

Research Article

Optimization of Retaining Ditch Height for Gentle Slope Turning in Inclined Coal Seam Open-pit Mines

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Abstract

Inclined coal-seam open-pit mines with internal dumping commonly reserve an end-side retaining ditch when turning from horizontal advance to along-strike excavation. Selecting a single fixed ditch level is straightforward but ignores year-to-year variability in stripping volumes and haulage distances, which can inflate the combined transportation and secondary stripping costs. This study proposes a two-stage optimization framework for planning the ditch-height trajectory during the turning period. First, a maximum economic ditch height is derived via an economic-compensation model that balances the revenue from overlying coal recoverable after turning against the added costs of longer haulage and increased external dumping, with cost/revenue streams discounted using a compound-interest formulation. Second, within this upper bound, a total-cost minimization model couples annual stripping transportation costs during turning with the secondary stripping cost after turning. The model enforces annual waste-volume balance among inner dumping, ditch storage, and external dumping, preferred waste-flow directions, bounds on ditch height, and limits on height differences between adjacent years. Haulage distances are calculated from centroid locations of stripping and dumping stages extracted from 3DMine, and the resulting dynamic program is solved using a sequential recursion method. A seven-year case study (2023-2029) outputs an optimized fluctuating ditch scheme with yearly ditch heights of 214.5, 190.5, 206.7, 201.3, 189.6, 181.2, and 166.0 m, reducing the cumulative cost by 148.32 million CNY compared with the conventional constant-level ditch plan. The framework offers a practical decision tool for parameterizing retaining ditches and improving the overall economics of gentle-slope turning in inclined coal-seam open-pit mines.

Keywords

Open-pit Mine, Inclined Coal Seam, Ditch Height Optimization, Fluctuating Ditch, Optimization Modeling

1. Introduction

In the whole life cycle of open-pit mines, since the mining area is generally large, direct mining of the whole area will

cause problems such as poor economics. Therefore, mining mines is often divided into two or several mining areas for

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staged or partitioned mining [1]. For near-horizontal or gently inclined open-pit coal mines, since the inclination angle of the coal seam does not change much, whether digging along strike or along the horizontal mining of the coal seam if the internal drainage conditions are met, a certain distance between the stope and the inner dump site will be maintained, and follow up synchronously. However, for open-pit mines with inclined or steeply inclined coal seams, it is almost impossible to completely transport the wastes excavated along the extension direction of the coal seam to the inner dump, and compared with longitudinal mining, horizontal mining releases a larger inner drainage space [2]. Therefore, during the transition from horizontal mining to vertical mining, trenches

need to be used in open-pit mines with internal drainage to reduce the amount of secondary stripping in the next mining area and increase the mine's economic benefits.

At present, the ditch retention methods in steering mainly include end-side inverted triangular ditch, dump site inverted triangle ditch, end-side horizontal ditch, etc. Among them, the horizontal ditch at the end side is the most commonly used method. This method is bounded by a certain level of the side wall [3]. Below this level, the normal internal drainage mode of internal pressure covering the side wall is still adopted, and the method of non-discharge is adopted above this level to keep the minimum groove width. As shown in Figure 1.

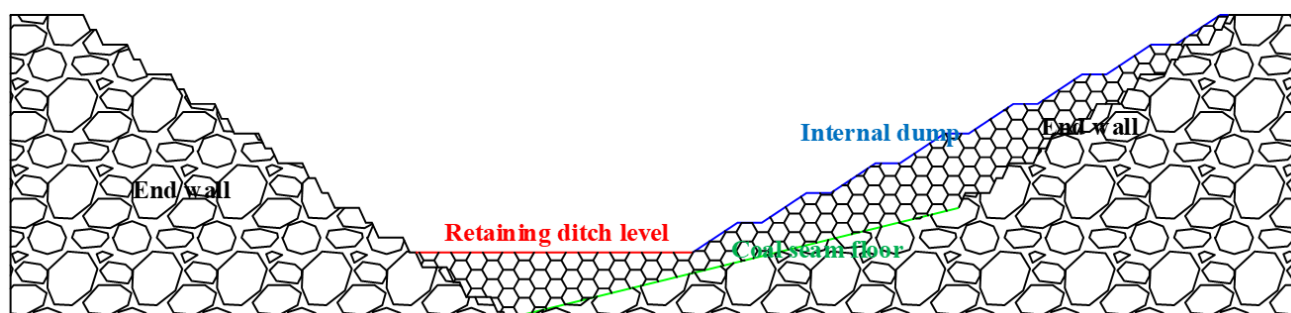


Figure 1. Schematic diagram of the horizontal stay trench of the end gang of the open pit mine with inclined coal seam.

