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Height of Fractured Zone for Fully Mechanized Mining

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Abstract Since 1983, Yanzhou mining area has carried out test and study on coal mining technology under loose layers with great thickness. By applying a series of technical methods including surface drilling flushing fluid consumption observation, digital ultrasonic image of boreholes, exploration alley observation, water-conducting fracture zone depth data under extremely thick coal bed fully mechanized mining, slicing fully mechanized mining, underground fully mechanized mining and different mining conditions have been obtained and the systematical water-conducting fracture zone height prediction empirical formula has been counted and formed to fill the domestic gap. In recent years, based on study on a series of factors including fully mechanized mining working face parameters, roof rock stratum structure type and strength and maximum ground stress value, the water-conducting fracture zone height multi-factor influence regression prediction formula under the fully mechanized mining (exploration) conditions has been obtained, thus prediction precision has been significantly improved. Yanzhou mining area has applied the comprehensive water control technology for the extremely thick coal bed fully mechanized mining to free coal pillar resources overlaid by water body, which has gained significant benefits.
Keywords fully mechanized mining, slicing, overlying rock, water-conducting fracture zone, multi-factor, prediction formula

Since 1960s, China has achieved fruitful results (Li 2007, Yang et al. 2007, Xu 2009, Liu 1995) in aspects of thin coal bed and thick coal bed's slicing mining overlying rock failure law and mining technology under the water body; in addition, for study on thick coal bed fully mechanized mining's overlying rock failure law and coal mining technology under the water body (Li et al. 2005, Yu et al. 1994), Yankuang Group Co., Ltd. has cooperated with scientific research units and taken a lead in development of relevant test and study (Kang et al. 2001) as well as comprehensively applied traditional surface drilling flushing fluid method accompanied by drilling digital ultrasonic image method, drilling sound velocity method, transient electromagnetic method and a number of technical methods (Kang et al. 1995) to perform study on water-conducting fracture belt height and obtained breakthrough progress.

The paper has performed study on actual failure data of thick coal bed of Yanzhou mining area under different mining conditions and obtained water-conducting fracture zone development rules and empirical formula under corresponding conditions ("fully mechanized mining", "mining with limited thickness" and "underground fully mechanized mining after slicing"); further explored a number of factors (working face parameters, roof rock stratum structure type, strength, embedding depth, etc.) affecting development rules of the water-conducting fracture belt and perfected the multi-factor prediction formula of the fully mechanized mining water-conducting fracture zone height, thus offering practical experience for the mechanical mining and water control technology of thick coal bed.

Actual study on the overlying rock failure law of thick coal bed's fully mechanized mining

Slicing fully mechanized mining

(1) Engineering cases

For the pilot mining working face (2301~2306 working face) of No. 2 mining area of Xinglongzhuang Coal Mine, the average thickness of coal bed is 8.65m, the dip angle is smaller than 10°, the overlying bedrock pillar is smaller than 80m, lithology of mid-fine grained sandstone and compressive strength of 30-45 MPa. The comprehensively mechanized coal mining method with inclined longwall will be applied and mining will be carried out in three layers, with the sub-layer mining thickness of 2.4~3.3 m and recovery sequence of upward section and downward sub-layer. During the working face recovery process, 40 boreholes will be observed and studied by means of borehole flushing fluid method, borehole ultrasound velocity method, ultrasound image method, under-shaft drilling network parallel electrical survey method and other test methods and approaches. The actual result is as follows: For No. 1 sub-layer, the water-conducting fracture zone height is 17.9~42.2 m and the ratio of the height of the fracture zone to the mining height 6.4~15.9 m; for No. 2 sub-layer, the water-conducting fracture zone height is 38.4~51.5 m and the ratio of the height of the fracture zone to the mining height is 7.4~9.2 m; for No. 3 sub-layer, the water-conducting fracture zone height is 39.1~44.7 m and the ratio of the height of the fracture zone to the mining height is 4.6~5.2 m.

