

# Mining scheme design for super-high water backfill strip mining under buildings: a Chinese case study

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**Abstract** Considerable coal resources are buried under buildings in No. 5 mining area of Hengjian Coal Mine, which greatly shortens its service life. Working on the premise that the degree of mining-induced damage to surface buildings should not exceed the protective indicator, the mine proposes to use super-high water backfill technology so as to ensure maximum exploitation of these resources. However, according to monitoring of observations of surface movement in the first-mined 2515 working face, mining-induced damage to the surface buildings will exceed level I if this technology is also used to exploit other working faces. A technology combining super-high water backfilling with strip mining is proposed. Numerical simulation is used to study the influence of different retaining pillar widths on surface subsidence characteristics. A reasonable design of these combined technologies is achieved based on the numerical simulation and theoretical analysis. Predicted results indicate that the designed scheme can ensure the safety of the surface buildings. These research results provide a reasonable and reliable technical solution for mining of coal resources buried under buildings.

**Keywords** Super-high water material · Backfill strip mining · Mining under buildings · Numerical simulation · Mining scheme

## Introduction

China is an energy superpower and a large energy consumer. Coal is the main source of China's energy and provides the basis of the energy infrastructure necessary for its long-term rapid economic growth (Lin and Liu 2010). Many coal resources are, however, buried under buildings, railways, and water bodies. It is estimated that the resources of state-owned coal mines located beneath such structures approach 13.8 billion tons, of which some 9.5 billion tons (69 %) is buried under buildings. At present, the coal buried under buildings and other structures in the Kailuan, Fengfeng, Jinniu, and Jingkuang Groups has reached 3.4 billion tons, accounting for 42 % of coal reserves in Hebei province (Zhao 2008). Hengjian Coal Mine, located in Handan City, Hebei province, also has considerable coal resources located beneath buildings in No. 5 mining area, which not only greatly shortens the service life of the mine but also restricts production planning and increases the difficulty of subsequent mining activities.

Various mining methods have been applied to control surface subsidence when extracting coal resources buried under buildings and other natural and built structures. These include strip mining (Guo et al. 2011, 2016; Zhang et al. 2011a, b; Xu et al. 2012), harmonic mining (Yu et al. 2004), and backfill mining (Guo et al. 2009, 2014; Huang et al. 2011; Zha et al. 2011; Xu et al. 2013; Zhang et al. 2014, 2015). The basic practice of strip mining divides the areas to be exploited into formal stripped shapes. The mining operation exploits one strip at a time, maintaining

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one un-mined strip. The remaining strip coal pillar can usually support the load of the overlying strata, allowing slight, even surface movement and deformation; however, the coal recovery ratio is very low, and coal resources are excessively wasted. Harmonic mining and deformation control technology comprises a reasonable layout of the working faces in relation to the positions of various protected objects to ensure that the resulting deformation that occurs on mining is less than the allowable deformation of the protected objects. Harmonic mining is difficult to achieve because it is limited by the considerable requirement of organization and geological and mining conditions, and the surface subsidence-reducing coefficient is limited. Backfill mining uses filling materials sourced from outside the mining area, such as sands, stones, slags, and ashes, to fill the goaf directly or to make pastes to fill the goaf; the supportive effect of the filling materials can reduce roof subsidence and caving. In recent years, backfill mining has been widely used to exploit coal resources buried under buildings. Technologies such as early hydraulic backfilling, cemented backfilling, paste backfilling (Archibald et al. 1999), gangue backfilling (Guo et al. 2014; Zhang et al. 2015), and high-water material consolidation tailings backfilling used in metal mines are crucial to reducing surface subsidence and sudden underground disasters.

To reduce mining costs and save the use of filling materials, super-high water backfill (Feng 2009) has been tested and used on a large scale as a new mining technology. Results achieved in practice show that the application of super-high water backfill can not only reduce mining costs but also protect surface buildings. Hengjian Mine, therefore, plans to use this technology to maximally exploit coal resources buried under buildings on the premise that the degree of mining-induced damage to surface buildings will not exceed their protective indicator. Considering that there is relatively little research concerning surface subsidence characteristics of super-high water backfill mining, the 2515 working face was selected as the first mining face; a surface movement observation station was installed above the face to enable the surface subsidence characteristics during super-high water backfill mining to be studied.

The monitoring results for this first face, however, showed that the degree of mining-induced damage to the surface buildings would exceed level I if the super-high water backfill mining was also used to exploit other working faces. To continue to exploit other working faces, it was proposed to combine super-high water backfill mining with strip mining. Because there is no research into the surface subsidence characteristics of super-high water backfill strip mining, numerical simulation was used to study this behavior. The optimum width of the retaining coal pillar was determined by numerical simulation and

theoretical analysis, enabling a mining scheme using super-high water backfill strip mining under buildings to be designed. These research results can improve the production life and recovery ratio of Hengjian Coal Mine as well as provide important references for other similar coal mines.

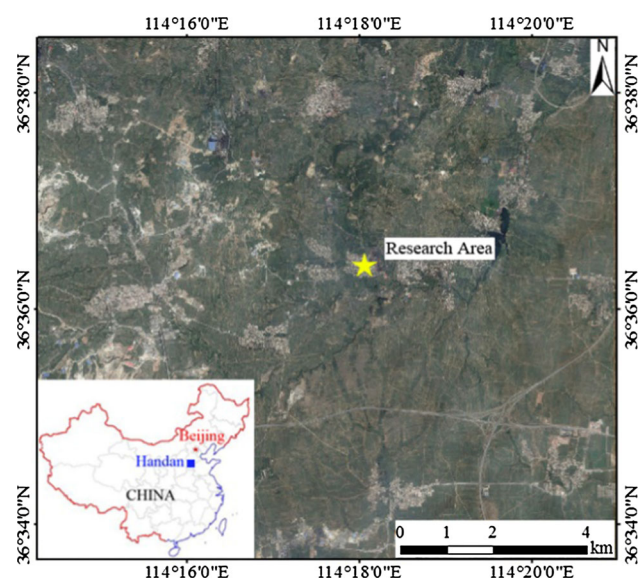
## Overview of region and super-high water backfill mining technology

### Region

The mine field of Hengjian Mining Company is located in East Jizhuang Village, Handan City, and West Handan City, Hebei Province. The mining area is about 15 km from Handan. The geographic coordinates of the center of the mine field are  $36^{\circ}36'23''$  N and  $114^{\circ}17'45''$  E, as shown in Fig. 1.

