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CHDE Excel solver: Differential evolution with feasibility rules for optimizing cantilever retaining wall design

Công cụ CHDE tích hợp trong Excel: Sử dụng thuật toán tiến hóa vi phân kết hợp các quy tắc khả thi cho việc tối ưu hóa thiết kế tường chắn đất

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Abstract

Finding economical designs of cantilever retaining wall is a crucial task in civil engineering. This problem can be formulated as a constrained nonlinear optimization problem in which the objective is to identify a design solution having the lowest cost and satisfying all the required constraints. This study employs the Differential Evolution (DE) metaheuristic coupled with feasibility rules proposed by Mezura-Montes, et al. [1] to tackle the problem of interest. To enhance the applicability of the newly developed tool, a CHDE Excel solver incorporating the DE and Mezura-Montes rules has been constructed in Excel VBA platform. Experimental result points out that the CHDE Excel solver can be very potential to assist civil engineering in the task of designing cantilever retaining walls.

Keywords: Differential evolution; Mezura-Montes feasibility rules; evolutionary algorithm; retaining wall design.

Tóm tắt

Việc tìm kiếm thiết kế tối ưu về mặt kinh tế của tường chắn đất là một nhiệm vụ quan trọng trong xây dựng dân dụng. Vấn đề này có thể được mô hình hóa như là một bài toán tối ưu hóa phi tuyến bị ràng buộc trong đó mục tiêu là xác định một giải pháp thiết kế có chi phí thấp nhất và đáp ứng tất cả các ràng buộc. Nghiên cứu này sử dụng thuật toán tiến hóa vi phân (DE) kết hợp với các quy tắc khả thi được đề xuất bởi Mezura-Montes et al. [1] để tối ưu hóa thiết kế của kết cấu tường chắn. Công cụ mới được phát triển trên nền tảng Excel VBA. Kết quả thí nghiệm chỉ ra rằng công cụ CHDE Excel solver là một công cụ hiệu quả để hỗ trợ các kỹ sư trong việc thiết kế tường chắn đất.

Từ khóa: Tiến hóa vi phân; quy tắc khả thi của Mezura-Montes; thuật toán tiến hóa; thiết kế tường chắn.

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1. Introduction

In practice, soil retaining structures are widely employed to retain slopes during the construction phase of building foundations, bridge abutments, and mountain roads. These structures must be used to guarantee the construction safety and structural stability where a soil slope is not stable because of its inherent angle of inclination [2]. Particularly, the cantilever retaining wall is widely applied because of various advantages [3]: (i) This structure facilitates open excavation; (ii) Cantilever walls do not necessitate installation of tiebacks below adjacent areas; (iii) It is required in a simple construction procedure.

The main focuses of retaining wall design are geotechnical stability, structural strength, and economic efficiency [4]. In conventional method, the trial and error approach is often employed to obtain a good design solution iteratively. However, this traditional method is time consuming and cannot ensure a good design solution. To replace the trial and error approach, various scholars have resorted to modern metaheuristic algorithms including the Charged System Search algorithm [5], Big Bang Big Crunch [6], Biogeography-Based Optimization [7], Firefly Algorithm [8], etc. The employed metaheuristic algorithms are shown to be capable of determining economical design solutions with satisfaction of all the required constraints.

Generally, to design a simplified case of retaining wall structure, the objective function can be the weight of the structure and the constraints are established to ensure the stability of the structure. The problem of interest is complex because the decision variables are search in continuous space with nonlinear constraints. This study contributes to the body of knowledge by constructing an optimization tool based on the well-known Differential Evolution coupled with feasibility rules proposed by Mezura-Montes, et al. [1] to optimize the design of a cantilever retaining wall. This tool is developed in Excel VBA platform to facilitate its application. The Excel solver, named CHDE, is then used to solve a design optimization problem presented in the work of Xiao [2].

2. Constrained optimization problem

A constrained optimization task can be generally stated as follows [9, 10]:

Find min. of an objective function $f(x)$

where $f(x_1, x_2, x_d, \ldots, x_D)$, $d = 1,2,\ldots,D$ (1)

Subjected to:

$g_q(x_1, x_2, x_d, \ldots, x_D) \leq 0$, $d = 1,2,\ldots,D$, $q = 1,2,\ldots,M$ (2)

$h_r(x_1, x_2, x_d, \ldots, x_D) = 0$, $d = 1,2,\ldots,D$, $r = 1,2,\ldots,N$ (3)

$x_d^L \leq x_d \leq x_d^U$ (4)

where, $f(x_1, x_2, \ldots, x_D)$ denotes the objective function. $x_1, x_2, \ldots, x_D$ are design or decision variables which are to be determined by the optimization algorithm. $g_q(x_1, x_2, \ldots, x_D)$ and $h_r(x_1, x_2, \ldots, x_D)$ denote inequality and equality constraints; x_d^L, x_d^U represent lower and upper boundaries of x_d; D is the number of design variables; M and N denote the numbers of inequality and equality constraints, respectively.

