Numerical Simulation Analysis of Stress and Displacement Field Variation of Chamber Group Disturbed by Excavation

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Abstract: Based on the actual excavation conditions of the large deformation chamber group in XianDeWang coal mine, through the FLAC3D numerical simulation software, the changing trends of vertical stress $\sigma_z$, horizontal stress $\sigma_x$ and the shear stress $\tau_{xz}$ have been analyzed by all steps; also concludes that besides the stress concentration zone, the deflection trend of contour in the compressive stress heightening zone is “when they are near, be away; when they are away, be together”, that is, as to the horizontal stress and vertical stress, because of the disturbance influence of the lower roadway, the contour of the wall near the upper roadway deflects to the side which is away from the upper roadway and the contour of the wall which is away from the upper roadway deflects to the side which is near the upper roadway; finally concludes that the surrounding rock of the chamber has “displacement tendency” influenced by excavation disturbance, that is, the chambers and roadways in the chamber group are influenced by each other and finally the displacement direction of surrounding rock will move towards the direction of the vector sum of “the main moving direction” and “the disturbing moving direction”. Due to the excavation disturbance, the magnitude of the displacement will be influenced by the factors of the relative distance between the disturbing chamber and the geometric size of them.

Keywords: chamber group; excavation disturbance; contour deflection tendency; surrounding rock displacement tendency

1. Introduction

Due to other chambers or tunnels excavation, the steady stress field of original roadway is destroyed, which result in the stress field in the surrounding rock of underground engineering bringing about re-distribution and re-transference. Excavation disturbance refers to the stress impact of original roadway influenced by the excavation of neighbor roadway. Generally speaking, the construction of underground engineering is not only the excavation of a particular single roadway, but also involves the excavation of many complex crossed roadways or chambers according to a certain sequence. So the stress impact of the original roadway is bound to be induced by the new excavation, which results in chambers’s disturbance which have been already stabilized or tend to be stabilized, and then new damage and deformation of the original roadway will reformed⁵⁶⁷. On the contrary, the phenomenon of the disturbance is the result of the interaction between disturbers, rather than one roadway or chamber influencing another simply. So, in the theory, while the excavation is ongoing, the two or more adjacent roadways are both disturbers which disturb each other until the final stable balance of the whole underground engineering body form. According to controlling difficulties of the -200m pump chamber group of XianDewang coal mine, the shift and distribution of the stress at each stage of excavation and the deflection trend of the displacement influenced by the excavation should be analyzed firstly, therefore this can provide theoretical basis for the establishment and optimization of the comprehensive controlling technology scheme.

2. Geological and Engineering Conditions

2.1. Geological Conditions

-200m Pump chamber groups are located under the floor of NO.7 coal seam, the inclination is about 10°, and the height of the overlying strata is about 450m. Near the water pump chamber and water distribution drift, The main property of the rock mass is siltstone, black-gray, thin or mid-thick, layered, brash, fragile, include mudstone and a little of pyrite.

2.2. Project Conditions

As the coal resource reserve of upper group coal seam is exhausted in XianDewang coal mine, in order to extend the service life, the under-group coal seam should be mined urgently. However, because of the threat of the Ordovician limestone water, drainage capacity of the coal mine directly restricts the production of lower coal group. The pump chamber is the main project of the second level, is also the “pre-conditions and key control engineering” of the production of under-group coal.
of the second level are opened at the district station of the 29° inclined roadway, which is mainly used for the drainage of the second level, the total quantities of construction is 240m; the water pumping chamber is used for installing the pumps of the second level and engineering quantity is 57m (Figure 1).

![Figure 1. Engineering condition diagram of -200m Water Pump chamber group](image)

3. Numerical Simulation Analysis of the Excavation Disturbance

3.1. Sequence Program of the Excavation

The main rock parts which will be excavated of the Xiandewang -200m pump chamber group are divided into five parts:

Part I is the main water pump chamber, part II is water distribution drift, part III is the niche, part IV is the connecting roadway, part V is absorbing well and the part VI is the bottom of absorbing well. The sequence and serial numbers of pump chamber group excavation are shown in Figure 2.

