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STUDY ON INTENSIVE DESIGN AND CONTROL OF CHAMBER GROUP UNDER THE CONDITION OF WEAK SURROUNDING ROCK

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Abstract: In order to study the design and stability control of deep soft rock chamber group, taking ninth coal mine of Hebi Coal Power Co., Ltd. as the engineering background, The main problem in normal design is analyzed with the combined method of FLAC3D numerical simulation and field engineering test. and then puts forward targeted control measures and carries out field application. The results show that, compared with the conventional design, the intensive design can reduce the stress concentration degree and plastic zone range of the surrounding rock, as well as reduce the quantities. Compared with conventional supporting schemes, the surrounding rock deformation greatly reduces by more than 82% after adopting bolting and shotcreting with wire mesh + anchor cable + floor anchor supporting. Among them, the floor heave control has obvious effect, and the decreasing amplitude reaches more than 93%. The field application shows that the surrounding rock deformation of the main chamber is within the allowable range, and the chamber control effect is good. Therefore, the research results can provide reference for the design and control of similar chamber groups.

Keywords**:** *deep soft rock; chamber group; intensive design; field test; surrounding rock control*

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1. INTRODUCTION

Of the explored coal reserves in China, 53% of the total coal resources are buried below 1000 meters. With the increase of mining depth, the ground stress increases, the geological condition deteriorates, and the broken rock mass increases, so the traditional mining technologies and supporting methods are challenged, especially the deep intersecting chamber groups, whose stress concentration degree is high, deformation is big, and support is difficult, and small suction well system of pump house substation is a typical representative. Due to its own structural characteristics, the intersecting chamber group is more significantly affected by engineering disturbance, construction sequence, etc., and requires higher engineering geological conditions for surrounding rocks. With different layout of deep soft rock chamber group, the final state formed by excavation is also different, and different excavation sequence will lead to different displacement and failure. Therefore, the structural layout and stability control of the underground chamber group has always been the focus of research.

Since the late 1970s, scholars began to study the impact of the stability of large chambers, and they mainly focused on water conservancy and hydropower. T.N. Hagan (1984) proposed that the copies of the rock mass failure strain should be considered as an important parameter in the process of large cavern group's design and construction and improved the diameter and depth of the blasting hole during construction. H. Yoichi and R. Yamashita (1985) applied elastic finite element to analyze the stability factor of cavern group and proposed the conception of stability index and the critical stability index. Y. Yu et al. (1987) studied the impact of excavation mode, ground stress and geological structure on the stability of surrounding rocks, and pointed out that the excavation times should be minimized in large chambers. S. Li et al. (1996) studied the optimal construction scheme of chamber group with the principle of dynamic programming, and optimized the construction sequence by using the area of damaged area around the hole as revenue function. Y. Zhang (1998) discussed the optimization and stability evaluation method of chamber construction under complex geological conditions. M. Xiao et al. (1987) proposed a three-dimensional finite element numerical analysis method for dynamic simulation of large underground chamber construction process. C. Yan (2006) analyzed the changing rules of partition displacement and plastic zone under different conditions through taking the vertical arrangement of underground chamber groups as the research object.

Due to the complex engineering geological conditions and intricate chamber group structure, the research and development on the deep intersecting chamber group of pump house suction well is very slow. At present, the suction well of conventional pump house at home and abroad is designed as a pump with a small suction well, and then it is connected to the sump via the water distribution drift. The number of pumps and small suction well s is determined by the displacement requirements. The larger the displacement requirement is, the larger the number of suction wells and the depth of water distribution drift will be. Along with the increase of the well lane construction depth of basic construction mines and production mines, deep surrounding rocks are in soft rock conditions, and construction conditions tend to be more complicated, and the difficulty and destroying degree of the roadway and chamber supporting also increase. Especially, conventionally designed pump house chamber, suction well, distribution well and water distribution drift system were very complex. Various intertwined factors cause bad chamber and roadway support conditions, pump house system is destroyed seriously. Meanwhile, unstable overhaul frequently appear which affects the normal operation of pump house and endangers the safety production of mines.

In terms of deep soft rock chamber support, M. He (2014) proposed anchor support technology with constant resistance and large deformation based on the nonlinear large deformation design theory of soft rock. W. Wang et al. (2008) took the coal bunker of Tuzhu coal mine as an example, studied the excavation effect of surrounding rock by using damage mechanics, compared and analyzed the deformation and control of surrounding rock under the condition of no support and anchor injection support. X. Sun et al. (2015) put forward the coupling support countermeasures of slip casting to restore the rock mass strength and anchor cable to strengthen the support at key positions, which met the requirements for the stability control of the pump house under the influence of secondary dynamic pressure. Y. Kang et al. (2014) developed a new hollow grouting anchor cable and proposed a combined support technology, which solved the difficulty in the heaving floor of broken soft rock chambers. To solve the problem of surrounding rock support, S. Chen et al. (2015) proposed the control measures centering on full-face grout injection through taking the main inclined shaft of a mine's structural fracture zone as the research object. A.K. Naithani (2017) proposed the combination of steel fiber reinforced shotcrete anchor supporting system with detailed surveys.Aiming at the deformation and failure of -650 level main substation in Shangzhuang Mine, Peng Gang et al. (2008) put forward the repair scheme of anchor injection + anchor cable hanging net. M. Behnia and M.C. Seifabad, (2018) proposed the supporting system of underground cavern considering surrounding rock deformation through statistic method of quantifying rock engineering parameters.

