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## Research Article

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# Optimization of a cable support strategy for roadways in coal mines by using the PSO algorithm

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**Abstract:** Cables are commonly used for roadway support in coal mines. Traditionally, support schemes show characteristics of excessive strength and resource waste; therefore, determining how to scientifically and economically arrange the distribution of cables is important for engineering practice. To obtain the best distribution of cables, in this paper, the particle swarm optimization (PSO) algorithm and FLAC3D numerical simulation were combined to conduct numerical simulations. Finally, the best cable distribution considering safety and economy was determined. By analyzing the numerical simulation results, it can be concluded that the PSO algorithm can be applied to determine the optimal cable distribution for roadway support and can be applied to engineering practice. In addition, the best cable arrangement of a roadway under different lateral stress coefficients was obtained, and it can be concluded that the cable arrangement should be adjusted according to specific circumstances.

**Key words:** cable support; particle swarm optimization (PSO) algorithm; roadway; lateral stress coefficient

## 1 Introduction

Differences in the ground stress and lithology of rock masses lead to roadways with different engineering condition, making is difficult to find a suitable support scheme. To ensure the safety of rock mass engineering in coal mines, the support scheme must vary accordingly. In most cases, to guarantee the stability of the rock mass engineering of coal mines, roadways with excessively high strength support are commonly used, and different kinds of supporting materials are used, such as cables and ceramic grouting. From the perspective of safety, this approach is helpful. However, on the other hand, this approach wastes resources, increases the expense of roadway

support, delays the construction rate and decreases the benefits. In contrast, if the support strength is insufficient, local collapse of the surrounding rock mass, or even cause large deformation and overall failures of rock mass engineering may occur, which will destroy destruct the long-term development of coal mines, hence, insufficient support strength is not suggested. Therefore, the means by which to guarantee the safety of roadways in coal mines and save the support expenses should be given enough attention.

The study of support technology under different conditions mainly uses three methods: theoretical analysis, numerical simulation and experimental study. Understanding the mechanical characteristics and cable and rock mass is the basis for identifying a better economic support scheme, and the corresponding theoretical analysis is necessary. To study the constitutive law of fully grouted cables, Martin et al. (2010, 2013) performed a related theoretical and experimental study. Seo et al. (2012) invented a new pillar-reinforcement technique to strengthen pillar stability, which is important for the construction of water storage caverns. Based on the rock mass rating, a corresponding support design system using bolts was proposed by Paul et al. (2012), which provided an efficient means to support roadways. Fahimifa and Soroush (2005) developed a nonlinear strength criterion of a rock mass and derived the corresponding relationship between the rock and support. Li et al. (2012) developed a new technique to estimate the grout cohesive strength and the friction angle. These theoretical analyses provided a solid foundation for roadway support technology.

In addition, the support scheme is another important study field for researchers. Wang et al. (2018) developed a joint support technology with bolts, cables and U-shaped sheds. The support parameters of the bolt-grouting reinforcement of the roadway in the 5302 face of the Zhaolou Coal Mine were investigated by Pan et al. (2018). He et al. (2019) put forward a suitable strengthening control technology for the surrounding rock “all cross-sectional bolt-wire mesh + high strength and lengthen bolt + high pretightening force cable”. This supporting technology provided a basis for engineering practice.

In general, the existing studies mainly focused on different combinations of supporting techniques; however, there are few studies on the optimization of support parameters that consider safety and economy. In this paper, to avoid blind cable arrangement, excessive strength and resource waster of roadway support in coal mines, both the economy of support and the stability of roadways are considered. In this paper, the PSO algorithm and FLAC3D numerical simulation are combined, and the cable arrangement of roadways with different lateral stresses is proposed. In addition, the proposed method can be used for cable support under different conditions. The proposed method in this paper can guarantee the safety and economy of mining production. The research conclusions provide references for the support design of similar roadways in coal mines.

## **2 Determine the cable distribution by using the PSO algorithm**

### **2.1 PSO algorithm**

The particle swarm optimization (PSO) algorithm was proposed by Eberhart and Kennedy in 1995 (Coello et al. 2004; Trelea 2003; Robinson and Rahmat-Samii 2004; Van Den Bergh and Engelbrecht 2004; Gaing 2003; Wang and Wan 2019; Wang et al. 2020), and the concept of PSO is based on birds finding food. It is assumed that a bevy of birds are randomly

searching for food; however, food is only found in a certain area. None of these birds know the location of the food, but they know how far away they are from the food. The best technique for solving the problem is to search for food using the nearest bird.