Forming the initial stress field is the first step of this calculation and then the excavation steps (or the construction process) will be as follows:

a) Setting up boundary conditions and forming the initial stress field;
b) Full-face excavation of main pump chamber I;
c) Excavation of niche III;
d) Excavation of water distribution drift II;
e) Excavation of connecting roadway IV;
f) Excavation of the bottom of absorbing well VI.

3.2. Analysis of Multiple Re-distribution of Vertical Stress with the Excavation Steps of Chamber Group Construction

From the Figure 3-8 “vertical stress $\sigma_z$ contour of all steps in the excavation”:

1) Step I of the excavation (main pump chamber)

The vertical stress is concentratally created in the two walls of the roadway. The stress concentration zones are located in 1.5 ~ 7m depth of the two walls. The focus stress is 14.0 ~ 17.0MPa. Tensile stress zone is located in the shallow surrounding rock of the roof and the floor of the roadway, and the stress is 0 ~ 0.27Mpa. Stress of the deep surrounding rock gradually turns into compressive stress, and increases with depth gradually until it returns to the original rock stress, forming “tensile stress - 0 - compressive stress gradually increasing” zone.

![Figure 2. Excavation step of pump chamber](image)
water distribution drift gradually connect with each other, the compressive stress contour of the water distribution drift has evident leaning symmetry influenced by the pump chamber.

3) **Step III of the excavation (niche)**
The niches are connected with the pump chamber and disturb the pump chamber greatly. Stress concentration zone of the pump chamber’s wall which is near the niche has moved towards the deep surrounding rock continuously. The stress concentration is generated in the upper top corner of the connecting part of the niche and the pump chamber. The concentration stress is 2.5~5.6MPa.

4) **Step IV of the excavation (water distribution drift)**
The increasing compressive stress range outside the main engineering structure is gradually expanding, and compressive stress zones are superimposed with each other. The stress concentration zone is generated in the wall of water distribution drift which is near the pump chamber, and the depth is about 0.5 ~ 1m.

5) **Step V of the excavation (rising shaft)**
The range of the stress concentration zone of the pump chamber wall which has no well further expands, and the other side reduces. The tensile and compressive zones are mutually integrated and linked up, forming the equivalent stress circle of the underground engineering body. The part of the inner corners have a relatively large vertical tensile stress, the two walls of the well and the top of the water distribution drift are evidently influenced by the tensile stress which has range of 0~5.6MPa.

6) **Step VI of the excavation (bottom of the well)**
The external stress increasing zone of the underground engineering body is gradually expanded downwards and the destroyed range is further enlarged.

### 3.3. The Analysis of the Multiple-time Redistribution of the Horizontal Stress and the Shear Stress in Each Step of the Excavation of the Chamber Group

According to the disturbance analysis of the vertical stress $\sigma_z$ in each excavation step, we can know that the stress filed outside the chamber group is redistributed for several times, leading to the further enlarging of the outer plastic circle of the main body engineering, and then the final stable stress distributing structure is formed. The excavation disturbance status of the horizontal stress $\sigma_x$ and the shear stress $\tau_{xz}$ is basically similar to the vertical stress $\sigma_z$, which are all along the normal
direction of the stress to form the stress concentration zone and a "tensile stress - 0 - compressive stress gradually increasing" zone is formed along the stress direction. As the progress of the excavation steps of the chamber group, the stress is transferred, enhanced and reduced according to the above rules. Then the balance status of the stress will be finally formed, which we will not talk about further here.

In particular, after several-time redistribution, the horizontal stress $\sigma_x$ finally forms a stable stress filed structure. Owing to the influence of the geometrical shape (similar to a parallelogram) of the main structure of the chamber group, the horizontal stress concentration zone is steadily distributed along the symmetrical oblique axis of the main chamber group (Figure 9).

After the excavation of the chamber of the pump house, the shear stress $\tau_{xz}$ is concentrated in the four corners of the roadway[6] and is redistributed along the excavation of other chambers or roadways. After the excavation of the water distribution drift, the shear stress concentration occurs in the four corners at the same time, especially in the disturbance direction (the connecting line of the two chambers), and the shear stress is overlaid and connected. After the rising shaft, the shear stress concentration occurs at the lower side of the small well which is near the pump chamber and is concentrationly connected with the stress of the upper bottom corner, the shear stress concentration zone along the disturbance direction disappears. At last, the shear stress concentration zones are generally distributed according to the parallelogram shape of the main chamber group (Figure 10).

