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Sizing Optimization of Retaining Wall by Firefly Algorithm

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ABSTRACT

Retaining wall is used to retain the lateral pressure of soil and surface loading. It has been widely used for application in civil engineering structure such as fill application, roadway cut, etc. This paper considered a firefly algorithm to find out the optimum size and shape of retaining wall with 7m of height and subjected to various loading (5kN/m^2, 10kN/m^2, 20kN/m^2, 40kN/m^2). There are four design variables considered for optimization. The objective is to minimize the weight of the retaining wall without violating the requirement of retaining wall. This paper considered stability check of the retaining wall such as overturning stability, sliding stability, and bearing capacity of the soil under the retaining wall. The result shows that the shape of retaining wall with load of 5kN/m^2 and 10kN/m^2 were similar, the body of the retaining wall were rectangular while the shape of retaining wall with load of 20kN/m^2 and 40kN/m^2 were trapezoidal. Sliding stability became design control for all loading cases compared by other stability problem (overturning and bearing capacity of soil under the retaining wall). Therefore, it can be concluded that firefly algorithm has successfully been applied to optimize the retaining wall.

Keywords: firefly algorithm, retaining wall optimization.
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1. INTRODUCTION

Retaining wall is one of kind structure in civil engineering with important function, and applied for several types of construction, such as for roadway cut and fill application [1]. This paper focused on the optimum size of the retaining wall subjected to lateral earth pressure and external loading on the ground surface. In order to obtain the optimum size of retaining wall, this paper considered one of the optimization technique which has good ability to find out the optimum parameters in optimization problem called firefly algorithm. The optimum size of retaining walls which corresponding to shape of the retaining wall's body was considered on certain height condition of the retaining wall but only for stabilization requirement. The objective is to find the lightest size of retaining wall without violating the design requirement using firefly algorithm (FA). This paper is only considered the stability of retaining wall hence the reinforcement detailing is not discussed here.

A. Concept of Retaining Wall

Retaining wall is a type of structure which designed and constructed to retain the lateral pressure of soil. Retaining wall can be categorized two four types: gravity retaining walls, semi gravity retaining walls, cantilever retaining walls, counterfort retaining walls. Another type of retaining wall such as anchored retaining wall [2]. There are basic parameters which must considered to design the retaining wall, e.g. unit weight, angle of friction, and cohesion of the soil retained behind the retaining wall and the soil parameters below the retaining wall construction [3]. Retaining walls are constructed either by stone masonry or plain concrete called gravity retaining wall. The stability of this type of retaining walls based on the self-weight of the structure and the based soil of the retaining walls.

B. Stability Check For Retaining Wall

There are three types of retaining wall stability check, namely overturning stability, sliding stability, and bearing capacity. Sometimes, the possibility of excessive settlement should be check caused of a weak soil layer located a shallow depth.

a. Overturning stability

Active lateral pressure which caused by the soil behind the retaining wall tend to overturn the retaining wall with center of rotation at point A (**b**). Hence, for resist the external overturning moment, the safety factor from equation (1) should be 1.5 for granular soil and 2 for cohesive soil.

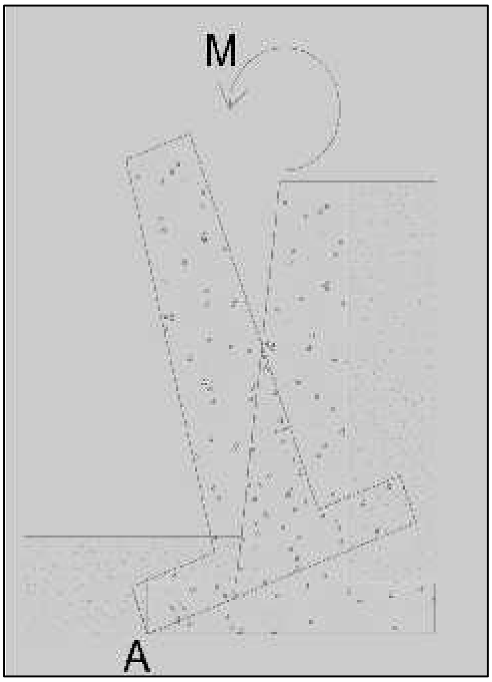

Fig.1. Failure of retaining wall by overturning moment.

$$FS_{(overturning)} = \frac{\sum M_R}{\sum M_o} \qquad 1)$$

Where:
- $FS_{(overturning)}$ is safety factor for overturning,
- $\sum M_R$ is sum of the moment of forces tending to resist overturning at point A,
- $\sum M_o$ is sum of the external moment tending to overturn at point A.

b. Sliding stability

Figure 2 shows the failure mechanism of retaining wall due to sliding. The safety factor against sliding follows the equation (2) and should be more than 1.5 for granular soil and 2 for cohesive soil.

$$FS_{(sliding)} = \frac{\sum F_R}{\sum F_d} \qquad 2)$$

where,
$FS_{(sliding)}$ is safety factor for sliding,
$\sum F_R$ is sum of the horizontal resisting forces, $\sum F_d$ is sum of the horizontal driving forces (external forces).

