Research Article

Searching Method of Critical Slip Surface of Slope Based on Improved Wolf Swarm Algorithm

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Determining the critical sliding surface and calculating the safety factor of slope stability are the key problems of slope stability analysis. Firstly, according to the characteristics of the existing wolf swarm algorithm, an improved wolf swarm algorithm is proposed, which abandons the assumption of a circular sliding surface. Then, a multipoint spline curve is introduced to describe the shape of a slope sliding surface. The optimization of the curve can determine the critical slip surface of slope and avoid falling into the local optimum. This method is programmed and implemented in Python, and then, accuracy and reliability are verified through typical slope cases and engineering examples, and the sensitivity analysis of factors that have great influence is carried out. The research results show that the slope sliding surface search method based on the improved wolf swarm algorithm can effectively and quickly determine the critical sliding surface of the slope. Compared with traditional methods, it has higher convergence accuracy and reliability. It provides an effective method for slope stability analysis.

1. Introduction

Slope stability analysis is one of the important research topics in geotechnical engineering. The main objective of slope stability analysis is to evaluate the safety factor of a given slip surface and determine the critical slip surface of a given slope [1]. Therefore, it is valuable to improve and optimize the method of searching the most critical sliding face.

In the traditional slice method slope stability calculation, for example, Fellenius (or Swedish) (1927) proposed an arc slip analysis method for slope stability analysis or the Swedish arc slice method [2] and Bishop method [3], which is based on the Mohr–Coulomb shear strength theory [4]. They all assume a sliding surface, then divide the sliding surface into several vertical slices, and solve the sliding force and sliding resistance of each slice based on the equilibrium equation. Finally, the factor of safety is usually obtained by the limit equilibrium method (LEM) as the ratio of resistance forces by driving forces along the slip surface [1]. Natural rock and soil mass are in an elastic-plastic deformation state, and when it yields, stress can be transmitted to the surroundings. Therefore, the sliding resistance and sliding force at the bottom of each section obtained by the section method often deviate from the actual situation. Although the numerical simulation method fully satisfies the constitutive relationship among statics, strain compatibility, and stress-strain relationship and is not restricted by the irregular slope geometry and material heterogeneity, the stress field of rock and soil can be obtained truly, but the stability coefficient cannot be directly calculated directly. If the slope stress field is obtained by numerical simulation, then the slope stability safety factor is calculated, and it will provide a good reference value for slope stability analysis.

In recent years, with the rapid development of computer software and hardware, heuristic global optimization
methods have gradually been adopted to locate the critical failure surface. The term heuristic is used for algorithms, which find solutions among all the possible ones, but they do not guarantee that the best will be found, and therefore, they may be considered as approximate and not accurate algorithms. These algorithms usually find a solution close to the best one, and they find it fast and easily [5], such as simulated annealing algorithm [6], genetic algorithms [7], particle swarm optimization algorithm [8], and modified harmony search algorithm [9]. Cheng et al. [5] studied various critical slip surface search methods and their principles, advantages, and disadvantages and made a comprehensive comment on the development in this field. Compared with the exhaustive methods and dichotomy methods used in the early days, the accuracy and convergence of the above methods have improved a lot, and it has played a positive role in slope stability research and practical engineering applications. However, sometimes the results are not globally optimal, and once the complex slope is considered, the calculation may take a long time.

Reference [10] proposed a wolf pack algorithm (WPA) based on the predation behavior of wolves in the biomimetic nature, which has the characteristics of strong global optimization ability and fast convergence speed. The traditional wolf pack algorithm has shortcomings such as the exploration of wolves in h directions, there is no communication with each other, and the exploration space will be repeated. The WPA has been successfully used in neural network optimization [11], traveling salesman problems [12], path planning [13], etc. A variety of wolves in the wolf swarm algorithm undertake different tasks and cooperate to complete the search task, which is very suitable for searching the critical sliding surface of complex slopes. However, it has not yet been applied to the search of the critical slip surface for the slope. Solving slope safety factor based on the basic principle of limit equilibrium stability analysis and based on the basic theory of the wolf pack algorithm and the characteristics of the slope slip surface, the concept of she-wolf and fitness is introduced and restricts the search direction and area of the wolf detection, which effectively avoids the shortcomings of confusion in the search direction and duplication of the search area. Then, we developed a computer program to determine the critical slip surface based on an improved wolf swarm algorithm and calculate the safety factor. Finally, the performances of the proposed method and developed computer program were verified during comparative studies and sensitivity analysis [1]. The research results show that the slope stability analysis method based on the improved wolf swarm algorithm has higher accuracy and efficiency.

