Research on Displacement Failure Characteristics of Deep Roadway Surrounding Rock

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Abstract: In order to explore the displacement failure characteristics of deep roadway surrounding rock, the surrounding rock stress field model of the uniform stress field in the circular tunnel is simplified. It analyzes the stress evolution features of deep coal rock and discusses the mechanism of zonal disintegration. It observes the deep displacement surrounding rock of Qujiang mine at the depth of 1000m, the displacement shows that the wave crests and troughs appears alternately; wave crest position for damage area, trough part for non-damage zone. The surrounding rock of roadway exists zonal disintegration phenomenon, each roadway section is a total of four fracture zones. Due to different positions of roadway section tunnel excavation time rheological effect, the longer the tunnel is excavated, the more serious the surrounding rock is damaged.

1. Preface

With the increase in coal demand and mining intensity, domestic and foreign coal mines have entered deep mining. According to incomplete statistics, the average mining depth of large and medium-sized coal mines in China is close to 500 m, and it extends to the depths at a speed of nearly 20 m/a. Among them, 30% of the coal mines have a mining depth of more than 600 meters, and more than 50 coal mines have a mining depth of more than 1000 kilometers. Scholars at home and abroad have done a lot of research on the deformation and failure of the surrounding rock [1~2]. As the mining depth increases, the coal mining conditions become more complicated, especially the displacement failure law of deep roadways is different from that of shallow parts, which cannot be explained by traditional continuum mechanics theory, such as the rupture of the surrounding rocks [3~4]. Based on the theoretical analysis, this paper studies the displacement failure characteristics of the surrounding rock of the deep well, taking the kilometer deep well as the test object.

2. Partial rupture mechanism of deep surrounding rock

The stress field of the surrounding rock is complicated in the high stress environment of the deep roadway, and the roadway is simplified as a circular roadway with a diameter. From the analysis of elastic mechanics, for an ideal elastoplastic medium, when the differential stress after the stress redistribution reaches the yield limit of the surrounding rock, a plastic ring will be formed. With the dynamic evolution of the surrounding rock, the strength of the structural surface decreases from the peak value to the residual value, and under the action of shear slip and deflection under approximately
unidirectional compression, the structure near the tunnel wall at the plastic radius The surface will be pulled apart, forming an open crack or cavity. At this time, the coal body from the coal wall to the open joint is similar to an isolated body with only residual stress in it, and the coal body stress is expressed as [5-6]:

\[
\sigma_r = \sigma_y \left(1 + \ln \frac{r}{a} \frac{R_p^2 - a^2}{R_p^2 - R_p^2 - a^2} \ln \frac{R_p}{a} \right) \left(1 - R \log t\right)
\]

\[
\tau = \sigma_y \left( \ln \frac{r}{a} \frac{R_p^2 - a^2}{R_p^2 - R_p^2 - a^2} \ln \frac{R_p}{a} \right) \left(1 - R \log t\right)
\]

In the formula: \(\sigma_y\)—the yield strength of the coal body in the rupture zone.

Due to the opening of approximately parallel joints, in a local range, it is equivalent to re-excavating a larger diameter tunnel space (a=R_p). Therefore, the coal outside the fracture zone, a new plastic ring \(R_{p2}\) will be formed again, and different fracture zones will be formed under high ground stress. The redistribution of stress in the roadway surrounding rock is shown in Figure 1.

In summary, when \(r_0=a\) and \(r=R_p\), \(\sigma_r = 0\). Due to the formation of the fracture zone, it still exists a certain residual stress in the coal body from the coal wall to the fracture. As the redistribution of the coal body stress and the shear slip of the structural plane, it will inevitably cause the joints deeper parallel to the coal wall to open. Each opening of the joint will affect the structure of the coal body and further cause the redistribution of the coal body stress. Therefore, the surrounding rock of deep roadway sometimes occurs alternately with expansion zone and compression zone, and its geometric size (width) increases in an equal-numbered sequence, and the regional rupture phenomenon occurs, as shown in Figure 2.
monoclinic, and the occurrence is relatively stable. The coal seam has a trend of 40~60 °, a tendency of SW, a dip angle of coal is 10-13 °, and thickness of coal is 1.0~3.87 m, an average thickness of coal is 2.16 m. The buried depth of 213 floor rock lane is 1 000 m, net section is 3.8×2.8 m, lithology is mainly fine sandstone, off-white, thin~medium thick layered, calcium muddy cemented with thin layered mudstone, rock is relatively broken. The geological structure of the roadway is more complicated. During the process of tunneling, 7 faults are exposed, one drop is greater than 2m, other six drop is 0.3~1.3 m.

3.2. Research methods
It observed the displacement and failure characteristics of the roadway surrounding rock in three different locations of 213 floor rock roadway. First, it drill a Φ32 mm borehole along the tunnel section (the hole depth is generally 10 m). Then, it observed the destruction of the surrounding rock, used YTJ20 rock formation detection recorder to record all the boreholes. Then, it to observe the displacement of the surrounding rock of the tunnel at different depths, used the DW-6 multi-point displacement meter (that is, 6 measuring points). The observation time is more than 3 months. Five boreholes are arranged in each observation section, which are 15 m lower, 7.5 m lower, directly above, 7.5 m upper and 15 m upper, respectively. The arrangement of measuring points is shown in Figure 3.

