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Mono-objective Optimization of Retaining Wall Using Genetic Algorithm

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Abstract

This paper examines the importance of geotechnical optimization techniques for soil engineering applications, with a particular emphasis on evaluating geotechnical structures. Due to its prevalence in civil engineering, the complex interplay of geotechnical, structural, and financial considerations necessitates a trial and error approach. The study focuses on design elements, geometric dimensions, and volume considerations in order to highlight the economic viability of reinforced concrete retaining walls. Three code files are created using MATLAB to analyze their impact on active and passive thrusts and, as a result, the structure's volume. The slope angle, backfill overload, and friction angle are varied. The results demonstrate the effectiveness of using evolutionary algorithms to precisely optimize a single goal and demonstrate that this approach can enhance the design of retaining walls in reinforced concrete. This method demonstrates the ability to improve design procedures in this crucial area, which makes it an invaluable resource for structural engineering researchers and civil engineers.

Keywords: geotechnical engineering, genetic algorithm, retaining wall, optimal design, mono-objective optimization

1 Introduction

Structures known as retaining walls are frequently employed in civil engineering projects. These kinds of structures are frequently utilized to stabilize and maintain unstable land masses on their naturally occurring slopes. Due to the frequent occurrence of these soil slopes during the construction of highways, bridges, railroads, and other projects, the minimal cost design of reinforced concrete retaining walls is a crucial task in design optimization for the civil engineering industry. Multiple studies have examined the best design for retaining walls. Saribas and Erbatur, presented a detailed study on the optimal design of reinforced concrete cantilevered retaining walls using the cost and weight of the walls as objective functions, they controlled the overturning breaks, slip breaks, resistance, shear and moment capacities of the

foot slab, the heel slab, and the foot of the wall as constraints [1]. Ceranique and Fryer proposed an optimization algorithm based on simulated annealing to calculate the minimum design cost of reinforced concrete retaining walls [2]. Sivakumar and Munwar, presented a new approach to reliability for the optimization of the design of retaining walls [3]. Ahmadi Nedushan and Varaee, have proposed an optimization algorithm based on particle swarms. They claim that this method requires fewer function evaluations, while leading to better results in the optimization of the support structure [4]. Deep, Singh, Kansal and Mohan applied the real coded genetic algorithm (RCGA) to test a large number of different walls sections and select the gravity retaining wall design with the lowest construction cost [5]. Khajehzadeh, Taha, El-Shafie and Eslami, the objective function was considered as the design of the total cost of the retaining walls, in addition, geotechnical and structural constraints were used for the optimization procedure of the retaining wall, [6]. Ghazavi et al., to arrive at an optimal design of the concrete retaining wall used the ant colony optimization algorithm (ACO), which is a technique based on the indirect communication of a colony of simple agents, called artificial ants, mediated by artificial phenomena, serve as distributed digital information, which the ants use to build probabilistically solutions to the problem to be solved [7]. Sheikholeslami et a.l, according to ACI318-05, the hybrid Firefly (FA) algorithm with an upper bound strategy is used to minimize the concrete wall cost [8]. Rowshanzamir and Aghayarzadeh, their study concerns the retaining walls of the layers reinforced by geogrids with different oblique angles as well as an inclined face in order to obtain optimized design alternatives [9]. Another study by Sheikholeslami et al., concrete retaining walls combined the two algorithms, Firefly and Ceiling strategies, demonstrating the superior performance of the hybrid approach compared to other approaches [10]. Jellali and Frikha, discussed deterministic and stochastic nonlinear constrained optimization methods, by applying a partial swarm optimization (PSO) algorithm which required the transformation of the problem into an equivalent unconstrained problem in order to determine the critical stability factor [11]. In the study by Gandomi et al., three evolutionary metaheuristic optimization algorithms (evolutionary strategy (ES), differential evolution (DE) and optimization algorithm based on biogeography (BBO)), are applied to the optimal design of reinforced concrete retaining walls using two objective functions the cost and the weight of the structure [12]. Chen, Asteris, Jahed Armaghani, Gordan, Pham, designed intelligent models, considering parameters such as wall thickness, stone density, wall height, soil density and the internal friction angle of the soil which were examined under different dynamic conditions and assigned as inputs to predict the safety factor (SF) of retaining walls [13]. BagheriSereshki and Derakhshani, studied the optimization of mechanically stabilized earthen walls with the algorithm of the Salpswarm and the gray wolf optimizer, and the classical algorithm of particle swarm optimization, to this end the results reveal that the modification of the internal friction angle of the reinforced soil has a fairly identical effect on the optimal costs of walls of different heights, in addition, it is shown that by increasing the height of the wall, the effects of variations in the unit weight of the reinforced soil and the angle of the slope of the embankment on the optimal cost are increased [14]. Mergos and Mantoglou, studied the flower pollination algorithm (FPA) applied for the first time, to the optimal design of reinforced concrete (RC) cantilevered retaining walls, where it was concluded that the optimal costs increase rapidly and non-linearly with the height of the wall, on the other hand, they increase almost linearly but rather regularly with the surcharge [15]. Kalemci, Ikizler, Dede, Angın, in their article the retaining wall was formulated as an optimization problem based on the ACI code 318-05 and Rankine's theory for the lateral pressure of the earth, the geotechnical constraints were

