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Analysis on Typical Spatio-temporal Characteristics of Open-cast Mining and Its Countermeasures

Qingyou AO[1], Qiang FU[2], Zhihua LIU[3], Yu XUN[2], Lin LIN[4*]

1. State Power Investment Corporation Inner Mongolia Energy Co., Ltd., Tongliao 029200, China; 2. Huolinhe South Surface Mine of Inner Mongolia Power Investment Energy Co., Ltd., Tongliao 029200, China; 3. Huolinhe North Surface Mine of Inner Mongolia Power Investment Energy Co., Ltd., Tongliao 029200, China; 4. CCTEG Shenyang Engineering Company, Shenyang 110015, China

Abstract In order to deal with the special spatio-temporal environmental changes encountered in the process of open-cast mining, taking Huolinhe No.1 Open-cast Mine as the research object, this paper studied its typical problems in river reconstruction and cultural relics protection. The study focused on eight key core aspects, including the design optimization of the spatial layout of the mining area, the accurate estimation of the mineral resources reserves, the scientific theoretical demonstration of the mining scale, the fine analysis and calculation of the stripping ratio, the comprehensive consideration of the transport distance and efficiency, the accurate judgment of the best time for the implementation of the transformation, the analysis and evaluation of the slope stability, and the overall planning of the production system. The results show that the extracted problem-solving strategies and scheme system for special mining conditions can not only provide specific and practical guidance for Huolinhe No.1 Open-cast Mine, but also serve as a valuable reference and practical reference for other open-cast mine enterprises facing similar challenges.

Key words Open-cast mining in the mining area, Typical space-time environment, River reconstruction, Cultural relics protection, Spatial layout

1 Introduction

Open-cast mining is a process involving the full and deep excavation of mineral resources. The open-cast mining operation first needs to strip the surface and surrounding coverings of the ore body, and then needs to thoroughly reveal the initial occurrence state of the mineral products through the fine excavation operation[1]. Next, advanced mining, transport and disposal technologies are used to systematically and orderly extract mineral products from the deep crust to the surface, thus completing the whole open-cast mining process. In this process, all links are closely connected, aiming at realizing the value transformation of mineral resources efficiently, safely and environmentally friendly.

In view of the characteristics of long mining cycle, large land occupation and complex factors, some specific geological structures and external environmental conditions pose a direct challenge to the normal operation of open-cast mines. Problems such as historical and cultural heritage protection restrictions, river system boundary constraints, and coordinated development of adjacent mineral resources[2] deeply shape the trajectory and production efficiency of open-cast mining operations[3-4]. Therefore, how to properly deal with these constraints that evolve with time and space has become a key issue to be solved urgently in the current open-cast mining industry.

In this study, we intended to make an in-depth analysis of this topic, focusing on the significant phenomenon of open-cast mine in the change of space-time dimension, and taking Huolinhe No.1 Open-cast Mine, a highly representative case, as the breakthrough point, to make a detailed analysis and discussion of its unique space-time characteristics. On this basis, we further explored and refined the targeted coping strategies and solutions, hoping to provide valuable reference and enlightenment for other similar open-cast mines confronted with similar problems.

2 Overview of the study area

Huolinhe No.1 Open-cast Mine is located in the Shaerhure exploration area in the north of the coalfield, with a length of 10 km from north to south, a width of 3.4 km from east to west, and an area of 33.996 4 km^2. The coalfield is 60 km in length, 9 km in average width and 540 km^2 in area. It is distributed in the north, southeast and west. Up to now, the cumulative proven geological reserves of the coalfield are 11.92 billion t. The northwestern boundary of the mining area is bounded by the isobath of the minable coal seam with a depth of 1 200 m, and the other boundaries are bounded by the coal seam outcrop line. The mining area has a strike length of about 51 km, an inclined width of about 10 km, an area of about 380 km^2, and a total coal resource of 12.1 billion t. The mining area is divided into 12 well (mine) fields and 2 resource integration areas, with a total production and construction scale of 92.20 Mt/yr. Among them, there is one pro-

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Qingyou AO, senior engineer, research fields: mining engineering, mainly engaged in supervision and management of coal mine safety production.
* Corresponding author. Lin LIN, master, professorate senior engineer, research fields: optimization of open-cast mining technology, comprehensive analysis and evaluation of ecology, safety and resource environment of green open-cast mine.

