Prace Instytutu Mechaniki Górotworu PAN
Tom 20, nr 2, Czerwiec 2018, s. 147-158

High-intensity mining characteristics and its evaluation system of thick coal seam in China's coalmines

GUO WEN-BING[1,2], BAI ER-HU[1,2], YANG DA-MING[1,2]

[1] *School of Energy Science and Engineering, Henan Polytechnic University, Jiaozuo 454000, China*
[2] *Collaborative Innovative Center of Coal Safety Production in Henan Province, Jiaozuo 454000, China*

Abstract

With the transfer of coal mining strategy and the continuous improvement of mining technology and equipment, the high-intensity mining of thick coal seam has become an important development direction of China's coal mining technology. High-intensity mining would cause worse strata and surface movement and deformation and environment effects than general geological and mining conditions due to its geological and mining factors. According to analyzing the status and definition of high-intensity mining in China's coalmines, the main characteristics of high-intensity mining in thick coal seam were systematically studied from aspects of geological and mining conditions, panel sizes, technical equipment, face advance speed, production and efficiency, ratio of depth to thickness, overburden strata and ground surface destruction. Based on the theory of green mining, the main indexes and evaluation system of high-intensity mining had been established from the aspects of geological and mining factors and mining damage factors. Meanwhile, the analytic hierarchy process (AHP) was used to analyze the mining damage factors. The results demonstrate that geological and mining factors and mining damage factors are important parts of high-intensity mining of thick coal seam. Moreover, mining damage factors are an important characteristic that cannot be ignored in high-intensity mining of thick coal seam, and it can be used to determine whether the longwall mining face of coal mine is high-intensity mining, or judge and analyze the damage to buildings, overburden strata, ground surface and ecological environment. The research results provide theoretical and technical basis for safe and efficient green production, mining damage and protection in coalmine.

Keywords: green mining; high-intensity mining; thick coal seam; geological and mining factors; mining damage factors

The exploitation and utilization of coal resources guarantee the energy supply for Chinese industry and China's economic growth. However, the coal resources in the central and eastern of China are gradually depleted, therefore the strategic focus of coal mining has shifted to the western region. Meanwhile, the latest proposed "Silk Road Economic Belt" also brings new opportunities for China's coal enterprises. The "13th Five-Year" plan of the coal industry is designed to compress the coal mining in eastern, limit that in central and northeastern, and optimize that in western. Especially, this plan focuses on the construction of the billion tons of large-scale coal bases, such as Jinbei, Jinzhong, Jindong, Shendong, Shanbei, Huanglong, Ningdong, Luxi, Lianghuai, Yungui, Jizhong, Henan, eastern of Mongolia and Xinjiang. The Northwest China is rich in coal resources with a simple geological condition, which is suitable for high-intensity mining. At the same time, the Shendong Mining Area is the first billion tons of coal production base in China, therefore, northwest China will become the main base of energy supply in China.

As the strategic focus of coal mining is transferred to the west region, more and more people pay attention to the thick coal seam mining based on the safe and efficient green mining. With the continuous development of mining technology, the improvement of machinery and equipment manufacturing, high-intensity mining with large panel size, fast face advance, high production and efficiency has become an important development direction of the thick coal seam in China [1-2]. For example, the Shangwan coal mine of Shendong, Wangzhuang coal mine of Lu'an, and Tashan coal mine of Datong have all successfully completed the fully-mechanized mining face with a height of 8.8 m, 7.2 m and 20 m, respectively. In the first half of 2017, the total coal production in Shanxi, Shaanxi and Mongolia are accounted for 67% of the national coal production. However, due to the arid and semi-arid climatic conditions (strong evaporation, poor rainfall, low vegetation coverage), poor ability of anti-disturbance, and fragile ecological environment in these regions, large scale high-intensity mining not only results in more severe strata pressure, mining disasters such as roof collapse, water and sand inrush in the mining process, but the destruction of land surface, the loss of water resources, grassland desertification and ecological environment pollution during exploitation [3-6].

In recent years, high-intensity mining of thick coal seam is getting more and more attention. Fan [7] indicated that the coal mining intensity had obvious relationship with geological disaster development, and defined the high-intensity mining from the aspects of the proportion of mining area, the size of panel and the mining speed, finally, he divided the high-intensity mining according to the standard of mining intensity. Guo [8] pointed out that the high-intensity mining not only correlates well with the geological and mining technical parameters, but also the destruction degrees caused by mining. He then proposed a new high-intensity mining definition based on the green mining theory, by combining the high-intensity mining with surface damage and environmental impacts. Based on the definition of high-intensity mining, this paper further studied the technical characteristics and indexes of high-intensity mining. Meanwhile, the analytic hierarchy process (AHP) was used to analyze the weight value of each technical parameters. This research provides theoretical and technical basis for safe, efficient, and green mining, mining damage and protection in high-intensity mining coalmines.

1. Characteristics composition and its parameters of high-intensity mining

Based on the green mining theory and mining status in western region, the characteristics of high-intensity mining are mainly including geological and mining factors, and mining damage factors. According to the research, they are mainly as follows: simple geological and mining conditions, large panel sizes, advanced equipment and mining technology, fast face advance speed, high production and efficiency, large mining thickness, small *H*/*M* ratio, serious destruction to overburden strata, severe surface movement and deformation. The parameters of coal mine under high-intensity mining in Northwest China are shown in Table 1.