In practice, a particle is used to simulate an individual bird, a particle can be deemed a searching individual in  $N$  dimension space, and the location of a particle  $X_i$  can be deemed a solution.

$$X_i = (x_1, x_2, \dots, x_N) \quad (1)$$

where  $X_i$  is the location of the particles and  $N$  is the dimension space.

However, the flying process is the process of finding the best solution, and the flying speed  $V_i$  can be adjusted by the best location of the particle and the best location of the best population.

$$V_i = (v_1, v_2, \dots, v_N) \quad (2)$$

where  $V_i$  is the flying speed.

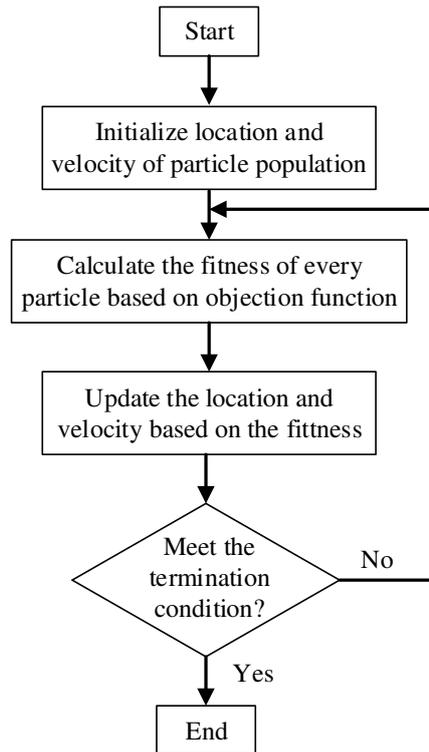
The velocity and location updating process can be denoted as follows:

$$V_{i+1} = wV_i + c_1r_1(p\_best_i - X_i) + c_2r_2(g\_best_i - X_i) \quad (3)$$

$$X_{i+1} = X_i + V_i \quad (4)$$

where  $w$  is the inertia learning factor;  $c_1$  is the individual learning factor; and  $c_2$  is the social learning factor. In most cases,  $c_1$  and  $c_2$  are set as within the range  $[0, 4]$ ;  $r_1$  and  $r_2$  are the random numbers between 0 and 1. In this paper, the superparameters  $c_1$ ,  $c_2$ ,  $r_1$  and  $r_2$  are 2, 2, 0.6 and 0.3, respectively.  $p\_best_i$  is the best position for a particle, and  $g\_best_i$  is the best position of the population.

When the termination condition is satisfied, the search process is terminated, and the best results are obtained. To better understand the PSO algorithm, the PSO procedure is illustrated in Fig. 1.



**Fig. 1.** The procedure of the PSO algorithm

The PSO algorithm is a typical bionic algorithm, and it is widely applied in different kinds of fields. In this paper, the PSO algorithm was used to determine the best support cable distribution of roadways in coal mines.

In this paper, the optimization problem can be simplified as an objection of the minimum cable used for the supporting roadway, and the subjection should be the safety factor, which should be larger than or equal to a certain value. Combining the objection and subjection, the problem would be resolved by the PSO algorithm, which can be specifically explained in the following.

## 2.2 Procedure of determining the cable distribution using the PSO algorithm

In this paper, commercial FLAC3D numerical simulation software was used, FLAC3D was developed by Itasca Company (2002), and can be widely used in different kinds of fields: slope stability analysis, support design, underground space design, excavation, mining engineering, etc.

To combine the commercial FLAC3D numerical simulation software and PSO algorithm, Python language was used, the corresponding Python script was compiled, it was used to control the FLAC3D numerical simulation and implement the PSO algorithm. The main procedure of applying the PSO algorithm to the cable distribution can be explained as follows.

1. The superparameters of PSO algorithm are initialized.
2. The cable parameters, the number of cable, cable length and the cable location are initialized
3. The FLAC3D command flow is written by using the cable parameters (number of cables, length and location of cables).
4. The FLAC3D numerical command flow is executed in FLAC3D software, and the safety factor is calculated by using the cable distribution. The safety factor can be calculated by the

following equation.

$$\begin{cases} c' = \frac{c}{K} \\ \varphi' = \arctan\left(\frac{\tan \varphi}{K}\right) \end{cases} \quad (5)$$