duction coal mine, which is Huolinhe South Open-cast Mine 15.00 Mt/yr; three coal mines are planned to be reconstructed and expanded, with a construction scale of 38.00 Mt/yr, including the reconstruction and expansion of Zhahanaoer Open-cast Mine from 15.00 Mt/yr to 25.00 Mt/yr, the reconstruction and expansion of 958 Jinyuanli Underground Mine from 1.20 Mt/yr to 3.00 Mt/yr, Huolinhebei Open-cast Mine is transformed from three mining areas into one mining area of 10.00 Mt/yr. It is planned to build 8 new mines with a construction scale of 39.20 Mt/yr, including 6.00 Mt/yr for Huolinhe Well No.1, 6.00 Mt/yr for Huolinhe Well No.2, 6.00 Mt/yr for Huolinhe Well No.3, 5.00 Mt/yr for Huolinhe Well No.4, 6.00 Mt/yr for Huolinhe Well No.5, 2.40 Mt/yr for Huolinhe Well No.6, 6.00 Mt/yr for Jinzheng Mine, and 1.80 Mt/yr for Baoerhushun Mine.

With the development of mining engineering, Huolinhe No.1 Open-cast Mine encounters double constraints in the mining process and spatial layout. The primary challenge comes from the regulation of the Heremute River, which runs through the mining area from west to east, and its dynamic changes directly affect the pace and scope of mining operations. If scientific and reasonable measures are not taken in time, mine production will face incalculable heavy losses, and may even have a far-reaching impact on the surrounding ecological environment. In addition to the time and space constraints brought about by natural and geographical factors, there is also an important historical and cultural heritage in the mining area, Jinjiehao (Great Wall of the Jin Dynasty). In order to prevent the historical features of the site from destruction, this special condition once again has an impact on the normal space-time progress of the open-cast mine. In the planning process of maintaining the normal development sequence and space expansion of open-cast mines, these typical special problems undoubtedly introduce new considerations to mining enterprises.

3 Analysis of research methods and countermeasures

In view of the unique space-time constraints and challenges confronted by Huolinhe No.1 Open-cast Mine, we intended to conduct in-depth and comprehensive research and analysis from eight core dimensions, and formulate corresponding countermeasures. The eight dimensions include: spatial layout optimization to improve utilization efficiency[5], accurate reserve accounting to clarify resource potential[6], scale demonstration to determine the appropriate degree of exploitation[7], in-depth analysis of stripping ratio to maximize economic benefits[8], scientific calculation of transport distance and volume to reduce transport costs, accurate judgment of timing to adapt to market dynamics, rigorous analysis of slope stability to ensure safe production and comprehensive planning of production systems to build efficient and sustainable operations[9-10].

3.1 Spatial layout analysis According to the current mining situation of Huolinhe No.1 Open-cast Mine, the specific location of its river layout and Great Wall of the Jin Dynasty (Jinjiehao), a precious historical and cultural heritage, as well as the spatial correlation between them and the mining area of open-cast coal mine, which can be visualized by Fig.1. It can be clearly seen from the figure that the river runs straight through the core areas of the north and south mining areas, while the Great Wall of the Jin Dynasty (Jinjiehao) lies on the north edge of the north mining area, keeping a fairly close distance from the mining operation area. This situation undoubtedly poses a severe challenge and high requirement for the protection of the site.

According to the study on the spatial location of the current situation of the mining area, the river diversion measures were formulated, and the average distance of about 900 m to the south was adjusted on the basis of the regulation of the river location. For the protection scope of Jinjiehao on the west side of North Open-pit Coal Mine, the protection scope was defined as extending 100 m to both sides according to the outer edge of the remains, and the construction control zone was extending 500 m according to the boundary of the protection scope, that is, the area within 100 m on both sides of the outer edge of Jinjiehao remains was the protection scope; the area beyond 100 m and within 600 m on both sides of the outer edge of Jinjiehao remains was the construction control zone (Fig.2).

3.2 Evaluation of reserves Based on the detailed data at the end of 2022 and the actual situation, the remaining geological resource reserves after the river diversion were calculated in detail, and on this basis, the specific value of recoverable reserves was further deduced scientifically. In addition, we made a comprehensive and detailed evaluation and analysis of the expected amount of raw coal that can be mined, and strives to accurately grasp its potential value. The calculation results of remaining resources after river diversion are shown in Table 1.

