APPLICATION OF CUCKOO SEARCH METHOD IN 3D SLOPE STABILITY ANALYSIS FOR LIMESTONE QUARRY MINE

APLIKASI METODE CUCKOO SEARCH *PADA ANALISIS KESTABILAN LERENG 3D UNTUK TAMBANG KUARI BATU GAMPING*

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ABSTRACT

The Cuckoo Search (CS) is a very fast and efficient global optimization method to locating the slip surface which carried out by iteration. However, the Grid Search (conventional method) method in 3D slope stability analysis takes longer than this method on the computation process. Slope stability analysis was performed using the 3D limit equilibrium method "Bishop" with Cuckoo Search of slip surface by maximizing iteration of the simulation and columns in X or Y. To ensure that the slip surface within the global minimum slip surface, the maximum iteration in CS was also specified from 40 to 1200. Based on maximum columns in X or Y, the safety factor value of the 3D CS results was then compared to the Grid Search results to determine the final 3D safety factor and the estimated volume of potential failure. The final 3D safety factor obtained from the average 3D safety factor (with maximum iteration 400, 800, 1000, and 1200) is about 2,01 with the average estimated volume of slope failure of 190.000 m^3 that located at the north of the pit.

Keywords: open pit mine, limestone, slope stability analysis, 3D-limit equilibrium method, Cuckoo Search.

ABSTRAK

Cuckoo Search *(CS) adalah metode pengoptimalan global yang sangat cepat dan efisien dalam menemukan lokasi permukaan gelincir. Pencarian dilakukan dengan iterasi, sedangkan pada analisis kestabilan lereng 3D, metode* Grid Search *(metode konvensional) membutuhkan waktu yang lebih lama dibandingkan metode ini pada saat proses komputasi. Analisis stabilitas lereng dilakukan menggunakan metode kesetimbangan batas 3D "Bishop" dengan pencarian permukaan luncuran metode* Cuckoo Search*, dengan cara memaksimalkan iterasi variabel simulasi iterasi dan kolom X atau Y. Untuk memastikan lokasi permukaan luncur pada saat seluruh permukaan tergelincir minimum, iterasi maksimum dalam CS juga ditentukan, mulai dari 40 hingga 1200. Berdasarkan kolom maksimum pada X atau Y, nilai faktor keamanan hasil CS 3D kemudian dibandingkan dengan hasil* Grid Search *untuk menentukan faktor keamanan 3D akhir dan perkiraan volume potensi keruntuhan. Faktor keamanan 3D akhir yang diperoleh dari rata-rata (dengan iterasi maksimum 400, 800, 1000, dan 1200) sekitar 2,01 dengan perkiraan jumlah volume rata-rata keruntuhan lereng sebesar 190.000 m^3 dan terletak di sebelah utara* pit*.

Kata kunci: tambang terbuka, batu gamping, kestabilan lereng, metode kesetimbangan batas 3D, Cuckoo Search.

INTRODUCTION

Slope stability analysis in this research is performed using limit equilibrium method (LEM). Such the method requires slip surface assumption by calculating the safety factor (SF), namely circular or non-circular assumption. To obtain the surface with the lowest safety factor, the computation is performed in different potential slip surfaces (McCombie and Wilkinson, 2002). In 2D slope stability analysis, Grid Search is commonly used as a method to search slip surface because the principle is simple and easy-to-understand. However, this method can only calculate the SF of circular slip surfaces, so it cannot represent the slope stability in real condition. The Cuckoo Search (CS) method with iteration process is useful to avoid manual determination and makes the calculation more representative. However, 3D-slope stability analysis with the grid search method takes longer than the CS on computation time.

Cuckoo Search (CS) is an algorithm used for solving the optimization problems. CS has been used in engineering field, such as welded beam and optimization in spring design but few used it for slope stability issue. Wu (2012) and Gandomi *et al.* (2013) used this method in 2D slope stability analysis. Wu (2012) did a performance comparison between simulated annealing (SA) and CS and concluded that the CS performance was better and more efficient than the SA. Gandomi *et al.* (2013) has implemented 3 latest swarm intelligence techniques in the model of 2D slope stability analysis which are adopted from few researches; considering that these 3 techniques have been carried out to solve the civil engineering problems. The 3 techniques involve firefly algorithm (FA), CS, and Levy Flight Krill Herd (LKH). The results of these applied techniques were compared to the traditional swarm intelligence technique, particle swarm optimization (PSO). The PSO results imply that CS and LKH were absolutely outperformed the traditional PSO, especially the LKH which demonstrates the best algorithm between those techniques in order to solve the complicated slope stability problems.