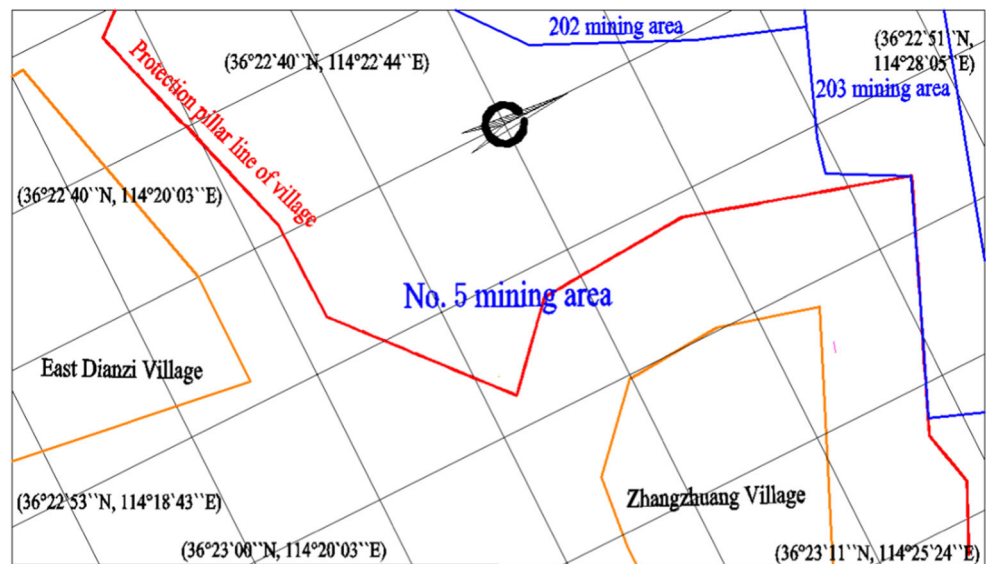
No. 5 mining area is situated to the south of Hengjian Mining Company. It is adjacent to the 202 mining area in the west and the 203 mining area in the north, as shown in Fig. 2. Its inclination length is 800 m, the length in the north–south direction is 1000 m, and the mining area is about  $770,298$  m<sup>2</sup>. The No. 2 and No. 4 coal seams are available for exploitation, and the No. 2 coal seam is currently being mined. The average mining thickness of the No. 2 coal seam is 4.41 m, the mining elevation is between  $-20$  and  $-220$  m, and the buried depth is between 200 and 400 m.

The 2515 first-mined face is located to the west of Zhangzhuang village, which comprises loess terraced fields and village buildings. Its ground elevation is between 160



**Fig. 1** Location of Hengjian Coal Mine

**Fig. 2** Mining area distribution



and 180 m. The No. 2 seam is the main mining seam and has an elevation between  $-200$  and  $-180$  m. The 2515 working face has a mining thickness of 4.4 m, a dip angle of  $5^\circ$ , the length along the strike is 386 m, and the inclination width is 100 m. Long-wall retreated comprehensive mechanization full-seam mining was adopted for the working face, while pocket super-high water backfill mining was used to control the roof.

**Super-high water backfill mining technology**

Super-high water backfill material was invented by Feng (2009). The material comprises two main ingredients and small amounts of compound accelerators and composite retarders. Ingredient A mainly contains bauxite and super-retarding dispersant. Ingredient B is mainly gypsum and a compound accelerator. Grout A is made up from Ingredient A and water; Grout B is made up from Ingredient B and water, where the water content exceeds 95 %. Grouts A and B are mixed before filling the goaf. The mixed grout agglutinates after 30 min in the goaf and reaches its final condensation intensity (1 MPa) after seven days. Industrial experiments at Tianzhuang and Taoyi coal mines have used this super-high water material backfill mining technology and proved that surface subsidence can be effectively controlled (Feng 2009; Xu et al. 2013).

**Surface movement characteristics of super-high water backfill mining**

To meet mine production needs, it is necessary to study the influence of super-high water backfill mining on surface movement. A surface movement monitoring station was

therefore laid along the strike and inclination of the 2515 working face in No. 5 mining area of Hengjian Coal Mine, to monitor surface movement and deformation and determine the surface subsidence characteristics under these mining conditions.

**Design of the surface movement observation station**

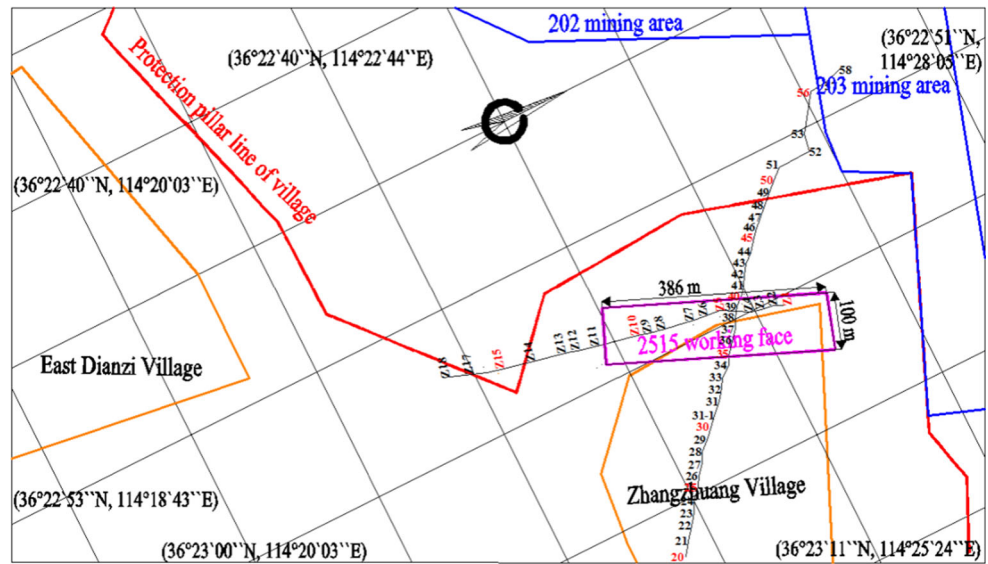
The strike and inclination observation lines along the main section of the 2515 working face were laid out according to the requirements of the geological and mining conditions and relevant regulations, location of the working face, terrain and surface conditions above the goaf, long-term storage of monitoring data, and the cost of land occupation. Global positioning system (GPS) technology and station instruments were used for the horizontal control survey; fourth-grade leveling was used for the vertical control survey. Tie, full, and daily surveys of the observation station were conducted at specified intervals and observation accuracies.

