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Raw Gangue Filling Mining under Construction—A Case Study in China

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Abstract

In order to recover the strip pillar coal resources, reduce the amount of gangue mountain and realize remediation of the goaf environment in the old mining area, the raw gangue filling mining technology was proposed. According to the previous practical experience, the feasibility of the implementation of raw gangue filling mining technology in the coal-pressed area was analyzed. Through the filling gangue compaction test, the deformation under different loading stages was obtained. Further, a reasonable prediction of the deformation beyond the experimental limited loading load was made based on the experimental results. Through the deformation source analysis of the whole process of gangue filling, the key factors for controlling deformation before, during, and after filling were determined. Additionally, the proportion of deformation during different stages was quantified. Considering the protection of surface buildings, mining fullness of the working face and mining technology, the production parameters of 1209 and 1210 filling working faces were preliminarily determined. Through numerical simulation, the rationality of mining scheme was verified. Based on the practice of 1209 working face and the key factors to control the deformation of gangue filling, the mining system and process in 1210 working face were optimized. According to the measured surface rock movement, raw gangue filling mining technology can meet the requirements of surface building protection level. Especially, this paper provides a method to quantitatively calculate the equivalent mining height (EMH) of raw gangue filling and its mining deformation, which has reference significance for old mining areas.

Keywords

Coal Resource Recovery under Construction, Raw Gangue Filling Mining, Principle of Space-Time Control, Filling System and Process Innovation

1. Introduction

For a long time, the coal mining under construction has mainly adopted village relocation, strip mining, overburden strata separation grouting and paste filling. Village relocation land requisition difficulties, costs and relocation distance are too large. The strip mining recovery rate is only 40% - 60%, tunnel digging is large, and the production management is complex [1] [2]. It is generally believed that the surface subsidence reduction of overburden strata separation grouting is not more than 40%, which basically fails to achieve the purpose of protecting buildings [3] [4]. Paste filling mining can effectively support the roof structure, but the filling process is relatively complex and the efficiency is relatively low [5] [6] [7].

Coal gangue is a waste produced in the process of coal production and washing, and its annual emission is equivalent to 10% - 15% of coal production [8] [9] [10]. The spontaneous combustion, stacking and collapse of coal gangue have caused a series of problems such as air pollution, water pollution and farmland occupation. At present, the total amount of coal gangue in China has reached 4.5 billion tons, forming more than 1700 gangue hills, covering more than 30000 ha, and is increasing at the rate of 100 million tons per year. Coal gangue is stored for a long time, occupying a large amount of land, polluting water sources, and generating harmful gases such as H_2S and SO_2 after spontaneous combustion [11]. Negative environmental effects caused by coal mining have caused three-dimensional harm to the environment [12] [13].

In order to realize the comprehensive utilization of gangue and solve the mining problem of "Three under One above" coal scientifically and reasonably, the comprehensive mechanized solid filling coal mining technology is gradually developed and widely used in the coal mine site, which has become an effective way to solve the mining problem of "Three under One above" coal [14]. With the development of gangue filling technology in recent 20 years, through the evolution of four generations of technology, especially the continuous upgrading and transformation of solid filling coal mining hydraulic support, the integrated production system of coal mining, gangue separation, gangue filling and strata control, gob-side entry retaining, gas drainage, disaster prevention and water conservation mining can be directly constructed in the underground, and the cooperative production mode of coal mining, separation and filling + X (control, retention, drainage, prevention and protection) is formed [15].

Scholars often use different compression equipment for compaction tests indoors to simulate the deformation process of filling gangue on site. Due to the limitations of test equipment and test conditions, there are some differences in the particle size composition between the gangue samples used in the test and the natural coal gangue [16] [17]. Nevertheless, as a simulation test, the test results can reflect the basic characteristics of the filling gangue in the goaf, which is of great significance for understanding the physical and mechanical properties of the filling gangue in the goaf under different conditions [18] [19].

After the gangue filling mining, under the action of the moving strata, the broken gangue will be compacted and denser [20]. There are many indexes that affect the compaction process and final status of filling gangue. These indexes can be divided into two kinds: one is the external factors like stress, constraint condition, water, etc. [21]. The other is internal factors like strength, particle, shape, etc. According to the characteristics of coal gangue particle materials, the PFC is usually used to simulate the compression characteristics of coal gangue, and reproduce its complex macromechanical behavior and microscopic characteristics [22].

However, for old mining areas with exhausted resources under buildings, raw gangue filling mining will become a preferred mining method for extending the service cycle. The raw gangue filling is a systematic project, it is necessary to pay attention to quality control in the whole filling process, otherwise, it will cause the risk of chain out of control. Before production, it is necessary to quantitatively analyze the surface subsidence and deformation by combining the previous mining experience of this mine or other mining areas and various means to ensure the filling effect and the safety of buildings.

Taking a raw gangue-filling coal mine in China as the engineering background, in view of the above problems, the influencing factors of roof subsidence and its control principles are proposed. During the production process, the existing production equipment and production system are reused to minimize investment. Based on the experience of mining the 1209 working surface, the raw gangue filling technology and equipment are innovated to improve the production efficiency and reduce the working intensity of labor.

2. Background

Gucheng Coal Mine is located in Yanzhou Coalfield in the northeast of Jining Coalfield. The minefield is determined by 23 inflection points. The coordinates of mine boundary range are shown in **Table 1**, and the minefield area is 16.66 km^2. There are lots of buildings above Gucheng Minifield, as shown in **Figure 1**. Gucheng coal mine approved an annual production capacity of 1.8 million tons, dense ground buildings. The study area is located in No. 1 level No. 12 mining area, as shown in **Figure 1**, No. 1 level elevation is −505 m.

As shown in **Figure 1**, the strip mining method was used to mine the coal under construction outside the industrial square coal pillar. The strip mining scheme was 50 m mining and 80 m remaining. In recent years, roadway gangue replacement filling has been tested, 20% more coal resources are recovered, but

Table 1. Coordinate list of inflection points at the boundary of Gucheng Mine.