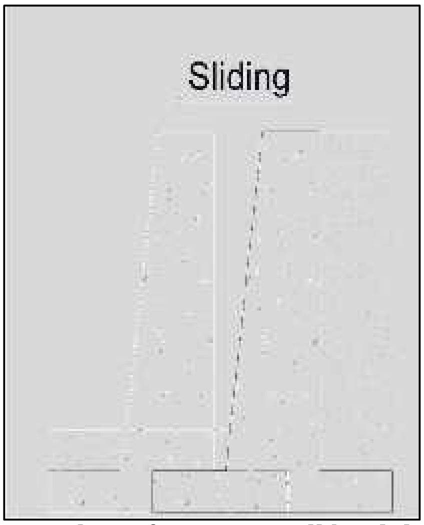

Fig. 2. Failure of retaining wall by sliding

c. Bearing capacity

The base slab of the retaining wall which is transmitted by vertical pressure due to the soil must be checked against the bearing capacity of the soil (Figure 3). The equation for determining the bearing capacity of the soil used Hansen (1970) expressed on equation (3) below.

$$q_u = d_c i_c c N_c + d_q i_q D_f ¥ N_q + 0 \quad 3)$$

$$FS_{(bearing.capacity)} = \frac{q_u}{q} \quad 4)$$

where,

- d_c, d_q, d are depth factor,
- i_c, i_q, i are inclined loading factor,
- N_c, N_q, N are bearing capacity factor,
- is soil volume weight,
- B is base width of retaining wall,
- $FS_{(bearing\ capacity)}$ is safety factor for bearing capacity which should more than 3,
- q_u is ultimate bearing capacity,
- q is pressure due to weight of the structure.

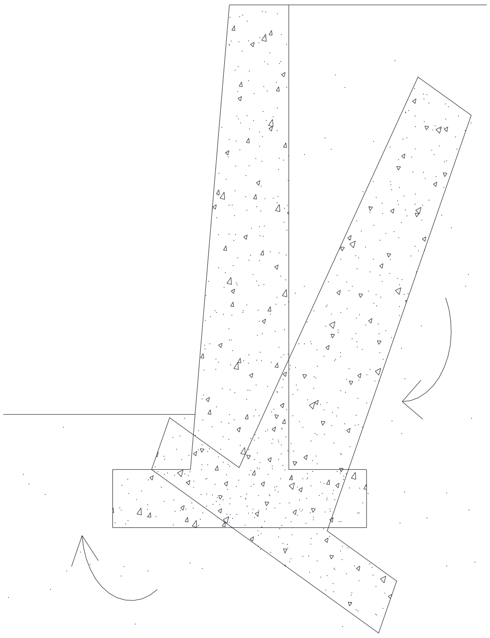

Fig. 3. Failure of retaining wall by bearing capacity

2. MATERIAL AND METHODS

A. Firefly Algorithm (Fa)

Firefly algorithm (FA) was first proposed by Xin-She Yang (2008). This theory is based on the behavior of firefly. The flashing light of fireflies is an amazing sight in the summer sky in the tropical and temperate regions. There are about 2000 firefly species, and most of the fireflies produce short, rhythmic flashes. A particular species has a unique pattern of flashes.

In the firefly algorithm, there are two important variables: formulation of the attractiveness, and the variation of the light intensity. In simple, the attractiveness of firefly is determined by its brightness which corresponding to the objective function. The basic step of the firefly algorithm (FA) can be summarized as follow [4]:

1. Generate the objective function.
2. Generate an initial population of n fireflies x_i (i = 1,2,3,4,…,n).
3. Determining light intensity I_i at x_i is determined by $f(x_i)$.
4. Defining light absorption coefficient, □□
5. For i=1:n (all fireflies)
   For j=1:n (all fireflies)
   If $I_i<I_j$
   Move firefly from I to j
   end if Vary attractiveness with distance r via exp(-□r^2)
   Evaluate new solutions and update light intensity
   end for loop j
   end for loop i
6. Ranking the fireflies and find the current global best g_*.
7. Post process results and visualization.

