping unit price, RMB/(m^3·km).

The above equation can be reduced to its simplest form to give the following:

$$n_j = \frac{k}{x + A_2} + B_2, \quad (38)$$

where $A_2 = L_b + (b_2/k_2) B_2 = k_1 c_c / k_2 c_b$, $k = (d_L/1 + \varepsilon) - (k_1 b_2 c_c / k_2) - k_1 L_b c_c + k_1 L_c c_c + b_1 c_c$.

In order to ensure $n \leq n_j$, expand the mining boundary area to meet the economic and reasonable stripping ratio. The relationship between the length of the working line and the stripping ratio in the second slow gang turning phase is shown in Figure 9. The relationship between the length of the working line and the stripping ratio during the second slow gang turning phase is shown in Figure 9. As can be seen from Figure 9, there is an intersection point between the realm stripping ratio and the economically reasonable stripping ratio curve when $x = x_0$. The maximum reasonable working line length in the II mining area is when the realm stripping ratio is equal to the economic reasonable stripping ratio.

The length of the uppermost flat pan working line during the second slowing down phase is

$$L_{2max} = L + \left(h_f + m\right) cot \beta_4 - L_{12} + x_0. \quad (39)$$

The optimized working line length of the upper most flat plate after normal slow gang steering is

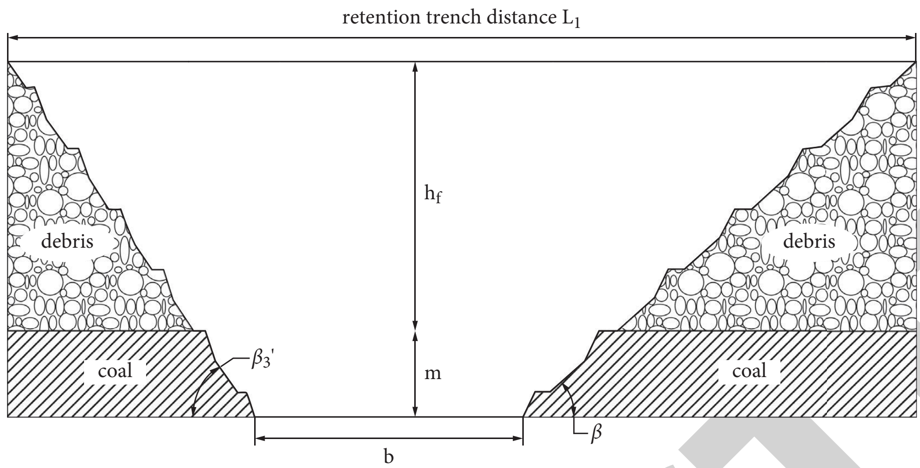

FIGURE 5: Schematic diagram of the location and morphology of the I-I section at the location of the transitional retention trench in the mining area.

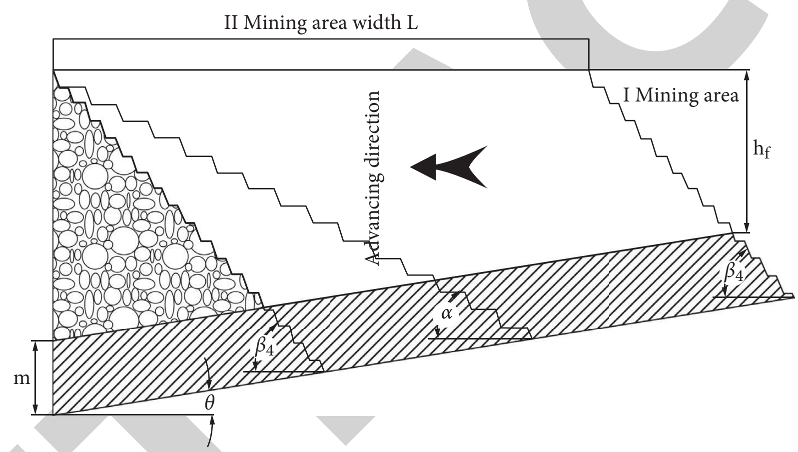

FIGURE 6: Schematic diagram of the position and shape of the south gang slope angle change II-II profile in mining area II before and after a slow gang turn.

