

# Optimization of soil slope stabilization with evolution algorithm

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## 1 INTRODUCTION

In terms of geotechnical, soil slope is likely to collapse due to excavation or changes in the ground conditions. In addition, the local stress concentration caused by eccentric earth pressure is difficult to solve and can be costly (Lee & Lee 2001). Therefore, various methods such as retaining wall, shotcreting, grouting, and soil nailing should be applied by identifying expected problems to secure stability. These methods involve optimization problems such as arrangement of supports including selection of construction method. In this study, soil nailing and shotcrete were applied for soil slope stabilization and optimization process of reinforcement by using a differential evolution algorithm is constructed. *FLAC3D* (Itasca 2012) numerical analysis was performed with the constructed algorithm to select the optimal arrangement plan to secure the stability of soil slope.

## 2 COUNTERMEASURE OF SOIL SLOPE

Reinforcement methods for soil slope include a way of reducing the active force, such as counter weight, reclamation of slope, and a way of increasing resistance, such as soil nailing, rock bolt (Park & Bae 2015). The principle of slope reinforcement by soil nailing method can be explained by studying tensile force, shear force, and bending moment exerted on soil nail when shear strength is affected by shear. The following results are presented by the experimental study (Marchal 1984) and the theoretical study (Schlosser 1982, Blondeau et al. 1984) using the theory of elasticity and plasticity. If soil nail mass is affected by shear, the nail may undergo tensile-shear fracture at the intersection with the fracture plane, or fracture may occur due to plasticization at the maximum moment location outside the fracture plane. When the nail has mild steel, the plasticization occurring at the point of maximum bending moment does not cause destruction.

## 3 DIFFERENTIAL EVOLUTION ALGORITHM(DEA)

From the three different vectors randomly selected in the group  $X_G = [x_{1,G}, x_{2,G}, \dots, x_{NP,G}]$ , next generation of mutant vector ( $v_{i,G+1}$ ) is generated as shown in Equation (1) for each of the transformation target vectors,

$$v_{i,G+1} = x_{r1,G} + F \cdot (x_{r2,G} - x_{r3,G}) \quad (1)$$

where NP is the population size and F is a mutation constant with a value between 0 and 2. Equation (2) represents the crossing step. The parent vector is crossed with a mutant vector to generate a trial vector. Here, rand means that the vector to be used for the change is randomly selected, and CR is a mating constant having a value between 0 and 1.  $I_{rand}$  is a random integer of  $[1, 2, \dots, D]$ .

$$v_{ji,G+1} = \begin{cases} v_{ji,G+1} & \text{if } rand_j \leq CR \text{ or } j = I_{rand}, \\ v_{ji,G} & \text{if } rand_j > CR \text{ or } j \neq I_{rand} \end{cases} \quad (2)$$

$$x_{i,G+1} = \begin{cases} u_{i,G+1} & \text{if } f(u_{i,G+1}) \leq f(x_{i,G}), \\ x_{i,G} & \text{otherwise} \end{cases} \quad (3)$$

Equation (3) represents the selection step. The target vector ( $x_{i,G+1}$ ) is compared with the trial vector ( $u_{i,G+1}$ ). In the next generation, individuals of superior traits are selected. Therefore, each trial vector will deliver an excellent genetic trait in the next generation through comparison with the parent vector. Through this process, the best individuals in the population are retained in the next generation. This process is repeated until the specified end criterion is reached. Differential evolution algorithm (DEA) is embedded in the *FLAC3D* and factor of safety analysis is combined with DEA.

#### 4 NUMERICAL ANALYSIS BY DEA

The purpose of this study is to investigate the optimal arrangement of soil nailing method, and it is necessary to consider the minimum nail, and we applied it to the optimization algorithm. In addition, for the stability evaluation, the Shear Strength Reduction Method (SSRM) embedded in the *FLAC3D* program was used.

Table 1 shows the combination of analysis cases and the soil and DEA properties used in the analysis. The arrangement condition of the nail to be installed on the slope was analyzed by combining the number, the length and the thickness of shotcrete. The slope shape used in the analysis is shown in Figure 1. The imaginary slope was idealized to apply  $K_0 = 0.5$ . The nail has an elastic modulus (E) of  $8.33 \times 10^6 \text{ kPa/m}$ , a compressive yield strength ( $Y_c$ ) of  $1 \times 10^7 \text{ kN/m}$ , and a cross-sectional area (A) of  $7.85 \times 10^{-3} \text{ m}^2$ , using cable elements. The elastic modulus of the shotcrete was 20 GPa, and Poisson's ratio was 0.2, and shell elements were used.