In the process of turning to the retention ditch, the determination of the height of the retention ditch plays a vital role in it. Research by researchers on retaining trenches during diversion in open pit mines has focused on a single retaining trench height. For example, Liu Guangwei [4], established a mathematical model of the height of the inner discharge pressure gang and repeated peeling, and determined the optimal repeated peeling depth by using the minimum repeated peeling ratio. Zhang Ding [5], calculated the key parameters of the trench height between the two mining intervals by establishing a mathematical model of the economic trench height of the adjacent mining interval of the open-pit mine. Liu Peng [6], calculated the upper lag time value of different pressure heights based on the input lag time of the secondary divestiture cost as an independent variable. Ma Li [7], proposed the semi-pressure gang mode of grooved horizontal grooves, and determined the comprehensive optimization model of the height of the inner row pressure gang and the optimization model of the inner row bypass transfer step distance based on the cost compensation method. V. I. Cheskidov [8] increased the capacity of the inner row and reduced the height of the trench by increasing the high slope ratio of the dumping site.

The determination of the height of the above-mentioned ditch is only considered from the perspective of economic compensation or the optimal amount of secondary stripping and does not comprehensively consider factors such as the time during the steering period, the dynamic changes of the

stripped objects, and the transportation distance [9]. Moreover, for inclined seam open pit mines, during the transition period of the mining area, the stripping volume of the mining site is uneven for each year or each phase due to the different coal seam inclination, different coal seam thickness, geological formations, etc., and once the retention trench level is fixed during the steering period, it means that the inner drainage field can accommodate a certain amount of stripping for each year [10]. When the maximum retention level is determined with cost compensation, there is no constraint on the minimum retention level, in this case, if the internal drainage field is discharged at the maximum retention level for each year, and the internal discharge is given priority over the external discharge, the economic benefits are maximized in terms of the minimum amount of secondary stripping after turning, but in terms of the overall service life of the mine during turning. Therefore, in this paper, we consider the stripping flow and freight costs during the conversion from horizontal to vertical mining and the secondary stripping costs after the conversion to determine the optimal economic benefits of the mine as a whole to constrain the changes in the height of the retention ditch in each period.

In this paper, we study the change in trenching level during the turnaround of the crosscutting row in a tilted seam open pit mine based on the maximum trenching height level and constrain the change in trenching height from year to year by maximizing the overall economic efficiency. This process not only increases the overall internal drainage space, equalizes

the annual drainage volume, and reduces the amount of secondary stripping after turning, but also optimizes the trench height to improve the overall economic efficiency. It also provides considerable guidance for the selection of retention trench level parameters during the subsequent open pit turnaround.

2. Maximum Trench Height Under Cost Compensation Constraint

Taking the open-pit mine with a single huge thick inclined coal seam as an example, the economic cost compensation method is used to analyze the maximum trench level. When the full pressurization of the inner drainage field is changed to

partial pressurization, the recovery of the overburdened coal resources in this process is compared with the cost of secondary stripping, the cost of increasing the transport distance of the stripped material, and the cost of increasing the external drainage, so as to determine the maximum level of trenching.

When partial pressurization is carried out, the most significant impacts are: the economic benefits generated by the overburdened coal extracted after leaving the trench turned, the stripping costs of the second stripping after turning, the costs resulting from the change from double-loop transport to single-loop transport above the elevation of the left trench to increase the haul distance of the inner row, and the costs of the increased haul distance of the outer row stripping due to the left trench [11].