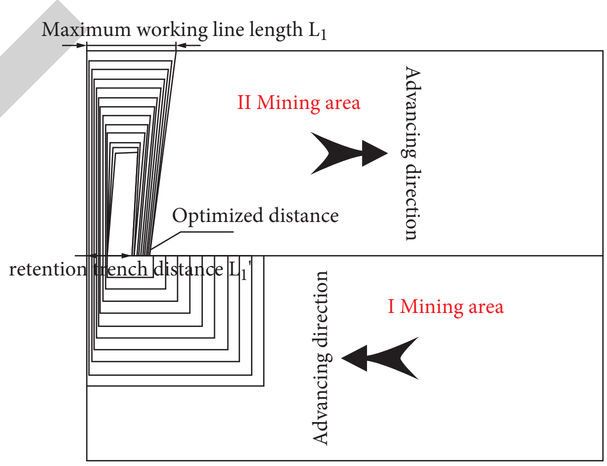

FIGURE 7: Schematic representation of the morphology after optimizing the width of the retention groove.

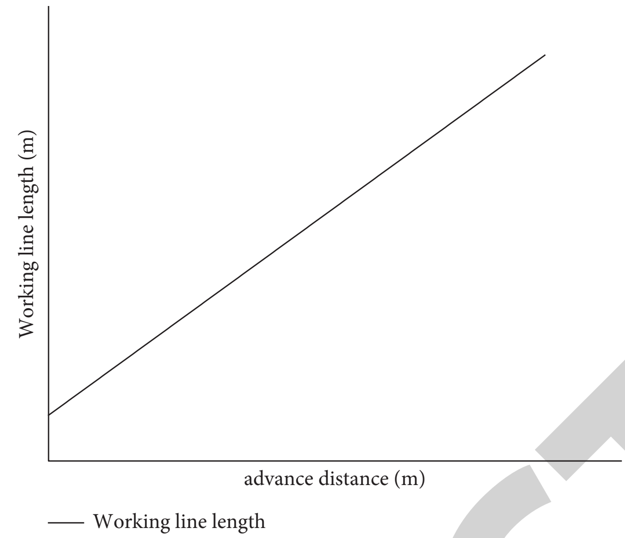

Figure 8: The uppermost flat plate working line pattern after optimizing the distance of leaving grooves.

Table 1: The relationship between the inner row space and the width and level of the groove.

Projects	Length of retention trench	Retained ditch level
$V_p \geq V_1$	$\frac{V_p}{(m+h_f)b+((m+h_f)^2/2\tan\beta_4)+((m+h_f)^2/2\tan\beta)}$	Coal seam
$V_1 \geq V_p \geq V_2$	$\frac{V_p}{(m+h_f)b+((m+h_f)^2/2\tan\beta_4)+((m+h_f)^2/2\tan\beta)}$	Coal seam
$V_p < V_2$	L_1' L_1'	L_L H_{max}
Note	$V_1 = L_1(m+h_f)b + (L_1(m+h_f)^2/2\tan\beta_4) + (L_1(m+h_f)^2/2\tan\beta)$ $V_2 = (m+h_f)b^2 + (b(m+h_f)^2/2\tan\beta_4) + (b(m+h_f)^2/2\tan\beta)$	

Table 2: The relationship between the inner row space and the width and level of the groove.