According to the supporting characteristics of deep soft rock roadway, He Manchao put forward the idea of intensive design of pump house suction well (2004), which has been well applied in many soft rock mines in China. In this paper, based on the previous studies, and taking new auxiliary shaft –420 m level pump house suction well system in ninth coal mine of Hebi Coal Power Co., Ltd. as the engineering background, the deformation and failure of chamber group under conventional scheme and intensive scheme are contrasted, and at the same time, the field test of surrounding rock control is carried out, so as to provide reference and guidance for the design and support of deep soft rock chamber group.

2. INTRODUCTION TO ENGINEERING BACKGROUND

2.1. PROJECT PROFILE

The small suction well system of ninth Mine new auxiliary shaft –420 m level pump house is an electromechanical chamber group, which is composed of substation channel, substation, pump house, pump house pipe way, pump house channel, niche and small suction well, external sump, internal sump, etc. Its service life is longer.

Taking the geological section of pump house in Fig. 1 for example, the surrounding rocks of the chamber group are mainly mudstone (including sandy mudstone), and part of them are sandstone, limestone and seam, so it belongs to the carboniferous Taiyuan group, with a burial depth of 557.74~645.00 m and a thickness of 87.26 m. The surrounding rocks present a medium-thick-thin shape, with well-developed bedding and relatively broken rock masses. The layer whose RQD indicator is less than 50% accounts for about 78%, and the rock mass quality is extremely poor. It belongs to IV class poor rock mass, which is adverses to the support.

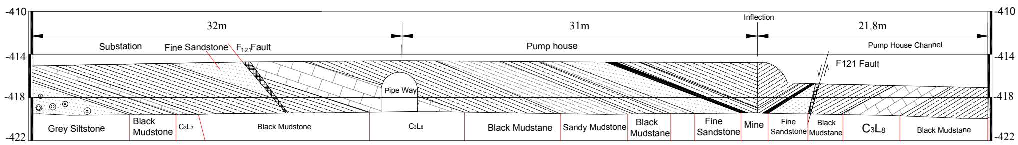


Fig. 1. Geological profile of pump house in new shaft –420 level

2.2. ANALYSIS OF SURROUNDING ROCK LITHOLOGY

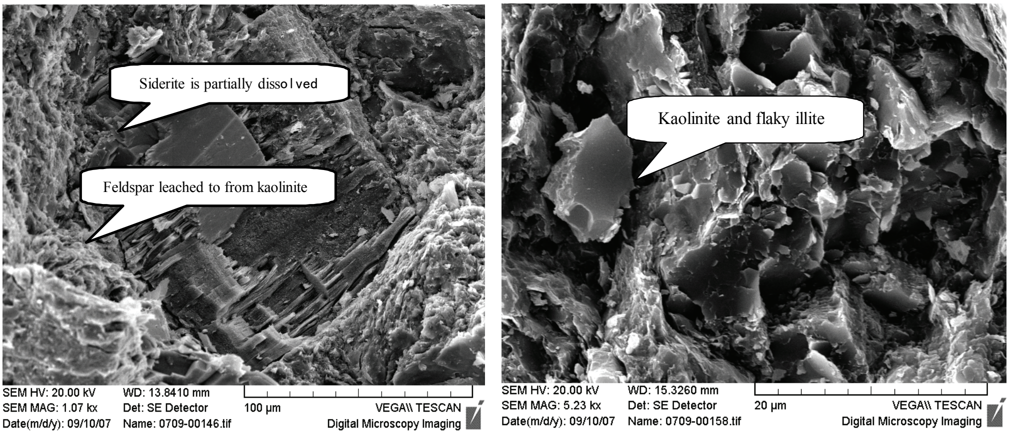
Typical rock samples in the field are selected to carry out scanning electron microscopy and X-ray diffraction tests to analyze the microstructure and mineral composition of rock samples. Figure 2 shows the electron microscope view of some typical rock samples.

Based on the analysis, the following conclusions can be obtained:

1. As for the rocks containing clay minerals, the particle surface of the montmorillonite or the mixture of illite and montmorillonite minerals is mostly schistose and filiform, has a directional distribution. There is corrosion hole development in local part, and some is filled in the microcracks and corrosion pores of the rock particles. Schistose clay minerals, rod-like quartz, feldspar and schistose kaolinite are distributed more widely.

