5th SASTech
Iran | Mashhad
May 12 - 17 | 2011
5th Symposium on Advances in Science & Technology

Optimum layout of Soil Nailed Wall by Genetic Algorithm

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Paper Reference Number: 0103-692
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Abstract

An optimization process for soil-nails deployed for stabilization of slopes and trenches is presented in this article using the limit equilibrium approach. A number of factors such as inclination, length, size and spacing of the nails affect the stability number of a slope with a specific geometry (i.e. height and slope angle). Furthermore, the influences of these parameters on the factor of safety vary with shear strength parameters of soils. Therefore, in order to arrive at a specific factor of safety (FS) for a particular slope with minimum number and length of nails, a genetic algorithm (GA) procedure using GA toolbox of MATLAB software is utilized. Diagrams presenting the influences of the above mentioned parameters on the factor of safety are developed, thus offering simple means of evaluating optimized pattern of soil-nail system. It is shown that this process will lead to the desired factor of safety with a minimum number and length of installed nails.

Key words: Slope stability, Soil nail, Factor of Safety, Genetic Algorithm, Optimization

1. Introduction

Slopes with not allowable F.S, should be reinforced by either soil nailing, soil anchoring etc. In practice the engineers always use constant nail spacing and length, in this way they lead to material consumption more than the required material, because in some cases not all the length of nails are used as reinforcement. There are several nail parameters which can have influence on FS (i.e. nail diameter, length, space, inclination). Shear force in nails induced by soil movement depend on height of nail installation, nail inclination and on how nails intersect shear failure surface (Jewel (1980)). One of the engineers concern is amount of force activated in each nails, so nail inclination could be

one of the most important concerns. Besides this fact and considering the inclination of nail to be constant, the other factor which can have an influence on the FS is nail length and diameter. In most of practical project, the nails length considered to be constant for all height of wall while this fact could lead to consumption of materials (nail, grout, etc) more than the required ones. So by GA process which is presented in this paper, the length of nails which is not required could be omitted. And also the diameter of nails which could have better influence on FS can be selected.

2. Literature review

Several studies have been done for calculating the optimum layout of soil nailed wall. P. Ponterosso et al. (2000) produced a GA solution to the cost optimization problem of reinforcement layout for reinforced soil slopes. In their study, the solution incorporate different types of reinforcement within a single slope. The GA described is implemented with the aim of optimization the cost of materials for a preliminary layout of reinforcement soil embankments. Patra et al. (2005) reported a generalized method of computer based optimum design of soil nailed slopes. Besides the nail length and diameter optimization, the process of critical slip surface calculation could be an objective which can be achieved by GA. Ali. R. Zolfaghari et al. (2005), Jianping Sun et al. (2008) and Paul McCombie et al (2002) have done several studies by GA for obtaining the critical slip surface.

3. Optimization Process

Genetic algorithms are a form of evolutionary search that makes use of operators that mimic the natural world. The most commonly used operators are selection, reproduction and mutation. The solution (or potential solution) of a problem are coded in such a way that they can be thought of as forms of genetic material (DNA). A population of solution is generated randomly and the "fitness" of each individual is assessed by reference to the Fitness Function for that particular problem. The more fit individuals then have a greater chance of reproducing and thus promoting their fitter characteristics through to the subsequent generation(s). Reproduction takes place by swapping part of the 'DNA' from two individuals. In order to ensure that no potential solution has zero probability of occurring the mutation operator can, according to a user defined probability, randomly alter any small element of a solution

Before starting of length and diameter calculation, the first step is calculation of critical slip surface. The method which is used for calculation the factor of safety is simplified bishop method (limit equilibrium method). The program which calculates the FS of a slope is written in MTLAB software and by using the GA toolbox of MTLAB software, the critical slip surface which has the minimum FS can be calculated. As it was described in literature review section, several studies have been done for this part of calculation, so by passing this part of calculation, the part which is the more important than the previous part begins. For getting familiar with GA and how it works, it is recommended to the reader to refer to Goldberg DE (1989).

In this part, by using GA and a try and error process, an optimum layout of nails can be achieved. the calculation stages are as below and are shown in figure 2:

1. Calculation of critical slip surface and FS_{min} by GA.
2. Calculation of optimum nails length layout by GA for the calculated slip surface from step 1.
3. Calculation of critical slip surface and FS_{min} by GA for the nail layout which has been obtained from step 2
4. If FS_{min} =1.5 (8), step 3 is the final step, if not, the process should be repeated again from step 2.

