

Calculation of Stability Limit Displacement of Surrounding Rock of Deep-Buried Soft Rock Tunnel Construction Based on Fuzzy Logic Matching Algorithm

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Abstract. With the continuous development of society and economy, infrastructure construction is expanding on a large scale. The stress concentration after excavation in deep-buried soft rock masses may cause the stress level of the rock mass to exceed the strength of the surrounding rock and form plastic stress, the area where plastic shear slip or plastic flow occurs. Based on the fuzzy logic matching algorithm for the surrounding rock of deep-buried soft rock tunnel construction, this paper analyzes the development law of surrounding rock deformation and supporting force over time in actual construction by establishing elementary function mathematical calculation equations, and tries to construct a set of It is used to determine the actual deep-buried soft rock tunnel surrounding rock stability limit displacement value process. Practical results show that the process based on fuzzy logic matching algorithm can effectively meet the requirements of actual deep-buried soft rock tunnel engineering.

Keywords: fuzzy logic matching algorithm; field test; numerical simulation; squeeze deformation; surrounding rock stability

1 INTRODUCTION

With the continuous development of my country's social economy, infrastructure has shown a large-scale expansion [1-3]. However, due to the topography of our country, we usually encounter mountainous conditions. The stress concentration phenomenon after the excavation of the cavern in the deep and weak rock mass may cause the stress level of the rock mass to exceed the strength of the surrounding rock, forming a plastic stress area. Plastic shear slip or plastic flow tends to increase the risk of construction and threaten the quality and safety of the project [4-8]. Therefore, it is extremely necessary to calculate the stability limit displacement of surrounding rock for deep-buried soft rock tunnel construction [9-12].

Usually mathematical models are used for scientific research and analysis of natural phenomena. Especially after the advent of calculus theory, differential equations are used to describe natural phenomena. However, if the calculus equation has its shortcomings, it can only be used to describe continuous and smooth change phenomena cannot describe discontinuous mutation phenomena. In the material world, most of the existing phenomena are non-continuous mutation phenomena. Scene changes will develop to a certain extent and become qualitative changes, which are indifferntiable. Functions, such as earthquakes, volcanic eruptions, tsunamis, stratum movement, etc., for these common discontinuities in the material world, the use of catastrophe theory can better explain the nature of these phenomena [13-15]. With the in-depth understanding of the material world, people began to realize the need for a non-linear, discontinuous theory to study these material phenomena. Catastrophe theory was born and developed under this background.

Based on the fuzzy logic matching algorithm, this paper analyzes the development of surrounding rock deformation and supporting force over time by establishing elementary function mathematical calculation equations, and tries to construct a set that can be used to determine the actual deep buried soft rock tunnel surrounding rock. The process of stabilizing the limit displacement value.

2 CATASTROPHE CRITERION OF SURROUNDING ROCK INSTABILITY OF DEEP-BURIED SOFT ROCK TUNNEL BASED ON CATASTROPHE THEORY

In the simulation calculation of deep soft rock excavation, we define the plastic yield zone volume $V(k)$ of surrounding rock after k times of excavation construction as:

$$V(k) = \sum_{i=1}^N V_i(k) \quad (1)$$

In Eq. (1), k is the number of excavation steps, N is the number of rock mass units that yield, and $V_i(k)$ is the volume of the i -th yield unit. Tunnel excavation is often accompanied by loading or unloading. $V(k)$ will change under the influence of loading and unloading. At this time, the yield zone volume $V(k)$ can pass through a continuous volume function. $V(k) = f(t)$ represents the above changes, where t is the moment of loading or unloading.

Carry out tyler series expansion on the yield volume function $V(k)$, generally taking the 4-th power term, then:

$$V(k) = f(t) = \sum_{i=1}^4 a_i t^i \quad (2)$$

In the formula, $a_i = \frac{\partial^i f}{\partial t^i} \Big|_{t=0}$, through the Chirnhaus

transform, $t \rightarrow x - A$, $A = \frac{a_3}{4a_4}$, Eq. (2) through the

transformation, the standard function of the cusp catastrophe model can be obtained:

$$V(x) = b_4 x^4 + b_2 x^2 + b_1 x + b_0 \quad (3)$$

Among them, the relationship between a_i and b_i is:

$$\begin{pmatrix} b_0 \\ b_1 \\ b_2 \\ b_4 \end{pmatrix} = \begin{bmatrix} A^4 & -A^3 & A^2 & -A & 1 \\ -4A^3 & 3A^2 & -2A & 1 & 0 \\ 6A^2 & -3A & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{pmatrix} a_4 \\ a_3 \\ a_2 \\ a_1 \\ a_0 \end{pmatrix} \quad (4)$$