2. Basic Principles of Limit Equilibrium Stability Analysis

2.1. Calculation of Sliding Force and Anti-Sliding Force. For a potential sliding surface in a two-dimensional slope, when calculating the stability safety factor, pore pressure and interslice forces are ignored. If the load applied to the slope surface needs to be considered, it can be considered when the numerical model is established.

When calculating the sliding force and anti-sliding force of slope, the sliding surface is generally divided into several segments as shown in Figure 1. The intersection of different segments is called a state point. A path can be formed by the state points, which are connected from the start point to the endpoint, and each path is a potential sliding surface. Assuming that the sliding direction is to the right and counterclockwise is the positive direction of the sliding force, the calculation formulas for the shear strength $\tau_f$ and tangential stress $\tau$ on a certain section are as follows:

$$\tau_a = 0.5(\sigma_y - \sigma_x)\sin 2\alpha + \tau_{xy}\cos 2\alpha,$$
$$\sigma_a = 0.5(\sigma_x + \sigma_y) - 0.5(\sigma_x - \sigma_y)\cos 2\alpha - \tau_{xy}\sin 2\alpha,$$
$$\tau_f = \sigma_a\tan\varphi + c,$$
Average shear force of the i section: $\bar{\tau}_i = 0.5|\tau_{ai} + \tau_{ai+1}|,$
Average resistant shear force of the i section: $\bar{\tau}_{fi} = 0.5|\tau_{fi+1} + \tau_{fi}|.$

$$F_s = \frac{\int_A \tau_f \, dL}{\int_A \tau \, dL} = \frac{\left(\sum_{i=1}^n \tau_f \Delta d_i\right)}{\left(\sum_{i=1}^n \tau \Delta d_i\right)}. \quad (2)$$

In the above formula: $A$ and $B$ are the starting point and ending point of the slope, $n$ is the number of segments the sliding surface passes through, $\tau$ is the shear stress along the sliding direction of the sliding surface, $\tau_f$ is the shear strength, and $dL$ is the length of each segment along the sliding surface increment, $\tau_i$ is the shear stress on the path from node $i - 1$ to node $i$, $\tau_{fi}$ is the shear strength on the path from section $i - 1$ to section $i$, and $\Delta d_i$ is the length of the path from stage $i - 1$ to the stage $i$ [14].

$\sigma_x$, $\sigma_y$, and $\tau_{xy}$ are the normal stress and shear stress of the element along the $x$ and $y$ directions, respectively, $\varphi$ and $c$ are the internal friction angle and cohesion of the material, $\sigma_a$ is the normal stress of the inclined plane, and $\alpha$ is the angle between the inclined plane and the horizontal plane.
This definition has the following obvious advantages. First, it only needs to solve the slope nonlinearly once. Second, the influence of stress path on safety factor can be considered, and the physical meaning of safety factor is relatively clear.

3. Improved Wolf Pack Algorithms for Sliding Surface Search

For slopes with known sliding surfaces, the above limit equilibrium stability analysis method can be used to calculate the safety factor. However, it is difficult to determine the position of sliding surface points and the critical sliding surface for slopes with an unknown sliding surface. The position of the critical failure surface can be viewed as a form of nonlinear non-smooth global optimization problem [15], and heuristic global optimization algorithms can quickly and efficiently solve such optimization problems due to their good global searchability and direction searchability. In recent years, the wolf swarm algorithm is proposed as a bionic algorithm with good robustness and strong global optimization ability, which can be used to solve path optimization problems [13]. Therefore, for a two-dimensional slope mesh, the position of the sliding-out point and the sliding-in point are regarded as the position of the alpha wolf and the female wolf, and the stress value at a certain point is regarded as the odor concentration of the prey. The position of the head wolf and the she-wolf plays a decisive role on the slope. The wolves wander along a certain direction and determine the shape of the slope sliding surface together with the head wolf and the she-wolf. Fierce wolves are the points regularly distributed on a wolf group curve. After each generation of siege behavior is completed, the wolf group will update through the survival of the fittest mechanism to determine the global optimal solution.

