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Key Technology of Ground Grouting Treatment for Inclined Shaft under Condition of Super Thick Water-Rich Loose Layer

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Abstract

Shaft is one of the important links of mine production. In recent years, wellbore deviation has occurred many times in various regions of China, especially under the condition of thick water-rich loose layer, wellbore deviation has become an important factor that seriously affects the safety of mine production and miners' life. Taking the serious deviation of shaft in Guotun Coal Mine in Shandong Province as an example, this paper analyzes the causes of wellbore deviation from the aspects of wellbore geological conditions and wellbore construction methods, and grouting treatment engineering carried out on the deviated shaft under the condition of mine production. Through on-site grouting construction, repair and treatment are remarkable, which provides reference for the subsequent surface grouting treatment engineering of wellbore deviation.

Keywords

Wellbore Deviation, Water Pressure, Grouting, Pressure Relief

1. Introduction

Since coal mining, there have been dozens of shaft rupture accidents caused by shaft deviation, which seriously affects the safety of mine production. Domestic scholars in our country have made in-depth research around the problem and made outstanding research results. For example, Yu Baohua [1], Cui Jinfei [2], Jing Laiwang [3] [4], Liu Huanxin [5] [6], etc., obtained the causes of coal mine shaft deviation through research; Wang Baoliang [7] *et al.* repaired and reinforced the wellbore by studying the method of ground grouting, and achieved a relatively significant effect, which provided a direction for future research. This paper takes Guotun Coal Mine in Shandong province as an example to study the causes and treatment measures of coal mine shaft deviation.

Shandong Guotun Coal Mine was put into operation in September 2009. There are three shafts including main shaft, auxiliary shaft and air shaft. The loose layer and bedrock weathering zone of the shaft are constructed by freezing method, and the bedrock is constructed by ordinary drilling method. By May 2016, serious deviation had occurred in the three shafts.

1.1. Deviation of Wellbore Deviation

- Main shaft: The maximum deviation to the north is 30 mm, and the maximum deviation to the west of the wellbore is 348 mm, in which the deviation of the topsoil section (at 580.8 m vertical depth) is 300 mm.
- Auxiliary shaft: The maximum deviation to the north is 104 mm, and the maximum deviation to the west of the wellbore is 336 mm, in which the deviation of the topsoil section (at 580.8 m vertical depth) is 320 mm.
- Air shaft: Due to the influence of deviation, the observation of the ladders in the shaft of the air shaft found that there were many damages in the ladders, such as the deformation of the telescopic shaft wall, the shedding of concrete, and the emergence of reinforcement.

1.2. Overview of Main Water-Resisting Layer in Wellbore Loose Layer

The thickness of the loose layer near the wellbore is about 571 - 581 m, which belongs to the typical thick water-rich loose layer. The thickness of the loose layer is generally thin in the southwest and thick in the northeast. The loose layer can be divided into three aquifers (groups) and two water-resisting layers (groups) from top to bottom. The hydrogeological characteristics of the water-bearing and water-resisting layers (groups) are shown in Table 1.

2. Mechanism Analysis of Wellbore Deformation Deviation

Through the monitoring work of the shaft after the mine was put into operation, it was found that the three shafts all showed the characteristics of the main westward deviation, followed by the northward deviation, and the main deviation was near the bottom interface of the loose layer. The deformation deviation mechanism of wellbore is analyzed from the following three aspects.

2.1. Variation of Wellbore Flow Field

There is a small secondary complex syncline structure near the wellbore, which causes the wellbore to bear considerable concentrated tectonic stress, and the tensile structural fractures are more developed. Under the influence of mine mining and drainage, the aquifer at the bottom of the loose layer and the goaf form a large head pressure difference. In addition, the goaf is mainly located in the northwest of the wellbore. The groundwater at the bottom of the loose layer

Table 1. Hydrogeological characteristics of loose aquifer.