2. Micro-cracks of rocks are well developed, and most of them are well connected. Some cracks are filled with feldspar, small quartz crystals or carbonaceous materials. The surface corrosion phenomenon on the particle surface is relatively serious, and

feldspar is often changed into schistose kaolinite. There are a large number of corrosion pits and corrosion holes on the surface.



(a) sandy mudstone: ×2460 times (b) mudstone: ×5230 times

Fig. 2. SEM of typical rock samples

Figure 3 is X diffraction pattern of typical rock samples, and Table 1 shows the statistics of clay mineral content.

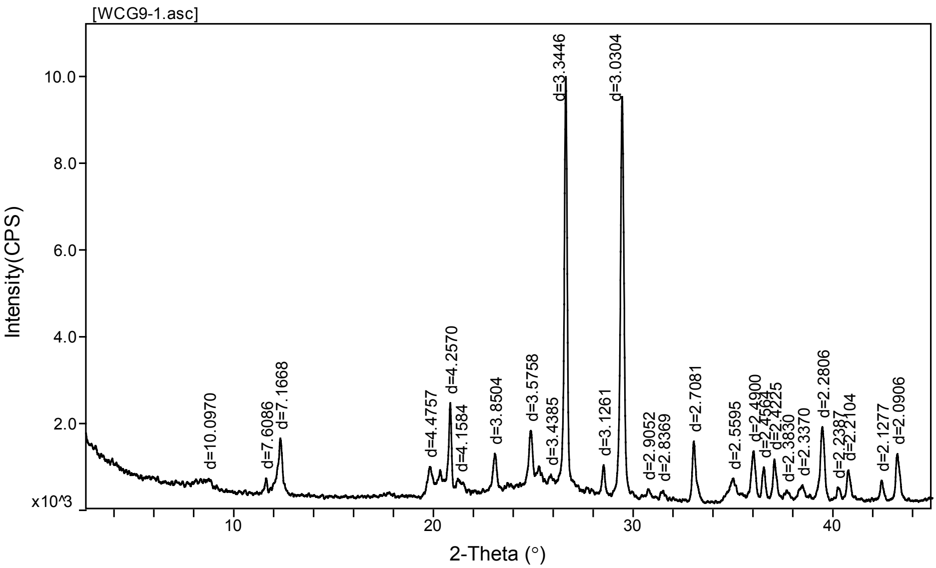


Fig. 3. X-ray diffraction pattern of sandy mudstone

Table 1. Types and relative contents of clay minerals

Sampling spots	Lithology	Relative content of clay minerals (%)			Mixed-layer ratio (%)
Roof of pipe way heading face	Sandy mudstone	I/S	I	K	I/S
Left side of Pipe way heading face	Black mudstone	14	8	78	20
Left side of substation channel heading face	Sandy mudstone	40	7	53	20
Right side of substation	Black mudstone	37	7	56	20
Right side of shaft station heading face	Black mudstone	25	2	73	25
Roof of pipe way heading face	Sandy mudstone	37	6	57	25

I/S – mixture of illite and montmorillonite minerals, I – illite, K – kaolinite.

According to the test results, the main adverse factors to roadway stability are as follows:

1. Higher clay mineral content

The clay mineral content of the sandy mudstone and left side mudstone of the roof of the new auxiliary shaft –420 m level pipe way heading face is 36.3% and 56.4%, respectively, and the clay mineral content of the sandy mudstone and left side mudstone of the channel heading face of the substation is 50.6%. Meanwhile, the clay mineral content of the substation heading face and the shaft station heading face of the new auxiliary shaft is up to 88.3% and 69.3%, respectively. The higher the clay mineral content is, the worse the rock structure will be, and the lower the strength will be.

2. Higher content of the strongly expanding mineral illite /montmorillonite mixed layer

In addition to the lower content (14%) of illite/montmorillonite mixed layer in the clay minerals of the sandy mudstone at the roof of the pipe way heading face, the content of illite/montmorillonite mixed layer in other rock samples is higher, reaching 40%, 37%, 25% and 37%, respectively. It can be determined that the surrounding rocks of the new auxiliary shaft –420 m level chamber group is expansive soft rocks. When the illite/montmorillonite mixed layer in clay minerals are exposed to water, it is prone to swell, so as to soften and disintegrate the rock mass. On the one hand, its strength is greatly reduced, and on the other hand, a large expansive force is generated, which is very unfavorable to roadway stability.

2.3. ORIGINAL DESIGN PLAN AND DEFICIENCIES

Figure 4 shows the general layout of the small suction well chamber group of the new auxiliary shaft –420 m level substation.