The strike line of observation passes through farmland. In light of the relationship between industry and agriculture and the protection of monitoring points, the strike line of observation was laid out near ridges along the main section. The inclination monitoring line was laid out along the village road that runs almost parallel to the main inclination. Figure 3 shows the layout of the observation lines.

**Analysis of surface movement characteristics of super-high water backfill mining**

Mining of the 2515 working face began on November 26, 2012, and ended on August 11, 2013. The data of November 2013 were therefore used to determine the final

**Fig. 3** Layout of surface movement observation station of the 2515 mining face



surface subsidence caused by mining of this face. Processing of the observation data yielded the final subsidence curves along the strike and inclination directions, as shown in Fig. 4.

Figure 4 shows that the surface movement characteristics of super-high water backfill mining are same as for full-caving mining. The maximum subsidence of the 2515 working face was 265 mm, accounting for 6.0 % of the mining thickness. This proves that super-high water backfill mining can effectively control surface subsidence. The maximum movement of the actual surface and the deformation of the 2515 working face were obtained by processing the monitoring data, as shown in Table 1. The values of the maximum surface inclined deformation  $i_n$ , maximum surface curvature deformation  $K_n$ , and maximum surface horizontal deformation  $\epsilon_n$  can be obtained from Eqs. (1), (2), and (3), respectively.

Maximum surface inclined deformation:

$$i_n = \frac{W_n - W_{n-1}}{L_{n \sim n-1}} \quad (1)$$

where  $i_n$  is the maximum surface inclined deformation;  $W_{n-1}$  is the subsidence of a point near the point of maximum surface subsidence;  $W_n$  is the maximum surface subsidence; and  $L_{n \sim n-1}$  is the horizontal distance between points  $n$  and  $n - 1$ .

Maximum surface curvature deformation:

$$K_{n+1 \sim n \sim n-1} = \frac{i_{n+1 \sim n} - i_{n \sim n-1}}{\frac{L_{n+1 \sim n} + L_{n \sim n-1}}{2}} \quad (2)$$

where  $K_{n+1 \sim n \sim n-1}$  is the maximum surface curvature deformation;  $i_{n+1 \sim n}$  is the inclined deformation between points  $n + 1$  and  $n$ ;  $i_{n \sim n-1}$  is the inclined deformation between points  $n$  and  $n - 1$ ; and  $L_{n+1 \sim n}$  is the horizontal distance between points  $n + 1$  and  $n$ .

Maximum surface horizontal deformation:

$$\epsilon_n = \frac{U_n - U_{n-1}}{L_{n \sim n-1}} \quad (3)$$

where  $\epsilon_n$  is the maximum surface horizontal deformation;  $U_{n-1}$  is the surface horizontal movement of a point near the point of maximum surface maximum horizontal movement; and  $U_n$  is the maximum surface horizontal movement.

According to the above parameters, the full mining coefficient of the face can be calculated using the data provided in Sect. 2.1 (He et al. 1991):

Full mining coefficient along the inclination:  $n_1 = K_1 \times D_1/H_0 = 0.8 \times 100/360 = 0.22$ .

Full mining coefficient along the strike:  $n_3 = K_1 \times D_2/H_0 = 0.8 \times 386/360 = 0.86$ .

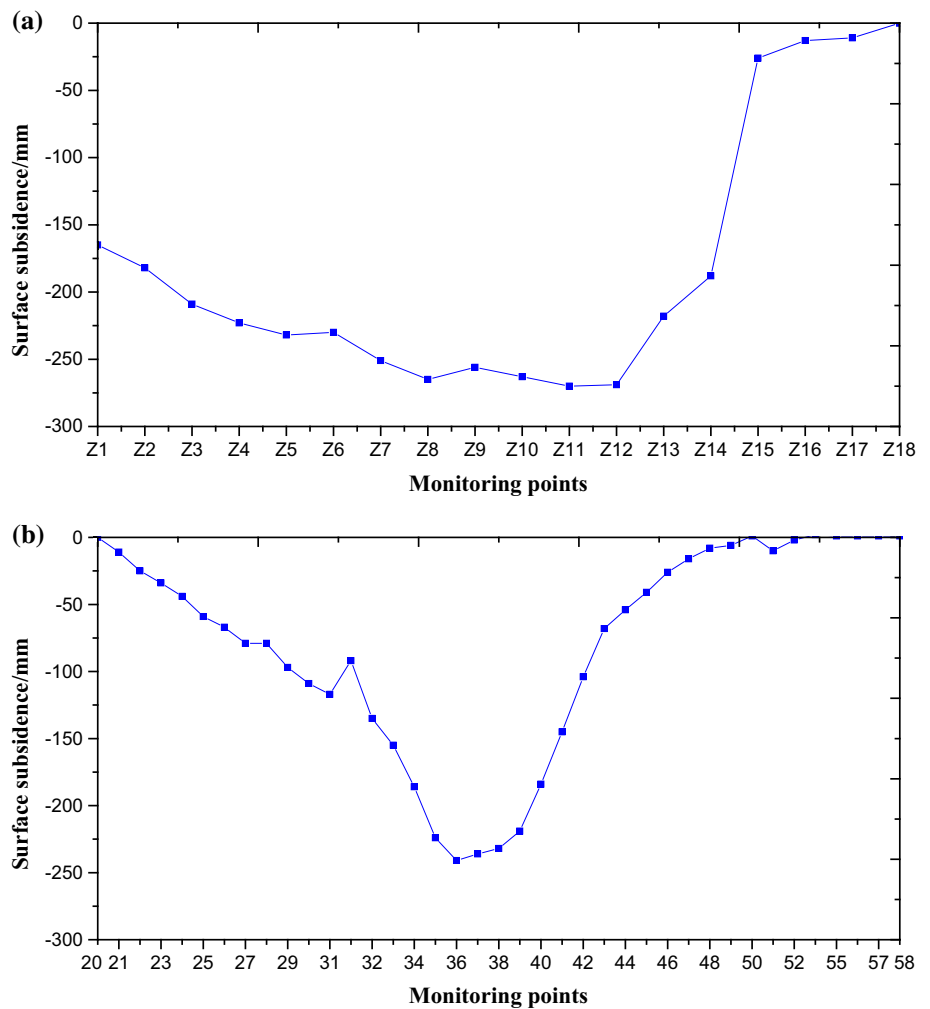
where  $K_1$  is a coefficient  $<1$ , the value of which is related to the geological conditions ( $K_1 = 0.8$ , in this case);  $D_1$  is the inclination length of the working face;  $D_2$  is the strike length of the working face; and  $H_0$  is the average mining depth.