Number	Latitude distances/m	Longitude distances/m	Number	Latitude distances/m	Longitude distances/m
G1	3940464.21	39485480.75	G8	3937134.16	39488945.74
G2	3939879.20	39486350.75	Z12	3935744.17	39486755.72
G3	3939484.19	39487290.75	Z13	3936774.18	39486045.72
D11	3939534.19	39487445.75	Z8	3937194.19	39485300.72
D10	3939994.18	39488585.77	Z7	3937679.20	39485020.72
D9	3940074.18	39488445.77	Z6	3937829.20	39485000.72
D8	3941019.18	39489460.78	Z5	3938819.21	39484980.73
D7	3940929.18	39489780.79	Z4	3939184.21	39484930.73
G4	3941474.18	39490185.79	Z3	3939384.21	39484910.73
G5	3940854.17	39490725.79	Z2	3939694.21	39484915.74
G6	3940094.16	39490675.78	Z1	3940264.22	39485000.74
G7	3938684.17	39489225.76			

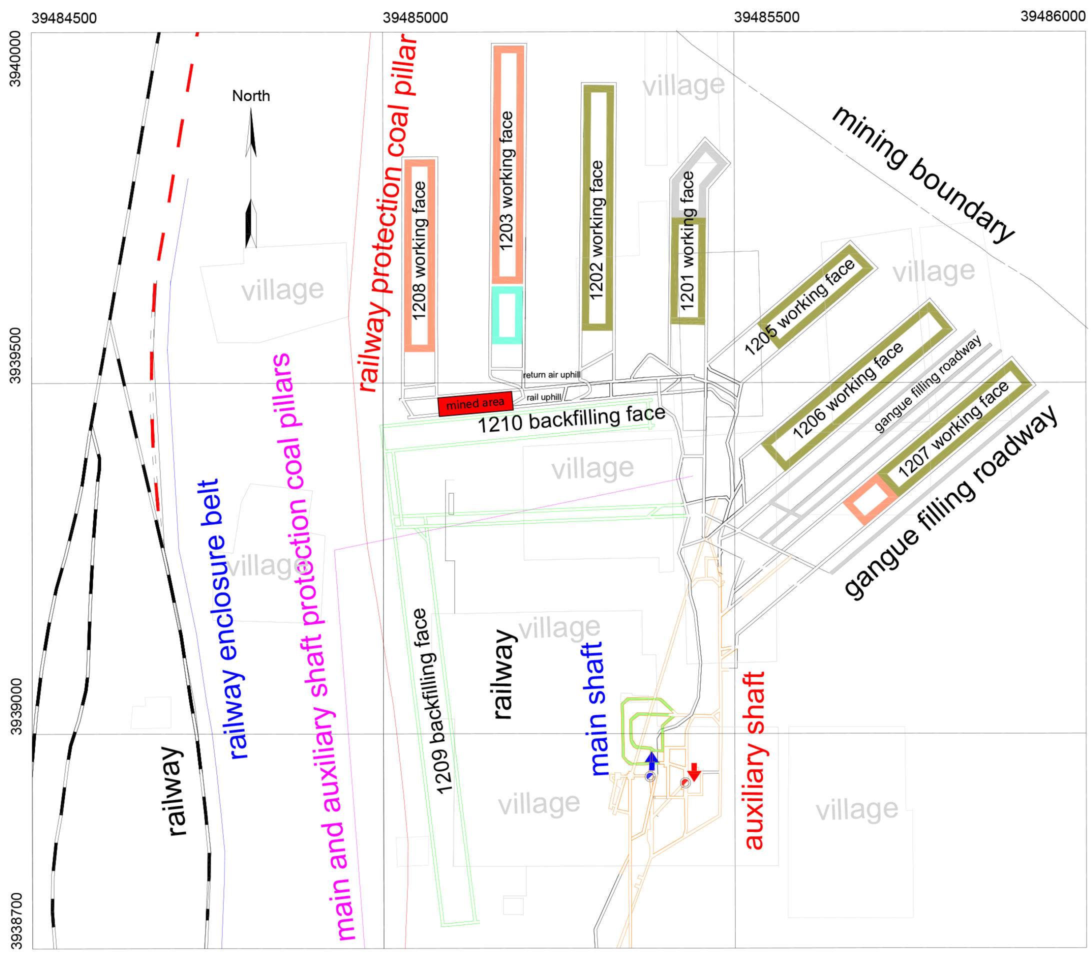


Figure 1. Early strip mining and roadway gangue replacement and filling mining.

about 40% of the coal resources are still not recovered. In order to deal with underground gangue, improve coal recovery rate, Gucheng coal mine put forward the inadequate mining with raw gangue replacement filling coal pillar under the industrial square.

3. Analysis

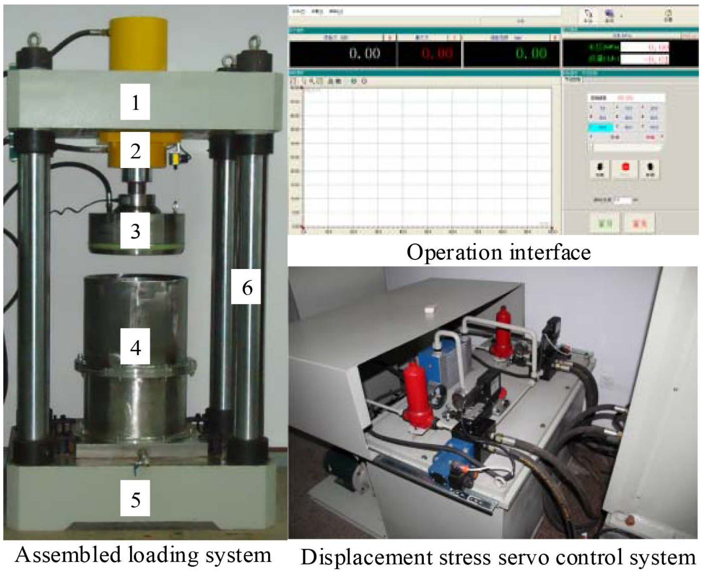
3.1. Empirical Analysis

Since Gucheng Coal Mine was put into operation, almost all of the mining faces were mined under buildings. The previously designed mining schemes can ensure the safety and normal use of buildings. In addition, Gucheng Coal Mine also set up a ground movement observation station and obtained a large number of measured data. Based on the above analysis, it is feasible for Gucheng Coal Mine to dispose of gangue by arranging insufficient mining face in the coal pillar of an industrial square.

