

Research Article

Influencing Factors' Analysis of Disturbance Degree of Key Stratum Based on the Response Surface Method

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The key stratum controls the activities of the overlying strata or the whole strata up to the surface, which is one of the important research objects in the coal seam mining. Based on the analysis of several geological factors affecting on the key stratum, the definition of “disturbance degree of key stratum” (KSDD) was proposed. And, the KSDD is quantified by the value among 0 to 10. Through the response surface method, experiments of three factors (mining height, buried depth, and interlayer spacing) with three different lithology types (soft, medium, and hard) between key stratum and coal seam are signed. And, the KSDD of each scheme is calculated by the developed calculation system. The response surface regression models of KSDD with three lithology types are established. And, the single influence and interactive influences of the three factors on the KSDD with different lithology types are studied. The results show that the following. (1) Mining height and buried depth are positively correlated with the value of KSDD, and the interlayer spacing is negatively correlated with KSDD. However, when the value of interlayer spacing exceeds 30 m, the change of the KSDD tends to be gentle. (2) The value of KSDD is not only affected by a single factor but also affected by the interaction of various factors. With the increase of burial depth, the decrease of interlayer spacing and the impact of mining height on key stratum are more severe. (3) The influence order of each factor on KSDD is as follows: the interlayer spacing > mining height > buried depth. (4) Although the three factors interact with each other, the three factors decrease with the increase of the lithology proportional coefficient. According to the above research results, based on the calculation results of KSDD on five mines, the variation laws of KSDD with actual situation are analysed. And, the calculation results further verify the above experimental rules, which provide a certain reference and theoretical basis for the design of backfilling parameters and the management of the roof.

1. Introduction

Rock strata with different thickness and strength were formed above the coal seam because of different diagenetic time periods. According to the key stratum theory, the stratum which controls the whole or part of rock mass activity are called key stratum [1, 2]. A large number of engineering practice show that the key stratum was hard. So, a new structure still can be formed to support the overlying strata when key stratum was broken [3–5]. Therefore, the studies of key stratum, such as the breaking position, structural stability, and integrity of key stratum, are of great significance to the safety and production of coal seam mining [6–10].

A large number of scholars have enriched and expanded the theory of key stratum in order to control strata

movement. Based on the medium-thick plate theory, the influences of the thickness on the fracture mode of the key layer have been studied. The criterion of fracture mode of key stratum with different thickness has been obtained [11, 12]. Based on the theory of double key strata, the roof structure models of double key strata have been established, and the mining methods of graded water conservation have been obtained [13, 14]. Based on the model of the key stratum structure after sliding and instability, the restability condition of the key stratum has been obtained [15]. The degree of subsidence deflection has been proposed through the establishment of the surface deflection subsidence model. Based on the key stratum theory, the influences of the thickness of loose strata and the bulking factor on the surface deflection subsidence have been analysed [16]. The stability

and periodic pressure mechanism of single and double key strata in overlying strata with large mining height have been revealed. The calculation formula of support resistance has been obtained [17]. Based on numerical simulation, the influences of different distances of double seams' mining on overlying water resisting key stratum have been studied [18]. The above studies have analysed various failure laws of key stratum under different geological conditions. A series of relatively complete theoretical and surrounding rock control methods are established. However, the current research studies mainly focus on the influences of key stratum on the working face. And, there are few studies on the influences of mining geological conditions on the disturbance of key stratum. In addition, there is no corresponding evaluation method and theoretical basis.

Therefore, in order to explore the influences of different geological conditions on key stratum, this paper focuses on the following three research objectives. (1) Several geological factors affecting the key stratum and the proposal of the "disturbance degree of key stratum" are analysed (hereinafter referred to as KSDD). (2) The Design-Expert software will be used to design the response surface [19–21] experimental scheme of three factors (mining height, buried depth, and interlayer spacing) with three different lithology types (soft, medium, and hard) between key stratum and coal seam. The response surface regression model of KSDD will be established. (3) The single influence and interactive influences of the three factors on the KSDD with different lithology types will be explored. These studies will provide a certain reference and theoretical basis for the stability identification of key water resisting stratum, the design of backfilling parameters, and the control of surface subsidence.

2. Definition and Influencing Factors of the KSDD

2.1. The Definition of KSDD. Underground coal mining breaks the original stress state of surrounding rock [22–24]. Due to the coal seam mining, the degrees of disturbance on the stratum above the coal seam are different. Therefore, in order to explore the change laws of disturbance degree on key stratum with different mining geological conditions. The degree of disturbance caused by coal seam mining on key stratum is defined as the "Disturbance Degree of Key Stratum" (KSDD), which is expressed by the symbol φ .

According to the definition of the KSDD, which means the key stratum is greatly affected by the disturbance with coal seam mining with large value of KSDD, the key stratum under the same conditions is more likely to be destroyed at this time. Conversely, the key stratum is relatively affected by the disturbance with coal seam mining with a small value of KSDD. And, the key stratum under the same conditions is easier to keep intact at this time.