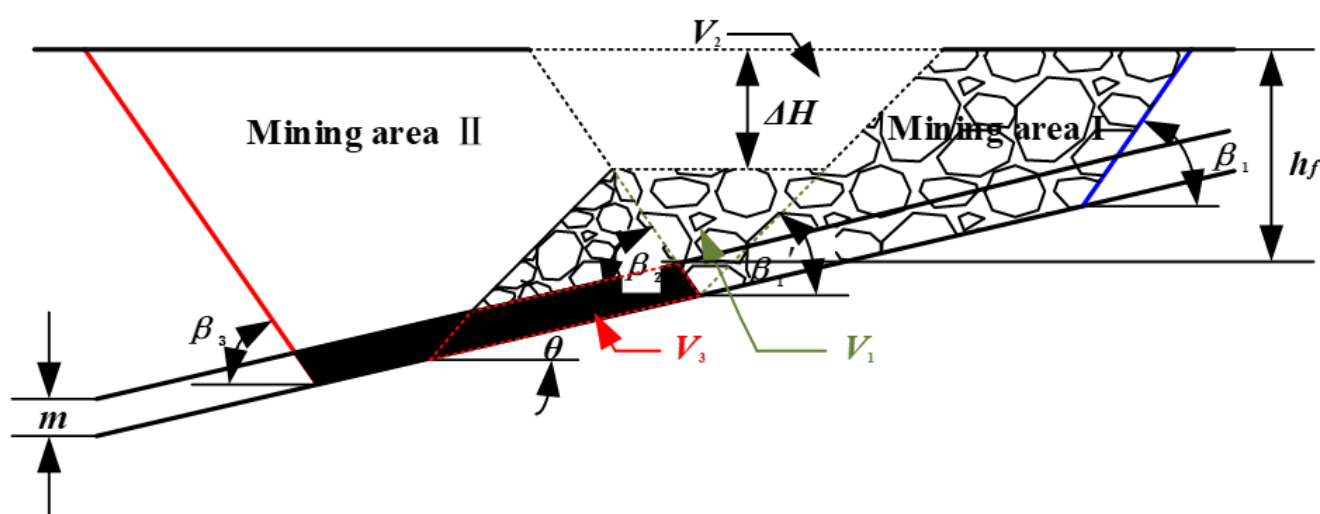


Figure 2. Diagram of the steering of the horizontal stay trench in the end gang of the adjacent mining area of the inclined coal seam open pit mine.

Among them, the secondary stripping amount of the next mining area under the unit advance degree is:

$$V_1 = \frac{1}{2} (h_f + m - \Delta H)^2 (\cot \beta_1' + \cot \beta_2) \quad (1)$$

In the formula:

V₁—The amount of secondary stripping under the height difference of ditch retention per unit advancing degree in adjacent mining areas, m³

ΔH —Height difference between the ditch level and the surface, m;

h_f —Pit bottom depth in the first mining area, m;

m —coal seam height difference, m;

β_1 —side slope angle of the first mining area;

β_1' —The side slope angle of the next mining area.

The volume per unit propulsion degree in the unrejected space is:

$$V_2 = \frac{\Delta H}{2} (2h_f + 2m - \Delta H) (\cot \beta_1' + \cot \beta_2) \quad (2)$$

In the formula:

V_2 —The amount of waste dumped in the outer dump site increased by leaving ditches under the unit advance degree, m^3

β_2 —The west bank slope angle of the first mining area.

The volume of overlying coal mined after steering:

$$V_3 = m \cos \theta \left[\left(\frac{h_f - \Delta H}{\sin \beta_2} + \frac{1}{2} m \cos \theta \right) \sin(\beta_2 + \theta) \right] \left[\cot(\beta_2 + \theta) + \cot(\beta_3' - \theta) \right] \quad (3)$$

In the formula:

β_3' —side slope angle without secondary stripping;

θ —Inclination angle of the inclined coal seam.

(1) Under the unit propulsion degree, the economic benefit W_1 brought by mining the overlying coal after turning is a positive benefit:

$$W_1 = P_c \square V_3 \square \gamma \quad (4)$$

In the formula:

P_c —The unit price of coal, yuan/t;

γ —The bulk density of coal, t/m³

(2) Under the unit propulsion degree, the economic benefit W_2 brought by the secondary stripping amount after steering is a negative benefit:

$$W_2 = P_r \square V_1 \quad (5)$$

In the formula:

P_r —Unit secondary stripping cost, yuan/m³.

(3) Under the unit propulsion degree, the economic benefit W_3 generated by the double-loop transportation of internal dump wastes above the ditch level is converted into single-loop transportation and the increased internal discharge distance is a negative benefit:

$$W_3 = B \square Q \square \Delta L \quad (6)$$

$$Q = \left[L - (h_f + m) \cot \beta_1' \right] \Delta H - \frac{1}{2} \Delta H^2 (\cot \beta_1' + \cot \beta_1) \quad (7)$$

In the formula:

B —The unit price of truck transportation, yuan/m³ km;

Q —The volume of the waste discharged from double-loop transportation to single-loop transportation, m³;

L —The length of the working line at the bottom of the pit in the first mining area, m;

ΔL —The distance length increased by double-loop transportation transformed into single-loop transportation, m.

(4) Under the unit propulsion degree, the unused disposal space of the inner dump site will result in the difference cost W_4 caused by transporting part of the stripped material to the outer dump site, which is a negative benefit:

$$W_4 = C \square V_2 \quad (8)$$

In the formula:

C —The cost of land expropriation for the unit's outer

dump site and the increase in the transportation distance of the outer dump, yuan/m³;

Through the comparative analysis of the cost compensation of the three types of costs, combined with the calculation method of compound interest in economics [12], the maximum level of ditch retention is determined as follows:

$$W_1 = (W_2 + W_3 + W_4)(1 + \rho)^n \quad (9)$$

In the formula:

ρ —Bank annual interest rate, %;

n —The service life of mining area turning, a.

