Mining Roadway Support Technology Based on Rheological Analysis in Malin Coalmine

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Abstract

In order to safety, efficient, and economy of roadway excavation in Malin coal, No.8 coal seam is chosen to study mining roadway support technology. Rheological properties of surrounding rock is studied by triaxial rheological test under step loading, a reasonable rheological model and parameters are selected and determined, and rheological mechanics model of surrounding rock is established; Considering with rock mass rheological properties, numerical model of mining roadway excavation process is established, deformation and failure mechanism of roadway rock is studied in different supporting structure parameters, and bolting optimized design scheme is proposed, which can control the deformation of roadway rock effectively; the field test result of sound wave on surrounding rock loosing zone shows that the design scheme can control the deformation roadway surrounding rock effectively and maintain its stability. The research has a certain guiding significance for the optimized design scheme of bolting projects.

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Keywords: roadway, bolting, theological properties, optimization design, surrounding rock loosing zone.

1. Introduction

With the significant increase of coal mining intensity and scale in China, roadway support in coal seam have been influenced the safety and high effective product of coal mine. Which support form using can effectively control the deformation of surround rock has been an important subject. Rheology is the inherent mechanical property of geomaterials. Not only soft rock, soft clay, etc. have rheological characteristics, but also some degree of rheology is also happened in rock of moderate strength or hard

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rock of rich growth with joints under high in-situ stress level\cite{1}. And one of important reasons for deformation and failure characteristics of surrounding rock is rheology, a great amount of engineering practice showed that consideration of rheological property of roadway surrounding rock has extreme important and distinct practical significance in project design and construction\cite{2}. So many scholars\cite{3-6} at home and abroad have done systematic studies on rheological characteristics of rock. But the situation on application of rock rheological characteristic in roadway support design of coal mine is not more at present. Recent years, bolt support technology\cite{7} has been the main way of coal roadway support because of high efficiency, supporting effective, low cost and so on, so it provides an effective solution for coal roadway support. But, currently, roadway support design parameters are singer, and pertinence and cost concept are not strong\cite{8}. In view of this, to determine the most reasonable roadway support parameters based on maintenance, to lift the mine economic benefit, to ensure the safety and high efficient production of mine roadway.

In this paper, by the support of the mining roadway in C8 coal seam of Malin, numerical model of roadway excavation formation conditions and rheological characteristic of roadway surrounding rock, and to obtain the optimal design scheme of roadway support, which has important practical significance to reduce the workload of roadway mprocess is established based on rheological properties of surround rock, deformation and failure mechanism of roadway rock is studied in different supporting structure parameters, bolting optimization design scheme is proposed; the result comparison between the numerical simulation and the field test of sound wave on surrounding rock loosing zone shows that using the optimized design scheme can control the deformation of roadway rock effectively and maintain the stability of roadway surrounding rock.

2. Engineering situation

Malin mine is located in Donghuang town, Xishui county in Guizhou province. The main coal-bearing strata is Longtan Formation in Permian system, thickness is 76.98~108.64m, and the average thickness is 87.34m, the strata mainly consists of shaly sandstones, siltstones, clay rocks, coal seams, siderite and a little limestone. It contains 25~32 coal seams, the total thickness is 5.21~11.43m, the average thickness is 9.18m, coal coefficient is 10.20 percent. Among the coal seams, two main mineable coal seams are C8, C12 and they are rather stable. The total thickness of C8 coal seam is 1.202~2.29m, and the average thickness is 1.82m, which is the main mining coals in here. So coal rock roadway of C8 coal seam is taking as the research object in this paper.

Workingface lay out is adopted by strike longwall, haulage roadway and return airway are tunnel along the roadway roof. Combined support with anchor network and cable is applied in roadway, cross-section of roadway is trapezoidal, height is 2.3~3.35m, width is 3.7m; cross-section area is 10.4m2. the layout drawing of bolting supporting structure of coal rock roadway is applied in the Fig.1.In order to ensure the safety of roadway and to save investment, so it is very necessary to exercise optimal design of scheme for bolt support.

3. Rheological constitutive model

In order to analysis the deformation and failure trend of surrounding rock in tunneling of coal rock roadway. Laboratory rheological tests on shaly sandstone at the top of C8 coal seam under the uniaxial step loading is using RLW-2000 rheometer, and theological constitutive model of shaly sandstone, which can provide more reliable basic information for optimization design of roadway. The test results show in Fig.2.