B. Fitness Function and Penalty Function

The fitness function of this study is to minimize the weight of the structure (total weight of the concrete used). The penalty function was applied to the program and activated while the constraint is violated. Because there are three stability check hence there are three bounding constraints which following equation:

$$if \quad FS_{(overturning)} < 1.5 \quad g_{(overturning)} = 1 \tag{5}$$

$$if \quad FS_{(sliding)} < 1.5 \quad g_{(sliding)} = 1 \tag{6}$$

$$if \quad FS_{(bearing)} < 3 \quad g_{(bearing)} = 1 \tag{7}$$

$$g_{(sum)} = g_{(overturning)} + g_{(sliding)} + g_{(bearing)} \tag{8}$$

If the $g_{(sum)}$ value on equation (8) is more than 1, then the penalty function will be activated, and the fitness value of the particle become maximum real value. Moreover, the penalty function can also be activated if the value of the variables on equation (5) to (7) are violated.

3. RESULT AND DISCUSSION

A. Numerical Example

This study considered a concrete retaining wall to be optimized against the external forces for stability checking. There were five design variables to be optimized using firefly algorithm which were DV1, DV2, DV3, DV4, and DV5 and it can be seen on Figure 4. Height of the retaining wall usually first determined according to the design plan. In this study, the height of the retaining wall (H) was taken to 7 meters. There are some suggestions about the dimension length of the retaining wall related to the five design variables which can be seen on equation (9) to (11).

$$0.3 \le DV3 \le \frac{H}{12} \qquad 9)$$

$$0.5H \le B \le 0.7H \qquad 10)$$

$$\frac{H}{8} \le DV5 \le \frac{H}{6} \qquad 11)$$

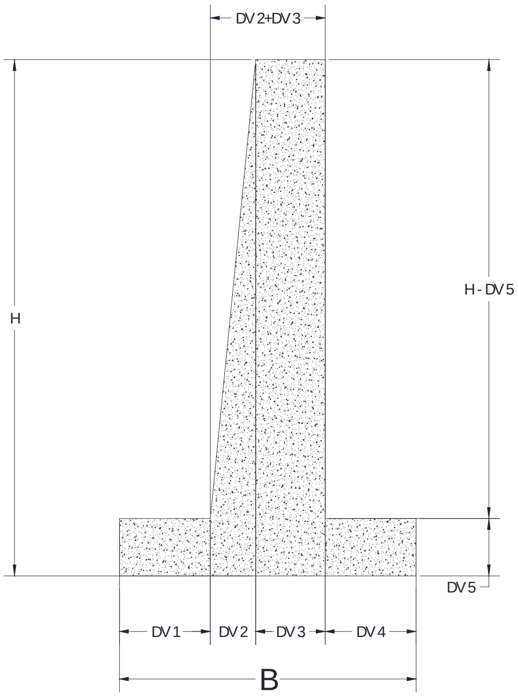

Fig. 3. Design variables of retaining wall for optimization problems

The coding for optimization using FA was done using MATLAB [5,6]. All the function has been programmed before to find the optimum design variables of retaining wall. The parameters of the optimization can be seen on Table 1. The program was run four times with different lower bound and upper bound (Table 2) to ensure the convergence result of the design variables and to find out the ability of firefly algorithm for obtaining the stable result.

Table 1. Parameters of FA

Parameters	
Number of iteration	250
Number of fireflies	25
Light absorption coefficient	1
Attraction coefficient	0.2

Table 2. Lower bound and upper bound limit

Run	Lower Bound	Upper Bound
1	0	50
2	0	100
3	0	150
4	0	200

Four loading cases were applied to find out the optimum shape of the retaining wall. The loading variations were 5kN/m^2, 10kN/m^2, 20kN/m^2, 40kN/m^2. Figure 4.(a) and Figure 4.(b) show the result of optimization with 5kN/m^2 loading and 10kN/m^2 loading respectively while Figure 5.(a) and Figure 5.(b) show the result of optimization with 20kN/m^2 and 40kN/m^2 respectively. Based on the result, the section properties of retaining wall with 5kN/m^2 and 10kN/m^2 were almost similar, the third design variables was zero, so the shape of the retaining wall became rectangle. Different result obtained when the loading were 20kN/m^2 and 40kN/m^2, the shape of the retaining became trapezoidal. It can be concluded that the shape of the retaining wall was based on the loading condition, but must be noticed that this study only considered similar soil condition with certain height of the wall. Sliding stability became controlled variable for obtained the optimum size of the retaining wall for all loading cases.