From the above calculation, it is evident that the 2515 working face has not yet achieved complete mining both along the strike and along inclination.

### Surface movement characteristics of super-high water backfill strip mining

Although mining had not yet been completed along both the strike and inclination on the 2515 working face, the maximum surface horizontal deformation was 1.9 mm/m and the maximum inclined deformation was 2 mm/m. According to *Buildings, Water Bodies, Railways, and Main*

**Fig. 4** Final subsidence curves of strike and inclination observation lines. **a** Final subsidence curve of strike observation line. **b** Final subsidence curve of inclination observation line



**Table 1** Maximum surface movement and deformation values for the 2515 working face

| Surface subsidence (mm) | Horizontal movement (mm) | Inclined deformation (mm/m) | Horizontal deformation (mm/m) | Surface curvature (mm/m <sup>2</sup> ) |
|-------------------------|--------------------------|-----------------------------|-------------------------------|--|
| 265                     | 105                      | 2                           | 1.9                           | 0.06                                   |

*Roadway Unexploited Coal Pillars and Compressed Coal Mining Regulations*, the indicators for level I damage are that the horizontal deformation should not exceed 2 mm/m, and the inclined deformation should not exceed 3 mm/m. The continued use of super-high water backfill mining in the 2513, 2516, 2517, and 2521 working faces would therefore cause mining-induced damage of surface buildings to exceed level I. Maximum exploitation of coal resources is only permitted under the condition that damage to surface buildings is less than level I, so it was proposed to combine strip mining with backfill strip mining to exploit the coal resources buried under the buildings. Numerical simulation was used to analyze the influence of different retaining widths on pillar stress distribution and

surface subsidence characteristics, so as to provide a scientific basis for determining the retaining pillar width and designing a mining scheme.

**Establishing the numerical simulation and scheme design**

The strata for the model were based on the composition of the 2515 working face. The dip angle of coal seam was 5°, so it was considered horizontal. The mining thickness was 4.41 m. Fast Lagrangian analysis of continua 3D (FLAC3D) was adopted for establishing the numerical model, as shown in Fig. 5. The geometric dimensions of model were established based on the 2515, 2513, and 2517

working faces, the strike lengths of which were 386, 424, and 434 m, respectively, and the inclination lengths were 100, 83, and 120 m, respectively. In light of the boundary effect, the model dimensions should be larger than the actual working face dimensions: the model was 1200 m long, 1200 m wide, and 393 m high. The plan size of the grids was 10 m × 10 m, and the height varied slightly with the height of the rock strata. The model was divided into 547,200 zones and 717,409 grid points. Mohr–Coulomb was selected as the constitutive model. The initial geomechanical parameters selected were those of Taoyi Mine (Zhang 2012); the final values were fixed by parameter inversion based on measured data from the 2515 working face, as shown in Table 2 (Oreste 2005). The surface subsidence three-dimensional cloud figure is shown in Fig. 6.

The bottom boundary of the model was defined by  $u = v = w = 0$  (where  $u$  refers to the displacement in the  $x$ -direction,  $v$  is that in the  $y$ -direction, and  $w$  is that in the  $z$ -direction) for full constraint. The top of the model was a free boundary, and the left and right boundaries were constrained by horizontal displacement.

The numerical simulation aimed to study the influence of the width of the retaining pillar on surface subsidence and enable a reasonable determination of this width to be made. Five schemes were designed, with retaining widths of 0, 10, 20, 30, and 40 m; i.e., pillars of these widths were set between the 2513 and 2515 working faces and between the 2517 and 2515 working faces under the condition that the mining dimensions of the three working faces were maintained.

### Pillar stress distribution during backfill strip mining for different retaining pillar widths

Five calculation models were established according to the above five experimental schemes to analyze the effect of different retaining pillar widths on the pillar stress distribution during backfill strip mining. Data pertaining to the

pillar vertical stresses for different retaining widths were extracted from the simulation results: the stress distribution is shown in Fig. 7.

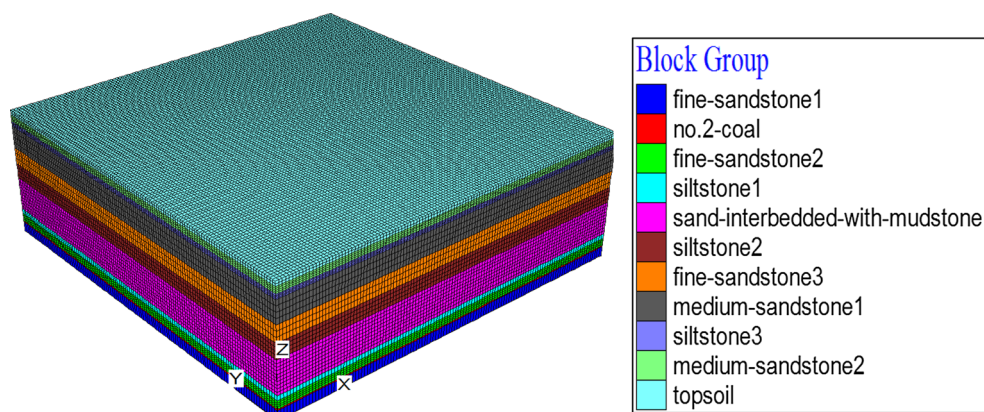
Figure 7 indicates that with an increase in the retaining width, the pillar vertical stress reduces, but the extent of the decrease differs: when the retaining width increased from 10 to 20 m, the pillar vertical stress decreased by 14.2 MPa; when the retaining width increased from 20 to 30 m, the stress decreased by 0.1 MPa; and when the retaining width increased from 30 to 40 m, the stress decreased by 1.3 MPa. Therefore, a coal pillar retaining width of 20 m between the working faces can effectively decrease pillar stress and guarantee stability of the pillar.