Nowadays, the necessity to analyze the slope stability in 3D approach is more essential. The reason is that slope stability problem should not be assumed in 2 dimensionally approach. It has been explained in Gens, Hutchinson and Cavounidis (1988). The 2D analysis cannot be used as the main standard to assess the stability of open pit mine slope because it has not been considered as the spatial problem, thus a volume of potential failure of slope could not estimate in this approach (Azizi, Marwanza and Hartanti, 2018). The importance of estimation in a volume of slope failure is for risk calculation of slope failure. The risk is defined as a probability of slope failure multiply by consequences of slope failure (Rodriguez-Lopez, Jimenez-Rodriguez and Hruskovic, 2006). The volume of slope failure is counted as one of the consequences. It can be obtained by analyzing the slope stability in the 3D approach. Furthermore, there is a relationship between the failure probability and the volume of failure (Azizi *et al.*, 2014). Another issue is that when 3D analysis is performed using a Grid Search, the use of 3D slope stability analysis on a vast area can be complicated (Azizi *et al.*, 2018). This supports the statement of Hu *et al.* (2015) that more advanced optimization methods are required in real cases. Therefore, through this research, the authors tried to apply the CS in order to determine the slip surface with minimum SF in 3D analysis. Thus, the research suggest the CS as an alternative or other better option in 3D analysis. However, there is a weakness in this method. The geometric object is required to be in a good condition. When the object is damaged, it is necessary to cut the 3D pit model and manually determine the slip surface.

METHODS

Material in this location consists of 2 types of rocks, namely high-grade limestone and low-grade limestone. The material properties for the high-grade limestone are unit weight 20.6 kN/m^3, cohesion 170 kPa, internal friction angle 53.0 degrees and tensile strength 2500 kPa, whereas the low-grade limestone properties are unit weight 20.5 kN/m^3, cohesion 120 kPa, internal friction angle 46.9 degrees and tensile strength 2250 kPa (included geotechnical model adopted from Azizi *et al.* (2018). Slope stability analysis was performed in LEM 3D "Bishop" (Cheng and Yip, 2007) with Cuckoo Search (CS) of slip surface using simulation variable of max iteration and max columns in X or Y. To ensure the slip surface was the global minimum slip surface, the maximum iteration in CS was also specified from 40 to 1200.

Based on max columns in X or Y, SF value of the 3D CS results were then compared to the Grid Search results as carried out by Azizi *et al.* (2018) to determine the final 3D SF, and the estimated volume of potential failure. Finally, it would be clear if the CS could be used in analyzing slope stability or not. In this research, the authors using Slide3 of Rocscience software that has a basic concept of slip surface search methods.

CUCKOO SEARCH (CS)

CS is a metaheuristic optimization method (Yang, 2014) that was developed by Yang and Deb (2010). The method was inspired from cuckoo's breeding behavior. In this research, the CS is used as a slip surface search tool that has the lowest SF. CS is coupled with Lévy Flights random walk. There are few rules to use this algorithm as stated in Yang and Deb (2009):
- 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 $pa \in [0, 1]$. In this case, the host bird can either throw the egg away or abandon the nest so as to build a completely 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 be replaced with a new nest randomly. 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. In a certain condition, the nest may have 2 eggs (2 solutions) but this problem is simplified so one nest has only 1 solution (Yang and Deb, 2010; Mohammed and Duaimi, 2018).

The random walk as determined by Lévy Flights can be described in the following formula:

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus Lévy(\lambda) \quad \text{.................................} (1)$$

where $\alpha > 0$ is the step size and $Lévy(\lambda)$ is the position function from Lévy Flights.

$$Lévy \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \quad \text{...............................} (2)$$

CS has been applied in many optimizations and computer intelligence with promising efficiency. As stated in Yang and Deb (2014) this has been proved from design application in engineering field, scheduling problems, thermodynamic calculations, etc. Few examples of CS application in engineering field are designing spring, welded beam, and steel frame. The CS's performance has also been compared with some metaheuristic algorithms such as PSO and Genetic Algorithm (GA), and the result shows that the CS has a higher success rate than the two others (Yang and Deb, 2009).