Projects	Length of retention trench	Retained ditch level
$V_p \geq V_1$	Mining status L_0	Coal seam
$V_1 \geq V_p \geq V_2$	Mining status L_0	L_L
$V_p < V_2$	$L_0 - \frac{V - n_j \Delta S_m}{(1/2)\cot\beta_4(m+h_f)^2+(m+h_f)b+(1/2)\cot\beta(m+h_f)^2}$ Minimum is b	H_{max}
Note	$V_1 = L_0(m+h_f)b + (L_0(m+h_f)^2/2\tan\beta_4) + (L_0(m+h_f)^2/2\tan\beta)$ $V_2 = L_0 H_{max} B_{min} + (L_0(2H_{max}m + 2H_{max}h_f - H_{max}^2)/2\tan\beta_4) + (L_0(2H_{max}m + 2H_{max} - H_{max}^2)/2\tan\beta)$	

$$L_2' = L + \left(h_f + m\right)\cot\beta_4. \quad (40)$$

It is possible to reduce L_{12}-x_0.

4.3. Length of the Uppermost Flat Work Line in the Second Mining Area under Reasonable Production Capacity. In order to ensure that surface mining can meet the demand for surface mine capacity, the production capacity of the inclined seam surface mine when mining normally to the east is analysed. According to the inclined seam opencast mine, the coal mining workings are advanced along the coal seam direction and the production capacity is mainly dependent on the annual advance and the length of the workings.

The amount of coal recovered per unit advance S is

$S = (m^2/2(\tan\beta_4' + \tan\theta)) + ((m\tan\theta/\tan\beta_2' - \tan\theta) + m)[L - L_{12} + (h_f + m)\cot\beta_4 - (h_f + m + \tan\alpha/1 + \cot\beta_4'\tan\alpha)(\cot\beta_4' + \cot\beta_2')] + (m^2/2\tan\beta_2' + 2\cot\beta_2') + (x_0^2/2\cot\beta_4 + 2\cot\beta_2') + mx_0 - (x_0/\cot\beta_4 + \cot\beta_2') + (x_0 L_{12} - x_0^2/\cot\theta - \tan\beta_2') + (x_0^2\tan\theta/2 - 2\cot\beta_2'\tan\theta)$

The normal production capacity of an inclined seam opencast mine to the east A_P is calculated by the following formula:

$$A_p = v\gamma\mu S. \quad (41)$$

Based on the annual production capacity of the open pit that has been determined, the length of the uppermost flat pan working line is derived L_2 The relational function between the annual advance and its reduction to its simplest form is given by

$$v = \frac{A_p}{\gamma\mu\left(A_3 L_2 + B_3\right)}, \quad (42)$$

where $A_3 = (m\tan\theta/\tan\beta_2' - \tan\theta) + m$,

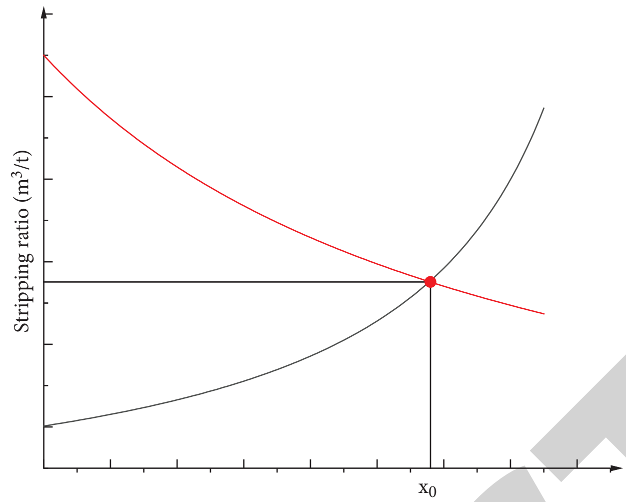

FIGURE 9: Schematic diagram of x versus stripping ratio.

