DETERMINATION OF ULTIMATE PIT LIMITS USING ARTIFICIAL BEE COLONY ALGORITHM

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Abstract: Various methods have been proposed to determine the ultimate pit limits. Artificial intelligence-based methods such as heuristic genetic algorithms, ants and colony competition algorithms. Artificial bee colony (ABC) algorithm is one of the most powerful heuristic algorithms inspired by the social life of bees. In this paper, a hypothetical example of the life of bees is primarily described to find the source with the highest amount of nectar by this algorithm. Then, a method based on the bee algorithm is proposed to determine the ultimate pit limit, and to examine its performance, a two-dimensional example is described step by step. In this example, it was found that in cases where the moving cone can not find the optimal ultimate pit limit, the ABC method is well suited for introducing solution. Then, this algorithm was used to determine the ultimate limits of Sungun Copper mine pit with a number of 120*100*45 blocks. To validate the proposed algorithm, the graph theory and moving cone techniques were used. Results showed that the profit obtained by ABC algorithm is just 1.6% less than that of graph theory algorithm, which is a rigorous technique and entails finding the true optimum. Meanwhile, the ABC algorithm provides 12.3% more profit when compared to heuristic moving cone algorithm.

Keywords: Ultimate pit limit, Bee colony algorithm, Graph theory, Moving cone.

INTRODUCTION

After exploration of a reserve, the ultimate limit of the mine has to be determined in case open pit method is chosen for the exploitation. Manual or computational methods can be used to determine the ultimate pit limit. Using manual methods, the design of ultimate pit limit is a time-consuming process, requiring experienced engineers and designers. Computational methods are divided into two general categories of rigorous and search-based methods. Rigorous methods are always able to find the optimal ultimate pit limit, but they are limited in solving large problems and require a very long time to solve, and researchers have been looking for ways to solve problems more quickly in order to overcome this limitation. Using search-based algorithms, problems are solved within a reasonable amount of time with an acceptable accuracy. The search-based algorithms may be divided into two sub-categories of heuristic and meta-heuristic algorithms. Moving cone and Korobov algorithms are among heuristic algorithms, while GA, ACO, and ICA are among meta-heuristic algorithms to determine ultimate pit limit. Recently, artificial intelligence has been commonly used to solve many engineering problems. The meta-

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heuristic algorithms belong to a branch of artificial intelligence methods. The artificial bee colony (ABC) algorithm is one of the algorithms based on collective intelligence. In this paper, the application of ABC algorithm to determining ultimate pit limit is described. Also, floating cone algorithms and graph theory are used to validate this algorithm.

METHODS

Determining ultimate pit limit involves making a decision to extract or not to extract each block of the mine economic block model.. Binary variables could be used to solve the problem, so that the variable for each block equals 1 if the block is extracted, otherwise it equals zero. To solve this problem, the ABC optimization algorithm is used. First, a matrix is created with equal element numbers as the number of ore blocks inside the economic block model in order to determine the ultimate pit limit. Each element of this matrix represents a binary variable of a block, which can have either 0 or 1 value, depending on the status of the block, extracting or not extracting. All blocks with a variable value of 1 will be inside the ultimate pit limit, , and a variable value of 0 means the block is outside the ultimate pit limit. Also, for each response, a zero matrix A_{L*M} is created (L is the number of rows and M is the number of columns in the block model). The elements of the matrix are initialized using corresponding elements in the solution matrix. Obviously, if block ***a*** is within the extraction cone of block ***b***, and if block ***b*** is extracted, then ***block a*** must also be extracted. In other words, for the stability of the pit slope, Equation 1 must be satisfied for l=(2,3,…,L) و m=(2,3,…,M-1).

$$if\ A(l,m) = 1\ \ then\ \ A_{l-1,m-1} + A_{l-1,m} + A_{l-1,m+1} = 3 \qquad 1$$

Then Equation 2 is used to calculate the value of each solution.

$$V_i = \sum_{l=1}^{L} \sum_{m=1}^{M} A_i(l,m) \times BEV(l,m) \qquad 2$$

where BEV is the economic value of the block.

After defining the problem, the steps of modified ABC algorithm to determine the ultimate pit limit are briefly described.

Step 1:

The first step in the ABC algorithm is to create initial answers (solutions). Each of the initial SN (number of initial answers) matrixes have D number of elements (D is the number of blocks or variables to be decided for). The elements of each matrix are randomly selected with values of 0 and 1.

Step 2:

In the second step, a new answer is created using Equation 3. After creating the answer, the value of this answer is calculated using Equation 2. If the value of the new answer is equal or more than the previous answer, the new answer replaces the previous answer, otherwise the answer needs to be fined.

$$v_{i,j} = x_{i,j} + \mathrm{round}(\varphi_{i,j}(x_{i,j} - x_{k,j})) \qquad 3$$

where j is the block number of the answer array, j=[1,2,...,D] and φ are random numbers within the range of [-0.65,0].