One of case studies using the CS approach in slope stability analysis is an open cut coal mine in Queensland, Australia.

LEM 3D "Janbu" was used to determine the likely behavior of an open cut coal mine excavated slope. As the slope's actual performance was known, this was an ideal case study to test the reliability of the slope stability analysis methodology in Slide3 (McQuillan *et al.*, 2018).

RESULT AND DISCUSSION

The topographic map, pit design and drill point data are overlaid to produce a geotechnical model (Figure 1). The model is used for a 3D pit modeling by importing it into the Slide3 software to produce a 3D pit model that is ready for slope stability analysis (Figure 2). After the stability of the slopes is analyzed using the LEM 3D "Bishop" method, the results are presented in Tables 1 and 2.

An example of the results of the analysis using the max iteration and max column variables in the x and y directions in the search for the slip surface using the CS method can be seen in the Figure 3, 4 and 5.
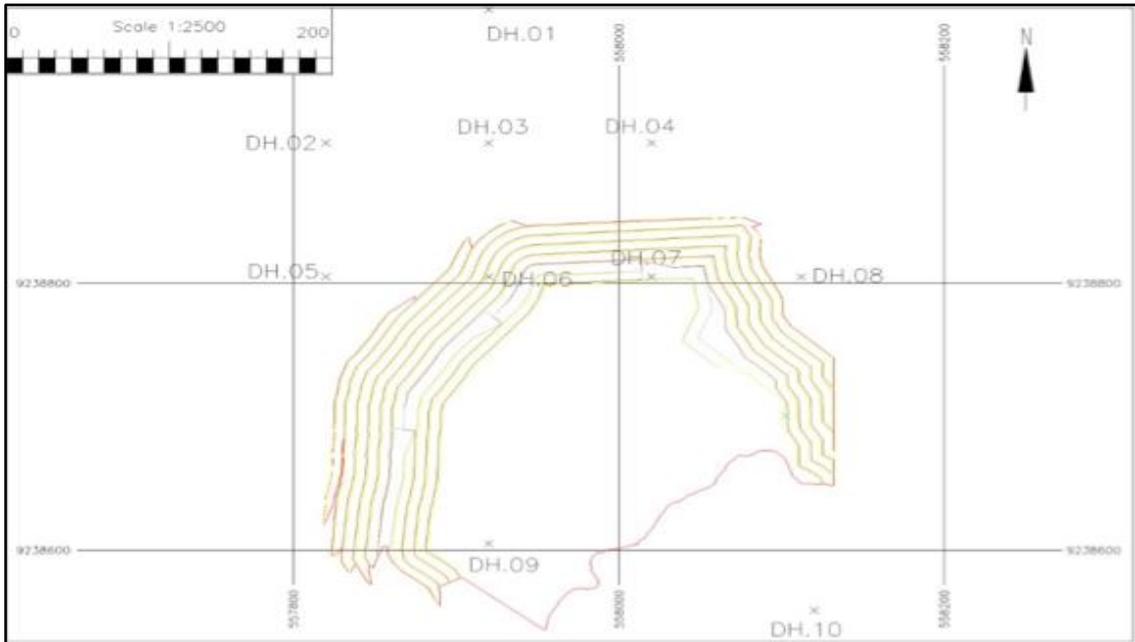
Figure 1. Geotechnical for slope stability analysis model
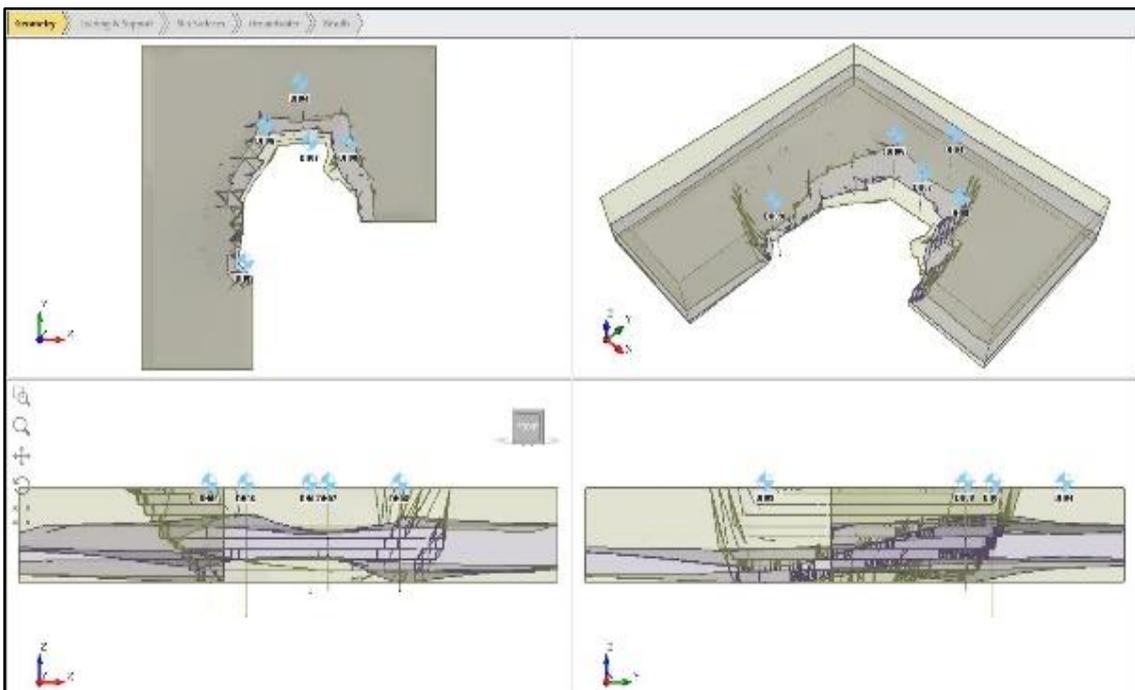