Tab. 1. Parameters of coalmines under high-intensity mining in Northwest China

Coal mines		Depth m	Mining height m	Dip °	Panel sizes m	Daily footage $m \cdot d^{-1}$	Production 10^4 t	Mining method
Daliuta	#52304	136-281	6.80	1-3	301×4547	13.80	1212	LMH
Bulianta	# 32301	183	6.10	1-3	301×5220	9.20	1248	LMH
Changhangou	# 15106	94-136	5.20	1-3	300×2800	17.20	569	LMH
Huojitu	# 12205	30-100	4.60	0-3	230×2235	15.50	331	LMH
Shangwan	# 51102	85-170	5.20	1-3	240×3500	8.38	569	LMH
Sihe	# 2307	199-347	6.20	1-10	221.5×2984	6.40	534	LMH
Wanli	# 42301	90-175	4.80	3-7	300×3322	12.60	623	LMH
Sandaogou	# 85203	121.3	6.30	1-3	295×3160	15.00	765	LMH
Halagou	# 22407	121.3	5.39	1-3	284×3224	15.57	643	LMH
Yangchangwan	# Y110206	330	6.20	15-20	299×1976	13.38	476	LMH
Hongliu	# 1121	278	6.00	0-18	302×1900	9.44	448	LMH
Zhangjiamao	# 15201	88-133	6.10	1-3	261×2295	7.00	475	LMH
Yushuwan	# 20102	110-300	11.62	0-3	250×5850	5.90	2213	FMTCC
Buertai	# 42105	261-394	6.70	1-9	230×5231	5.20	1050	FMTCC
Tongxin	# 8101	411-486	14.13	0-4	200×1678	9.75	617	FMTCC
Hanglaiwan	# 30101	230	5.00	1	299.5×4252	14.40	829	FMTCC
Majialiang	# 14101	574.5	9.15	3-4	250×2309	13.60	686	FMTCC

Note: LMH is large mining height; FMTCC is fully-mechanized top coal caving.

(1) Simple geological and mining conditions

As well known, geological and mining conditions are the basic conditions for coal mine production, and mainly includes the occurrence conditions of coal seam and overburden strata characteristics. According to the analysis of geological data of 25 mines in Northwest Mining Area, it can be found that the high-intensity mining is suitable for coal seams with simple geological and mining conditions, namely, the stable occurrence and simple structure, mainly near the horizontal coal seam, a shallow buried depth, a stable and complete overburden strata structure, and a low degree of tectonic influence. Moreover, the production capacity of mines with simple geological condition is generally larger, this is because mines under the simple geological condition has less restrictions on its production system. Therefore, the coalmines with simple geological and mining conditions are more suitable for high-intensity mining.

(2) Large panel sizes

Generally, the panel production is determined by panel sizes and coal thickness. To reflect the relationship between the width and advancing length of high-intensity mining face, the distribution graph of these indexes is plotted in Fig. 1. As shown in Fig. 1, the panel width is basically on the smooth concentric circle, which indicates that the panel width distribution is centralized and consistent under the high-intensity mining, the width is generally greater than 200 m, and most of them are distributed between 200~300 m, some even can reach up to 450 m (for example, Halagou coal mine [9]). However, the advance length shows approximately circular shape, indicating that the advancing length and width are in harmony and in synchronicity. Because of the large panel width, the advance length is relatively long, generally, between 1000~5000 m, a few can reach more than 6000 m (for example, Bulianta coal mine and Daliuta coal mine). The large panel size can indirectly reflect the high production of the working face, which is in line with the geological and mining factors of high-intensity mining.

(3) Advanced equipment and mining technology

In fact, different mining conditions have different supporting equipment. Due to the large panel sizes of high-intensity mining, the technical requirements for its supporting equipment are correspondingly higher. High-intensity mining generally adopts large mining height or fully-mechanized top coal caving mining method for the extra-thick coal seam mining, which has the characteristics of high production, efficiency and mechanization, and low energy consumption. Meanwhile, the technical equipment is the key to the safety and high efficiency of panel mining with high recovery rate.

