Research on High Confined Water Water Rich Gob Area Growing Treatment Technology

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Abstract. Above the goaf, resource-based communities must construct civil buildings, industrial buildings, highways, bridges, and other transportation amenities. For the foundation treatment of the goaf, grouting technology is employed for the safety of the construction above the goaf. The selection of injection paste material and the investigation of grouting treatment technology of a high confined water rich gob region were thoroughly investigated based on the treatment project of a high confined water rich gob area in Zhangqiu District, Jinan City, Shandong Province. First and foremost, thoroughly grasp and analyze the project's geological circumstances and coal mining. Second, it is comprehensively determined that the goaf management adopts the partition management mode, and adopts the grouting and filling management scheme combining vertical drilling and directional drilling, and conducts experimental research while grouting construction, in order to improve the dynamic mode of grouting scheme at any time. Finally, the injecting paste material was tested to determine the best slurry ratio, and the grouting technology of "curtain", "Divide", "use", and "Out" was tested, as well as the grouting effect, which solved the practical problems of the grouting treatment project.

Keywords: confined water · water rich gob area · injecting paste material · grouting treatment technology

1 Introduction

In recent years, China's coal output has ranked first in the world, and raw coal output is expected to exceed 4 billion tons in 2021. A significant region of coal goaf has formed as a result of big-scale coal mining. Simultaneously, with China's rapid urbanization and industrialization, construction land is becoming increasingly scarce, and some resource-based cities may not have built some civil buildings, industrial buildings, highways, bridges, and other transportation facilities above the goaf. Years of research and practice have shown that grouting treatment of mined-out regions can successfully reduce sinking. The treated mined-out lands can meet the requirements of construction land by combining various technical ways, considerably reducing the problem of land scarcity [1].

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After decades of research and engineering practice, goaf grouting technology has made significant advances in both material and technology, and many experts and scholars both at home and abroad have conducted extensive research. Xu Li [2] analyzed the grouting method used in foundation treatment in goaf, described the basic principle and effect of grouting method in foundation treatment, and then analyzed the application of grouting method from the process of foundation treatment engineering to solve the problem of foundation treatment in goaf. Li Hanguang [3], using the example of a grouting treatment project on the Beijing-Taiwan Expressway's Xuzhou section, systematically studied the reasonable proportion of fly ash main material with an appropriate amount of cement, water glass, and other mixed slurry, and analyzed and evaluated the slurry performance under various proportions. Wang Haiming et al. [4] combined the goaf treatment project of the new substation in Sihe No. 2 well, put forward the corresponding grouting scheme and grouting technology, and adopted the method of combining grouting treatment with surface subsidence prediction and building deformation resistance technology to ensure the normal and safe use of the new substation. Zhu Yisheng et al. [5] combined the goaf treatment project of the new substation in Sihe No. 2 well, To solve the grouting and filling problem of the multi-layer water rich gob area around Xuzhou east of the Beijing-Fuzhou Expressway, the methods of pumping and grouting, strictly controlling grouting pressure, and intermittent grouting were used. A cement fly ash slurry with water-solid ratios of 1:1, 1:3, and 3:7 was chosen, and an accelerator containing 2% of the cement weight was added to the slurry. The grouting procedure used segmented two-layer grouting to accomplish goaf control. It is stated that grouting design and grouting technologies require further investigation, particularly the diffusion radius of grout and the influence of groundwater on grout.

Summarizing the research findings, it can be concluded that cement-fly ash mixed slurry is primarily employed in the selection of injecting paste material in goaf, and that the technology and technical method of grouting in goaf have grown increasingly mature. As we all know, water is easily formed following coal mining, and it is primarily constituted of surface water and groundwater. These bodies of water reach the goaf via mining cracks, geological structural faults, and unfinished drilling holes [6]. In most circumstances, the water content of the goaf is not significant, so it is not required to take this into account while planning the goaf grouting. When the buried depth of the goaf is substantial, however, the phenomena of high confined water will arise when there is a water level differential of the source water in the goaf, resulting in the formation of a high-pressure water rich gob area. In this situation, whether traditional injecting paste material and grouting technology can match the needs of foundation treatment is uncommon both at home and abroad, and it is also an urgent problem that must be solved on the spot.

Based on the treatment project of a high-conflicted water rich gob area in Zhangqiu District, Jinan City, Shandong Province, this paper comprehensively studies the selection of injecting paste material and the research of grouting treatment technology of high-confined water rich gob area.