### Simulation and analysis of surface deformation for different retaining pillar widths

Figure 8 shows a cloud picture of the surface subsidence basins for different retaining pillar widths. This indicates that the extremes of the surface subsidence reduce and the extent of the basin is basically unchanged with increasing width. To determine a reasonable retaining width for controlling surface subsidence under the geological and mining conditions of Hengjian Coal Mine, curves of the surface subsidence along the main section were extracted from the five models, as shown in Fig. 9.

Figure 9 indicates that the extremes of the surface subsidence values reduce with increasing retaining width, but the extent of the decrease differs: as shown in Fig. 10, increasing the retaining width from 0 to 10 m decreased the surface subsidence by 279.8 mm; increasing the retaining width from 10 to 20 m decreased the surface subsidence by 35.3 mm; increasing the retaining width from 20 to 30 m decreased the surface subsidence by 28.0 mm; and increasing the retaining width from 30 to 40 m decreased the surface subsidence by only 18.98 mm. As indicated in Figs. 9 and 10, the coal pillar retaining width of 20 m between the working faces could effectively control surface subsidence.

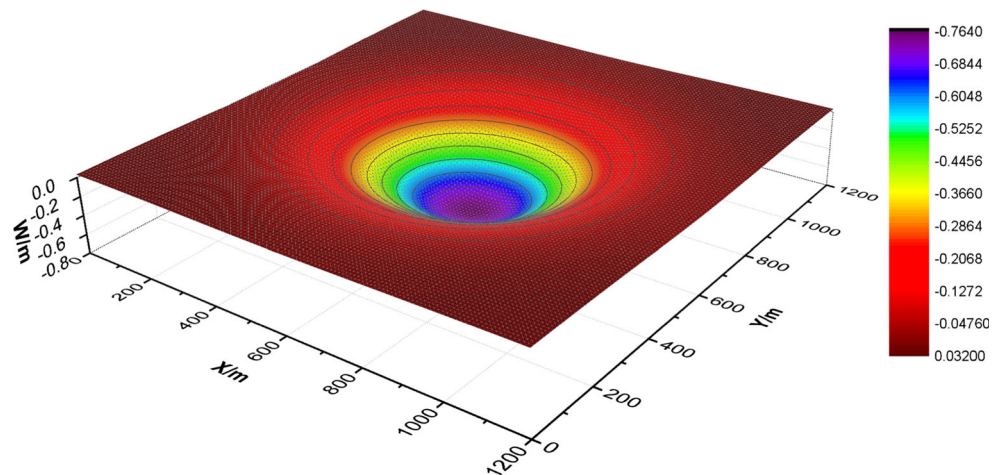
Fig. 5 Numerical model



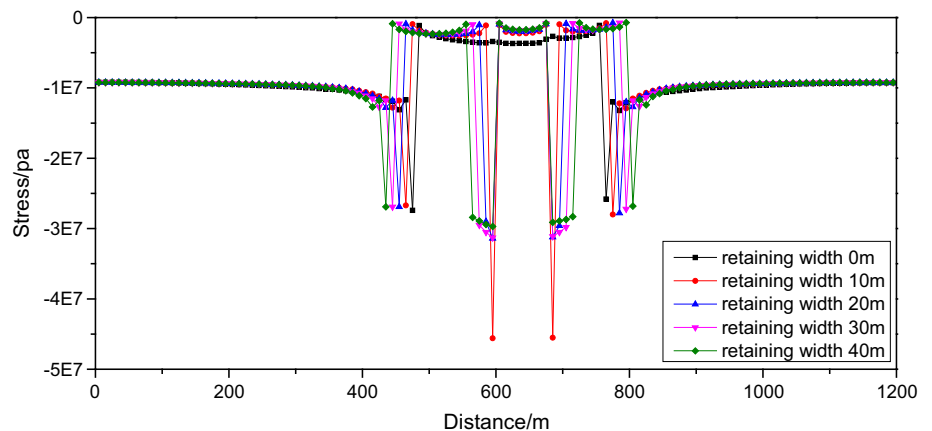
**Table 2** Strata distribution and geomechanical parameters

| Lithology                       | Elasticity modulus (GPa) | Poisson's ratio | Tensile Strength (MPa) | Cohesion (MPa) | Internal friction angle (°) | Thickness (m) | Model height (m) |
|---------------------------------|--------------------------|-----------------|------------------------|----------------|-----------------------------|---------------|------------------|
| Fine sandstone                  | 1.75                     | 0.29            | 0.81                   | 1.78           | 39                          | 20            | 20               |
| No.2 coal                       | 0.8                      | 0.3             | 0.44                   | 0.238          | 30                          | 4.41          | 24.41            |
| Fine sandstone                  | 1.75                     | 0.29            | 0.81                   | 1.78           | 39                          | 24.44         | 48.85            |
| Siltstone                       | 1.5                      | 0.29            | 0.81                   | 1.73           | 38                          | 15.51         | 64.36            |
| Sand inter-bedded with mudstone | 0.625                    | 0.29            | 0.51                   | 0.435          | 28                          | 103.7         | 168.06           |
| Siltstone                       | 1.5                      | 0.29            | 0.81                   | 1.73           | 38                          | 47.6          | 215.66           |
| Fine sandstone                  | 1.75                     | 0.29            | 0.81                   | 1.78           | 39                          | 51.3          | 266.96           |
| Medium sandstone                | 1.625                    | 0.29            | 0.75                   | 1.438          | 37                          | 69.2          | 336.16           |
| Siltstone                       | 1.5                      | 0.29            | 0.81                   | 1.73           | 38                          | 15.3          | 351.46           |
| Medium sandstone                | 1.625                    | 0.29            | 0.75                   | 1.438          | 37                          | 19.5          | 370.96           |
| Topsoil                         | 0.05                     | 0.4             | 0                      | 0.05           | 20                          | 15            | 385.96           |

