Study on Stability of Rounding Rock When Mining on Confined Water in Reliability

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Abstract. In order to research the stability of roadway rock and water-resisting layer of the baseboard, the paper use the theory of reliability to build a calculate model and regarding the mechanical parameters related to rock as random variables. Basis on the limit state during its stability and the relationship of stress-strain, the paper built limit state equation. And then it can solve the reliability of each unit. The research shows that roadway system is a series system. The law of rock changing shape can be regarded as normal distribution, which can help to solve the random variable.

Introduction

With the increase of mining depth, the second stress and water pressure continue to increase, and the disaster of deep mining is becoming more and more serious. Because the number of accidents and casualties caused by the seepage of coal mine and the instability of the surrounding rock remain high, and the economic loss has been the first place in the coal mine disaster. Therefore, the study of the stability of coal mine surrounding rock and the water inrush from faults have become the key scientific and technical problems in the development of coal technology and economy in China.

In the study of the stability of surrounding rock, Manchao He carried out the analysis with the relevant theory of reliability of stability of coal roadway \cite{1}; Yonghua Su and other people have calculated the stability of the structural stability of the bolt lining tunnel\cite{2}; in the research on the mining of confined water, the former Soviet scholar based on the statics theory and deduced the calculation formula of the safe water pressure value of the base plate theory. Baiying Li puts forward the theory of “next three zones”\cite{3}. After mining, the coal seam floor was divided into the mining failure zone, the whole water resisting belt and the water bearing rising belt from top to bottom. Previous studies are of great significance. In this paper, on the basis of previous studies, we use the reliability theory to analyze the stability of surrounding rock and rock bottom, based on the stress-strain relationship establish the limit state equation for reliability of each unit body and roadway system.

Establishment of Reliability Analysis Model

More and more people recognized the reliability analysis of the rock, but more problem should be solved with the use of reliability analysis, the decisive factor is the establishment of the reliability analysis model, which is how to establish the limit state equation.

If the resistance of the structure is \(Q\), the load effect is \(S\), select random variables \((X_1, X_2, X_3, \cdots, X_N)\) which plays a major role in the stability of structures in reliability analysis, it serves as a function of the organizational parameters and the supporting structural material; the state of the engineering structure is expressed in terms of function \(Z\), so

\[
Z = Q - S = g(X_1, X_2, X_3, \cdots, X_N)
\]
In the type: when \(Z>0\), the element is reliability; when \(Z=0\), the element is at the limit; when \(Z<0\), the element is invalid.

Therefore, the limit equation of state can be expressed as:

\[
g(X_1, X_2, X_3, \ldots, X_N) = 0
\]

The reliability of the element is:

\[
F = P[g(X_1, X_2, X_3, \ldots, X_N)]
\]

When the rock sample is tested on a rigid test machine, its stress-strain curve is shown in figure 1.

When the rock is subjected to repeated loading-unloading experiments on the rigid test machine, the stress-strain curve is obtained, as shown in figure 2.

Based on the rock stress-strain curve diagram analysis show that when the rock have the loading unloading test, the stress-strain curve of rock will form a ring-shaped hysteresis loop, and then after loading curve always seems to be along the track of the development of the original stress-strain, so the rock is 'the function of memory'. So in the reliability analysis of surrounding rock and the bottom of the calculation, it cannot use the exponential function to study, but the whole process of rock stress and strain curve and the normal distribution function curve is consistent, so the author of this assumption of random variables \(g(X_1, X_2, X_3, \ldots, X_N)\) obey normal distribution and introduce standardized variables, we can get:

\[
x_i = \frac{x_i - \mu_{X_i}}{\sigma_{X_i}} (i = 1, 2, 3, \ldots, n)
\]

In the type: \(\mu_{X_i}\) is the mean of \(x_i\), \(\sigma_{X_j}\) is the equation of \(x_i\).

So the limit state equation is the limit state equation of the standard normal space, that is:

\[
g\left(\sum_{i=1}^{n} x_i \sigma_{x_i} + \mu_{x_i}\right) = 0
\]

The element reliability is:

\[
F = P[g\left(\sum_{i=1}^{n} x_i \sigma_{x_i} + \mu_{x_i}\right)] = 0 (i = 1, 2, 3, \ldots, n)
\]
The Eq. 6 can obtain the reliability of surrounding rock of roof F₁, reliability of surrounding rock of two groups F₂, and reliability of bottom plate F₃.

**Calculation of Element Reliability**

To solve the Fᵢ, Eq. 6 is necessary to know the unit resistance Q and the load S. Based on the existing research and a large number of engineering practices can learn[4], the roof of the roadway and the load of the two groups are:

\[ g(X₁, X₂, X₃, \cdots, Xₙ) \]

\[ S₁ = \gamma a b K_a \cos \frac{\alpha}{2} \left(1 + \frac{\gamma H}{1000 K_γ \sigma_{cr}}\right) \]  

\[ R = \frac{a[kγ[kγ / 3 - 1/π²] + γ(kH + h₁)]}{2H[\left(\frac{π}{a}\right)^2(\frac{15}{8π²}) + (\frac{π}{a})^2(\frac{15}{8}) + (\frac{π}{b})^2(\frac{2}{3})^2 - (\frac{1}{4})]} \times \sin^2(\frac{πX}{a}) \sin^2(\frac{πY}{b}) \]  

In the type, S₁, S₂ - the roof and the support loads of the two sides respectively, Mpa; h₀-all high of the roadway, m; H-the deep of the roadway, m; hₖ-the thickness of coal seam cut by roadway, m; λₖ-the average weight of coal seam, KN/m³; γ-the weight of the coal seam, KN/m³; Kₖ-the stress concentration factor; σₓₓ -unidirectional compressive strength, Mpa; σᵧᵧ -roof single layer compressive strength, Mpa; α - the dip angle of coal seam; Kᵧ-the integrity coefficient of roof strata; a - the half span of the cantilever rock, m; b - the roof damage height, m.