Water-bearing and Water-resisting Layers	Buried Depth of Floor (m) Minimum-maximum Average	Pure Thickness (m) Minimum-maximum Average	Hydrogeological Characteristics
First aquifer	85.20 - 86.30 85.70	37.30 - 45.75 40.41	It is composed of clay, sandy clay and fine sand. It is recharged by atmospheric precipitation and surface water. It has medium water-rich property and multi-layer groundwater. Unit inflow 0.6396 L/s·m, hydrochemical type SO_4·Cl − K + Na, salinity 1.522 g/L.
First aquifer	136.10 - 138.30 136.87	44.80 - 48.20 46.23	Gray green, brown yellow clay, sandy clay, plastic index 17.1 - 24.8, water barrier performance is good.
The second aquifer	332.20 - 334.30 333.37	73.00 - 78.10 75.27	Medium and fine sand, clay, sandy clay composition. The sand layer is loose, with many layers but small single layer thickness and strong water-rich property.
The second waterproof layer	542.00 - 546.60 544.47	144.00 - 159.70 151.19	Clay, sandy clay, with columnar, tabular gypsum crystals, rich in montmorillonite, stable thickness, good water insulation performance.
The third aquifer	583.10 - 587.40 585.57	25.50 - 37.00 30.81	It is also called "bottom contains". Coarse sand, medium sand, sand layer thickness changes greatly, poor continuity part of clay 2 - 4 layers. Unit inflow 0.0009 - 0.0152 L/s·m, permeability 0.0028 - 0.0512 m/d, hydrochemical type SO_4 − K + Na·Ca, salinity 2.216 - 2.844 g/L.

is connected with the bedrock weathering zone through structural fractures, and continues to recharge to the goaf in the northwest direction, resulting in the decline of the bottom water level near the wellbore and the surface settlement. Under the self-weight of the wellbore and its ancillary facilities, the main body deflects westward and then northward. The location of goaf is detailed in Figure 1.

2.2. Variation of Water Level at Bottom of Loose Layer

The thickness of the loose layer near the wellbore is generally thin in the northwest and thick in the southeast, indicating that the bedrock surface is high in the northwest and low in the southeast. The buried depth of the bottom water level in the three wellbore ranges from 235 m to 245 m, and the buried depth of the bottom water level in the lower section is about 301 m (the original water level buried depth before the well construction is 4.68 m to 6.43 m), which shows that the bottom water level in the area is obviously affected by the drainage of the mine, and the decrease is large.

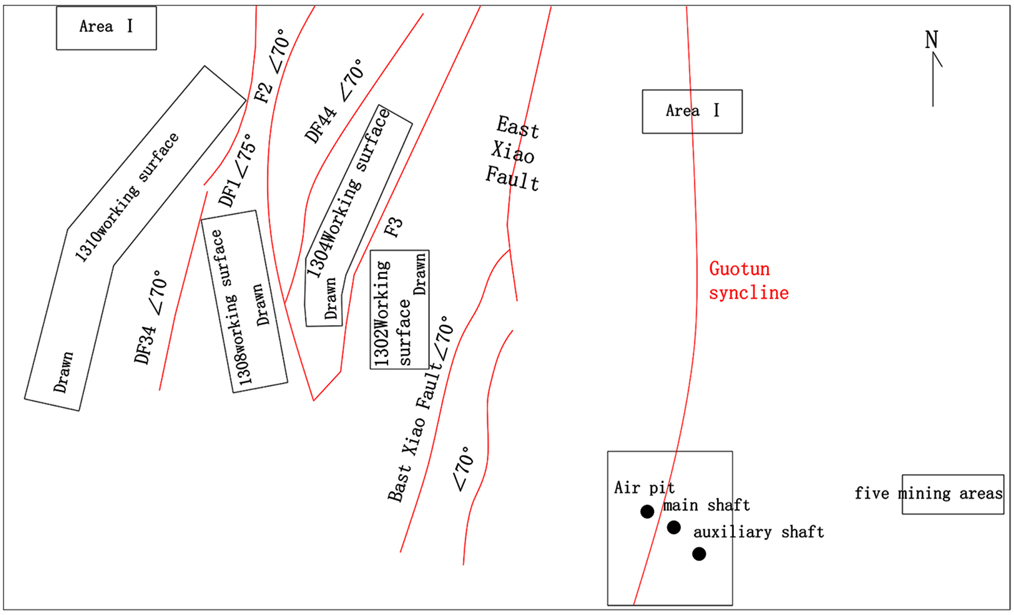

Figure 1. Location of goaf.

In addition, the flow direction of the surface soil aquifer in ICG is 105˚ - 115˚. When the wellbore is hydrophobic, the upstream strata of the flow in the northwest direction are easier to be hydrophobic, and the self-weight effect of the wellbore and its ancillary facilities also leads to the deviation of the main body of the wellbore from the west to the north.