The filling mining area is 12 mining areas of Gucheng Coal Mine, the buried depth of coal seam is shallow, the occurrence of coal seam is stable, and there is no fault in the design working face area. The mining of working face in this area can use the original 12 mining area system or form a production system after repair and transformation, and the mining conditions are also available.

3.2. Experimental Analysis

The deformation of filling gangue is the key to controlling the deformation of filling mining. In order to quantitatively analyze the deformation of filling gangue under overburden gravity, a set of gradient loading tests of filling gangue were carried out.



1: test system beam; 2: load oil cylinder; 3: load pressure head; 4: test module; 5: test system base; 6: column.

Figure 2. Experimental system for deformation and seepage of broken gangue.

3.2.1. Experimental Method

The large-scale broken rock deformation-seepage test system was used to carry out the compaction test of filling gangue. The test system is shown in Figure 2. The test system is mainly composed of a displacement-stress dual-control servo system, a pressurized water tank, a test tube, and a main bearing bracket. The diameter of the test chamber is 400 mm, and the height of the test chamber is 680 mm.

The filling gangue comes from the site, and the particle size was between 40 - 50 mm. In order to simulate the group caving phenomenon of roof strata, the compressive deformation test of broken rock was carried out by gradient loading. The loading stages were 100 kN, 200 kN, 300 kN, and 400 kN, respectively. The loading gradient of 100 kN converted into stress was about 0.8 MPa, each level of load to maintain 2.5 hours constant loading time.

3.2.2. Experimental Results

The test results are shown in Figure 3 and Figure 4, the axial strain of the filling gangue increased in step type along with the gradient loading. When the axial stress was 100 kN, which was about 0.8 MPa, the strain peak was 0.08. When the axial stress was 400 kN, that was about 3.2 MPa, the strain peak was 0.21. As shown in Figure 4, with the increase of gradient loading, the strain and the percentage of each loading stage showed a decreasing trend. This phenomenon indicates that, during the compaction of broken gangue, the deformation is concentrated in the early loading stages.

After filling mining, the mined area can basically recover to the original rock stress with time passing. The depth of coal seam is about 420 - 500 m, and the overburden gravity is about 10 MPa. Due to the limitation of experimental

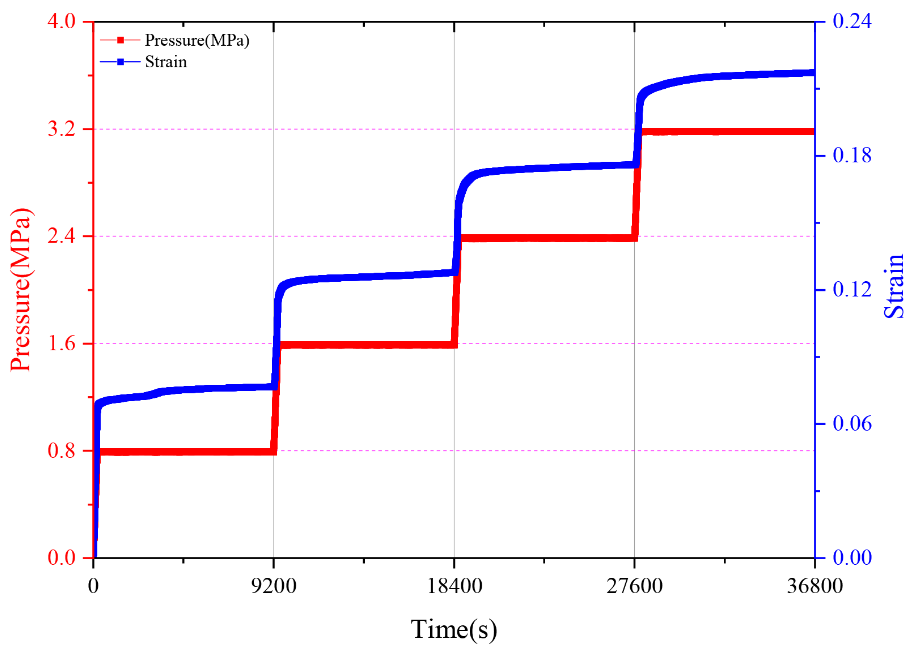


Figure 3. Stress and strain-time of broken gangue under gradient compaction.

equipment, it is impossible to load to 10 MPa. According to the experimental results, it can be qualitatively determined that the strain increased with the increase of loading stress, but the growth rate became slow. By using the method of mathematical software Origin fitting, the fitting relationship between the quadratic function of loading stress and strain was obtained. As shown in **Figure 5**, the error of fitting results was very small. When the loading stress was 10 MPa, the strain was 0.351.