Eq. (4) dividing both sides by b_4 at the same time and transforming can obtain the mathematical function of the cusp catastrophe model:

$$V(k) = x^4 + \mu x^2 + vx + c \quad (5)$$

In Eq. (5), c is a constant that can be ignored, and Eq. (6) can be further simplified into the standard functional formula of the cusp catastrophe model:

$$V(k) = x^4 + \mu x^2 + vx \quad (6)$$

In Eq. (6), $u = \frac{a_2}{a_4} - \frac{3a_3^2}{8a_4^2}$, $v = \frac{a_1}{a_4} - \frac{a_2a_3}{2a_4^2} + \frac{a_3^3}{8a_4^3}$.

From $\frac{\partial V}{\partial x} = 0$ and $\frac{\partial^2 V}{\partial x^2} = 0$, the expression of the divergent set equation can be solved simultaneously:

$$8u^3 + 27v^2 = 0 \quad (7)$$

Take $\Delta = 8u^3 + 27v^2$ as the distance between the continuous evolution state and the critical state of the rock mass, and Δ is the mutation characteristic value. If and only if $\Delta \leq 0$, the system will generate a sudden change across the bifurcation set, and the Δ value is the criterion for volume change. The specific criteria are as follows:

- When $\Delta > 0$, the surrounding rock system is considered to be a stable state;
- When $\Delta = 0$, the surrounding rock system is considered to be in critical equilibrium;
- When $\Delta < 0$, the surrounding rock system is considered to be unstable and damaged.

In the numerical simulation, according to the standard, the conclusion obtained from the analysis of the displacement monitoring data of the measuring point is only accurate for the surrounding rock within the 5m range of the current fault front and back. Taking into account the convenience of the numerical simulation, the numerical simulation is correct. The statistics of the volume of the plastic yield zone are only for the surrounding rock within 2 meters of the measurement point section. The measurement point is located at the section 15 meters away from the entrance of the tunnel, and the monitored space is the surrounding rock range of 14 to 16 meters from the tunnel entrance.

Through the monitoring of each excavation step, the volume of the plastic yield zone of the surrounding rock within two meters is measured, and the change in the volume increase of the plastic yield zone in each excavation step is calculated, thereby establishing the volume increase of the plastic zone of the surrounding rock

in each excavation step. Measure value sequence $\{V\} = \{V(1), V(2), V(3), \dots, V(m)\}$, where m represents the m -th excavation step. Repeat the above volume increment value sequence four times. The polynomial fitting is transformed into a polynomial to solve for the polynomial coefficients a_1, a_2, a_3, a_4 , and then the polynomial coefficients are substituted into the relevant calculation equations to obtain the values of μ and v , and the mutation characteristic values are solved by $\Delta = 8u^3 + 27v^2$. Finally use the catastrophe criterion to judge whether the state of the surrounding rock system is stable or not.

The length of the tunnel in the numerical simulation of deep soft rock tunnel excavation is 80 meters. Because the tunnel entrance is greatly affected by the end restraint effect during the excavation of the footage, this study set the tunnel section 15 meters away from the entrance as the main Monitoring the cross-section, there are 57 steps in the 3D simulation tunnel excavation sequence, using the pre-written "plastic zone volume" related command flow statistics to obtain the cumulative plastic zone volume change value of the surrounding rock in 57 excavation steps, and comparing the phase The cumulative yield zone volume change value of adjacent excavation steps can be calculated to obtain the plastic zone volume increment value, and the plastic zone volume increment value sequence $\{V\} = \{V(1), V(2), V(3), \dots, V(m)\}$, use MATLAB to fit the 4-th degree polynomial of the maximum volume increase sequence of the plastic zone, fit the 4-th degree polynomial of the volume increase value V in the excavation step sequence, and solve the polynomial coefficients of the phase. Substitute a_1, a_2, a_3 , and a_4 into the formula to calculate the size of μ and v , thereby calculating the numerical size of the mutation characteristic value Δ .

