The effect of maximum iteration using 3 dimensional limit equilibrium method in open pit mine

F M Syahputra¹, M A Azizi*, I Marwanza¹

¹Mining Engineering Department, FTKE, Trisakti University, West Jakarta, 11440, Indonesia
masagus.azizi@trisakti.ac.id

Abstract. Nickel ore mines have a high potential of landslides due to their weak material base, which consists of soil. It is caused by the increase of soil density in rain conditions, leading to decreased soil shear strength (c) and internal friction angle (ϕ). This research aims to determine the optimum value of the maximum iteration number based on the Cuckoo Search and Particle Swarm Optimization search method. In this research, the slope is analyzed using the 3 Dimensional limit equilibrium method “Simplified Bishop,” a slope stability analysis method that uses the principle of static equilibrium. Alongside this method, the Cuckoo Search and Particle Swarm Optimization is adopted. The Cuckoo Search and Particle Swarm Optimization are metaheuristic optimization techniques used as the slipped surface search method. Series of 3-dimensional limit equilibrium computation is performed using different amounts of nests in the cuckoo search method and different particle values and maximum iteration number. Cuckoo Search method to achieve optimal nest 100 and iteration of 80 with the fastest compute time of 3 minutes 49 seconds. While the Particle Swarm Optimization to achieve optimal on particles 60, iteration as much as 480 with a compute time of 6 minutes 46 second, with a factor of safety value of 1.12.

1. Introduction
In PT. X mining activity, 3-dimensional models of the pit design were made to ensure the stability of the slope for safe and productive mining practice. Slope stability is one of the essential aspects of mining practice because it determines the efficiency and productivity of production. Mine stability is highly governed by rock mass characteristics and other external factors such as groundwater and vibrations caused by the mining activities. The stability of a slope is represented by the Factor of Safety. Therefore, slope stability analysis plays an integral role in the mining process. There is various type of slope stability analysis method. The 3-dimensional Limit Equilibrium with simplified Bishop is one of the most applied in the field. This research utilizes this method to determine the FoS value and estimate the landslide volume. In the 3D LEM with simplified Bishop, the metaheuristic optimization method, cuckoo search, and PSO were applied to determine the slide surface.

The PSO and CS are algorithms that are used to determine the optimum and sub-optimum in numerical problems. The PSO is a population-based metaheuristic optimization method. Cuckoo search is a metaheuristic optimization method inspired by the breeding of cuckoo birds by Yang and Deb (2013) [2].
1.1. Limit equilibrium method
In this method, the calculation of slope stability analysis only uses static equilibrium conditions and ignores the stress-strain relationship on the slope. The geometry of the slip, the surface must be known or determined first.

There are two types of landslide analysis using the limit equilibrium method: the translational type and the rotational type. The analysis of the rotational type of landslide can use the slice method. The slice method itself can be divided into two, named the method that complete all conditions of forces balance and moments (Spencer, Morgenstern-Price, and General Limit Equilibrium) and which does not complete all conditions of forces equilibrium and moments (Ordinary Slice, Simplified Bishop, and Simplified Janbu).

1.2. Factor of Safety
The stability level can be determined with the safety factor. FoS is the value of the difference between the restraining force with the driving force.

\[
\text{FoS} = \frac{\text{resisting force}}{\text{driving force}} \quad (1.1)
\]

Direction:
- \(\text{FoS}\) = Factor of Safety
- \(\tau\) = Shear Stress
- \(\sigma_n\) = Normal Stress
- \(c\) = Cohesion
- \(\phi\) = Friction Angle

Shear Stress \((\tau) = c + \sigma_n \tan \phi\) (1.2)

If the FoS value for a slope is > 1.0 (resisting force > driving force), the slope is in a stable condition. However, if the value of FoS < 1.0 (resisting force < driving force), the slope is unstable, and landslides may occur on the slope.

1.3. Search methods slide3
The slipped surface search method in Slide3 is highly automated and requires a little user input. The shape of the surface can be made and selected with two existing surface types, named Spherical and Ellipsoid; then, with the optimization of surface changes (Surface Altering Optimization (SAO)), the overall landslide area can be searched with a lower FoS. The 3D avalanche direction will be automatically determined during the analysis.

In Slide3, four slip surface search methods are provided, named Grid Search, CS, and PSO. Based on the development of optimization methods, two of the four mentioned above are the most modern methods and have a high level of effectiveness in solving engineering problems. The methods are CS and PSO.

1.4. Cuckoo search
Cuckoo Search is a metahuristic optimization method [1] developed by Yang and Deb (2010). The method was inspired by cuckoo's breeding behavior. In this research, the CS is used as a slip surface search tool with the lowest SF. CS is coupled with Lévy Flights random walk. There are few rules to use this algorithm as stated in [2]:
- Each cuckoo lay one egg at a time and dumps it in a randomly chosen nest;
- The best nests with high quality of eggs (solutions) will carry over to the next generations;
- The number of available host nests is fixed, and a host can discover an alien egg with a probability \(p_a\in [0, 1]\). In this case, the host bird can either throw the egg away or abandon the nest to build an entirely new nest in a new location.