For dealing with constrained optimization, penalty functions are commonly employed [10-15]. These methods are simple and easy to be incorporated into metaheuristic. Nevertheless, they often suffers from certain drawbacks such as the selection of penalty coefficients [13] and low performance when dealing with complex constrained optimization problems. To obtain better optimization performance, various constraint-handling strategies have been proposed including the rules of Deb [11], DE with Deb's rules [16], ε methods [17, 18], feasibility rules based approaches [1] etc.

3. Differential evolution (DE) with feasibility rules

The DE aims at exploring and exploiting the search space by first creating an initial population of *NP* solutions. In each evolutionary generation, this optimizer attempts to identify the most desired values of decision variables by employing a novel mutation-cross over strategy. Subsequently, the newly created trial vector (a product of the DE's mutation-cross over strategy) competes with its parents via a greedy selection operation. The mutation and cross over operations of the DE algorithm are presented in the equations 5 and 6:

$$V_{i,g+1} = X_{r1,g} + F(X_{r2,g} - X_{r3,g}) \quad (5)$$

where *r1*, *r2*, and *r3* are three random indexes lying between 1 and *NP*. *F* denotes the mutation scale factor. $V_{i,g+1}$ denotes the mutant vector.

$$U_{j,i,g+1} = \begin{cases} V_{j,i,g+1}, & if \ \ rand_j \le Cr \ \ or \ \ j = rnb(i) \\ X_{j,i,g}, & if \ \ rand_j > Cr \ \ and \ \ j \ne rnb(i) \end{cases} \quad (6)$$

where $U_{j,i,g+1}$ is a trial vector. $rand_j$ is a uniform random number ranging between 0 and 1. *Cr* is the crossover probability. *rnb(i)* denotes a randomly chosen index of $\{1,2,..., NP\}$.

The standard DE is only designed to solve unconstrained optimization problems. To deal with constrained ones, Mezura-Montes, et al. [1] put forward the following feasibility rules for coping with constrained optimization problems:

(i) Between two feasible solutions, the solution with the lower cost function value wins.

(ii) If the first solution is feasible and the second one is infeasible, the first solution wins.

(iii) If both solutions are infeasible, the one with less constraint violation wins.

4. Application of the CHDE-Excel solver

Since the spreadsheet in Microsoft Excel is a helpful tool for civil engineering design and the available Excel solvers have not employed these two aforementioned computational methods for coping with constrained optimization problems, this research develops the CHDE Excel solver which implements the DE algorithm and the feasibility rules proposed by Mezura-Montes, et al. [1]. This section of the article presents the application of the newly developed CHDE Excel solver with a case study adopted from the previous work of Xiao [2].

The graphical user interface of the tool is presented in **Fig. 1** and can be opened by clicking on the button '**Open CHDE Solver**' The user also can define the decision variables, upper bounds, lower bounds, type (real, integer, or binary), constraints, and the cost function of the optimization problem. It is noted that the default optimization problem is minimization and all of the constraints are given in the following form:

$$G(x) \ge 0 \quad (7)$$

A case study presented in **Fig. 2** is used to demonstrate the usefulness of the newly developed Excel solver. There are 7 decision variables needed to be searched by the CHDE solver (refer to **Fig. 3**). The type of the variables is real value (denoted as 1). The problem parameters including the information regarding soil layers are provided in **Table 1**.