Figure 6, 7, 8, and 9 show the relationship between iteration and best cost (weight of the retaining wall) for each loading condition. It can be shown from figure, although the lower bound and upper bound of each run was different, the last result still same for all loading cases. Therefore, the convergence result has successfully obtained. Besides, FA shows the fast convergence result since the optimized variable has been obtained before 25th iteration. FA shows its ability to rapidly find out the optimum variable without any divergent result. Hence, FA has successfully applied to obtain the optimum variable of retaining wall (retaining wall optimization).

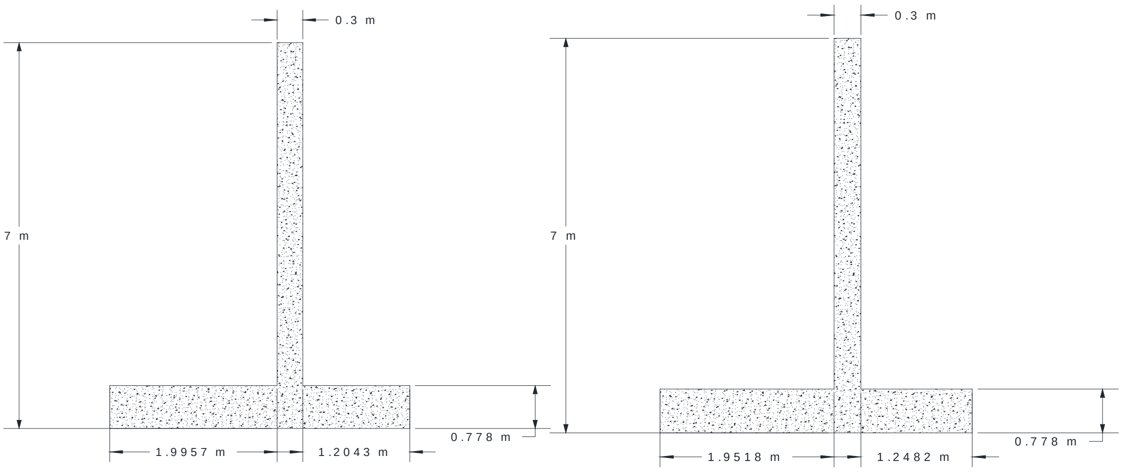

Fig. 4. Optimum shape of retaining wall with load of (a) 5kN/m^2, (b) 10kN/m^2

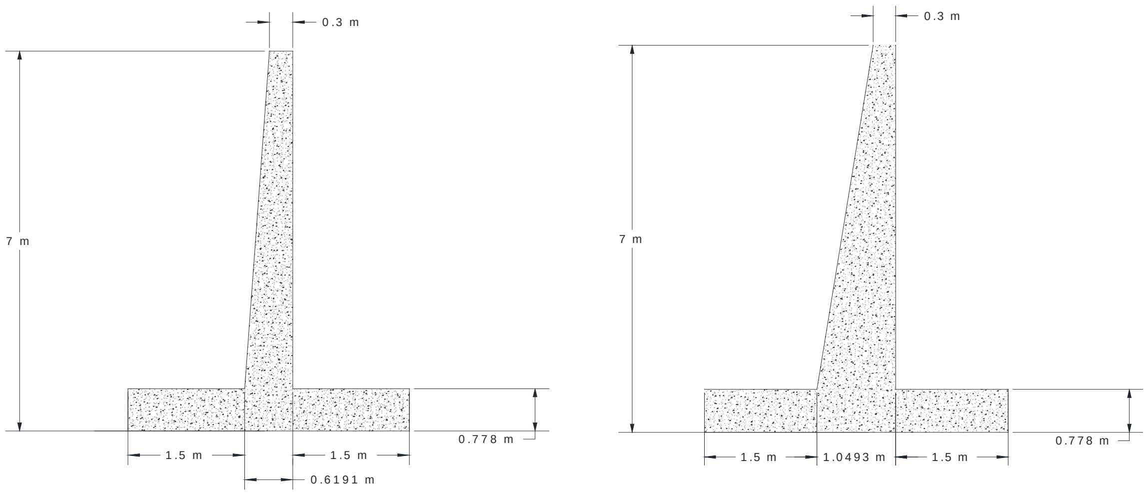

Fig. 5. Optimum shape of retaining wall with load of (a) 20kN/m^2, (b) 40kN/m^2

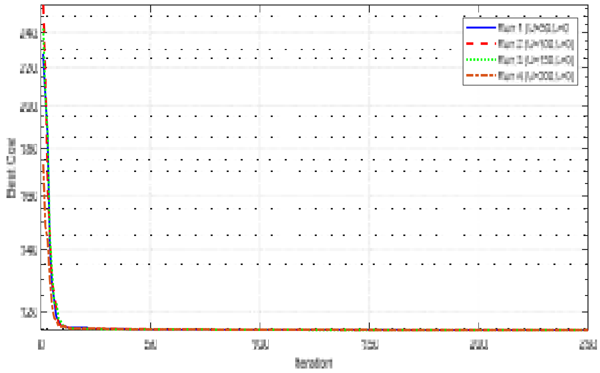

Fig. 6. Iteration vs best cost for load of 5 kN/m^2

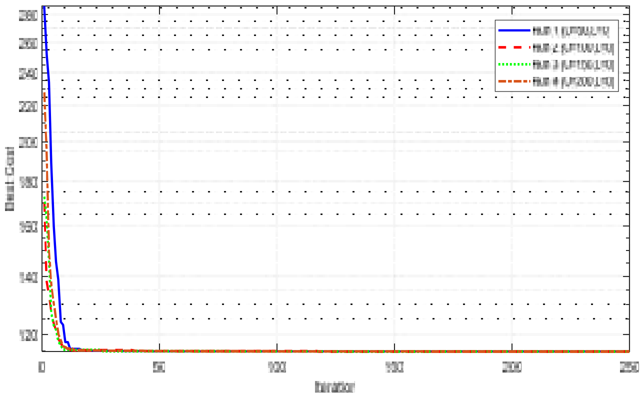

Fig. 7. Iteration vs best cost for load of 10 kN/m^2

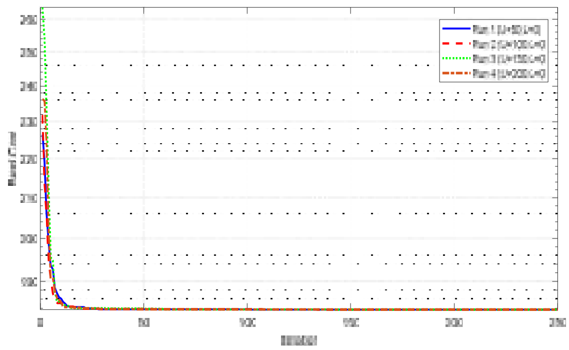

Fig. 8. Iteration vs best cost for load of 20 kN/m^2

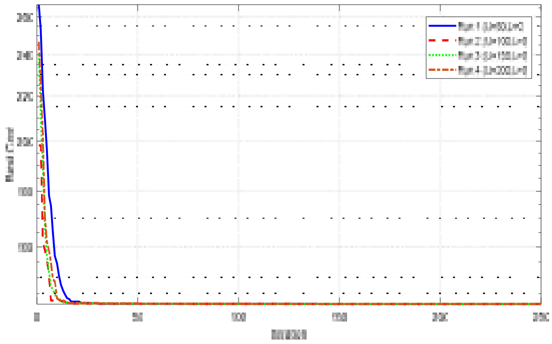

Fig. 9. Iteration vs best cost for load of 40 kN/m^2

4. CONCLUSIONS