Put the above formula into the simplification to get the function expression relation of ΔH :

$$\begin{cases} a\Delta H^2 + b\Delta H + c = 0 \\ a = \frac{1}{2} \left[(P_r - 1) (\cot \beta_1' + \cot \beta_2) - B \square \Delta L (\cot \beta_1' + \cot \beta_1) \right] \\ b = \frac{B \square \Delta L \square L + \frac{P_c \square \gamma \square m \cos \theta \sin(\beta_2 + \theta)}{\sin \beta_2 (1 + \rho)^n} + \frac{[\cos(\beta_2 + \theta) + \cos(\beta_3' - \theta)]}{\sin \beta_2 (1 + \rho)^n}}{(h_f + m) [B \square \Delta L \square \cot \beta_1' + (P_r - 1) (\cot \beta_1' + \cot \beta_2)]} \\ c = \frac{\frac{1}{2} P_r (h_f + m)^2 (\cot \beta_1' + \cot \beta_2) - P_c \square \gamma [m \cos \theta \sin(\beta_2 + \theta) (2h_f + m \cos \theta)]}{\frac{[\cos(\beta_2 + \theta) + \cos(\beta_3' - \theta)]}{2 \sin \beta_2 (1 + \rho)^n}} \end{cases} \quad (10)$$

Through the above formula, this paper constrains the maximum height of the ditch at the end side. When the level of the ditch exceeds this height, the economic benefits brought by the ditch are negative. When the ditch is less than or equal to this part What is produced is a positive economic benefit value. The top view and cross-sectional view of the mining area are shown in Figure 3:

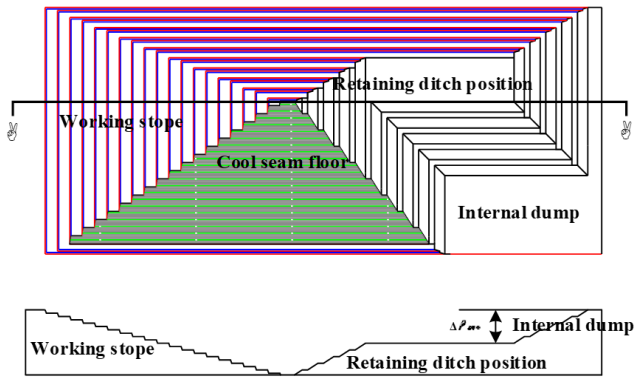


Figure 3. Schematic diagram of maximum ditch height in inclined seam open-pit mine.

3. Ditch Height Under Overall Constraints of Total Cost Minimization

Through the above economic benefit compensation method, this paper determines that the maximum height of the ditch during the diversion of the inclined coal seam open-pit mine is $\Delta H_{\max}$, and the height of the ditch will be further restricted in the following.

During the diversion period, the stripping material produced in the stope every year is divided into three parts, which are transported to the inner dump, the ditch space (the amount of ditch discharge) and the outer dump [13]. Among them, it is assumed that the stripped objects transported to the inner dump every year are fixed, that is, the inner dump is discharged according to the normal elevation every year, while the stripped objects transported to the ditch part and the outer dump every year are dynamic change. From this, the relationship between the total cost and these quantities can be determined: when the height of the ditch becomes smaller, the amount of drainage in the ditch is increasing. For the stripped material, the transportation distance decreases, and the economic benefits increase. The economic benefit is also improved when the displacement is reduced, but for the amount of secondary stripping after steering, the amount of secondary stripping increases and the economic benefit decreases; The displacement is reduced, the transportation distance of some stripped objects is increased, the economic benefit is reduced, the external discharge is increased, the economic benefit is reduced, and the secondary stripping volume after the steering is reduced, the economic benefit becomes larger [14]. Now the objective function is to minimize the sum of transportation costs during the steering period and the secondary stripping costs after the steering, accumulate the costs of each part of each year during this period, and make the annual stripping logistics Change to the flow, so that the overall accumulated total economic benefit value is optimal [15].

3.1. Establishment of Ditch Height Planning Model

The ditch height planning model during the turning period divides the entire model cycle into several stages according to the year, and gives the horizontal height of the ditch in each stage, so that the mine can be stripped in the entire cycle of model calculation, and the economic benefits of transportation plus the two after the steering. The sum of the economic benefits of each stripping is optimal. The engineering position of each stage includes the height of the inner dump and the shape of the slope. The unit cost of production links such as perforation, blasting, and mining basically does not change with the change in the height of the ditch. Therefore, the economic benefits of the dynamic programming model for the horizontal height of the ditch during the diversion period mainly consider the cost caused by the change in the amount of stripped objects transported to different locations and The cost of the secondary stripping amount when mining the next mining area after the diversion is completed.