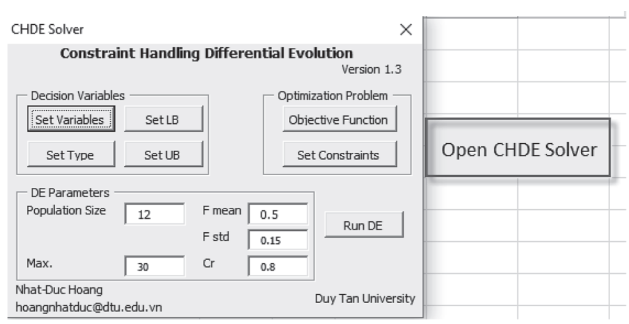

Fig. 1 The CHDE-Excel Solver's graphical user interface

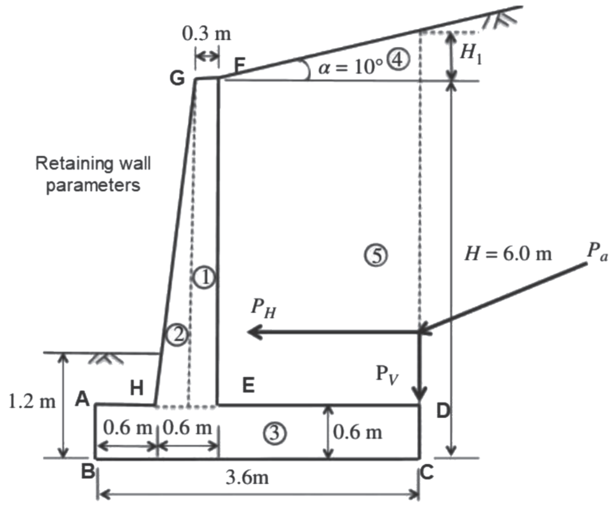

Fig. 2 Graphical presentation of the case study

	A	B	C	D	E
1	**Decision variables**		**Lower Bound**	**Upper Bound**	**Type**
2	H_dv =	0	5	8	1
3	D_dv =	0	1	1.5	1
4	AB_dv =	0	0.2	2	1
5	AH_dv =	0	0.2	2	1
6	HE_dv =	0	0.2	2	1
7	GF_dv =	0	0.2	2	1
8	ED_dv =	0	2	8	1

Fig. 3 The decision variables

Table 1 Problem parameters

γ'1	18.10	kN/m^3
φ'1	0.52	Rad
c'1	0.00	
γ'2	17.30	kN/m^3
φ'2	0.35	Rad
c'2	38.30	kPa
α	0.17	Rad
γ (Concrete)	23.56	kN/m^3
D	1.20	m

For more details of the computing process needed to obtain the resisting moment, the overtuning moment, the factor of safety against overtuning, the factor of safety against sliding, and the factor of safety for bearing capacity, the readers are guided to the previous work of Xiao [2]. The cost function of the problem is the total structure weight; the constraints are constructed by forcing the factors of safety to be greater than certain thresholds. For instance, the thresholds for overtuning, sliding, and bearing capacity are 2, 1.5, and 3, respectively. Moreover, the condition of eccentricity must be satisfied. In addition, HE must be longer than GF. Thus, in total, there are 6 constraints. The optimization results of the CHDE after 30 generations are presented in **Fig. 4**. The cost function is 63.3 kN/m and all of the six constraints are satisfied. As can be observed from the results, the Excel Solver based on DE and feasibility rules is able to identify good values of the decision variables.

	A	B	C	D	E	F	G	H	I	J	K
1	**Decision variables**		**Lower Bound**	**Upper Bound**	**Type**				**Objective Function**		
2	H_dv =	**6.247**	5	8	1			MIN	f =	**63.30**	kN/m
3	D_dv =	**1.001**	1	1.5	1						
4	AB_dv =	**0.201**	0.2	2	1			**Constraint 1**	**10.09**	>=	**0**
5	AH_dv =	**0.234**	0.2	2	1			**Constraint 2**	**0.10**	>=	**0**
6	HE_dv =	**0.215**	0.2	2	1			**Constraint 3**	**1.09**	>=	**0**
7	GF_dv =	**0.201**	0.2	2	1			**Constraint 4**	**0.01**	>=	**0**
8	ED_dv =	**6.671**	2	8	1			**Constraint 5**	**2.66**	>=	**0**
9								**Constraint 6**	**0.01**	>=	**0**

Fig. 4 Optimization results of the CHDE-Excel Solver

4. Conclusion

This work develops a CHDE-Excel solver based on the DE algorithm and the feasibility rules proposed by Mezura-Montes, et al. [1] to tackle the constrained optimization problem of cantilever retaining wall design. The CHDE-Excel solver has been programmed in Visual Basic with Application. Users can further implement the tool for optimizing similar retaining wall structures and the other structure design optimization problems.

Supplementary material

The Excel solver can be downloaded at https://github.com/NhatDucHoang/CHDE-Solver

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