2.3. Construction Methods of Pit Shaft

The geological condition of the mine belongs to the thick and multi-segment water-rich loose layer, and the shaft loose layer is drilled by freezing method. Because of the nature of the soil layer, the direction of the aquifer flow, the uneven settlement of the frozen strata and other reasons, the main shaft of the Yellow River alluvial strata is more prone to settlement or settlement is larger in the west and north. The occurrence of settlement and the continuous impact of aquifer flow and the vacuum negative pressure after flowing through the wellbore lead to different degrees of deviation of the wellbore.

3. Study on Key Techniques of Ground Grouting Treatment for Inclined Shaft under Condition of Large Thick Loose Layer

Ground grouting needs to control the uneven settlement and deviation of the wellbore. The value and control of grouting pressure must ensure the safety of the wellbore, and then ensure the effect of grouting treatment [8].

In this grouting treatment project, four key technologies were studied, including grouting pressure, grouting diffusion radius, grouting hole-pressure relief hole combined intermittent grouting reinforcement technology and single well multi-layer grouting technology.

3.1. Study on Grouting Pressure

Unit water absorption refers to the water absorption per meter of aquifer under different pressures (refers to the water absorption per meter per minute of aquifer, unit: L/min·m);

- Calculation of unit water absorption and permeability of grouting section

The permeability of test section expresses the permeability index of rock mass. The unit of permeability is Lu (Lu). When the test pressure is 1 MPa, the inflow rate per meter test section (L/min).

In this study, 11 water pressure experiments were carried out on five aquifer sections in the loose layer. From Table 2.

1) The unit water absorption of each grouting layer increases with the increase of pressure, which is basically proportional. However, with the increase of pressure, the unit water absorption is obviously weakened after reaching a certain degree.

2) In this paper, the pressure of each injection point is about twice the hydrostatic pressure to evaluate the aquifer permeability. It is found that the Lugeon value of the upper part of the loose layer is 1.81 - 5.25 Lu, and the Lugeon value of the lower part of the loose layer is 1.36 - 1.46 Lu.

Table 2. Statistical table of experimental results of pressurized water.

Pressurized Layer (m)	Hydrostatic Pressure (mpa)	Head Pressure	Injection Point Pressure (mpa)	Hydrostatic Pressure Multiple of Injection Point	Water Inflow Rate (L/min)	Unit Water Absorption (L/min·m)	Hydraulic Conductivity (Lu)
540.46 - 574.90	5.74	3	8.75	1.52	49.74	1.44	0.48
	5.74	4	9.75	1.70	121.17	3.52	0.88
	5.74	5	10.75	1.87	220.91	6.41	1.28
	5.74	6	11.75	2.05	281.64	8.18	1.36
430.33 - 462.43	4.62	3	7.62	1.65	60.50	1.88	0.63
	4.62	4	8.62	1.87	96.08	2.99	0.75
	4.62	5	9.62	2.08	234.15	7.29	1.46
	4.62	6	10.62	2.30	296.00	9.22	1.54
332.27 - 364.27	3.64	2	5.64	1.55	29.54	0.92	0.46
	3.64	3	6.64	1.82	151.09	4.72	1.57
	3.64	4	7.64	2.10	231.63	7.24	1.81
	3.64	5	8.64	2.37	310.68	9.71	1.94
247.34 - 282.00	2.82	2	4.82	1.71	190.61	5.50	2.75
	2.82	3	5.82	2.06	315.15	9.09	3.03
	2.82	4	6.82	2.42	406.00	11.71	2.93
175.05 - 196.11	1.96	1.5	3.46	1.77	164.00	7.79	5.19
	1.96	2	3.96	2.02	221.17	10.50	5.25
	1.96	2.7	4.76	2.43	306.38	14.55	5.39

- Test grouting

According to the permeability evaluation results, the grouting section at the upper part of the loose layer has good injectability. When the pressure of the injection point is 2 times of the hydrostatic pressure, the cement slurry can be injected smoothly. The grouting section at the lower part of the loose layer can appropriately increase the pressure of the injection point. This paper considers that the grouting effect is detected by experimental grouting when the hydrostatic pressure is 2.5 times. The test grouting was carried out in the five grouting layers in the wind inspection hole 3. The water-cement ratio was 1.25:1, and the initial pressure of the test grouting was started at twice the hydrostatic pressure according to the pressure of the injection point. Under the condition of stable grouting amount, the pressure was gradually increased to 2.9 times the maximum pressure. The grouting results are shown in Table 3.