2 General Situation of the Project

The treatment area is in Zhangqiu District, Jinan City, Shandong Province, at the crossroads of steep and mountainous terrain and plains. It is part of the piedmont hilly basin with flat topography and covers around 1,800 mu. The Quaternary has unconformity contact with bedrock, a thickness of 6070m, a movement angle of 45, a strike movement angle of 68, an inclined upward movement angle of 68, and an inclined downward movement angle of 62. It is made up of loess, sand, loam, conglomerate, and gravel. The gravel layer's composition is diverse, containing magmatic rock, metamorphic rock, sandstone, and limestone with good roundness. From top to bottom, the mine contains several aquifers: ① Quaternary sand and gravel pore aquifer. ② Carboniferous-Permian sandstone aquifer of Shanxi Formation of Yuemengou Group. ③ Carboniferous-Permian thin limestone aquifer of Taiyuan Formation of Yuemengou Group. ④ Carboniferous-Permian fractured aquifer of Xu Shang sandstone in Taiyuan Formation of Yuemengou Group. ⑤ Carboniferous-Permian Yuemengou Group Taiyuan Formation Xujiazhuang limestone fissure aquifer. ⑥ Ordovician Majiagou Formation limestone fissure karst aquifer. Hydrogeological types are complex.

The coal seams mined in the treatment area are mostly three coal and nine coal, with three coal being a strip mining area. After mining coal bodies with a strip width of approximately 40–90m, a mining thickness of 1.38m1.43m, a minimum mining depth of about 280m, a mining time of 1995–2015, and a coal seam dip angle of around 10, 20–50m strip coal pillars are typically left. The coal mining thickness is 0.9 m–1.51 m, the minimum mining depth is approximately 400m, the mining period is from 1995 to 2015, and the coal seam dip angle is approximately 7. Figure 1 shows a mining map of No. 3 and No. 9 coal in the governance area.

The hazard degree was calculated using probability integral prediction and structural mechanics based on geological and mining conditions, geophysical investigation, drilling, and buried depth of mined-out region in the treatment site [7, 8]. The majority of the mined-out areas are strip mining, and several coal pillars remain. Underground mining causes rock caving, which poses significant security risks. Furthermore, repeated mining of coal seams can lead to the instability of coal pillars, which is extremely harmful to future buildings (structures) and must be treated [8–11]. After careful examination of the economy and technology, it was decided to treat the goaf with grouting filling.

3 Grouting Treatment

Through scheme comparison and selection, it is comprehensively determined that the goaf treatment adopts the zoning treatment mode, and the grouting and filling treatment scheme combining vertical drilling and directional drilling is adopted, and experimental research is carried out while grouting construction is underway, in order to improve the dynamic mode of grouting scheme at any time.

3.1 Drilling Engineering

There are 190 vertical boreholes with a total length of 87683m m in the governing area's red line of land requisition. There are 47,986 m/118 grouting holes in the No. 3 coal

Fig. 1. Mining Map of No. 3 Coal and No. 9 Coal in Governance Area

seam, and the row spacing between drilling holes is approximately 30–50m, arranged in a plum blossom shape. 9. There are 39697m/72 coal grouting holes, with drilling spacing of around 40–60m and row spacing of approximately 50–60m. The footage is 55468.41m, and there are 30 cluster directional wells outside the red line of land requisition, with 3–7 branches for each well. As shown in the Fig. 2,There are 14 cluster directional wells with second spudding shaft structure in No. 3 coal goaf, with a length of 22,831.23 m and a spacing of 45–70 m between branch well target locations. 16 cluster directional wells with third spudding shaft construction are placed in 9 coal goaf, with footage of 32,637.18, and the spacing between branch well target locations is 50–70m. Each branch hole's goals can be constantly modified based on the geological conditions disclosed by the first-order drilling.

According to field drilling study, this site's Quaternary system is a multi-layer gravel layer, and the bedrock section is severely damaged, with an RDQ value of 1–4% and high water permeability. The observed water level after drilling is 11.61m19.82m, and a significant amount of water returns to a point about 3m below the coal floor, indicating high confined water. The particular drilling layout is shown in Fig. 3.