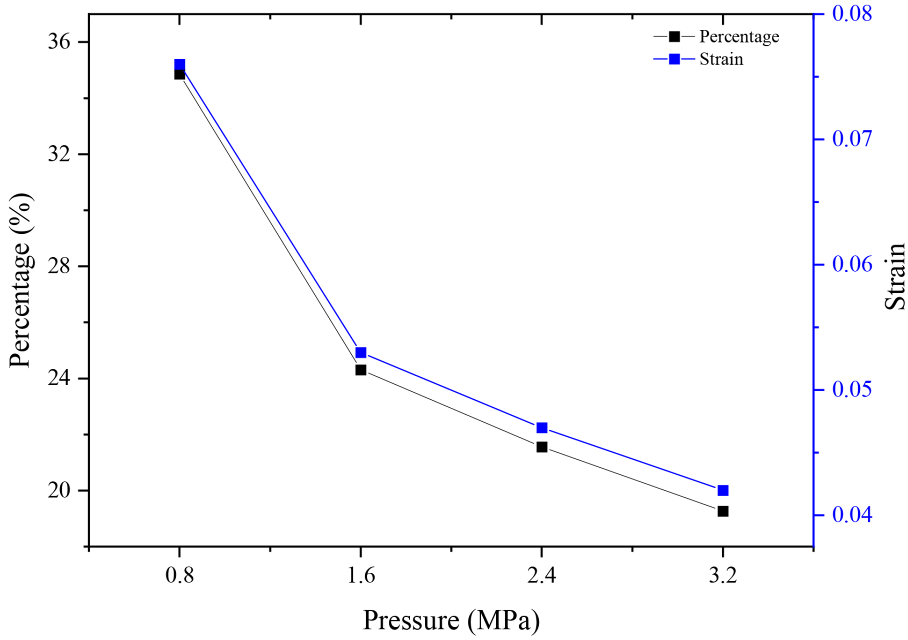


Figure 4. Strain sectional features of broken gangue under gradient compaction.

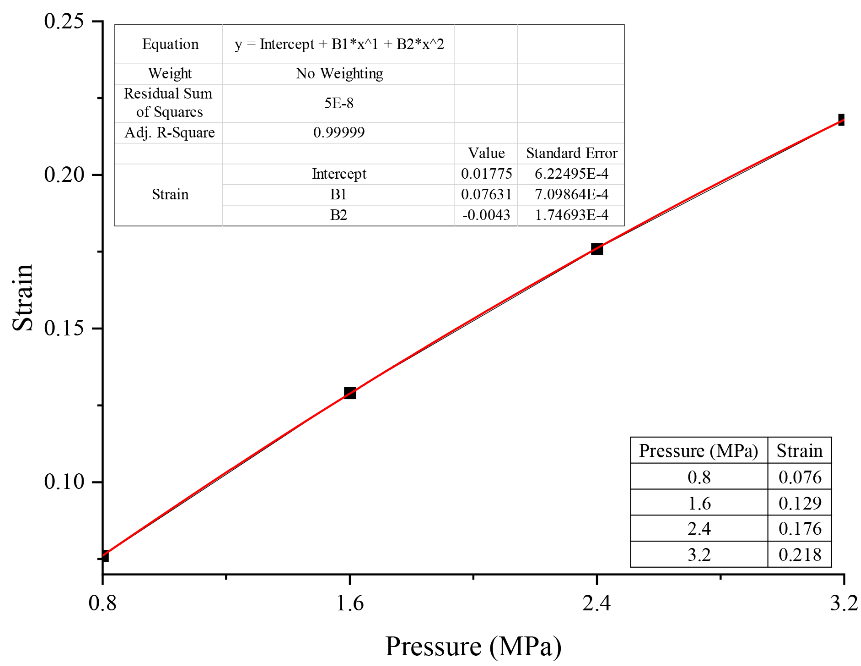


Figure 5. Fitting of gradient loading stress and strain for broken gangue.

3.3. Theoretical Analysis

Mining subsidence deformation is mainly determined by mining thickness. Filling mining essentially reduces the degree of mining subsidence damage. The surface subsidence caused by filling mining is equivalent to the surface subsidence caused by the mining of the coal seam with the thickness of the spacing between the filling body after full compaction and the roof before mining. The thickness is defined as the equivalent mining height M_c.

As shown in **Figure 6**, surface subsidence of raw gangue filling mining mainly includes roof subsidence before filling S_1, lacking distance of roof-contact S_2, gangue compression S_3, gangue compression ratio is ε, then equivalent mining

Figure 6. Source and control method of gangue filling subsidence at different stages.

height M_c:

$$M_c = (S_1 + S_2) * (1 - \varepsilon) + M * \varepsilon \tag{1}$$

According to the measured statistical law of stope roof and floor, the roof subsidence before filling is proportional to the mining height of coal seam and the roof control distance, which can be calculated according to the following formula:

$$S_1 = \eta \cdot M \cdot D \tag{2}$$

where η—sink coefficient; *M*—coal seam mining height, m; *D*—maximum control distance, m.

According to the statistical results of the measured data of 50 working faces in China, the subsidence coefficient η is 0.025 - 0.05, which is based on the early friction pillar [23]. With the optimization of support equipment and the increase of support strength, the subsidence coefficient can be taken as the lower limit of 0.025, the maximum roof control distance is about 1 m, and the roof subsidence before filling is about 0.025 *M*.

With the maturity of filling equipment and the improvement of filling process, pay attention to filling quality management, which can be basically realized touching roof by filling, that is $S_2 \approx 0$.

Equivalent mining height can be simplified as:

$$M_c = 0.025M + 0.9M * \varepsilon \tag{3}$$

When the gangue is filled, the preloading is generally carried out, and the stress is about 2 MPa. At this time, the strain is 0.153, and the difference is 0.198, namely, at this time $\varepsilon = 0.198$. Equivalent mining height can be further simplified as:

$$M_c = 0.203M \tag{4}$$

In summary, according to the equivalent mining height theory, combined with the existing field experience and test results, it is reasonably predicted that the gangue filling mining with a mining thickness of *M* is equivalent to the caving mining with a mining thickness of 0.203 *M*. It is also deduced that the roof subsidence before filling accounts for 12.3%, which is about 1/8 of the total subsidence, and the compression of the gangue-filled body is 87.7%, which is about 7/8 of the total subsidence.

As shown in **Figure 6**, in view of the deformation source of the rock movement, put forward the principle of space-time control, namely raising the filling speed to reduce the deformation before filling. During the filling process, equipment improvements should be made to ensure roof contact. Further, through the precompaction, improving the filling density, reduce the gangue compression deformation after filling. The space-time control principle reduces the roof subsidence from time and space, and maintains the stability of the overlying rock layer. Among them, filling rate and filling density have great influence on the subsidence reduction effect of filling mining. In the filling mining, the filling rate and filling density should be ensured to improve the filling effect.