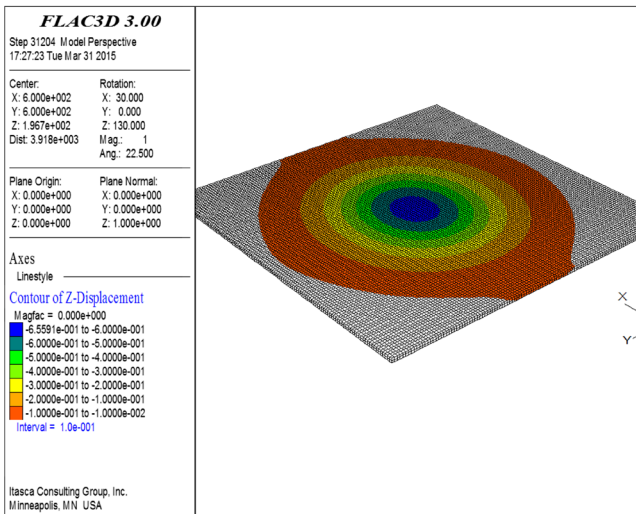
**Fig. 6** Surface subsidence three-dimensional numerical simulation (m)



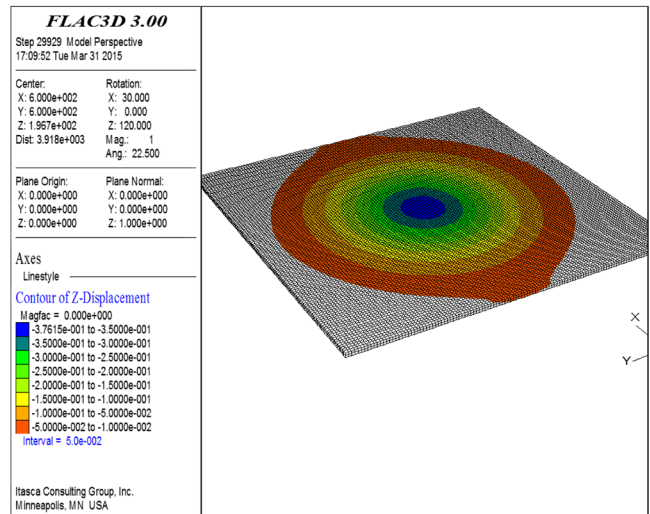
**Fig. 7** Pillar vertical stress distribution during backfill strip mining with different retaining pillar widths



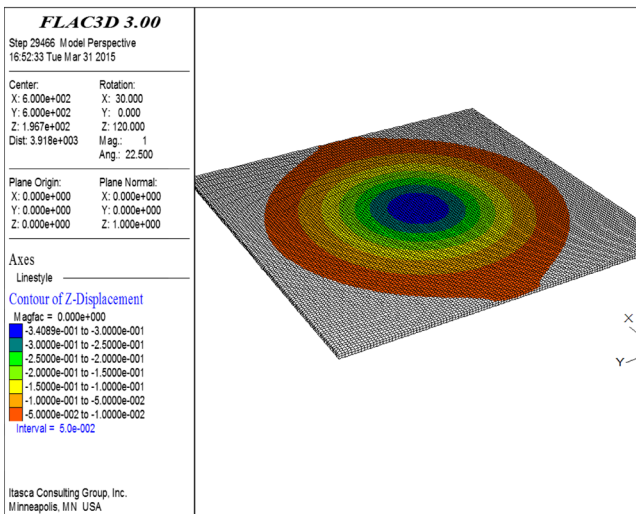
(a)



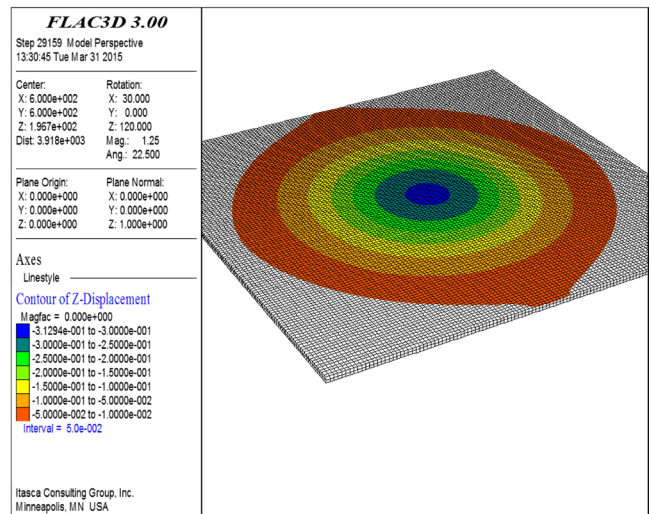
(b)



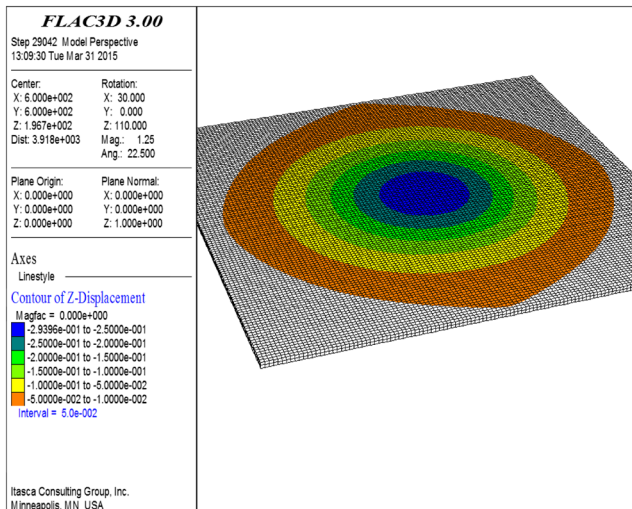
(c)



(d)



(e)





**Fig. 8** Surface subsidence basins for different retaining pillar widths. **a** 0 m retaining width. **b** 10 m retaining width. **c** 20 m retaining width. **d** 30 m retaining width. **e** 40 m retaining width

deformation is 2 mm/m, maximum surface curvature deformation is 0.2 mm/m<sup>2</sup>, and surface inclined deformation is 3.0 mm/m.