determined as the safety factor against overturning, bending, the rupture of the load-bearing capacity and the structural stresses were determined as the moment and shear capacities of the wall elements to evaluate the effectiveness of the GWO algorithm compared to similar studies [16]. Kaveh, Hamedani, Bakhshpoori, concrete retaining walls were optimized for optimal design using eleven population-based metaheuristic algorithms; all algorithms used quickly converged to high-quality optimal designs [17]. Chen et al., indicated that the multiparametric optimization approach has also been applied in the field of geotechnics, in the design of backfill piles with basal reinforcement [18]. Pradeep et al., examine the in-depth reliability of cantilever sheet pile walls buried in a coherent soil and backfilled with a coherent soil. Through the use of various optimization strategies, namely the artificial bee colony, the optimization of the ant colony, the ant-lion colony, the imperialist competitive algorithm, the mixed complex evolution and the optimization based on teaching and learning, the artificial neural network (ANN) widely used to predict the embedding depth of a cantilever sheet pile wall; according to the experimental results, hybrid models (ANN) and optimization based on teaching and learning (ANN-TLO) are more efficient in predicting the reliability of cantilever sheet pile walls [19]. Boumezrane carried on, optimization according to different deterministic and stochastic optimization schemes by a selection on a mathematical basis, of the objects best suited with respect to defined criteria, by choosing values or input functions within a certain range of parameters. It can be mono-objective (a single function) or multi-objective (several objective functions), sometimes even contradictory (Pareto optimization) [20]. Even though the weight and the cost of the task do not have opposing goals, the cost of the work increases as its weight increases. The retaining wall optimization problem has been approached as a multi-objective optimization problem employing the functions (cost, weight, and safety factor) that need to be minimized in each of the aforementioned studies. In this study, we choose to optimize a retaining wall using a genetic algorithm, one of the single-objective artificial intelligence techniques. Important design variables, such as geometric variables that describe the thickness of the veil and sole as well as the lengths of the foot and heel, are included in the formulation of the problem. The main goal of this work is to use the genetic algorithm to find the best design for a cantilever type retaining wall. MATLAB software was used to create a code consisting of three files (objective function file, constraints file, and main file).

2 Application of the Genetic Algorithm

It has been demonstrated that most of the techniques used are based on metaheuristic methods, but the Genetic Algorithm GA and the Particle Swarm Optimization PSO (optimization by surface modification) have been widely used compared to other methods and appear to effectively treat the non-linearities encountered in many geotechnical problems [20]. Therefore, the application of the genetic algorithm is highly recommended (Table 1).