(2) Relation between water-conducting fracture zone height and mining thickness of the slicing fully mechanized mining

According to actual statistics and analysis of the development height of the water-conducting fracture zone, the fracture height and mining thickness laws under the slicing fully mechanized mining conditions are as follows:

$$H_{li} = \frac{100M}{1.64M + 2.36} \pm 3.13 \quad \text{(The vertical height of bedrock column is larger than 80 m)}$$

$$H_{li} = \frac{100M}{2.32M + 0.80} \pm 2.36 \quad \text{(The vertical height of bedrock column is smaller than 80 m)}$$

Where in:

H_{li}——Maximum height of the water-conducting fracture zone, m;

M——Accumulated mining thickness, m.

Fully mechanized mining

(1) Engineering cases

Observation and study are made to water-conducting fracture zone of 1301, 4314, 5306 fully mechanized mining working face of Xinglongzhuang Coal Mine. The 1301 working face coal bed has a thickness of 8.13m, dip angle of 6°~13°, overlying rock lithology of mid-fine grained sandstone and compressive strength of 30-45 MPa. The top coal caving method with longwall direction will be applied for coal mining, with a mining height of 6.36 m. The "leakage check by under-shaft upward hole water injection" technology is applied to test the water-conducting fracture zone, thus obtaining following results of the working face water-conducting fracture height of 72.9~55.9 m and the ratio of the height of the fracture zone to the mining height of 8.8~11.5 m. 4314 and 5306 working face is observed by contrast test and the "drilling flushing fluid consumption" method is also applied to test the water-conducting fracture belt, thus obtaining following results of the development height of 33.0~79.2 m and the ratio of the height of the fracture zone to the mining height of 4.9~11.3 m(table 1).

Table 1 *Actual result of the water-conducting fracture zone height of the fully mechanized mining of Xinglongzhuang coal mine*

Working Face	Hole No.	Borehole Position	Caving Thickness/Accumulated Mining Thickness (m)	Water-conducting Fracture Zone	
				Height (m)	Ratio of the Height of the Fracture Zone to the Mining Height
1301	Upward 1	Lower boundary	6.36/6.36	72.9	11.5
	Upward 2	Lower boundary	6.36/6.36	68.5	10.8
	Upward 3	Lower boundary	6.36/6.36	55.9	8.8
5306	Downward 1	Upper boundary	6.9/6.9	76.7	11.1
	Downward 2	Middle	6.9/6.9	33	4.9
	Downward 3	Lower boundary	7.0/7.0	79.2	11.3
4314	Downward 4	Upper boundary	7.0/7.0	54.0	7.7
	Downward 5	Lower boundary	7.4/7.4	66.5	9.0

(2) Relation between water-conducting fracture zone height and mining thickness of the fully mechanized mining

According to actual statistics and analysis of the development height of the water-conducting fracture zone, the fracture height and mining thickness laws under the fully mechanized mining condition are as follows:

$$H_{li} = \frac{100M}{0.94M + 4.31} \pm 4.22$$

Where in:

H_{li}——Maximum height of the water-conducting fracture zone, m;

M——Accumulated mining thickness, m.

Underground fully mechanized mining

According to study on the water-conducting fracture belt height under conditions of slicing fully mechanized mining and fully mechanized mining, Yankuang Group puts forward the new underground fully mechanized method combined with the "slicing mining and underground fully mechanized mining", namely the extremely thick coal bed is divided into two layers, the upper sub-layer and the lower sub-layer are all applied with the fully mechanized mining method. In case of the upper sub-layer mining, the wire mesh will also be equipped to resist fracture height development.

(1) Engineering cases

For 2303 working face coal bed of Xinglongzhuang Coal Mine, the thickness is 8.8m and the vertical height of bedrock pillar in the mining range is 66~94 m. Firstly, fully mechanized mining will be done to the top sub-layer, thus obtaining results of the mining thickness of 2~2.5 m, residual coal bed thickness of 6.3 m, underground fully mechanized mining, actual development height of the water-conducting fracture zone of 37.2~44.5 m and the ratio of the height of the fracture zone to the mining height of 4.5~5.1; for 23S1 working face coal bed, the thickness is 8.5 m, the vertical height of bedrock pillar in the mining range is 46~71 m, the fully mechanized mining top sub-layer coal thickness is 2.8 m, the underground fully mechanized thickness is 5.7 m, the actual development height of the water-conducting fracture zone is 36.6~37.4 m and the ratio of the height of the fracture zone to the mining height is 4.3~4.4 (Table 2).