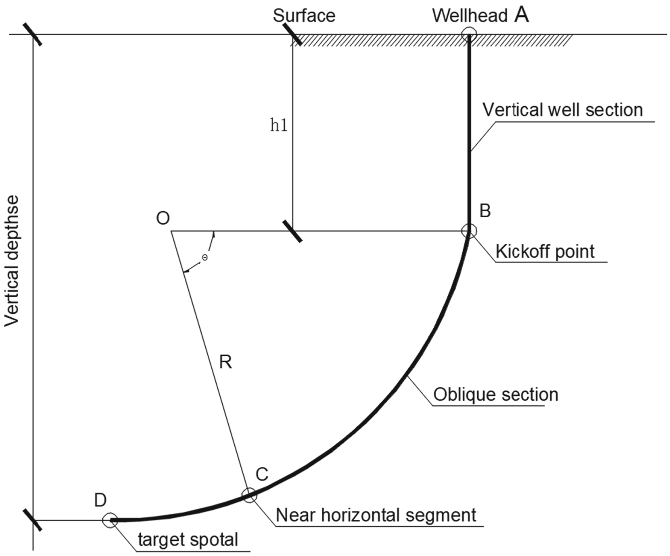

Fig. 2. Schematic diagram of well type

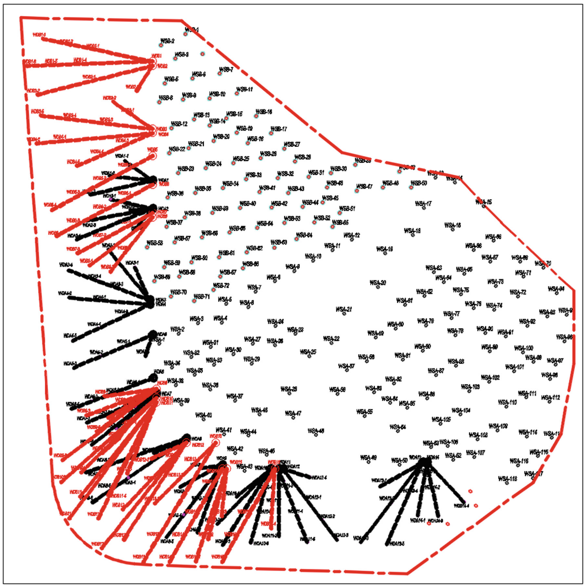

Fig. 3. Drilling Layout of Governance Area

3.2 Grouting Project

Vertical drilling adopts subsection downward intermittent static pressure grouting filling technology. The subsection position can be based on the drilling process and stratum conditions. When the drilling circulating fluid leaks seriously, the goaf can be filled with grouting. After the initial setting of the slurry, sweep the hole and continue drilling. The first grouting position should be 10m into the fracture zone (15–20m before the final hole), and the second grouting position should be the depth of the final hole. The specific grouting times can be determined according to the actual situation on site.

Cluster well grouting adopts progressive subsection grouting technology, and each branch well carries out drilling grouting work according to the order of coal seam occurrence from low to high. The segment length is determined according to the drilling exposure, and the drilling footage of a single segment should not be greater than 50m. If there is no leakage of washing liquid, press water, and determine whether to inject according to the situation. In case of total leakage of flushing fluid, the drilling tools should be recovered in time, and the holes should be washed by pressure water first, and then grouted, and the slurry concentration should be injected in the order of first dilution, then concentration and then dilution.

For the control area with multiple coal seam goaf, the multilateral wells are drilled and grouted from top to bottom in general. After the upper goaf reaches the grouting end standard, the holes are re-swept and drilled to the grouting target interval of the lower goaf to carry out the control work.

According to the survey results, the mined-out area in the project area is fully filled with water. After the mined-out area is exposed by drilling, measures such as low-pressure thick slurry, adding accelerator, intermittent grouting and drainage should be adopted to ensure the grouting effect.

The process flow of grouting and filling is shown in Fig. 4. The design process of goaf grouting can be divided into four links, namely: ① construction waste regeneration. ② preparation of cement fly ash slurry. ③ preparation of high (low) concentration solid waste paste filling material. ④ Goaf filling.

4 Grouting Experimental Study

4.1 Injecting Paste Material Test

The treatment area's mined-out section is located in a high constrained waterwater rich gob location. To meet the treatment requirements, the design employs the low-pressure thick slurry method, intermittent grouting for many times, and the use of accelerator. The seed setting rate and grouting solid strength of this approach must be checked and validated to ensure that they match the specification requirements. Furthermore, whether the slurry's effective diffusion radius meets the design requirements must be confirmed. As a result, several tests on the mixing ratio and slurry performance have been conducted using the testing while constructing approach, and the results are displayed in Table 1.

It has been discovered that increasing the slurry concentration can significantly enhance the setting rate and compressive strength of the slurry, but it has an influence on the slurry's effective diffusion radius. Finally, as the major filler material, an aggregate-free slurry with a water-solid ratio of 1:1.1 and a solid ratio of 2.5:7.5 is used. The principal filling material is aggregate slurry with a water-binder ratio of 1:1.1, a mud-cement ratio of 2.5:7.5, and a cement-bone ratio of 1:1.