Table 1: Occurrence of different optimization methods [20]

Methods	**Foundations**	**Slope Stability**	**Soil Properties and Investigation**	**Total geotechnical optimization methods**
GeneticAlgorithm GA	5	4	3	12
ParticleSwarmOpt PSO	3	7	1	11

Artificial Neural Networks ANN	3	2		5
Surface AlteringOptimization SAO		4		4
Differential Evolution DE	1	2	1	4
Artificial Bee Colony ABC	2	1	1	4
Non LinearProgramming NLP	1	3		4
ANFIS and Fussy sets	1		3	4
DiscreteLayoutOptimization DLO	4			4
EvolutionaryAlgorithm EA	3			3
Harmony Search HS		3		3
Reliabilitymethods	1	1	1	3
BBO Boo-geo Based Algorithm	2			2
Monte Carlo Optimization MCO	1	1		2
Ant Colony AC	1			1
Multiple Regressions MR		1		1
GrasshopperOpt. Algorithm CAA		1		1
MultiverseOpt. Algorithm MVO		1		1
GravitationalSearchAlgorithm GSA		1		1
Smooth Part. Hydrodynamics SPH		1		1
Improved Arith Optimizer IAO	1			1
Interior Point Method IPM		1		1
MARS M.variate Adap. RegrSplines		1		1
TopologyOptimization	1			1
RSM Res. Surface Methodology		1		1
Least Squares Method		1		1
Geostatistics			1	1
Adaptive Metamodels			1	1
Inverse Analysis			1	1
Other	8	4	3	15
Total optimization methods used	38	41	16	95

In geotechnical engineering, retaining walls are used to secure embankments that are not stable in the long term against lateral loads from the ground. The design of the retaining wall is divided into two phases: Geotechnical design and structural design, which are evaluated using selected wall dimensions. Varga et al pointed out that if the initially selected dimension does not satisfy the stability constraints, a new dimension is selected and reassessed until the stability constraints are satisfied. Even if the conditions are met, it is not certain that the determined wall dimensions will result in the most economical wall design [21]. In the geotechnical design phase, the wall must withstand the different modes of rupture by calculating the safety factors sliding, overturning and bearing capacity. As regards the structural design phase, the wall must be checked for breakage due to shearing and at the moment at the junction of the veil with the sole and the junction of the veil with the heel and the skate. The design procedure used in this work to verify the two design phases is based on Rankine's theory. Figure 1 shows the different geometric variables and the forces taken into consideration in this study. Geometric constraints are made of boundary constraints and linear constraints of equalities and inequalities defined to

produce practical designs. Based on Rankine's theory and the geometry of the example studied in this work, several constraint formulas have been used, the latter direct the algorithm to search for solutions (in our example from *X1* to *X*6) within a certain interval fixed by the lower and upper limits of each part of the work.

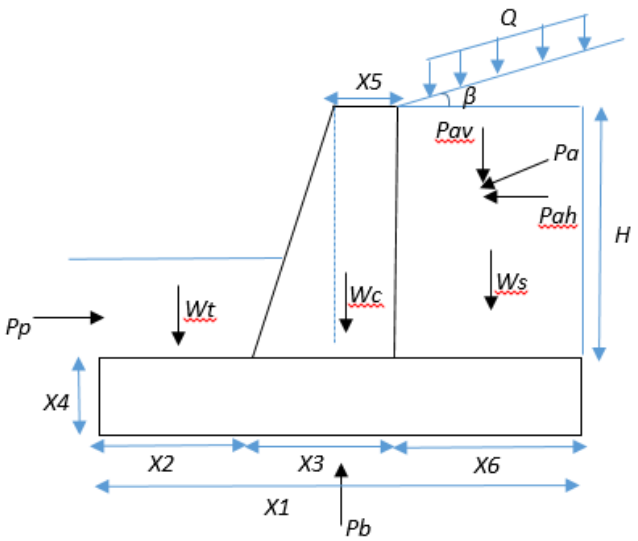


Figure 1: The retaining wall's design parameters

where

Ws: the backfill's weight pressing against the wall's heel;

Wt: the floor's weight on the wall's foot;

Wc: the total weight of the reinforced concrete wall's individual sections;

Q: is an overload;

Pb: the reaction of the soil;

Pa and *Pp*: are the resulting forces from the lateral pressures, both active and passive;

Equations 1 and 2 are used to calculate the active and passive earth pressure coefficients based on Rankine's theory.