The last rule can be approached using a fraction \(p_a\) to determine the worst solutions of \(n\) nests that will randomly replace a new nest. In order to solve the problem, it can be simply illustrated that every egg in a nest represents one new solution. The purpose is to use the new and potentially better solution to
replace the current solution in the nest. The nest may have two eggs (2 solutions) in a specific condition, but this problem is simplified, so one nest has only one solution [3,4].

1.5. Particle swarm optimization
Kennedy and Eberhart initialized PSO by simulating the behavior of a bird swarm with defined instructions for individual behaviors and intercommunications. These instructions help in the decision-making process of individuals, which is based on the following items [5]:

- Experience of the individual as its best results so far;
- An outlay of experience of a swarm is the best result among all individuals.

This process starts by randomly generating a certain number of individuals, namely particles, representing a possible solution for the problem. It is based on the individual attitude (Particle) and the influence of other individuals within the pack (Swarm). Every individual acts according to their intelligence and is influenced by the collective behavior of the pack. Therefore, if a particle finds a practical path to the food source, the pack will follow the path to the source wherever they are located.

2. Methodology
The slope stability analysis of this open-pit mine uses the 3D Bishop's limit equilibrium method with two parameters of the landslide field search method, named Particle Swarm Optimization (PSO) and Cuckoo Search. Research variables include the number of particles, the number of nests, and maximum iterations. The assumption of the type of landslide is circular because the limonite and saprolite materials have almost the same mechanical properties as the soil.

3. Result and discussion
In this study, the data was obtained in the final pit in 3D form and data on material properties of soil (limonite and saprolite) and rock (bedrock) such as tensile strength, cohesion, internal friction angle, and physical properties. Testing is carried out in the laboratory to obtain material properties. The material results can be seen in Table 1.

| NO. | Lithology  | Unit Weight (kN/m³) | Cohesion (Kpa) | Friction angle (°) |
|-----|------------|---------------------|----------------|-------------------|
| 1.  | Limonite   | 17.2                | 41.1           | 15.7              |
| 2.  | Saprolite  | 15.8                | 38             | 12.6              |
| 3.  | Bedrock    | 41.7                | 3.270          | 29                |

Slope stability analysis was carried out on the entire slope of the pit, which has limonite, saprolite, and bedrock lithology, along with the mechanical and physical parameters of the material entered into the Slide3 software, as shown in Figure 2.
Figure 1. 3D Model Pit Design and Lithology.

Table 2. Computing result with 10.

| Max Iteration | Nest | FOS | Volume (m$^3$) | Position | Time (Second) |
|---------------|------|-----|---------------|----------|---------------|
| 20            | 100  | 1,63| 34.708        | North    | 65            |
| 40            | 100  | 1,16| 37.182        | North    | 114           |
| 60            | 100  | 1,19| 46.280        | North    | 179           |
| 80            | 100  | 1,12| 45.423        | North    | 229           |
| 100           | 100  | 1,14| 42.073        | North    | 291           |
| 120           | 100  | 1,12| 10.103        | North    | 345           |
| 140           | 100  | 1,14| 41.384        | North    | 403           |
| 160           | 100  | 1,12| 43.591        | North    | 447           |
| 180           | 100  | 1,14| 38.988        | North    | 509           |
| 200           | 100  | 1,12| 50.680        | North    | 564           |
| 220           | 100  | 1,12| 43.599        | North    | 636           |
| 240           | 100  | 1,13| 8.951         | North    | 696           |
| 260           | 100  | 1,12| 8.732         | North    | 773           |
| 280           | 100  | 1,13| 43.322        | North    | 838           |
| 300           | 100  | 1,13| 41.299        | North    | 919           |
| 320           | 100  | 1,12| 7.767         | North    | 947           |
| 340           | 100  | 1,12| 40.812        | North    | 1038          |
| 360           | 100  | 1,12| 43.649        | North    | 1060          |
| 380           | 100  | 1,12| 9.097         | North    | 1143          |
| 400           | 100  | 1,12| 42.008        | North    | 1207          |
Table 3. Computing result with 60 Particle.

| Max Iteration | Particle | FOS  | Volume (m3) | Position | Time (Second) |
|---------------|----------|------|-------------|----------|---------------|
| 40            | 60       | 1,47 | 20.197      | North    | 32            |
| 80            | 60       | 1,31 | 48.432      | North    | 103           |
| 160           | 60       | 1,26 | 51.856      | North    | 149           |
| 240           | 60       | 1,19 | 55.037      | North    | 251           |
| 320           | 60       | 1,14 | 50.867      | North    | 306           |
| 400           | 60       | 1,13 | 48.953      | North    | 350           |
| 480           | 60       | 1,12 | 49.656      | North    | 406           |
| 560           | 60       | 1,12 | 49.662      | North    | 480           |
| 640           | 60       | 1,12 | 49.689      | North    | 638           |
| 720           | 60       | 1,12 | 49.675      | North    | 683           |
| 800           | 60       | 1,12 | 49.690      | North    | 747           |

The table above shows the result of Particle Swarm Optimization and Cuckoo Search consisting of Factor of Safety, critical position, potential failure volume, and computation time. Based on the results from both search methods, the nest, particle, and iteration number will influence the LEM analysis results. The high amount of particle, nest, and iteration computation needs more time to calculate. When the number of iteration is high, the analysis will have more repetition in the calculation and yielding an accurate FOS value, but it takes a longer computation time. In this research, the particle and nest number used varies from 60 to 100, with the maximum iteration of 20 to 400 in the CS search and 40 to 800 iterations for PSO.