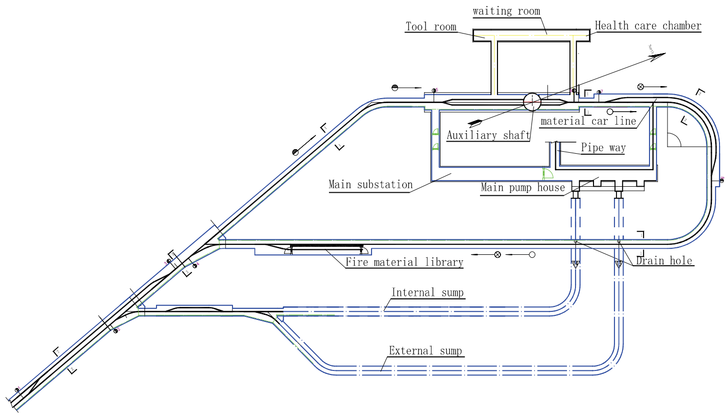


Fig. 4. Schematic of conventional design for suction well system of pump house

The main problems of conventional design are as follows:

1. High degree of stress concentration

The size of pump house is according to the type and quantity of drainage equipment in pump house The layout of the small suction well and water distribution drift makes the pump house become the denser area of the three-dimensional roadway, which is easy to cause the stress concentration of the surrounding rocks as well as the damage of the pump house chamber.

2. Poor stability of the chamber

Limited by the space of the pump house chamber, the size of rock column between small suction wells cannot be too large, which may result in the stress concentration of the surrounding rocks between the small suction wells. Meanwhile, the well wall of small suction well is generally supported by brickwork, and its support strength is lower and it is easy to damage the small suction well, thus affecting the stability and normal use of the pump house.

3. Severe floor heave

The excavation of pump house and small suction well leads to the destruction of surrounding rocks. In addition, the high degree of stress concentration affects the stability of floor and leads to large deformation, floor heave or cracking, which leads to the destruction of equipment foundation and the failure of equipment's normal operation, and thus affects the normal operation of the whole drainage system.

4. Large quantities

Each small suction well is equipped with a water distribution drift connected to the sump. The more the small suction wells are, the longer the longer the water distribution drift will be, and the larger the quantities will be. The roadways are densely crisscrossed and the stress of surrounding rocks overlaps, which makes it difficult to support.

5. Difficulties in cleaning and maintenance

The water distribution drift connecting the suction well with the sump, although the section of is small, is affected by the pump house and the suction well, which is easy to cause damage, resulting in difficulty in cleaning and maintenance.

2.4. INTENSIVE DESIGN SCHEME

In view of the problems existing in the conventional design, the intensive design of the small suction well of the deep soft rock pump house is put forward. Its purpose is to provide a design method that can eliminate the spatial effect of three-dimensional roadway chamber group, which greatly improves its overall stability and reduce the quantities. The design principle and guiding thought are as follows: several small suction wells are combined into one suction well to eliminate the spatial effect of three-dimensional roadway chamber group; The radial reinforced concrete partition of shaft wall is used to divide each small suction well, so as to make the surrounding rocks and supporting force of the suction well be in good condition, improve the overall stability of the suction well, and avoid the adverse impact on the pump house. The system is simple and reliable, and the number of suction wells reduces. Meanwhile, the length of water distribution drift reduces (or completely canceled), and the quantities is saved. The construction is simple and convenient, and the economic benefit is remarkable. Figure 5 is the schematic diagram of the intensive design scheme layout for the suction well of the new auxiliary shaft –420 m level pump house.

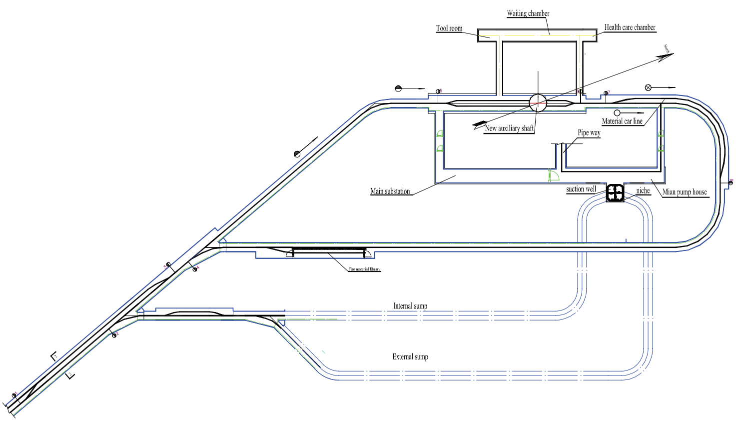
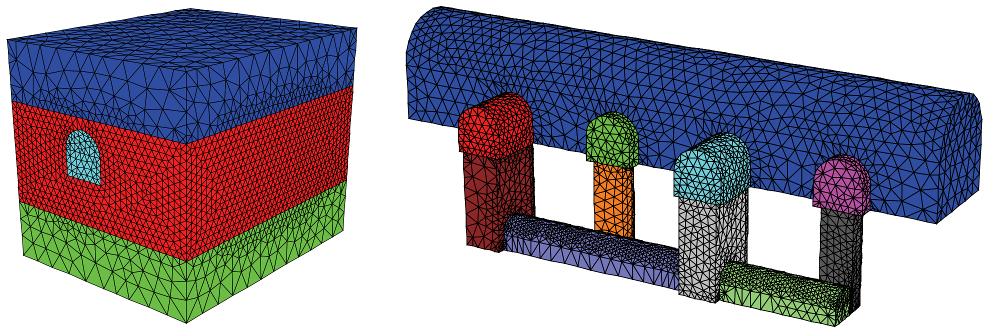


