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Slope Stability Optimization with Non-Circular Slip Surface and using Firefly Algorithm, Simulate Annealing and Imperialistic Competitive Algorithm

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ABSTRACT

Taking into account that the stability analysis of the earth slopes is a complicated geotechnical problem and conventional methods of analyses because of circular slip surface assumption, are incapable to estimate the location of the slip surface especially in non-homogeneous earth slopes. Therefore, the new methods for the study of these types of slopes are necessary. Nowadays, the methods based on optimization principles are developed and the main point in the application of these new methods is the evaluation of the capability of these methods. Therefore, optimizing these problems needs robust algorithms. In this research, three meta-heurestic algorithms were applied for the slope stability analyzing of three studied and selected cases from literature. For all three cases of study, a non-circular slip surface is considered. Factor of safety was computed and compared with the same cases analysed analytically. The obtained results indicated that ICA had the best performance and FA had the worst results for the cases studied in this research.

KEYWORDS:

Optimization, Non-Circular Slipe Surface, Meta-Heurestic, IC

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1- INTRODUCTION AND OBJECTIVES

In the most recent researches done, the shape of the slip surface of the soil slopes has been mostly assumed circular slip. Which, this would be a very good assumption for the homogeneous soils, but, for the multy layered soil slopes, this assumption could not provide perfect shape and results. Therefore, it is necessary that another shape for the slip surface is considered.

Usually, the slip surface shape in multy layered soil slopes does not have a specific shape.

In order to determine the slip surface in this type of slopes, the heuristic optimization methods have been applied recently by researchers. The major issue and problem of these methods, is none convergency of the objective function. The factor of safety function is usually complicated and inconsistent across the domain solution.

Heuristic optimization methods and even some dynamic optimization methods usually encounter with none convergency problem of the solution. With regard to the limitation of hurestic optimization methods, a few meta-heuristic optimization algorithms are developed recently by a number of researchers.

These types of algorithms are very powerful in operation and have none of the restrictions which are facing with the heuristic algorithms. So it is necessary to identify evaluate the performance of the best meta-heuristic algorithms. Cheng [1] applied the fish swarm algorithm method to solve the problems of a few multy layered soil slopes. In order to solve the problem of these types of slopes, Zolfaghari et al. [2] have applied a simplified genetic algorithm. Mangen et al. [3] applied the limit state analysis method to optimize the problem of stability of a few slopes. Gandomi et al. [4] also analized stability analysis of five case studies reported by Zolfaghari [9] For those non-homogeneous soil slopes, they applied the method of particle swarm optimization.

In this research, after producing for the non-circular slip surfaces, the safety factor has been calculated and handled based on Spencer method [5].Then by the application of three meta- heuristic algorithms, such as, Firefly Algorithm (FA), Simulated Anneling (SA) and Imperilistic Competition Algorythms (ICA) applyied to optimize the safety factors. At the end of the performance for three case studies these algorithms are evaluated and the obtained results have been presented and compared together.

2- HOW TO GENERATE THE SLIP SURFACES

To resolve the problem step by step, in the first stage, it is necessary to produced a good none circular sliding surface. Producing method is based on vertical part division method. The method applied in this research is based on Zolfaghari's approach [2].

It is necessary to determine the coordinates of the corner points of the bottom line of each piece or divided part. By specifying these points, sliding surface can be easily produced. In addition, it is necessary for the sliding surface not only to be concave upward but also to be prevented from the creation of zigzag slip surface.

This type of producing of sliding surface is very efficient, because in this method, α, the angle of the bottom line of each vertical segment (Figure 1) is completely dependent on its previous adjacent piece or segment (Figure 2).

Slip direction is along the bottom of each piece and drown from left to right. The rotation angle of the bottom line of each piece is in counter clockwise.

3- EVALUATION OF THE CREATED SLIDING SURFACES

After the formation of the sliding surface, the

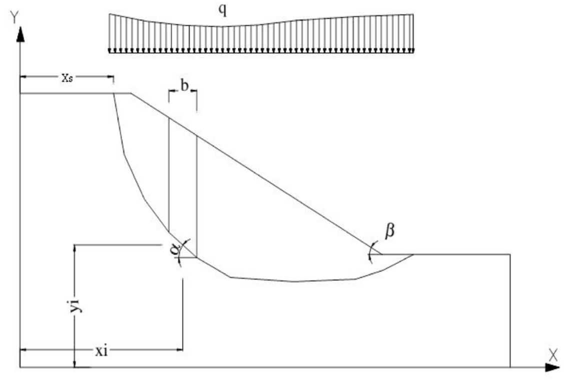

Figure 1. The overall shape of the sliding surface

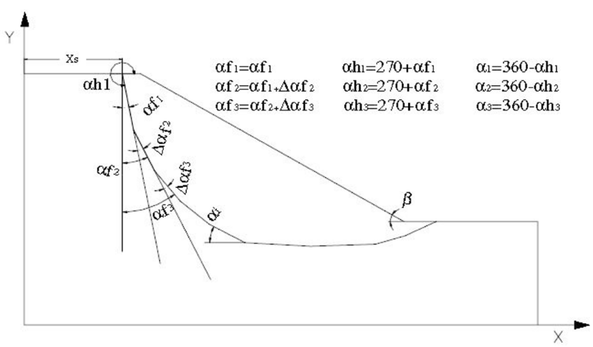

Figure 2. Producing of sliding surface [2]