Step 3:

In this step, the fitness of each answer is calculated first. In this research, Equation 4 is proposed to determine the fitness of each solution.

$$fit_i = \begin{cases} value_i + \varepsilon & if\ value_i \geq 0 \\ |value_i| & if\ -1 < value_i < 0 \\ \dfrac{1}{|value_i|} & if\ value_i \leq -1 \end{cases} \qquad 4$$

Where fit_i is the fitness of the answer i, $value_i$ is the value of the answer i (the value of the pit formed for the answer i), and ε is a very small number.

After calculating the fitness of the answer, the probability of each answer to attract the bee is calculated using Equation 5, and according to that fitness, this probability is assigned to the answers of a number of bees. If the value of the new answer is equal or more than the previous answer, the new answer replaces the previous answer, otherwise the answer needs to be fined.

$$p_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \qquad 5$$

Step 4:

In this step, all answers that their fines have reached C_{max} are replaced by new random answers, the new answer has a C value of zero. Finally, the end condition of the algorithm is examined. If this condition is met, the algorithm stops, otherwise its control turns back to the second stage.

FINDINGS AND ARGUMENT

In this research, ABC algorithm was used to determine the ultimate pit of Sungun mine. After the modeling of this mine in Datamine software using the Equations 6-7, the economic block model was provided.

$$v = [(p - r) * g * y - m - c]Q \qquad 6$$

$$v = \begin{cases} v & if\ \ (p - r) * g * y > c \\ -mQ & if\ (p - r) * g * y < c \end{cases} \qquad 7$$

In these equations, ***v*** is the value of the block, ***p*** is the price, *r* is the costs of melting, refining and sales of metal per ton, ***g*** is the block grade, ***y*** is the recovery of metal, ***m*** is the mining costs of rock per ton, ***c*** is the costs of processing ore per ton, and ***Q*** is the tonnage of the block.

Then the ABC algorithm was used to determine the ultimate pit limit of the Sungun mine. For this purpose, ABC algorithm was formed using Matlab software, and used for determining ultimate pit limit of sungun mine. By implementing of the honey bee algorithm, the profit derived from extraction of the final pit was 21.184 billion$, which is 12.3% higher than the profit obtained using the moving cone algorithm (18.572 billion $).

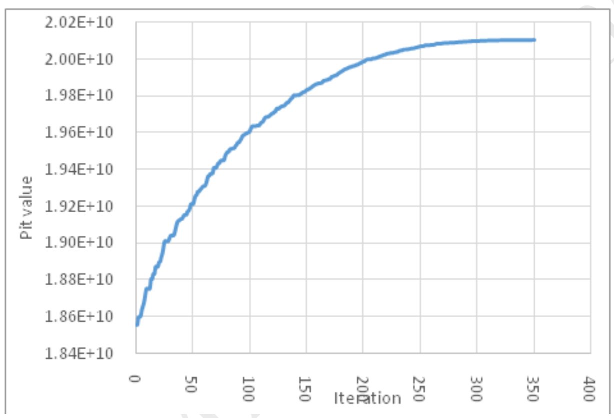

Figure 1:Pit value vs. Iterations

For validation of the obtained results, NPV Scheduler software was used, which determines the ultimate pit limit based on the graph theory. Results showed that the profit obtained using the ABC algorithm is just 1.6% less than that of graph theory algorithm, a rigorous technique that provides the true optimum.

CONCLUSIONS

1. The axial strength of smooth plane discontinuities having different orientations is less than the axial strength of rough undulating and tooth-shaped asperity discontinuities under the different confining pressures.

2. Failure occurred through the body of specimens having rough undulating and tooth-shaped asperity roughness of discontinuities for orientation angle of 30 degree, whereas for tooth-shaped asperity discontinuities having orientation angles of 45 degrees, failure also occurred at the body of the specimens particularly with increasing the confining pressure.
3. Sliding occurred at the one side of tooth-shaped asperities of discontinuity having orientation angles of 60 degree under uniaxial loading, and displacement took place at the direction of discontinuities. But tooth-shaped asperities were broken along the discontinuities under the higher confining pressures.
4. The ratio of maximum axial strength to the minimum axial strength ratio ($Rtriax=\sigma_{1max}/\sigma_{1min}$) has high value for the zero confining pressure and it decreases sharply as a negative power function of confining pressure, and then approaches a constant value.
5. Mine benches and boundary of the tunnels are subjected to smaller values of confining stresses; therefore, orientation angle of discontinuities particularly 60o can greatly affect the safety factor.

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