3.2. Scientific Simplification of the Problem

In reality, the flow direction of the stripped material from the internal drainage period of the inclined coal seam open-pit mine to the transition to the longitudinal mining period is to be able to be discharged inward as much as possible (excluding the level of the ditch), and the remaining stripped material is released in the form of internal drainage heightening or external drainage. In this process, factors such as the tracking distance of the inner row, the highest discharge elevation of the inner and outer dumps, the height of each step, the width of the working flat, and the slope angle of the dump all have an impact on it. Complete description, analysis, and analysis: It is costly and difficult to solve all the problems involved in turning to ditch retention, so it is necessary to further simplify the stripping flow each year. The simplification is as follows: determine the minimum tracking distance between the inner dump and the stope as $L_{\min}$; determine that the inner dump will be discharged according to the highest elevation except for the ditch part; Only the centroid position of the stripping and discarding stages is considered in each year. The horizontal and vertical distances were calculated according to the position changes of the center of mass in the stripping stage and the corresponding discarding stage; the slope angle β of the inner dump site was determined to be a constant value [16].

3.3. Ditch Dynamic Adjustment Constraint Range

After the relevant simplification of the above problems, according to the development law of mining stripping and drainage engineering, it is necessary to adjust the dynamic planning of relevant stages [17].

(1) The height of the ditch should be less than the maximum horizontal ditch height $\Delta H_{\max}$, and in the limit state, no ditch should be left, that is, the height of the ditch should be greater than 0.

$$0 \leq H_i \leq \Delta H_{\max} \quad (11)$$

In the formula:

$\Delta H_{\max}$ —The height of the ditch for each year, m.

(2) Under ideal conditions, the total amount of waste W in each year should be equal to the loose volume corresponding to the stripped amount W in the stripping stage, and the volume of the total amount of waste is equal to the sum of the volumes of waste in each part:

$$\begin{cases} V_i^p = \lambda V_i^c \\ V_i^p = n_i + w_i + v_i \end{cases} \quad (12)$$

In the formula:

λ —is the loose coefficient, dimensionless;

V_i^c —is the stripping amount in the year, m^3 ;

V_i^p —is the amount of discharge in the year, m^3 ;

n_i —Internal displacement per year, m^3 ;

w_i —Exhaust discharge per year, m^3 ;

v_i —is the volume of material corresponding to the height of the ditch in each year, that is, the amount of secondary stripping after turning, m^3 .

(3) Considering the follow-up open-pit mine reclamation work, stripping, and the working parameters of the dumping equipment, the height difference between the horizontal stages of adjacent ditch retention should not be too large, and should be less than or equal to the internal dump site Maximum height difference between adjacent stages:

$$|H_i - H_{i+1}| \leq \Delta h \quad (13)$$

In the formula:

H_{i+1} —Height of ditch in the next year, m;

Δh —Maximum height difference between adjacent stages of the internal dump, m.

3.4. Model Building

The mining stripping and discarding in the model solution period are considered year by year, and the stope determines the location of the stripping stage, the centroid of the stripping stage and other data according to the fixed advance rate or production capacity, as the known conditions for the model solution [18]. Taking the minimum sum of the transportation cost in the whole diversion and the secondary stripping cost after the diversion as the optimization goal, the height of the

trench retention in different engineering positions of the retention level is solved and the optimal cost in the entire calculation period is obtained.

The objective function of the model needs to consider the calculation method of transportation cost [19], and the calculation mainly considers the horizontal transportation distance, vertical lifting height, and the volume of waste. Right now:

$$\begin{cases} C_i^n = f(l_i^s, l_i^h, n_i) \\ C_i^w = f(l_i^{s'}, l_i^{h'}, w_i) \end{cases} \quad (14)$$

In the formula:

C_i^n —transportation cost in a year, yuan;

C_i^w —The transport cost of efflux in the year, yuan;

l_i^s 、 $l_i^{s'}$ —the horizontal transportation distance between the discarding stage and the corresponding stripping stage in each year, km;

l_i^h 、 $l_i^{h'}$ —Height difference between the centroid of the discarding stage and the stripping stage of each year, km.

The height of the ditch is H_i as follows:

$$\begin{cases} C_i^l = f(l_i^s, l_i^h, v_i) \\ v_i = f(H_i) \end{cases} \quad (15)$$

In the formula:

C_i^l —The transportation cost of stripped objects to the ditch in year i , yuan;

The height of the ditch is H_i and the second stripping fee per year after turning:

$$\begin{cases} C_i^b = f(v_i) \\ v_i = f(H_i) \end{cases} \quad (16)$$

In the formula:

C_i^b —The corresponding secondary stripping fee in the i year after the diversion, yuan;

Based on the above simplification and analysis, an optimization model for the ditch height during the diversion period of the inclined coal seam open-pit mine under the condition of internal drainage is established:

$$\min C = \sum_{i=1}^n (C_i^n + C_i^w + C_i^l + C_i^b) \quad (17)$$

$$\begin{cases} V_i^p = \lambda V_i^c \\ V_i^p = n_i + w_i + v_i \\ 0 \leq H_i \leq \Delta H_{\max} \\ |H_i - H_{i+1}| \leq \Delta h \end{cases} \quad (18)$$

In the formula:

C —total cost of expenses, yuan;

That is, the constraint conditions only include four groups of variables: the amount of ditch discharge v_i , the amount of internal dump n_i , the amount of outer dump w_i , and the height of the ditch H_i , and the conditions for the height of the ditch are known according to the above formula. Then, the corresponding amount of ditch discharge can be calculated, and because the height of the internal dump is determined, the annual discharge of the internal dump can be determined. According to the total amount of annual discharge, the discharge volume of the outer dump can be obtained. Therefore, the constraint condition is simplified as an expression of a group of variables of ditch height H_i (ditch discharge amount v_i).