After obtaining the value of the mutation characteristic value Δ , this paper uses the value change of Δ to determine the stability limit displacement value of the surrounding rock of the deep-buried soft rock tunnel. The limit displacement of the surrounding rock occurs in the excavation sequence of Δ positive and negative conversion, in simple terms. If $\Delta > 0$ at the n -th excavation step and $\Delta < 0$ at the $n + 1$ excavation step, the displacement value of the surrounding rock at the $n + 1$ -th step sequence is the limit displacement value sought.

Since there are a total of 18 test groups in this simulation, and each simulation has 57 excavation steps, if the calculation of the Δ value is performed on 57 excavation steps, the workload will become very huge, so this Secondly, the dichotomy was used to determine the critical point of the mutation characteristic value Δ positive or negative. The specific search process is as follows:

- (1) First calculate the mutation characteristic value Δ of the last step, the 57-th excavation sequence;
- (2) When the mutation characteristic value $\Delta > 0$ in step 57, it indicates that the surrounding rock is in a stable state of the system, that is, no instability occurs during the excavation process, and the search ends;
- (3) When the mutation characteristic value of the 57-th step $\Delta < 0$, it indicates that the surrounding rock is in a system instability state, and the mutation characteristic value of the 29-th step is calculated according to the dichotomy;
- (4) When the mutation characteristic value of the 29-th step sequence $\Delta > 0$, continue to use the dichotomy to calculate

the Δ value between the steps 29 and 57; when the mutation characteristic value of the 29-th step sequence $\Delta < 0$, the limit uses the dichotomy to calculate the Δ value in the sequence between the 1 st step and the 29-th step;
 (5) In this cycle, keep calculating and searching to find the excavation sequence where the mutation characteristic value Δ changes from greater than 0 to less than 0, then the cumulative displacement of the measuring point under this sequence is the stability of the surrounding rock of the deep-buried soft rock tunnel Limit displacement value.

Taking the 10-th group in the uniform test design as a typical example, a specific method for determining the limit displacement value of surrounding rock stability using the plastic zone volume mutation criterion in this section is shown.

Use the compiled plastic zone volume statistics command stream to perform plastic zone volume statistics on the FLAC3D files of 57 excavation steps in the 10-th group to obtain the cumulative plastic zone volume under each excavation step, and then pass the adjacent excavation steps. The difference of the cumulative plastic zone volume is calculated to calculate the change of the plastic yield zone volume increment value in each excavation sequence.

Obtain the volume increment value sequence of the yield zone in each excavation step sequence through statistics, use MATLAB to fit the volume increment value sequence of different excavation steps sequence with 4th degree polynomial, and then use the formula to calculate each excavation step. The volume mutation characteristic value Δ under the sequence finally obtains the stability limit displacement of the surrounding rock under the factor level.

$$\Delta = 8u^3 + 27v^2 \quad (8)$$

The following data processing uses the polynomial curve fitting function in Matlab to fit the data in the table. The fitting function used in Matlab is:

$$p = \text{polyfit}(x, y, n)[p, s] = \text{polyfit}(x, y, n) \quad (9)$$

Among them, x, y are data points, n is the polynomial order, and return p is the polynomial coefficient vector p from high to low.

In the first step, the plastic zone volume increase value sequence of the 57-th excavation sequence is fitted and calculated.

Corresponding coefficients are obtained by the fourth-degree polynomial obtained by fitting the volume enhancement of the plastic zone in the 57-th excavation step: $a_4 = -0.0012, a_3 = 0.2, a_2 = 6, a_1 = 32.6$

Substituting the above fourth-degree polynomial coefficients into the correlation formula:

$$\mu = \frac{a_2}{a_4} - \frac{3a_3^2}{8a_4^2}, v = \frac{a_1}{a_4} - \frac{a_2a_3}{2a_4^2} + \frac{a_3^3}{8a_4^3} \quad (10)$$

Solve it, $\mu = -15416.7, v = -1022537$.