Figure 2. 3D pit model in Slide3

Figure 3. The display of 3D analysis result using Max Columns in X or Y 150 and
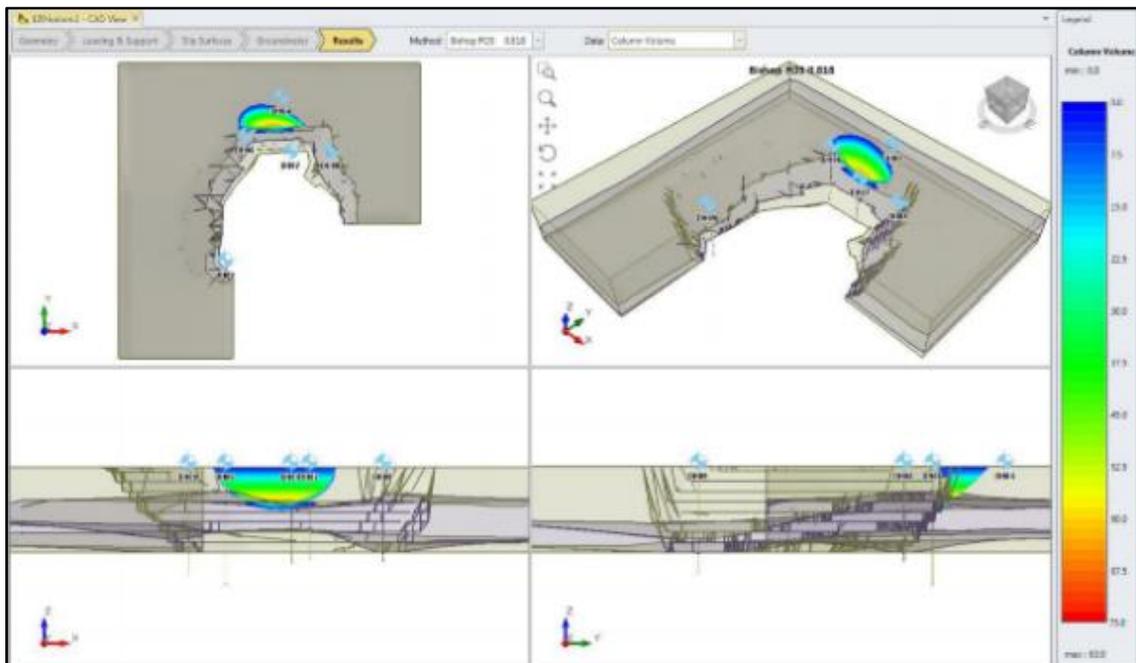maximum CS iteration 1000

Figure 4. The display of 3D analysis result using Max Columns in X or Y 120 and
maximum CS iteration 1200

Figure 5. The display of 3D analysis result using Max Columns in X or Y 90 and maximum CS iteration 160

From 3D CS results (Table 1), the critical position of the slip surface is in the northern pit. It shows that there are few outliers, which happened because of the CS performance itself. Yang and Deb (2010) and Yang (2014) in Gandomi *et al.* (2013) stated that there is no guarantee in discovering the best solution, or when an algorithm will work and why it can work.