4. Design

4.1. Preliminary Determination of the Mining Scheme

As shown in **Figure 1**, Gucheng coal mine preliminary plan filling mining 1209 and 1210 working face. The 1209 face is located in the protective coal pillar of the main and auxiliary shafts. The Beijing-Shanghai Railway is a national first-class main railway with high protection level. In order to ensure the safety of the railway, the working face cannot be arranged in the railway protective coal pillar. Because the railway protective coal pillar basically coincides with the boundary line of the minefield, 1209 sides are arranged on the east side of the boundary line of the minefield, and left 20 m boundary coal pillars.

The 1209 working face is located in the range of protective coal pillars of main and auxiliary shafts, and its mining will have a certain impact on the main and auxiliary shafts. According to the mining subsidence theory [8] [24], the adequacy of working face mining is a key factor affecting the surface movement and deformation. In order to reduce the influence, the mining width is considered 1/10 of the mining depth. The average mining depth of 1209 working face is about 420 m, and the mining width of 1209 working face is 50 m.

The 1210 working face is located outside the railway coal pillar and also outside the protection coal pillar of the main and auxiliary shafts, its mining will not affect the railway and the main and auxiliary shafts. However, the track uphill in the 12th mining area is in the north of 1210 working face, and the coal pillars between the uphills in the 12th mining area have been partially mined. The mining of 1210 working face may cause the activation of the mined coal pillar. In order to eliminate the above adverse effects, the open-off cut position of 1210 working face is arranged outside the mined area of the uphill coal pillar. Therefore, the width of 1210 working face is preliminarily determined to be 40 m.

In summary, the 1209 working face is located in the west under the industrial square. The average mining depth of the working face is 420 m, the advancing length is 600 m, the width of the working face is 50 m, and the designed mining thickness is 3 m. The 1210 working face is located in the north under the industrial square. The average mining depth of the working face is 500 m, the advancing length is 400 m, the width of the working face is 40 m, and the designed mining thickness is 3 m.

4.2. Simulation Verification of the Mining Scheme

According to the production practice and equipment of Gucheng Coal Mine, taking into account the actual situation of gangue compression, the filling rate was initially determined to be 85%. The exploration depth range of the study area is multi-layer strata with different thickness and properties as shown in **Table 2**.

In order to simplify the calculation, referring to the relevant literature [22] [25], the strata in the study area are divided into six rock groups according to lithology and integrity: loose rock group (Quaternary), mudstone rock group,

Table 2. Formation graphic of Gucheng Mine.

Depth (m)	Thickness (m)	Strata name
161.3	161.3	Loose layer, sand, sandy clay, quaternary system
200.3	39	Mudstone and fine sandstone alternate layers
212.5	12.2	Medium-grained sandstone, siltstone
216.5	4	Mudstone
237.2	20.7	Mudstone, sandy mudstone, fine sandstone
256.9	19.7	Siltstone, mudstone
278.6	21.7	Medium-grained fine-grained sandstone
294.1	15.5	Mudstone, medium-grained sandstone
311.4	17.3	Sandy mudstone
316.9	5.5	Fine-grained sandstone, medium sandstone
332.8	15.9	Fine sandstone and sandy mudstone
340	7.2	Mudstone
348	8	Fine sandstone
358.6	10.6	Sandy mudstone, fine sandstone
372.6	14	Gravel-bearing coarse-grained sandstone
378.4	5.8	Interbedded sandy mudstone and siltstone
379.2	0.8	No. 2 coal
398.3	19.1	Fine sandstone, siltstone, sandy mudstone
403.7	5.4	Medium sandstone
408	4.3	Sandy mudstone, mudstone, mudstone
417	9	No. 3 coal
418.05	1.05	Sandy mudstone
427.95	9.9	Siltstone, medium-grained sandstone, fine sandstone

limestone rock group, sandstone rock group, broken rock group (water flowing fractured zone) and filling gangue group. The relevant parameters are shown in Table 3.

4.2.1. Establishment of the Numerical Model

In order to study the surface movement and deformation of filling mining in 1209, 1210 working face, the strata are divided into 16 layers, and the mining coal seam is No. 3 coal. FLAC3D models with length (x direction), width (y direction) and height (z direction) of 600 m, 1000 m and 420 m are established. The Mohr-Coulomb model is used in the simulation. The layout of 1209 working face and 1210 working face is shown in Figure 7. 1209 working face 600 m * 50 m, 1209 working face 400 m * 40 m, mining thickness is 3 m, and filling height is 2.5 m.

Table 3. Rock mechanics parameters in numerical simulation.

Rock group	Bulk modulus (GPa)	Shear modulus (GPa)	Cohesion (MPa)	Friction angle (˚)	Tensile Strength (MPa)	Density (kg/m³)
Loose rock	0.08	0.009	0.036	20	0.001	1800
Mudstone rock	2.45	1.76	1.00	25	0.78	2500
Limestone rock	13.4	6.15	6.00	32	6.00	2800
Sandstone rock	17.80	9.85	5.00	30	5.00	2760
Broken rock	0.25	0.03	0.042	18	0.002	1800
Filling gangue	2.0	1.43	1.20	20	0.002	2050

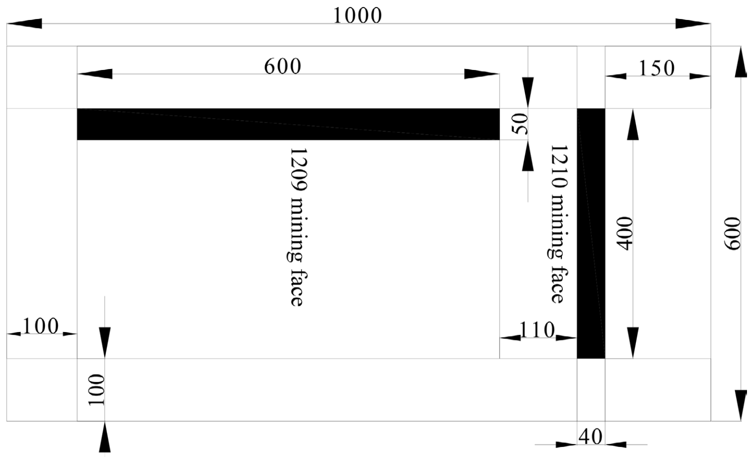


Figure 7. Working face layout drawing.

