International Journal of Education and Humanities
ISSN: 2770-6702 | Vol. 21, No. 2, 2025

Overlying Strata Separation Grouting Mining Design for Working Face 23041 of Gaocheng Coal Mine

Huaiyang Shi*

Henan Polytechnic University, Jiaozuo, Henan 454000, China
* **Corresponding author**: Huaiyang Shi (Email: 707070712@qq.com)

Abstract: To address the requirements of protecting cultural relics such as the Yangcheng Ruins and tackling the overlying rock reverse-inclination zone formed by the influence of sliding structures at the 23041 working face of Gaocheng Coal Mine, this study employed similar simulation tests (with a geometric similarity ratio of 1:1000). It was verified that after mining at this working face, the actual height of the caving zone reaches 53 meters and that of the fractured zone is 121 meters, and the optimal grouting horizon was determined to be 145 meters below the main key stratum. Based on these findings, an overlying rock separation grouting scheme and a layout of 5 grouting boreholes were designed. After implementation, the maximum surface subsidence was reduced from 3215 mm (Grade IV damage) under conventional mining to 598 mm (within Grade I deformation). This research fills the gap in studies on mining laws in overlying rock reverse-inclination zones under the influence of sliding structures and provides support for cultural relic protection and the mining of coal resources under "three under" (under buildings, railways, and water bodies) conditions.

Keywords: Strata Movement, Bed Separation Grouting, Mining Fractures, Similar Simulation.

1. Engineering Background

A sliding structure is formed by the sliding of upper plate rock strata from high to low along an inclined sliding surface under the action of gravity [1]. Studies have shown that abundant coal resources are often hosted in such geological structures [2]. For example, a large amount of coal is hosted under the sliding structures in the coalfields of western Henan Province [3]. The Ludian sliding structure area is a typical case within the sliding structures of western Henan. Under complex crustal movements, the early overlying system slid from north to south, and the late system slid from south to north, resulting in a special geological structure where the dip direction of the overlying rock in the upper plate of the sliding mass is opposite to that of the coal seam, i.e., the overlying rock anti-dip [4]. Gravity sliding structures (referred to as sliding structures) belong to the category of normal faults in fracture structures [5]. During the formation of the structure, the rock strata experienced two sliding movements: first, downward compression and upward tension with a southward thrust, followed by a northward slide[6]. As a result, whether it is the upper sliding surface or the lower sliding surface, the strata of the sliding mass are opposite to the dip direction of the sliding surface, forming an overlying rock anti-dip zone[7].

Dengfeng is one of the famous tourist cities in China. Within the Gaocheng mining area, there is the oldest existing astronomical observatory in the world-the Site of the Star Observation Platform, which is a national key cultural relics protection unit. In addition, the mining area also contains five key cultural relics protection units at the Henan provincial level, including the Shuangmiaogou Site, Wangchenggang Site, Bafang Site, Yangcheng Site, and Shiconghe Cliff Inscriptions. The ancient city wall of the Yangcheng Site runs through the working face from west to east. The 23041 working face, which is currently being succeeded, corresponds to the ground area of the Yangcheng Site, a national key cultural relics protection unit (verified to be an ancient city from the Eastern Zhou Dynasty to the Han Dynasty).

2. Overview of Gaocheng Coal Mine

2.1. Stratigraphic Conditions of the Gaocheng Coalfield

Gaocheng Coal Mine is affiliated to Zhengzhou Coal & Electricity Co., Ltd. The coalfield, belonging to the Dengfeng Coalfield of the North China sedimentary type, is located in the eastern section of the southern limb of the Yingyang-Ludian syncline, with most areas affected by the Ludian-Dajindian sliding structure. The structural framework of the Dengfeng Coalfield is dominated by fracture structures, followed by fold structures. Among them, the Ludian-Dajindian sliding structure is a unique structural type in this region, characterized by the separation of the upper plate rock mass from the lower plate and their independent movement, eventually overlaying on older strata. Its distribution range is shown in Figure 1.