Table 1. Parameters and design conditions used in the numerical analysis (Kim & Moon 2016).

Stiff soil		Design Condition	
E (Elastic modulus)	250 MPa	Vertical spacing (m)	0.9, 1.1, 1.3, 1.6, 2.1
$\gamma_t$ (Unit Weight)	21 kN/m <sup>3</sup>	Horizontal spacing (m)	2.1, 2.3, 2.6, 3.0, 3.5
C (Cohesion)	20 kPa	Length (m)	6, 7, 8, 9, 10
$\Phi$ (Friction angle)	31 °	Thickness of shotcrete (mm)	0, 50, 70, 100, 150
$\nu$ (Poisson's ratio)	0.32	DEA	
K (Bulk modulus)	$E / 3 * (1 - 2\nu)$	F (Mutant Constant)	0.8 (0~2)
G (Shear modulus)	$E / 2 * (1 + \nu)$	CR (Crossover Constant)	0.8 (0~1)
Model	Mohr-Coulomb	NP (Number of population)	50
Analysis Type	SSRM	Itermax (Max. Iteration)	100

The search condition was found to be a safety factor of 1.5 or more and an analysis condition satisfying the minimum number of nails. The nail was arranged in a rectangular shape while changing the number of nails from 6 to 10 and from 3 to 7 in the horizontal direction and the vertical direction with respect to the center point of the inclined surface. The inclination angle of the nail was set to the same value in the analytical model, and it was selected as 35°.

Figure 2 shows a flowchart of a DEA for optimal soil slope reinforcement. The *FISH* function was constructed to place the nail and shotcrete in *FLAC3D* based on the design variable object values generated by the DEA. The first step was to calculate the safety factor for the ground before nail reinforcement. The safety factor before reinforcement was calculated to be 1.26, which is less than the permissible safety factor of 1.5. After that, slope stability was analyzed by using the SSRM, and the condition with the permissible safety factor of 1.5 or more was searched. After constructing the next generation by the DEA with the calculated object values, the slope stability analysis is performed by repeatedly placing the nails repeatedly. If the nail arrangement close to the permissible safety factor is obtained or exceeds the set limit number, the iterative calculation is terminated.

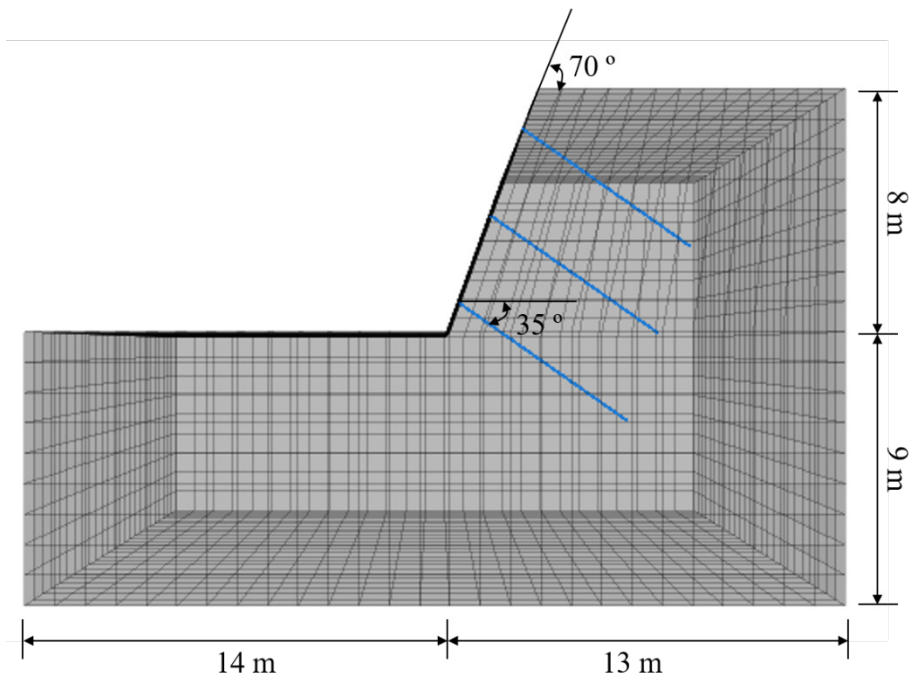


Figure 1. The feature of representative section modeling in *FLAC3D* (Matsui & San 1992).

