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Published in:
IOP Conference Series: Materials Science and Engineering

DOI:
10.1088/1757-899X/800/1/012009

Published: 01/03/2020

Document Version
Publisher's PDF, also known as Version of record

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IOP Conf. Series: Materials Science and Engineering **800** (2020) 012009 doi:10.1088/1757-899X/800/1/012009

Application of genetic algorithm method for soil nailing parameters optimization

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Abstract. Soil nailing is a reinforcement technique used in constructing excavations and stabilizing slopes by reinforcing the ground in situ. The number of horizontal or inclined nails and their spacing is a key issue. The aim of this work is optimization of soil nailing parameters using genetic algorithm method. We look to obtain the optimal design and improve the parameters of soil nailing which affect stability. Analysis and parametric study of effect of algorithm configuration was carried out to search for optimum combination of the design variables to satisfy the required safety factor. The obtained results are discussed in comparison to existing literature.

1. Introduction

Although optimization is an elegant mathematical tool it was used quite early by researchers in many disciplines, geotechnical engineers have noticed the techniques quite late. Most advances in the development and application of classical optimization methods has taken place over the last 50 years. (Little and Price 1958) presented a computerized approach of slope stability analysis . An elementary beginning of application of optimization with (Baker and Garber 1978) to determine the critical slip surface and the corresponding minimum factor of safety.

Among the optimization methods, the genetic algorithm is a powerful stochastic optimization method based on the principles of genetics and natural selection. For near two decades, GA has been shown to be suitably robust for a wide variety of complex geotechnical problems : (Simpson and Priest 1993), (Pal et al 1996),(Deb et al 1999),(Goh A.T.C 1999) used genetic algorithm procedure to locate the critical circular slip surface, (Ponterosso et al 2000) produced a GA solution for the cost optimization problem of reinforcement layout for reinforced soil slopes, (McCombie and Wilkinson

2002),simple genetic algorithm is applied to the search for the minimum factor of safety in slope stability analysis.The first application of tree genetic programming (TGP) in the fields of geotechnical engineering is carried out by (Yang et al 2004) to analyze the stability of slopes. (Patra et al 2005) generalized method of computer based optimum design of soil nailed slopes is reported. (Zolfaghari et al 2005) and (Jianping et al 2008) have done several studies by GA for obtaining the critical slip surface. (Levasseur et al 2007) used a genetic algorithm to identify the soil parameters of a sheet pile wall retaining an excavation. (Prabir and Basudhar 2008) described methods that are available for optimal design and analysis of geotechnical engineering problems. (Torres and al 2009) discussed a characterization of different criteria for model classification while dealing with a system modeling. (Chao Li 2010) produced an efficient approach for locating the critical slip surface in slope stability analyses using a real-coded genetic algorithm.(Gandomi 2011) applied a LGP,GEP,MEP to the formulation of several complex geotechnical engineering problems. (C.hsein and al 2013) studied a reliability-based robust geotechnical design of spread foundations using multi-objective genetic algorithm. (Momeni and al 2014) developed an ANN-based predictive model enhanced with genetic algorithm (GA) optimization technique to predict the bearing capacity of piles [18] [25].(Hoseini.M et al 2016) used GA, PSO and multiple regression in the estimation of mechnical resistance value of soils. (Zhen- yu yin et al 2017) a comparative study of optimization techniques(genetic algorithms,particle swarm optimization and the artificial bee colony algorithm) are used for identifying soil parameters in geotechnical engineering .**(**Seyyed.M.H et al 2018) back analysis is carried out using genetic algorithm and particle swarm optimization in order to determine the soil strength parameters in an excavation project.

2. Genetique alghorithm optimization

Genetic algorithms (GA) were developed with the primary intention of imitating the processes that exist in nature. Basic principles of genetic algorithms were published in 1962 (Holland) and the mathematical framework for their development was published in 1975.

A genetic algorithm (GA) is classified as a global search heuristic, which is used in the calculation to find exact or approximate solutions to optimization and search problems.The genetic algorithm is implemented in a computer simulation in which a solution of the problem is represented using a genome or a chromosome. The genetic algorithm creates a population of solutions and applies genetic operators as mutation and crossover to evolve solutions in order to find the best solution.