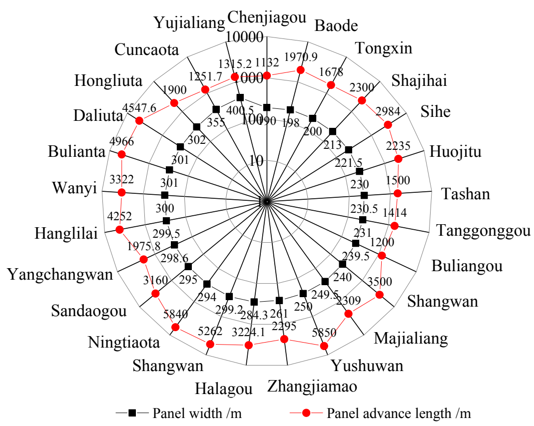


Fig. 1. Width and length distribution of high-intensity mining

For the LMH mining method and equipment, it has developed rapidly since introduced into China in 1978. In 1994, whole set advanced equipment from abroad were imported to Shendong mining area to realize the comprehensive mechanization and modernization of coal mining system. Additionally, with the improvement and re-selection of equipment, the domestic have also conducted independent research and development to increase the recovery rate. For example, the 5.5 m hydraulic support for large mining height was successfully developed in 2005. At the same time, it opened a homemade precedent for high-end hydraulic support, and broke the monopoly situation of the international coal machinery giant to the fully-mechanized equipment in China's high-end coal mines. With the improvement of equipment capacity of fully-mechanized mining with large mining height, the height of primary cutting coal increases continuously. Furthermore, an ultra large mining height shield (8.8 m) has been developed with the largest working resistance, the highest shield height, the largest production capacity and the most advanced intelligent technique in the world in 2015. As of July 2017, the working face with 8.2 m mining height of Jinjitan coal mine has been produced for one year. The coal production is 13 million tons. The highest daily production is 60 thousand tons, and the average is 50 thousand tons with the recovery rate 95%. In January 2017, 8.0 m mining height hydraulic shield was successfully equipped in Bulianta coal mine in Shendong mining area. In August, the world's first 8.8 m mining height fully-mechanized mining face (length 5262 m, width 299.2 m) was successfully completed the preparatory work for mining in Shangwan coal mine.

In the aspect of fully-mechanized top coal caving mining and equipment, Tashan coal mine successfully carried out an average thickness of 18.44 m industrial test in 2010. In 2014, the key technology and equipment of fully-mechanized top coal caving mining with extra thick coal seam and large mining height developed by China Coal Technology Engineering Group Co., Ltd. successfully solved the difficult mining problem of 14-20 m extra thick coal seam. It can be seen that advanced equipment and mining technology is an important characteristic of high-intensity mining.

(4) Fast face advance speed

For the face advance speed, the above indexes provide it with the basis, conditions and guarantees, respectively. Meanwhile, the high-intensity mining working face of thick coal seam usually adopts large mining height or fully-mechanized top coal caving mining technology. Therefore, the face advance speed is generally large. According to the 25 sample statistics of high-intensity mining panel in thick coal seam, the maximum advance speed is the 45203 fully-mechanized face of Yujialiang coal mine, with a speed of 18.9 m/d. In the case of ideal coal seam conditions, several coal mines in Shendong mining area even achieved an advance rate of 20 m/d. Among these data, the face advance speed more than 5 m/d and 10 m/d account for 84% and 40%, respectively, which are shown in Fig. 2.

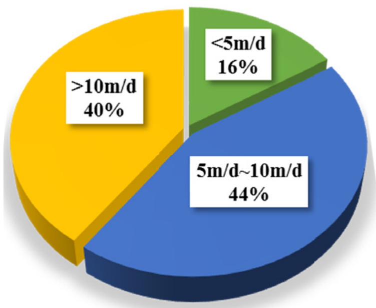


Fig. 2. Velocity distribution of high-intensity mining

Besides, there is also a relevant research on the advance speed in China. Previous studies [10-11] show that the proper improvement of the advance speed can effectively prolong the periodic pressure step distance and reduce the roof subsidence, which is beneficial to the stability of roadway and the safe production of working face. However, with the face advance speed increasing, the maximum principal stress loading rate and minimum principal stress unloading rate of coal increased. The dynamic disturbance of roof makes the coal body bear the form of dynamic and static loading simultaneously, and the strain energy density in the shallow surrounding rock and the peak value in the coal seam increase, which lead to the increase of the probability of rock dynamic disaster and the damage degree [12]. Due to the influence of high-intensity mining, the working face will occur coal rib spalling accident, and the dynamic loading impact caused by roof cutting can lead to cutting top pressure frame accident (for example, Shendong mining area, and the panel 8101 of Wangzhuang coal mine), resulting in a more severe movement of rock and ground surface. Therefore, the fast face advance speed is one of the characteristics of high-intensity mining, and is also a factor inducing the roof disaster.

(5) High production and efficiency

High production and efficiency, a sign of modernization for coalmines, is a development direction of coalmine in the future. The direct factors affecting the panel production are panel sizes, mining thickness and advance speed. According to the technical characteristics and the definition of high-intensity mining, the large face sizes and thickness of coal seam determine the high production of working face. Similarly, advanced equipment and mining technology and fast face advance speed determine the high efficiency of working face. Based on the data statistics, the production distribution of high-intensity mining is shown in Fig. 3 and Table 2. It is seen that the maximum recovery efficiency is up to 890.9 t/worker.

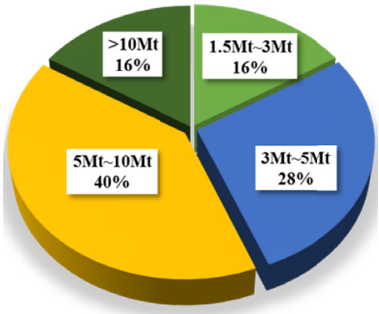


Fig. 3. Production distribution of high-intensity mining

Recently, the state vigorously advocated to promote industrialization with information and to promote informatization with industrialization for the development of "intelligent mine" technology. The new technologies, such as informatization, digitization, Internet of things, artificial intelligence and big data, were adopted to upgrade and transform the traditional coal mining mode. The intelligent mining and less or no artificial working face will greatly improve efficiency. For example, the intelligent coal mining technology was pioneered by Shenhua Group, and a new mining method combined intelligence and remote intervention was established to achieve the visual remote intervention type of intelligent coal mining.