Figure 2. Critical position using CS with 100 nests and 80 iterations.
Figure 3. Critical position using PSO with 60 particle and 480 iterations.

Figure 4. Computing time versus maximum iteration based on the number of the nest.
Figure 5. Computing time versus maximum iteration based on the number of particles.

Figure 6. Minimum FOS versus iterations based on the number of nests.
Figure 7. Minimum FOS versus iterations based on the number of particles.

From the result of figure 5, the limit equilibrium analysis using the Cuckoo Search slipped surface search method with the number of nest research variables and maximum iteration proves the more number of safety factor value iteration, the more critical it is to reach the optimal value. The result of the graph is in figure 4, which shows that after the iteration is 200, the changes of the safety factor are not too significant and stable. From the result of the CS graphic method, in the next iteration, the number of the nest is no longer influential. Based on the result of the CS graphic method can be concluded that in the next iteration, the number of nests is no longer influential, and the value has reached the optimum in the 1,12 safety factor. From the CS (figure 6.) method simulation, the optimal number of the nest and maximum iteration is in the 100 nests and 80 iterations with the fastest computation time of 3 minutes and 49 seconds.

The graph (figure 7.) of iteration number and the FoS compared to the one generated in the research by (Kalatejhari, 2014). From these graphics, it can be concluded that the FoS value will increase with the increase of particle, nest, and iteration number. The research was conducted on a single slope with slope forming material consisting of soil. From the graphic, the FoS value tends to stabilize with iteration above 680. The same trend is also seen in the cuckoo search graphic. From this point, it is safe to say that the particle number no longer influences the actual FoS value if 1.2 is reached. The PSO simulation method found that the optimum number of particles and iteration is when particle amount is 60 with the iteration number of 480 and 46 seconds computation time.

The graph proves that the more maximum iteration is, nest or even the particle, the more accurate the safety factor value will be. This research could optimize the number of nests, particles, and maximum iteration based on the safety factor value result and the critical slipped surface position.

4. Conclusion

Based on the research conducted, it can be concluded as follows:

Computation using Slide3 software with Cuckoo and PSO as the slip surface search method generated an FoS value of 1.12 and a circular failure located on the north side of the pit. The analysis will yield an accurate FoS value at a higher amount of iteration. In the CS, the fastest computation time recorded is 3′ 49″ with iteration numbers of 80 and 60 particles. For the PSO method, the fastest computation time recorded is 6′ 46″ with the iteration number of 480 and 60 particles. In this location, the CS is more realistic because it generated the optimum value of FOS in a shorter computation time. The estimated volume of potential landslide for the Cuckoo search method is 42.286 m³ and 47.694 m³ for the PSO method.
References

[1] Yang X S and Deb S 2010 *International Journal of Mathematical Modelling and Numerical Optimisation* 1(4) p 330

[2] Yang X S and Deb S 2013 *Computers & Operations Research* 40 p 1616–1624

[3] Anderson L R, Kiefer F W 1980 *Fundamentals of Geotechnical Analysis* (New York : John Wiley & Sons, Inc)

[4] Azizi M A, Marwanza I, Hartanti N A 2020 *Indonesian Mining Journal* 23(2) p 57-65

[5] Azizi M A 2018 *Three dimensional slope stability analysis of open pit limestone mine in Rembang District, Central Java* (IOP Publishing Ltd)

[6] IOP Conference Series: Earth and Environmental Science, Volume 212, International Conference on Earth Science, Mineral, and Energy 11–12 October 2018, Yogyakarta, Indonesia

[7] Azizi M A, Karim R 2019 *Indonesian Mining Professionals Journal* 1(1)

[8] Azizi M A 2019 *Proceedings in Earth and geosciences* 6 (CRC Press)

[9] Azizi M A 2021 *Three Dimensional Slope Stability Analysis of Open Pit Mine, in Slope Engineering Book* (IntechOpen Publishing)

[10] Muhammad Z A 2020 *Indonesian Mining Professionals Journal* 2(2) 51-56

[11] Reyes A and Parra D 2014 *3D Slope Stability Analysis by The Using Limit Equilibrium Method Analysis of A Mine Waste Dump, Proceedings Tailings and Mine Waste, Colorado, USA, 127–139

[12] Rocscience 2018 *Slide3 – 3D Limit Equilibrium Slope Stability Overview*

[13] Roohollah Kalatehjari et al 2014 *The Scientific World Journal* 2014 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC) IEEE p 210–214