- Determination of grouting pressure

According to the results of water pressure test, test grouting and rock and soil sample analysis, the formal grouting pressure is finally determined (calculated according to the static water level of ground 0) on the premise of ensuring the safety of wellbore: the grouting pressure in the upper part of the loose layer is twice the static water pressure, and the grouting pressure in the lower part is 2.5 times the static water pressure. At the same time, the grouting pressure can be adjusted according to the monitoring situation.

3.2. Study on Diffusion Radius of Grouting

In this study, the influence of water pressure and grouting on the three holes of wind inspection was observed, and the diffusion radius of grouting was analyzed [9].

- The observation hole of wind detection 1 (13.47 m away from the observation hole of wind detection 3)

Wind inspection 3 holes in the water pressure test and test grouting 20 minutes, the hole began to water, two holes have been communicated, but no cement slurry in the hole.

Table 3. Statistical table of test grouting data.

Hole Number	Grouting Layer (m)	Point Pressure (Mpa)	Inpouring Flowrate (m^3/h)	Comparison of Injection Point Pressure and Hydrostatic Pressure
Wind examination 3	540.46 - 574.90	11.82 - 13.92	7.5	2.1 - 2.4 times
	430.33 - 462.43	8.73 - 13.40	8.75	1.9 - 2.9 times
	332.27 - 364.27	7.18 - 9.99	9.58	2.0 - 2.7 times
	247.34 - 282.00	4.89 - 6.69	9.42	1.7 - 2.4 times
	175.05 - 196.11	4.24 - 4.80	9.69	2.2 - 2.4 times
	average			2.0 - 2.5 times

- The observation hole of wind inspection 2 (21.26 m away from the observation hole of wind inspection 3)

1) The first layer (bottom hole depth: 540.46 - 574.90 m): the measured water level depth is 54.017 m before grouting, and the overall water level changes little during grouting, ranging from 0 to 1.444 m. The water level shows a trend of rising first, then falling and rising again, but the overall trend remains downward.

2) The second layer (hole depth: 430.33 - 462.43 m): the water level measured before grouting is 12.180 m, and the overall water level shows an upward trend during the period of water pressure and grouting, but each increase is not large, and the change range is 0 - 2.390 m.

3) The third layer (hole depth: 332.27 - 364.27 m): the measured water level is 10.66 m before grouting, and the overall water level change is on the rise during grouting, and the change range is 0 - 5.15 m.

4) The fourth layer (hole depth: 247.34 - 282.00 m): the measured water level is 7.37 m before grouting, and the whole water level has been declining during grouting, but each decline is not large, and the change range is 0 - 1.42 m.

5) Fifth layer (hole depth: 175.05 - 196.11 m): the measured water level before grouting is 10.507 m, and the overall water level shows a downward trend during grouting, but decreases and increases from time to time. The amplitude is not obvious during the grouting period, and the decline is not large each time. The range of change is 0 - 0.186 m.

The third hole of wind inspection is 39.89 m away from the center of the shaft. During the water pressure and grouting of the third hole of wind inspection, there is no obvious change in the monitoring system of the shaft wall, especially the shaft wall of the wind well. There is no tracer and water increase in the shaft wall, indicating that the water pressure and grouting of the third hole of wind inspection have no effect on the shaft. The plane position diagram of wind inspection test is detailed in **Figure 2**.

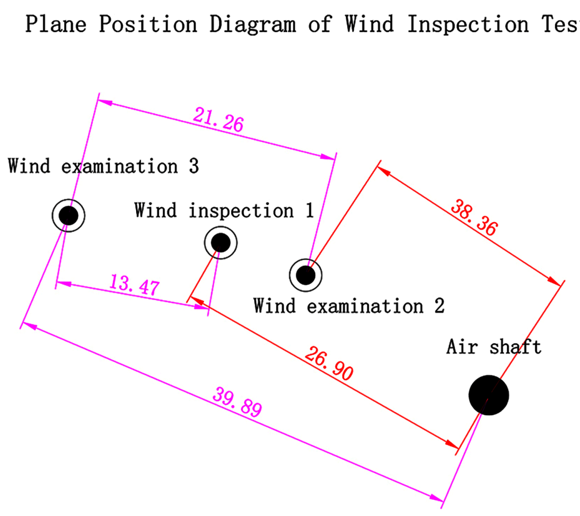

Figure 2. Plane layout of wind test holes.