***Table 2** Actual result of the water-conducting fracture zone height of the underground fully mechanized mining of Xinglongzhuang coal mine*

Working Face	Hole No.	Borehole Position	Mining Thickness (m)			Water-conducting Fracture Zone	
			Top Sub-layer Mining Thickness	Caving Coal Mining Thickness	Accumulated Mining Thickness	Height (m)	Ratio of the Height of the Fracture Zone to the Mining Height
2303	Donward 6	Upper boundary	2.0	6.3	8.3	37.2	4.5
	Donward 7	Upper boundary	2.5	6.3	8.8	44.5	5.1
23S1	Donward 8	Upper boundary	2.8	5.7	8.5	37.4	4.4
	Donward 9	Middle	2.8	5.7	8.5	36.6	4.3

(2) Relation between water-conducting fracture zone height and mining thickness of the underground fully mechanized mining

According to the actual statistics and analysis of water-conducting fracture zone of Xinglongzhuang Coal Mine, it is found out that the relation between the fracture height and the mining thickness under the underground fully mechanized mining condition is as follows:

$$H_{li} = \frac{100M}{2.03M + 1.55} \pm 2.55$$

Where in:

H_{li}——Maximum height of the water-conducting fracture zone, m;

M——Accumulated mining thickness, m.

The water-conducting fracture zone height of the underground fully mechanized mining (repeated mining in 2 layers) is significantly smaller than fully mechanized mining (primary mining for the whole layer) condition of the full coal thickness and slightly higher than the fully mechanized mining condition of sub-layers, as shown in curves 1, 4 and 5 in fig. 1. It shows that, in case of repeated mining in 2 layers, if reducing the initial mining thickness and increasing the repeated mining thickness simultaneously, the increased amplitude of the water-conducting fracture zone height will be far less than the primary mining condition of the whole layer. And, it is a kind of effective technical approach beneficial to achieve high yield and high efficiency backwater and safe coal mining.

Mining method impact on the water-conducting fracture zone height

For fully mechanized mining of North China type Permian System coal bed of Yanzhou mining area, the relation curve between the water-conducting fracture zone height and the mining thickness is as shown in fig. 1.

In fig.1, 1 is fully mechanized mining of the full coal thickness of Yanzhou coal field (vertical height of the bedrock pillar>122 m); 2 is fully mechanized mining (mining in 3 layers, vertical height of the bedrock pillar>80 m) of Yanzhou coal field; 3 is common blasting mining of domestically medium-hard overlying rock; 4 is Underground fully mechanized mining of Yanzhou coal field (mining in 2 layers, vertical height of the bedrock pillar<87 m); 5 is fully mechanized mining of Yanzhou coal field (mining in 3 layers, vertical height of the bedrock pillar<80 m).

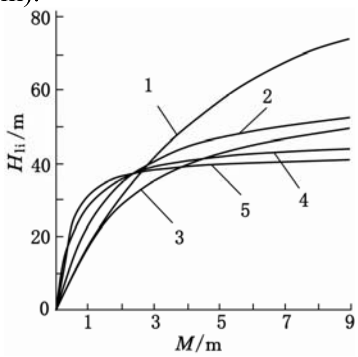

Fig.1 *Curve diagram of coal mining method and water-conducting fracture zone height*

The relation between the overlying rock damage height and the mining thickness of the fully mechanized mining of the coal bed working face has failed to satisfy the approximate linearity relation in case of initial blasting mining or single-layer mining of the thin coal bed, which presents an approximate fractional function relation. However, with increasing mining thickness, the facture height value increase speed will be significantly larger than blasting mining or slicing fully mechanized mining condition in case of fully mechanized mining. It shows that increase of the initial mining thickness or primary mining thickness of whole layer will lead to the significant increase of the overlying rock damage height, which will be unfavorable to backwater and safe coal mining, which shall be noted. It indicates a new direction to reduce the initial mining thickness of the thick coal bed to control the development height of the water-conducting fracture zone as well as increase the repeated mining thickness to reduce coal mining production costs and improve coal mining efficiency and economic benefits of the mine.

