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Optimization of earth dams clay core dimensions using evolutionary algorithms

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ABSTRACT

Slopes stability and seepage of earth dam are two important items to design earth dam core in field of geotechnical engineering. Recently, using of evolutionary algorithms have been widely attracted attentions for optimizing the earth dams. In this study, three evolutionary algorithms including Shuffled Complex Evolution (SCE), Simulated Annealing (SA) and Genetic Algorithm (GA) have been developed to optimize the geometry of Birjand Hesar Sangi earth dam core based on seepage integration, hydraulic gradient, and safety factor of stability constraints. Several parameters including material type, size and shape of the core dam have been considered to perform the optimization process. Furthermore, material volume and dam seepage are two objective functions which are minimized. The results of performances indicated that SCE, SA, and GA algorithms produced 14, 12.8 and 12.4 percent reduction of the dam cost, respectively. Also, the values of the core dimensions, coefficient of stability, leakage from the body, and hydraulic gradient were obtained from alternative evolutionary algorithms. Development of SCE algorithm was proven remarkably prosperous capability in form of 24 percent reduction for material type in dam core and 8.5 percent in shell dam.

Keywords: Shuffled Complex Evolution (SCE); Simulated Annealing (SA); Genetic Algorithm (GA); Earth Dam; Seepage; Clay Core

INTRODUCTION

Dams are structures that are used especially for water storage, energy production, and irrigation. Dams are mainly divided into four parts on the basis of the type and materials of construction as gravity dams, buttress dams, arch dams, and embankment dams [8].These dams are divided into two types: homogeneous and non-homogeneous earth dams. Non- homogeneous dams are made of different parts that each part has much influence separately on the dam body's performance, stability, and other design components. In designing of an earth or rock fill dam, the foundation, abutments, and embankment should be considered as a unit. The entire assemblage must retain the reservoir safely without excessive leakage. Provisions for seepage control have two independent functions. The first is reduction of water losses loss water reduction to an amount compatible with the project purpose. Another independent function is that, eliminating the possibility of structure failure by piping. It may also be concerned with the stability of construction slopes and slopes around the reservoir after impoundment. One of the most important components in dam designing is the dam core. The dam core is significant factor in caulking and controlling dam body seepage. In unconsolidated terrain, when leakage velocities reach critical values, erosion takes place giving rise to sub fusion and subsidence leading to the dam collapse [19, 24]. Also, it establishes the importance of mapping the seepage paths and monitoring the changes in seepage as a function of time. In case of dam designing, the core should be made of fine materials due to its low permeability. Furthermore, dam core has relatively lower shear strength compared to the other parts. So considering the dam persistence, it is better to choose the core thinner on the other hand the thicker the core the more resistant the dam is. The seepage process will be reduced because the seepage and inner corrosion and the cracking risk [27]. From the previous investigations, it is established that the economic considerations can be determined as one of the most significant factors in selection of the dam core geometry. Several studies of dam seepage were carried out with different conditions of field and laboratory. Occasionally, using of experimental and field investigations cause too much cost of equipments to measure data sets, compared to the numerical and mathematical methods. Mathematic solutions take times and these methods can be produced inaccurate performances. Recently, various numerical methods have been used widely to identify different aspects of dam problems. Goldin and Raskaz (1985 [10]) initiated optimization studies for the clay core of the homogeneous dam using complete factor test and factor analysis. They utilized factor analysis method to optimize the design of the dam in charge of choosing various sources of bond and shell slopes. For optimum design of a 70 meters dam, four alternative options were presented for different sources of bond and side slopes of dam. They also applied the full operatingmethod for a high dam (300 meters) to choose the effects of the stability factor. Results indicated that the shell side's embankment plasticity is more than the core itself. Also, and it imposes a thin and straight core. On the other hand, if the shell side's embankments are much less plastic than the clay dam core, an inclined core will be more justifiable [10]. Pavlovsky (1956 [25]) developed an approximate method which allowed the piecing together of flow net fragments to develop a flow net for the total seepage problem. This method termed the "Method of Fragments" that, allows seepage problems with relatively higher complication to be resolved by breaking them into parts, analyzing flow patterns for each, and reassembling the parts to provide an overall solution. Harr (1962 [13]) explained the use of transformations and mapping to transfer the geometry of a seepage problem from one complex plane to another. Hadi (1978 [12]) studied the seepage through embankments into adjacent drains. In his investigation, the soil has been assumed to be homogeneous and isotropic. Also, the water flow was steady state condition. Flow nets for the different flow patterns were drawn using the circle method, for predicting the seepage discharges. Ishaq (1989) used a finite difference coordinate transformation to get pressure distribution under hydraulic structure and exit gradient with and without sheet pile in upstream or downstream only, resting on anisotropic porous media. Hillo (1993 [14]) used finite element method for seepage below hydraulic structures on anisotropic soil foundation. The structural appearance of the dam was examined by Hitashy (1996 [15]) using genetic algorithm. In their study, decision and construction supporting systems were developed to design the dam appearance. Aubertin *et al*, (1996 [4]) used commercial code/software to solve the unsaturated problems of multi-layer covers for an infinite aquifer pumping test. This software solves the underground water problems for stable, unstable, saturated and unsaturated conditions.