Substituting the values of μ and v into Eq. (10), we get:

$$\Delta = 8\mu^3 + 27v^2 = -1.08256 \times 10^{12} < 0 \quad (11)$$

According to the above judgment criteria in this chapter, it is considered that the surrounding rock of deep-buried soft rock is in a systemic unstable state during the 57-th excavation step. According to the dichotomy, the same method is used to determine the volume of the plastic zone in the 29-th excavation step. Incremental fitting analysis.

Fit the volume increment value sequence at the 29-th excavation step sequence.

The corresponding coefficients are obtained by fitting the fourth degree polynomial obtained by fitting the volume increment of the plastic zone in the 29-th excavation step: $a_4 = 0.004, a_3 = -0.1494, a_2 = -0.8591, a_1 = 71.1651$.

Substitute the above fourth-degree polynomial coefficients into the correlation formula:

$$\mu = \frac{a_2}{a_4} - \frac{3a_3^2}{8a_4^2}, v = \frac{a_1}{a_4} - \frac{a_2a_3}{2a_4^2} + \frac{a_3^3}{8a_4^3} \quad (12)$$

Solve it, $\mu = -737.908, v = 7267.341$.

Substituting the values of μ and v into Eq. (12), we get:

$$\Delta = 8\mu^3 + 27v^2 = -1.7884 \times 10^9 < 0 \quad (13)$$

According to the above-mentioned judgment criteria in this chapter, it is believed that during the 29-th excavation step, the surrounding rock of the deep-buried soft rock is unstable and damaged. According to the dichotomy, the same method is used to increase the volume of the plastic zone in the 12-th excavation step. Once the fitting analysis is performed.

Fitting and calculating the volume increment value sequence at the 12-th excavation step sequence, the corresponding coefficients are obtained by fitting the fourth degree polynomial obtained by fitting the volume increase of the plastic zone at the 12-th excavation step: $a_4 = -00353, a_3 = 0.8647, a_2 = -8.6257, a_1 = 89.4070$.

Substitute the above fourth-degree polynomial coefficients into the correlation formula:

$$\mu = \frac{a_2}{a_4} - \frac{3a_3^2}{8a_4^2}, v = \frac{a_1}{a_4} - \frac{a_2a_3}{2a_4^2} + \frac{a_3^3}{8a_4^3} \quad (14)$$

Solve it, $\mu = 19.33843, v = -1377.27$.

Substituting the values of μ and v into Eq. (14), we get:

$$\Delta = 8\mu^3 + 27v^2 = 9.5043 \times 10^{10} > 0 \quad (15)$$

It is believed that in the 12-th excavation step, the surrounding rock of the deep-buried soft rock is in a stable state. According to the dichotomy, the same method is used to fit and analyze the volume increase of the plastic zone in the 20-th excavation step.

3 THREE-DIMENSIONAL NUMERICAL SIMULATION ANALYSIS OF DEFORMATION CHARACTERISTICS

3.1 Calculation Model and Parameter Selection

Establish a finite difference grid model according to

the actual size of the tunnel section. In order to minimize the boundary effect, the calculation domain is: $XYZ = 120 \text{ m} \times 60 \text{ m} \times 120 \text{ m}$. The front and back and left and right boundary surfaces adopt horizontal displacement constraints, and the bottom surface vertical displacement constraints. The rock mechanics parameters are taken as: $E = 1.0 \text{ GPa}$, $\nu = 0.36$, $\gamma = 21 \text{ kN/m}^3$, $c = 0.18 \text{ MPa}$, $\phi = 25^\circ$. The E and c values of the rock mass in the small duct grouting zone within the depth of 3 m at the tunnel arch and side wall were increased by 30%. The values of the support structure parameters are: the initial support and bottom plate $E = 21.0 \text{ GPa}$, $\nu = 0.20$; the second lining $E = 28.0 \text{ GPa}$, $\nu = 0.20$.

The stress release of the surrounding rock after excavation is achieved by applying a certain ratio of the maximum unbalanced force of the joint in the opposite direction of the joint within the range of the surrounding rock loosening zone. The calculation conditions are as follows: (1) Condition 1, step method excavation, initial support is applied after 30% stress release, the length of the upper and lower steps is 5 m, the excavation stops at 45 m, and the excavation of each analysis step is 1 m; (2) Condition 2, bench excavation, initial support is applied after 30% stress release, the upper and lower steps are 5 m in length, and the second lining is applied at 10 m from the tunnel face. The excavation stops at 45 m, and the excavation is 1 m for each analysis step.