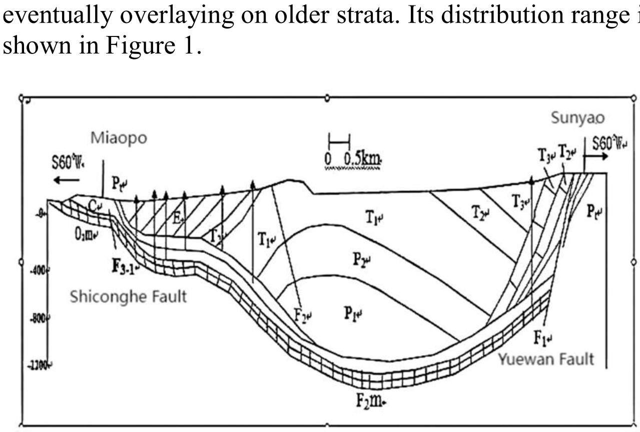

Figure 1. Distribution of the Ludian Sliding Structure

2.2. Characteristics of the Sliding Structure in Gaocheng Coal Mine

The sliding structure system in the Gaocheng mining area takes Lu F1 as the main sliding surface and Lu F1-2 as the secondary sliding surface. Among them, the main sliding surface Lu F1 constitutes the bottom boundary of the fracture system, while the sliding surface Lu F1-2 is usually located in the overlying rock series of the main sliding surface, and is compounded with the lower sliding surface in local areas. The No. 2-1 coal seam and No. 1-1 coal seam in the mining area are minable coal seams, and nearly the entire mine is located within the Ludian sliding structure area. Specifically, the strata near the No. 2-1 coal seam are structurally fractured, especially the upper strata of the coal seam generally have a relatively thick sliding structure zone, which is characterized by fragmentation and well-developed joints and fractures.

In addition to the typical characteristics of sliding structures, the 23rd mining district of Gaocheng Coal Mine has experienced two sliding movements in opposite directions during its formation. This causes the dip direction of the overlying rock in the upper plate of the sliding mass to be opposite to that of the underlying No. 2-1 coal seam, forming a special geological structure of overlying rock anti-dip. The coal seams in the study area have typical "three soft" unstable characteristics. Approximately 75% of the coal seam roofs are controlled by the Lu F1 fault, belonging to sliding structure roofs. The thickness of the sliding structure fractured zone varies significantly, ranging from 0.45 to 113.4 meters, with complex lithological composition. It mainly includes purplish-red and grayish-green fault gouge, fault breccia, as well as Permian sandstone, sandy mudstone and mudstone. Locally, Triassic red and green sandstone and sandy mudstone can be seen, with obvious differences in rock mass mechanical properties.

3. Similar Simulation of Mining-induced Rock Movement of Rock Strata

Similar simulation test is a laboratory model test technology based on similarity theory, which utilizes the similarity and analogy existing between things or phenomena. This experiment adopts the method of similar material simulation test to study the laws of strata movement and mining fractures during coal mining under anti-dip rock in the sliding structure zone. This research plays a guiding role in the selection of grouting horizons during overlying rock separation grouting mining in the 23041 working face, thereby providing theoretical support for the protection of the Yangcheng Site and other places of interest during coal mining under the sliding structure zone.

3.1. Introduction to Relevant Theories

Similar model tests must not only meet the similarity requirements for the physical properties and geometric shapes of similar materials but also conform to the similarity criteria for initial states and boundary conditions.

(1) The First Theorem of SimilarityThe core content of the First Theorem of Similarity can be summarized as follows: If similar phenomena exist between two systems, their similarity indices are either 1 or have a constant similarity criterion. This conclusion indicates that in simulation test research, the similarity criteria derived from the model system can be extended to the simulated prototype system, providing a basis for the analysis of prototype characteristics.

(2) The Second Theorem of SimilarityThe core content of the Second Theorem of Similarity can be summarized as follows: The relational equations between different physical quantities can be expressed by converting them into dimensionless equations; each term in the dimensionless equation is defined as a similarity criterion, which provides ideas for simplifying the analysis of physical quantity relationships.

(3) The Third Theorem of SimilarityThe core content of the Third Theorem of Similarity can be summarized as follows: When the physical equations are consistent, if two phenomena can meet a series of prerequisites including geometric similarity, time similarity, physical parameter similarity, boundary condition similarity, initial condition similarity, and mathematical similarity, then the two phenomena must be similar.

3.2. Establishment of the Model

Based on Borehole 12602 in the 23041 working face (Table 1), rock strata with similar or nearly similar lithology are merged. Using this software to identify key strata from the columnar section, it is found that there are a total of 4 key strata in the approximately 200-meter-thick overlying rock of the coal seam in the 23041 working face, among which the first sub-key stratum is located within the sliding structure zone.