Height multi-factor influence regression prediction of the fully mechanized mining water-conducting fracture zone

Determination of the influence factor

The prediction empirical formula of the fully mechanized mining water-conducting fracture zone height of Yanzhou mining area has been popularized and applied in Shandong Province, thus making contributions to the scientific and technological progress of the coal industry in the whole province. However, due to single coal thickness factor, it still remains to be perfected. In recent years, Yanzhou mining area has studied the multi-factor influence of the development height of the fully mechanized mining (downward) working face water-conducting fracture belt, mainly considering following factors:

(1) Coal bed mining thickness M: The index reflects the impact of the size of the vertical height of underground excavation on the stress redistribution, deformation and rupture range of the excavated roof rock mass.

(2) Hard rock lithology proportion b: It replaces uniaxial compressive strength and the roof rock stratum structure type (Hu et al. 2012) of combined roof rock stratum; reflects the coal bed roof strength type and lithology combination and avoid uniaxial compressive strength statistics and omission of roof's soft and hard rock stratum combination structure problem during hard, medium hard, soft and very soft roof types classification in the current specification. It refers to the ratio of the hard rock and the statistical height in the above

statistical height ranges of the coal bed roof (water conducting fracture zone height); hard rocks participating in statistics mainly refer to sandstone, mixed rock and igneous rock. The expression formula is as follows:

$$b = \frac{\sum h}{(15 \sim 20)M}$$

Where, M is coal thickness, m; $\sum h$ refers to accumulated thickness counted by the hard rock stratum in the estimated water-conducting fracture belt height range (according to the locally estimated height conduction experience, consideration will be given to coal thickness times, which is generally 15~20 times coal thickness of the roof).

Table 3 *Data list of the actual height value of the water-conducting fracture zone and relevant influence factors*

Mine	Working Face or Hole No.	Mining Thickness M (m)	Hard Rock Lithology Proportion Coefficient b	Working Face Inclination Length L (m)	Mining Depth s (m)	Advance Speed v (m/d)	Actual "Fracture Height" H_f (m)
Baodian Mine (Shandong)	1314	7.5	0.47	173.5	367	4.5	75.5
	1316	7.53	0.38	170	357	3.82	61.9
	5306	7.52	0.41	190	367	4.78	61.77
Jisan Mine (Shandong)	13_L01	6.1	0.37	170	475	2.7	64.6
Liangbaosi Mine (Shandong)	3202	3	0.23	186	649.1	2.1	42.99
Nantun Mine (Shandong)	63_U10	5	0.81	122	320	4.19	67.7
	93_U01	4.8	0.36	175	485	5.83	62.5
Gaozhuang Mine (Shandong)	3_U503	4.6	0.5	170	86.1	3.0	53.9
Jiangzhuang Mine (Shandong)	803	3.8	0.65	168	270	3.5	54.6
Xinglongzhuang Coal Mine (Shandong)	2308-2 D7	2.8	0.68	156	269	2.6	50.34
	2306-1 D4	2.8	0.93	156	264.5	1.03	44.34
	2302-1 D13	2.6	1．0	168	290	2.83	46.22
	2300-1 D17	2.5	0.93	192	265	3.9	40.21
	2301-1 D24	2.6	0.64	185	295	2.5	40.5
	5306 F1	7	0.52	168	433	2.23	70.3
	4314 F5	7.4	0.55	160	331	1.53	64.25
	2303F7	5.3	0.24	145.7	312	3.8	44.2
	23s1 F8	5.7	0.63	177.9	283.9	4.5	51.4
Jier Mine (Shandong)	1301	2.94	0.85	180.4	568.4	4.18	57
	2301	2.95	0.74	206.1	516	2.44	54.5
Yangcheng Mine (Shandong)	1305	7.5	0.19	222	665	2.2	53.7
Shengda Mine (Henan)	5-21010	2.1	0.46	180	679	2.1	44.54
Tingnan Mine (Shaanxi)	106	7.6	0.62	116	463	4.7	86.4
Tianchi Mine (Shanxi)	201	4.5	0.55	175	387.5	2.5	58.5
Panyi Mine (Anhui)	1121(1)M14-2	3	0.04		431.1		21.93
Paner Mine (Anhui)	1201(1)92-13	2	0.14		316.8		31.61

