Numerical Simulation of Compression Characteristic of Layered Rock Mass in Coal Series Strata

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Abstract. Taking layered rock mass of coal series strata as the research object, numerical model of its uniaxial compression is established by FLAC3D software. The layered rock mass is regarded as discontinuous medium, and interface in FLAC3D is used to simulate layer. Compression failure characteristic of layered rock mass under the condition of single structural plane and multiple structural planes are studied systematically, and numerical solution is compared with theoretical solution. The results show that for single structural plane rock mass, under the same axial pressure, when dip is in the range of 0°-25° and 80°-90°, the compression strength does not change with dip. In the range of 25°-80°, with the increase of dip of structural plane, the compression strength curve of the rock mass shows a "U" shape, which decreases first and then increases, the change of numerical solution and theoretical solution is basically the same; When dip of structural plane is fixed and the number of structural plane in the same group increases, the compression strength of rock mass decreases with the increase of the number of structural plane. This is because rock mass with multiple structural planes is relatively broken, the compression strength of rock mass is reduced. The research results can provide theoretical reference for stability analysis of surrounding rock in stope and tunnel.

1. Introduction

Coal resource is an important mineral resource formed by sedimentation. With the rapid development of China's industry, the demand for basic energy such as coal is increasing[1, 2]. There are also many problems in coal mining, such as roof collapse[3, 4], water inrush[5], bed separation[6], etc., which are mostly related to mechanical properties of rock mass. The coal series rock is a kind of sedimentary rock, its obvious structural feature is that it has stratification, that is it has layered structure. It is a kind of original structure formed in the process of sedimentation and diagenesis. Its mechanical properties are controlled by layers obviously. Therefore, it is of great significance to study compression characteristic of layered rock mass in coal series strata, and many scholars have done a lot of research work on it. He Zhongming[7] et al. (2010) studied the change of layered rock mass under uniaxial compression, and found that with the increase of dip of structural plane, compression strength of layered rock mass decreased first and then increased. Huang Chun[8] et al. (2014) made layered rock mass with different dip into standard specimens for uniaxial compression test, modulus of elasticity, peak strength and residual strength of rock specimens are obtained, and their variation law with dip is also obtained. Yu Yongqiang[9] et al. (2009) used similar materials to make models, and studied stress-strain relationship and failure mode of similar models of layered composite rock mass through uniaxial compression test. The test results well verified theoretical analysis conclusions. Jia shanpo[10] et al. (2014) carried out indoor model tests on failure characteristic of layered rock mass, and...
discussed influence law of dip and interlayer change on strength and failure of rock mass. Lu Haifeng[11] et al. (2014) used FLAC3D numerical software to regard layered rock mass as a transversely isotropic elastic body, carried out compression simulation, and obtained the relationship between its strength and structural plane dip.

The above research results have played a positive guiding role in mastering deformation strength characteristic of layered rock mass in different periods and degrees. However, theoretical analysis can only be carried out for simple models, and can not effectively reflect deformation and failure mechanism of layered rock mass and its development process. Numerical simulation can test and evaluate different schemes simultaneously, and it is easy to operate, low cost and high precision. However, in the early stage, when using numerical simulation to model layered rock mass, it is generally regarded as a continuous medium, which has a certain gap with actual situation. Therefore, on the basis of previous studies, based on FLAC3D numerical software platform, this paper regards layered rock mass as a discontinuous medium, uses interface to simulate layer in layered rock mass, and carries out uniaxial compression simulation, The failure modes and laws of layered rock mass with single and multiple structural planes are studied systematically. The research results can provide theoretical guidance for layered rock mass engineering.

2. Establishment of numerical model for layered rock mass
In order to obtain compression failure characteristic of layered rock mass, The numerical calculation model of layered rock mass is establish by FLAC3D software, and plane strain model is used. The model size is 0.05m(width)×0.001m (thickness)×0.1m(height), and interface is used to simulate layer. The mechanical parameters of the rock model and structural plane are shown in Table 1. After the parameters are assigned, the uniaxial compression test is carried out, and the speed loading mode is adopted, which is applied to the upper and lower parts of the model simultaneously, with the application speed of 2e-6m/s, as shown in Figure 1.

| Material        | Density (kg·m⁻³) | Friction angle(°) | Cohesion (MPa) | Elastic modulus(MPa) | Poisson ratio | Normal stiffness(MPa) | Tangential stiffness(MPa) |
|-----------------|------------------|-------------------|----------------|----------------------|---------------|-----------------------|--------------------------|
| Rock            | 2300             | 35                | 1              | 1000                 | 0.3           |                       |                          |
| Structural plane| 25               | 0.2               |                | 5500                 |               | 4000                  |                          |

Figure 1. Numerical model diagram.

