Instability Mechanism of Surrounding Rock of Weakly Cemented Soft Strata in Shallow Coal Seam of West China

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ABSTRACT

Roadways in one of the west China coals are subjected to the complex geologic, such as shallow buried depth, weakly cemented, and soft surrounding rock. A numerical model was modeled based on the experimental results of X ray diffraction for surrounding rock. Based on the results of numerical modeling, distributing law on the stress and displacement of surrounding rock were analyzed. An negative exponent attenuation function was found between convergence value, *s*, in deep point and distance to surface, *h*. The scope of plastic zone varying from 2m to 3.5m was also determined. It is in good agreement with field test results from geological radar, which could detect the fracture zone in the surrounding rock. Thus, this proposed approach could be utilized for applications involving stability analysis and scheme design of rock reinforcement under similar geo-mining conditions.

KEYWORDS: Shallow coal seam; Weakly cemented soft strata; Soft roadway; Plastic zone; Numerical simulation

INTRODUCTION

As the increasing exhaustion of coal resources in the middle and eastern China, the extraction of shallow coal resources in western China has been paid more attention. However, for the mining of shallow mines in the west, it is inevitable to deal with soft strata with low strength, poor consolidation, easy weathering, easy hydrolysis and incomplete diagenesis. These problems will have great effect on the stability of roadways. At present, a series of useful results on the deformation and failure mechanism of soft rock roadway were achieved by the experts and scholars in China[1-12]. Chen Z J had divided the convergent deformation mechanism of roadway surrounding rock into five aspects, such as plastic wedge, flow deformation, rock expansion, expansion and deflection. He M C had divided the mechanical mechanism of deformation and failure of soft rock into three types, so as physical and chemical expansion, stress expansion and structural deformation. Liu C W had believed that the tectonic stress was the main cause of the deformation of soft rock roadway. Pan L Y had put forward the intrusion theory of soft rock floor which included the mechanical mechanism of the intrusion, the influence factors and the supporting theory. These results had a certain guiding role for the soft rock roadway, but it was not applicable to the weakly cemented soft rock roadway in west China mine with shallow being buried. So one mine in west China of Dongsheng mining area had been taken as the project background, and the numerical simulation, theoretical analysis and field monitoring had been synthetically to propose a new method to calculate the damage range of weakly cemented soft rock that was verified viably.

PROJECT BACKGROUND

One mine in Dongsheng mining area was buried in the shallow, about 200m below surface in the mine. Most of the overburden strata was soft rock with low mechanical strength, which brought serious impact on production and mine construction. The field sampling and X ray diffraction showed that the mudstone is composed of quartz, potassium feldspar, plagioclase and clay. The component content of mudstone is shown in Figure 1. Of these minerals, the clay account for a content up to 60.6%. The clay minerals are composed of high swelling montmorillonite, illite and kaolinite with content shown in Figure 2. The montmorillonite accounts for 82% in clay and 49.7% in mudstone. According to the classification of strong swelling soft rock[13], the rock who should be called extremely strong swelling soft rock that had strong swelling and strong rheological properties when pure montmorillonite content reached 40% ~ 60% which could lead the surrounding rock of roadway to instability and failure.

In process of excavation, as the extending of damaged area, four supporting forms of 29U-steel beam+ bolt, 36U-steel beam+ bolt, pair of 16# ordinary I-beam+ bolt and pair of 12# mining used I-beam+ bolt have been tested, but failed.

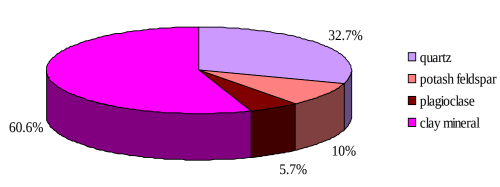


Figure 1: Mineral composition of mudstone

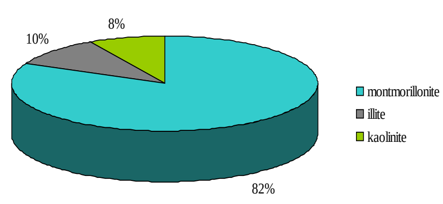


Figure 2: Mineral composition of clay

ANALYSIS OF EVOLUTION LAW OF STRESS AND DISPLACEMENT IN SURROUNDING ROCK

Given large deformation in scene, and unique advantages of large deformation simulation, numerical simulation software of FLAC^{3D} was selected to simulate and analyze, in order to explore the mechanism of large deformation in soft rock roadway [14-17]. Model was set up according to site, and the strata's mechanical parameters were shown in table 1. In order to monitor evolution law of stress and displacement in surrounding rock, eight monitoring lines were set up in the model. Specific layout of monitoring lines was shown in Figure 3. By view of the obviously influence of maximum principal stress on roadway stability, we mainly analyzed evolution law and influence of maximum principal stress and displacement on surrounding rock.