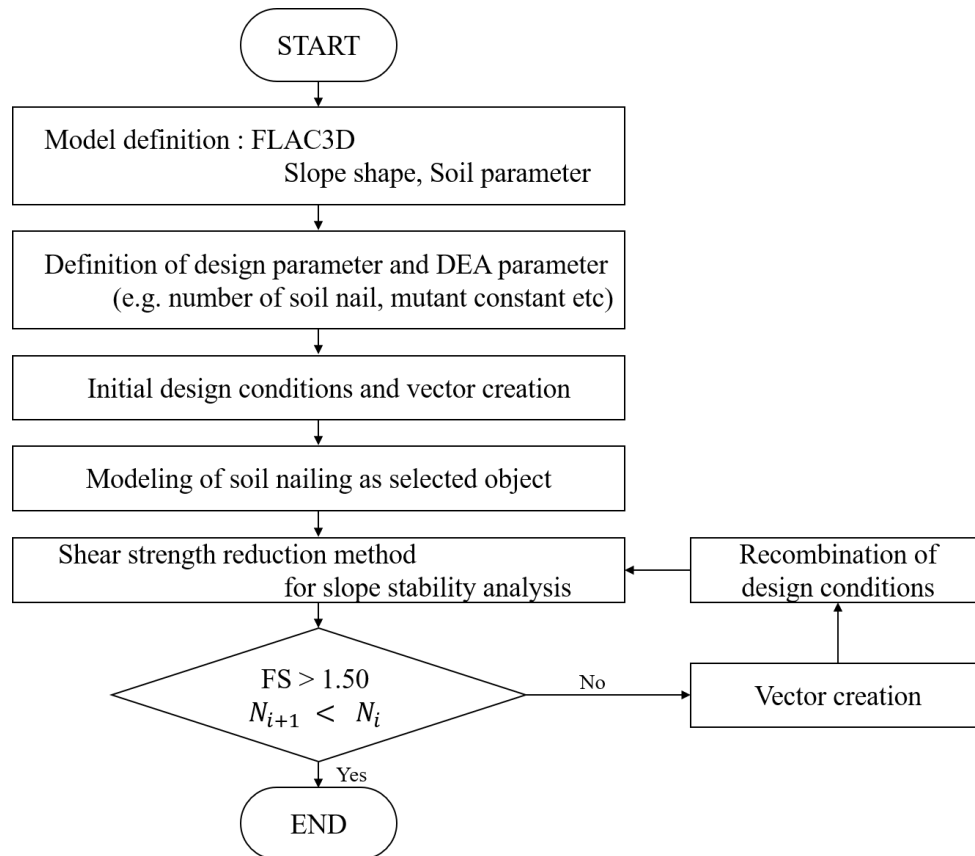


Figure 2. Flowchart of optimization analysis.

The analysis results and the process of changing the slope factor of safety for each generation are summarized in Table 2. As a result of all case analysis, it was confirmed that the factor of safety exceeded 1.5 when the shotcrete was more than 50mm, and the optimal arrangement design was the result that the shotcrete was 50mm and the number of nails was the minimum. And the safety factor was increased to 1.54. The factor of safety converged after 50 times in 100 iterations.

Table 2. The results of optimization analysis.

Items	Optimal value	Iteration	Factor of safety
Vertical spacing (m)	2.1	0	1.26
Horizontal spacing (m)	3.5	30	1.74
Length (m)	6	60	1.54
Thickness of shotcrete (mm)	50	100	1.54

## 5 SUMMARY AND CONCLUSIONS

In this study, the optimal arrangement of soil nailing was investigated by using DEA and SSRM as *FLAC3D*'s built-in language, *FISH*, for the reinforcement design of soil slopes. Optimization techniques are generally known to decrease the accuracy and increase the number of searches as the design variables increase. DEA has found that the target value satisfying the constraint condition is precisely found for the four parameter problem, and the soil nailing and shotcrete conditions, which are not correlated with each other, can be searched. It was confirmed that the factor of safety of the slope increased from 0.72 to 1.50, considering only the number and length of the nails and the thickness of shotcrete. It was confirmed that the optimal arrangement was found through about 100 repetitions among the entire analysis case  $5^4 = 625$ . This study is an initial study to deal with the optimization problem of soil slope reinforcement, and confirmed that the slope reinforcement design condition (nail length, vertical spacing, horizontal spacing, and thickness of shotcrete) satisfying the factor of safety 1.5 can be optimized by using DEA-*FLAC3D*.

## ACKNOWLEDGEMENT

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