Table 1. Columnar Diagram of Key Layer Discrimination for Drilling Hole 12602

Layer No	Thickness/m	Buried Depth	Lithology of Rock Strata	Key Strata Position
16	6.1	334.6	Medium sandstone	
15	18.6	353.1	Fine sandstone	
14	12.5	378.2	Medium sandstone	Main key layer
13	16.1	394.3	Medium sandstone	Secondary key layer
12	16.3	410.9	Mudstone	
11	16.4	427.3	Fine sandstone	
10	15.5	442.5	Medium sandstone	Secondary key layer
9	9.5	452	Fine sandstone	
8	7	459	Fine sandstone	
7	8.9	467.9	Medium sandstone	
6	11	476.9	Fine sandstone	
5	4.9	481.8	Fine sandstone	
4	4.1	474.1	Fine sandstone	
3	6.2	492.3	Medium sandstone	
2	3.2	495.5	Mudstone	
1	18.5	514	Mudstone	
0	5.4	519.4	Fine sandstone	

3.3. Proportioning of Similar Materials

Five proportions were designed for the experiment. Considering potential errors in proportioning tests, two to three specimens were prepared for each proportion. The average compressive strength of the three specimens was taken as the compressive strength of that material proportion. The proportioned specimens are shown in Figure 3-5. After measurement, the compressive strengths of the specimens are listed in Table 2. Based on this, the mechanical strength of the simulated rock strata can be determined. Referring to the material proportioning in Similar Simulation Tests of Mine Pressure, the model proportions were obtained, as shown in Table 2.

Table 2. Compressive Strength of Specimens

Lithology	Proportion No	Compressive Strength/MPa			Average Compressiv/MPae Strength/MPa
Sandy Mudstone	773	0.025	0.027	0.023	0.025
Mudstone	755	0.026	0.021	0.024	0.023
Fine-Grained Sandstone	555	0.031	0.029	0.030	0.030
Fault Breccia	873	0.009	0.011	0.007	0.009
Medium-Grained Sandstone	473	0.041	0.040	0.037	0.039
Siltstone	573	0.033	0.030	0.028	0.031

3.4. Analysis of Results

After the mining of the working face is completed, the roof rocks of the working face gradually bend under the action of their own weight and the gravity of the overlying strata. When their deformation exceeds the ultimate deformation or their internal stress exceeds the stress strength of the rock strata, fractures and fragmentation will occur. During the simulation of coal seam mining, the coal seam within the range of the simulated working face is extracted at one time, and then the deformation process of the overlying rock is observed and analyzed. After the mining is completed, it can be seen from the rear of the device that the roof has basically collapsed completely, showing an irregular shape.

Figure 2. Roof Caving Morphology

The rock strata within the sliding structure zone above the working face have basically collapsed completely, with the caving morphology showing an irregular parabolic shape. The highest point is biased toward the downhill direction of the working face, and the caving zone has a relatively large range, with the caving range in the uphill direction of the working face being larger than that in the downhill direction. According to measurements, the final height of the caving zone is 5.3 cm, which corresponds to an actual caving zone height of 53 m, approximately 10 times the thickness of the coal seam.

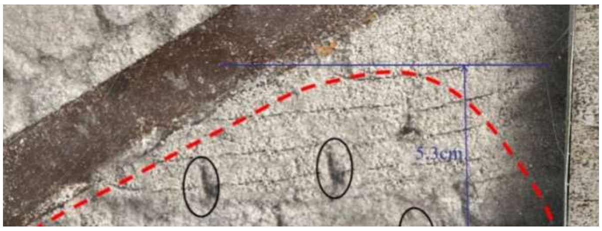

Figure 3. Morphology and Height of the Caving Zone

4. Grouting Design for the 2304 Working Face

Based on the numerical simulation research and similar material simulation research calculated from the relevant geological data of the 23041 working face in Gaocheng Coal Mine, the strata where the separations required for overlying rock isolation grouting occur can be determined. On this basis, a reasonable overlying rock isolation grouting filling scheme can be designed.

4.1. Grouting Technology and Principle Process

"Overlying Rock Isolation Grouting Backfilling Technology for Coal Mining Without Village Relocation" is an efficient and low-cost backfilling technology. Its principle is as follows: design a reasonable mining width of the working face and reserve an isolation coal pillar of a certain width to control adjacent working faces to be in a state of insufficient mining. High-pressure grouting through surface boreholes is used to backfill the separation zone, ultimately forming a bearing structure of "backfilled compaction zone - isolation coal pillar - key stratum". This structure transfers the overlying rock load borne by the isolation coal pillar, reduces the width of the isolation coal pillar, improves the recovery rate, controls surface subsidence, and realizes coal mining without village relocation.