Tab. 2. Efficiency distribution of high-intensity mining

Coal mines	Panel sizes m	Mining height m	Dip °	Efficiency, $t \cdot man^{-1}$	
				Recovery	Whole worker
Bulianta	301×5220	6.10	1~3	890.9	150.5
Shangwan	240×3500	5.20	1~3	859.0	158.0
Halagou	284×3224	5.40	1~3	805.5	198.0
Yujialiang	400.5×1315	3.60	0~1	704.7	/
Daliuta	301×4547	6.80	1~3	618.0	125.0
Sandaogou	295×3160	6.30	1~3	541.7	/
Buertai	230×5231	6.70	1~9	490.5	/
Tongxin	200×1678	14.13	0~4	443.6	79.2
Tashan	230×1500	17.00	3~10	299.1	98.0

Intelligent mining without worker has been applied in 15 mining areas, e.g., Shenhua Group, Shaanxi Coal and Chemical Industry, Jizhong energy and Yangquan Coal Group. More than 40 non-artificial working faces have been produced. For example, the first unmanned mining in thick coal seam was the 1001 working face of Huangling No.1 coal mine. The production mode of human-machine intelligence integration and mixed control was first time carried out by Hongliulin coal mine for thick coal seam with the maximum height of 7.2 m, and the annual production was up to 10.1 million tons. Xinyuan coal mine adopts the linkage control of coal shearer speed and gas concentration to conduct mining on high gas working face, and Meihua coal mine mining the coal seam with the dip of 9~20°. The Shigetai coal mine had realized the remote control of coal shearer, hydraulic support, mobile transformer substation and other key equipment.

These successful applications of these techniques are good news for coal workers, i.e., it not only improves the working environment, reduces the labor intensity, saves more than 90% of labor costs, but also has a very important significance for improving the efficiency and safety factor of working face. For the coal mine with high-intensity mining, the development of fully-mechanized mining equipment will develop in the direction of high intelligence and informatization under the influence of the whole industry environment, and finally realize unmanned mining of working face [13]. At the same time, the working efficiency of working face will be greater.

(6) Large mining thickness and small H/M ratio

As is known, underground mining activities are prone to cause movement, deformation and destruction in the geological strata, leading to surface subsidence. Therefore, there should be a parameter to connect the geological and mining factors and the mining damage factors. The *H*/*M* ratio is the ratio between the coal seam depth and mining thickness, which is a parameter to measure the deformation degree of overburden strata and surface movement. In the qualitative evaluation, the *H*/*M* ratio is used to determine the intensity of overburden strata and surface deformation above the goaf. Generally, the value of *H*/*M* ratio is negatively related to the surface movement and deformation, i.e., the larger the ratio, the smaller the deformation degree of the surface movement. This is because the surface points in the temporal and spatial evolution are gentle gradual change with regularity. When the *H*/*M* ratio is smaller, the surface movement and deformation is intense and abrupt, and the damage to the ground surface is more severe. Fig. 4 shows the *H*/*M* distribution in high-intensity mining coal mines of 25 samples, in which the buried depth is calculated with the average depth.

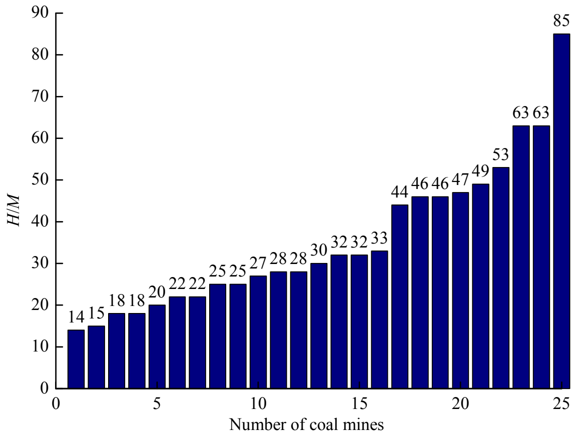


Fig. 4. The *H*/*M* distribution in high-intensity mining coal mines

As shown in the above figure, due to the shallow buried depth of coal seam and the large mining thickness of high-intensity mining working face, its *H*/*M* ratio is relatively small. The maximum *H*/*M* ratio is 85, and the depth less than 300 m accounts for 80%. It is also known from research that the values of surface horizontal strain and slop are greater than the values of damage grade IV [14] when the *H*/*M* is less than or equal to 100 [8]. Considering the mining influence and destruction factors of high-intensity mining, the *H*/*M* ratio is one of the common characteristics of high-intensity mining.

(7) Serious destruction of overburden strata

When coal is extracted underground, it destroys the equilibrium of in-situ stresses in the mining area and its surrounding strata. As a result, the stresses redistribute until they reach a new equilibrium. During this process, the overlying strata move, deform and break up [15]. Therefore, rupture failure of overburden strata is the internal cause of dynamic instability in goaf. Because of the large panel sizes and fast face advance speed of the high-intensity mining, the overburden strata are damaged seriously, mainly reflected in two aspects. Firstly, the "two-zone" height is large and leads to the evolution of groundwater seepage field and the deterioration of the surface ecological environment, which makes the eco-environment in the arid and semi-arid areas worse. Secondly, the overburden failure mode in partial samples is transformed from "three-zone" to "two-zone" (as shown in Fig. 5), which can easily form the breaking and leaking channels and threaten the safety of coal production. Meanwhile, the field observation, theoretical calculation and physical simulation experiment have verified the two aspects [16].