Griffiths and Fenton (1997 [11]) combined random field generation and finite-element techniques to model steady seepage through a three-dimensional (3D) soil domain in which the permeability was randomly distributed in space Furthermore, Khsaf (1998 [20]) used finite element method to analyses seepage flow through pervious soil foundation underneath hydraulic structures that provided with flow control devices. it can be eliminated. Irzooki (1998 [17]) applied different technical study of seepage problems on the left side of Al-Qadisiya dam. Boger (1998 [6]) solved three-dimensional flux equations in transient condition by neglecting capillary forces. the capillary force in steady sate condition was considered as significant parameter through seepage problem. Akyuz and Merdun (2003 [2]) carried out experiments for predicting the seepage from an earth dam placed on an impervious base by using the Hele-Shaw viscous fluid. They validated their results with several traditional equations. Benmebarek *et al*, (2005 [5]) used the finite difference method to numerical studies of seepage failure of sand soil within a cofferdam. Based on this study, the conditions for seepage failure are clearly identified by using the boiling. Abdul Hussein *et al*, (2007 [1]) used multi-objective functions by weighting method to optimize the designing of the homogeneous earth dam. Andrew and Anop (2009) applied genetic algorithm to determine the critical failure level in slope stability analysis. Furthermore, Nazari Giglou and Zeraatparvar (2012 [23]) presented the physical and geometric factors of earth dam such as permeability, upstream and downstream slope of the dam to solve seepage problem. The seepage rate through homogeneous earth includes saturated and unsaturated flow. The amount of water seeping through and under an earth dam, can be estimated by using the theory of flow through porous media. This theory is one of the most common analytical tools that are used widely by engineers. The computed amount of seepage is useful in estimating the loss of water from the reservoir. The estimated distribution of pressure in the pore water is used primarily in the analysis of stability against shear failure that is used widely by engineers study the hydraulic gradient at the point of seepage discharge which gives a rough idea of the piping potential (Sherard *et al*, 1963).

Different aspects of seepage phenomena have been investigated because seepage through the dam body and under the foundation adversely affects dam stability. This study specifically investigated seepage in dam body. The seepage in the dam body follows a phreatic line. In order to understand the degree of seepage, it is necessary to measure it. In this study, a numerical model is developed to analyze the seepage problem. The core thickness depends on the seepage, the anticipated resistance to cracking and erosion of the available materials. In all but the more pervious core materials, a relatively thin core will suffice to keep the seepage to a negligible amount. A thin core will dissipate pore pressures more rapidly than a thick one. Also, it is safer during sudden drawdown. A thick core is more resistant to erosion, particularly if small cracks should develop from settlement. Also the core volume reduction as an impermeable part helps to economize plan. Determination of the appropriate core size which has a minimum size is necessary in order to supply the demands and constraints. In this way, powerful optimized methods including the SA, SCE, and GA algorithms based multi-objective function and specified constraints are proposed to find out the size of the clay core dam.

MATERIALS AND METHODS

One of the key aims of this study is to develop the numerical model for measuring seepage through dam, stability factor and hydraulic gradient based on materials and geometry specification of earth dams. Figure1 shows the sample model of problem.

