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Application of Intelligent Optimization Algorithm in Slope Engineering Stability

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Abstract. Slope stability analysis is a very important part of engineering design, which is related to the safety of the construction process. In this paper, the lag effect of intelligent algorithms in solving landslide thrust and the characteristics of slope deformation are studied in depth. The purpose of studying slope engineering stability in this paper is to apply theoretical research to practical operation, so as to reduce unnecessary hazards. This paper mainly applies qualitative analysis and comparative analysis to control the variable of single and double row spacing, so as to explore the spacing of piles in slope engineering to determine the stability. The experimental data shows that when the pile spacing is 2 m, the stability of slope engineering can be strengthened.

Keywords. Intelligent optimization algorithm, slope engineering, stability analysis, interval evaluation

1. Introduction

There are many theories to study intelligent optimization algorithms and slope engineering stability analysis. For example, some scientists combined the simplified Bishop method to find the global optimal solution [1, 2]. Other experts claim that the commonly used slope stability analysis methods in engineering mainly include the limit equilibrium method and finite element subtraction method [3, 4]. In addition, some experts use the rigid body boundary equilibrium method to analyze the advantages and disadvantages of the calculation results [5, 6]. In the stability analysis of slope engineering, we mainly rely on mathematical theory, establish mathematical models, and simulate the actual landslide structure through numerical simulation.

This paper first studies the intelligent optimization algorithm, describes its application in slope stability, and briefly analyzes the characteristics and differences between the three intelligent algorithms. Secondly, slope stability is analyzed, and the influencing factors and methods of slope stability are expounded. Then, it briefly discusses the interval evaluation standard of slope safety and stability. Finally, relevant stability analysis methods and the reasonable range of slope engineering spacing are obtained through slope safety-related experiments, and relevant data and conclusions are obtained.

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2. Application of Intelligent Optimization Algorithm in Slope Engineering Stability

2.1. Intelligent Optimization Algorithm

By applying an intelligent optimization algorithm to calculate slope stability, the minimum safety factor can be searched more effectively. Genetic algorithm (GA) cannot work directly on the slope. It must use code to convert the safety factor into the chromosome and apply it to the work of genetic algorithm. After the operation, it must also convert the chromosome into a safety factor. Unlike genetic algorithm, particle swarm optimization does not use the competition mechanism of population solution, but uses the cooperation mechanism of population solution to iteratively generate the best solution. Differential evolution (DE) algorithm obtains the best solution by continuously updating the iterative population. When selecting individuals for surgery, it is relatively random and has no rules to follow. The two randomly selected individuals are weighted by their vector differences and added to the third individual. If the sliding surface is planar, a small safety factor will also be obtained, which is confused with finding dangerous sliding surfaces, which will affect the calculation results, so it must be eliminated [7, 8]. The calculation results and time analysis of the three optimization algorithms are shown in Table 1.

Table 1. Optimization algorithm time and result comparison.

	Safety factor	Computing time
GA	2.5	14.26
PSO	2.48	10.35
DE	2.41	6.75

The differential evolution algorithm has the lowest safety factor, the shortest computing time, and the highest computing efficiency. The particle swarm optimization algorithm is superior to the genetic algorithm. The analysis shows that the main differences between the genetic algorithm and particle swarm optimization and differential evolution algorithm are as follows:

Compared with the genetic algorithm and differential evolution algorithm, the optimized particle population does not need coding, hybridization and mutation operations, but only needs to update the particle position and speed, fewer control parameters and simple operations. The “particle” in the particle algorithm has memory, while the individuals in the genetic algorithm and differential evolution algorithm undergo gene mutation as the population evolves, and do not retain the previous memory. Considering the adaptability of organisms to the environment, the differential evolution algorithm is higher than the genetic algorithm.

2.2. Slope Stability Analysis

As the slope surface is inclined, the whole slope tends to slide up and down under the gravity of the slope itself and various external forces. The slope should be prevented from slipping and causing resistance. Generally speaking, if the resistance is greater than the sliding force, the slope is considered stable.