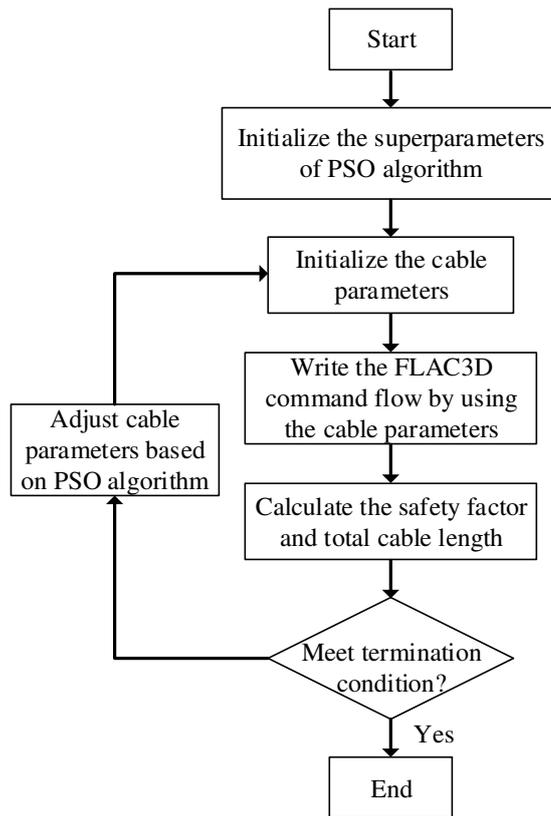
where  $K$  is the reduction coefficient;  $c$  is the original cohesion of the rock mass;  $c'$  is the cohesion of the rock mass after reduction;  $\varphi$  is the original friction angle of the rock mass; and  $\varphi'$  is the friction angle of the rock mass after reduction. The safety factor has been widely used to describe the stability of rock mass engineering (Griffiths and Lane, 1999; Zhao et al. 2002). In the process of determining the safety factor  $s$ , the reduction coefficient increases gradually, and the corresponding friction angle  $\varphi'$  and cohesion  $c'$  of the rock mass decrease, then, the rock mass tends to be unstable. The  $K$  value is determined when rock mass engineering is in a critical stability state, and the critical reduction coefficient  $K$  is the safety factor  $s$  of rock mass engineering.

5. The total length of cable is calculated. It is the sum value of all cable length.

6. When the safety factor  $s$  is larger than or equal to 1.25 (because rock mass engineering with a safety factor  $s$  1.25 is safe enough (Zhao et al. 2010)), the safety factor value is widely adopted to determine whether rock mass engineering is stable). The number of cables, cable length and cable location can be adjusted according to the PSO algorithm. When the termination condition is met, go to the next step; otherwise, go to step 2.

7. End.

The process is illustrated in Fig. 2.



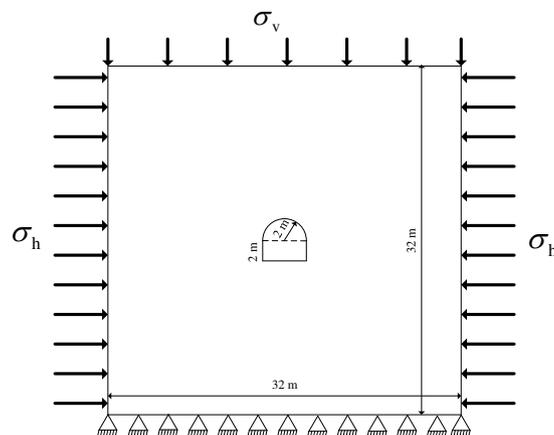
**Fig. 2.** Flow chart of cable distribution adjustment using the PSO algorithm

In the process, writing FLAC3D command flow, executing the FLAC3D software and adjusting cable parameters based on the PSO algorithm are all controlled by Python script. To further verify the validity and rationality of the proposed method, some examples are given in the following section.

## 2.3 Examples

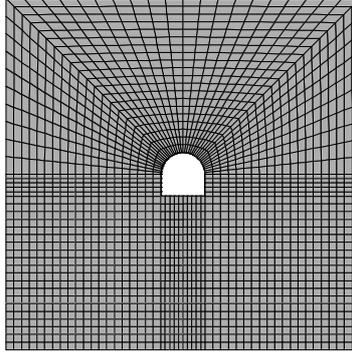
### 2.3.1 Numerical simulation model

To specifically illustrate the proposed method, numerical simulation examples are given in the following. In the numerical simulation example, the size of the numerical simulation model is  $32\text{ m} \times 32\text{ m} \times 2\text{ m}$  (Fig. 3). To simplify the problem, the cable support of the roadway was simplified into a 2-dimension problem.



**Fig. 3.** The model of numerical simulation

Moreover, the FLAC3D numerical simulation was constructed, which is displayed in Fig. 4.