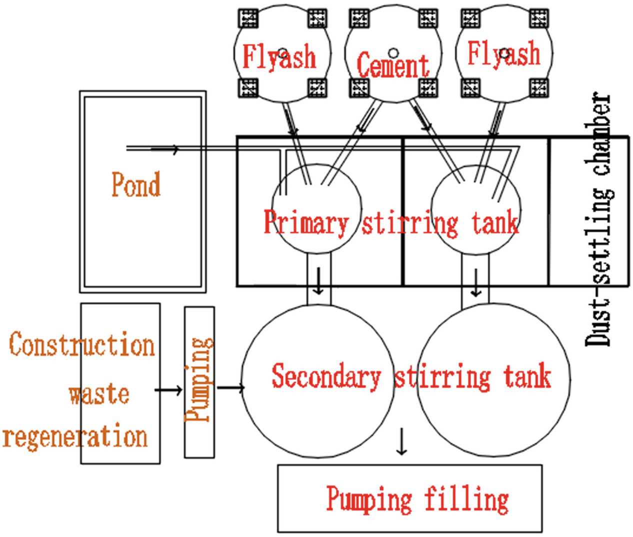

Fig. 4. Process flow chart of grouting and filling in goaf

4.2 Grouting Technology Test

In the treatment of this site, in addition to the experimental research on material selection, the construction methods and methodologies were also examined.

When a water-rich gob area is filled with water, the slurry separates and the diffusion radius shrinks, reducing the filling effect significantly. More importantly, water conductivity destroys the surrounding environment, and it is difficult to assure that the slurry reaches the bottom of the hole during grouting, so it confronts two problems: (1) How to handle the problem of high confined water in the subsurface goaf at the treatment site. (2) How to ensure the stone rate and compressive strength of the slurry in water-filled goaf grouting.

After drilling holes, a big amount of water will gushe into the treatment area's surface. The laboratory analysis of the water quality reveals that it is mostly old empty water. When dealing with this high confined waterwater rich gob area, the solutions of "hanging", "dividing", "using", and "guiding" are determined by referring to previous experiences and combining them with the actual situation on site.

(1) "Curtain" means that after drilling holes, grouting treatment is promptly performed for holes with little or no water inflow, and a curtain is produced in the subsurface goaf to separate large amounts of groundwater.
(2) "Divide," that is, divide the treatment area again into several areas and carry out grouting treatment in different areas, which is conducive to the formation of a curtain in a small underground area, so that the slurry does not conduct to nearby rivers or other areas through groundwater and cause environmental pollution.
(3) "Use" means that pipelines are directly installed for boreholes with large water inflows, which are then led to the reservoir and used as construction water.

Table 1. List of Proportion and Performance Test Results of Aggregate-containing Slurry

serial number	Water-binder ratio	Mud-ash ratio	Glue-bone ratio	Specific gravity	Stone rate (%)	Viscosity (Pa.s)	Mobility (mm)
1	1.3	1:4	1	1.46	87	0.1	260
2	1.3	1:3	1	1.4	75	0.08	263
3	1.3	3:7	1	1.45	77	0.39	258
4	1	1:4	1	1.52	89.2	0.36	213
5	1	1:3	1	1.57	90.5	0.49	223
6	1	3:7	1	1.58	88.9	0.38	253
7	1	1:4	1:1.5	1.68	94.8	0.64	265
8	1	1:3	1:1.5	1.68	95.2	1.01	285
9	1	3:7	1:1.5	1.74	96.4	1.16	269
10	1	1:4	1.5:1	1.48	84	0.27	275
11	1	1:3	1.5:1	1.44	82.9	0.23	287
12	1	3:7	1.5:1	1.45	84.7	0.24	293
13	1:1.1	1:4	1	1.61	94	0.93	288
14	1:1.1	1:3	1	1.67	92.6	0.93	294
15	1:1.1	3:7	1	1.65	94.2	0.91	203
16	1:1.1	1:4	1:1.5	1.71	96	1.29	188
17	1:1.1	1:3	1:1.5	1.74	98.9	1.16	198
18	1:1.1	3:7	1:1.5	1.75	98.1	1.49	178
19	1:1.1	1:4	1.5:1	1.5	90	0.65	231
20	1:1.1	1:3	1.5:1	1.51	89	0.45	265
21	1:1.1	3:7	1.5:1	1.51	92	0.53	254
22	1	1:5	1	1.54	91.9	0.45	220
23	1	1:5	1	1.5	86.8	0.51	230
24	1	1:5	1:1.5	1.65	96	0.69	269
25	1	1:5	1:1.5	1.61	91.1	0.73	293
26	1	1:5	1.5:1	1.42	85	0.2	268
27	1	1:5	1.5:1	1.4	83	0.23	271
28	1:1.1	1:5	1	1.57	91	0.54	199
29	1:1.1	1:5	1	1.58	92.1	0.59	196
30	1:1.1	1:5	1:1.5	The slurry is viscous.		1.66	170