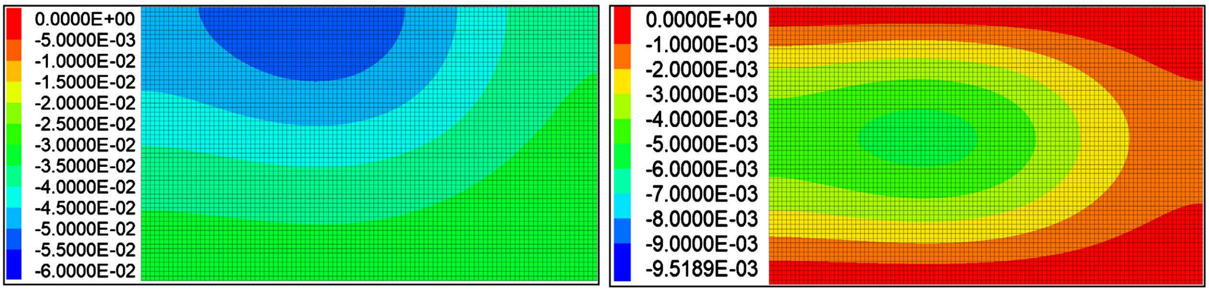
4.2.2. Mining of the Numerical Model

Firstly, the 1209 working face is filled and mined, and the surface deformation cloud map is shown in Figure 8. The maximum surface subsidence is 60 mm, which is located in the center of the 1209 working face. The maximum horizontal displacement of the surface is 6mm, which is located in the center of the modeling area.

Continue mining 1210 working face, the surface deformation cloud picture as shown in Figure 9, the maximum surface subsidence is 70 mm, located in the surface position of 1209 working face center. The maximum horizontal displacement of the surface is 7 mm, which is located in the center of 1209 working face about 250 m east, that is in the center of the modeling area.

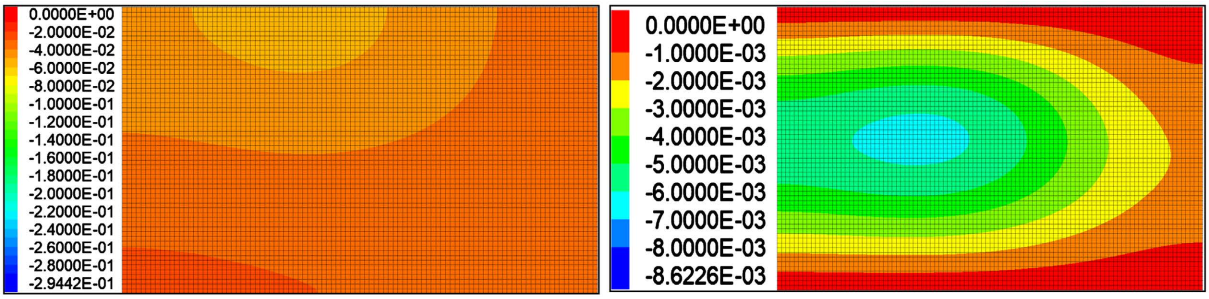
It is found that when the superposition effect of mining face is considered, the surface movement deformation value increases. However, due to the distance between the two working faces being far, the increase is limited.

According to the practice of coal mining under buildings and coal mining regulations: the maximum allowable horizontal deformation of wellbore is 1 mm/m, the maximum allowable inclined deformation of high-rise buildings such as coal bunker is 1 mm/m, the maximum allowable horizontal deformation



(a) Surface vertical displacement (b) Surface horizontal displacement

Figure 8. Surface deformation after mining 1209 working face.



(a) Surface vertical displacement (b) Surface horizontal displacement

Figure 9. Surface deformation after mining 1210 working face.

of multi-storey buildings, flats and other buildings with brick-concrete structure is 2 mm/m, and the maximum allowable inclined deformation is 3 mm/m.

By using the horizontal and vertical deformations of the surface of 1209 and 1210 working faces after filling mining obtained by numerical simulation, and according to the calculation formula of inclined deformation and horizontal deformation of mining subsidence, it is calculated that the horizontal deformation of the industrial square of Gucheng Coal Mine is less than 1 mm/m, and the inclined deformation is less than 1 mm/m. The above deformation values can ensure the normal use of surface buildings.

5. Application

In Gucheng Coal Mine, the raw gangue filling mining technology was first used in mine 1209 mining face. The materials needed for gangue filling are all from underground. The double drum MG250/601-QWD shearer was used to cut and load coal. The roof was supported by ZC4000/14.5/30 filling hydraulic support. After passing through the coal gangue separation system, the coal and gangue were separated, and the gangue entered the filling working face. The gangue filling in the working face was carried out by SGZ630/220 scraper conveyor suspended behind the special filling hydraulic support.

5.1. Process Innovations

Based on the mining practice of 1209 working face, according to the theoretical analysis of the subsidence sources and the main control factors, the following technology innovations of filling process were realized in 1210 working face to further reduce the mining-induced influence.

5.1.1. Reduce Early Subsidence Rate-Advanced Support

With the advancement of the working face, due to the mining depth of the mine reaching −400 m, the local broken roof falls in time with the forward movement of the support, resulting in smaller filling space, which greatly raises the subsidence before filling mining. As shown in Figure 10, the metal mesh is suspended ahead the working face, and the bolt is punched at a suitable spacing between the supports to control the local broken roof, so as to slow down the roof subsidence rate, and make the smaller subsidence before filling mining.