3. Numerical analysis of compression failure characteristic of layered rock mass

3.1. Compression failure characteristic of rock mass with single structural plane
It is assumed that there is only one structural plane in the numerical model of layered rock mass, and the structural plane with different dip are designed for numerical simulation of uniaxial compression. The range of dip $\beta$ of the structural plane is 0°-90° and the change gradient is 5°. The calculation
model of the test piece is established, and the partial numerical models are shown in Figure 2. The relationship between stress and strain in the simulation process was recorded. The numerical analysis of the failure characteristic of structural plane with different dip by using the simulation rules of the last section can obtain the compression strength values under different dip.

Figure 2. Numerical models of rock mass with single structural plane (part).

Meanwhile, the compression strength and failure characteristic of single structural plane are analyzed by theoretical analysis. For single structural plane rock mass, once dip $\beta$ of structural plane changes, rock mass strength ($\sigma_1-\sigma_3$) will also changes. In this case, the relationship between structural plane failure and $\beta$ can be obtained according to Mohr-Coulomb criterion, specifically:

$$\sigma_1 - \sigma_3 = \frac{2(c_j + \sigma_3 \tan \varphi_j)}{(1 - \tan \varphi_j \cot \beta) \sin 2\beta}$$  \hspace{1cm} (1)$$

Among them, $c_j$ and $\varphi_j$ are internal friction angle and cohesion of layer.

Fixed $\sigma_3$, when dip $\beta$ of structural plane approaches 90° and $\beta$ approaches $\varphi_j$, $\sigma_1$ will approaches infinite. In fact, it is not infinite. When it reaches a certain value, rock mass will be destroyed. Therefore, it can be known that the failure of rock mass will occur only at $\varphi_j < \beta < 90^\circ$. If $\beta = 45^\circ + \frac{\varphi_j}{2}$, the rock mass strength ($\sigma_1-\sigma_3$) gets minimum value, and the corresponding minimum value is:

$$\sigma_{1_{\text{min}}} = \sigma_3 + \sigma_3(N_{\varphi_j} - 1) + 2c_j \sqrt{N_{\varphi_j}}$$  \hspace{1cm} (2)$$

Among them, $N_{\varphi_j} = \tan^2 \left(45^\circ + \frac{\varphi_j}{2}\right)$.

According to the above analysis, the strength of layered rock mass is controlled by dip of structural plane $\beta$, and the anisotropic characteristic are obvious. Figure 3 is a comparison diagram of the relationship between the compression strength and dip of layered rock mass obtained by numerical analysis and theoretical calculation.

Figure 3. Numerical solution and theoretical of rock mass compression strength with different dip of structural plane.

It can be seen from Figure 3 that since the numerical solution adopts interface to simulate layer, it is a non continuum, which is different from the compression strength obtained through theoretical
solution based on the continuum, especially in the case of failure along layer, but the general change rule of the two is the same. When the dip is in the range of 0°-25° and 80°-90°, the compression strength value does not change with the dip. When the dip is in the range of 25°-80°, with the increase of $\beta$, the compression strength of rock mass decreases first and then increases. The curve presents "U" shape with low middle and high two ends, and the dip of the most unfavorable structural plane exists. When the dip $\beta$ of the structural plane shown in the figure is 60°, the compression strength of the test piece is the smallest and the most easily damaged. Compared with the theoretical results, it can be seen that the change trend of the numerical solution and the theoretical solution is basically the same. When $\beta$ is in the range of 0°-25° and 80°-90°, the difference between them is very small. This is because the rock mass is mainly damaged by shear failure, which is consistent with with the hypothesis of theoretical derivation. When $\beta$ is in the range of 25°-80°, the difference between the two is large, and the theoretical result is obviously smaller than the numerical simulation result, which may be due to the rock sliding along the structural plane and rock failure occur simultaneously within this angle range.