3.1. The Basic Principle of the Classic Wolf Pack Algorithm

The classic wolf pack algorithm has the following three intelligent behaviors:

(1) Wandering Behavior: the $S_{num}$ best wolves are selected at a certain ratio $\alpha$ as the detective wolves. They walk around in $h$ directions with a constant step length $step_a$. If the odor concentration at the detective wolf $Y_i$ is greater than the odor concentration $Y_{lead}$ at the head wolf, that is $Y_i > Y_{lead}$, the detective wolf will replace the current head wolf.

(2) Summoning Behavior: the head wolf sends out a call to summon the fierce wolves. The fierce wolves run towards the current head wolf with a larger step length $step_b$. If the prey odor concentration of the fierce wolf $Y_j$ is greater than the prey odor concentration of the head wolf $Y_{lead}$, the fierce wolf transforms into a head wolf and starts a summoning behavior until the distance is less than the minimum distance $d_{near}$.

(3) Siege Behavior: after the fierce wolves’ long-range raid, they joined the detective wolf to siege their prey when they were very close to the location of the head wolf. After each generation of siege behavior, the wolves will update the wolves through the survival of the fittest update mechanism to eliminate the worse wolves.

3.2. Improvement of the Wolf Pack Algorithm

3.2.1. Steps to Improve the Wolf Pack Algorithm. The wolf swarm algorithm is actually an idea that assigns different tasks to different types of wolves. Each wolf completes their own work, transmits and exchanges information with other types of wolves, and finally continuously replaces iteration to find the optimal solution. There are only abstract wolves in the traditional wolf group algorithm. The wolves swarm algorithm is combined with the actual slope by giving the abstract wolf specific meaning, each wolf has a specific division of labor, and introducing the she-wolf to cooperate with the head wolf work, and the wandering direction and step size of the wolves are specifically limited. Finally, the concept of fitness is introduced as the standard to evaluate
the adaptability of the wolf swarm. Through the improvement of the above steps, the slope stability analysis method based on the improved wolf swarm algorithm is proposed.

(1) Model Establishment: according to the shape of the slope and the distribution of the stratum, combined with its boundary conditions, a reasonable finite element meshing of the slope is carried out to obtain the stress field and node coordinates of the slope. Regarding the entire slope as grassland, the stress at the node is the prey odor concentration.

(2) Head Wolf and She-Wolf Generation: In the wolf pack, the head wolf is dominant, and the she-wolf is inferior to the head wolf only and it works with the head wolf. Obviously, the quality of the wolf pack depends on the head wolf and the she-wolf. The sliding-out point and the sliding-in point are regarded as a head wolf and a she-wolf, respectively, which play a decisive role in the pros and cons of the slope. The initial head wolf and she-wolf are, respectively, the points with the smallest abscissa among the given sliding-in and sliding-out points.