2.2. The Calculation Formula of KSDD. The related factors are considered comprehensively, including quantitative discrimination method of the feasibility of upward mining in close multiple coal seams [25], mining height, buried depth

[26], distance between key stratum and coal seam (hereinafter referred to as interlayer spacing), tensile strength, and rock bulking coefficient. Then, according to the definition of KSDD, the disturbance intensity of the key stratum caused by coal mining is quantified by the value from 0 to 10. Formula (1) [25] is obtained:

$$\varphi = 10 - \left[\lambda \sum_{i=1}^n \left(K_{p_i} \cdot \frac{H_i}{H} \cdot R_{t_i} \right) \cdot \frac{H^2}{D \cdot M} + C \right], \quad (1)$$

where φ is the disturbance degree of key stratum (KSDD), M is the mining height, m , H is the interlayer spacing, m , D is the buried depth of the coal seam, m , $H_1, H_2 \dots H_i$ are the thicknesses of the i th ($i = 1, \dots, n$) rock above the mining coal seam, m , $R_{t1}, R_{t2} \dots R_{ti}$ are the tensile strength of the i th ($i = 1, \dots, n$) rock above the mining coal seam, MPa, $K_{p1}, K_{p2} \dots K_{pi}$ are the rock bulking factors of the i th ($i = 1, \dots, n$) rock above the mining coal seam, n is the number of all rock strata between the Kay stratum and coal seam, λ is the influence factor of the disturbance degree of the key stratum, and C is the geological constant.

The value of KSDD is closer to 10, and the disturbance effect of coal mining on the key stratum is greater. In contrast, the value of KSDD is closer to 0, and the disturbance effect of coal mining on the key stratum is smaller.

2.3. The Influencing Factors of KSDD. The location distribution of the various factors included in formula (1) are shown in Figure 1:

In order to simplify formula (1), according to the location relationship of various factors, the ratio of the interlayer spacing and the mining height (H/M) in formula (1) is defined as "disturbance influence coefficient." The ratio of the interlayer spacing and the buried depth (H/D) is defined as "interburden-to-overburden," And, the $K_{p_i} \cdot (H_i/H) \cdot R_{t_i}$ in formula (1) is defined as "lithology proportion coefficient," which is expressed by the symbol ξ .

In order to simplify the experimental research and analysis, based on formula (1), the lithology proportion coefficient (ξ) is expressed as follows:

$$\begin{aligned} K_{p_i} \cdot \frac{H_i}{H} \cdot R_{t_i} &= K_{p_i} \cdot R_{t_i} \cdot \frac{H_i}{H} \\ &= \alpha \cdot \beta = \xi, \end{aligned} \quad (2)$$

where ξ is the lithology proportional coefficient, α is the lithology strength coefficient, and β is the lithology ratio:

$$\begin{aligned} \alpha &= K_{p_i} \cdot R_{t_i}, \\ \beta &= \frac{H_i}{H}. \end{aligned} \quad (3)$$

Figure 2 shows the relationship between the defined above and the factors in formula (1) with the KSDD.

2.4. Calculation System of KSDD. As the geological conditions of coal seam are complex and various, the calculation process of KSDD is cumbersome. Therefore, based on

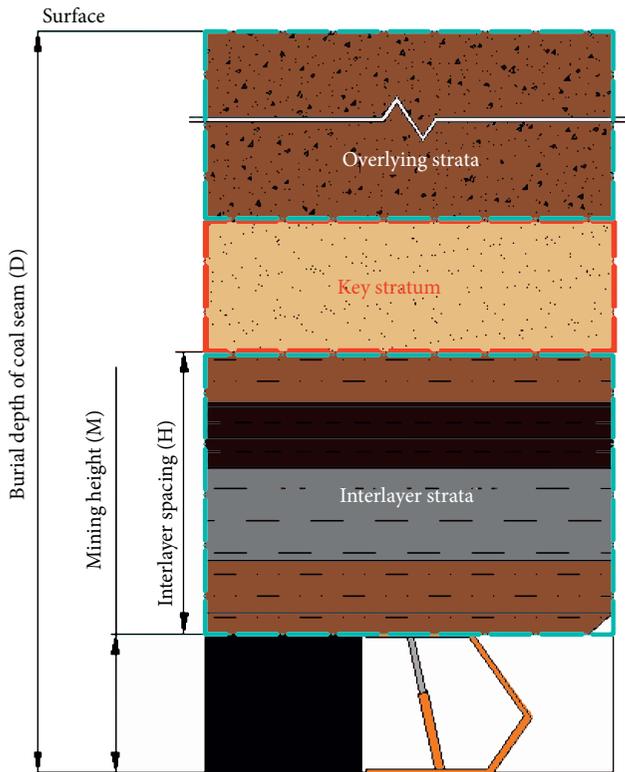


FIGURE 1: The location relationship of various factors.