(3) Working face inclination length L: The inclination length as well as the coal thickness, is the index of mining space dimensions influencing the height conduction.

(4) Mining depth s: According to coal mine engineering geology and basic rock mechanics theory, the ground stress size and condition of the rock stratum near the underground excavation space will significantly influence the damage range size of the excavated surrounding rock (Hu et al. 2012). In general, the original rock stress of the surrounding rock of the working face will increase along with the increasing depth, so the mining depth will cause certain influence to the high conduction.

(5) Advance speed v: The working face advance speed will have obvious influence to deformation and damage process of the roof and overlying rock.

Data acquisition

To study relevancy between the influence factors and the development height of the water-conducting fracture belt and establish the regression prediction formula of the water-conducting fracture zone height under the fully mechanized mining condition, the paper selects 40 fully mechanized mining water-conducting fracture zone height examples of Shandong Province (southwest part of Shandong Province) and adjacent Anhui Province.

Regression analysis

When analyzing relevant relation between the water-conducting fracture zone height and the single factor indexes, we consider and select representative data under conditions close to other influence factors and we apply the simple regression to find out the simple regression model with the maximum relevant coefficient.

Apply Matlab to draw the scatter diagram of the water-conducting fracture zone height and five influence factors and perform analysis and find out followings: The water-conducting fracture zone height, mining thickness and hard rock lithology coefficient have better linear relation, which have a natural logarithm function relation with the working face inclination length and an index function relation with the mining depth (fig. 2). It has minor relevancy with the advance speed.

Apply the multi-factor regression analysis method in SPSS to study the fitting formula between the relation between the water-conducting fracture zone development height and the multi-factor under following four conditions:

(1) Consider the mining thickness and hard rock lithology proportion coefficient

$$H_f = 4.24M + 39.8b + 12.8 \quad (1)$$

(2) Consider the mining thickness, hard rock lithology proportion coefficient and working face inclination length

$$H_f = 3.74M + 37.52b + 1.95\ln l + 6.84 \quad (2)$$

(3) Consider the mining thickness, hard rock lithology proportion coefficient, inclination length and mining depth

$$H_f = 3.47M + 28.36b + 1.89\ln l + 0.13e^{5.346 - \frac{426.243}{s}} + 6.04 \quad (3)$$

(4) Consider the mining thickness, hard rock lithology proportion coefficient, inclination length, mining depth and advance speed

$$H_f = 3.41M + 27.12b + 1.85\ln l + 0.11e^{5.346 - \frac{426.243}{s}} + 0.64v + 6.11 \quad (4)$$

Where in:
H_f—— water-conducting fracture zone height, m;
M—— coal bed mining thickness, m;
b—— hard rock lithology proportion coefficient;
L—— working face inclination length, m;
s——mining depth, m;
v—— advance speed, m/d.