$$K_a = \cos\beta \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\theta}}{\cos\beta + \sqrt{\cos\beta^2 - \cos\theta^2}} \quad (1)$$

$$K_p = tan^2\left(45 + \frac{\theta}{2}\right) \quad (2)$$

where

θ: The backfill's internal friction angle

β: The embankment's angle

To build a retaining wall, three geotechnical rupture modes are taken into account. These requirements are as follows:
Equation 3 provides the safety factor with relation to overturning.

$$F_{S0} = \frac{\sum M_R}{\sum M_0} \quad (3)$$

$\sum M_0$: total of the unstable moments
$\sum M_R$: sum of the resistant moments
Safety factor with respect to sliding is given by the Equation 4.

$$F_{SS} = \frac{\sum F_R}{\sum F_D} \quad (4)$$

$\sum F_D$: total of the horizontal forces that are unstable
$\sum F_R$: total of the horizontally resisting forces

$$\sum F_R = \sum (W_{wall}) \tan\left(\frac{2\emptyset_{base}}{3}\right) + \frac{2BCbase}{3} + P_p \quad (5)$$

$$\sum F_D = P_a cos\beta \quad (6)$$

P_p: the stop
P_a: the push
$\sum W_{wall}$: total weight of the wall
$\emptyset_{base}$: friction angle of the foundation soil
B: total width of the sole
C: cohesion of the sole and foundation soil interface
Safety factor with respect to the lift of the ground is given by the Equation 7.

$$F_{SB} = \frac{q_u}{q_{max}} \quad (7)$$

q_{max}: maximum pressure produced as a result of the forces acting on the retaining wall, as shown by Equation 8.
q_u: ultimate bearing capacity of the foundation soil

$$q_{min_{max}} = \frac{\sum V}{B}\left(1 \mp \frac{6e}{B}\right) \quad (8)$$

B: the width of the base
$\sum V$: maximum pressure generated by the forces acting on the retaining wall given by Equation 8.
e: the resulting force system's eccentricity, which is stated as follows:

$$e = \frac{B}{2} - \frac{\sum M_R - \sum M_0}{\sum V} \quad (9)$$

3 Using a Genetic Algorithm to Optimize a Cantilever Wall

3.1 Formulation of an Optimization Problem Mathematically

The majority of the time, optimization issues aim to minimize an objective function *f(x)* while taking needs or restrictions into account. It might be non-linear or linear. A formulation for an optimization issue is as follows:

$$\begin{aligned} hj\,(x) &\leq 0 \qquad j = 1, 2, \ldots, m \\ gi\,(x) &\leq 0 \qquad i = 1, 2, \ldots, p \\ Lk \leq Xk &\leq Yk \quad k = 1, 2, \ldots, n \end{aligned} \tag{10}$$

h (x): are equality constraints
g (x): are inequality constraints
L, *Y*: are constraints to the limits

In the following we describe the objective function *f(x)* and the constraints used in this work, in order to achieve an optimal design using meta-heuristic techniques, since our problem is a mono-objective optimization problem, a single objective function which is the volume of the work has been used in this work. According to (Fig. 1), the volume of the wall can be given by Equation 11.

$$f(x) = XI \text{ x } X4 + (X3 + X5) \text{x } H/2 \tag{11}$$

According to Algerian earthquake laws (RPA 99), designing safe and stable retaining walls necessitates fulfilling a number of requirements pertaining to the stability, capacity, and geometry of the wall. According to the technical engineer's document, Equations 11, 12, and (13) describe the stability of a retaining wall as follows:

$$F_{SO} \geq F_{SO\ design} \tag{12}$$
$$F_{SS} \geq F_{SS\ design} \tag{13}$$
$$F_{SB} \geq F_{SB\ design} \tag{14}$$