Table 1: Strata's mechanical parameters

Name	Compressive strength/MPa	Tensile strength /MPa	Cohesion /MPa	Angle of internal friction/(°)	Bulk density (g/cm^3)
Mudstone	0.12~5.12	0.06~0.39	0.24~0.39	25.16~29.01	1.66~2.14
Siltstone	0.64~8.00	0.07~0.61	0.23~0.50	13.70~25.50	2.01~2.65
Fine-grained sandstone	0.42~1.26	0.02~0.10	0.25	14.20	1.52~2.16

Maximum principal stress, vertical displacement and horizontal displacement contours were shown in Figure 4, 5, 6. After roadway excavation, stress in surrounding rock redistributed. There existed pressure relief area around roadway. The larger relief area lay in roof and floor, so roof and floor were the main weak plane for stress releasing. Deep in rock, stress increased gradually. And stress concentration area was formed deep in two sides.

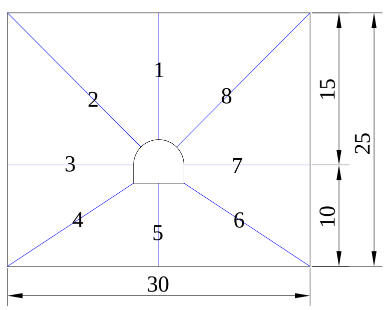


Figure 3: Monitoring lines

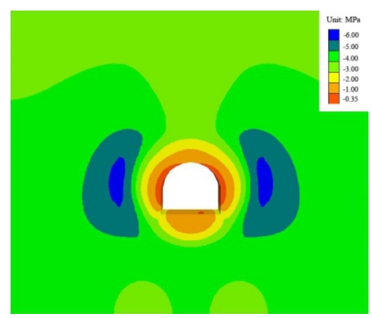


Figure 4: Maximum principal stress

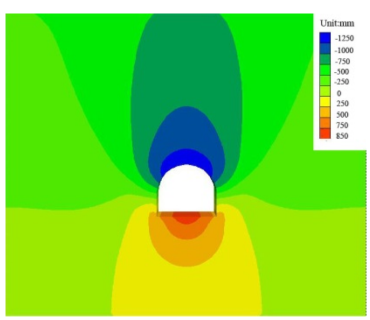


Figure 5: Vertical displacement

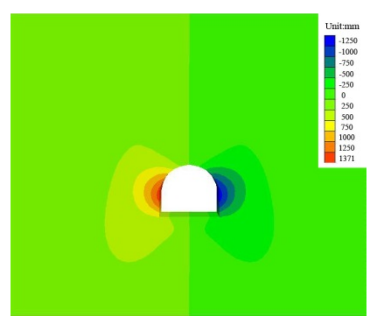


Figure 6: Horizontal displacement

Analysis of Evolution Law of Stress and Displacement in Roadway Floor

Because of roof sank seriously when surrounding rock failure, we considered that roof sank only when failure. Supposed that displacement in horizontal and axial direction was 0, evolution curves of stress and displacement in roof strata were shown in Figure 7. As depth in rock increasing, roof subsidence decreased gradually and demonstrated attenuation law of negative exponential. Relationship of roof subsidence s_1 and distance above roof h_1 was fitted as follows:

$$s_1 = 685.71e^{-\frac{h_1}{5.059}} + 735.41 \tag{1}$$

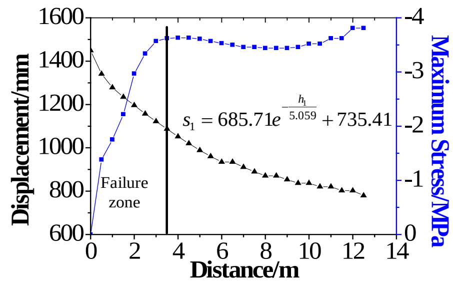


Figure 7: Evolution curves of stress and displacement in roof strata

After excavation, stress relieved and reduced to 0 on roof. As distance increasing, the stress rose gradually and restored to original rock stress level at position of 3.5m above roof. In this range, stress is lower but roof sank largely, which achieved range of 1000~1450mm. According to rock characteristics of high compressive strength but low tensile strength, based on research on damaged zone of surrounding rock [18-23], we concluded that rock in this range had lost capacity of carrying and caved. In other words, range of 3.5m above roof was the failure zone.

Analysis of Evolution Law of Stress and Displacement in Roadway Shoulders

45º positions on both sides of vault were defined as roadway shoulders. Supposed that along axial direction, the roadway was infinitely long, so roadway deformation could be equivalent to plane strain problem. The strain along roadway's axial ε_y was 0, so the displacement in position of shoulder u could be got as follows:

$$u = \sqrt{u_x^2 + u_z^2} \tag{2}$$

where u_x and u_z were point's displacement of horizontal direction and vertical direction respectively.

Evolution curves of shoulders stress and displacement, obtained by calculating, were shown in Figure 8, 9. Displacement was pointed into roadway. Right and left sides demonstrated as the same law. As distance to roadway increasing, stress increased gradually and restored to original stress level at position of deep in rock 1.6m, and continued to rise. In place of deep in rock 2.58m, the stress reached its peak and led to stress concentration. The stress concentration factor (1.42) in right side was slightly higher than the left one (1.36). After peak, the stress decreased gradually and became stable. Roadway shoulders deformed largely. Especially in range of 2.58m, its displacement reached extent of 800~1580mm. As depth increasing, movement of surrounding rock tended to be stable. Through analysis, we determined that failure zone was the range of deep in rock 2.58m. Relationship between roadway shoulder displacement s_2 and distance to roadway h_2 was fitted as follows:

$$s_2 = 1075.14e^{-\frac{h_2}{2.275}} + 470.36 \tag{3}$$

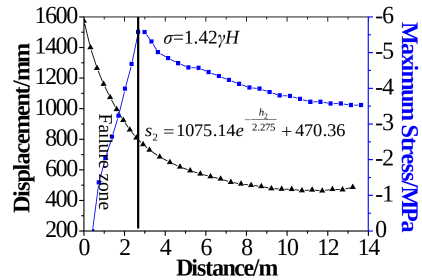


Figure 8: Evolution curves of stress and displacement in right shoulder strata

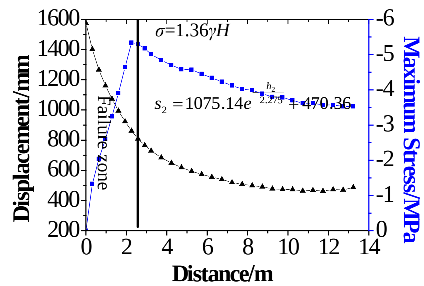


Figure 9: Evolution curves of stress and displacement in left shoulder strata

Analysis of Evolution Law of Stress and Displacement in Roadway Arch Bases

Rock in base arch occurred horizontal displacement mainly, which pointed to roadway. Ignoring the impact of vertical displacement, stress and displacement evolution laws were shown in Figure 10, 11. As distance to roadway increasing, rock stress increased gradually and deformation declined gradually. Rock stress restored to original level at position of deep in rock 2.1m, and reached peak at position of deep in rock 3.5m, where occurred a certain degree of stress concentration. The stress concentration factor (1.75) in right side was slightly higher than the left one (1.65). After the peak, stress reduced gradually and restored stable as the distance to roadway increasing. Correspondingly, we obtained that the fracture zone in two sides was the range deep in rock 3.5m, in which the displacement reached range of 300~1400mm. Relationship between displacement in base arch s_3 and distance to roadway h_3 was fitted as follows:

$$s_3 = 1311.55e^{-\frac{h_3}{2.202}} + 44.08 \tag{4}$$

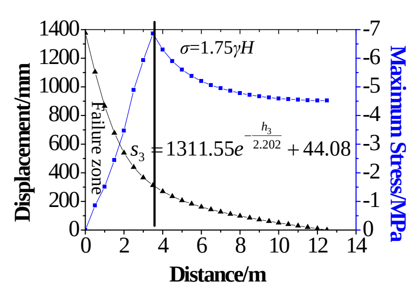


Figure 10: Evolution curves of stress and displacement in right base arch strata

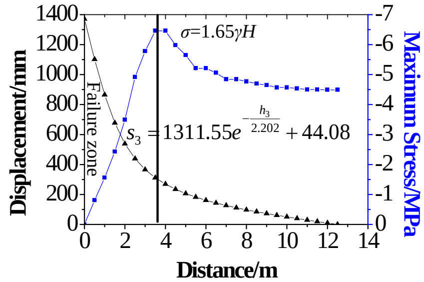


Figure 11: Evolution curves of stress and displacement in left base arch strata

Analysis of Evolution Law of Stress and Displacement in Roadway Bottom Corners

At roadway bottom corner, rock's deformation mainly demonstrated horizontal displacement and vertical displacement. According to displacement calculated at roadway shoulders, bottom corners deformation was got and evolution laws of stress and displacement were shown in Figure 12, 13. As distance to roadway increasing, rock stress declined firstly, and then increased gradually and restored to original level at position of 1.0m deep in rock. The stress reached its peak (1.32γH) at position of 2.0m deep in rock, and then decreased and was to stabilize. But the final stable stress was slightly higher than the original one. Correspondingly, we decided that the range of failure zones at bottom corner was 2.0m deep in rock, where rock displacement achieved range of 350~650mm. Relationship between rock displacement s_4 and distance to roadway h_4 was fitted as follows:

$$s_4 = 576.27e^{-\frac{h_4}{6.209}} - 32.29 \quad (5)$$

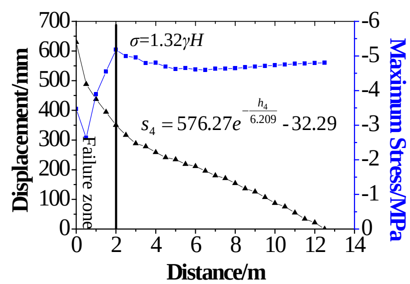


Figure 12: Evolution curves of stress and displacement in right bottom corner strata

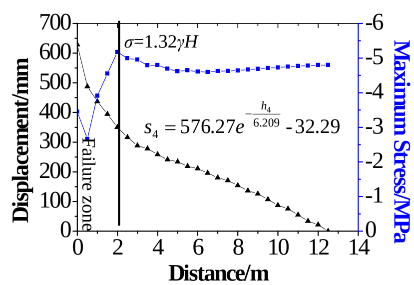


Figure 13: Evolution curves of stress and displacement in left bottom corner strata

Analysis of Evolution Law of Stress and Displacement in Roadway Floor

In axis of roadway floor, evolution laws of stress and displacement were shown in fig.14. As distance to roadway increasing, stress grew and experienced three stages of linear-nonlinear-linear. Rock stress restored to original level at place of 2.6m below floor, and reached its peak stress (1.22γH) at place of 3.2m below floor, and then stress attenuated in law of negative exponential and stabilized gradually. But the final stable value was slightly higher than the original one. So we got that the range of failure zone is 3.2m below floor. In this range, rock displacement reached 330~850mm. Relationship between rock's displacement s_5 and distance to roadway h_5 was fitted as follows:

$$s_5 = 992.68e^{-\frac{h}{4.318}} - 133.97 \quad (6)$$

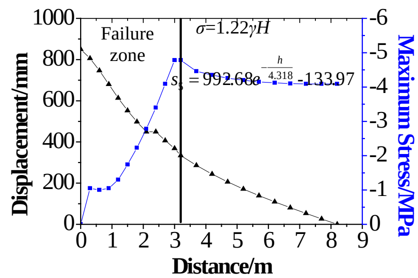
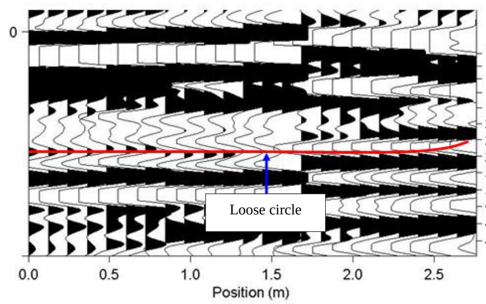