sliding surface geometry might be unacceptable sliding surface, if the slope edge is not cut. If the slope edge is cut by of a sliding surface and the vertical distance from the intersection point to the top of the slope is less than half of the height of the slope that sliding surface is also inappropriate, otherwise it is a suitable sliding surface.

The initial angle of the slip surface for the first slice is φ/2 + 45 degrees to the horizon based on Rankine Rupture theory. So, αf1 amount is equal to 2/φ+45 degrees. The values of the Δαfi displaed in Figure (2) would be between 0.0 and 15.0 degree.

4- SPENCER METHOD TO CALCULATE SAFETY FACTOR

The formulation and equation used in this study were based on Spencer method. In this method, it is necessary after the formation of the sliding surface, Ff and Fm, safety factor functions which are applied forces and momentums individually for each slice should be calculated [5]. Fm, safety factor of momentum around point (o) as indicated in Figure (3), should be calculated from Equation (1) as follows:

$$F_m = \frac{\sum (c_1' + (P - ul).\tan\phi')}{\sum W \sin\alpha} \qquad (1)$$

F_f, safety factor can also be evaluated from Equation (2) as follows:

$$F_f = \frac{\sum (c_1' + (P - u_1)\tan\phi')\sec\alpha}{\sum (W - (X_R - X_L))\tan\alpha} \qquad (2)$$

To solve equations, the trial and error method was used. The process of the trial and error would be initialized by meta-heuristic optimization algorithms.

5- A BRIEF INTRODUCTION TO OPTIMIZATION METHODS APPLIED IN THIS RESEARCH

Three types of meta-hurestic algorithms were applied in this study. For more information, it is recommended to refer the articles cited in Refference section.

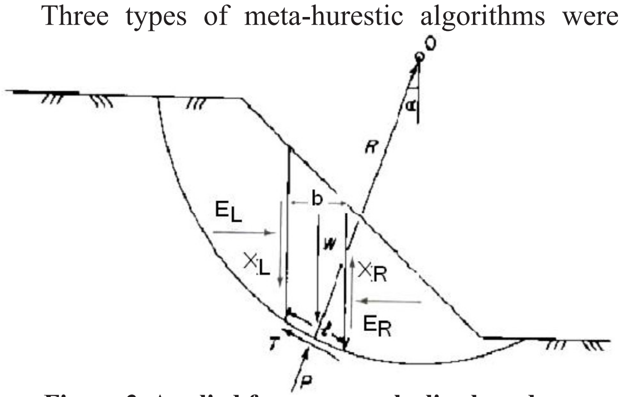

Figure 3. Applied forces on each slice based on Spencer method

a) Firefly Algorithm

Firefly algorithm is one of the meta-heuristic optimization algorithms recently was develope d by Yang [6]. This algorithm is inspired from the social behaviors of firefly worms.

b) Simulated Annealing Algorithm

This algorithm is based on the annealing of metals and introduced by Kirkpatrick [7].

c) Imperilistic Competitive Algorithm

Imperialist Competitive Algorithm was presented by Esmail Atashpaz and Caralox [8]. In this algorithm instead of nature, a social phenomenon is inspired for the optimization process.

6- CASE STUDIES EVALUATION AND PRESENTATION OF RESULTS

In this research, in order to assess a correct and effective comparison of functioning of meta-heuristic algorithms, three case studies shown in Figures (4), (5) and (6) and reported by article Cheng [9] are investigated.

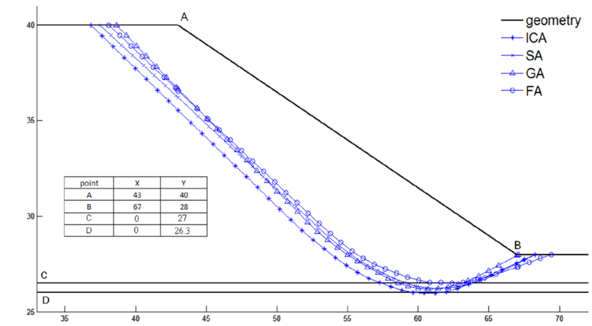

Figure 4: The geometric, shape and estimated results of three different sliding surfaces pricted for the case study (1)