$F_{S0design}$: safety concern with regard to overturning equal to 1.5.
$F_{SSdesign}$: safety factor with regard to sliding equal to 1.5.
$F_{SBdesign}$: safety factor with regard to the bearing capacity equal to 3.
Based on Rankine's theory and the geometry of the case explored in this work, various constraint formulae have been employed for the geometric constraints, which are made up of limit constraints and linear constraints of equalities and inequalities defined to build practical designs. The latter tell the algorithm to look for answers (in our example, from *X1* to *X6*) inside a predetermined window determined by the lower and upper bounds of each component of the work. In Figure 1, it is shown how much the variables *X1* through *X6* might vary.

$$X1 = X2 + X3 + X6 \tag{15}$$
$$X3 > X5 \tag{16}$$
$$X6 > X2 \tag{17}$$

$$X6 > X3 \tag{18}$$

Linear constraints are shown by the equations above. Three of the constraints are linear inequality constraints, while the first is a constraint on linear equality. The steps taken in this section are described in the form of an algorithm in Figure 2.
The three files (the main file, the constraints file, and the objective function file) that make up the process used in this study were created using the MATLAB programming language. This is depicted in Figure 2.

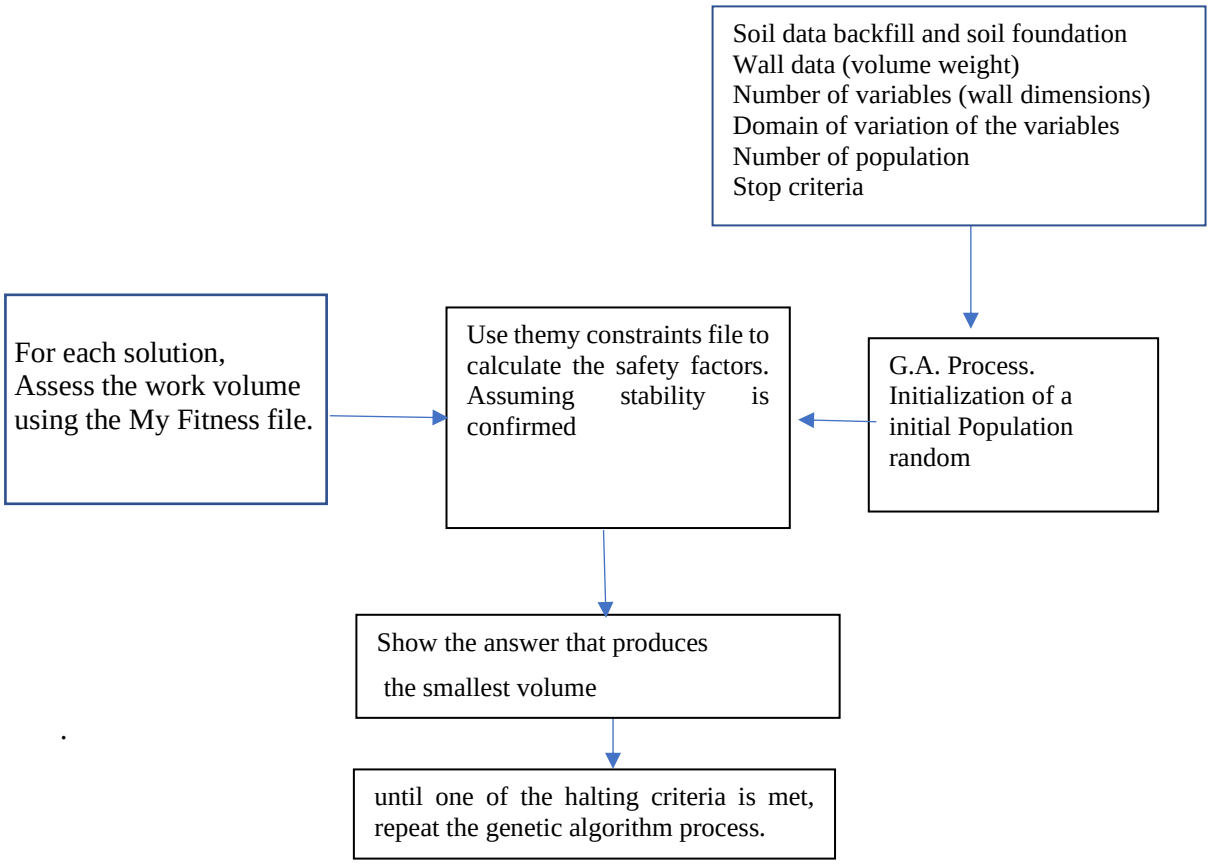


Figure 2: Application of the genetic algorithm in optimization flowchart

4 Validating the Model

Our findings show that there are three key differences among all metaheuristics, regardless of their objective type: The parameters used in our study to illustrate the genetic algorithm's efficacy and performance in solving restricted mono-objective optimization problems are displayed in Figure 3. These parameters encompass the fitness attributing method, the diversity maintenance technique, and the elite conservation strategy.

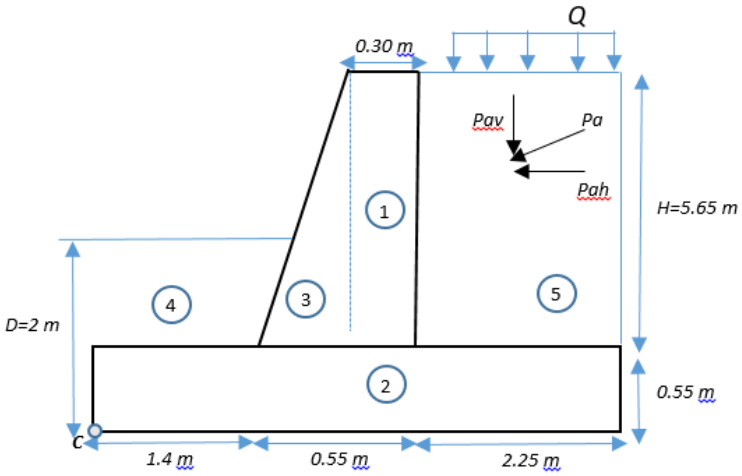


Figure 3: The validation retaining wall's dimensions.