Firefly algorithm (FA) has been considered as optimization tools for retaining wall optimization problem. There were four loading condition tested (5kN/m^2, 10kN/m^2, 20kN/m^2, 40kN/m^2) to find out the optimum shape of retaining wall. The program was run four times with different lower bound and upper bound to ensure the convergence result of each loading case. Based on the result, all run had convergence result and was rapidly obtained. Other conclusion which can be noted is the optimized shape of retaining wall depends on the loading condition. For load of 5kN/m^2 and 10kN/m^2, the shape of the retaining wall's body was rectangular while for load of 20kN/m^2 and 40kN/m^2, the retaining wall's body was trapezoidal. It can also be seen that the sliding stability is the most critical for all cases.

REFERENCES

[1] Hassan, K.A., and Abbas, A.M. (2017). Optimum design of semi-gravity retaining wall subjected to static and seismic loads. International Journal of Civil Engineering and Technology (IJCIET), Volume 8, Issue 1, January 2017, pp. 873–881.
[2] Talatahari, S., Sheikholeslami, R., Shadfaran, M. (2012). Optimum design of gravity retaining walls using charged system search algorithm. Mathematical Problems in Engineering, Volume 2012.
[3] Das, B.M. (2011). Principles of Foundation Engineering 7th Edition. Cengage Learning, USA.
[4] Xin She Yang. (2008). Nature Inspired Metaheuristic Algorithm. Luniver Press.
[5] MathWorks. (2015). "MATLAB: *Primer*, *Version* 8.6". The Mathworks, Inc.
[6] MathWorks. (2015). "MATLAB: *Programming Fundamental*, *Version* 8.6". The Mathworks, Inc.