(3) Wandering and Regional Setting: As shown in Figure 2, after the sliding-out and sliding-in points are determined, the abscissa from the sliding-out point to the sliding-in point is divided into three equal parts, denoted as \( X = X_{t1} \) and \( X = X_{t2} \), as shown in Figure 3. The shaded part is regarded as the wandering area of the detective wolf. The initial location of the detective wolf is the intersection of the connection between head wolf and she-wolf and \( X = X_{t1} \) and \( X = X_{t2} \), denoted as \( (X_{i1}, Y_{i1}) \) and \( (X_{i2}, Y_{i2}) \). The initial detective wolves walk downstream with step \( \text{step}_{a1} = (Y_{1max} - Y_{1min})/n \) and step \( \text{step}_{a2} = (Y_{1max} - Y_{1min})/m \). Points on the wandering path are marked as \( TL_{1i} = (X_{t1}, Y_{t1} - \text{step}_{a1}) \), \( TL_{1i} = (X_{t2}, Y_{t2} - \text{step}_{a2}) \), \( TL_{2i} = (X_{t2}, Y_{t2} - \text{step}_{a3}) \). .. Detective wolf at slide out point and slide in point to the right with step \( \text{step}_{1} = ((Y_{ld})_{max} - (Y_{ld})_{min})/t \) and step \( \text{step}_{2} = ((Y_{wm})_{max} - (Y_{wm})_{min})/t \), the points on the walk path are marked as \( \text{Lead}_{1} = (X_{ldmin} + \text{step}_{c1}, Y_{c2}), \text{Lead}_{2} = (X_{ldmin} + \text{step}_{c1}, Y_{c2}), \ldots, \text{ML}_{1} = (X_{ldmin} + \text{step}_{c1}, Y_{c2}), \text{ML}_{2} = (X_{ldmin} + \text{step}_{c2}, Y_{c2}), \ldots, \) and the size of \( m, n, t \) is negatively correlated with the length of the walking path.

(4) Summoning Behavior: Wolves at the head wolf, \( X = X_{t1} \) and \( X = X_{t2} \), and the she-wolf are regarded as a sample point, and a cubic spline curve is constructed by the four sample points. After the spline curve expression is solved, according to the characteristics of the sliding surface of the slope, for example, the first two curves are monotonously reduced, and the entire curve is a concave function (spline curves are naturally smooth and continuous). After obtaining the spline which meets the requirements, the head wolf sends a call. After receiving the call command, the fierce wolves rush to the nearest spline point. According to the characteristics of the sliding surface, the closer to the sliding-in point, the steeper the spline curve. Therefore, when the abscissa spacing is the same, the steeper the curve path is longer, so the number of wolves to be summoned should also be greater. After iteration, the KNN algorithm (reference 2.2.2) is used to judge the classification of the soil layer where each wolf is located, and the stress information at the corresponding point is predicted by machine learning (reference 2.2.2).

(5) Siege Behavior: after the prey odor concentration (stress information) of all wolves on the current path is known, the overall fitness of the wolf pack needs to be judged by \( D_i = 1/F_i = \max \left( \frac{\int_a^b \tau \ d\lambda}{\int_a^b \tau_j \ d\lambda} \right) = \max \left( \frac{\sum_{i=1}^n \tau_x \Delta d_i}{\sum_{i=1}^n \tau_y \Delta d_i} \right) \). When the fitness reaches the maximum, the corresponding wolf pack is called “one-stage optimal wolf pack,” and the detective wolf at this time is denoted as TL11 and TL2i. After the “first-stage optimal wolf pack” is produced, the wolf pack is already closer to the prey. To obtain more accurate prey information, TL1 walks towards TL1i+1 or TL1i−1 with a step length \( \text{step}_{a1} = \text{step}_{a1}/5. \) TL2 walks towards TL2i+1 or TL2i−1 with step length \( \text{step}_{a2} = \text{step}_{a2}/4 \) and then executes step (4) summoning behavior. Finally, current wolf pack fitness is calculated, and the optimal wolf pack is found as the “second-stage optimal wolf pack.”

(6) The Wolf Pack Update Mechanism of “Survival of the Strong”: the detective wolves at the head wolf and the she-wolf swam to the right, respectively, and new wolves are continuously produced. After steps (3), (4), and (5) are executed, a new optimal wolf will be produced. The new optimal wolf is compared with the current optimal wolf pack until calculating the fitness of the last group of wolf packs. The wolves with poor fitness are eliminated, and wolves with the best fitness are regarded as “globally optimal wolves.”

3.2.2. Determine the Parameters of the Improved Wolf Pack Algorithm. In the process of using the improved wolf pack algorithm, it is necessary to determine the information such as the physical and mechanical parameters of the rock and soil of the wolves that do not coincide with the grid node. The method of determining the cubic spline curve is as follows:

(1) Using the KNN method determines the physical and mechanical parameters of the rock and soil to which the wolf and the wolves belong: the k-nearest neighbor (KNN) algorithm [16–18], which is one of the most well-known algorithms in pattern recognition, has been proven to be very effective in prediction. The k-nearest neighbor (KNN) algorithm, as one of the basic machine learning algorithms, is
Dective wolf
Initial head wolf and she-wolf
Initial Dective wolf 1
Initial Dective wolf 2
Cubic spline
(possible sliding surface)
The fierce wolf rushed here
Global optimal path
First stage optimal path
Second stage optimal path
Fierce wolf
Wandering area

Figure 2: Schematic diagram of wolf division.