In order to get more accurate compression failure characteristic of rock mass, three cases of $\beta=20°$, 45° and 90° are selected as representatives for analysis. The compression curve and displacement vector diagram are shown in Figure 4.

![Figure 4. The compression curve and displacement vector diagram.](image)

It can be seen from Figure 4 that when the dip of structural plane is 20° and 90°, the change rule of compression curve is basically the same, the rock deformation changes from elastic stage to plastic stage, the model is slightly damaged, the upper and lower parts produce vertical displacement, and the reverse local slight displacement occurs along the structural plane; when the dip of structural plane is 45°, the change rule is quite different, the model is greatly damaged, and the rock along the structural plane produces reverse slip.

The conclusion can be drawn from the comprehensive analysis of Figure 3 and Figure 4, when dip $\beta$ is in range of 0°-25° and 80°-90°, rock failure does not occur along structural plane; when dip is 25°-70°, rock failure occurs along structural plane.

### 3.2. Compression failure characteristic of rock mass with multiple structural planes

When there are multiple structural planes in rock mass, there is a significant difference between compression failure characteristic and single structural plane rock mass. In order to obtain the compression characteristic of the multiple structural plane rock mass, taking dip of the structural plane of rock mass $\beta=20°$ and $\beta=45°$, two, three, four and five structural planes rock mass uniaxial compression models are designed respectively. Some numerical models are shown in Figure 5.
The compression curve and displacement vector diagram of rock mass with multiple structural planes are shown in Figure 6. Limited to the spacing, only partial results are shown. From the figure, it can be seen that the failure mode of rock mass in different structural planes is basically the same, and the number of structural plane has no impact on the failure mode of rock mass. At 20°, the rock mass with multiple structural planes does not slide along the structural plane, and the rock block only has compression failure. The compression curves of rock mass are similar, but the strength values of rock mass are slightly different. At 45°, the rock mass with multiple structural planes slips along the structural plane, and the rock blocks slide and compress simultaneously. The compression curves of rock mass are basically similar, showing continuous increase at first, reaching the yield strength of rock mass and then stabilizing. The compression strength of rock mass at 20° and 45° can be obtained by exporting result data of each model, as shown in Figure 7.

It can be seen from Figure 7 that when $\beta=20^\circ$, the compression strength of rock mass decreases rapidly with the increase of the number of structural plane, which is different from the numerical simulation results in the case of single structural plane. This may be because the rock mass is broken with the increase of the number of structural plane, thus the compression strength of rock mass decreases. When $\beta=45^\circ$, the compression strength of rock mass decreases first, then tends to be stable, and then decreases, which is caused by the joint action of sliding and compression of rock mass.
4. Conclusion
Taking layered rock mass of Coal Series Strata as the research object, the FLAC3D numerical model was established, the layered rock mass is regarded as discontinuous medium, and layer in the layered rock mass was simulated by interface. Compression failure characteristic of layered rock mass under the condition of single and multiple structural planes are studied systematically, and the following conclusions are drawn:

(1) For single structural plane rock mass, under the same axial pressure, with the increasing of dip of structural plane, the compression strength of rock mass decreases in the range of 25°-60°, increases in the range of 60°-25° and 80°-90°, and the overall compression strength curve is "U-shaped"; in the range of 0°-25° and 80°-90°, the results of numerical solution and theoretical solution are almost the same; but in the range of 25°-80°, the theoretical solution is smaller than the numerical solution. This is because the rock mass sliding along the structural plane and rock mass failure occur simultaneously within this angle range;

(2) For multiple structural plane rock mass, when dip of structural plane is fixed and the number of structural plane in the same group is increased, the failure mode of rock mass with different structural plane is basically the same, the number of structural plane has no effect on failure mode of rock mass, and the compression curve of rock mass is similar basically. With the increase of structural plane, the compression strength of rock mass will be reduced. This may be because with the increase of the number of structural planes, the rock mass is broken and the compression strength of rock mass is depressed.

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