Table 1 Calculation of remaining resources after river diversion

Item		South area west wall	Middle overburdenarea of south and north areas	North area
Raw coal that can be mined//10^4 t		23 875.81	16 207.05	15 321.29
Stripping volume//10^4 m^3	Soil	2 674.00	577.375	2 429.25
	Rock	66 671.50	33 790.875	30 283.875
	Internal stripping	10 101.01	5 833.38	4 446.11
	External stripping	1 083.05	515.26	496.04
	Total	80 529.56	40 716.89	37 655.28
Average stripping ratio//m^3/t		3.37	2.51	2.46

Fig. 1 3D spatial illustration of Huolinhe No. 1 Open-cast Mine

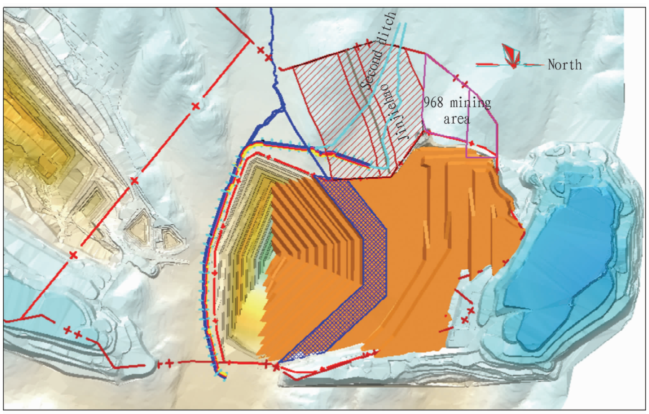

Fig. 2 The 3D spatial location after river diversion

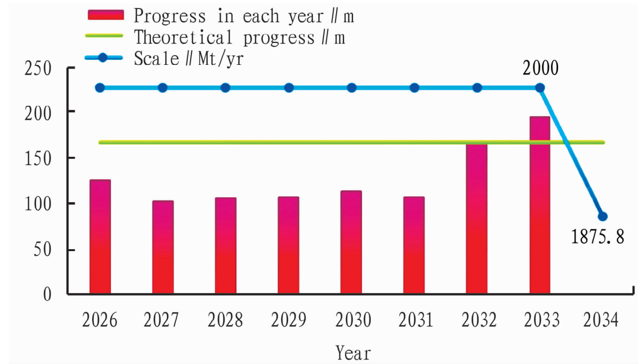

Fig. 3 Matching relationship between mining area scale and progress after river diversion

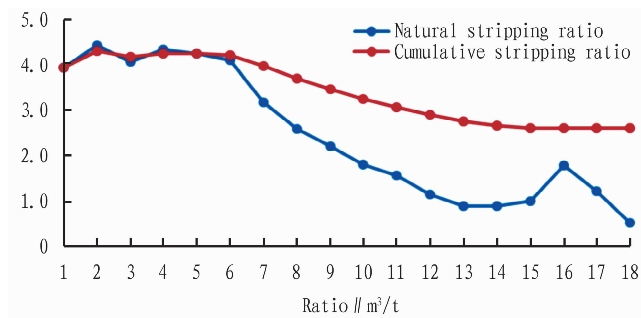

Fig. 4 Schematic diagram for stripping ratio in the south area after river diversion

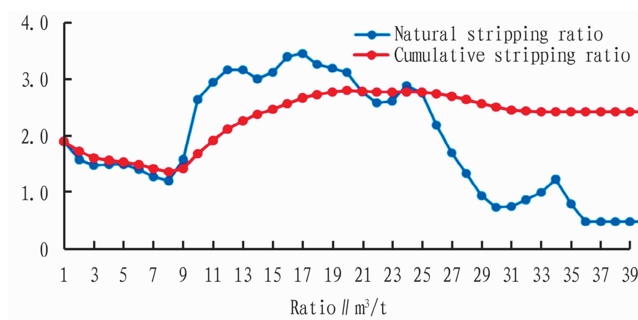

Fig. 5 Schematic diagram for stripping ratio in north area after river diversion

Through in-depth excavation and accurate quantification of the remaining resources, it is able to reveal the mineral resources hidden underground after changing the river, and also accurately estimate the total amount of coal resources available for exploitation and utilization. This series of calculation and evaluation aims to provide solid data support and decision-making basis for future resource development planning, so as to realize the maximization and sustainable utilization of geological resources.

3.3 Scale demonstration When studing the initial production layout of the two open-cast areas in the north and south of the open-cast mine after the adjustment of the river diversion and the planning of the cultural relics protection area, based on the current annual production capacity of 20 and 10 Mt in the two areas, a deep and comprehensive demonstration and consideration was carried out to fully assess and tap the production potential of the north and south areas, so as to achieve optimal production layout planning (Fig. 3).