(*continued*)

Table 1. (*continued*)

serial number	Water-binder ratio	Mud-ash ratio	Glue-bone ratio	Specific gravity	Stone rate (%)	Viscosity (Pa.s)	Mobility (mm)
31	1:1.1	1:5	1:1.5	1.67	94.8	1.1	267
32	1:1.1	1:5	1.5:1	1.45	87.8	0.47	225
33	1:1.1	1:5	1.5:1	1.42	83.5	0.53	273
34	1	1:4	1	1.52	86.1	0.25	282

Note: the 28-day compressive strength of the test block with aggregate is between 2.35 MPa and 4.14 MPa

(4) "Out," that is, using slurry characteristics to drive water, high-pressure thick slurry to inject, and observing whether adjacent drilling holes return water during grouting, it can judge whether the state of mined-out areas and rock fractures are connected, but it can also lead groundwater out of the ground.

4.3 Detection and Scheme Adjustment

To assess if the grouting stone rate and compressive strength satisfy the criteria, the preceding test methods and means must pass the effect test. Because the mined-out area is completely filled with water, the mined-out area's cavity volume can be used to estimate the groundwater reserve. The flow calculation is utilized to verify the water quantity, and the slurry filling degree can be generally estimated in conjunction with the grouting quantity, that is, V grouting $\times$ 85% $\geq$ V mined-out $=$ V water can meet the design requirements. After calculation, the V mined-out in the pilot injection area is 490,000 m^3, the V water is 490,000 m3, and the grouting volume V grouting is 590,000 m3, so it can be judged that the filling rate of slurry meets the design requirements. Combined with the stone rate data of injecting paste material in the previous laboratory, it can basically be considered that the stone rate meets the design requirements. Acoustic detection is required to further validate the filling effect. According to real measurements, the acoustic wave velocity range before grouting is 2655 m/s–2712 m/s, and the acoustic wave velocity range after grouting is 3285 m/s–3298 m/s. According to past experience, when the acoustic wave velocity exceeds 3200m/s, the filling density is thought to be higher [11].

The compressive strength of the test block formed of the selected material ratio fulfills the design criteria, according to the laboratory test, however whether the strength of the stone body in the water-filled goaf meets the requirements requires further verification. We know from earlier study that the strength of fly ash concrete rises slowly at low temperatures [12], so we can wait 28 days after grouting filling in the experimental area to see if the grouting stone fits the requirements. Figure 5 depicts a photograph of the removed serous calculus body.

The quantity of slurry stones recovered by field examination after drilling and coring is modest, and the majority of them are fractured. According to the investigation, it could be due to a variety of circumstances, including deep drilling and challenging coring.

Fig. 5. Photos of coring in the treatment test area

A limited number of slurry stones retrieved from the field had compressive strengths ranging from 2.28 MPa to 3.05 MPa, which matches the design criteria.

When the grouting effect in the experimental region is summarized, it is discovered that the grouting procedure in the goaf filled with high confined water must be gradual. After successfully addressing the issue of water collection in the subterranean goaf, it is required to correctly control the slurry concentration and raise the grouting pressure in order to ensure the diffusion radius. The slurry ratio is finally adjusted to a water-solid ratio of 1:1.1, a solid ratio of 2.5:7.5, a water-solid ratio of 1:1.1, and a solid ratio of 3:7 after extensive analysis and research. As the main filling material, aggregate slurry with a water-cement ratio of 1:1.1, a mud-cement ratio of 2.5:7.5, a cement-bone ratio of 1:1, and a water-cement ratio of 1:1.1 is used, and the compressive strength of the grouting stone body is improved on the basis of ensuring the filling rate.

5 Conclusion

(1) A concept and technical method for treating high constrained waterwater rich gob area are proposed. The injection paste substance and grouting technology of high confined water water rich gob area are researched in conjunction with engineering practice, and the accuracy of technical methods is validated.

(2) The slurry ratio of the treatment project is finally determined through the test summary, which not only confirms the project's quality, but also saves money and creates significant economic benefits.

(3) The practical issues encountered in grouting treatment engineering are solved through experimental research, which covers the domestic research gap and provides technical support for grouting engineering under comparable conditions in the future.

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