Based on the 3D Grid Search result in Azizi *et al.* (2018), the final global minimum location was directed at the north of the pit. The same result is obtained from 3D CS result. The comparison between the average 3D SF using CS and Grid Search (Table 2) enumerates that the difference is only 0,01 (the averaged 3D CS SF and 3D Grid Search SF values are almost the same). Therefore, the research concludes that the CS and Grid Search can be reliable in seeking the global minimum slip surface. However, judging from the efficiency of both methods, the CS is more efficient than the Grid Search. The computation time to get the SF in Grid Search was longer than that of the CS computation time. This is because Grid Search depends on the number of points assigned. The more points are assigned, the longer computational time will be. The

incoming problem will occur if 3D analysis using Grid Search performed on a vast area. Indeed, the larger the area, the larger grid box should be made, and if it needs accuracy, the number of points should be made tightly. Albataineh (2006) has stated that automating the search techniques can be a cumbersome task if using classic search techniques. Advanced optimization techniques showed promising potential for further developments and future applications in slope stability and in geotechnical engineering (Albataineh, 2006).

Based on the results of 3D CS analysis, it shows that most of the locations with the lowest SF are located in the north and northeast of the pit. The difference in the global minimum location is caused unmet requirement of global minimum in the quest, and only after the increase in iteration that the potential of failure at north of the pit could be located entirely, as indicated by the results with maximum iteration of 400, 800, 1000, and 1200. Subsequently, the final 3D SF obtained from the average 3D SF (with maximum iteration 400, 800, 1000, and 1200) is about 2,01 with the average estimated volume of potential failure of 190.000 m^3 and located at the north of the pit.

Table 1.   Recapitulation of 3D CS analysis results

Max Iteration	Max Columns in X or Y	FoS	Volume (m^3)	Location	Slip Surface Position
40	50	2.06	159816	north	a
	60	2.02	179523	north	a
	70	2.10	229704	northeast	-
	80	2.10	303186	northeast	-
	90	2.01	183631	north	a
	100	2.01	187898	north	a
	110	2.00	185461	north	a
	120	2.14	178230	northeast	-
	130	2.10	255444	northeast	-
	140	2.09	297896	northeast	-
	150	2.11	297771	northeast	-
80	50	2.03	179192	north	a
	60	2.02	192951	north	a
	70	2.03	167961	north	a
	80	2.02	178858	north	a
	90	2.02	171821	north	a
	100	2.01	183469	north	a
	110	2.11	298457	northeast	-
	120	2.17	170457	northeast	-
	130	2.00	183204	north	a
	140	2.01	191916	north	a
	150	2.10	265182	northeast	-
120	50	2.02	175113	north	a
	60	2.02	180573	north	a
	70	2.01	178671	north	a
	80	2.01	193606	north	a
	90	2.01	180490	north	a
	100	2.02	190336	north	a
	110	2.11	272365	northeast	-
	120	2.04	180305	north	a
	130	2.08	167245	north	a
	140	2.00	199989	north	a
	150	2.00	195607	north	a
160	50	2.00	194125	north	a
	60	2.01	174180	north	a
	70	2.03	170430	north	a
	80	2.01	179233	north	a
	90	1.00	19008	northeast	b
	100	1.99	199321	north	a
	110	2.04	174759	north	a
	120	2.00	194403	north	a
	130	2.00	194988	north	a
	140	2.00	191965	north	a
	150	2.00	191338	north	a
200	50	2.01	180821	north	a
	60	2.01	179535	north	a
	70	2.10	258302	northeast	-
	80	2.19	270897	northeast	-
	90	2.04	172299	north	a
	100	1.99	192171	north	a
	110	2.10	315329	northeast	-
	120	2.02	186531	north	a
	130	2.09	303241	northeast	-
	140	2.01	183645	north	a
	150	1.99	197361	north	a
400	50	2.00	195539	north	a
	60	2.05	174848	north	a
	70	2.02	199719	north	a
	80	2.00	195231	north	a
	90	2.00	194572	north	a
	100	2.00	186047	north	a
	110	2.00	187918	north	a
	120	2.01	190101	north	a
	130	2.00	197552	north	a
	140	2.00	197629	north	a
	150	1.99	193761	north	a
600	50	2.05	157244	north	a
	60	2.04	171805	north	a
	70	2.02	178812	north	a
	80	2.01	184185	north	a
	90	2.00	200779	north	a
	100	2.00	195602	north	a
	110	2.00	191515	north	a
	120	2.04	186207	north	a
	130	1.02	21725	southwest-west	b
	140	2.03	185630	north	a
	150	2.00	197891	north	a
800	50	0.82	38239	north	b
	60	2.01	192786	north	a
	70	2.01	204299	north	a
	80	2.01	196060	north	a
	90	2.01	187613	north	a
	100	2.01	187709	north	a
	110	1.99	197197	north	a
	120	2.05	171951	north	a
	130	2.00	195292	north	a
	140	1.99	188645	north	a
	150	2.00	203026	north	a
1000	50	2.02	185006	north	a
	60	2.04	173577	north	a
	70	2.03	175154	north	a
	80	2.01	187845	north	a
	90	2.01	189787	north	a
	100	2.01	177988	north	a
	110	2.01	187164	north	a
	120	1.99	196072	north	a
	130	2.00	195552	north	a
	140	2.01	192773	north	a
	150	2.00	182345	north	a
1200	50	2.02	174381	north	a
	60	2.01	192164	north	a
	70	2.02	196821	north	a
	80	2.01	194283	north	a
	90	2.00	195594	north	a
	100	2.01	198190	north	a
	110	2.00	191729	north	a
	120	0.82	64369	north	b
	130	2.01	189788	north	a
	140	2.00	184077	north	a
	150	2.00	188461	north	a