3.4 Stripping ratio analysis Through the stripping ratio analysis of the remaining reserves in the north and south areas of the open-pit mine, it can be clearly revealed that after the implementation of the river diversion and cultural relics protection planning, the natural stripping ratio and balanced stripping ratio of the two areas show a significant jumping trend, especially in the north area. The specific data comparison and changes are illustrated in Fig. 4 and Fig. 5.

3.5 Transport distance and transport efficiency analysis In consideration of the transport distance and volume, the two areas in the north and south of the open-cast mine show large transport distance characteristics in the initial stage, and the average transport distance after weighted calculation was roughly stable at about 3.0 km. However, with the progress of mining, this situation will change significantly after 2032, when the overall average weighted transport distance will be significantly reduced to 2.0 km, showing a more optimized transport efficiency and layout planning.

3.6 Analysis of transformation opportunity With the gradual southward expansion of the working face of the excavation site, the steps of the internal wastedump will also synchronously advance the dumping operation southward. Through in-depth analysis by using 3D space-time simulation technology, it is finally determined that the internal wastedump will have enough space to meet the layout requirements of the permanently diverted river in 2034, and the 3D shape is shown in Fig. 6.

Table 2 Analysis of transport distance and transport work in south and north areas after river diversion

Year	South area					North area		Weighted average transport distance km	Transport work $m^3 \cdot km$
	West wall		North wall						
	Internal dumping 10^4 m^3	Transport km	Internal dumping 10^4 m^3	Transport km	Weighted average km	Internal dumpingt 10^4 m^3	Transport km		
2023	6 100	3.8			3.81	1 800	3.7	3.79	29 919
2024	6 100	3.8			3.77	2 050	3.3	3.65	29 742
2025	6 800	3.9			3.89	2 400	3.1	3.69	33 940
2026	6 800	4.0			3.97	2 400	3.1	3.75	34 484
2027	7 260	3.6			3.55	2 900	3.1	3.43	34 821
2028	7 260	3.5			3.45	2 900	3.0	3.31	33 602
2029	7 260	3.5			3.45	2 900	3.0	3.31	33 602
2030	7 260	3.5			3.45	2 900	3.0	3.31	33 602
2031	7 260	3.1			3.10	2 900	2.9	3.04	30 916
2032	7 260	2.8			2.80	2 900	2.9	2.83	28 738
2033	6 800	2.6			2.60	2 600	2.7	2.63	24 700
2034	4 370	2.1	1 200	3.1	2.32	2 600	2.7	2.44	19 916
2035			5 000	3.1	3.12	2 600	2.7	2.98	22 620
2036			4 000	3.1	3.12	2 200	2.7	2.97	18 420
2037			4 000	2.6	2.60	2 200	2.4	2.53	15 680
2038			2 600	2.6	2.60	2 200	2.4	2.51	12 040
2039			2 600	2.6	2.60	1 800	2.4	2.52	11 080
2040			2 600	2.6	2.60	1 800	2.4	2.52	11 080
2041			2 000	2.4	2.40	1 800	2.2	2.31	8 760
2042			2 000	2.2	2.20	1 800	2.2	2.20	8 360
2043			1 600	2.0	2.00	1 400	1.8	1.91	5 720
2044			800	1.4	1.40	923.67	1.4	1.40	2 413
Total	80 530		28 400			49 974		3.05	484 155

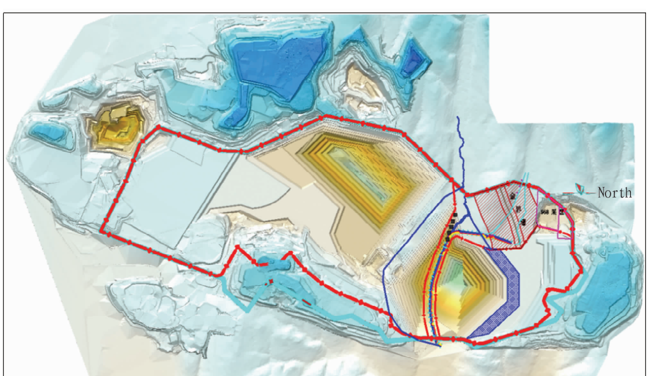

Fig. 6 Spatial illustration of the location of permanent river diversion in the open-cast mine

2.7 Slope stability analysis The limit equilibrium method was applied to analyze the slope stability after river reconstruction and cultural relics protection planning. This method is not only the earliest slope analysis technology, but also one of the most mature and perfect methods. According to the mining status, the current slope area on the upper part of the fault above the nose bridge crushing station has a local slope angle of 12° and a slope height of about 165 m, and its stability coefficient is accurately calculated as 1.02, which means that the slope is in a sensitive limit equilibrium state (Fig. 7). However, if the footwall slope of the fault is directly mined, it is very likely to cause disastrous consequences such as local floor heave and slump.