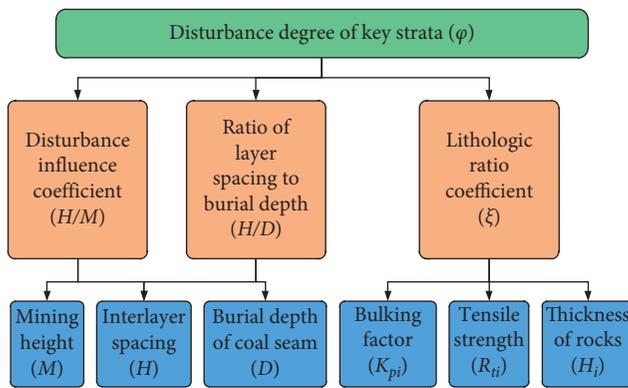


FIGURE 2: The relationship between influencing factors and KSDD [25].

formula (1), the calculation system of KSDD is developed with C# language on “. NET” platform. The home page of the system is shown in Figure 3.

According to Figure 4, the calculation of KSDD can be divided into the following four steps. (1) Click “File”-“New” to enter the calculation interface. (2) Click “Add Rock Stratum” to enter the rock information input interface. (3) Input parameters including the rock strata, the thickness of the single stratum, the cumulated thickness of the rock strata, the tensile strength, the bulking factor, the mining height, the interlayer spacing, and the buried depth. (4) Finally, click to “Calculate the KSDD” to get calculation results.

In addition, batch calculation can be performed according to Figure 5, and the calculation steps are as



FIGURE 3: Calculation system of KSDD.



FIGURE 4: Calculation process of KSDD.



FIGURE 5: Operation flow of batch calculation for KSDD.

follows. (1) Save relevant data as “.csv” file in fixed “Excel” format. (2) Click “File”-“Import” and select the “.csv” data file to be imported. (3) After the data is imported, the

KSDD can be calculated. (4) Wait until the data calculation is completed, click “File”-“Export” to get a lot of data.

3. Experimental Design

In order to simplify the subsequent data analysis, the lithology between key stratum and coal seam is set as soft, medium, and hard, respectively. According to the actual geological conditions, the tensile strength of three lithology is set as 1 MPa, 3 MPa, and 5 MPa, respectively. Similarly, the bulking factor is set as 1.2, 1.3, and 1.4, respectively, as shown in Table 1.

In order to obtain the lithology proportion coefficient and show the superimposed influences between strata, three experimental schemes are set up. As shown in Table 2, the soft rock in Scheme 1 reaches 80%, which means the overall lithology between the key stratum and the coal seam is relatively soft. However, the hard rock in Scheme 3 reaches 80%, which means the overall lithology between the key stratum and the coal seam is relatively hard.

According to Table 2, the influences of various factors on KSDD are studied in three schemes. Each scheme selected mining height (M), buried depth (D), and interlayer spacing (H) as the research object. Then, three levels are obtained. The final three factors and three levels' experimental scheme is shown in Table 3.

4. Results and Analysis

4.1. The Experimental Results. The Box-Behnken in Design-Export [27] is used to obtain the experimental design table. The KSDD of each scheme is calculated by the calculation system, and the results are shown in Table 4. In addition, the response surface functions of KSDD with the three kinds of lithology matching schemes are obtained as follows.

(1) Soft:

$$Y_1 = 0.213X_1 + 0.128X_2 - 0.3525X_3 + 0.0502X_1X_2 - 0.2543X_1X_3 - 0.1518X_2X_3 + 0.0081X_1^2 - 0.0049X_2^2 + 0.02531X_3^2 + 7.25(R^2 = 0.96). \quad (4)$$

(2) Medium:

$$Y_1 = 0.1316X_1 + 0.0791X_2 - 0.218X_3 + 0.0312X_1X_2 - 0.157X_1X_3 - 0.094X_2X_3 + 0.0051X_1^2 - 0.0029X_2^2 + 0.1569X_3^2 + 4.48(R^2 = 0.96). \quad (5)$$

(3) Hard:

$$Y_1 = 0.0184X_1 + 0.0184X_2 - 0.0406X_3 + 0.0045X_1X_2 - 0.0227X_1X_3 - 0.0272X_2X_3 + 0.0003X_1^2 - 0.0009X_2^2 + 0.0456X_3^2 + 1.28(R^2 = 0.96). \quad (6)$$

TABLE 1: Value of lithological strength coefficient.

Lithology	Tensile strength R_{ti} (MPa)	Bulking factor K_{Pi}	Lithological strength coefficient α
Soft	1	1.2	1.2
Medium	3	1.3	3.9
Hard	5	1.4	7.0

TABLE 2: Value of lithology proportion coefficient.