In the determination of resistance, and is divided into shear slip theory and the compression ring theory of bearing belt, the resistances under these two theories are respectively:

\[ R₁ = \frac{Q(\frac{π}{8} + \frac{\varphi}{2}) \cos(\frac{π}{4} + \frac{\varphi}{2})}{D \cos(\frac{π}{4} + \frac{\varphi}{2})} \]  

\[ R₂ = \frac{ηQ}{D} \]  

In the type: Q - element resistance; R₁-reliability under shear slip; R₂ - reliability of the compression zone; φ - internal friction angle of rock mass; η - resistance factor.

In the course of the study on stability of water inrush, plate failure mechanism and hydraulic fracturing principle are all under the drive of hydraulic rock crack initiation and extension and tracking transfer, until coalescence lead to instability rupture, floor water-irruption is depended on the blocking ability of floor water-resisting layer.

During the study, based on the theory of thin plate, simplifying the water-resisting layer to four edges clamped, sheet model by linear load, and take the face behind the stress reducing area into consideration [5], so the mechanics model of aquifuge can be shown in picture 3.
The mechanical model shows that:

\[ Q = k \gamma \gamma H(x/a) \]  \hspace{1cm} (11)

\[ R = \frac{a[k \gamma \gamma H(x/a)]}{2 H[\pi a^2 \left(1 - \frac{15}{8 \pi^2} + \frac{\pi^2}{a^2} + \frac{15}{8} \right) + \left(1 - \frac{1}{4 \pi^2} \right) + \frac{1}{4 \pi^2} \left(2 \pi^2 \right) + \frac{1}{4 \pi^2} \right]} \times \sin^2 \left(\frac{\pi x}{a} \right) \sin^2 \left(\frac{\pi y}{b} \right) \]  \hspace{1cm} (12)

In the type, \( Q \) - vertical downward load; \( x, y \) - the function value of coordinates, m; \( \gamma \) - the average bulk density of the aquifer, KN/m³; \( a \) - the sheet length of bottom plate, m; \( b \) - the sheet width of the bottom plate, m; \( J \) - the bending stiffness of sheet; \( H \) - the buried depth of coal seam, m; \( h_1 \) - the bottom plate mining failure zone depth, m.

Reliability Model of Roadway System

In the stability of the whole calculation process of roadway, the roof and floor, two sides are considered as an independent unit, only when each unit is stable, the roadway can be stable and reliable positioning; any unit failure, the entire roadway is regarded as fault, so the roadway system composed of a plurality of unit body composition meet series system reliability model.

According to the above picture, the reliability of roadway stability is:

\[ P = F_1 F_2 F_3 \]  \hspace{1cm} (13)

In the type, \( F_1 \) - the reliability of the roof; \( F_2 \) - the reliability of the two sides; \( F_3 \) - the reliability of the floor; \( P \) - the reliability of the overall roadway system.

Summary

1) The surrounding rock of the roadway has a ‘memory’, and its deformation curve and distribution curve is similar, so use the normal distribution to determine the random variables \( X_i \), so as to establish the limit state equation.

2) The water inrush from the floor depends on the stability of the water resisting layer of the floor, in the case of load and resistance, in addition to considering the weight of the failure zone of the floor, the stress reduction zone after the working face should be considered.

3) The reliability model of the roadway system is a series system, so the overall reliability of the roadway is:

\[ P = F_1 F_2 F_3 \]  \hspace{1cm} (14)

References

[1] Manchao He, Yonghua Su, Xiaoming Sun. Reliability Analysis of Stability of Cal Roadway Supported by Blt [J]. Journal of Rock Mechanics and Engineering, 2002, 21(12):1810-1814.

[2] Yonghua Su, Xiang Li, Nengxiong Xu. Calculation of Structural Stability Reliability of Shotcrete Lining Tunnel [J]. China Civil Engineering Journal, 2011, 44(3):113-119.

[3] Baiying Li, Weijia Guo. Mining Damage and Environmental Protection [M]. Beijing Geological Publishing House, 1997:46-53.

[4] Weitao Liu, Shiliang Liu, Wencheng Song. Study on the Stability of the Water Resisting Layer on the Bottom of the Work Face Based on the Thin Plate Theory [J]. Coal Science and Technology, 2015, 43(9):144-148.
[5] Li Li, Jianjian Zhao, Shiqing Zhang. Study on Rock Pressure Behavior in Steep Working Face [J]. Coal Technology, 2014, 33(5):98-100.

[6] Weijin Wang, Chaojiong Hou. Reliability Analysis of Bolt Support in Coal Roadway [J]. Journal of Rock Mechanics and Engineering, 2001, 20(6):813-816.