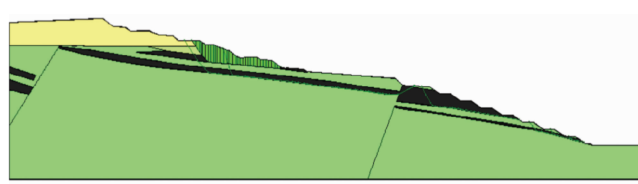

Fig. 7 Schematic diagram for slope stability evaluation

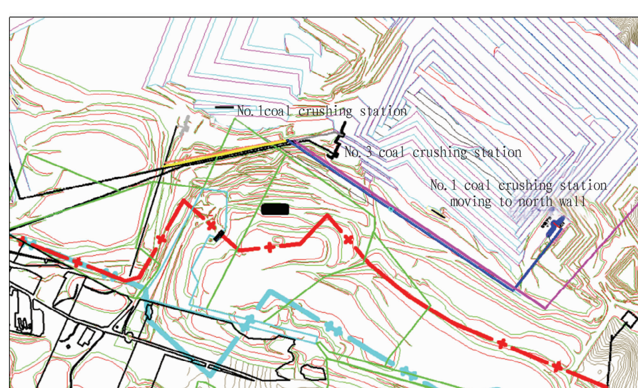

Fig. 8 Schematic diagram for production system relocation and transformation

In addition, it is worth noting that the slope above the crushing station has been abandoned, and the current actual situation does not have the conditions to take wall cutting, wall pressing and other engineering strengthening measures to further improve the stability of the slope. Therefore, for the slope management and mining activities in this special area, we need to be cautious and seek more scientific and reasonable solutions.

2.8 Production system planning Through scientific layout and reasonable planning (Fig. 8), it is intended to ensure that the No. 1 coal crushing station can meet the requirements of river reconstruction and cultural relics protection, while maximizing production efficiency and effectively controlling operating costs. The relocation benefits and feasibility analysis are shown in Table 3. Therefore, under the dual background of river reconstruction and cultural relics protection planning, the production system of open-cast mines urgently needs to be comprehensively and strategically reconstructed. At present, the No. 1 rock crushing station is located at the 848 horizontal line on the east side wall of No. 8 Road. Considering the follow-up process of internal drainage and the progress of the upcoming lowering and demolition works of No. 8 Road, the analysis predicts that the relocation of the crushing station will be completed by 2025. After in-depth research and comprehensive evaluation, the No. 1 coal crushing station was finally relocated to the 824 horizontal line area at the north side wall.

Table 3 Benefit and feasibility analysis of relocation

No.	Item	Indicator
1	Transport distance of No. 1 semi-continuous truck//km	1.9
2	Direct dumping distance of truck//km	4.26
3	Freight difference of truck//yuan/m^3	3.55
4	No. 1 semi-continuous truck lifting//m	12
5	Truck direct dumping lifting//m	48
6	Cost difference of truck lifting//yuan/m^3	0.41
7	Cost difference of truck//yuan/m^3	3.962
8	Semicontinuous cost//yuan/m^3	1.2
9	Cost savings//yuan/m^3	2.76
10	Cost saving//10^4 yuan	12 427.85

3 Conclusions

In this study, we explored the unique spatio-temporal evolution encountered in the mining process of open-cast mines. Taking the river channel remodeling and cultural relics protection in the mining process of Huolinhe No. 1 Open-cast Mine as a typical example, we constructed a comprehensive research framework through the deep excavation and analysis of the future spatio-temporal characteristics. On this basis, we carried out analysis from eight core dimensions, including but not limited to spatial layout optimization, accurate assessment of reserves, rational demonstration of mining scale, intensive analysis of stripping ratio, in-depth analysis of transportation distance and efficiency, scientific judgment of transformation timing, rigorous consideration of slope stability and efficient planning of production system, so as to extract a set of solutions and coping strategies to deal with such complex situations. We intend to provide valuable reference and practical reference for open-cast mining enterprises facing similar situations, and then actively promote the sustainable development process of the whole industry, and strive to achieve harmonious coexistence between environmental protection and mining enterprises.

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