Fig. 5. Schematic of intensive design for suction well system of pump house

3. CONTRAST OF DESIGN AND SUPPORT SCHEME OF CHAMBER GROUP

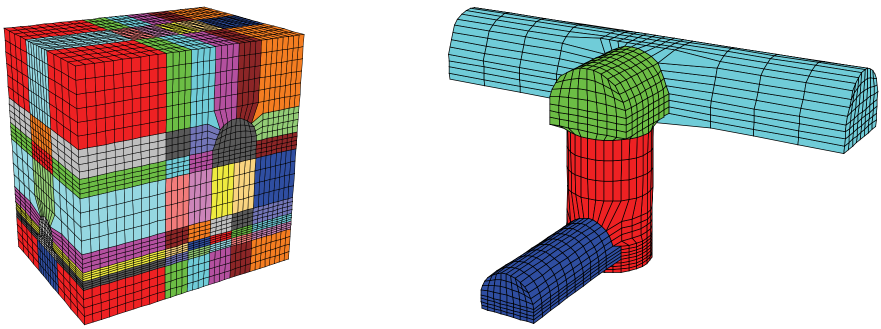
3.1. NUMERICAL COMPARISON OF DESIGN SCHEME

According to the conventional and intensive design schemes of the power substation of the pump house and the chamber group of the suction well, the corresponding calculation models (Figs. 6 and 7) are established, respectively. The model length, width and height are 40 m, 40 m and 40 m, respectively, with a total of 357 152 units and 60 985 nodes. The load imposed on the upper surface of the model is 14MPa, and the lateral pressure coefficient is 0.35. Mohr–Coulomb strength criterion is adopted for the model body, and the physical and mechanical parameters of the rock body are shown in Table 2.



(a) Engineering geological model (b) Geometric model of roadway

Fig. 6. Calculation model of conventional design



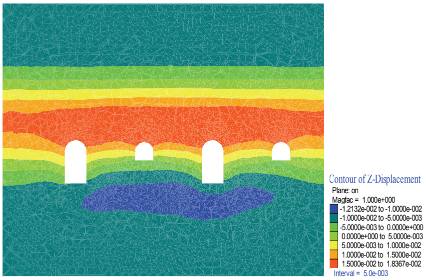
(a) Engineering geological model (b) Geometric model of roadway

Fig. 7. Calculation model of intensive design

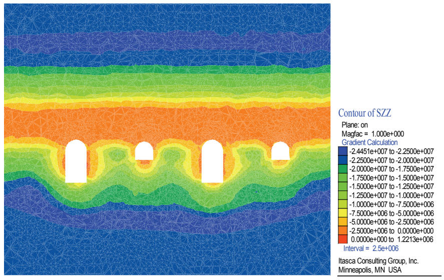
Table 2. Physical and mechanical parameters of rock mass

Lithology	γ (kg/m^3)	K (GPa)	G (GPa)	σ_t (MPa)	c (MPa)	φ (°)
Fine sandstone	2600	2.77	2.08	2.0	3.5	42
Medium sandstone	2650	5.55	4.16	2.5	3.0	45
Sand-shale	2450	4.62	1.89	0.6	1.2	25

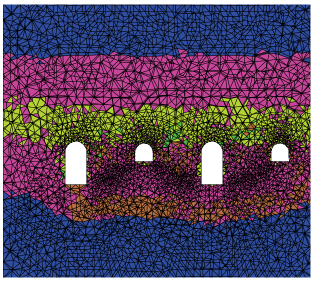
Figures 8 and 9 show the partial displacement, stress and plastic zone distribution of the two schemes.