1) Position arrangement of grouting hole

As mentioned above, according to the diffusion influence radius parameters obtained by the experimental grouting, the grouting diffusion radius should be comprehensively determined to be about 8 m. In order to ensure the grouting effect, the designed hole spacing of the grouting borehole is less than or equal to 14 m.

According to the water pressure test of three holes in wind inspection, test grouting and indoor test of test hole sampling and the analysis of the results obtained, it is determined that the minimum uneven coefficient of loose layer near the wellbore is 2.80, the maximum is 20, and the maximum radius of influence is 13.47 m. The circle diameter of the grouting hole is centered on the center of the wellbore, and the radius is 30 m. At the same time, it is considered that the grouting of three holes in wind inspection has an influence on the wind inspection 1 hole away from 13.47 m. Therefore, the grouting pressure relief observation hole is arranged within 14 m on the circumference of the grouting hole arrangement. The grouting hole and the pressure relief hole are arranged in flower arrangement. The drilling arrangement is detailed in Figure 3.

2) Grouting hole-unloading hole combined with intermittent grouting reinforcement technology

Grouting hole-unloading hole combined with intermittent grouting reinforcement technology is a kind of wellbore deviation grouting reinforcement technology under the condition of thick loose layer. The outer ring hole and inner ring hole are arranged in the surrounding strata of vertical shaft, respectively as grouting hole and pressure reducing hole.

When the grouting hole in the loose layer is grouted, with the continuous injection of slurry in the formation, the slurry will squeeze the pore water in the formation, thus forming the excess pore water pressure. At this time, the excess pore water pressure will pose a great threat to the safety of the wellbore. Therefore, the pressure relief hole is arranged between the grouting hole and the wellbore. When the water level in the pressure relief hole rises to the surface, the

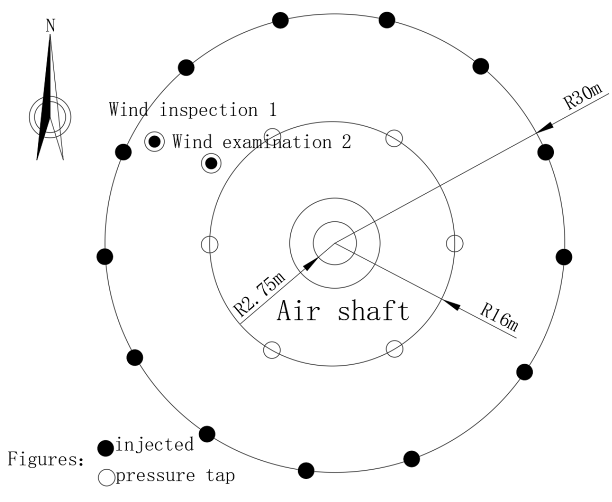

Figure 3. Diagram of grouting hole arrangement.

grouting can be stopped. At the same time, in the process of water level rising in the pressure relief hole, the excess pore water pressure is effectively released, and the transmission to the wellbore is stopped, thus achieving the purpose of pressure relief and wellbore safety protection. As shown in **Figure 4**.

The grouting hole adopts the jump grouting method to complete the grouting work, and the intermittent grouting-pressure relief-grouting-pressure relief function is formed around and over until the grouting hole completes the design grouting amount. Through the grouting hole and pressure relief hole joint intermittent grouting, greatly improve the stability of thick loose layer wellbore reinforcement grouting [10].

3) Study on grouting technology of single well multi-layer section in loose layer

In view of the difficulties in grouting of single well and multi-layer section in loose layer, one-time down-pipe and cementing are adopted, and upward layered grouting is adopted. The specific steps are as follows:

a) Use the Φ190 mm tricone bit to the end hole and enter the Φ139.7 mm tube and flower tube. The grouting layer is flower tube.

Flower tube adopts special processing, flower tube hole adopts layered arrangement, which is beneficial to the sealing of flower tube hole with seamen belt. After the sealing of flower tube hole, the 80 mesh nylon net yarn is wrapped in the second layer and twisted with tie wire, One is to protect the seam band; the second is to prevent sand from entering the tube.

b) Clay cement slurry is used for full-hole cementing and the annular gap is completely closed.