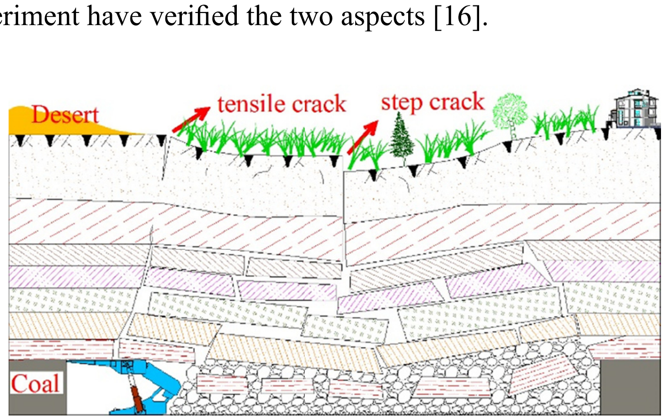
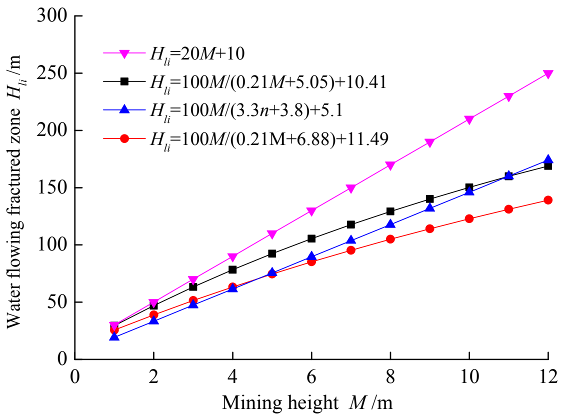
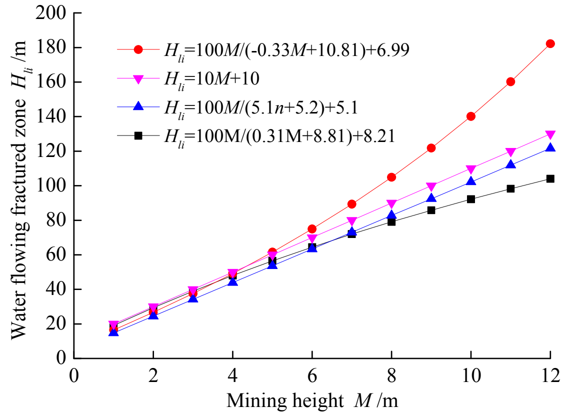


Fig. 5. The "two-zone" mode in overburden strata

Many Chinese scholars have studied the damage of overburden strata in high-intensity mining. Previous literatures on the field survey of overburden strata failure in high-intensity mining [17] show that the water conducted zone was very well developed, and its height was approximately proportional to the mining thickness. Also, the saddle shape of the overburden strata failure was verified. However, the calculated "two-zone" height value is greater than that by the traditional empirical formula from the "Criterion", as shown in Fig. 6. It can be seen that the serious disturbance to overburden strata is one of the main characteristics of high-intensity mining.



(a) Medium hard rock strata



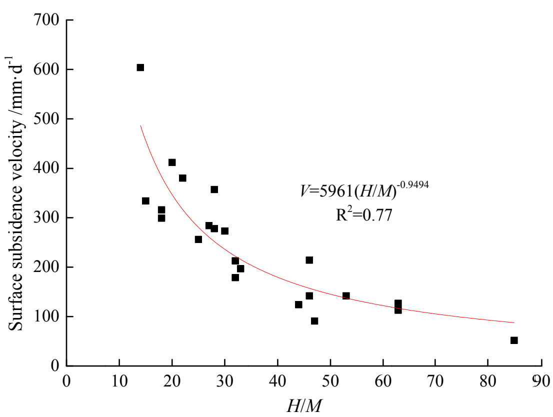
(b) Soft rock strata

Fig. 6. Comparison of "two-zone" height formula

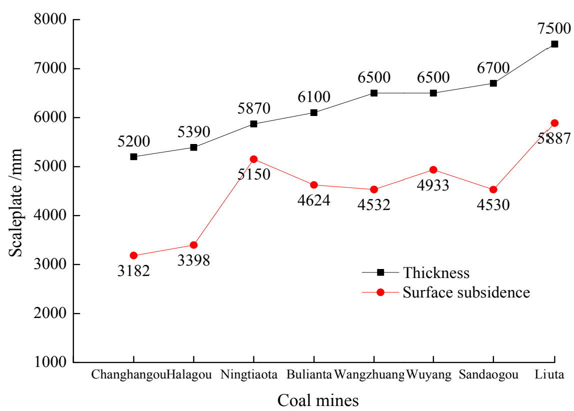
(8) Severe surface movement and deformation

During and after underground mining, surface movement and deformation has a direct connection with mining activities. Due to the geological and mining factors of high-intensity mining, the surface movement and deformation is very severe (Fig. 7a). The surface cracks, caused by the factors of shallow burial, large

(a) Surface step cracks



(b) Surface subsidence velocity



(c) Surface subsidence values

Fig. 7. Severe surface movement and deformation

mining thickness and fast face advance speed, can be divided into tensile cracks, shear cracks and collapse cracks according to the formation mechanism. The high-intensity mining in thick coal seam has the characteristics of fast surface subsidence (Fig. 7b), large surface movement and deformation (Fig. 7c), serious and remarkable influence on the surface building and ecological environment etc.

Based on the statistical sample data and analysis of Cuncaota 2# coal mine with the maximum *H*/*M* ratio, it is observed that the ground surface began to collapse when the working face was advanced 41 m away from the setup room, and the width of crack is 100~600 mm, the depth is 1~7 m.