(a) Vertical displacement



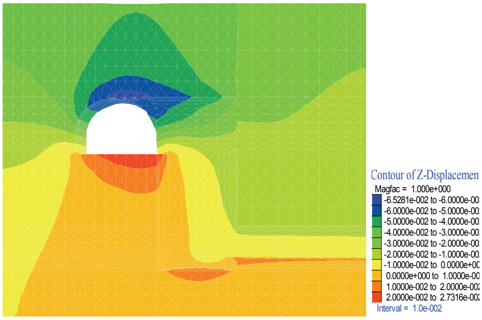
(b) Vertical stress



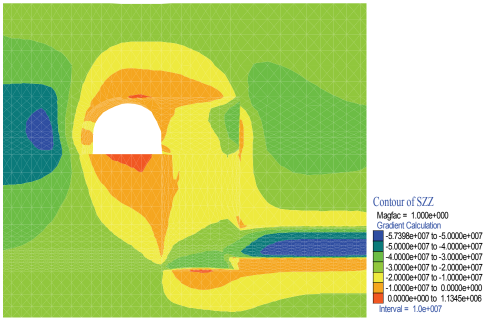
(c) Plastic zone

Fig. 8. Calculation results of conventional design

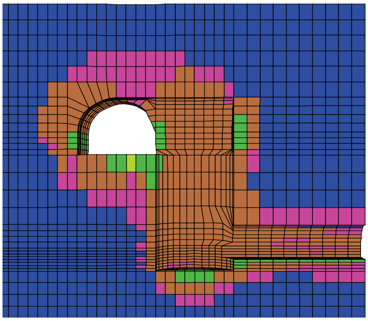
Based on the comparative analysis, it can be known that the excavation quantities of chamber group of the intensive design group is significantly lower than that of the conventional design, and the region of stress concentration after excavation obviously reduces. In the meantime, because the number of chamber groups reduces, the mutual influence and stress superposition between large and small chambers are avoided, and the range of plastic zone obviously reduces, which provides relatively good surrounding rock conditions for chamber support. Therefore, the intensive design scheme is superior to the conventional design scheme, and its difficulty of surrounding rock stability control is relatively lower.



(a) Vertical displacement



(b) Vertical stress



(c) Plastic zone

Fig. 9. Calculation results of intensive design

3.2. NUMERICAL COMPARISON OF SUPPORTING SCHEMES

Based on the actual engineering geological conditions of the new auxiliary shaft –420 m level, the pump house, power substation and other chambers intend to adopt the supporting scheme of bolting and shotcreting with wire mesh + anchor cable +floor anchor.

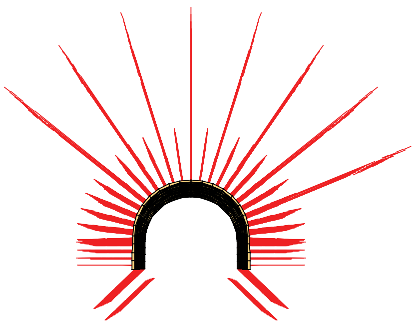


Fig. 10. bolting and shotcreting with wire mesh + anchor cable +floor anchor

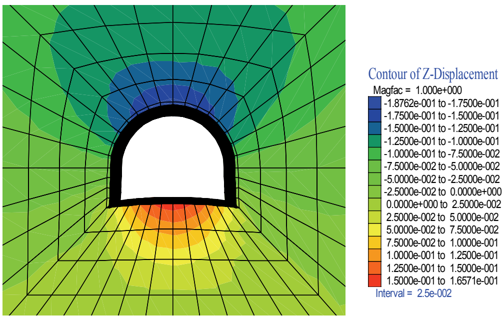
Taking the substation for example, the surrounding rock control effect under the three schemes are compared, and the three schemes are: scheme 1: bolting and shotcreting; scheme 2: bolting and shotcreting with wire mesh + anchor cable; scheme 3: bolting and shotcreting with wire mesh + anchor cable +floor anchor.

The model's length, width and height are 30 m, 50 m and 50 m, respectively, with a total of 21 120 units and 23 300 nodes. The load imposed on the upper surface of the model is 10.5 MPa, lateral pressure coefficient is 0.3, and rock mass parameters are shown in Table 3.

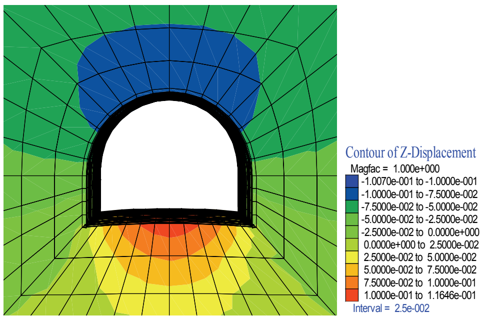
Table 3. Physical and mechanical parameters of rock mass

Lithology	γ (kg/m^3)	E (GPa)	μ	σ_t (MPa)	c (MPa)	φ (°)
Silty mudstone	2700	23	0.42	2.0	3.9	33
Sandstone	2600	21	0.30	1.0	1.2	26
Medium sandstone	2650	32	0.16	1.0	6.5	30

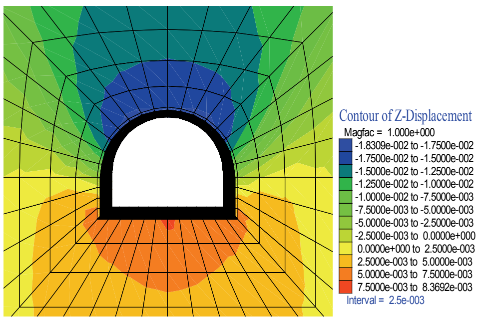
Due to limited length, only the vertical displacement cloud diagram shown in Fig. 11 is listed.