![Figure 3. Schematic diagram of displacement measurement points of surrounding rock](image)

YTJ20 rock formation detection recorder is composed of color camera probe, video transmission line, guide rod and host. After drilling, the guide rod is used to manually advance the camera probe along the drilling axis. The image of the rock formation in the borehole is measured by a color camera probe, and the video signal is transmitted to the LCD screen of the host by a video transmission line. The depth of the borehole is recorded by a guide rod or a steel tape. The instrument has high resolution (up to 0.1 mm), clear image, and can detect the situation in the hole. The DW-6 multi-point displacement gauge has 6 base points, which are mainly composed of base point anchors, steel strands, sleeves, cursors, guide rods, and tightening screws. After drilling, use the guide rod to advance the anchor anchor to the observation position along the drilling axis, and then tighten the steel strand to make the sleeve and cursor at a certain scale, fix the tightening screw, and record the scale at this time. The data is observed every 1~2 days until the data does not change.

4. Research on displacement and failure characteristics of deep surrounding rock

4.1. Investigation and analysis of displacement of surrounding rock
The observation results of surrounding rock displacement of 213 floor rock lane are shown in Figure 4.
In Figure 4, the abscissa is the distance between the measuring point and the wall of the tunnel, and the ordinate is the displacement of the surrounding rock. It can be seen from Fig. 4 that the displacement from the outside to the inside of the same borehole is characterized by the change of "wave peak" and "wave valley". This change law is different from the monotonous change law of the displacement of shallow surrounding rock, that is, the displacement is smaller with the distance from the roadway wall. It is preliminarily judged that after excavation of deep roadway, the surrounding rock appears to be broken by zones. The "wave peak" part with large displacement is the surrounding rock destruction area, and the "wave valley" part with small displacement is the complete surrounding rock area.

4.2 Surrounding rock failure observation and analysis

4.2.1 Observation results.

The damage inside different rock formations is clearly distinguished by YTJ20 rock formation detection recorder. According to the degree of damage, it can be divided into complete, broken, fissure and crack. The measured image is shown in Figure 5.
4.2.2. Analysis of surrounding rock failure characteristics.
It can be seen from Fig. 6 that there are generally 4 rupture zones in the surrounding rock of each tunnel section, and the damage degree of the rupture zones is directly above, 7.5 m on both sides, and 7.5-15 m on both sides. The destruction of surrounding rock on the surface of the roadway is the most serious, mainly caused by severe crushing and breaking. This area is the surrounding rock loosening circle of the roadway, and outside this area is the complete area. Further out is the second rupture zone, and the damage is relatively large, mainly broken and cracked. Then there is the intact area, followed by the third rupture area. This rupture area is less damaged, mainly with cracks. Complete the interval and enter the fourth rupture zone.

It statistically calculated the average initial rupture position (distance from the tunnel wall) and the average width of the rupture area of the surrounding rock rupture zone (i) at different locations within 15 m above and below the test tunnel, as shown in Figure 6.

From 6 (a), it can be seen that the average initial rupture position of the rupture zone of the first to third group of tunnel cross-sections increases linearly, that is, the initial rupture position of each rupture zone of the first group is closer than that of the second and third groups. This is because the cross section of the first group of tunnels is farther away from the heading than the second and third groups. That is, the excavation time of the first group of tunnel sections is longer, and the energy of the surrounding rock of the tunnel is fully released. As can be seen from Figure 6 (b), the average width of the rupture zone of the first to third group of tunnel sections basically shows a trend of gradually decreasing with the increase of the depth of the rupture zone, which is due to the characteristics of the energy release and propagation of the surrounding rock. This shows that due to the time rheological effect, the more severe the surrounding rock damage, the more fully the pressure relief of the floor roadway.

5. Conclusion
The stress field of the surrounding rock of the deep roadway is complicated. The state of the surrounding rock of the roadway sometimes occurs in the expansion zone and the compression zone alternately, and its geometric size (width) is increased by a proportional sequence, and occurs a regional rupture phenomenon.
The displacement of the surrounding rock in deep roadways is characterized by the change of "peaks" and "troughs" from outside to inside. The "wave crests" with large displacements are the failure areas of surrounding rocks, and the "wave troughs" with small displacements are surrounding rock non-destructive zone.

On-site measured that the surrounding rock of 213 floor rock roadway in Qujiang Company has zoned fracture phenomenon, there are 4 fractured areas, and the rheological effect of time is investigated at different locations. The energy of the surrounding rock of the roadway is fully released, and the more sufficient the pressure relief is, the more serious the rock damage is.

Acknowledgments
This work was financially supported by the national key research and development program of China (2017YFC0804206).

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