5.1.2. Improve the Filling Speed-Support + Belt Filling Process behind Support

As shown in Figure 11, through the study on the adaptability of the filling method of hanging belt behind the support, it is determined that the filling method of "support + belt" was used in the 1210 filling face, which can accelerate the flow of filling gangue, meanwhile, greatly reduce the subsidence before filling mining.

5.1.3. Ensure Roof-Contacted Filling-Composite Filling Process

On the working face, the wind power auxiliary filling mode with the original "support + belt" is created as shown in Figure 12. The auxiliary filling system is constructed in belt roadway for transporting gangue in the upper trough

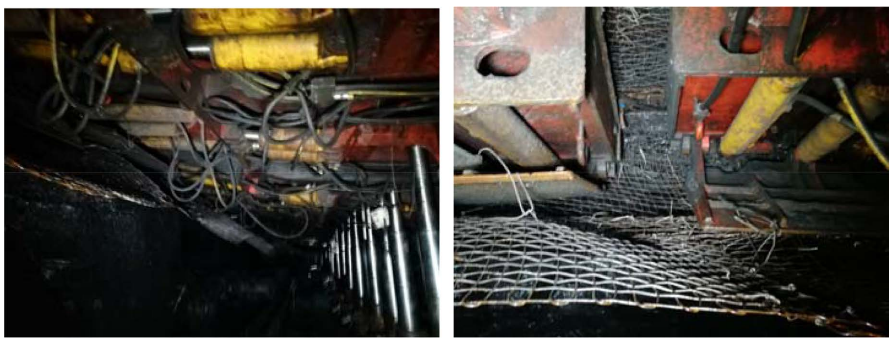


Figure 10. Hanging metal mesh and support technology ahead support.

Figure 11. Support + belt filling process behind support.

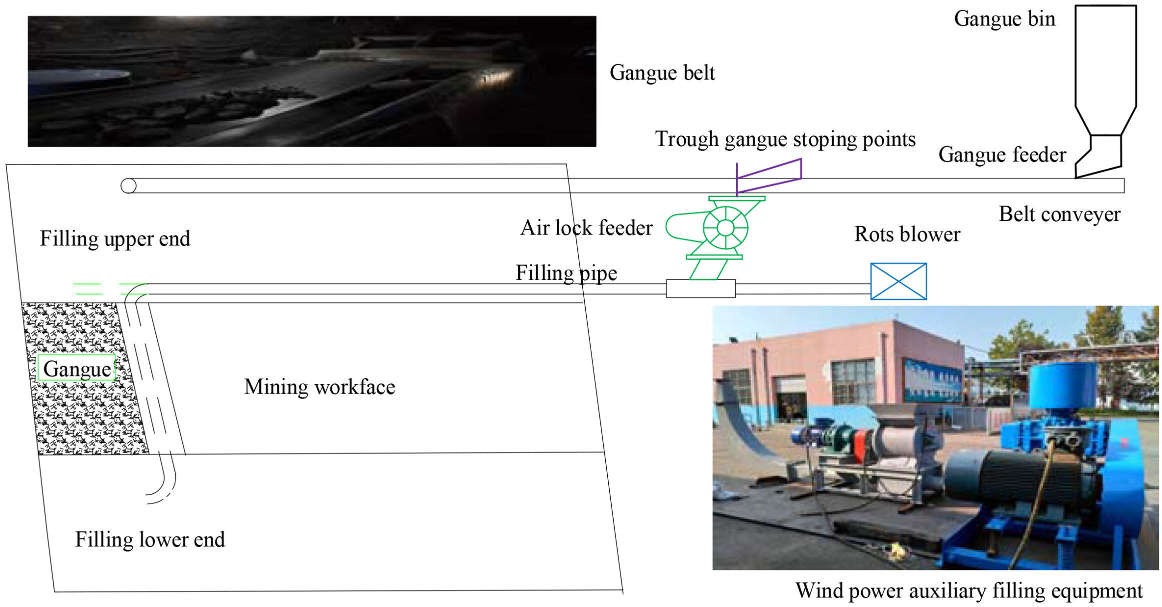


Figure 12. Innovations of wind power auxiliary filling process.

150 meters from the mining face. After crushing, the raw gangue falls from the belt conveyor into the rotary valve and pipeline. The Roz blower acts as the gas source to transport the gangue from the rear to the back of working face through the pipeline, which is conducive to the roof-contacted filling and reduce the subsidence during filling.

5.1.4. Improve the Pre-Compaction Rate-Improving Compaction Mechanism

In the filling process of 1209 working face, the extension of tamping mechanism is limited and affects the preloading effect. There are four gaps in tamping mechanism block seal that are processed by gas cutting process as shown in Figure 13. The liquid can flow out through the four gaps during operation, and then return the liquid through the return hole. Based on this improvement, the complete extension and contraction of the cylinder body are realized, which is beneficial to improve the compaction rate and reduce the compression deformation after filling.

5.2. Surface Movement Monitoring after Filling Mining about Two Year Later

5.2.1. Effective Measuring Point Distribution

In order to monitor the surface deformation after raw gangue filling mining, a series of displacement monitoring points were set up on the surface above 1209 working face. However, due to the interference of natural factors and human factors, some monitoring points were damaged. The layout of the filtered effective measuring points is shown in Figure 14(a).

5.2.2. Displacement Feature Analysis

As shown in Figure 14(b), the displacement monitoring points after the surface

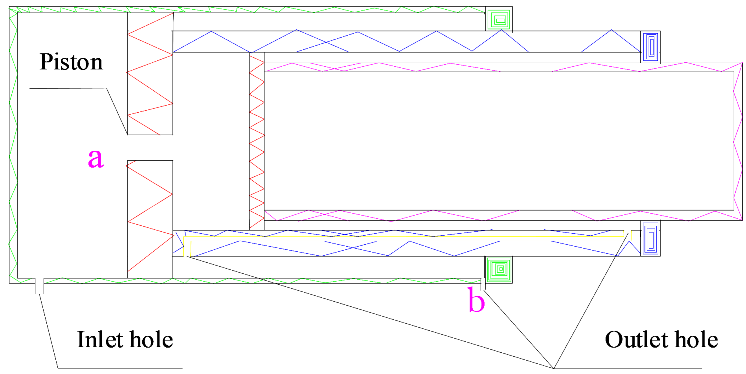


Figure 13. Innovations of compaction mechanism.