Factors affecting slope stability include: physical and mechanical properties of slope materials, shape and size of the slope, working conditions of the slope, etc. The slope body is composed of a variety of materials, which have different physical and mechanical properties. Due to doping, the physical and mechanical properties of the slope itself are more complex, so different physical and mechanical properties have a great impact on the stability. The shape and size of the ramp refer to the total height, slope and section shape of the ramp. Generally speaking, the higher the total height of the ramp, the more likely it is to lose stability. The lower the total height, the more stable the ramp is. The slower the slope, the more stable it is. The steeper the slope, the easier it is to lose stability. This influencing factor not only affects the slope but also affects the physical and mechanical properties and indicators of the slope material.

With the development of science and technology, the ways and methods of slope reinforcement are also different. Manual reinforcement measures restore the unstable slope to a stable state. Different reinforcement measures have different effects and changes on the slope. But the most important premise is to ensure that the slope finally reaches and remains stable [9, 10].

The general steps of slope stability analysis are shown in Figure 1.

Its main content is the study of mechanical model, mathematical model and calculation method. The development process of rock slope stability research can be roughly divided into three stages.

The qualitative analysis method mainly includes the analysis of the main factors affecting the stability of the slope. Through the influence of technical geological research, the stability state of the evaluated slope is qualitatively explained. Quantitative analysis is a method to analyze slope stability based on mechanical principles, and is currently the main design and calculation method.

2.3. Interval Evaluation Accuracy of Slope Safety and Stability

The safety and stability evaluation of the slope shall determine whether the slope is stable under various conditions that may occur during normal operation. If the slope stability coefficient is greater than 1, it is considered stable; If the slope stability factor is less than 1, the slope is considered unstable. However, in many practical work, some slope coefficients are far greater than 1, which eventually leads to slope instability. This is partly due to the shortcomings of the calculation method, and another important reason is the influence of geotechnical uncertainty. When analyzing the stability of slope technology, engineers seldom consider the influence of uncertain information on the calculation results of safety factor. It is necessary to use intelligent optimization algorithm to design software for slope stability analysis, and its structure is shown in Figure 2.

If interval evaluation criteria are used to analyze slope stability, it is sufficient to use the lower limit of slope safety factor to evaluate slope stability. Only consider the interval where the lower limit of the safety factor is higher than the lower limit, and then analyze and evaluate the safety and stability of the slope according to the interval [11, 12].

3. Experiment Related to Slope Safety

3.1. Slope Calculation Method

There are many slope calculation methods, each with its advantages and disadvantages.

The rigid body limit equilibrium method is to study the slope problem as a rigid body equilibrium problem in theoretical mechanics. The safety coefficient on each arc of the Swedish slice method is converted into:

$$L = \frac{N_s}{N_{\mathrm{p}}} \tag{1}$$

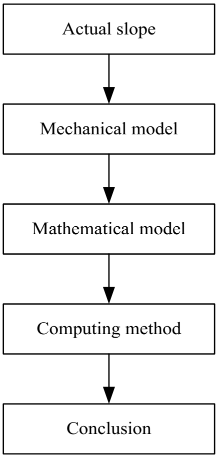

Figure 1. Slope stability analysis process.

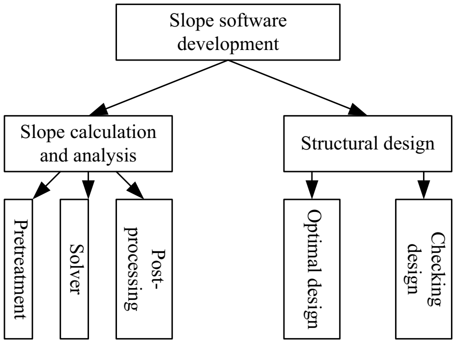

Figure 2. Slope software development.

All moments are centered on the center p of the sliding surface. The forces acting on the sliding mass by other parts of the soil slope can be regarded as the superposition of moments acting on each block. The simplified stress condition N_p is to bear only the dead weight, N_p expressed as:

$$N_{\mathrm{p}} = \sum_{i=1}^{m} v_i a_i \tag{2}$$

Then the maximum anti-sliding force is calculated and each strip can provide on the bottom surface:

$$S_{\mathrm{i}} = d_i k_i + g_i M_i \tag{3}$$

Among them, M_i is a valid normal force on the bottom of sub-clause i. K_i is the length of the strip bottom. Anti-slip pile is a kind of engineering construction against landslide. According to the calculation or simulation results, it shall be placed at a position suitable for the landslide. The unknown quantity of the cantilever pile method is the ground pressure at the bottom above the sliding surface and before stacking under the sliding surface. The application of the foundation coefficient method regards the stress of anti-skid pile as elastic foundation support.