According to the field survey of Halagou coal mine, three characteristics can be concluded as follows.

Firstly, the surface discontinuity is serious. In the high-intensity mining area, the surface cracks are dense, wide, and often accompanied by step crack, and even collapse pit in some areas. The cracks are generally developed to the outer edge of goaf with the shape of "C" or "O" type.

Secondly, the surface subsidence velocity is fast. The surface subsidence velocity can reach up to 700.5 mm/d, which is larger than the general longwall mining. In the short term after mining, the ground surface has obvious movement deformation and short duration. In the active stage, the surface subsidence value is large and has mutation characteristics.

Thirdly, the surface movement and deformation are severe. The influence range of surface movement and deformation is relatively small and the subsidence curve is steep, which are caused by the smaller main influence radius. The angle of the outmost crack (72~90°) and the maximum subsidence (89~90°) are large, but the main influence radius is small, and the subsidence factor and horizontal movement factor are large. Due to the geological and mining factors of high-intensity mining generally cause serious damage to the surface, the severe surface movement and deformation is the main characteristic of high-intensity mining.

In summary, the characteristics of high-intensity mining include the following 8 aspects, namely, simple geological and mining conditions, large panel sizes, advanced equipment and mining technology, fast face advance speed, high production and efficiency, large mining thickness and small *H*/*M* ratio, serious destruction of overburden strata, and severe surface movement and deformation.

2. The evaluation system and parameters of high-intensity mining

Based on the analysis of the characteristics of high-intensity mining and the concept of green mining, 12 indexes of high-intensity mining were given as shown in Fig. 8.

From the indexes system of high-intensity mining, two factors are in contact with each other. The geological and mining factors show that the mine has the ability of high production and efficiency, while the mining damage factors reflect the degree of mining to the ecosystem. The former is the basis of the latter, and in general, they are symbiotic. Both are important parts of the definition of high-intensity mining in thick coal seam. Meanwhile, the mining damage factors are the important characteristics that cannot be ignored in high-intensity mining of thick seam. Based on the current development status of high-intensity mining in thick coal seam, the index parameters of high-intensity mining are shown in Table 3.

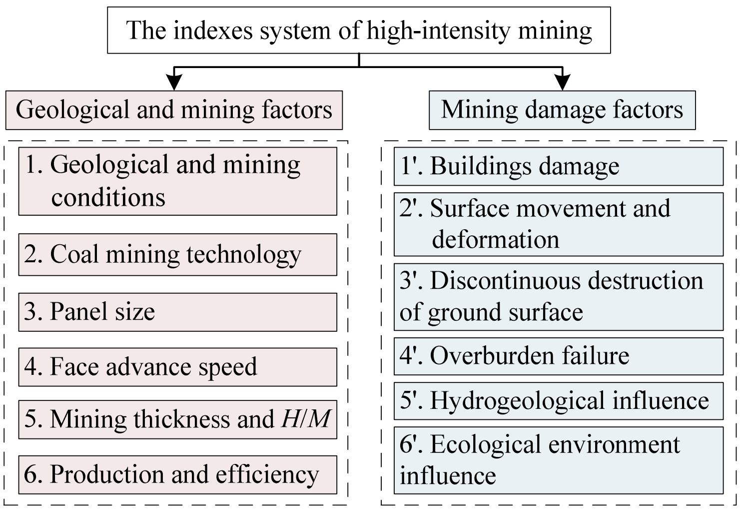


Fig. 8. Indexes system of high-intensity mining

3. Characteristic analysis of high-intensity mining

According to the mining status in northwestern mining area, high-intensity mining has gradually become a hot issue. The northwest region is a typical high-intensity mining area in China, and many scholars have made a great deal of researches on the mechanism and prevention of geological disasters under high-intensity mining, and obtained some achievements [18-20]. In order to verify the rationality of the high-intensity mining characteristics considering the mining damage factors, the analytic hierarchy process (AHP) method was used to analyze the weight of the indexes based on the principle of fuzzy mathematics.

Tab. 3. Index system parameters of high-intensity mining

Index type	No.	Index content	Index characteristics	Sample statistical index
Geological and mining conditions factors	1	Geological and mining conditions	Simple	Simple structure, stable, and structurally-complete
	2	Coal mining technology	LMH or FMTCC	LMH and FMTCC mining
	3	Panel size /m	Length ≥ 1000, Width ≥ 200	Length: 1200~5850, Width: 198~400.5
	4	Face advance speed /m·d^{-1}	≥ 5	2.2~20
	5	Mining thickness *M* and *H*/*M*	*M* ≥ 3.5, *H*/*M* < 100	Thick coal seam 3.5~8.0 m; LMH 3.5~8.8 m; Extra-thick coal seam >8.0 m; *H*/*M*: 14~85
	6	Production /Mt	≥ 300	176~2212
Mining damage factors	7	Buildings damage	IV damage grade	Based on the specification
	8	Surface movement and deformation	Large subsidence and horizontal movement; Slope > 10 mm/m, Curvature > 0.6 mm/m^2, Horizontal strain > 6 mm/m	Field observation: Subsidence 2.55~11.90 m, Slope 40.2~215 mm/m, Curvature 0.27~8.40 mm/m^2, Horizontal movement 799~3284 mm, Horizontal strain 8~89.3 mm/m
	9	Discontinuous destruction of ground surface	Cracks; Step cracks; Collapse pit; Slope instability; Mine earthquake	Based on the field investigation and observation
	10	Overburden failure	"Two-zone" mode, with large height, crack development	Based on the field observation, calculation and borehole observation
	11	Hydrogeological influence	Aquifer failure, groundwater loss, water table decline, water pollution	Based on the criteria and field observation
	12	Ecological environment influence	Vegetation degradation, land use reduction, ecological damage, biodiversity reduction	Based on the field investigation and observation

3.1. Analytic hierarchy process (AHP) method

AHP method, put forward by T.L. Saaty in 1977, is the mainstream method for evaluating the index weighting. It realizes the combination of quantitative and qualitative analysis, decomposes complex problems into different factors, and determines the importance of each factor through comparison with each other. The multi-level structure model is established through the hierarchical analysis of each evaluation index, and the 9-scale method is used to compare and quantify.