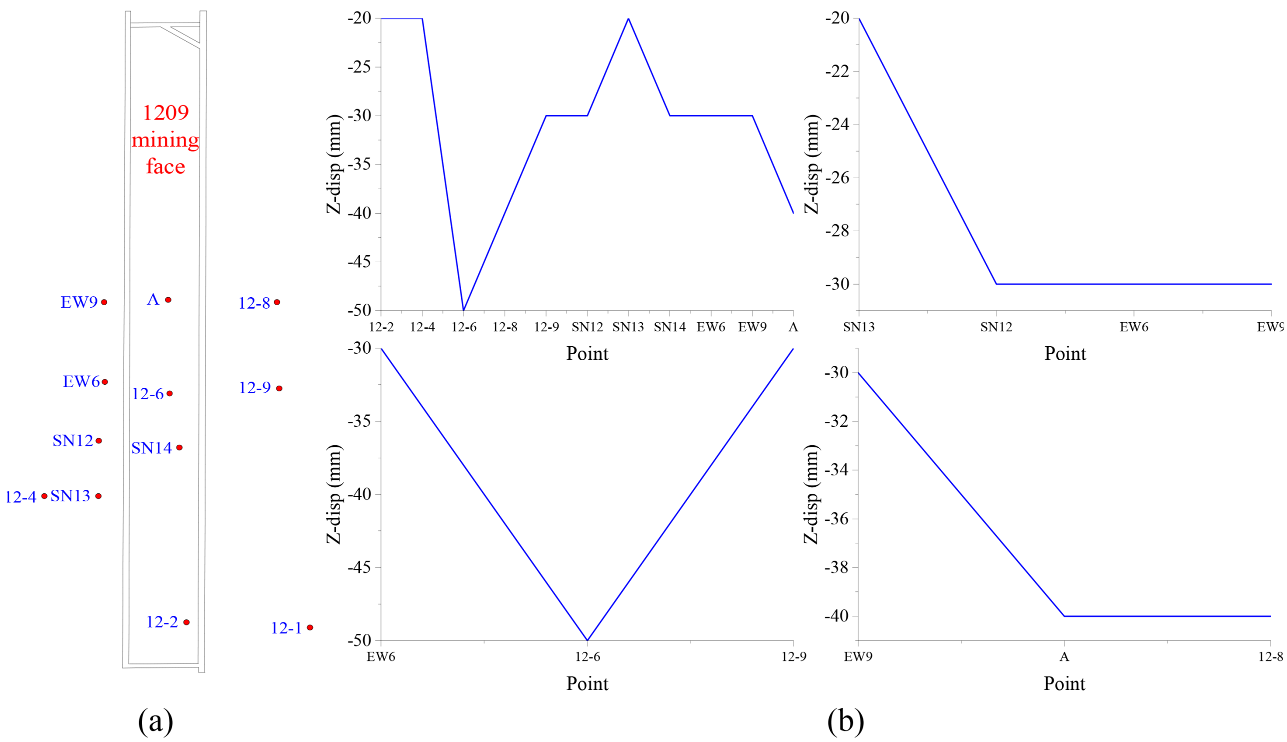


Figure 14. Effective displacement measuring point and surface subsidence.

subsidence was stable after filling mining 1209 and 1210 working face (about two year later). The subsidence of all effective measuring points was between 20 - 50 mm, which was close to the predicted displacement of numerical simulation. The maximum subsidence value was point 12-6, followed by point A, which was also the two points closest to the center of 1209 working face.

The measuring points SN13-SN12-EW6-EW9 were roughly located outside the edge of the mined-out area parallel to a straight line along the trough. The subsidence of the four monitoring points was between 20 - 30 mm. The measuring points EW6-12-6-12-9 were roughly located on a straight line perpendicular to the trough, and the three monitoring points subsidence were between 30 - 50 mm. As all the measuring points close to the center of the goaf, the subsidence value showed an increasing trend.

In conclusion, after filling mining 1209 and 1210 working face, surface subsidence distribution was orderly and subsidence values were small, especially comparing the mining thickness of 3 m. At the same time, according to the deformation observation of key buildings on the surface (shown in **Figure 15**), it is found that there is no obvious deformation and cracks, which can maintain normal use.

Figure 15. Key buildings on the surface.

6. Conclusions

1) According to the equivalent mining height theory, combined with the existing field experience and test results, the gangue filling mining with a mining thickness of M is equivalent to the caving mining with a mining thickness of 0.203 M, corresponding to Gucheng Coal Mine being only about 0.6 m. The roof subsidence before filling accounts for about 1/8 of the total subsidence, and the compression of the gangue filling body is about 7/8 of the total subsidence.

2) Through the characteristics analysis of raw gangue filling mining, the roof subsidence source and corresponding control factor in different filling stages are obtained. The deformation before, during, and after filling comes from the advanced subsidence of the roof, lack of roof contact distance, and gangue compression deformation, respectively. The corresponding control factors are the filling speed, filling equipment, and the filling density.

3) Considering the protection of surface buildings, mining adequacy of working face and mining technology, 1209 face was designed to locate in the western part under the industrial square, with a strike length of 600 m, a working face width of 50 m and a mining thickness of 3 m. 1210 face was designed to locate in the north under the industrial square, with a strike length of 400 m, a working face width of 40 m and a mining thickness of 3 m.

4) Based on the 1209 working face filling mining experience and the time-space control principal, the 1210 filling system and process were innovated: Advanced support to reduce early subsidence rate; Support + belt filling mode behind support to improve the filling speed; Wind power auxiliary filling to realize multi-level, full-cover composite filling; Transformed compaction mechanism to improving pre-compaction rate.

Conflicts of Interest

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

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