The basic components common to almost all genetic algorithms are:

- a fitness function for optimization;
- a population of chromosomes;
- selection of which chromosomes will reproduce;
- crossover to produce next generation of chromosomes;
- random mutation of chromosomes in new generation.

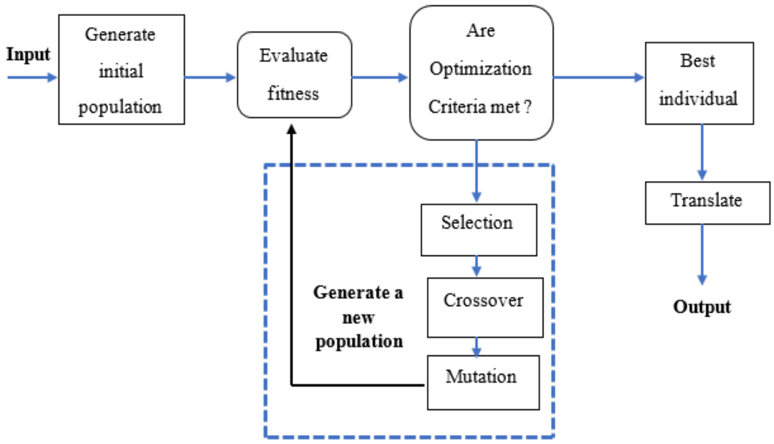

Fig 1. Basic structure of genetic algorithm [12]

3. Case study

Soil nailing is the technique used in slope and excavation to make it more stable with the use of passive inclusions, usually steel bars, termed as soil nails. It consists of passive reinforcement which is encased in grout to provide corrosion protection and improved load transfer to ground. As the excavation proceeds, the shotcrete, concrete or other grouting materials are applied on the excavation face to grout the reinforcing nails [6].

The studied nailed wall is inspired by the thesis [21] some results of modelization were used for the problem of optimization. The geometric model adopted is modeled with Plaxis 2D, a two-dimensional finite element program with a plane strain problem and long-term behavior is simulated using drained analysis conditions, Fifteen (15) -noded triangular elements are used for generating finite element mesh of appropriate density. Coarse mesh density is adopted globally, which is refined to fine density mesh around nails.

Figure 2 shows the simulated soil nail wall with dimensions and various parameters including in situ soil properties, mesh boundaries and conditions fixities.

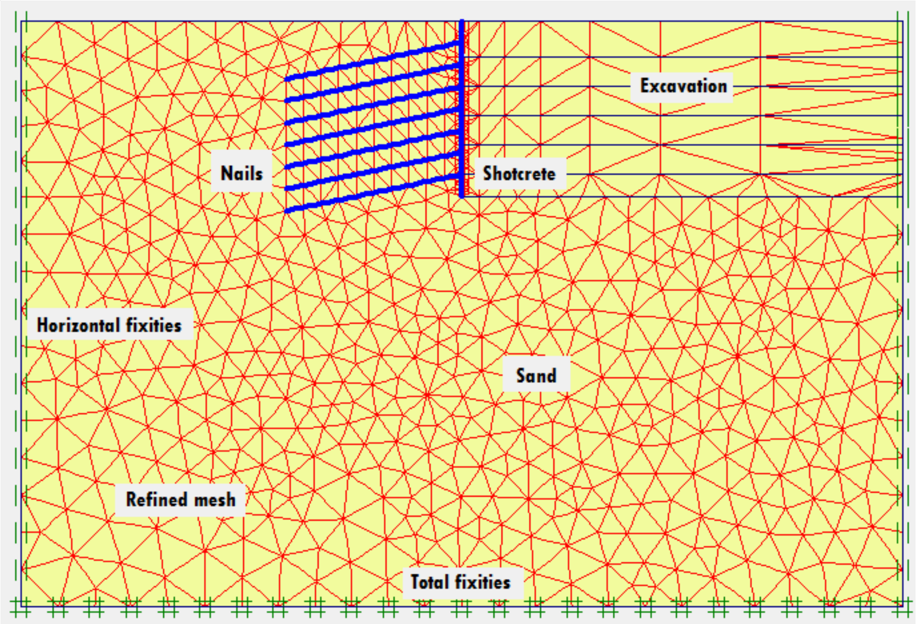

Fig 2. Geometric model.