3.2 Analysis of Calculation Results

The study of surrounding rock stability is mainly based on the displacement or stress changes to analyze its deformation laws and mechanical characteristics. This article discusses the deformation law and overall stability of the tunnel surrounding rock by simulating the spatial displacement distribution of the measuring points in different parts of the surrounding rock.

3.2.1 Deformation law of surrounding rock along the tunnel axis

Curve analysis of working condition 1: After the surrounding rock is excavated, relaxation deformation and plastic slip are generated, so that the unexcavated section of the surrounding rock within 8 m (about 1 times the diameter of the hole) in front of the tunnel has a convergent displacement, but the displacement value is very high. Small; the side wall has a large convergence rate within 15 m (about 2 times the hole diameter) behind the tunnel face, indicating that with the large release, transfer and redistribution of the stress after excavation, the surrounding rock will have a large displacement; the distance from the excavation face The closer it is, the smaller the deformation rate is. The reason is that the excavation has a certain three-dimensional space constraint on the deformation of the surrounding rock, indicating that timely reinforcement of the excavation surface during construction can inhibit the deformation of the surrounding rock within a certain range; the excavation surface Later, as the distance increases, the deformation rate gradually intensifies, and the displacement rate reaches a peak at 1.1 times the hole diameter. Since then, as the distance increases, the displacement rate becomes smaller and

smaller, and the deformation becomes stable at 3 times the tunnel diameter, indicating that the farther away from the excavation surface, the weaker the surrounding rock is restrained by the excavation surface, and the surrounding rock is stressed. The relationship with deformation gradually transitioned to a plane problem.

Analysis of the second curve of working condition: After the second lining is applied, the cumulative convergence value of the side wall of the tunnel is relatively small, only 5.35 cm; in the severely deformed section of the surrounding rock (within the range of 2 times the tunnel diameter behind the excavation surface), its displacement rate and displacement The magnitude is also obviously smaller. The closer the second lining section is, the smaller the deformation rate of the surrounding rock is. This is because the surrounding rock is subject to the strong rigid constraint of the second lining, which effectively restricts the deformation and development of the surrounding rock. The safety reserve structure to withstand the rheological pressure of the surrounding rock and the supporting force in the later stage, emphasizes the timeliness of the secondary lining support in the construction of soft rock tunnels, and is of great significance to control the deformation and mechanical behavior of the surrounding rock.

3.2.2 Deformation law of surrounding rock on the tunnel section

The cumulative settlement of the vault is 7.93 cm, and the cumulative convergence of the side wall is 11.7 cm. That is, in the high ground stress field dominated by the vertical direction, the horizontal displacement value of the cavern is greater than the vertical displacement value, which is consistent with the previous conclusions. After the bench excavation, the surrounding rock deformation rate is fast and the deformation value is large. When the calculation and analysis step reach 1300, the construction of the lower step is carried out. After the excavation of the lower step, the deformation appears abrupt, but the magnitude of the abrupt change is not large (a sudden change of the vault sinking The star value is 0.3 cm, and the convergence mutation value of the side wall is 1.4 cm), indicating that the upper step excavation is the main stage of surrounding rock deformation and stress release. Effective support should be provided in time after the upper step excavation to control the deformation; the lower step is opened. After excavation, the mutation amount of side wall deformation is significantly greater than the amount of vault deformation mutation, indicating that the excavation of the lower step has a greater disturbance to the horizontal displacement of the surrounding rock. It is recommended to strengthen the support of the side wall and the arch foot during the construction, such as construction Measures such as locking feet and rods.

4 FUZZY LOGIC MATCHING ALGORITHM

4.1 Fuzzy logic matching algorithm calculation process

The fuzzy logic matching algorithm is used to obtain a mathematical model. The generalization performance of the model is determined by three parameters: the penalty parameter C , the kernel parameter σ of the RBF kernel

function, and the error value ϵ . The selection of these three parameters determines the generalization performance of the network, so the optimization of the values of the three parameters is very important. This time, the decimal genetic algorithm is used to determine the optimal network

parameters, improve operation efficiency, and solve mathematical calculation equations.