According to the comparison results, the judgment matrix is constructed, and then the largest eigenvalue λ_{max} of judgment matrix and its eigenvectors ω are obtained. The weight values of each element are evaluated by the eigenvector normalization. Due to the complexity of the influence factors and the inconsistency of the experts' opinions, the judgment matrix may not meet the completely consistency. Therefore, the consistency of the results must be checked, and the consistency ratio *CR* can be calculated by formula (1):

$$CR = \frac{CI}{RI} = \frac{\lambda_{max} - 1}{RI(n-1)} \tag{1}$$

where *CR* is the consistency ratio of judgment matrix; *CI* is the consistency index; *RI* is an average random consistency index with variation of dimension *n*, values are shown in Table 4.

Tab. 4. Mean random consistency index

Dimension *n*	3	4	5	6	7	8
RI	0.58	0.89	1.12	1.24	1.32	1.41

Based on the AHP theory, there is a negative correlation between the *CR* value and the consistency of judgment matrix, i.e., the smaller the CR is, the more consistent the judgment matrix is. It is stipulated that the judgment matrix meet the consistency when $CR < 0.1$, and the weight of the model evaluation index is reasonable. Otherwise, the judgment matrix needs to be readjusted.

3.2. Determination of high-intensity mining characteristics

According to the analysis of chapter 1, it indicated that the characteristics of high-intensity mining are mainly divided into geological and mining factors, and mining damage factors. The geological and mining factors mainly include simple geological and mining conditions, large panel sizes, advanced equipment and mining technology, fast face advance speed, high production and efficiency, large mining thickness and small *H*/*M* ratio. While the mining damage factors mainly include serious destruction of overburden strata, and severe surface movement and deformation.

3.3. Judgment matrix and weight calculation

The judgment matrix is based on the comparison results to determine the importance of each influence factor, and is constructed by quantifying the influence factors. Table 5 shows the judgment matrix of technical characteristics of high-intensity mining.

Tab. 5. Judgment matrix of technical characteristics of high-intensity mining

	Geological type	Panel size	Technical equipment	Advance speed	Production and efficiency	*H*/*M*	Overburden failure	Surface deformation
Geological type	1	1/2	1/5	1/3	1/4	1/6	1/5	1/6
Panel size	2	1	1/2	1/3	1/3	1/4	1/3	1/4
Technical equipment	5	2	1	2	1/2	1/2	1/2	1/3
Advance speed	3	3	1/2	1	1/2	1/3	1/3	1/4
Production and efficiency	4	3	2	2	1	1/2	1/2	1/3
H*/*M	6	4	2	3	2	1	2	1
Overburden failure	5	3	2	3	2	1/2	1	1/2
Surface deformation	6	4	3	4	3	1	2	1

From table 5, the judgment matrix shows that the eigenvector and the largest eigenvalue of the matrix are the following, $\omega = (0.0286, 0.0471, 0.0985, 0.0723, 0.1198, 0.2186, 0.1614, 0.2537)^T$, $\lambda_{max} = 8.2753$. The consistency test of judgment matrix is carried out by formula (1) and Table 4, and the results show that: $CI = 0.039$, $CR = 0.028 < 0.1$. Therefore, the obtained judgment matrix is consistent with the consistency condition, i.e., it is reasonable to assign each component of the eigenvector $\boldsymbol{\omega}$ as the weight of each technical characteristic.

From the results above, the mining damage factors occupy the same important position as the geological and mining factors. As a result, the technical characteristics of high-intensity mining cannot be only considered the geological and mining factors. Meanwhile, the results [21-22] show that the overburden strata failure and surface movement and deformation caused by high-intensity mining are serious, and the impact on the ecological environment is severe. Therefore, the weight coefficient reflects the actual situation and has reliability. At the same time, it verifies that the definition of high-intensity mining based on green mining is reasonable.

4. Conclusions

On the basis of analyzing the current situation and the definition of high-intensity mining in thick coal seam in China, the main technical characteristics and its parameters of high-intensity mining are systematically studied. It includes 8 aspects as following, simple geological and mining conditions, large panel sizes, advanced equipment and mining technology, fast face advance speed, high production and efficiency, large mining thickness and small *H*/*M* ratio, serious disturbance to overburden strata, and severe surface movement and deformation.

Based on the theory of green mining, the main indexes and evaluation system of high-intensity mining in thick coal seam are established from the aspects of geological and mining, and mining damages. The evaluation index system includes a total of 12 indexes of geological and mining indexes and mining damage indexes.

The main indexes of high-intensity mining in thick coal seam are analyzed by AHP method, and it indicates that geological and mining factors and mining influence and failure factors are two important aspects of high-intensity mining in thick coal seam. However, mining influence and failure factors are the characteristics that cannot be ignored in high-intensity mining of thick coal seam.