Scheme number	Lithology ratio			Lithology proportion coefficient
	Soft (%)	Medium (%)	Hard (%)	
1 (soft)	80	10	10	2.05
2 (medium)	10	80	10	3.94
3 (hard)	10	10	80	6.11

TABLE 3: Three factors and three levels' design.

Factors	Levels		
	-1	0	1
Mining height (M) (m)	1	3	5
Buried depth (D) (m)	300	500	700
Interlayer spacing (H) (m)	20	40	60

The goodness-of-fit (R^2) of three schemes are close to 1, so the three regression models are significant.

4.2. The Analysis of Variance. The results of response surface variance are shown in Table 5.

In response surface experiment, the significance of each factor in the regression model is related to P valued. If $P < 0.05$, it means that the factor is significant, otherwise, it is not significant. In addition, if the F valued is larger, it means that the factor has a greater impact on the dependent variable [28, 29].

As shown in Table 5, it can be seen that the three factors are significant because P valued of three factors are more than 0.05. However, when the lithology proportional coefficient increases, the significance of the model decreases. Moreover, by comparing the F valued with three schemes, the influence order of each factor on KSDD can be obtained as follows: interlayer spacing > mining height > buried depth.

4.3. The Analysis of Single Factor. In order to more intuitively analyse the influence of each factor on KSDD, the relationships between each factor and the value of KSDD are obtained as shown in Figures 6–8.

4.3.1. Influences of Mining Height. As shown in Figure 6, the values of KSDD are linearly positively correlated with the mining height. That is to say, the increase of mining height increases the disturbance effect on the key stratum. In addition, the range of KSDD between 1 m and 5 m is 0.238 in (a), the range 1 m and 5 m is 0.147 in (b), and the range between 1 m and 5 m is 0.043 in (c). It can be inferred that, as the lithology proportion coefficient increases, the impacts' range of mining height changes on the key stratum decreases.

TABLE 4: Response surface calculation results.

Scheme number	Input			Output		
	Mining height (M)	Buried depth (D)	Interlayer spacing (H)	KSDD (φ) (soft)	KSDD (φ) (medium)	KSDD (φ) (hard)
1	1	700	40	7.152	4.421	1.286
2	3	700	20	8.175	5.054	1.470
3	1	300	40	7.106	4.393	1.278
4	3	300	60	7.117	4.400	1.280
5	3	500	40	7.246	4.479	1.303
6	5	500	60	7.200	4.451	1.295
7	3	500	40	7.246	4.479	1.303
8	1	500	20	7.306	4.517	1.314
9	3	700	60	7.179	4.438	1.291
10	3	500	40	7.246	4.479	1.303
11	1	500	60	7.097	4.387	1.276
12	5	500	20	8.426	5.209	1.515
13	5	700	40	7.493	4.632	1.347
14	3	500	40	7.246	4.479	1.303
15	5	300	40	7.246	4.479	1.303
16	3	500	40	7.246	4.479	1.303
17	3	300	20	7.506	4.640	1.350

TABLE 5: Variance results of the regression model.

Scheme number	Origins	Sum of squares	Freedom	Mean square	F valued	P valued
1 (soft)	Model	2.12	9	0.2357	17.72	0.0005
	Mining height	0.363	1	0.363	27.29	0.0012
	Buried depth	0.1311	1	0.1311	9.85	0.0164
	Interlayer spacing	0.9941	1	0.9941	74.73	0.0001
	Residual error	0.0931	7	0.0133		
	Summation	2.21	16			
2 (medium)	Model	0.8113	9	0.0901	17.7	0.0005
	Mining height	0.1386	1	0.1386	27.22	0.0012
	Buried depth	0.0501	1	0.0501	9.84	0.0165
	Interlayer spacing	0.3802	1	0.3802	74.67	0.0001
	Residual error	0.0356	7	0.0051		
	Summation	0.8469	16			
3 (hard)	Model	0.0684	9	0.0076	17.54	0.0005
	Mining height	0.0038	1	0.0038	8.65	0.0217
	Buried depth	0.0019	1	0.0018	4.15	0.0809
	Interlayer spacing	0.0088	1	0.0088	20.3	0.0028
	Residual error	0.003	7	0.0004		
	Summation	0.0715	16			

4.3.2. *Influences of Buried Depth.* As shown in Figure 7, the buried depth of coal seam has a positive linear correlation with KSDD. To be specific, the increase of buried depth increases the disturbance effect on the key stratum. In addition, the range of KSDD between 300 m and 700 m is 0.143 in (a), the range 300 m and 700 m is 0.088 in (b), and the range between 300 m and 700 m is 0.026 in (c). It can be inferred that, as the lithology proportion coefficient increases, the impacts of buried depth changes on the key stratum decrease.