**Fig. 4.** The FLAC3D numerical simulation model

The constructed numerical simulation model contained 2000 zones and 4200 gridpoints. To simplify the procedure, only cables are used for roadway support. The Mohr-Coulomb model was selected as the numerical model of the rock mass; the density of the rock mass is  $2500 \text{ kg/m}^3$ ; the bulk modulus is  $1.41 \times 10^9 \text{ Pa}$ , the shear modulus is  $0.887 \times 10^9 \text{ Pa}$ , the friction angle is  $15^\circ$ , and the cohesion is  $1.96 \times 10^6 \text{ Pa}$ . The modulus of the cable is  $200 \times 10^9 \text{ Pa}$ , and the tension of the cable is  $1 \times 10^20 \text{ Pa}$ .

After the numerical simulation model was constructed (Fig. 4), the boundary condition is assigned to the numerical simulation model. After the initial stress was assigned, the cable can be installed in the numerical model, and it should be noted that the vertical stress and lateral stress should be assigned to the numerical simulation model before the cable is installed. The vertical stress ( $\sigma_v$ ) is  $20 \times 10^6 \text{ Pa}$ , and the lateral stress coefficient  $\lambda$  is 1, 1.2, 1.4, 1.6, 1.8 and 2.0 because the horizontal stress is frequently larger than or equal to the vertical stress (Wang et al. 2019).

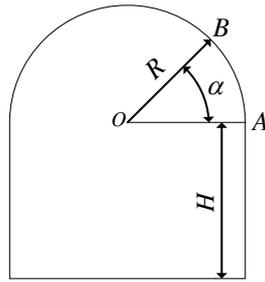
$$\sigma_h = \lambda \sigma_v \quad (6)$$

When the initial stress (vertical stress, lateral stress and gravity) is assigned to the numerical simulation model, the cable is installed. To ensure that the initial stress is in a balanced state, the mechanical ratio should be less than or equal to  $1 \times 10^{-5}$  (Wang and Cao, 2016; Itasca Consulting Group Inc, 2002); hence, when the mechanical ratio is equal to  $1 \times 10^{-5}$ , the initial stress stage is finalized.

### 2.3.2 Cable distribution

The distribution of the cable is critical in this paper. To solve the problem, two kinds of cables were used for roadway support: long cables and short cables. In addition, the numbers of long cables and short cables were not constant and were adjusted according to the PSO algorithm.

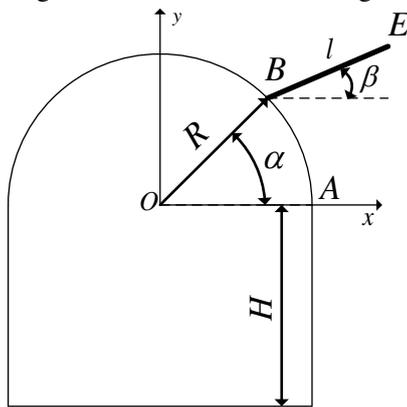
However, the location of cables is another problem that should be considered. In this paper, we assume that the start point of all cables is on the edge of the roadway; hence, the start points can be obtained based on the roadway shape and the corresponding start angle  $\alpha$ , which is displayed in the following figure.



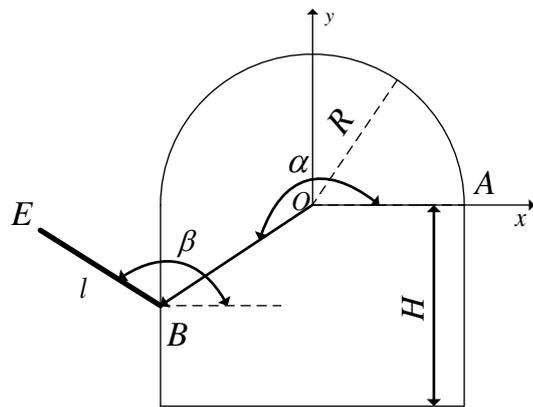
**Fig. 5.** The determination of the cable start point

As shown in the Fig. 5, the roadway is a combination of a half circle (radius is  $R$ ) and a rectangle (height is  $H$ , and the width is  $2R$ ); the start angle  $\alpha$  is from  $OA$  to  $OB$ , and the angle  $\alpha$  range is from  $0^\circ$  to  $360^\circ$ . In this way, all the points (point  $B$ ) on the edge of the roadway can be the start points of the supporting cables. By using this method, the start point (point  $B$ ) of the cable can be easily obtained on the basis of the start angle  $\alpha$ .