The specific flow chart of using decimal genetic algorithm to determine the optimal SVR network parameters is shown in Fig. 1.

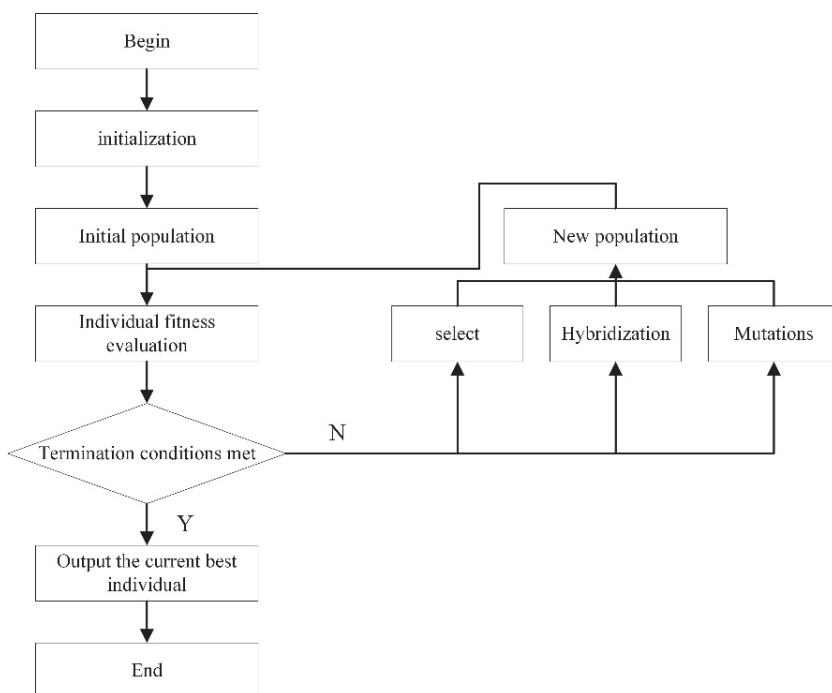


Figure 1 Flow chart of genetic algorithm

The specific process of genetic algorithm is:

- (1) Group the 18 sets of data obtained from the uniform experimental design in Chapter 3 and the mutation theory in Chapter 4 to determine the limit displacement, and set 14 of them as evolutionary support vector regression learning samples, and select 2 weaves as test samples, and the remaining 2 groups are set as test samples;
- (2) Initialize the genetic algorithm to randomly generate an initial population that supports the network parameters of the acyl machine, where the counter is recorded as $g = 0$, and the population size is recorded as N_p ;
- (3) Write the training samples and test samples into the halo regression algorithm to complete the network training and pre-cutting;
- (4) Pass the prediction results to the genetic algorithm one by one, and use the fitness function in the genetic method to find the fitness of each body, so as to complete the evaluation of the parameter fitness;
- (5) Determine whether the previously agreed evolutionary algebra has been met. If it is reached, the algorithm will end, return to the current individual with the highest fitness, and use the decoding to obtain the optimal support vector machine network parameters; if the required evolution has not met Algebra, then execute (6);
- (6) Selecting Zizi to select individuals with higher fitness in the initial population, and perform duplication, crossover, and mutation operations on the individuals to generate a population of offspring with SVR network parameters whose number of individuals is N_p , and the counter is recorded as $g = g + 1$; return (3);
- (7) Follow the steps (3) - (6) until the specified evolution algebra is reached, the algorithm ends, and the optimal support vector regression network parameters are returned.

4.2 Overview of Genetic Algorithm

(1) Genetic operator.