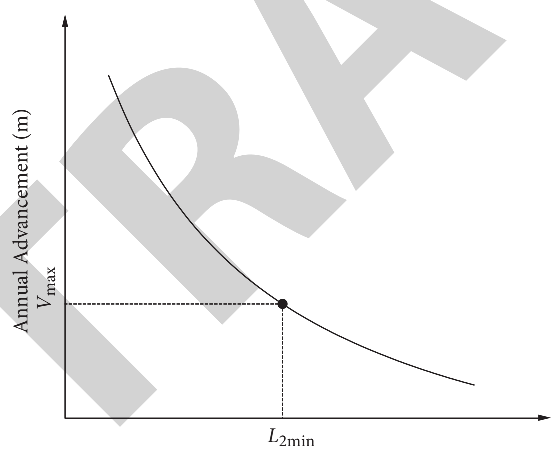

FIGURE 10: Schematic diagram of the relationship between the length of the uppermost flat plate working line L_2 and the annual advance.

$$B_3 = \frac{m^2}{2\left(\tan \beta_4' + \tan \theta\right)} - \left(\frac{m \tan \theta}{\tan \beta_2' - \tan \theta} + m\right)\left[x_0 + \frac{h_f + m + \tan \alpha}{1 + \cot \beta_4' \tan \alpha}\left(\cot \beta_4' + \cot \beta_2'\right)\right] + \frac{m^2}{2 \tan \beta_2' + 2 \cot \beta_2'} + \frac{x_0^2}{2 \cot \beta_4 + 2 \cot \beta_2'} + m x_0 - \frac{x_0^2}{\cot \beta_4 + \cot \beta_2'} + \frac{x_0 L_{12} - x_0^2}{\cot \theta - \tan \beta_2'} + \frac{x_0^2 \tan \theta}{2 - 2 \cot \beta_2' \tan \theta}. \tag{43}$$

The relationship between the length of the uppermost flat pan working line L_2 and the annual advance is plotted as a function of a curve, as shown in Figure 10. In the actual production of open-pit mines, due to the limitations of the mining process, mining equipment, and production procedures, there is an annual maximum

Table 3: Table of main parameters.

Projects	Unit	Numerical values
Coal seam thickness m	M	64.93
Coal seam inclination α	°	13
Inner drainage field slope angle β	°	20
End gang edge slope angle β_1、β_2、β_3、β_4、β_1'、β_3'、β_4'	°	35
End gang edge slope angle β_2'	°	20
Inside row tracking distance b	M	80.00
Width of first mining area L_0	M	1200.00
Width of secondary mining area L	M	1300.00
Thickness of overburden in the north gang of the first mining area h_f	M	230.00
Annual advancement v	M	300.00
Years of service in mining areas p	A	20
Raw coal capacity γ	t/m^3	1.29
Raw coal recovery rate η	%	97

advancement, and it can be seen from Figure 10 that when the annual advancement is less than the annual maximum advancement v_{max}, the corresponding uppermost flat working line length is the feasible working line length of the open pit. When the annual advance is equal to the annual maximum advance v_{max}, the corresponding uppermost flat working line length is the minimum uppermost flat working line length L_{2min} for open-pit production in mining area II. Therefore, the actual uppermost flat working line length L_2 for mining area II should be greater than or equal to the minimum uppermost flat working line length L_{2min}.

In summary, the final working line length for the uppermost workings of the II mining area is between L_{2min} and L_{2max}, depending on actual production in the open pit.

5. Example Analysis

The opencast mine is located in the eastern part of the western mining area of the Zhundong coalfield [17]. The opencast mine stratigraphy is a monoclinic structure that dips to the northwest, with little variation in production along strike and inclination and no-fault damage. The main coal seam to be mined is the single mega-thick coal seam, Group B, with an average recoverable thickness of 69.43 m. The seam inclination is 13°, and the final slope angle of the open pit is designed to be 35°, with an internal drainage slope angle of 20°. The width of the first mining area is 1200m, and the average width of the second mining area is 1300.00 m. The main parameters are shown in Table 3.

According to the actual situation of the Zhundong opencast coal mine, from the first mining area to the second mining area to stay ditch slow gang steering, its working line length in each stage can be obtained by calculating the following:

(1) The length of the uppermost working line in the first mining area L_0 is 1200.00 m.