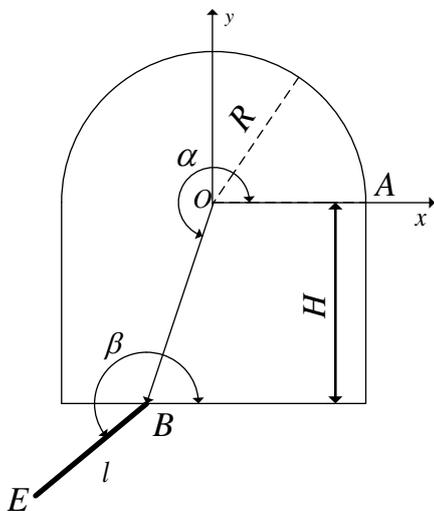
Once the start point of cables is determined, the end point should be determined. In this paper, the end point of the cable is determined by the location of the cable start point, cable length and cable angle, which is illustrated in Fig. 6.



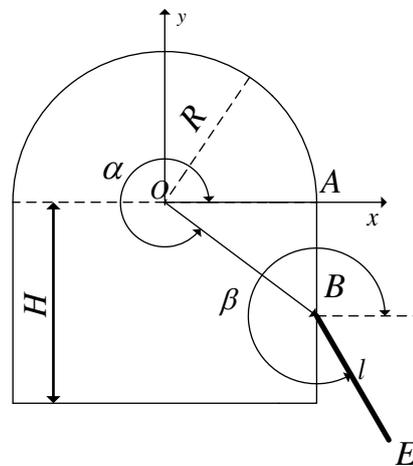
(a)  $0^\circ \leq \alpha \leq 180^\circ$



(b)  $180^\circ < \alpha < 180^\circ + \arctan\left(\frac{H}{R}\right)$



(c)  $180^\circ + \arctan\left(\frac{H}{R}\right) < \alpha < 360^\circ - \arctan\left(\frac{H}{R}\right)$



(d)  $360^\circ - \arctan\left(\frac{H}{R}\right) < \alpha < 360^\circ$

**Fig. 6.** The end point of cable angle

As shown in Fig. 6, when the angle  $\alpha$  is determined, the start point of a cable can be determined. In this paper, the start point of the cable should be on the edge of a cable. In addition, the cable angle  $\beta$  should be within a certain range, which can guarantee that the cable is in the rock mass. It can be specifically explained in the following.

In assessing the cable, the start point and end point were determined by three parameters, i.e, start angle  $\alpha$ , cable angle  $\beta$  and cable length  $l$ .

When the start point angle  $\alpha$  is within the range of  $0^\circ \leq \alpha \leq 180^\circ$  (Fig.6 (a)), the cable start point location  $(x_{\text{start}}, y_{\text{start}})$  can be expressed as:

$$\begin{cases} x_{\text{start}} = R \cos \alpha \\ y_{\text{start}} = R \sin \alpha \end{cases} \quad (7)$$

where  $R$  is the radius of roadway. To ensure that the cable is in the rock mass, the cable angle should be within a certain range, which is  $\alpha - 90^\circ \leq \beta \leq \alpha + 90^\circ$ . Then the end point  $(x_{\text{end}}, y_{\text{end}})$  can be determined on the basis of the start point  $(x_{\text{start}}, y_{\text{start}})$ , the start point angle  $\alpha$ , cable angle  $\beta$  and cable length  $l$ .

$$\begin{cases} x_{\text{end}} = x_{\text{start}} + l \cos \beta \\ y_{\text{end}} = y_{\text{start}} + l \sin \beta \end{cases} \quad (8)$$

When the start angle  $\alpha$  is within the range of  $180^\circ < \alpha < 180^\circ + \arctan(\frac{H}{R})$  (Fig. 6 (b)), the cable angle  $\beta$  should be within the range of  $90^\circ < \beta < 270^\circ$ . The start point coordination can be calculated:

$$\begin{cases} x_{\text{start}} = -R \\ y_{\text{start}} = -R \tan(180^\circ - \beta) \end{cases} \quad (9)$$

while the end point of cable can be determined based on the start point  $(x_{\text{start}}, y_{\text{start}})$ , start point angle  $\alpha$ , cable angle  $\beta$  and cable length  $l$ , the calculation equation is the same as the Eq. (8).

When the start angle  $\alpha$  is  $180^\circ + \arctan(\frac{H}{R})$ , the cable angle is within the range of  $90^\circ < \beta < 360^\circ$ , and the start point coordination is:

$$\begin{cases} x_{\text{start}} = -R \\ y_{\text{start}} = -H \end{cases} \quad (10)$$

The cable end points calculation equation is Eq. (8).