The geometric model is 60m long and 40m deep, the excavation height is 12m.

According to exploration data, the field is composed of Sand characterized by these parameters:

Table 1. Soil properties.

Soil properties	Sand
Unit Weight, γ (KN/M^3)	18
Cohesion, (KN/M^2)	10
Friction angle, Φ	35
Dilatancy angle Ψ	5
Young's modulus, E (KN/M^2)	6.25 10^4
Poisson's ratio ν	0.3

The nail parameters used are axial stiffness EA and Bending stiffness EI (it is modeled as plate element).

Table 2. Characteristics of nails.

Axial stiffness EA (kN / m)	Bending stiffness EI (KN.m^2/m)
6.87*10^4	12.5

The shotcrete facing was considered to be 24 cm thick, and also modeled as a beam element with axial rigidity (EA) of 2.5 x 10^6 kN/m and flexural rigidity (EI) of 1.22 x 10^4 kNm^2/m. The height of the wall (H) was assumed to be constant and equal to 12 m. Wall inclination (β=90°), soil properties and diameter of nails (22mm) are considered constants also. In order to obtain optimal design for soil nailing wall, a genetic algorithm optimization was executed . Plaxis 2D is used to simulate the change of nail's length, inclination, and spacing nail to study the effect of these parameters on safety factor.

The following variables were used:

• 3 different nail lengths to wall height ratio : 0.75, 1, 1.2;

• 3 different vertical spacings 1.2 m, 1.5 m and 2 m;

• 3 different nail inclinations : 10°, 15°, 20° below the horizontal, because the inclination has an effect on the overall stability of the nailed wall.

In this way, 27 simulations were performed.

4. Mathematical modeling and optimization problem formulation

From mathematical point of view, optimization is about finding the best solution in a search space of a function, which describes the problem and is often called a fitness or objective function. The fitness function or objective function has some boundaries, which are the constraints of the problem. The optimization procedure has two phases. First phase is mathematical modeling where an objective multivariable function should be defined. In this phase, all constraints and bounds of the variables should be defined too. Second phase is searching for a global minimum of objective function. In the process of optimization, soil nailing safety factor is set as the objective function and used to provide a measure of how individuals have performed in the problem posed. The objective function is the function that the algorithm is trying to optimize, it is one of the most pivotal parts of the algorithm.

The objective function is defined as follows:

$$Y(x_1,x_2,x_3)=-1.56049\,x_1^2+0.0166667x_2^2-0.0008x_3^2+0.0525259x_1x_2+0.0079932x_2x_3+0.00153005x_1x_3 +3.95007x_1-0.349882x_2+0.0184172x_3-0.115709$$

The variables are :

- x_1 :length to height ratio L/H
- x_2 :Vertical spacing
- x_3 :nail inclination

Constraints:

- Bounds on length height ratio: $0.75 \leq X_1 \leq 1$
- Bounds on vertical spacing(m): $1 \leq X_2 \leq 2$
- Bounds on nail inclination(°): $10° \leq X_3 \leq 20°$

Genetic algortithm technique is applied to optimize soil nailing parameters. This function is a nonlinear problem.

As we mentioned in previous paragraph, the second phase is solving of mathematical model and minimize the objective function $Y(x_1,x_2,x_3)$ using GA toolbox in Matlab.

5. Parameters of Genetic Algorithm

Parameters have to be prechosen to control the search process, and they include the population size for each generation, the number of generations, the probabilities of genetic operators (reproduction, crossover and mutation), the selection method, the termination conditions, etc. The parameters used in the case study are as follows:

Table 3. Parameters of Genetic Algorithm.

Parameter	Settings
Population type	Double vector
Population size	100
Crossover fraction	0.8
Generations	100
Selection	Stochastic uniform
Mutation rate	0.05

The optimum parameters obtained with this model for different variables conditions are:

Variables	L/H	Sv (m)	I°
Optimal	0.75	1.99994	10°

The parameters obtained are in accordance with the Clouterre recommendations 1991: the Length to height ratio of Nails = (0.5 - 1.2).