As for the objective function, on the basis of determining H_i and v_i , the geometry of the ditch area can be determined. With the help of mining software such as 3DMine, the coordinates of the centroid of the rejection stage can be determined by using differential, integral, and interpolation methods. The data such as the center of mass of the stripping stage can be obtained directly through 3DMine software, and the horizontal transportation distance and vertical lifting distance can be further calculated according to the centroid of the stripping stage and the discarding stage, and the entire mine can be obtained according to the calculation method of the transportation cost of the specific mine. The total cost for the model calculation period. The fluctuating ditch model is shown in Figure 4:

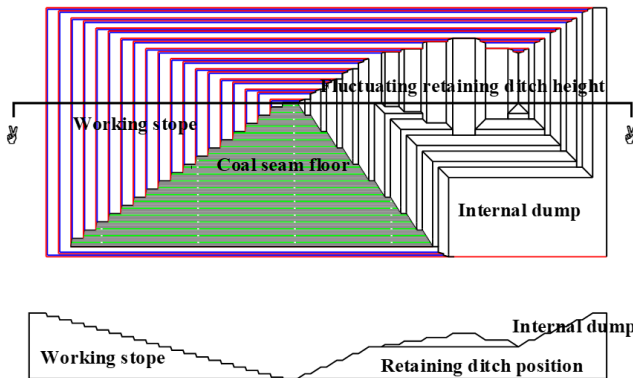


Figure 4. Schematic diagram of undulating ditch retention in inclined seam open-pit mine.

4. Case Analysis

An open-pit mine belongs to the inclined coal seam open-pit mine. The main recoverable coal seam is a single thick coal seam Group B coal seam, the coal seam dip angle is $4 \sim 31^\circ$, and the average mineable coal seam thickness is 69.43m. At present, mining is carried out from north to south in the first mining area, and the method of horizontal mining and internal row is adopted for advancement, and the stripping adopts the single-bucket truck intermittent process. Due to the large advance stripping, the uppermost flat plate is about 1583m away from the boundary of the mining area, and it will soon face the problem of turning. When determining the turning period of the open-pit mine, it is necessary to reserve the end side ditch in advance to reduce the amount of secondary stripping in the mining after turning to the next mining area. The author optimizes the level of ditch retention based on the direction and flow of the stripping material during the seven-year period from the start of ditch retention in 2023 to the end of ditch retention in 2029 in the open-pit mine [20].

The working line in the first mining area of the open-pit mine is arranged in a straight line, and the minimum tracking distance between the dump and the stope is maintained year by year. The inner dump is discharged according to the surface elevation. When the disposal space is insufficient, it is transported to the outer dump for disposal. Way. As shown in Figure 5:

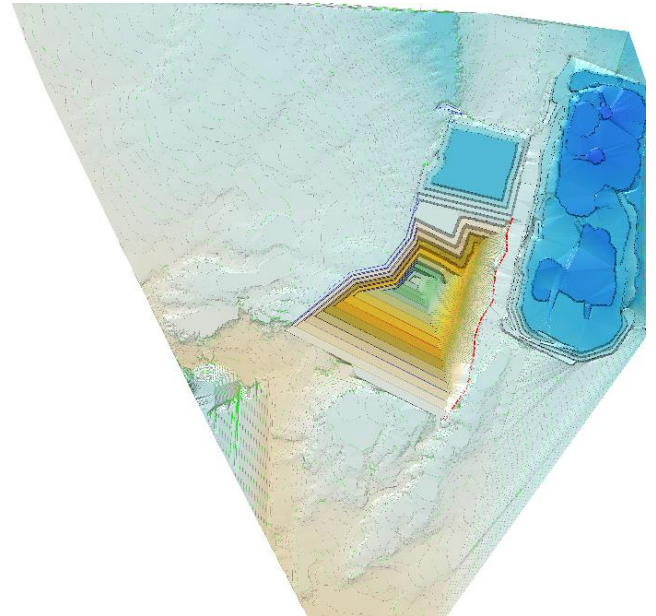


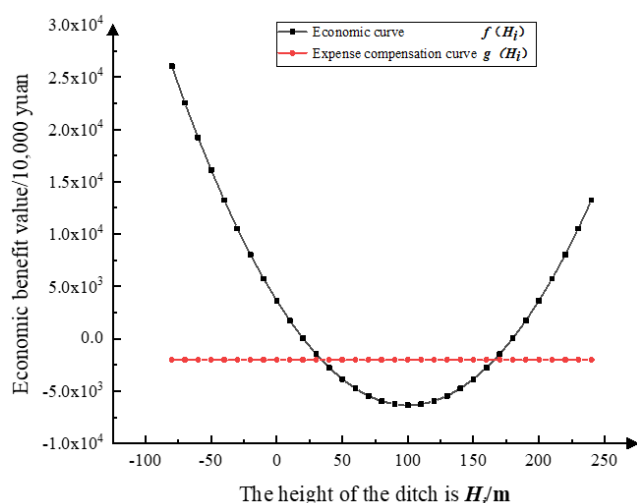
Figure 5. The current situation of an open-pit mine in 23 years.

The main parameters of the open-pit mine are as follows:

Table 1. Relevant parameters of the open-pit mine during ditch retention.

Main parameter symbol	Numerical size	Unit
β_1	35	°
β'_1	20	°
β_2	35	°
β'_3	35	°
θ	11	°
m	69.3	m
h_f	190.5	m
L	1300	m
$L_{\min}$	50	m
P_c	131.26	t/yuan
γ	1.27	t/m ³
P_r	8.80	yuan /m ³
B	2.00	yuan /m ³ km
C	3.50	yuan /m ³

Bring the above relevant data into the above formula to calculate the maximum ditch height under the effect of economic compensation.

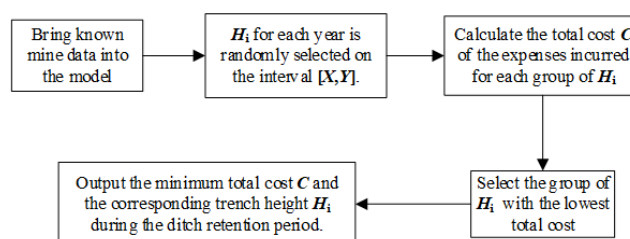
**Figure 6.** Maximum trench height under the economic compensation method.

It can be seen from Figure 6 that when the mining depth in the initial mining area is 260m, the maximum trench heights calculated by the cost compensation method are 20m and 180m respectively, does not meet the ditch steering requirements. Therefore, the maximum ditch height is taken as 180m.

At this time, the horizontal height of the ditch is 80m. On this basis, the model is used to solve the height of the ditch at each stage of the fluctuation change.

4.1. Model Solution Process

When the parameters and formulas are determined, the sequential recursion method is used to solve the model. The model solution process is shown in Figure 7:

**Figure 7.** Flowchart of solving the dynamic programming model of ditch height.

4.2. Model Calculation Results

According to the stripping flow direction and flow planning of the stripping plan of the open-pit mine from 2023 to 2029, the annual overall stripping volume, flow direction, and corresponding costs of fluctuating changes in the height of the ditch during this period were planned. The results are shown in Table 2. Table 3 shows:

Table 2. The annual stripping flow direction and flow chart of the fluctuating height of the ditch in the open-pit mine.

Year	Annual stripping volume/10,000 m ³	External discharge/10,000 m ³	Internal displacement/10,000 m ³	Amount of internal drainage ditch/10,000 m ³
2023	5463.91	1627.56	718.21	3114.14
2024	3861.5	968.17	679.32	2214.01
2025	4889.41	1143.13	984.94	2761.34
2026	5794.19	2140.59	723.67	2629.93
2027	4936.06	1414.14	1146.21	2375.71
2028	4624.38	1567.24	911.81	2145.33
2029	4531.67	2193.11	768.26	1570.03

Table 3. The annual cost of stripped objects in the fluctuating height of the ditch in the open-pit mine.

Year	Expenses for evacuation/10,000 yuan	Inner row cost/10,000 yuan	Internal drainage ditch cost/10,000 yuan	Second stripping cost/10,000 yuan	Total annual cost/10,000 yuan	Ditch height/m	Total cost/10,000 yuan
2023	20670.012	3231.945	7473.936	27404.432	58780.325	214.5	
2024	13263.929	2581.416	6642.03	19483.288	41970.663	190.5	
2025	15889.507	3447.29	6903.35	24299.792	50539.939	206.7	
2026	28255.788	2388.111	5785.846	23143.384	59573.129	201.3	362836.58
2027	20363.616	3553.251	4988.991	20906.248	49812.106	189.6	
2028	24762.392	2553.068	3647.061	18878.904	49841.425	181.2	
2029	33993.205	1997.476	2512.048	13816.264	52318.993	166	

The annual overall stripping volume flow direction and the corresponding cost planning results of the open-pit mine under the normal ditch level during this period are shown in Table 4 and Table 5:

Table 4. The open-pit mine maintains the normal ditch level annual stripping flow table.