When the start angle  $\alpha$  is within the range of  $180^\circ + \arctan(\frac{H}{R}) < \alpha < 360^\circ - \arctan(\frac{H}{R})$  (Fig. 6(c)), the start point can be:

$$\begin{cases} x_{\text{start}} = -\sqrt{H^2 + R^2} \cos(270^\circ - \alpha) \frac{\sin(270^\circ - \alpha)}{|\sin(270^\circ - \alpha)|} \\ y_{\text{start}} = -H \end{cases} \quad (11)$$

It can be easily obtained from Fig. 6 (c) that the cable angle is within the range of  $180^\circ < \beta < 360^\circ$ , and the end point can be calculated based on Eq. (8).

When the start angle  $\alpha$  is  $360^\circ - \arctan(\frac{H}{R})$ , the cable angle is within the range of  $-180^\circ < \beta < 90^\circ$ , and the start point is:

$$\begin{cases} x_{\text{start}} = R \\ y_{\text{start}} = -H \end{cases} \quad (12)$$

The end point can be calculated based on Eq. (8).

When the start angle  $\alpha$  is within the range of  $360^\circ - \arctan(\frac{H}{R}) < \alpha < 360^\circ$  (Fig. 6(d)), the start point is:

$$\begin{cases} x_{\text{start}} = -\tan(360^\circ - \alpha)R \\ y_{\text{start}} = -H \end{cases} \quad (13)$$

the cable angle is within the range of  $-90^\circ < \beta < 90^\circ$ .

Hence, based on the above analysis, the start point, range of cable angle and end point can be summarized in Table 1.

**Table 1** Start point, range of cable angle and end point of cable

Start angle $\alpha$	Start point	Range of cable angle	End point
$0^\circ \leq \alpha \leq 180^\circ$	$\begin{cases} x_{\text{start}} = R \cos \alpha \\ y_{\text{start}} = R \sin \alpha \end{cases}$	$\alpha - 90^\circ \leq \beta \leq \alpha + 90^\circ$	$\begin{cases} x_{\text{end}} = x_{\text{start}} + l \cos \beta \\ y_{\text{end}} = y_{\text{start}} + l \sin \beta \end{cases}$
$180^\circ < \alpha < 180^\circ + \arctan(\frac{H}{R})$	$\begin{cases} x_{\text{start}} = -R \\ y_{\text{start}} = -R \tan(180^\circ - \beta) \end{cases}$	$90^\circ < \beta < 270^\circ$	
$180^\circ + \arctan(\frac{H}{R})$	$\begin{cases} x_{\text{start}} = -R \\ y_{\text{start}} = -H \end{cases}$	$90^\circ < \beta < 360^\circ$	

$180^\circ + \arctan\left(\frac{H}{R}\right) < \alpha < 360^\circ - \arctan\left(\frac{H}{R}\right)$	$\begin{cases} x_{\text{start}} = -\sqrt{H^2 + R^2} \cos(270^\circ - \alpha) \frac{\sin(270^\circ - \alpha)}{ \sin(270^\circ - \alpha) } \\ y_{\text{start}} = -H \end{cases}$	$180^\circ < \beta < 360^\circ$
$360^\circ - \arctan\left(\frac{H}{R}\right)$	$\begin{cases} x_{\text{start}} = R \\ y_{\text{start}} = -H \end{cases}$	$-180^\circ < \beta < 90^\circ$
$360^\circ - \arctan\left(\frac{H}{R}\right) < \alpha < 360^\circ$	$\begin{cases} x_{\text{start}} = -\tan(360^\circ - \alpha)R \\ y_{\text{start}} = -H \end{cases}$	$-90^\circ < \beta < 90^\circ$

From the above analysis, it can be clearly concluded that the cable length and location were completely controlled by three parameters: start point angle  $\alpha$ , cable angle  $\beta$  and cable length  $l$ . Hence, based on the three parameters, the cable can be determined.

In the numerical simulation example, the  $H$  is 2 m and  $R$  is 2 m. Moreover, in the engineering practice, two types of cables are used, long cables and short cables. In practice, the types of cable can be changed according to the specific circumstances. The number of long cables and short cables can also be variables.