The technological process of overlying rock isolation grouting backfilling mining is as follows: Fly ash from the power plant is transported to the ground-level primary grouting station by cement tankers and stored in vertical tanks. The fly ash in the vertical tanks is transported to the primary mixing tank of the primary grouting station through a high-pressure air pump for mixing to make slurry, then flows into the secondary mixing tank for secondary mixing. Finally, the slurry in the secondary mixing tank is pressed into the delivery pipeline by the grouting pump in the pump room, and then enters the borehole for grouting backfilling. See Figure 4.

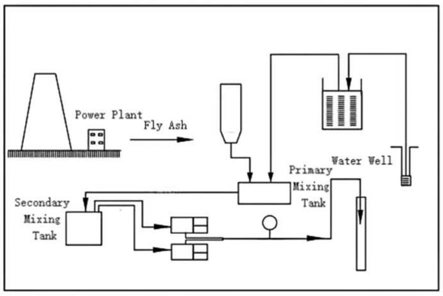

Figure 4. Grouting Backfilling **System**

4.2. Analysis of Grouting Strata

The thickness of the sliding structure zone gradually decreases from north to south. Within the mining influence range, its thickest part reaches 140 m, and the thinnest part is approximately 20-40 m. The coal seam is in direct contact with the sliding structure zone, with fault gouge and fault breccia overlying it. The principle for selecting key strata is to choose the junction of conformable and unconformable interfaces - here, the lower structural zone collapses while the upper rock mass remains intact, forming the separations required for grouting.

However, due to the relatively small thickness of the sliding structure zone at the locations of Grouting Hole 4 and Grouting Hole 5, which are 90 m and 60 m respectively, the height of the water-conducting fracture zone calculated using the empirical formula is 82 m (with the mined coal seam thickness taken as 5.4 m). If the thickness is less than this height, water seepage into the working face will occur. A safety factor of 1.2 needs to be reserved, so the thickness of the sliding structure zone should be greater than 100 m. Therefore, the working face is divided into two sections (0-400 m and 400-660 m from the open-off cut) based on the 100 m thickness of the sliding structure zone as the boundary, and two grouting methods are adopted accordingly.

5. Conclusion

According to the simulation results, both the caving zone and the fractured zone cover a relatively large range. After the mining of the working face, the roof and the rock strata within the sliding structure zone have basically collapsed completely. The morphology of the caving zone gradually takes on irregular parabolic and triangular shapes as the reverse dip angle of the overlying rock increases.

A scheme for overlying rock separation grouting filling mining in the 23041 working face was designed. Based on the surface deformation observation data and by means of the Matlab fitting method, the probability integral prediction parameters under the working condition of overlying rock separation grouting filling mining were obtained. According to the measured values of surface movement and deformation during the historical mining process of Gaocheng Coal Mine, the probability integral method prediction parameters corresponding to the normal mining of the 23041 working face were determined. The probability integral method was used to calculate the surface movement and deformation values under the two mining methods. It was found that under normal mining conditions, the maximum surface subsidence reached 3215 mm, and the surface deformation grade of buildings had reached the level IV damage degree; under the condition of overlying rock separation filling mining, the maximum surface subsidence was 598 mm, and the surface deformation of buildings near the working face was basically controlled within level I.

References

[1] Qian Minggao, Xu Jialin, Wang Jiachen. On the Scientific Mining of Coal Again [J]. Journal of China Coal Society, 2018, 43(01): 1-13.

[2] Guo Wenbing, Deng Kazhong, Zou Youfeng. Research Status and Prospect of Rock Strata and Surface Movement Control Technology [J]. China Safety Science Journal, 2005, 15(01): 6-10.

[3] Xie Renhai, Qu Tianxiang, Qian Guangmo. Structural Geology [M]. Xuzhou: China University of Mining and Technology Press, 2007.

[4] Wang Changxian, Cao Daiyong. Sliding Structures in the Carboniferous-Permian Coalfields of Songshan and Jishan Areas, Henan Province [J]. Journal of Xiangtan Mining Institute, 1989, (01): 28-33.

[5] Wang Zhirong. Sliding Structure Zones and Mine Geological Hazards in Gaocheng Coalfield [J]. Journal of Geological Hazards and Environment Preservation, 2003(04): 21-24.

[6] Cao Daiyong, Wang Changxian. Cenozoic Fault Block Tilting Movement in the Western Coalfields of Henan Province [J]. Journal of China Coal Society, 1988(03): 26-32.

[7] Sun Jinping, Li Wancheng. A Case of Gravity Sliding Structure: Introduction to the Ludian Sliding Structure in Henan Province [J]. Coal Geology of China, 2009, 21(04): 9-15.