4.3.3. *Influences of the Interlayer Spacing.* As shown in Figure 8, the values of KSDD are negatively correlated with the interlayer spacing. That is to say, the increase of interlayer spacing decreases the disturbance effect on the key

stratum. Then, when the value of interlayer spacing is less than 30 m, the influence is more severe. However, when the value of interlayer spacing is more than 50 m, the disturbance effects on the key stratum tend to be gentle. In addition, as the lithology proportion coefficient increases, the impacts of interlayer spacing changes on the key stratum decrease.

4.3.4. *Influences of Disturbance Influence Coefficient.* As shown in Figure 9, with the increase of the disturbance influence coefficient, the impact on the key stratum decreases. However, when the disturbance influence coefficient increases to a certain value, the decrease of KSDD tends to be gentle. And, when the disturbance influence coefficient is less than 10, the impact on the key stratum is more serious,

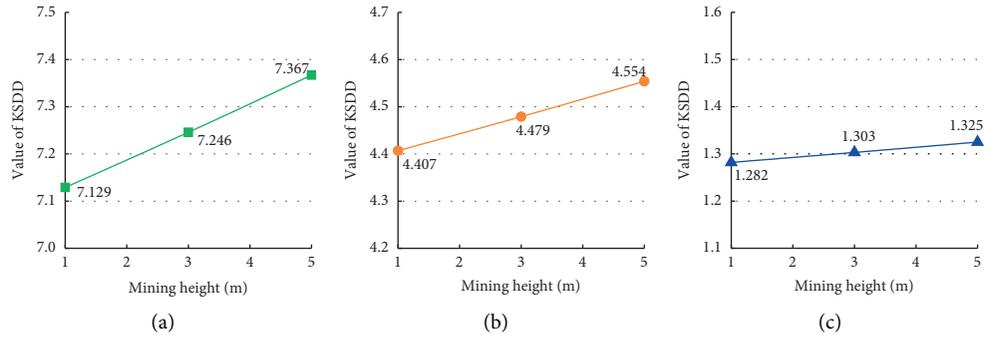


FIGURE 6: Impacts of mining height with different lithology proportion coefficients on the key stratum. (a) Soft. (b) Medium. (c) Hard.

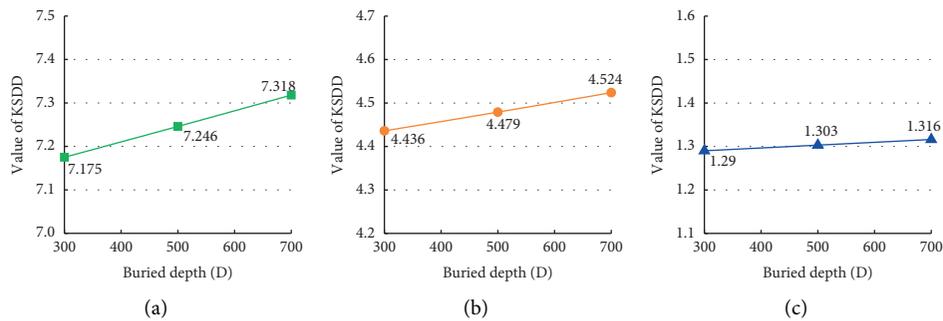


FIGURE 7: Impacts of buried depth with different lithology proportion coefficients on the key stratum. (a) Soft. (b) Medium. (c) Hard.

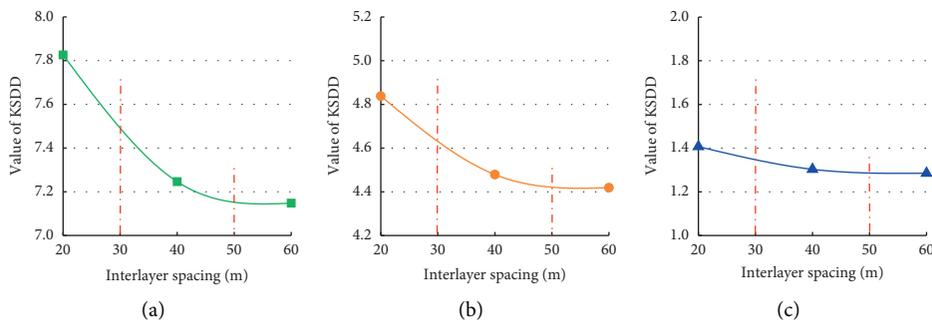


FIGURE 8: Impacts of interlayer spacing with different lithology proportion coefficients on the key stratum. (a) Soft. (b) Medium. (c) Hard.

but when the disturbance influence coefficient is more than 10, the impact is gentle. In addition, as the lithology proportion coefficient increases, the curve gradually becomes gentle. That is to say, the increase of lithology proportion coefficient reduces the influence range of the disturbance influence coefficient.