(a) Scheme 1



(b) Scheme 2



(c) Scheme 3

Fig. 11. Vertical displacement nephogram under different support schemes

It can be seen from the analysis that the deformation of the roof, two sides and floor of scheme 1 is 188 mm, 156 mm and 166 mm, respectively, scheme 2 is 101 mm, 80 mm and 116 mm, respectively, and scheme 3 is 18 mm, 14 mm and 8 mm, respectively. The displacement of scheme 3 is significantly reduced by more than 82% compared with other schemes. In particular, the control effect on floor heave is more significant, reaching more than 93%. Combining with the level displacement as well as the change of the plastic zone, it can be seen that under the conditions of scheme 3, the roadway stress is more uniform, the degree of stress concentration greatly decreases, and the plastic zone obviously reduces. Therefore, it is reasonable and effective to adopt the support scheme of bolting and shotcreting with wire mesh + anchor cable + floor anchor.

4. DESIGN AND CONTROL EFFECT ANALYSIS OF FIELD SUPPORT SCHEME

4.1. SUPPORT SCHEME DESIGN AND PARAMETERS SELECTION

The design sections of the main chambers in this test are all straight wall semicircular arch, and the section size is: the net section of the power substation is 5000 × 4000 mm (width × height, the same below); the net section of the pump house is 5300 × 6150 mm; the net section of internal and external sump is 3400 × 3100 mm; The reserved deformation is all 100 mm, and all the support schemes adopt bolting and shotcreting with wire mesh + anchor cable +floor anchor, as shown in Fig. 12.

Main supporting parameters are as follows:

1. Rock bolt

The high-strength whorl-steel bolt of ∅ 22 × 2500 mm such as sinistral rebar without longitudinal bar is adopted, with an inter-row spacing of 700 × 700 mm and adopt one row two, one row one a cross arrangement method. There is lengthening anchorage on end, and the pre-tightening force is not less than 80 kN.

2. Anchor cable

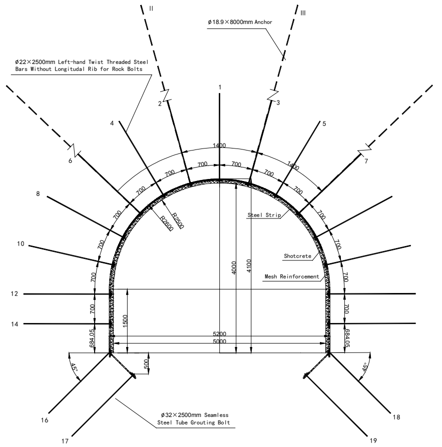
Steel strand of ∅ 18.9 × 8000 mm is adopted, with an inter-row spacing of 2100 × 1400 mm. There are four anchor cables in each row of the power substation and the pump house, and three anchor cables in each row of the internal and external sump, with adopt one row two, one row one a cross arrangement method. The spacing is 1400 (1000) mm, and the pre-tightening force is 100 kN.

3. Floor grouting anchor

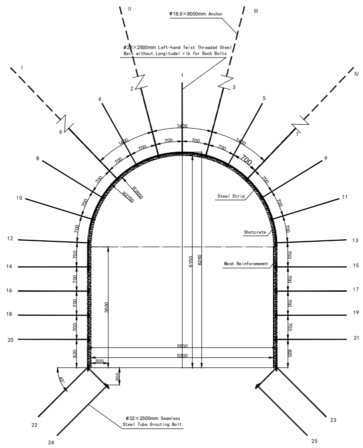
Seamless steel tube of ∅ 32 × 2500 mm is adopted, with an inter-row spacing of 700 mm. Each seamless steel tube rod body is equipped with 12 grouting holes of ∅ 6 mm, and the longitudinal spacing between holes is 200 mm.

4. Shotcrete lining

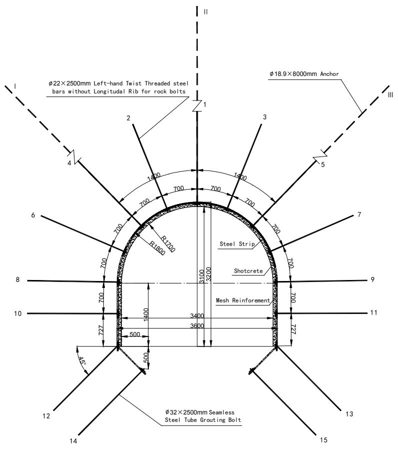
The initial spray thickness is 30 mm, the secondary spray thickness is 50 mm, and the grade is C20.



(a) Substation support design section



(b) Pump house support design section



(c) Sump support design section

Fig. 12. Design section of main chamber support

4.2. MONITORING ANALYSIS OF SURROUNDING ROCK CONTROL EFFECT

Figure 13 is the schematic diagram of test roadway and observation station layout, and Fig. 14 is the deformation monitoring curve of main chambers.