The evaluation of generations and the best values obtained by GA are shown in figure 3.

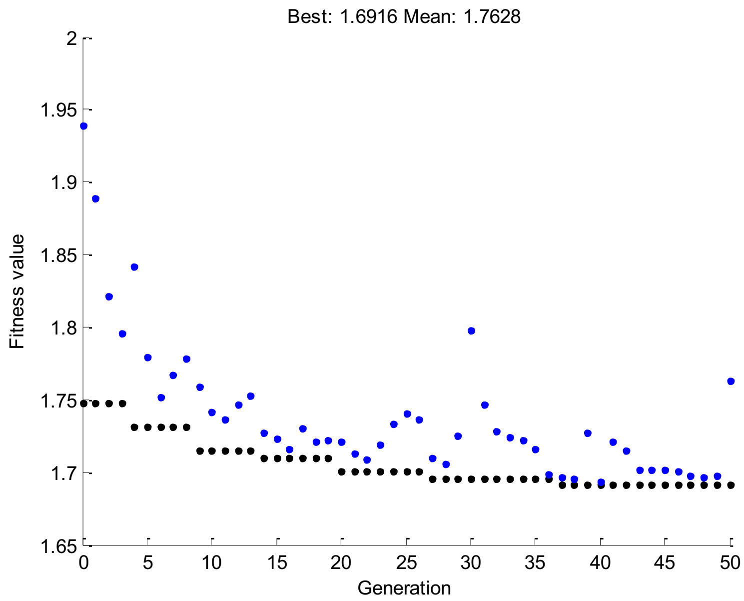

Fig 3. Variation of fitness values with generations.

Figure 3 the black point indicates the best value obtained from the objective function at each generation, shows little progress in lowering the fitness value, the blue point indicates the average value of the objective function at each generation, we have a number of points equal to the number of generations either for the mean or for the best, and for this cas we had 50 point for the best and 50 points for means.The fitness value is almost constant after generation 37, the final value obtained equal to 1.6916 expresses a very good result of minimization of safety factor.

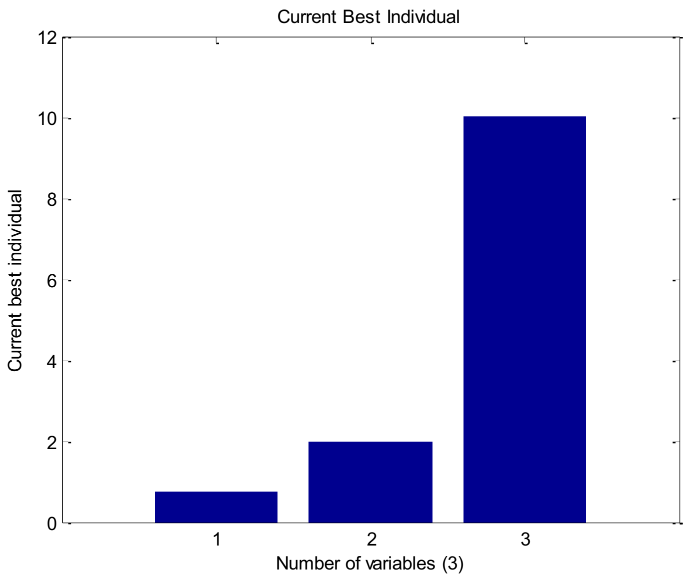

Fig 4. Current best individual with number of variables.

Figure 4 shows the number of best individuals that correspond to each variable in the optimized function. The best individual is inclination, then vertical spacing finally the height to length ratio.

6. Parmetric study

The parameters which condition the convergence of a genetic algorithm are:

- the size of the population of individuals
- the maximum number of generations
- the probability of crossing;
- the probability of mutation.

There are no parameters that are suitable for solving all the problems that can be posed to a genetic algorithm. However, some values are often used (defined in the literature) and can be good starting points for starting a search for solutions using a GA.

6.1. Selection type effect

Selection is the most important step it allows the individuals of a population to survive, to reproduce or to die. As a general rule, the probability of survival of an individual will be directly related to its relative effectiveness in the population (higher fitness).

Very strong selection will lead to highly fit individuals taking over the population, thus reducing the diversity needed for change and progress,on the other hand very weak selection may result in too slow evolution.We present a comparison using roulette wheel and uniform selection.