### Mining scheme design for super-high water backfill strip mining

#### Surface building conditions and protective indicators

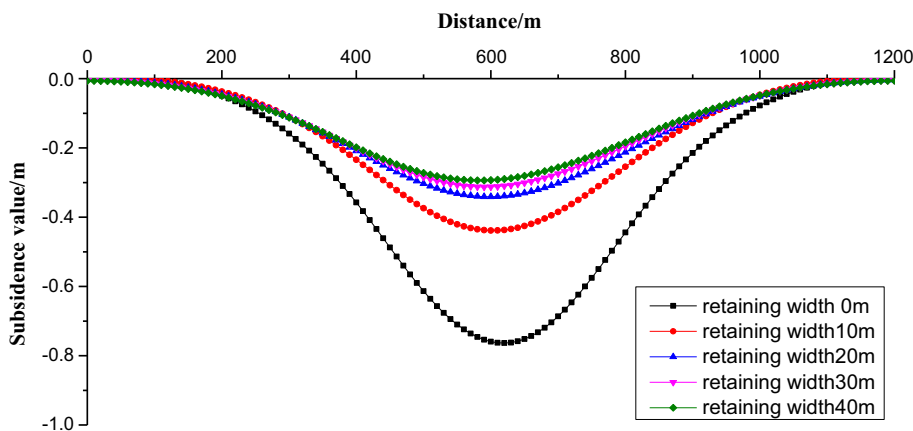
The surface of No. 5 mining area is situated in the north of East and West Dianzi Villages and to the west is Hengjian Company’s industrial square. Handan-Jizhuang Road passes through the central mining area. The houses in the village, most of which have one or two stories, have brick and concrete structures. Typical buildings are shown in Fig. 11. The conservation standards for exploitation under buildings in this area are that the surface horizontal

#### Mining scheme design

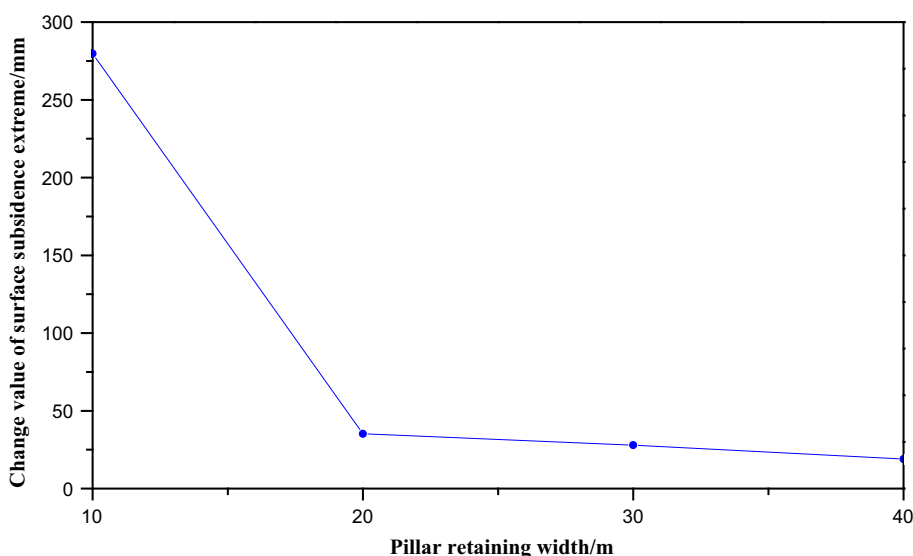
The mining and retaining widths of each working face were theoretical calculated according to the design requirements for strip mining. The concrete values can be seen in Tables 3 and 4. Considering that the influence of backfill strip mining on the surface is less than that of full-pillar mining, each working face’s exploitable area and numerical simulation results in Sect. 4, the mining width, and retaining width of working faces during backfill strip mining have been adjusted properly. The final values of retaining width are given in Table 4.

According to the specific geological and mining conditions in this area and technologies for mining coal resources under buildings, the following technical schemes

**Fig. 9** Surface subsidence curves of the main section for different retaining pillar widths



**Fig. 10** Relationship between change in value of surface subsidence extremes and retaining pillar width





**Fig. 11** Typical buildings above No. 5 mining area. **a** One-story house. **b** two-story houses

were designed by combining the above analysis results with a comprehensive contrast analysis. Super-high water backfill strip mining was used to exploit the protective coal pillar in villages in No. 5 mining area. The mining and retaining widths of the 2513 working face were 53 and 30 m, respectively; those of the 2516 and 2517 working faces were 80 and 40 m, respectively, and those of the 2521 working face were 63 and 30 m, respectively. Long-wall retreating comprehensive mechanization full-seam mining was used to exploit the coal resource outside the villages (2511 and 2519 working faces).

### Prediction of surface movement and deformation after exploitation of No. 5 mining area

According to the data obtained from Hengjian Coal Mine's surface movement observation station, its surface subsidence characteristics conform to a probability integral model. The mine's surface subsidence prediction and practice over the years indicate that the calculation precision by the probability integral method can meet the precision requirements of engineering design. Probability integral method was therefore adopted to predict surface movement and deformation following exploitation in No. 5 mining area. The *Mining Subsidence Prediction System*,

developed by the Mining Damage and Protection Research Institution of China University of Mining and Technology, was adopted. This system can be used for multiple arbitrarily shaped working faces and for static and dynamic prediction at random times and arbitrary surface points. The prediction results can be mapped.

Owing to space constraints, only the equivalent curve for surface subsidence in No. 5 mining area after exploitation is given according to the designed mining scheme, as shown in Fig. 12. Table 5 shows the maximum values of surface movement and deformation, and Table 6 shows the corresponding values for buildings.

Prediction results show that after exploitation according to the above schemes, the maximum surface subsidence of buildings in East Dianzi village is 160 mm, the maximum horizontal movement is 20 mm, the maximum horizontal deformation is 0.6 mm/m, the maximum inclined deformation is 0.9 mm/m, and the maximum curvature deformation is 0.012 mm/m<sup>2</sup>. Similarly, the corresponding values for Zhangzhuang village are 400, 90 mm, 0.8, 1.6 mm/m, and 0.012 mm/m<sup>2</sup>, respectively. The calculated results indicate that the above exploitation scheme can decrease the degree of damage to buildings in both East Dianzi and Zhangzhuang villages to less than that of level I and can ensure safe mining in No. 5 area.