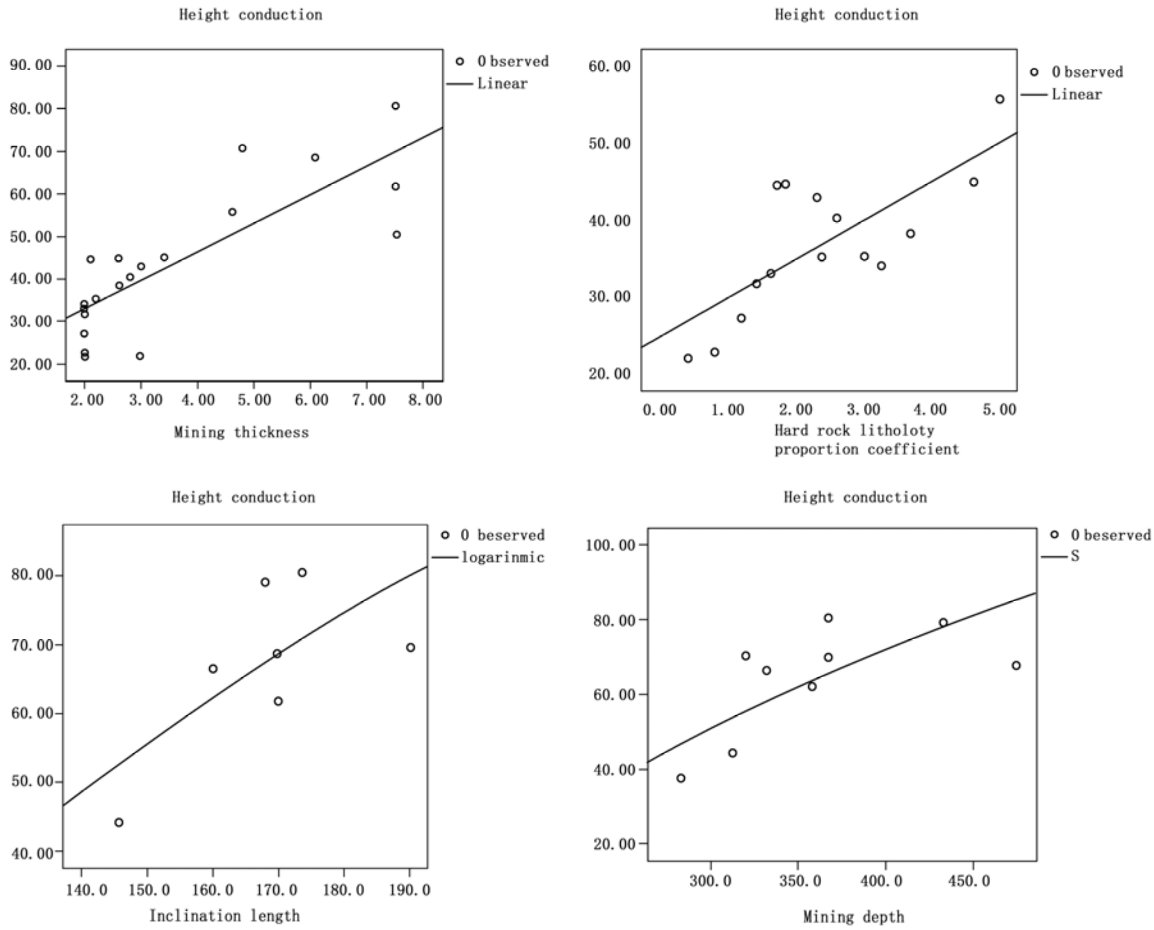

Fig.2 *Influence factor scatter diagram*

Comparative analysis

Estimation is made to the sample data through the fitting formula (1~4) and "three-lower" regulation formula and the predicted value is subject to contrastive analysis (table 4), and it is found out that the predicted error of the regulation empirical formula is larger but the predicted error of the fitting formula is smaller. More factors will bring more accurate predicted values. Accordingly, when predicting the fracture height, the predicted conduction height of the proper fitting formula can be selected based on the engineering geology prospecting conditions.

Conclusions

(1) By study on actual engineering cases of the water-conducting fracture zone height under conditions of the extremely thick coal bed slicing fully mechanized mining, fully mechanized

mining and underground fully mechanized mining, the prediction empirical formula has been deduced to fill the domestic gap.

(2) Perform single factor regression analysis and find out followings: The water-conducting fracture zone height under fully mechanized mining, mining thickness and hard rock lithology coefficient have better linear relation, which have a natural logarithm function relation with the working face inclination length and an index function relation with the mining depth. It has minor relevancy with the advance speed. Through the multi-factor regression analysis, the water-conducting fracture zone multi-factor regression prediction formula under the fully mechanized mining condition is deduced, thus significantly improving the prediction precision.