3.2. Impact of Slope Height and Slope Rate on Safety Factor

The trend can be determined by selecting a group of parameters and then changing one or more of them to study the change law of soil slope. Data collection requires a certain degree of accuracy. However, because the soil composition is very complex and the parameters vary from place to place, mechanical tests must be carried out on the local soil as part of the actual work. Other parameters remain unchanged: the higher the slope, the lower the safety factor, and the greater the maximum slope displacement. In order to reduce the impact of other factors on the slope, water and soil conservation measures can be taken, such as skeleton protection of the slope, and additional greening measures can be taken.

With the decrease in slope height, the calculation time is also greatly shortened. This is why the sliding surface is small. The smaller the area of the plastic region, the faster the results are obtained. The relationship between the safety factor and slope can be maintained by defining the slope length and modifying the slope of the ground slope. We can see that the influence of slope height on the safety factor is more obvious. For this type of soil slope, slope trimming or sorting measures can be taken to reduce soil load before adding support measures.

3.3. Scheme Design

Based on the above, the plan is being implemented. Scheme I: Single row layout is adopted, embankment reinforcement is adopted, spacing is 5m, and there are 4 piles in total. Scheme II: Compact arrangement is adopted based on a row of piles. Scheme III: Double-row piles are adopted.

The safety factor of single-row anti-skid piles is slightly increased. In order to further improve the slope safety factor, two or more anti-skid piles must be installed. The proper spacing of double-row piles should be checked to determine the best adjustment position, regardless of the front and rear direction or zigzag layout.

4. Analysis of Experimental Results

4.1. Improvement Effect of Double-Row Piles

The anti-skid pile has a certain range of action on the ground. When the action range of each pile is fully utilized to form a resultant force, the efficiency of the pile can be improved, and the deformation and soil flow can be controlled. If we further improve the safety factor, we must change from simply reducing the longitudinal distance to multi-row anti-skid piles. The improvement effect of double-row piles is shown in Table 2.

As shown in Figure 3, we can see that the third option may allow a higher slope to meet the safety requirements, but in order to use the anti-skid piles reasonably and balance the benefits, the front and rear lines are not ideal, and the zigzag layout is required. The combination of anti-skid piles and the ground has certain regularity, and its impact on the ground has a certain range. The most effective transverse and longitudinal distance is 2 m, and the safety factor will also be reduced beyond this distance.

Table 2. Improvement effect of double-row piles.

	Spacing distance	Safety factor (single row)	Safety factor (double row)
1	4	0.89	0.95
2	3	0.91	0.98
3	2	0.91	0.96
4	1	0.88	0.93

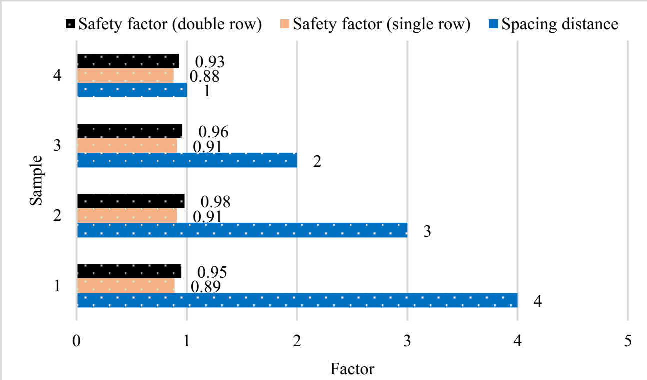

Figure 3. Improvement effect of double-row piles.

4.2. Impact of Front and Rear Pile Positions on Safety Factor

The maximum increase in pile safety factor is obtained on the upper slope. The longitudinal width of the model with slope ratio of 1:1 is 5 m. The distances are 4 m, 3 m, 2 m and 1 m respectively. The safety factor must be recorded. The deepest anti-skid pile is 5 meters from the bottom of the model as is shown in Figure 4.

According to the obtained safety factor data, the improvement of the safety factor of double-row piles with an interval of 4 m or more is not as obvious as expected. This indicates that the effect between anti-skid piles is limited by the distance. It is not only necessary to place two rows of batteries to significantly improve the safety factor but also to have an appropriate spacing length between the two rows. The distance is equal to or less than 1 m. Because its size is close to the pile diameter, the design and advantages are unreasonable, so it is more reasonable to determine the distance of 2 m.