The latter has a length of (130 m) and a height of (5.65 m) retaining a horizontal embankment with an overload Q =10.2 kN/m^2. The characteristics of the structure as well as of the soil are given in Table 2.

Table 2: Floor and retaining wall characteristics

Floor and retaining wall characteristics	**Value**
Tensile Strength (10^3kN/m^2)	2.1
Resistance of concrete to Compression (10^3kN/m^2)	25
Steel yield strength (10^3kN/m^2)	400
Veil height (m)	5.65
Volume weight of the backfill (kN/m^3)	18
Volume weight of the foundation soil (kN/m^3)	18.8
Internal friction angle of the embankment (°)	30
Cohesion of the embankment (kN/m^2)	0
Internal friction angle of the foundation floor (°)	15
Foundation soil cohesion (kN/m^2)	27.7
Installation of the structure (m)	2
Slope angle (°)	0

Table 3: The retaining wall's ideal construction

The design of the wall with GA	**Unit**	**The values**
X1	m	3.0881
X2	m	1.1010
X3	m	0.2928
X4	m	0.4713
X5	m	0.2033
X6	m	1.6940
fval (wall volume)	m^3	2.8566

Table 3 shows that the wall's design has a volume of 4.71 m^3, whereas the optimization method used in the study yielded a volume of 2.85 m^3. This shows a 1.86 m^3 difference in linear meters. Nevertheless, there is insufficient context or information in the search results to determine the importance or ramifications of this difference.

5 Parametric Study

We chose to conduct a parametric study in order to examine the sensitivity of the model created in this investigation. The values that the fixed parameters in this parametric study took are displayed in Table 4.

Table 4: Parameter values that were fixed during the parametric study

	distribution Laod over (kN/m^2)	**Unit Weight (kN/m^3)**	**Bearing Capacity (kN/m^2)**	**Embedding Df (m)**	**Friction angle (°)**	**Cohesion (kN/m^2)**	**Angle of slope (°)**
Retaining Wall		23.58		1.5	/	/	
Embankment	0	20			34°	0	10°
Soil Foundation		20	574.07		40°	40	

The margin of the values of the various parameters used is given in Table 5.