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Table 4 *Comparison between the predicted 擞racture height?value and actual value*

Mine	Working Face or Hole No.	Actual Fracture Height (m)	hree-lower Regulation Formula		Formula (1)		Formula (2)		Formula (3)		Formula (4)	
			Predicted Value (m)	Relative Error (%)	Predicted Value (m)	Relative Error (%)	Predicted Value (m)	Relative Error (%)	Predicted Value (m)	Relative Error (%)	Predicted Value (m)	Relative Error (%)
Baodian Mine	1314	75.5	53.68	28.90	63.31	16.15	62.58	17.11	63.68	15.66	64.07	15.14
	1316	61.9	53.72	13.21	59.85	3.31	59.27	4.25	60.92	1.58	61.03	1.41
	5306	61.77	53.71	13.05	61	1.25	60.58	1.93	62.22	-0.73	62.86	-1.76
Jisan Mine	13L01	64.6	51.26	20.65	53.39	17.35	53.55	17.11	58.52	9.41	45.56	29.47
Liangbaosi Mine	3202	42.99	24.98	41.89	34.67	19.35	36.88	14.21	46.99	-9.30	57.58	-33.94
Nantun Mine	63U10	67.7	71.4	-5.47	66.24	2.16	65.3	3.55	62.64	7.47	62.79	7.25
	93U01	62.5	48.15	22.96	47.48	24.03	48.37	22.61	53.99	13.62	55.11	11.82
Gaozhuang Mine	3U503	53.9	47.57	11.74	52.2	3.15	52.82	2.00	46.08	14.51	46.94	12.91
Jiangzhuang Mine	803	54.6	44.86	17.84	54.78	-0.33	55.43	-1.52	52.97	2.99	53.17	2.62
Xinglongzhuang Coal Mine	2308-2D7	50.34	40.25	20.04	51.74	-2.78	52.67	-4.63	50.18	0.32	49.84	0.99
	2306-1D4	44.34	61.14	-37.89	61.69	-39.13	62.05	-39.94	57.12	-28.82	55.49	-25.15
	2306-2D10	43.43	39.11	9.95	47.7	-9.83	48.81	-12.39	46.97	-8.15	47.15	-8.57
	2302-1D13	46.22	59.68	-29.12	63.62	-37.65	64.08	-38.64	59.38	-28.47	58.69	-26.98
	2300-2D26	42.81	39.69	7.29	46.54	-8.71	48.2	-12.59	46.69	-9.06	46.66	-8.99
	2301-1D24	40.5	39.11	3.43	49.3	-21.73	50.76	-25.33	49.51	-22.25	49.03	-21.06
	5306 F1	70.3	52.90	24.75	63.18	10.13	62.52	11.07	64.95	7.61	63.61	9.52
	4314F5	64.25	53.53	16.68	66.07	-2.83	65.05	-1.25	64.43	-0.28	62.99	1.96
	2303F7	44.2	28.73	35.00	44.82	-1.40	45.38	-2.67	47.61	-7.71	48.23	-9.12
	23s1F8	51.4	50.41	1.93	62.04	-20.70	61.9	-20.43	59.55	-15.86	60.24	-17.20
Jier Mine	1301	57	62.08	-8.91	54.76	3.93	56.03	1.70	55.87	1.98	57.76	-1.33
	2301	54.5	41.06	24.66	69.7	-27.89	67.8	-24.40	76.36	-40.11	69.29	-27.14
Yangcheng Mine	1305	53.7	30.55	43.11	52.16	2.87	52.55	2.14	62.03	-15.51	60.4	-12.48
Shengda Mine	5-21010	44.54	35.77	19.69	40.01	10.17	42.08	5.52	50.74	-13.92	49.01	-10.04
Tingnan Mine	106	86.4	53.82	37.71	69.7	19.33	67.8	21.53	69.84	19.17	69.83	19.18
Tianchi Mine	201	58.5	52.43	10.38	53.77	8.09	54.38	7.04	56.09	4.12	55.21	5.62