In the evaluation system of high-intensity mining, mining damage factors accounted for 6. It is mainly used to determine whether the longwall mining face of coal mine is high-intensity mining, or judge and analyze the damage to buildings, overburden strata, ground surface and ecological environment. The research results are of great significance for coal mine safety, high efficiency, green production, mining damage and protection for ecological environment, etc.

Acknowledgements

The research has been supported by the National Natural Science Foundation of China (No.51774111), and Program for Science & Technology Innovation Talents of Henan Province (No.184200510003). All support is gratefully appreciated.

References

Yajun S., Mengfei Z., Shang G. et al.: *Water-preserved mining technology and practice in typical high intensity mining area of China* [J]. Journal of China Coal Society, 2017, 42(1): 56-65.

Jinhua W.: *Key technology for fully-mechanized top coal caving with large mining height in extra-thick coal seam* [J]. Journal of China Coal Society, 2013, 38(12): 2089-2098.

Dengfeng Y., Zhonghui C., Qinfeng H. et al.: *Catastrophic analysis of support crushing disasters while roof cutting in shallow seam mining* [J]. Journal of Mining & Safety Engineering, 2016, 33(1): 122-127.

Bei Z., Guimin Z., Kai Z. et al.: *Water and sands bursting mechanism induced by geological borehole and control measures* [J]. Journal of Mining & Safety Engineering, 2015, 32(2): 219-226.

Shaogang L., Zhengfu B.: *Research progress on the environment impacts from underground coal mining in arid western area of China* [J]. Acta Ecologica Sinica, 2014, 34(11): 2837-2843.

Hui L., Chungui H., Kazhong D. et al.: *Analysis of forming mechanism of collapsing ground fissure caused by mining* [J]. Journal of Mining & Safety Engineering, 2013, 30(3): 380-384.

Limin F., Xiongde M., Yonghong L. et al.: *Geological disasters and control technology in high intensity mining area of western China* [J]. Journal of China Coal Society, 2017, 42(2): 276-285.

Wenbing G., Yunguang W.: *The definition of high-intensity mining based on green coal mining and its index system* [J]. Journal of Mining & Safety Engineering, 2017, 34(4): 616-623.

Jinghu Y., Shaolong S., Dezhong K.: *Effect of working face length and advancing speed on strata behaviors in high-intensity mining* [J]. Rock and Soil Mechanics, 2015, 36(S2): 333-340.

Jinan W., Shenhua J., Guangxiang X.: *Study on influence of mining rate on stress environment in surrounding rock of mechanized top caving mining face* [J]. Chinese Journal of Rock Mechanics and Engineering, 2006, 25(6): 1118-1124.

Guangxiang X., Jucai C., Xinzhu H.: *Influence of mining velocity on mechanical characteristics of surrounding rock in fully mechanized top-coal caving face* [J]. Chinese Journal of Geotechnical Engineering, 2007, 29(7): 963-967.

Shengli Y., Zhaohui W., Wei J. et al.: *Advancing rate effect on rock and coal failure format in high-intensity mining face* [J]. Journal of China Coal Society,2016,41(3):586-594.

Jinhua W., Leting H., Shoubin L. et al.: *Development of intelligent technology and equipment in fully-mechanized coal mining face* [J]. Journal of China Coal Society, 2014, 39(8): 1418-1423.

State Administration of Work Safety, State Administration of Coal Mine Safety, National Energy Administration, National Railway Administration of the People's Republic of China. *Mining criterion of coal pillars left for protecting surface structures, water bodies, railways and main shafts* [S]. 2017.

Wenbing G., Erhu B., Yi T. et al.: *Surface movement characteristics caused by fully-mechanized top coal caving mining under thick collapsible loess* [J]. Electronic Journal of Geotechnical Engineering, 2017, 22(3): 1107-1116.

Xuezhong L.: *Study on geological disaster regularity of coal mining subsidence in Ningdong coalfield.* Thesis, China University of Geosciences (Beijing), Beijing, 2006.

Wei Z., Yonghai T., Zhigang Z.: *Field measurement on ground subsidence and overburden failure by high intensity fully mechanized top-coal caving under thick loess* [J]. Metal Mine, 2015(4): 123-126.

Qiang W.: *Progress, problems and prospects of prevention and control technology of mine water and reutilization in China* [J]. Journal of China Coal Society, 2014, 39(5): 795-805.

Jiachen W., Zhaohui W.: *Impact effect of dynamic load induced by roof in high-intensity mining face* [J]. Chinese Journal of Rock Mechanics and Engineering, 2015, 34(S2): 3987-3997.

Zhixiang T., Zongsheng W., Yunjiang L. et al.: *Field research on ground subsidence rules of intensive fully mechanized mining by sublevel caving* [J]. Journal of Mining & Safety Engineering, 2008, 25(1): 59-62.

Xingping L.: *Derived dynamic disasters of large scale mined-out area for west coal mines* [J]. Journal of University of Science and Technology Beijing, 2004, 26(1): 1-3.

Research Group of National Key Basic Research Program of China (2013CB227900) (Basic Study on Geological Hazard Prevention and Environmental Protection in High Intensity Mining of Western Coal Area). Theory and method research of geological disaster prevention on high-intensity coal exploitation in the west areas [J]. Journal of China Coal Society, 2017, 42(2): 267-275.