Table 5: Different parameter values are taken into account in a parametric investigation

Load (kN/m^2)	**The embankment's angle of friction (°)**	**Angle of slope (°)**
20	29°	0°
30	30°	5°
40	34°	15°
	38°	25°
	42°	30°

5.1 The Influence of the Slope Angle *α*

As seen in Figure 4, the values in Table 6 show that an increase in the embankment's angle causes the structure's volume to increase. Instead of decreasing the slope's angle as is usually the case with the horizontal component, the rise in the height h was the reason for the increase in the active thrust. The fill angle affects the structure's stability, which results in the volume of the structure expanding. There is insufficient context or information in the search results to determine the significance or ramifications of this discovery. To guarantee that embankments are secure and stable, the findings do, however, imply that the stability of the structure should be taken into account during the design process [22].

Table 6: The influence of the slope angle *α*

***α* (°)**	***Fval* (m³)**	***X1***	***X2***	***X3***	***X4***	***X5***	***X6***
0°	2.23	2.5092	0.6133	0.3393	0.4068	0.2120	1.5561
5°	2.26	2.3939	0.6680	0.3996	0.3780	0.2041	1.3273
15°	2.43	2.5835	0.6087	0.4491	0.3750	0.2011	1.5252
25°	2.69	2.3610	0.4328	0.6002	0.3757	0.2030	1.3277
30	2.71	3.3325	1.1511	0.4445	0.3751	0.2056	1.7349

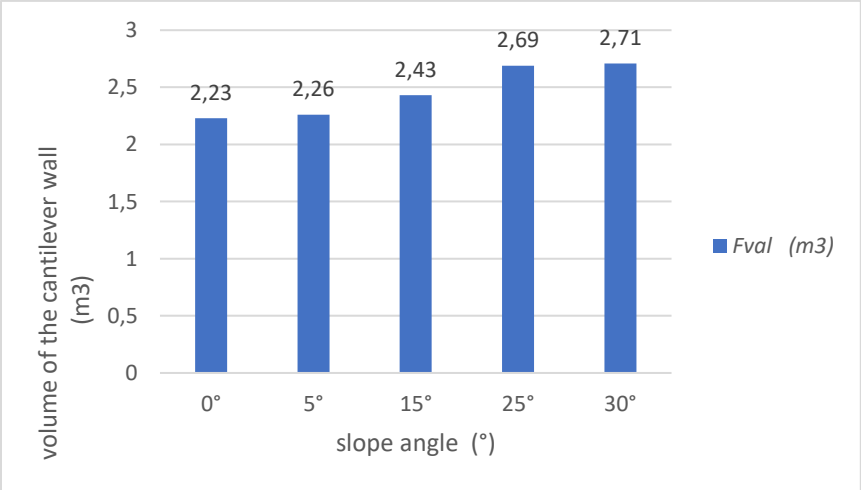


Figure 4: The Influence of the slope angle

5.2 The Influence of the Backfill Friction Angle

Table 7 lists the sizes of the different parts that make up the retaining wall. Keyhan [23] suggests that it makes sense for the cantilever wall's volume to decrease as the friction angle rises. As shown in Figure 5, the increase in the angle of friction causes a drop in the earth's active thrust coefficient, which reduces the active thrust. The search results contain more resources on the design and analysis of cantilever retaining walls, such as optimization evaluations, case studies, and design guidelines.

Table 7: The influence of the backfill friction angle

Ø1	***Fval* (m³)**	***X1***	***X2***	***X3***	***X4***	***X5***	***X6***
29°	2.88	2.6306	0.4250	0.6391	0.376	0.2023	1.5661
30°	2.78	2.6692	0.5618	0.5881	0.3780	0.2033	1.5191
34°	2.26	2.5450	0.5835	0.3741	0.3793	0.2055	1.5876
38°	2.06	2.4239	0.7135	0.2923	0.3773	0.2172	1.4180
42°	1.76	1.8996	0.5863	0.2622	0.3781	0.2035	1.0502