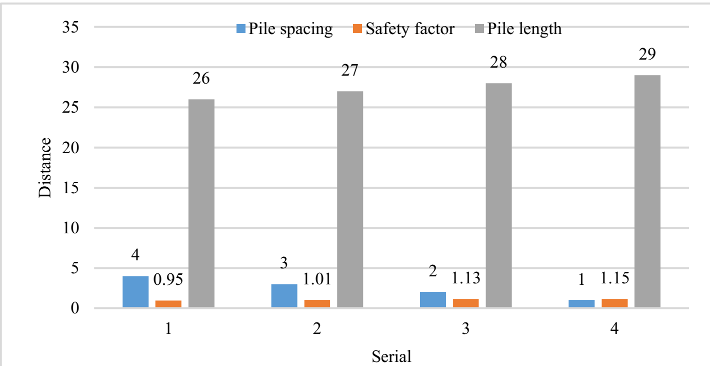

Figure 4. Relationship between distance and safety factor in front and rear row piles.

5. Conclusion

In engineering practice, slope stability analysis is a complex and cumbersome problem. In slope stability analysis, due to the uncertainty and complexity of the project itself, it is often necessary to carry out repeated tests to obtain satisfactory results. Therefore, in order to ensure the construction safety and reasonably arrange the construction period, the reliability value must be corrected or adjusted in time when factors such as the stability of the slope are affected. This paper mainly focuses on the application of intelligent optimization algorithm in slope stability analysis, and has achieved certain results. In view of the above situation, this paper proposes a qualitative analysis method based on the objective function and an improved method to analyze slope stability.

References

[1] Riyahi M, Rafsanjani MK, Gupta BB, Alhalabi W. Multiobjective whale optimization algorithm-based feature selection for intelligent systems. Int. J. Intell. Syst. 2022;37(11):9037-9054.

[2] Husnain G, Anwar S. An intelligent probabilistic whale optimization algorithm (i-WOA) for clustering in vehicular ad hoc networks. Int. J. Wirel. Inf. Networks. 2022;29(2):143-156.

[3] Neggaz I, Fizazi H. An intelligent handcrafted feature selection using archimedes optimization algorithm for facial analysis. Soft Comput. 2022;26(19):10435-10464.

[4] Chegini SN, Amini P, Ahmadi B, Bagheri A, Amirmostofian I. Intelligent bearing fault diagnosis using swarm decomposition method and new hybrid particle swarm optimization algorithm. Soft Comput. 2022;26(3):1475-1497.

[5] Dus M. Exponential stability of a general slope limiter scheme for scalar conservation laws subject to a dissipative boundary condition. Math. Control. Signals Syst. 2022;34(1):37-65.

[6] Azarafza M, Akgün H, Ghazifard A, Asghari-Kaljahi E, Rahnamarad J, Derakhshani R. Discontinuous rock slope stability analysis by limit equilibrium approaches - A review. Int. J. Digit. Earth. 2021;14(12):1918-1941.

[7] Moayedi H, Osouli A, Nguyen H, Rashid ASA. A novel Harris Hawks' optimization and K-Fold cross-validation predicting slope stability. Eng. Comput. 2021;37(1):369-379.

[8] Ospina-Dávila YM, Orozco-Alzate M. Parsimonious design of pattern recognition systems for slope stability analysis. Earth Sci. Informatics. 2020;13(2):523-536.

[9] Haque D, Reza MI. Parametric analysis of slope stability for river embankment. J. Adv. Eng. Comput. 2020;4(3):196-206.

[10] Mishra M, Gunturi VR, Maity D. Teaching-learning-based optimisation algorithm and its application in capturing critical slip surface in slope stability analysis. Soft Comput. 2020;24(4):2969-2982.

[11] Singh J, Banka H, Verma AK. A BBO-based algorithm for slope stability analysis by locating critical failure surface. Neural Comput. Appl. 2019;31(10):6401-6418.

[12] Koopialipoor M, Armaghani DJ, Hedayat A, Marto A, Gordan B. applying various hybrid intelligent systems to evaluate and predict slope stability under static and dynamic conditions. Soft Comput. 2019;23(14):5913-5929.