Year	Annual stripping volume/10,000 m ³	External discharge/10,000 m ³	Internal displacement/10,000 m ³	Amount of internal drainage ditch/10,000 m ³
2023	5463.91	3171.4	718.21	1570.3
2024	3861.5	1611.88	679.32	1570.3
2025	4889.41	2334.17	984.94	1570.3
2026	5794.19	3200.22	723.67	1570.3
2027	4936.06	2219.55	1146.21	1570.3
2028	4624.38	2142.27	911.81	1570.3
2029	4531.67	2192.84	768.26	1570.3

Table 5. The open-pit mine maintains the normal level of trench retention and annual stripping costs.

Year	Expenses for evacuation/10,000 yuan	Inner row cost/10,000 yuan	Internal drainage ditch cost/10,000 yuan	Second stripping cost/10,000 yuan	Total annual cost/10,000 yuan	Ditch height/m	Total cost/10,000 yuan
2023	40276.78	3231.945	3768.72	13818.64	61096.09	166	377668.50
2024	22082.76	2581.416	4710.9	13818.64	43193.71		
2025	32444.96	3447.29	3925.75	13818.64	53636.64		
2026	42242.9	2388.111	3454.66	13818.64	61904.32		
2027	31961.52	3553.251	3297.63	13818.64	52631.04		
2028	33847.87	2553.068	2669.51	13818.64	52889.08		
2029	33989.02	1997.476	2512.48	13818.64	52317.62		

From the above Table 2, Table 3, Table 4, and Table 5, it can be seen that when the same level of normal ditch height is used as a whole to retain the ditch, the total sum of the stripping flow, flow rate, and secondary stripping costs after the diversion is 377668.50 during the ditch retention period. 10,000 yuan; when using the fluctuating type of trench retention at different levels in each stage, the output trench heights are: 214.5m, 190.5m, 206.7m, 201.3m, 189.6m, 181.2m, 166m, and the total cost is the lowest, and the cumulative sum is 3,628,365,800 yuan. Compared with the traditional way of keeping trenches at the same level, it saves 148.3192 million.

5. Discussion

In this paper, based on the linear programming method commonly used in optimization design, combined with the economic benefit compensation method and the cost minimization method, the height of the ditch during the steering period is studied. With the goal of minimizing the total cost of stripping during the turning period and the total cost of the second stripping after the turning period, the influence of fluctuating ditch retention during the turning period is considered.

According to the production characteristics of open-pit mines, during the transition period of the mining area, the method of slowing the side and leaving the ditch is usually used. Drawing lessons from the concept of compound interest in economics, it is restricted to the maximum height of the trench; combined with the minimum sum of costs in this process, a corresponding model is established to constrain the optimal height of the trench at each stage.

Combined with a specific example, collect relevant important parameters of the mine from 2022 to 2028 during the transition period, and substitute them into the above solution model. Compared with the traditional scheme, the net benefit value has increased by 148.3192 million yuan. The optimiza-

tion effect is obvious.

The ditch height planning model established in this paper is based on the year as a unit, and the overall optimization of the ditch height within 7 years is carried out, and the overall optimal plan is obtained. At the same time, this paper also has the following deficiencies: (1) only considering the impact of the height of the ditch on the economy, ignoring the impact of the height of the inner row; (2) ignoring the planning of each year. But generally speaking, the method proposed in this paper can improve the efficiency of the enterprise as much as possible during the diversion period and has a positive effect on the formulation of the diversion ditch retention plan for inclined coal seam open-pit mines.

6. Conclusion

(1) Qualitative and quantitative analysis was carried out on the factors affecting the ditch level during the diversion of the inclined coal seam open-pit mine, and the height of the ditch and the internal displacement of the ditch, the internal displacement, the discharge of some stripped objects caused by the ditch, and the diversion were deduced respectively. The formula for calculating the amount of secondary peeling after.

(2) Taking the minimum value of the total cost of stripping material transportation costs during the diversion to ditch retention and the total cost of secondary stripping costs after diversion as the objective function, the overall cost is constrained by restricting the height of ditch retention in different periods, and the level fluctuation of ditch retention is established. Mathematical model of the formula change. Taking an open-pit mine as an example, during the 7-year period when it turned to ditch retention, a set of most suitable ditch heights was output through fluctuating ditch retention, and the horizontal position of the side ditch retention in each of the next 7 years was obtained. Thus, the annual internal discharge volume, external discharge volume, and internal drainage

ditch volume are further obtained. Through the comparison of the cumulative total cost, it can be concluded that compared with the traditional ditch at the same level, the total cost saved by this scheme is 148.3192 million.

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Author Contributions

Yu Wen: Data curation, Investigation, Methodology, Software, Validation, Visualization, Writing - original draft, Writing - review & editing

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Data Availability Statement

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no competing interests.

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