Usually after 3 or 4 times of try and error the desired nail layout which has the FS_{min} =1.5 is achieved. It should be noted that during the GA process the program forces the GA toolbox to use the values of nails length which increase from bottom to top. It means that, whenever the solution reaches the value of nails length which nails on the top have length less than bottom nails, the program consider a penalty for this layout (Solution has a penalty), in this way such these layout can be omitted (solution omitted). Another penalty function is considered in the program, it works in a way that if a solution reaches to a condition which FS_{min} does not meet the FHWA value, the program forces the GA toolbox to omit this kind of solution too. By introducing these two penalty functions the GA process can reaches to the final solution in an appropriate way. The program works in a way which the difference between nails length are not more than one meter. Also because of practical difficulties in sites, the nail inclination for vertical wall is considered to be 15 degree (FHWA0-IF-03-017). It should be considered in mind that the Fitness Function is sum of all nails length.

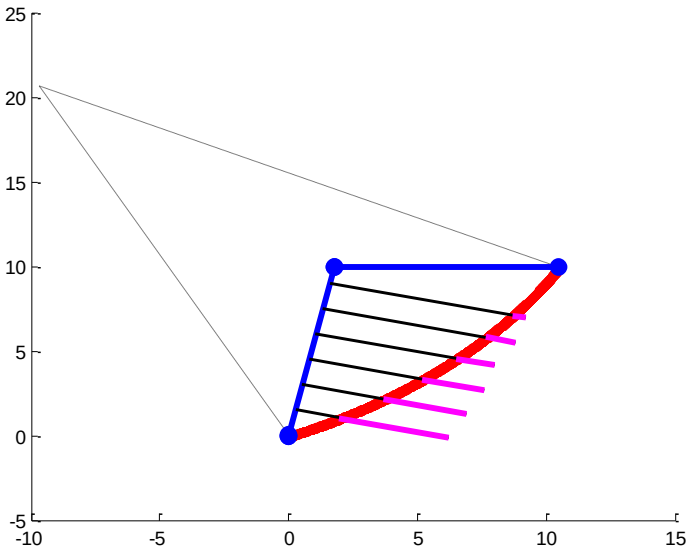

Figure 1. The wall which is modeled by MATLAB software

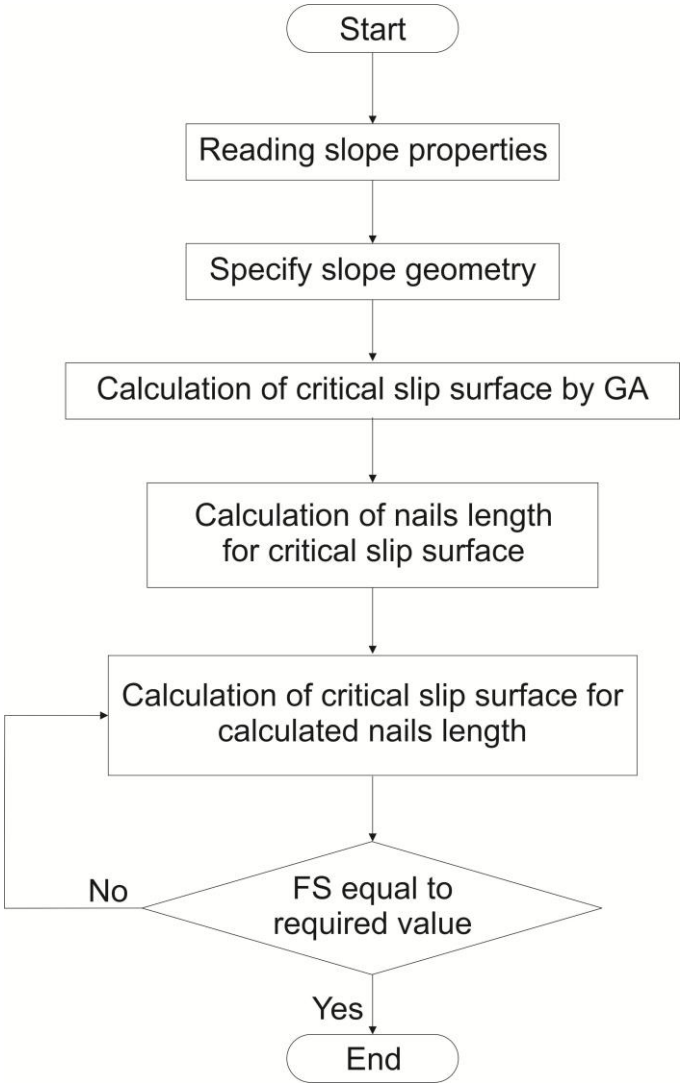

Figure 2. The process of calculating the nail length by GA

The nails diameter is considered to be 28 and 32 millimeters and the hole diameter which the nails are inserted in them have the `diameter of 100 and 127 millimeters. The final strength capacity of nails is considered to be 4200 kg/cm^2 and the soil density is 20 kN/m^3. Horizontal and vertical spacing of nails are considered to be 1, 1.25 and 1.5 meters for wall with 15 meter height and 1.25 and 1.5 for wall with 10 meter height. The soil shear strength parameters are not constant during the calculation. Three value for internal friction angle (25, 30 and 35 degree) and four value for cohesion of soil (10, 20, 30 and 40 kPa) are considered in the calculations. In this way the effect of soil properties can be studied.