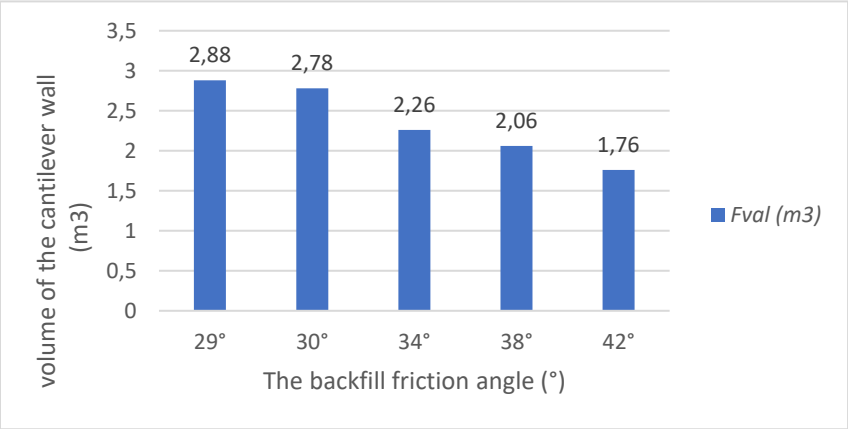


Figure 5: The Influence of the backfill friction angle

5.3 The influence of *Q* overload

Table 8: The influence of *Q* overload

***Q* (kN/m²)**	***Fval* (m³)**	***X1***	***X2***	***X3***	***X4***	***X5***	***X6***
20	1.98	2.5125	0.2432	0.6182	0.3863	0.2058	1.4694
30	2.14	2.7261	0.8189	0.2928	0.3775	0.2011	1.6142
40	3.08	2.7701	0.5123	0.7063	0.3751	0.2018	1.5516

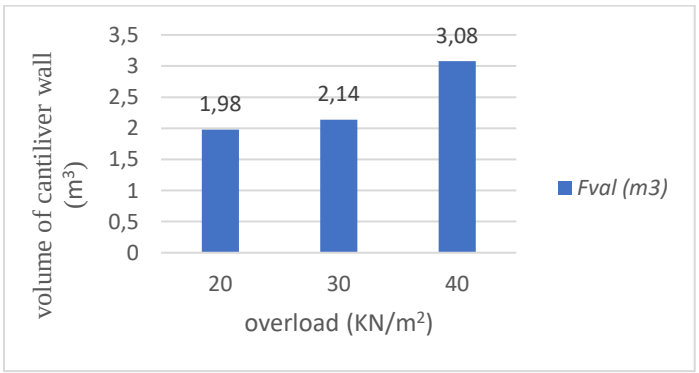


Figure 6: The Influence of the overload

Based on the values in Table 8, it is evident that an increase in overload causes an increase in the cantilever wall's volume, as shown in Figure 6. This is because an increase in overload leads to an increase in active thrust, as indicated by Huang's search results [24]. Therefore, it is required to increase the structure's dimensions in order to increase the stabilizing forces in response and resist this thrust, which is a destabilizing force.

6 Conclusion

The Genetic Algorithm (GA), a highly effective metaheuristic optimization algorithm modeled after the process of natural selection, is used in this work. This algorithm shows to be a reliable tool for solving optimization issues, especially when it comes to finding the best design for retaining walls made of reinforced concrete. A genetic algorithm with constraints is used to accomplish this goal, evaluating both passive and active pressure using the Rankine theory of earth pressure. The genetic algorithm places restrictions on the design structure, such as the need to provide a safety factor against overturning, sliding, and bearing capacity.
The suggested model was created by mono-objective optimization using a genetic algorithm, varying the load from 20 to 40 kPa, base soil friction angle from 29 to 42, and backfill slope from 0 to 30. A comparative study with retaining walls built in Skikda city, Algeria, used a traditional method. The parametric study's findings demonstrate that raising the load and slope angle causes the structure's volume to increase. On the other hand, the cantilevered wall's volume decreases as the friction angle increases. The suggested model, however, is an effective and ideal design procedure for cantilever retaining walls, according to the results obtained. These algorithms exhibit effective performance in meeting both structural and geotechnical stability requirements at the same time. GA has been used to design retaining walls with success and has shown to be a reliable optimization method.

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