Table 2. The difference between 3D SF using CS and Grid Search

Max Columns in X or Y	Grid Search		Cuckoo Search	
	Number of Radii per Point	SF	Max Iteration	SF
50	10	2.11	400	2.00
	20	2.04	800	X
	30	2.04	1000	2.02
	40	2.04	1200	2.02
	50	2.01		
60	10	2.09	400	2.05
	20	2.00	800	2.01
	30	2.01	1000	2.04
	40	2.00	1200	2.01
	50	2.03		
70	10	2.01	400	2.02
	20	2.00	800	2.01
	30	2.00	1000	2.03
	40	2.00	1200	2.02
	50	2.02		
80	10	2.02	400	2.00
	20	2.01	800	2.01
	30	2.00	1000	2.01
	40	2.01	1200	2.01
	50	2.02		
90	10	1.99	400	2.00
	20	2.01	800	2.01
	30	2.01	1000	2.01
	40	2.01	1200	2.00
	50	2.00		
100	10	2.03	400	2.00
	20	2.00	800	2.01
	30	2.06	1000	2.01
	40	2.00	1200	2.01
	50	1.99		
110	10	2.00	400	2.00
	20	2.01	800	1.99
	30	2.02	1000	2.01
	40	2.01	1200	2.00
	50	1.92		
120	10	2.00	400	2.01
	20	2.00	800	2.05
	30	2.08	1000	1.99
	40	2.00	1200	X
	50	2.00		
130	10	2.00	400	2.00
	20	2.00	800	2.00
	30	2.07	1000	2.00
	40	2.00	1200	2.01
	50	1.99		
140	10	2.01	400	2.00
	20	2.00	800	1.99
	30	2.00	1000	2.01
	40	2.00	1200	2.00
	50	2.02		
150	10	2.01	400	1.99
	20	2.00	800	2.00
	30	2.06	1000	2.00
	40	2.00	1200	2.00
	50	2.01		
Average		2.01		2.00
Delta		0.01		

CONCLUSION

Based on the discussion, CS can be used as the best alternative option to determine SF using LEM 3D "Bishop" without making an assumption of slip surface. Based on the max iteration values in X or Y, the difference in the safety factor between the grid search method and CS is relatively small. Moreover, the research find that it is more efficient to use the CS than the Grid Search on computation time. Using LEM 3D "Bishop" with CS approach, the SF is obtained 2.00 with estimated volume of slope failure in 190,000 m^3, and the location of the lowest SF is the north of the pit.