3.4. The Deflection Law of the Stress and the Displacement Field Influenced by the Excavation Disturbance

1) The deflection trend of the stress increasinging zone except the high stress concentration zone

The continuous excavation of the multiple roadways in the process of excavation made the stress distribution which was stable influenced by the stress disturbance for a second or more times and thus redistribute. In the excavation process of the short-distance of the chamber or roadways, the plastic destroyed circles is formed respectively. As the distance between the chambers or roadways which disturb each other is short, the destroyed circles of them may be overlaid, leading to the destroying degree of the cross rocks increase and therefore the stress loading ability of this part of surrounding rock decrease. The stress concentration zone will lose its stability and move toward the deep wall rock. When the strength of the wall rock surpasses the stress concentration strength, the stress balance is realized for a second time. The surrounding rocks which are deeply destroyed are located between two roadways, thus the stress increasing zone near the surrounding rock of one side of the roadway is further destroyed. As the surrounding rock of the disturber also form a stress increasing zone, the "tensile stress - 0 - compressive stress gradually increasing" zone of the one which is disturbed by the disturber deflex to ward the contrary direction in which the disturber exist, that is the tendency of “move away from the disturber”, the other side in order to keep the balance of the whole engineering structure, deflex towards the other side.

Being disturbed by other chambers, except the stress highly concentrated zone, the stress gradually increasing zone is provided with a deflection trend of “when they are near, be away; when they are away, be together” (Figure 11). That is, as for the stress increasing zone of each direction stress, take the lower roadway for example, the contour of the wall which is near the upper roadway influenced by the upper roadways deflex towards the direction which is away from the upper roadway, and contour of the wall which is far from the upper roadway influenced by the upper roadways deflex towards the direction which is near the upper roadway.

2) Deflection trend of displacement vector of chamber group

From the point of view of space and mechanics, chamber group is in a stable triaxial stress state. In essence, the roadway's roof and floor are also a kind of wall. The roadway is actually a rectangular or arched hollow space
structure in the underground which is in the triaxial stress state. In this state, the surrounding walls (including roof, floor and two walls) have to be closer to the convergence to form plastic circle destruction, that is, the roof goes down, floor heave, the two walls move closer. In this state, this tendency is what we will mention below, the "main direction of movement", which is the rock convergence patterns of no-disturbance state in the triaxial stress state. However, with the rest roadway excavation, excavation of space will inevitably be increased, which makes the disturbed rock converge towards the disturber's direction (displacement of disturbance direction). In this case, the displacement of the surrounding rock will appear an overlaying of the main stress moving direction and the disturbing moving direction displacement. That is, for the overlaying of the stress, and the vectors are added together by use of the parallelogram law and the final direction and trend of the surrounding rock is formed (Figure 12). In the same geological conditions, the larger the geometrical size of the chamber which works as a disturber is, the larger displacement of the original roadway is; when the geometrical size is fixed, the lower the strength of the rock is, the larger the disturbing displacement is; when the geological conditions and the rock properties are fixed, the smaller the distance between the disturber and the one which is disturbed is, the larger the disturbing displacement is.

From the above, the surrounding rock of the chamber has “displacement tendency” influenced by excavation disturbance. The chambers and roadways in the chamber group are influenced by each other and finally the displacement direction of surrounding rock will move towards the direction of the vector sum of “the main moving direction” and “the disturbing moving direction”. The disturbing influence largely depends on the relative distance, the geometrical size and rock mechanics qualities of the disturbers and the ones which are influenced by others.

4. Conclusions

(1) The changing tendency of the vertical stress, the horizontal stress and the shear stress in each step of the excavation of the chamber group was analyzed.

(2) By FLAC3D numerical simulation, the mutual disturbing influence caused by the excavation of the chamber group and, besides the stress highly increasing zone, the deflection trend of “when they are near, be away; when they are away, be together” of the stress heightening zone are described.

(3) Analyzed the changing conditions of the displacement of the surrounding rocks disturbed by the chamber group and put forwards that the surrounding rock has “displacement tendency” and the law of it.

References