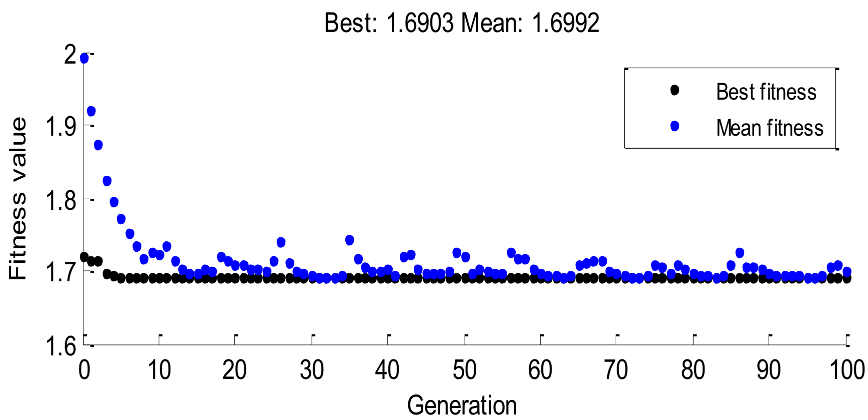

Fig 5. Variation of fitness values with generations (Roulette selection).

Roulette selection is the best known and the most used.With this method each individual has a chance of being selected proportional to his performance, so the more individuals are adapted to the problem, the more likely they are to be selected, In this case a rapid decreases and convergence is observed.

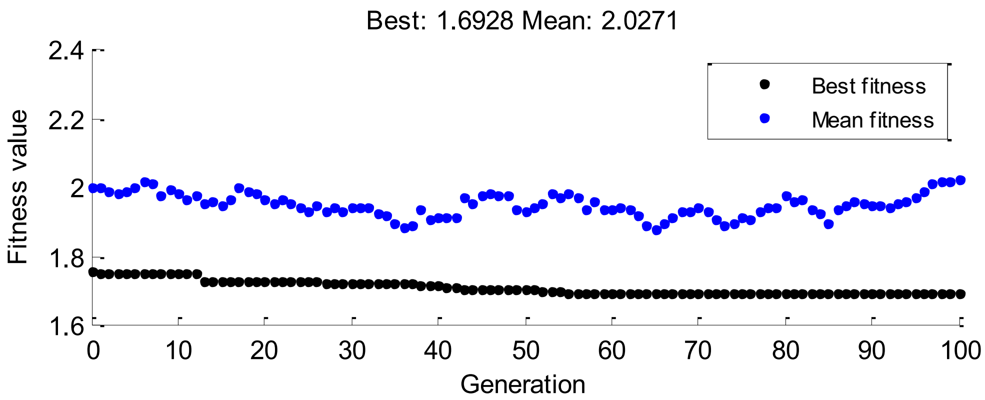

Fig 6. Variation of fitness values with generations (Uniform Selection)

In the uniform selection,parents are selected at random from a uniform distribution.This results is an undirected search.This selection is not a useful search because the selection is done randomly,each individual therefore has a 1 / P probability of being selected, where P is the total number of individuals in the population. In this case the best and mean fitness diverge at each generation.

7. Conclusion and perspectives

- This paper applies a methodology to arrive at optimal design parameters of soil nailing using GA optimisation;
- It has been demonstrated that the presented algorithm is able to find quickly the minimum safety factor and the optimum parameters. The optimum value for the process variables namely inclination vertical spacing and length to height ratio are found to be equal to 10°, 2.0m and 0.75 respectively;
- The results are satisfactory and in accordance with the recommendations Clouterre 1991.
- For a better optimization strategy the choice of the parameters of genetic algorithm is a really sensitive step (population size,mutation rate,crossover fraction ….etc);
- Multiobjective optimization techniques can be applied to solve this problem in future searches, as the shear resistance parameters also affect the safety factor value.
- The influence of the cost of realization of a soil nailed: cost of excavation, drilling, shotcreat ,steel …..etc poses a problem of optimization;
- This study will help engineers to choose reinforcement parameters of soil nailing that will produce economic and sable design.

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