The proportion of clay cement slurry is determined by laboratory to ensure the sealing effect, and the initial solidified clay cement slurry block with the upper clearance of the flower tube cleaning section will not collapse.

c) After 24 hours, the high-pressure jet well washing method was used for each flower tube layer, and the seam zone outside the flower tube and the clay cement slurry block were all washed out and the outlet was washed, after being immersed in sodium pyrophosphate solution for 24 h, the well in the grouting

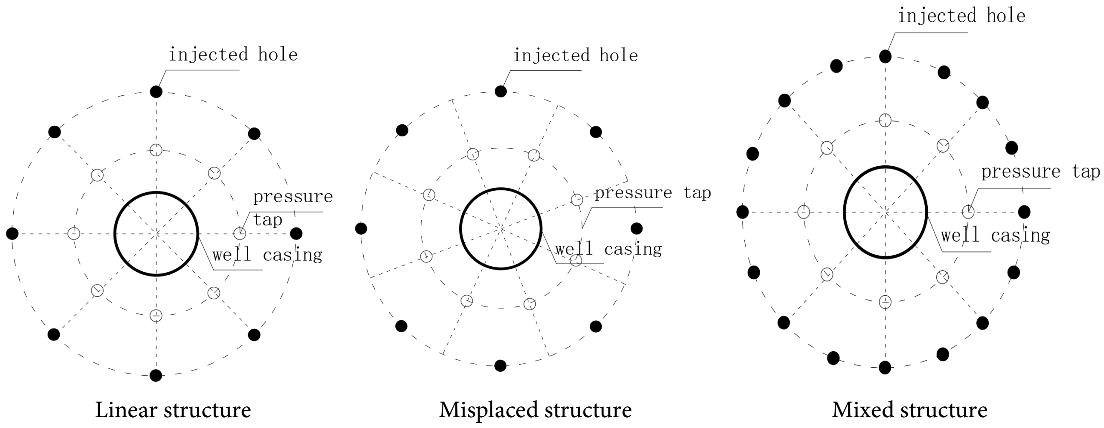

Figure 4. Grouting hole—pressure relief hole joint intermittent grouting reinforcement technology hole arrangement.

target section was repeatedly washed with piston and high-pressure jet until water was cleaned and sand was cleared.

d) Layered water pressure test, grouting from bottom to top, grouting to the end of the last layer, end hole.

4. Effect Evaluation of Shaft Deviation Grouting Treatment Project

4.1. Shaft-Lining Monitoring

The test results are automatically transmitted to the ground acquisition system at a time interval of one set of data per five minutes. The data analysis is as follows:

1) During grouting, grouting did not produce obvious deformation on the shaft wall, indicating that the grouting process and parameters are reasonable.

2) During the grouting period, the seam or crack of the shaft wall did not develop significantly, and the shaft wall was in a relatively stable state, indicating that grouting inhibited the re-failure of mining.

3) The data shows that grouting has a sensitive effect on stratum uplift.

4.2. Ground Survey Monitoring

A certain number of monitoring points and control points are arranged around each wellbore. The monitoring points are distributed around the wellbore, mainly in the west, and the control points are built at the stable coal pillar in the east of the wellbore. Continuous monitoring during grouting construction and half a year after project completion. After half a year of construction, each measuring point is basically in a stable state, indicating that grouting reinforcement is successful and achieves the desired effect.

5. Conclusions

1) Under the condition of super-thick and multi-segment water-rich loose layer, the wellbore deviation is mainly controlled by many conditions, such as the change of wellbore flow field, the change of water level in the bottom of loose layer and the wellbore construction method.

2) Through the coring of test hole, pre-grouting, hydrological observation and surface deformation monitoring, the ground pre-grouting scheme for the three shafts of main shaft, auxiliary shaft and air shaft in the mine is formulated, and the design principle for the treatment of deviation damage of in-service shaft and the treatment method for shaft repair are proposed.

3) The application of ground pre-grouting technology can effectively prevent the mine disaster caused by the deviation of the shaft, but there is still a lot of room for improvement in the ground grouting technology.

4) In this paper, the test of ground pre-grouting technology, the control measure of shaft deviation in Guotun coal mine in Shandong province, is successful, which can be used as reference for the corresponding grouting work.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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