The viscoelasticity property of shaly sandstone has been simulated obviously though the analyses of the characteristics of creep curve. There are many element combined models to describe the viscoelastic
creep. At present, the most commonly used models[15] are the generalized Kelvin model, Burger model and so on. In this paper the Burgers model (see fig.3) is used to describe the mechanical behavior of shaly sandstone.

![Fig.3 Schematic diagram of burgers constitutive model element](image)

One dimensional differential constitutive equation of Burgers model is:

\[
\sigma + \left( \frac{\eta_M}{E_M} + \frac{\eta_M + \eta_K}{E_K} \right) \dot{\sigma} + \frac{\eta_M \eta_K}{E_M E_K} \ddot{\sigma} = \eta_M \dot{\varepsilon} + \frac{\eta_M \eta_K}{E_K} \ddot{\varepsilon}
\]  \hspace{1cm} (1)

One dimensional creep equation is

\[
\varepsilon = \left[ \frac{1}{E_M} + \frac{t}{\eta_M} + \frac{1}{E_K} \left( 1 - \exp \left( -\frac{E_K t}{\eta_K} \right) \right) \right] \sigma
\]  \hspace{1cm} (2)

Eq.2 is a multivariable equation contained four unknown number \( E_M, E_K, \eta_M, \eta_K \), which can not solve directly. And the Excel’s programming solution is applied to solve the equation. The resolving thought is shown in Eq.3.
\[
\begin{align*}
\text{Variance:} & \quad E_M, \eta_M, E_K, \eta_K \\
\text{Goal:} & \quad \lim_{\sigma \to 0} \left[ \sum_{i=1}^{2} \sum_{t=0}^{\delta} \text{exp} \left( -\frac{E_K}{\eta_K} t \right) \right] = 0 \\
\text{Constraint:} & \quad E_M, \eta_M, E_K, \eta_K > 0
\end{align*}
\]

According to the method mentioned above and using original data of creep curve in Fig.2, concrete value of \(E_M, E_K, \eta_M, \) and \(\eta_K\) can be calculated by Eq.3. The solving results are shown in Eq.4. At last, the theoretical constitutive model of saly sandstone can be obtained through put Eq.4 into the Eq.2.

4. Optimum design of bolting supporting Parameter

The section of roadway is rectangle; the bottom width is 3.7m and the width of the two sidewalls is 2.3m and 3.35m respectively. According to the experiences, the range of calculation model can be determined as follows. Geological model’ width is 64m and the height is 32m, among the geological model the roadway is located in the center of the model (see Fig.4); the model has ten stratigraphic units, they are numbered 1, 2, ……, 10 in ascending order; lithology can be classified to 4 types, they are shaly sandstones, siltstones, clay rocks and coal rocks. The principle of discrete of the mesh is divided the more detailed. But the mesh generation can not very detail, because of the limitation of the computer capacity. In here, the model is divided into 2840 units; the entire element is quadrilateral elements; the mesh is divided by using equally distant method. Grid lines are divided sparse gradually from the surrounding of the roadway to the boundary of model.

Displacement constraint boundary and load constraint boundary are two form adopted in geological model. Among them, normal displacement is constrained by sidewall, Fixed constraint boundary condition, but as to the upper boundary, geological model does not contain all strata mentioned above, so those strata that are not contained in the model, according to their weight conversion, impose on the top boundary in the form of external load.

The constitutive model adopted of the different rocks should consistent with their mechanical properties in numerical simulation. At present, Faced with so many models, the practical Moore-coulomb plasticity model is determined to use in numerical simulation. Physical and mechanical properties of the related rock and soil are obtained according to laboratory tests. (table 1)

Table 1. Physical and mechanical properties of the rock and soil in Malin coal

<table>
<thead>
<tr>
<th>Lithology description</th>
<th>Stratum number</th>
<th>Elastic modulus Ee(GPa)</th>
<th>Deformation modulus E_d(GPa)</th>
<th>Poisson’s ration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shaly sandstone</td>
<td>2, 4, 6, 8, 10</td>
<td>18.8</td>
<td>13.6</td>
<td>0.23</td>
</tr>
<tr>
<td>Siltstone</td>
<td>7</td>
<td>14.8</td>
<td>9.5</td>
<td>0.24</td>
</tr>
<tr>
<td>Clay rock</td>
<td>1, 3, 9</td>
<td>2.42</td>
<td>1.69</td>
<td>0.30</td>
</tr>
<tr>
<td>Coal seam</td>
<td>5</td>
<td>2.34</td>
<td>2.05</td>
<td>0.26</td>
</tr>
</tbody>
</table>