1) Selection operator:

This article uses the queue selection method. The steps of the queuing selection method are: firstly, the fitness of each body is solved, the individuals are arranged in order according to the fitness, and then the probability table is assigned to each individual in order, which is regarded as their respective selection probability. Among them, the selection probability can be expressed as:

$$p = q'(1-q)^{r-1} \tag{16}$$

Among them, q is the probability of selecting the best individual; r is the rank of the individual, which is the best when $r = 1$; p is the population size; the formula for calculating q' is:

$$q' = \frac{q}{1 - (1-q)^p} \tag{17}$$

2) Crossover operator:

Ben again uses arithmetic hybridization. p_c is the probability of the hybridization operation, which is defined as the expected value of $p_c \cdot N$ chromosomes in the population to complete the hybridization operation. In order to find the parent of the cross operation, the operation is repeated from $i = 1$ to N : a uniform random number r is generated from the interval $[0, 1]$, if $r < p_c$, X_i is selected as the parent of the cross operation, where the parent The

generation is represented by \bar{X} , \bar{Y} , namely:

$$\begin{cases} \bar{X} = r\bar{X} + (1-r)\bar{Y} \\ \bar{Y} = (1-r)\bar{X} + r\bar{Y} \end{cases} \quad (18)$$

Test the feasibility of the newly produced offspring, if feasible, replace the parents with them; if it is feasible, keep the feasible part, continue to generate new random numbers, and then re-cross, continue to produce two usable offsprings.

3) Mutation operator:

This article uses non-uniform mutation. The essential difference between non-uniform mutation and uniform mutation is to replace the original component j with a non-uniform random number, the formula is as follows:

$$x_i = \begin{cases} x_i + (b_i - x_i)f(G), r_1 < 0.5 \\ x_i - (x_i + a_i)f(G), r_1 \geq 0.5 \\ x_i, otherwise \end{cases} \quad (19)$$

Among them:

$$f(G) = \left(r_2 \left(1 - \frac{G}{G_{\max}} \right) \right)^b \quad (20)$$

r_1, r_2 are uniform random numbers in the interval $\{0, 1\}$; G is the current generation; G_{\max} is the largest number in the generation; b is the shape parameter.

(2) Fitness function.

This article uses the following fitness function:

$$f(x) = \exp \left\{ -0.5 \times \max \left[\left| \frac{\text{SVR}(x_i) - y_i}{y_i} \right| \times 100\% \right] \right\} \quad (21)$$

where: $\text{SVR}(x_i)$ represents the SVR prediction of the stability limit displacement of the rock of the i -th test sample during training, and y_i is the actual stability limit displacement of the rock of the i -th test sample during the training.

5 FUZZY LOGIC MATCHING ALGORITHM TO SOLVE THE MATHEMATICAL MODEL OF SURROUNDING ROCK STABILITY LIMIT DISPLACEMENT

This chapter establishes a mathematical prediction model of elementary functions on the basis of fuzzy logic matching algorithm theory.

Considering that the calculation equations of the evolutionary support to the star regression algorithm for a single solution are in the form of one-dimensional variables, this time the mathematical calculation equations of the limit vault subsidence displacement and the limit horizontal convergence displacement are solved separately. Use MATLAB software and toolbox to complete the calculation and analysis work, the kernel function adopts the RBF kernel function, the value search pool of penalty

parameter C is $[0, 1000]$, the value search range of nuclear parameter σ is $[0, 1000]$, the error The search range of the value ε is $[0, 1]$, the evolutionary algebra is 1000 generations, and the population size is 20. Using queue selection, arithmetic crossing and non-uniform mutation, the probability of crossing is 0.9 and the probability of mutation is 0.05. The fitness function of genetic algorithm is:

$$f(x) = \exp \left\{ -0.5 \times \max \left[\left| \frac{\text{SVR}(x_i) - y_i}{y_i} \right| \times 100\% \right] \right\} \quad (22)$$

After the search by the genetic algorithm is completed, the optimal SVR model parameters of the limit dome subsidence displacement and the limit horizontal convergence displacement are obtained respectively.

5.1 Mathematical Model for Prediction of Limit Vault Subsidence Displacement

Using MATLAB and SVM toolbox, the SVM type of Svmtrain (training modeling) is epsilon-SVR, and the kernel function type is RBF by default, which is the p value required to establish the mathematical model of the ultimate vault subsidence displacement.