### 2.3.3 The subsection and objection of the cable supporting problem

In the process, the number of long cables ( $n_{\text{long}}$ ) and short cables ( $n_{\text{short}}$ ) and the length of long cables ( $l_{\text{long}}$ ) and short cables ( $l_{\text{short}}$ ) are variables, and the cable location is controlled by the start point angle  $\alpha$  and cable angle  $\beta$ . The objection of this numerical simulation is the total length of  $l_{\text{total}}$ , which should be a minimum value. In addition, the total length of all cables is:

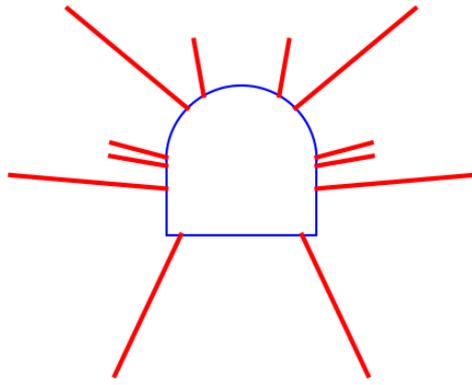
$$l_{\text{total}} = l_{\text{short}} n_{\text{short}} + l_{\text{long}} n_{\text{long}} \quad (14)$$

The subsection is quite clear: the cable should be installed in the rock mass, that is, the start point and end point of all cables should be in the rock mass. Moreover, the safety factor of a rock mass with cables should be larger than or equal to 1.25; then, the total length of all cables  $l_{\text{total}}$  is meaningful, while the safety factor  $s$  is less than 1.25, the calculation is invalid, and the total length of cables  $l_{\text{total}}$  is invalid.

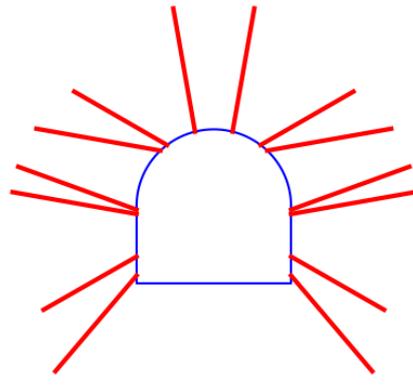
Hence, the problem is transformed to find the minimum value of the total length of cables  $l_{\text{total}}$  when the subsection is satisfied by using the PSO algorithm.

### 2.3.4 Numerical simulation results and analysis

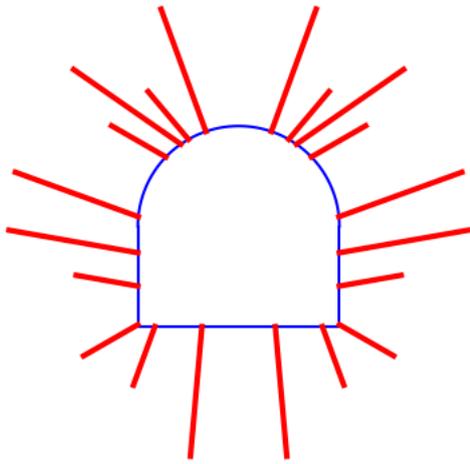
Combining the parameters and the PSO algorithm, the best cable distribution of cable when the lateral stress coefficients are 1.0, 1.2, 1.4, 1.6, 1.8 and 2.0 is illustrated in Fig. 7.