Figure 3: Flow chart of an improved wolf swarm algorithm.
simple to learn and is widely used to solve prediction problems. This method only determines the category of the sample to be classified based on the category of the nearest one or several samples in the decision-making of classification. For complex slopes, it is necessary to determine the geotechnical physical and mechanical parameters of the point not on the node and only needs to determine most of the K points closest to this point to determine the geotechnical physical and mechanical parameters of the point.

(2) Using machine learning method to determine the odor concentration (stress information) of the wolves: using the scikit-learn library in python, a part (usually 80%) of node information (coordinates, stress, etc.) is randomly selected in each soil layer as the training set and the remaining part (usually 20%) as the test set. After finding potential regularities in coordinates and stresses in the training set, the regularities are verified in the test set and the accuracy of the verification of the laws in the test set is used as the basis for evaluating the quality of machine learning. Then, the stress information is predicted at any node according to the found rule. Compared with the traditional interpolation method, the machine learning method to determine the stress at the required point has better accuracy, and it can also be more intuitive to see the quality of the training result. What is more, the more complex the slope and the higher the number of nodes, the more accurate the prediction will be.

(3) Cubic spline curve: a spline curve is a type of segmentally smooth function that also has a certain degree of smoothness at the junction of each segment. The cubic spline curve is most commonly used. The cubic spline curve will avoid the inflexibility of quadratic polynomials, which is not free enough, and it can also avoid the disadvantages of high-order (fourth and above) polynomials with many inflection points, which are prone to oscillations and large errors. Therefore, the cubic spline curve can well meet the characteristics of the slope sliding surface and overcome the shortcomings of the traditional arc sliding surface that sometimes does not conform to the actual situation.

4. Program Implementation and Verification of Calculation Examples

4.1. Verify the Accuracy of the Algorithm. Based on the above principles, an improved wolf pack algorithm slope sliding surface search method is formed. The calculation flow chart is shown in Figure 3.

The Python language was used to compile the program, and then, classic cases are introduced to verify the accuracy and effectiveness of the algorithm. Example 1 as shown in Figure 4 is a simple slope taken out from the study by Zolfaghari et al. [19]. The soil parameters are as follows: unit weight of 19.0 kN/m³, cohesion of 15.0 kPa, and effective friction angle of 20°. Zolfaghari [19] used a simple genetic algorithm and Morgenstern and Price method \( f(x) = 1.0 \) to obtain a minimum factor of safety of 1.75 for noncircular failure surface.

The critical slip surface obtained by the slope stability analysis method based on the improved wolf pack algorithm is shown in Figure 5, and the safety factor is 1.7443.

Example 2 as shown in Figure 6 is taken out from the ACADS study (1989) example 1, in which four different loading conditions are considered. This study considers only the third loading conditions in the original study [5]. The soil parameters for example 2 are given in Table 1. The recommended solution by the experts in the ACADS study is 1.39 (1989), while Bolton et al. [20] adopted the leapfrog optimization algorithm and obtained a minimum factor of safety of 1.359. The critical slip surface obtained by this method is shown in Figure 7, and the safety factor is 1.3549, which is basically consistent with the results of Bolton et al.

4.2. Sensitivity Analysis. When the wolf swarm algorithm is used for slope stability analysis, there are some unspecified parameters that need to be artificially given according to experience. The sensitivity analysis of the factors that have great influence is carried out as follows.