(2) The length of L in the second slow help phase L_{12} is 150.36 m, the length of L_2 is 1578.08+x m, and its realm stripping ratio is n=(169.07 + 0.21x)/(83.64–0.42x) m^3/t. From the equation, we can know that when x is larger, its realm stripping ratio is larger, the minimum value of x is 0 m, and the minimum value of realm stripping ratio is 2.02 m^3/t, and at this time, the length of L_2 is 1578.08 m; the maximum value of x is 150.36 m, and the maximum value of realm stripping ratio is 9.79 m^3/t, when the length of L_2 is 1728.44 m.

By analysing the relationship between n, n_j, and x, the graph was determined as shown in Figure 11. As can be seen from the graph, when x = 73.00, the economic reasonable stripping ratio and the boundary stripping ratio are equal, and at this time, the length of L_2 is 1651.08 m and the boundary stripping ratio is equal to the economic reasonable stripping ratio, which is 3.50 m^3/t, at this time, the annual advance is 271.42 m, which is less than the annual maximum advance and meets the requirements.

(3) Through the relationship between the discharge space and the remaining stripped material within the first mining area of the Zhundong opencast coal mine, it is calculated that the excess internal discharge space is 15,151.20 million m^3. The second condition of the first optimisation plan is satisfied, and the calculation results in a retention trench width of 1,430.01 m and a retention trench level of the coal seam floor. As the distance between the current situation and the mining area boundary is 3,400.00 m, and the economic and reasonable stripping ratio of Zhundong opencast coal mine is around 3.50 m^3/t, the calculated trench width is 2,630.51 m, and the trench level is 35.50 m above the coal seam floor.

(4) To sum up, the length of stay ditch is 1430.01 m at the first slow gang steering, and the level of stay ditch is the coal seam floor; the length of the uppermost flat working line is 1651.08 m at the second slow gang steering.

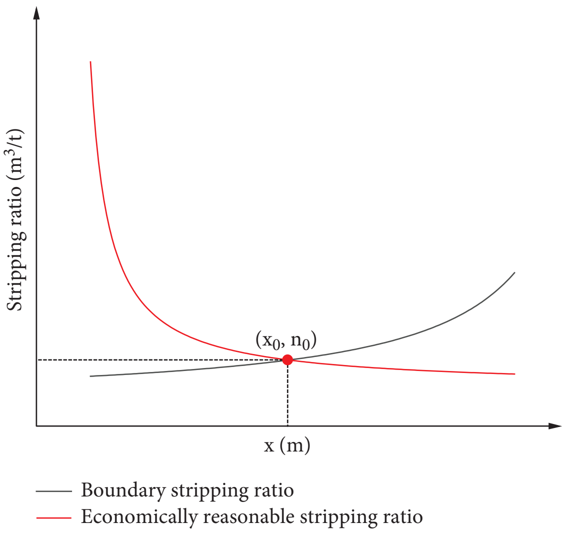

Figure 11: Plot of n, n_j versus x

6. Conclusion

(1) By analysing the work line arrangement and advancement method during the period of slow gang steering in inclined coal seam opencast mines, a steering simulation mining model was established for different stages.

(2) Analysis of the intersection part of I and II mining areas within the second slow gang, comprehensive consideration of the relationship between the realm stripping ratio and the economic reasonable stripping ratio, combined with the impact of the open pit production capacity, to determine the reasonable working line length of the uppermost step, so that the open pit mine at the maximum degree of economic efficiency best.

(3) The uppermost step of the two stages of reasonable working line length was determined separately by taking the Zhundong opencast coal mine as an example for analysis. The optimized ditch level is the coal seam floor, and the optimized ditch width is 1430.01 m; the optimized uppermost flat working line length for the second slow gang stage is 1651.08 m, and the stripping ratio of the southern gang realm is 3.50 m^3/t, which minimizes coal compression and improves economic efficiency.

(4) This article takes the example of slow gang steering in inclined coal seam opencast mines and analyses the length of the working line during the period of slow gang steering, which has certain guiding significance and promotion value.

Data Availability

The data of this article can be obtained through e-mail from the authors.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this work.

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