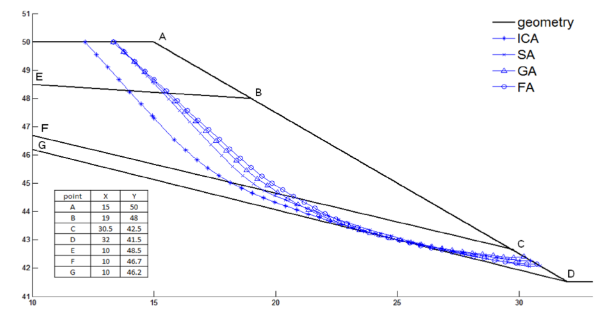

Figure 5: The geometric, shape and estimated results of three different sliding surfaces pridicted for the case study (2)

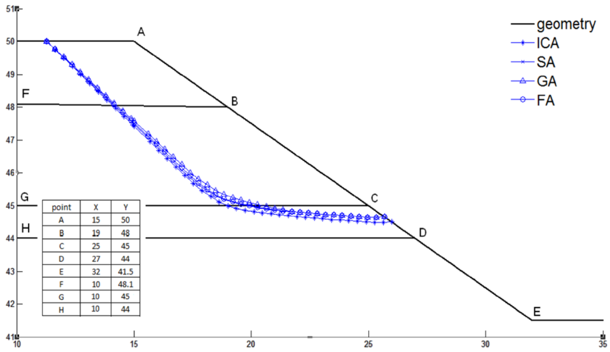

Figure 6: The geometric, shape and the estimated results of three different sliding surfaces pridicted for the case study (3)

In the selection of cases studies, it has been into consideration and tried to study the effect of the existence of a thin layer of weak soil on the formation of sliding surface. Loading status for all case of studies was supposed static loading. Coordinates of the corner points of all layers, for each case, are indicated in the tables presented next to each figure. Geometric and material properties for three case studies are presented individually in the Tables (1), (2) and (3).

Table 1. The geotechnical characteristics of the case study (1)

layers	1	2	3
c (kg/m^2)	1500	1000	3000
φ (deg)	25	0	20
γ (kg/m^3)	1900	1900	1900

Table 2. The geotechnical characteristics of the case study (2)

layers	1	2	3	4
c (kg/m^2)	1500	1700	500	3500
φ (deg)	20	21	10	28
γ (kg/m^3)	1900	1900	1900	1900

Table 3. The geotechnical characteristics of the case study (3)

layers	1	2	3	4
c (kg/m^2)	1500	1700	500	3500
φ (deg)	20	21	10	28
γ (kg/m^3)	1900	1900	1900	1900

For all optimizing algorithms, Population size = 40, which indicates the number of vertical segments, and the number of generations have been

Table 4. The optimized results for the case study (1)

algorithm	GA	FA	SA	ICA
Average F_s	1.7227	2.13491	1.4211	1.3741
Best value F_s	1.2425	1.2948	1.2311	1.1921
Standard devF_s	0.6251	0.8766	0.0911	0.5147

Table 5. The optimized results for the case study (2)

algorithm	GA	FA	SA	ICA
Average F_s	1.62	1.7241	1.4211	1.3741
Best value F_s	1.4201	1.5021	1.3521	1.3227
Standard devF_s	0.754	1.012	0.05411	0.0402

Table 6. The optimized results for the case study (3)

algorithm	GA	FA	SA	ICA
Average F_s	1.6021	2.1745	1.4621	1.3741
Best value F_s	1.4123	1.5128	1.3814	1.3312
Standard devF_s	1.1263	0.7654	0.0854	0.0647

performed for 3000. Therefore, in each optimization process the objective function was calculated about 120,000 times. Also, because the performance of each optimization algorithm was totally randomly, each problem was optimized 20 times. The minimum results of safety factor calculated by optimization algorithms, for three cases have been presented respectively in Tables (4), (5) and (6). Also, the best answer of the mean and with the standard deviation of each problem are presented by these tables. From the obtained results, it is easily concluded the best functioning belonged to ICA algorithm.

In Table (7), in order to compare with the evaluated results it is also provided the results calculated by analytical methods based on limit equilibrium analysis, such as Spencer, Bishop and Morgnstern.

7- CONCLUSIONS

According to the results, ICA showed the best estimation and FA the worst performance for the three

Table 7. Comparison between the results of the optimization with results of limit equilibrium ananlyses of three cases

Algorithm type	GA, Cheng[19]	FA	SA	ICA	F_s, Limit equilibrium method's
F_s for case1	1.4201	1.5021	1.3521	1.3227	Spencer method :1.4
F_s for case2	1.2425	1.2948	1.2311	1.1921	Bishop:1.475 / Morgenstern:1.5 [9]
F_s for case3	1.4123	1.5128	1.3814	1.3312	Spencer method: 1.48[8]

cases studied for the layered soil slopes reported in this research. So, ICA would be advised to evaluate the stability of this type of slopes. The reason that ICA algorithm performance has been better than the other two algorithms would be related to the logic of ICA. In ICA, the objective function is optimized directly, while, two other algorithms the objective function is optimized indirectly.

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