From the radial basis function kernel function (RBF), it can be known that if a brave SVR mathematical model display expression is required to be solved, only the form of the kernel function, the optimized kernel parameters of the kernel function, and the values of β_i and b are required. Substituting the β value into the formula, the following calculation formula is obtained:

The mathematical calculation equation for the prediction of the ultimate vault subsidence displacement for the stability of the surrounding rock of the deep-buried soft rock tunnel is:

$$\begin{aligned} f(x) = & f_1(x) + f_2(x) + f_3(x) + f_4(x) + \\ & f_5(x) + f_6(x) + f_7(x) + f_8(x) + f_9(x) + \\ & f_{10}(x) + f_{11}(x) + f_{12}(x) + f_{13}(x) + f_{14}(x) \end{aligned} \quad (23)$$

From the optimal SVR model of the ultimate displacement of the dome subsidence, we can see that $\sigma = 813.1$ in Eq. (23); $x_1, x_2, x_3, \dots, x_{13}, x_{14}, x_{15}$, known loops, take values in the order of the parameters, respectively representing the severity and deformation Modulus E_m , Deformation Modulus E_k , Poisson's Ratio, Internal Friction Angle, Cohesion, Dilatancy Angle, Maxwell Viscosity Constant, Kelvin Viscosity Constant, Horizontal Lateral Pressure Coefficient, Buried Depth, Shotcrete Thickness, Tracing Rod Length, Uranium rod spacing and trace rod diameter.

Substituting the influencing factor data of the inspection group into the formula, the prediction value of the limit vault subsidence displacement of the surrounding rock is solved, and the value is compared with the numerical simulation calculation value to check its reliability. It can be seen from the reliability result of the prediction model that the relative error between the predicted value of the 17-th set of vault subsidence limit

displacement and the calculated value in the group test group is 13.2%, and the actual worst value is 123 mm; the 18-th group of test groups in the two groups of test groups, the 18-th group of dome subsidence limit displacement predictions. The relative error between the value and the calculated value is 21.2%, and the actual worst value is 34.9 mm.

The average relative error between the predicted and calculated values of the two inspection groups is 17.2%, which can fully meet the requirements of actual deep-buried soft rock tunnel engineering.

5.2 Limit Horizontal Convergence Displacement Prediction Mathematical Model

Using MATLAB and SVM toolbox, the SVM type of Svmtrain (training modeling) is epsilon-SVR, and the kernel function type is RBF by default, and the β value required for the mathematical model of the limit horizontal convergence displacement is established.

From the radial basis function kernel function (RBF), it is known that if the optimal SVR mathematical model display expression is required to be solved, only the form of the kernel function, the optimal kernel parameters of the kernel function, and the values of β_i and β are obtained. The mathematical calculation equation of the limit horizontal convergence displacement prediction for the stability of the surrounding rock of the deep-buried soft rock tunnel can be obtained as:

$$f(x) = f_1(x) + f_2(x) + f_3(x) + f_4(x) + f_5(x) + f_6(x) + f_7(x) + f_8(x) + f_9(x) + f_{10}(x) + f_{11}(x) + f_{12}(x) + f_{13}(x) + f_{14}(x) \quad (24)$$

Substituting the influencing factor data of the test group into Eq. (24), the predicted value of the limit horizontal convergence displacement of the surrounding rock is solved, and the value is compared with the numerical simulation calculation to check its reliability.

It can be seen from the reliability results of the prediction model that the relative error between the predicted value of the horizontal convergence limit displacement of the 17-th group in the 2 test groups and the calculated value is 17.7%, and the actual worst value is 210.5 mm; The relative error between the predicted value and the calculated value of the 18-th group of dome subsidence limit displacement is 19.9%, and the actual worst value is 23.3 mm. The average relative error between the predicted value of the two inspection groups and the calculated value is 18.25%, and the maximum relative error is 18.8%, which can fully meet the requirements of actual deep-buried soft rock tunnel engineering.

6 CONCLUSION

Based on the fuzzy logic matching algorithm, by establishing elementary function mathematical calculation equations, this paper constructs a set of procedures that can be used to determine the stability limit displacement value of the surrounding rock of the actual deep-buried soft rock tunnel, aiming to stabilize the surrounding rock of the

deep-buried soft rock tunnel. The limit displacement calculation provides theoretical support. The criterion given in the current code is not directly related to some engineering construction conditions and the evolution process of surrounding rock deformation of some sections. For soft surrounding rock or soft rock under high ground stress, surrounding rock instability or large deformation may occur, but there is still a lack of an effective method. The above research and analysis in this paper will help to build a displacement prediction system for tunnel surrounding rock stability analysis to solve this complex problem.

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