**Table 3** Calculation of mining width

| Working face | Mining depth | Average mining depth | Max. mining width | Min. mining width | Pressure arch | Overlying strata | Filling strip mining comprehensive analyzed value |
|--------------|--------------|----------------------|-------------------|-------------------|---------------|------------------|---|
| 2513         | 351–362      | 357                  | 89                | 36                | 53.2          | ≤78              | 50  |
| 2516         | 347–390      | 369                  | 92                | 37                | 52.8          | ≤78              | 80  |
| 2517         | 364–390      | 377                  | 94                | 38                | 54.7          | ≤78              | 80  |
| 2521         | 297–340      | 319                  | 79                | 32                | 46.9          | ≤78              | 65  |

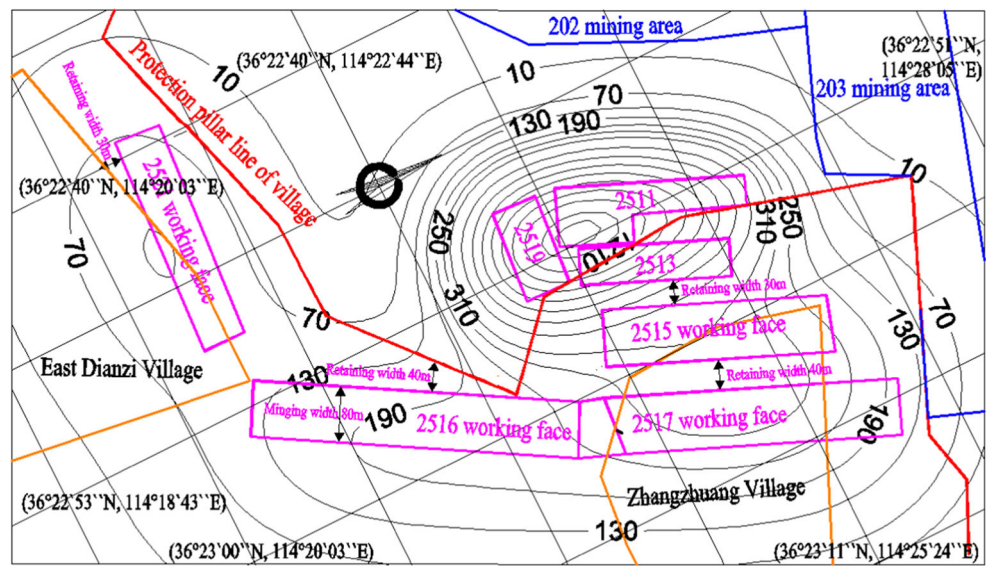
Unit: m

**Table 4** Calculation of retaining width

| Working face | Mining depth | Mining depth | Three-dimensional stress | Safety factor method | Empirical formula | Backfilling strip mining comprehensive analyzed value |
|--------------|--------------|--------------|--------------------------|----------------------|-------------------|---|
| 2513         | 50           | 351–362      | >24.7                    | 60                   | 43–47             | 30  |
| 2516         | 80           | 347–390      | >26.0                    | 84                   | 47–50             | 40  |
| 2517         | 80           | 364–390      | >26.0                    | 84                   | 47–50             | 40  |
| 2521         | 65           | 297–340      | >23.7                    | 70                   | 41–45             | 25  |

Unit: m

**Fig. 12** Surface subsidence curve of No. 5 mining area (mm)



**Table 5** Maximum value of surface movement and deformation

|                   | Subsidence (mm) | Horizontal movement (mm) | Inclination (mm/m) | Horizontal deformation (mm/m) | Curvature (mm/m <sup>2</sup> ) |
|-------------------|-----------------|--------------------------|--------------------|-------------------------------|--------------------------------|
| No. 5 mining area | 1390            | 347.5                    | 10                 | 9                             | 0.2                            |

**Table 6** Maximum value of surface movement and deformation of buildings

|                     | Subsidence (mm) | Horizontal movement (mm) | Inclination (mm/m) | Horizontal deformation (mm/m) | Curvature (mm/m <sup>2</sup> ) |
|---------------------|-----------------|--------------------------|--------------------|-------------------------------|--------------------------------|
| East Dianzi village | 160             | 20                       | 0.9                | 0.6                           | 0.012                          |
| Zhangzhuang village | 400             | 90                       | 1.6                | 0.8                           | 0.012                          |

**Safety measures for implementation of super-high water backfill strip mining**

To ensure that retained strip coal pillars and super-high water materials effectively support the load of overlying strata for a long time and that damage to surface buildings does not exceed the protective indicator after exploitation, the following rules should implemented.

1. During backfill strip mining, the designed widths of retaining and mining pillars should be strictly

followed. Over-exploitation should be prohibited. To ensure effective support and security of unexploited coal pillars, the retaining width of coal pillars should not be arbitrarily reduced.

2. The strength of coal pillars will reduce after disturbance. To maintain their integrity, roadways should not pass arbitrarily through unexploited coal pillars during mining.
3. Surface movement will greatly reduce after mining. To avoid short-term basin edges in the bottom of planned basins, mining should be continuous.

- During the entire surface movement process, regular inspections of surface buildings should be increased, especially near fault outcrops, so as to identify problems and take timeous remedial measures as necessary.

## Conclusions

The surface subsidence characteristics of super-high water backfill mining are studied based on measured data from the 2515 working face, and this super-high water backfilling strip mining technology is proposed for coal mining in areas above which buildings and other structures exist. A mining scheme, using this approach for No. 5 mining area, is designed reasonably and scientifically by numerical simulation and theoretical analysis. The conclusions are as follows:

- The surface subsidence characteristics of super-high water backfill mining are the same as those of full-caving mining. Super-high water backfill technology can effectively control surface subsidence in Hengjian Coal Mine.
- Maximum surface subsidence decreases with an increase in the width of the retaining pillar during super-high water backfill strip mining. Meanwhile, the scope of the surface subsidence basin is basically unchanged with increase of retaining pillar width. A width of 20 m between the working faces in super-high water backfill strip mining ensures stability of the partition coal pillars and effectively controls overlying strata movement and surface subsidence in Hengjian Coal Mine.
- A super-high water backfill strip mining scheme was designed for No. 5 mining area. The scheme is feasible, as verified by predicted results, which showed that the safety of surface buildings can be ensured. This approach provides a reasonable and reliable technical solution for exploitation of the No. 5 mining area of Hengjian Coal Mine and other coal resources buried under buildings.

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