4.2.1. Number of Wolves. The number of wolves can reflect the fine degree of slope division to some extent. As shown in Figure 8(a), the safety factor is drawn when the number of wolves is 30–90. According to the broken line diagram, it is easy to know that when the number of wolves is small, the calculated safety factor will be unstable. When the number of wolves increases to 60 or more, the safety factor is stable, at about 1.745. It can be concluded that when the number of wolves is large (not less than 60), the safety factor is not sensitive to the number of wolves. When the number of wolves is small, the safety factor is sensitive to the number of wolves because the classification of slope is not detailed. Therefore, it is reasonable to select more than 60 wolves for slope stability analysis.

4.2.2. Number of Wandering Steps. As shown in Figure 8(b), the number of wandering steps of the wolf in the vicinity of the head wolves needs to be determined artificially according to experience. When the number of wandering steps is small, the safety factor will fluctuate greatly. When the number of walking steps is large enough, the final determined point is closer to the actual optimal point, and the result is closer to the optimal solution, and the safety factor is also close to the global optimum.

5. Verified by an Engineering Example

The typical geological section of the valley shoulder accumulation body on the left bank of Xiluodu Hydropower Station is shown in Figure 9(a). A numerical model is established as shown in Figure 9(b), the rock and soil physical and mechanical parameters in Table 2 are used to
perform numerical calculations, and after obtaining the stress field, the wolf pack algorithm is used to search for the critical sliding surface.

As shown in Figure 9(c), the IN13 borehole inclinometer is relatively close to the profile. Figure 9(c) shows that the critical slip surface of the valley shoulder accumulation on
Figure 7: Critical sliding surface based on an improved wolf swarm algorithm of example 2.

Figure 8: Sensitivity analysis. (a) Diagram of the relationship between influencing factors and safety factor. (b) Diagram of the relationship between influencing factors and safety factor.

Figure 9: Continued.
the left bank of the Xiluodu Hydropower Station is located at the junction of the landslide accumulation and the upper part of the Xuanwei Formation. This is consistent with the sliding surface position revealed by historical monitoring data.

In [21], the dynamic programming algorithm was used under natural conditions, and the safety factor obtained by the circular sliding surface was 1.100, and it takes about 51 minutes to obtain the critical sliding surface and safety factor. Under the same conditions, the safety factor obtained by the wolf pack algorithm method was 1.044 and takes about 8 minutes to obtain the results. By comparing the sliding surface positions, it can be seen from Figure 9(d) that the method used in this study can ensure that more proportional areas are located in the Xuanwei Formation. The field investigation shows that the slope is in a creepy state, and the safety factor is between 1.00 and 1.05. Therefore, the results obtained by this method are closer to reality and have higher efficiency.

6. Conclusion

Based on the slope stress field obtained by numerical calculation, a method for searching the critical slip surface of slope based on the improved wolf pack algorithm is proposed, which provides a new and effective idea for slope stability analysis. The main conclusions are as follows:

1. The improved wolf pack algorithm is a slip surface determination method in the limit equilibrium finite element method. In the slope stability analysis process, a more accurate slope on most dangerous sliding surfaces and minimum safety factors can be obtained.

2. In the calculation process of using the improved wolf pack algorithm, the KNN algorithm is used to classify and predict the specified points, which has high accuracy. Using machine learning methods instead of traditional interpolation methods to calculate the stress at the specified coordinate points, the accuracy of the calculation results can be intuitively seen through the loss function, and the cubic spline curve can be used to fit the slope sliding surface to overcome the arc. The shortcomings of slip surface assumptions that sometimes do not match the actual slip surface can also avoid falling into the local optimum.

3. Through the analysis of classic slope calculation examples, the calculation results of the method proposed are in good agreement with the reference.
answers of typical calculation examples, which proves the rationality of the algorithm.

However, there are still some shortcomings when using the improved wolf swarm algorithm for slope stability analysis, and further research is needed. For example, when the cubic spline curve in this method is used to fit the slope image, if the slope sliding surface is a relatively smooth surface or a certain segment of a straight line is tangent to the curve, the derivative function will not change greatly, and the calculated results of the sliding surface and the safety factor can be obtained with satisfactory results. If there is a weak interlayer in the slope sliding surface and the slope of the interlayer is very different from that of the sliding arc, in this case, the cubic spline curve cannot be used to fit the slope sliding surface well, and the obtained results will also have large errors. It is necessary to further study this situation.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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References