4.3.5. *Influences of Interburden-to-Overburden.* Similarly, with the increasing values of interburden-to-overburden, the impacts on the key stratum decrease, as shown in Figure 10. However, when the value of interburden-to-overburden increases to a certain value, the decrease of KSDD tends to be gentle. And, when the value of interburden-to-overburden is less than 0.06, the impact on the key stratum is more serious, but when the disturbance influence coefficient is more than 0.06, the impact is gentle. In addition, as the lithology

proportion coefficient increases, the curve gradually becomes gentle. That is to say, the increase of lithology proportion coefficient reduces the influence range of interburden-to-overburden.

In general, the impacts of disturbance influence coefficient and interburden-to-overburden on KSDD are roughly similar. However, compared with the disturbance influence coefficient, the impact of interburden-to-overburden on the key stratum is relatively small. It further shows that the impact of buried depth on the key stratum is less than mining height.

4.4. *The Analysis of Multifactors.* The KSDD is affected not only by the single factor (mining height, buried depth, interlayer spacing, and lithology proportional coefficient) but also by the interaction of factors. Therefore, in order to

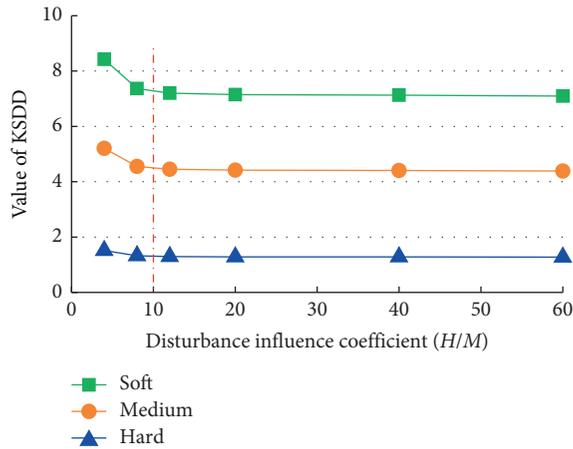


FIGURE 9: Impacts of disturbance influence coefficient on the key stratum.

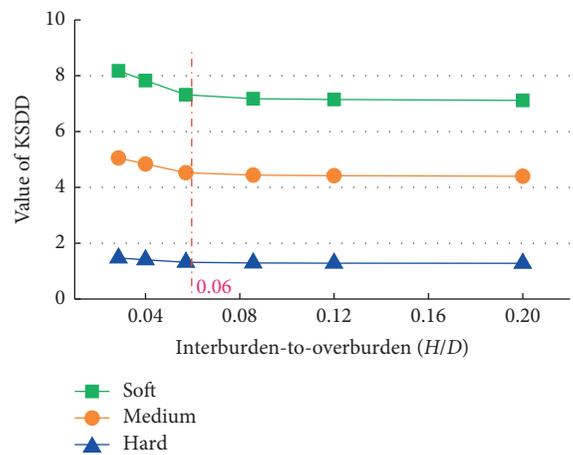


FIGURE 10: Influence of interburden-to-overburden on disturbance degree of the key stratum.

explore the impacts of the interaction between factors on the key stratum, based on the calculation results of KSDD, the 3D response surfaces of each factor interaction are obtained (Figures 11–13).

4.4.1. Interaction between Mining Height and Buried Depth on Key Stratum. As shown in Figure 11, with the increase of mining height and burial depth, the response surface becomes steeper, which indicates that the impacts on the key stratum increase. However, with the increase of the lithology proportion coefficient, the response surface gradually tends to be gentle. That is to say, the increase of lithology proportion coefficient decreases the range of impacts by mining height and buried depth on the key stratum. In addition, according to the distribution trend of contour, with the increase of buried depth, the disturbance effect of mining height on the key stratum is strengthened.

4.4.2. Interaction between Mining Height and Interlayer Spacing on Key Stratum. As shown in Figure 12, with the increase of interlayer spacing and the decrease of mining

height, the response surface gradually becomes gentle, which indicates that the impacts on the key stratum decrease. However, with the increase of the lithology proportion coefficient, the response surface gradually tends to be gentle. That is to say, the increase of the lithology proportion coefficient decreases the range of impacts by interlayer spacing and mining height on the key stratum. In addition, according to the distribution trend of contour, the impacts on the key stratum is the most severe when the interlayer spacing is within 30 m. Therefore, when the key stratum is close to the coal seam, the mining height can be appropriately reduced to slow down the disturbance effect of coal mining on the key stratum.

4.4.3. Interaction between Buried Depth and Interlayer Spacing on Key Stratum. As shown in Figure 13, with the increase of interlayer spacing and the decrease of coal seam buried depth, the response surface gradually becomes gentle, which indicates that the impacts on the key stratum decrease. However, with the increase of lithology proportion coefficient, the response surface gradually tends to become gentle. That is to say, the increase of lithology proportion coefficient decreases the range of impacts by interlayer spacing and buried depth on the key stratum. In addition, according to the distribution trend of contour, it can be seen that, with the increase of buried depth, the range of impacts by interlayer spacing on the key stratum increases. Therefore, when coal seam is in the deep area or the coal seam is close to the key stratum, the key stratum is more seriously affected by coal seam mining. And the method of backfilling can be used to reduce the disturbance effect of coal seam mining on the key stratum.