In the table 1, the value of nail length which are calculated by GA for different soil properties are shown. It should be noted that L1 means the nail length which are located in the bottom of the wall and Ln are the nail length which are located in the top part of the wall.

Seven other calculation for other nail and hole diameters and wall height are done and the nails length are calculated. But in this paper only the results which are achieved

from the tables are presented. by looking at the table 1, it could be concluded that by increasing the soil shear strength parameters, the nail length required to achieved FS_{min} =1.5, are decreased. To illustrate this fact, a sample result is shown in figure 3.

φ°	C (kPa)	Sv (m)	L1	L2	L3	L4	L5	L6	L7	ΣL	FS	FS(No Nail)
25	10	1.25	7.5	8	8.2	10.1	10.5	11	11.5	66.8	1.498	0.429
		1.5	10	10	10	10	10	10		60	1.14	
	20	1.25	6.5	7.1	7.5	8.2	8.4	8.9	9.4	56	1.507	0.654
		1.5	10	10	10	10	10	10		60	1.399	
	30	1.25	5.7	6.1	6.4	6.9	7.5	7.7	7.8	48.1	1.503	0.871
		1.5	7.2	7.9	8.9	9	9.8	10		52.8	1.504	
	40	1.25	5	5.1	5.2	5.4	6	6.2	6.5	39.4	1.495	1.071
		1.5	6.1	6.2	6.9	7.1	7.8	8.1		42.2	1.513	
30	10	1.25	7	7.2	7.7	7.9	8.4	8.7	9.1	56	1.51	0.498
		1.5	10	10	10	10	10	10		60	1.35	
	20	1.25	5.9	6.2	6.7	7.1	7.2	7.8	8.1	49	1.503	0.715
		1.5	7.5	8.2	8.9	9.4	9.6	10		53.6	1.499	
	30	1.25	5.5	5.5	5.7	5.8	6.1	6.2	6.5	41.3	1.504	0.92
		1.5	6	6.7	7.3	7.8	8.2	9		45	1.503	
	40	1.25	4	4.1	4.4	5	5.1	5.2	5.2	33	1.501	1.136
		1.5	5	5.1	5.5	6	6.5	6.8		34.9	1.499	
35	10	1.25	5.8	6.2	6.5	6.9	7.3	8	8.5	49.2	1.5	0.564
		1.5	8	8.1	8.6	9.3	9.6	10		53.6	1.499	
	20	1.25	5	5.3	5.6	6.1	6.5	6.9	7.1	42.5	1.491	0.78
		1.5	6.4	6.8	7.5	8	8.5	9.2		46.4	1.508	
	30	1.25	4.8	4.8	4.9	4.9	5	5.2	5.5	35.1	1.506	0.988
		1.5	5	5.2	5.9	6.8	7.7	9		39.6	1.509	
	40	1.25	3.3	3.5	3.8	4.2	4.4	4.5	4.7	28.4	1.497	1.2
		1.5	4.5	4.5	4.5	4.5	4.6	4.7		27.3	1.498	

Table 1. Calculated length of nail by GA for obtaining FS_{min} =1.5
(Wall height =10 m, nail diameter=28 mm and hole diameter=127 mm)

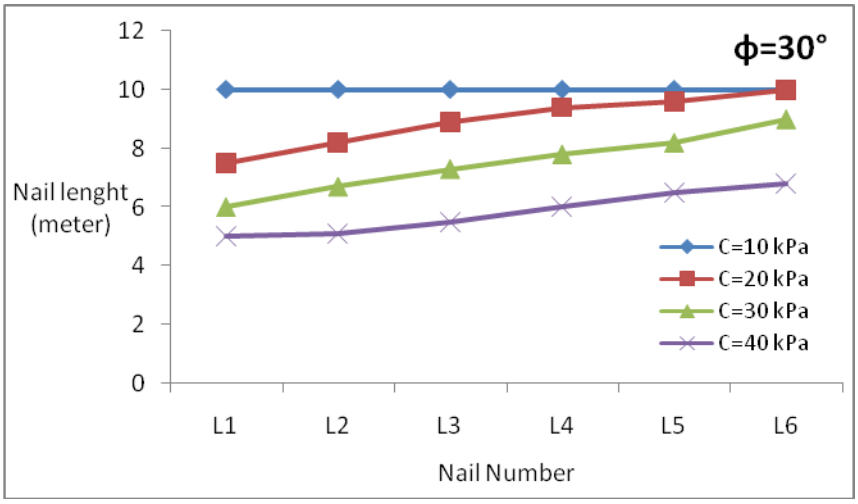

Figure 3. Calculated nail length by GA for soil with different cohesion (φ=30°, H=10 m, Sv=1.5 m)

By being more precise on the result which obtained by GA it could be concluded that the nail diameter has not significant effect on the required nails length, but on the other hand the hole diameter can have an effect on the required nails length. This fact is illustrated in figure 4.