In order to optimize the design of the supporting scheme of the roadway, there are 25 conditions are designed to carry out numerical simulation (See Table 1). Among all the supporting schemes structural parameters and the position laid of the bolt are unchanged, the only changed is the length of anchor and the pitch of the anchor. The concrete structural parameters of anchor can see Table 2, and the diameter of the anchor is 25mm.

The displacement of the roof of the surrounding rock of roadway is mainly the vertical displacement, and the sides of the surrounding rock of roadway is mainly the horizontal displacement, and the maximum vertical displacement of the roof and the maximum horizontal displacement of the sides of the
surrounding rock of roadway under all conditions can be obtained according to the results of numerical simulation, so related study is carry out. The final results is known in the Fig.4.

It can be seen from Fig.5: (1) the maximum vertical displacement of the roof and the maximum horizontal displacement are affected obviously by the length of anchor, (2) but anchor pitch does not. After the length of anchor beyond 2.3m, the maximum vertical or horizontal displacement decreases gradually with the increase of the anchor length, until the length of anchor is up to 2.8m or more, the displacement is influenced by anchor length only a little. So the thickness of roadway surrounding rock loosing zone is initially identified about 3m. (3) The maximum displacement is also influenced by anchor row distance. When anchor row distance is less than 1m, the maximum displacement is smaller. But when anchor row distance is more than 1m, the maximum displacement becomes bigger. So when anchor row distance is 1m. Roof anchor length is 3.2m, and other anchor length is 2.8m, the supporting scheme is optimal.

(a) maximum vertical displacement of roadway roof; (b) maximum horizontal displacement of roadway sides

Fig.4 Effect of parameters for support structure on roadway displacement

5. The field test of roadway surrounding rock loosing zone

In order to determine the thickness of roadway surrounding rock loosing zone caused by the excavation of cavern under blasting, the test of surrounding rock loosing zone is carried out using RS-ST01c ultrasonic detector. The thickness of rock mass loosing and the spatial distribution of unfavorable geologic bodies can be determined by acoustic velocity test of rock mass, which can provide basis for anchor support design and stability analysis of surrounding rock mass. According to on-site production situation, the test of surrounding rock loosing zone is carried out in roadway roof and coal roadway sides of 2083 haulage (machine) roadway. There are test results in the fig.5. the site measurement results show that range of surrounding rock losing zone in roof of roadway is about 2.0m, and range of surrounding rock losing zone in sides of roadway is about 2.4m. The results of the test and numerical analysis are basically tally, but they also have some difference; the thickness difference of surrounding rock zone in sides of roadway is 0.3m, and the difference in roof of roadway only is 0.1m. And if the design of roadway supporting scheme based on results of the test of surrounding rock zone and numerical simulation, results of numerical simulation is a bit more conservative, but numerical simulation is better under considering the premise of safety factors. So the result comparison between the numerical simulation and the field test of surrounding rock loosing zone shows that using the optimized design scheme of mining roadway determined above can control the deformation of roadway rock effectively and maintain the stability of roadway surrounding rock.
Fig.5 Testing results of roadway acoustic velocity with the hole depth

5. Conclusion

5.1 Rheological properties of rock in C8 coal seam of Malin coalmine are studied by triaxial rheological test under step loading, and Burgers model is determined to describe the mechanical behaviors of surrounding rock of roadway.

5.2 Considering rheological properties of rock, numerical model in roadway excavation process is established, and the optimization problem of bolt parameter was deeply studied through numerical analysis. The results indicate that the support scheme is optimal when anchor row distance is 1m. Roof anchor length is 3.2m, and other anchor length is 2.8m. That can control the deformation of roadway rock effectively.

5.3 The range of surrounding rock losing zone can be determined by numerical results, compared with the test results of acoustic in-situ, and both basically tallies. That indicates that the range of surrounding rock losing zone caused by excavation can be estimated reasonably, which provide a feasible and simple method for the determination of the range of surrounding rock losing zone

Acknowledgements

The study is supported by the National Natural Science Foundation (No: 50774058, No: 50974024).

References