5. Engineering Verification

Based on the geological data of Longde Coal Mine [30], Yuhua Coal Mine [31], Da'anshan Coal Mine [32], Qianjiaying Coal Mine [25], and Fangezhuang Coal Mine [33], the values of KSDD in each mining area is calculated by the calculation system of KSDD. The results are shown in Table 6.

As shown in Table 6, when the buried depth and interlayer spacing are basically the same, the values of KSDD are affected by mining height and lithology proportion coefficient. Therefore, roof management should be strengthened in areas with large mining height to prevent roof fall and other disasters caused by mining height increase. When the mining height and interlayer spacing are basically the same, the values of KSDD are mainly affected by the buried depth and the lithology proportion coefficient. Therefore, when mining in Yuhua Coal Mine and other areas with large buried depth, the key stratum is more likely to be destroyed, which makes the overlying strata more difficult to control and easily bring disasters such as rock burst. When the lithology proportion coefficient decreases, the values of KSDD are greatly affected by the changes of mining height, buried depth, and interlayer spacing. That is to say, when there is

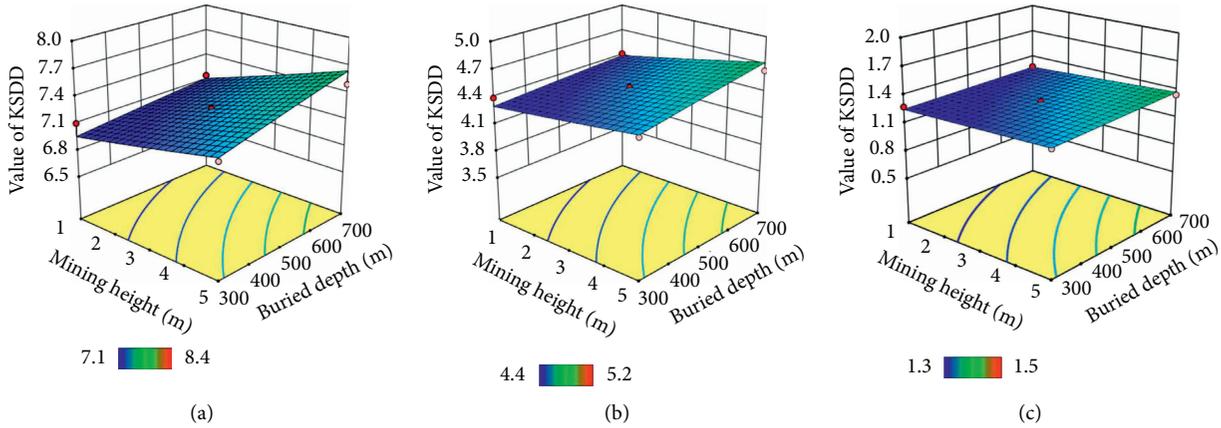


FIGURE 11: 3D response surface of interaction between mining height and buried depth. (a) Soft. (b) Medium. (c) Hard.

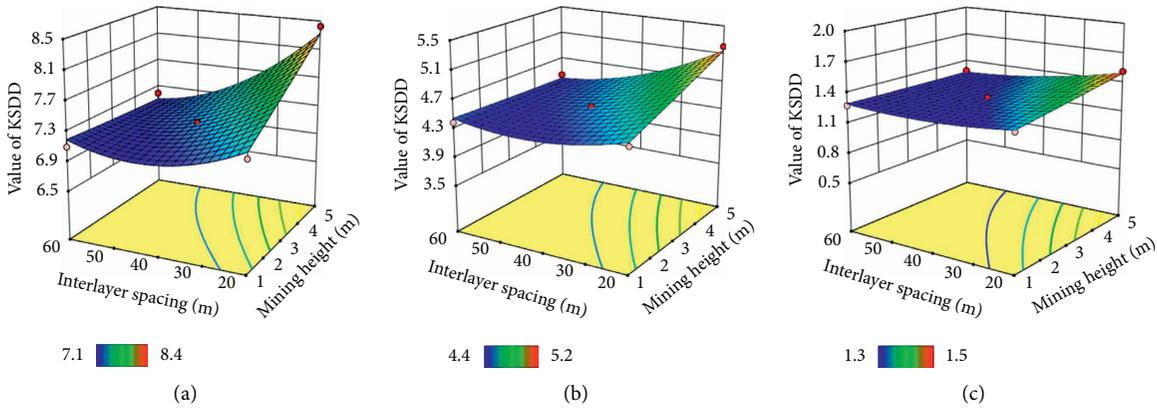


FIGURE 12: 3D response surface of interaction between mining height and interlayer spacing. (a) Soft. (b) Medium. (c) Hard.