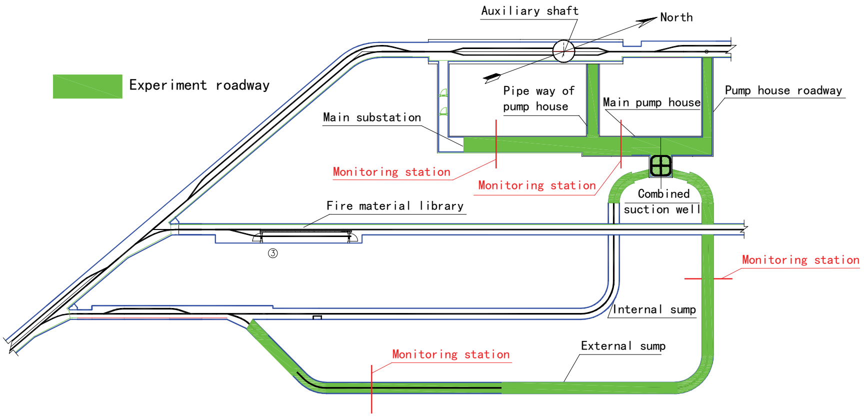
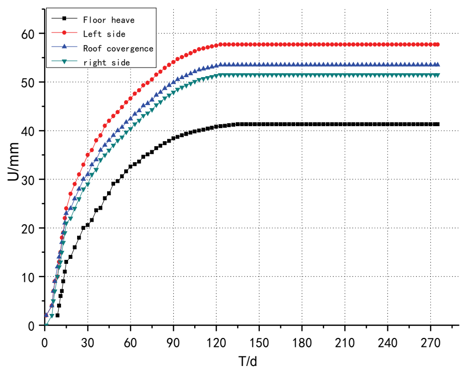
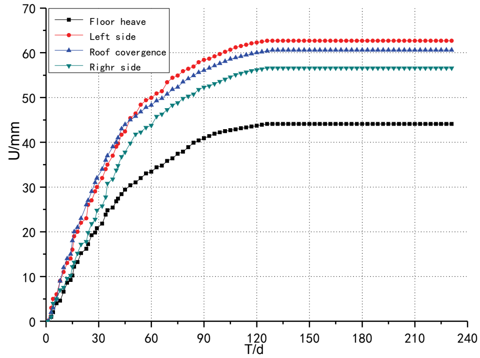


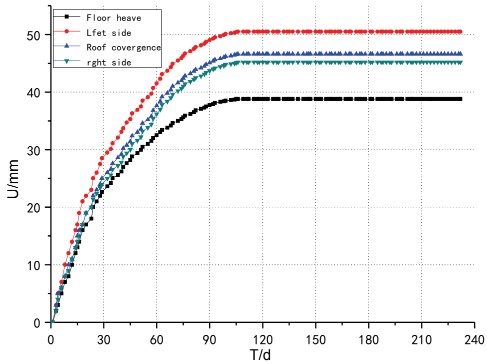
Fig. 13. Schematic of test roadway and survey station



(a) Substation



(b) Pump house



(c) Sump

Fig. 14. Displacement change of roadway surface

Based on the comparative analysis, the following conclusions can be obtained:

1. The roof subsidence of the power substation is 54 mm, the maximum displacement of both sides is 109 mm, and the floor heave is 41 mm; The roof subsidence of the pump house is 61 mm, the maximum displacement of both sides is 120 mm, and the floor heave is 44 mm. The deformation is generally within the allowable range. The deformation of the pump house is slightly larger than that of the power substation, and it spends a long time in stabilizing, which mainly because the section size of the pump house is larger than that of the power substation, and there is disturbance influence on the pump house caused by the construction of pipe way, pump house channel, niche and so on.

2. The roof subsidence of the inner and outer sump is 47 mm, the maximum displacement of both sides is 97 mm, and the floor heave is 39 mm. The overall deformation is relatively small, indicating that the intensive design and the matched supporting scheme are reasonable and reach the expected supporting effects.

(a) Substation

(b) Pump house

(c) Sump

Fig. 15. The effect of surrounding rock control on site

As it shown in Fig. 15, after substation, pump house, sump in three places chamber with intensive design and three kinds of supporting schemes, the surface of chamber became smooth. In the reasonable changing range of deformation, the whole effect of chamber was brilliant

5. CONCLUSION

1. Under the conventional design scheme, there are a series of problems existing in the suction well chamber group of deep soft rock substation pump house, such as high degree of stress concentration, poor stability, large quantities, etc. Intensive design provides a type of design method to eliminating the three-dimensional roadway chamber group of space effect and improves the whole stability of chamber groups, so it has a higher superiority.

2. Under the conditions of the calculation example in this paper, With the supporting plan of wire mesh + anchor cable + floor anchor, roadway stress is more even, stress concentration is lower and the area of plastic zone shrinks. The surrounding rock deformation index is over 82% and that of floor heave is over 93%.

3. According to the present experiments, with the supporting plan proposed in the article, main chamber deformation including substation, pump room and water inside - outside is in the allowed range with great control effect. The surrounding rock stress concentration area obviously shrinks and the quantities are also obviously less in the process of contribution, which means that intensive design and its matched supporting plan are reasonable.

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