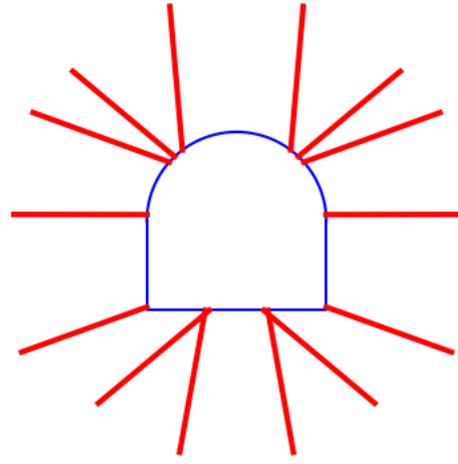
(a)  $\lambda = 1.0$



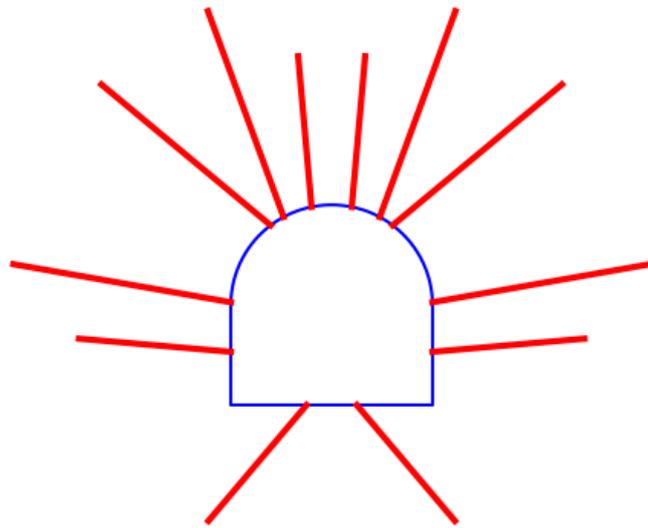
(b)  $\lambda = 1.2$



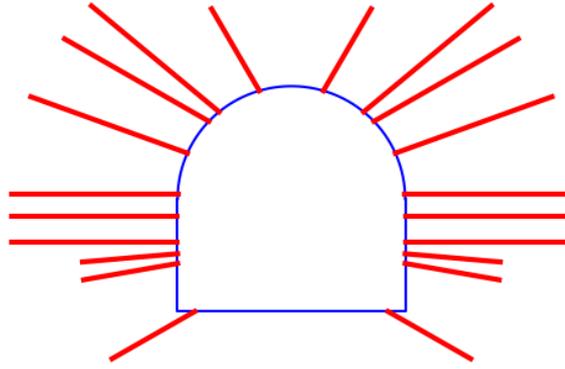
(c)  $\lambda = 1.4$



(d)  $\lambda = 1.6$



(e)  $\lambda = 1.8$



(f)  $\lambda=2.0$

**Fig. 7.** Best cable supporting distribution for roadways with different lateral stress coefficients

**Table 2** Cable parameters in Fig. 7

Lateral stress coefficient $\lambda$	Long cable length $l_{\text{long}}$ (m)	Long cable number $n_{\text{long}}$	Short cable length $l_{\text{short}}$ (m)	Short cable number $n_{\text{short}}$	Total cable length $l_{\text{total}}$ (m)
1.0	4.16	6	1.51	6	34.02
1.2	3.26	10	2.78	2	38.16
1.4	2.60	10	1.24	10	38.40
1.6	3.23	8	2.97	6	43.66
1.8	4.38	6	3.02	6	44.40
2.0	2.93	12	1.68	8	48.60

Based on the analysis of the numerical simulation results, it can be easily observed that the cable distribution is different when the lateral stress coefficient is used; hence, in engineering practice, the supporting strategies should be adjusted according to the specific circumstances. Moreover, with increasing of lateral stress coefficient, the total length of the supporting cable increased as well.

Through numerical simulation, it can be concluded that the proposed technique is workable and can be applied to engineering practice.

### 3 Discussion

There are two problems when controlling the deformation of roadway surrounding rock. The first problem is related to rock mass stability: the support intensity is large, and considering daily maintenance, the cost will be higher. Second, with a large project quantity, rock mass engineering should be stable enough. According to the original supporting method, guaranteeing the stability of the roadway is first considered in the supporting methods, and the economy is commonly ignored; hence, in this paper, the PSO algorithm and FLAC3D numerical simulation were combined to determine the best cable arrangement.

Through numerical simulation, the PSO algorithm can be successfully applied to determine the cable distribution, and the FALC3D software was completely controlled by the Python script. Through the numerical simulation, the best for supporting the roadway with cables under different

conditions was obtained. The numerical simulation results suggested that the proposed method is workable and can be applied to engineering practice. Moreover, it can be found that the best cable distribution is different when the lateral stress coefficients are different; hence, in engineering practice, the strategies for cable support should be adjusted according to the specific circumstances. With increasing lateral stress coefficient, the total cable length increases well, it is indicating that the supporting expenses increase.

However, in this paper, other complicated rock mass conditions were not considered, and other roadway shapes were not investigated, which will be our next tasks. In addition, only cables were used to support roadway in this paper; in engineering practice, steel belts and rebar net can be used. Furthermore, the objection function selected in this paper is the total cable length, and the results would vary if the objection function differs. In addition, the numerical simulation results were influenced by the rock mass mechanical parameters, cable mechanical parameters, and shape of the roadway, which was not discussed in this paper. In summary, this study is of great practical significance to reduce the production cost and promote the development of mining areas by rationally reducing the support strength and guaranteeing the safety.

## **4 Conclusions**

In this paper, to determine the best cable support strategy, the PSO algorithm and FLAC3D numerical simulation were combined to conduct the numerical simulation. Some conclusions can be summarized as below.

(1) The FLAC3D numerical simulations were completely controlled by the Python script, and the PSO algorithm was used to determine the best cable distribution. Through analysis of the numerical simulation results, it was indicated that the proposed method was workable and can be applied to engineering practice.

(2) By using this method, the best cable strategies for supporting roadway with different horizontal stresses with cables were obtained; obviously, when the lateral stress was different, the cable distribution also changed. In addition, as the lateral stress coefficient increases, the total cable length increases.

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## **Compliance with Ethical Standards**

## **Conflict of interest**

The authors declare that they have no conflict of interest.

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