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REFERENCES

Albataineh, N. (2006) Slope stability analysis using 2D and 3D methods. University of Akron.

Azizi, M. A. et al. (2014) "Risk assessment of open pit slope design at PT Adaro Indonesia," Indonesian Mining Journal, 17(3), pp. 113–121.

Azizi, M. A. et al. (2018) "Three dimensional slope stability analysis of open pit limestone mine in Rembang District, Central Java," IOP Conference Series: Earth and Environmental Science, 212, p. 012035. doi: 10.1088/1755-1315/212/1/012035.

Azizi, M. A., Marwanza, I. and Hartanti, N. A. (2018) "Penentuan volume potensi longsoran lereng tambang terbuka menggunakan metode kesetimbangan batas 3 dimensi," in Prosiding XXVII dan Kongres X PERHAPI 2018. Jakarta: PERHAPI, pp. 173–183.

Cheng, Y. M. and Yip, C. J. (2007) "Three-dimensional asymmetrical slope stability analysis extension of Bishop's, Janbu's, and Morgenstern–Price's techniques," Journal of Geotechnical and

Geoenvironmental Engineering, 133(12), pp. 1544–1555.
doi: 10.1061/(ASCE)1090-0241(2007) 133:12(1544).

Gandomi, A. H. et al. (2013) "Metaheuristic algorithms in modeling and optimization," in Metaheuristic Applications in Structures and Infrastructures. Elsevier, pp. 1–24.
doi: 10.1016/B978-0-12-398364-0.00001-2.

Gens, A., Hutchinson, J. N. and Cavounidis, S. (1988) "Three-dimensional analysis of slides in cohesive soils," Géotechnique, 38(1), pp. 1–23.
doi: 10.1680/geot.1988.38.1.1.

Hu, C. et al. (2015) "Determination of critical slip surfaces using mutative scale chaos optimization," Journal of Computing in Civil Engineering, 29(5), p. 04014067. doi: 10.1061/(ASCE)CP.1943-5487.0000373.

McCombie, P. and Wilkinson, P. (2002) "The use of the simple genetic algorithm in finding the critical factor of safety in slope stability analysis," Computers and Geotechnics, 29(8), pp. 699–714.
doi: 10.1016/S0266-352X(02)00027-7.

McQuillan, A. et al. (2018) Case study: Comparing slide3 models to actual slope failure in an open cut coal mine, www.rocscience.com. Available at:
https://www.rocscience.com/documents/pdfs/rocnews/2018spring/Slide3 Case Study.pdf (Accessed: June 22, 2020).

Mohammed, R. A. and Duaimi, M. G. (2018) "Association rules mining using cuckoo search algorithm," International Journal of Data Mining, Modelling and Management, 10(1), p. 73.
doi: 10.1504/IJDMMM.2018.089630.

Rodriguez-Lopez, F., Jimenez-Rodriguez, R. and Hruskovic, P. (2006) "Geotechnical risk management as a basis for quality assurance," in Risk Analysis V: Simulation and Hazard Mitigation. Southampton, UK: WIT Press (WIT Transactions on Ecology and the Environment, Vol 91), pp. 79–86.
doi: 10.2495/RISK060081.

Wu, A. (2012) Locating general failure surfaces in slope analysis via Cuckoo search, www.rocscience.com. Available at: https://www.rocscience.com/help/slide2/pdf_files/theory/Cuckoo_Search.pdf (Accessed: May 9, 2018).

Yang, X.-S. (2014) "Genetic algorithms," in Nature-Inspired Optimization Algorithms. Elsevier, pp. 77–87. doi: 10.1016/B978-0-12-416743-8.00005-1.

Yang, X.-S. and Deb, S. (2009) "Cuckoo search via Lévy flights," in 2009 World Congress on Nature & Biologically Inspired Computing (NaBIC). IEEE, pp. 210–214.
doi: 10.1109/NABIC.2009.5393690.

Yang, X.-S. and Deb, S. (2014) "Cuckoo search: Recent advances and applications," Neural Computing and Applications, 24(1), pp. 169–174.
doi: 10.1007/s00521-013-1367-1.

Yang, X. S. and Deb, S. (2010) "Engineering optimisation by cuckoo search," International Journal of Mathematical Modelling and Numerical Optimisation, 1(4), p. 330.
doi: 10.1504/IJMMNO.2010.035430.