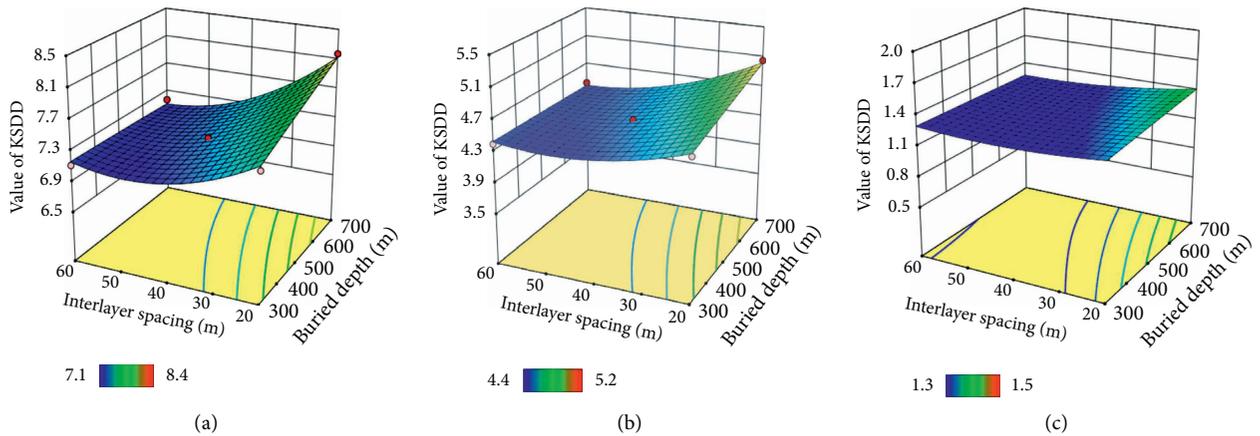


FIGURE 13: 3D response surface of interaction between buried depth and interlayer spacing. (a) Soft. (b) Medium. (c) Hard.

less intermediate hard rock, the changes of mining height, buried depth, and interlayer spacing need to be paid attention to, which will lead to more damage to the key

stratum. In general, the above rules are basically consistent with the actual situation, which further verifies the above experimental results.

TABLE 6: Statistics of KSDD in each mine.

Number	Name of mine	Mining height M (m)	Buried depth D (m)	Interlayer spacing H (m)	Intermediate stratum		Disturbance degree of key stratum
					Lithology	Percentage (%)	
1	Longde	3.96	120	80	Sandstone Mudstone	65.97 34.03	2.823
2	Yuhua	6.87	600	20	Siltstone Mudstone Fine sandstone	33.00 2.50 67.50	2.566
3	Da'anshan	2.23	500	10	Siltstone Mudstone	65.00 35.00	6.64
4	Fangezhuang	3.16	500	15	Siltstone Fine sandstone	35.00 65.00	4.512
5	Qianjiaying	2.3	500	14	Carbonaceous mudstone Siltstone	19.70 80.30	3.138

6. Conclusion

Synthesizing the experiment designed of response surface, calculation results of KSDD, and analyses of single factor and multifactors, the following main conclusions are drawn:

- (1) Though the analysis of the key stratum affected by several geological factors, the definition of “disturbance degree of key stratum” (KSDD) was proposed. To be specific, KSDD is the degree of disturbance caused by coal seam mining on the key stratum. Based on the calculation formula of KSDD, the calculation system is developed. And, the value of KSDD is quantified by the value among 0 to 10. In addition, the response plane method is used to design the experiment of three kinds of lithology proportional coefficient with a different mining height, buried depth and interlayer spacing. The response surface regression models of three lithology proportional coefficients are established.
- (2) By analysing the disturbance effect of a single factor on the key stratum and its significance, the following are found. ① The order of influence intensity of each factor on the KSDD is as follows: interlayer spacing > mining height > buried depth. ② Mining height and buried depth are positively correlated with the value of KSDD. ③ The interlayer spacing is negatively correlated with KSDD, but when the interlayer spacing increases to a certain value, the influence range of KSDD tends to be small.
- (3) The KSDD is affected not only by a single factor but also by the interaction of various factors. That is to say, with the increase of buried depth, the impacts of mining height on the key stratum increase. And, with the decrease of interlayer spacing, the disturbance effects of mining height on the key stratum are more severe. In addition, with the increase of buried depth, the change of interlayer spacing increases the influence range of KSDD. However, with the increase of lithology proportional coefficient, the influence range of KSDD decreases with the three factors.

- (4) The actual geological data of five mines are selected to calculate the value of KSDD. And, the variation law of KSDD in each mine is analysed. The calculation rules of KSDD of five mines further verified the above experimental results, which provide some reference and theoretical basis for the management of the roof and the design of backfilling parameters.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

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

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