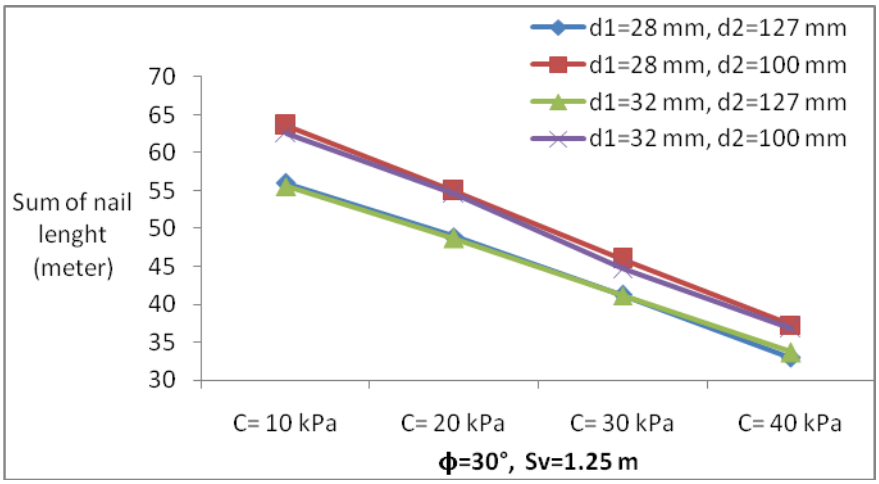

Figure 4. Effect of nails and holes diameter on required nail length (H=10 m)

By looking at table 1, it could be figured out that by increasing the number of nails (decreasing the nail spacing), the required length of nail for obtaining the FHWA condition (FS_{min} =1.5) could be decrease, and also in some cases which the FHWA condition could not be satisfied (φ=25,C=10, FS<1.5), by increasing the number of nail, this condition can be satisfied. This fact is shown in figure 5.

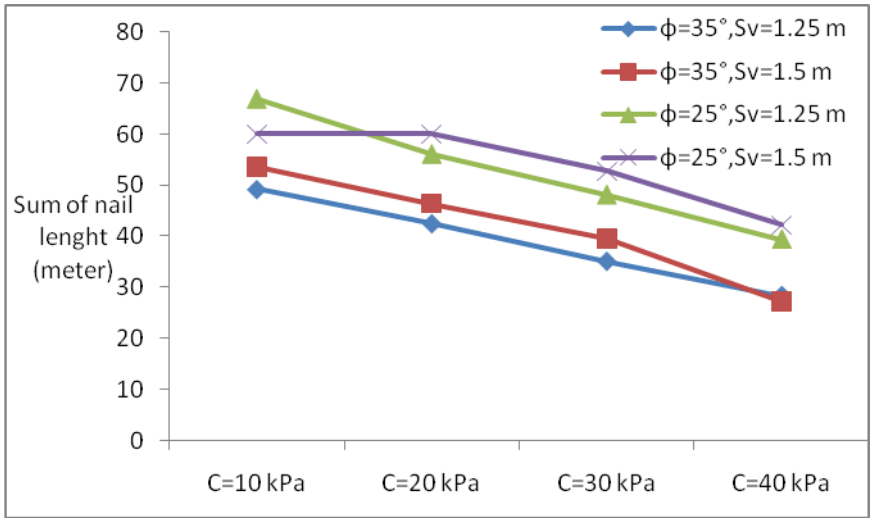

Figure 5. Effect of nail sp[acing on required nail length (H=10 m)

4. Conclusion

It was shown that GA has the ability of calculation of nails length in walls with different height and different soil shear strength properties (cohesion and internal friction angle). Also it was shown that by increasing the soil shear strength parameters, the required nails length for satisfying the FHWA condition (FS_{min} =1.5) are decreased, that is an obvious conclusion. By looking at the results, it could be concluded that the nail diameter has not significant effect on the required nails length, but on the other hand the holes diameter can have an effect on the required nails length and by increasing the holes diameter, the required amount of nails length for satisfying the FHWA condition could be decreased. Sometimes by increasing the number of nails (decreasing the nail spacing), the required length of nail for obtaining the FHWA condition (FS_{min} =1.5) could be decrease.

5. References

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