Figure 14: Evolution curves of stress and displacement in floor strata

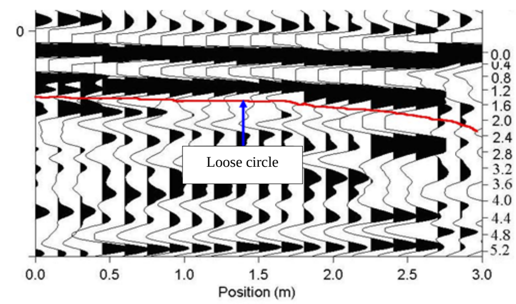
MONITORING OF ROCK LOOSE CIRCLE OF ROADWAY SURROUNDING ROCK

The surrounding rock loose circle is a common physical condition in the underground engineering. It has great influence on the stability of underground projects. The loose circle of surrounding rock is characterized by physical face in a form of macro fracture due to strata failure. The rock masses in the circle are in a state of fracture and loose. Geological radars are used to scan the cross section of roadway. When the radar electromagnetic wave passes through the interface between the loose circle and intact parts, strong reflection or scattering occurs from which the rock loose circle range can be determined[24].

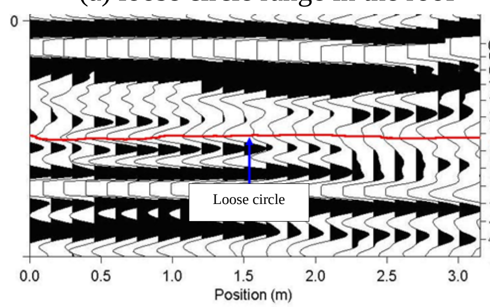
In order to determine the range and distribution rule of roadway surrounding rock loose circle in the initial supporting scheme. Three monitoring sections were arranged in the haulage roadway. Geological radars were used to detect the rock loose circle on the roadway roof, slope and floor. The monitoring results show that the loose circle range of the roof, left slope, right slope and floor are 2.4-2.8m, 1.8-2.4m, 2-2.6m, 2.2-2.6m, respectively. A local large circle in a range of 3.5-4m is also observed. In this case, as the plastic zone of the roadway surrounding rock always exceeds the bolting length, load bearing point or stable compression zone is not easy to form. In addition, if the bolt is too stiff to deform with the surrounding rock, it will be inserted into the rock, thus worsening the loose and fracture of strata. Figure 15 shows the radar detection of roadway roof, slopes and floor, and the results were consistent with the numerical simulation.



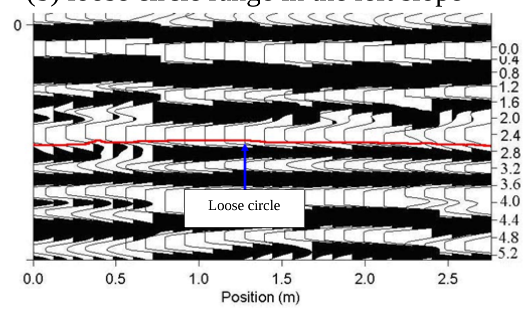
(a) loose circle range in the roof



(b) loose circle range in the left slope



(c) loose circle range in the right slope



(d) loose circle range in the floor

Figure 15: Measurement results of roadway surrounding rock by radars

CONCLUSIONS

(1) The weakly bonded soft strata have strong swelling, rheology, crack development and water softening that cause the mismatch of strength and the support structure which lead to the instability of roadway.

(2) The simulations by FLAC 3D showed that the maximum principal stress of the surrounding rock was increasing with the distance from the surface of the roadway, and the stress concentration at different levels in the deep part. An negative exponent attenuation function was found between convergence value, *s*, in deep point and distance to surface, *h*.

(3) The measured results by geological radars show that the loose circles of surrounding rock was so large that measures should be taken to control the expansion of plastic zones of surrounding rock in roadway.

(4) The plastic zone range of roadway surrounding rock was 2~3.5m by numerical simulation which consistent with the geological radar. The numerical simulation model could provide scientific guidance for the design of reinforcement scheme and the analysis on the stability of roadway surrounding rock.

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