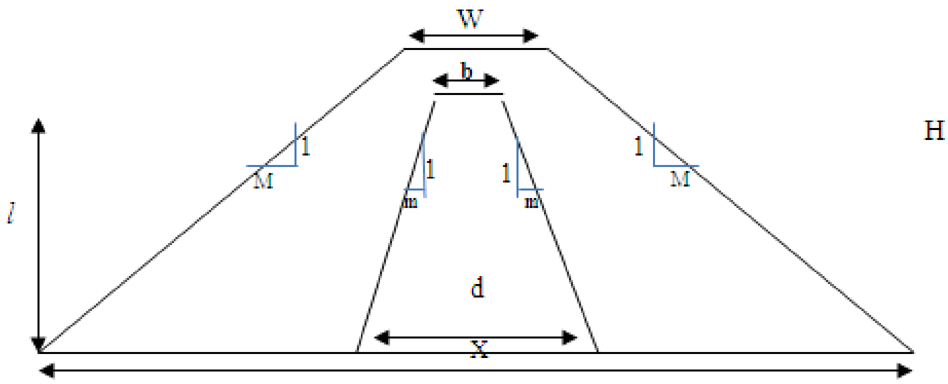

Figure 1. Sample model of problem

Description of the Simulated Annealing

SA algorithm is a computational stochastic technique for obtaining near global optimum solutions to combinatorial and function optimization problems. Kirkpatrick *et al*, (1983 [21]) stated that the method is inspired from the thermodynamic process of cooling (annealing) of molten metals to attain the lowest free energystate. When molten metal is cooled slowly enough it tends to solidify in a structure of minimum energy. This annealing process is minimized by a search strategy. The key principle of the method is to allowoccasional worsening moves so that these can eventuallyhelp locating the neighborhood to the true (global) minimum.

The associated mechanism is given by the Boltzmann probability:

$$P = exp\left(-\frac{\Delta E}{TK_B}\right) \tag{1}$$

where $\Delta E$is the change in the energy value from one point to the next, K_B is the Boltzmann's constant and T *is* the temperature (control parameter). The ΔE parameter refers to the value of the objective function and the temperature. Furthermore, the T is a control parameter that regulates the process of annealing. The consideration of such a probability distribution leads to the generation of a Markov chain of points in the problem domain. The acceptance criterion given by Eq. (1) is popularly referred to as the Metropolis criterion (Metropolis *et al*, 1953 [22]). Another variant of this acceptance criterion (for both improving and deteriorating moves) has been proposed by Galuber (1963 [9]) and can be written as:

$$P = \frac{exp\left(-\frac{\Delta E}{T}\right)}{1+exp\left(-\frac{\Delta E}{T}\right)} \quad (2)$$

In simulated annealing search strategy: at the start any move is accepted. This allows us to explore solution space. Then, gradually the temperature is reduced which means that one becomes more and more selective in accepting new solution. By the end, only the improving moves are accepted in practice. The temperature is systematically lowered using a problem-dependent schedule characterized by a set of decreasing temperatures. Prilot (1996 [26]) discussed more about the parameters used in simulated annealing algorithms. Due to its simplicity and versatility, simulated annealing has the distinction of being one of the most widely used techniques for both function and combinatorial optimization problems.

Description of the Genetic Algorithms

Genetic algorithms are stochastic numerical search procedures inspired by biological evolution, cross-breeding trial solutions and allowing only the fittest solutions to survive and propagate to successive generations. They deal with a population of individual (candidate) solutions, which undergo constant changes by means of genetic operations of reproduction, crossover, and mutation. These solutions are ranked according to their fitness with respect to the objective function where the fit individuals are more likely to reproduce and propagate to the next generation. Based on their fitness values, individuals (parents) are selected for reproduction of the next generation by exchanging genetic information to form children (crossover). The parents are then removed and replaced in the population by the children to keep a stable population size. The result is a new generation with (normally) better fitness. Occasionally, mutation is introduced into the population to prevent the convergence to a local optimum and help generate unexpected directions in the solution space. The more GAs iterates, the better their chance to generate an optimal solution. After a number of generations, the population is expected to evolve artificially, and the (near) optimal solution will be reached. The measure of success is the convergence to a population with identical members. The global optimum solution however cannot be guaranteed since the convexity of the objective function cannot be proven.

Description of the Shuffled Complex Evolution

The Shuffled Complex Evolution (SCE) algorithm combines the strengths of the controlled random search (CRS) algorithms with the strategy of competitive evolution and the newly developedconcept of complex shuffling. The SCE strategy is presented below (Duan et al., 1993).

Step 0. Initialize. Select p≥1 and m≥n+1, where p is thenumber of complexes, m is the number of points in each complexand n is the number of independent variables in the optimizationproblem. Compute the sample size s=p×m.
Step 1. Generate sample. Sample s points $x_1,\dots,x_s$ in the feasible Space ΩCR^n. Compute the function value f_i at each point x_i. In theabsence of prior information, use a uniform sampling distribution.

Step 2. Rank points. Sort the s points in order of increasingfunction value. Store them in an array $D=\{x_i,f_i, i=1\dots,s\}$, so that i=1 represents the point with the smallest function value.

Step 3. Partition into complexes. Partition D into p complexes$A_1,\dots,A_p$, each containing m points, such that:

$$A^k=\{x_j^k, f_j^k | x_j^k = x_{k+p(j-1)} f_j^k = f_{k+p(j-1)}, j = 1,\dots,m\}$$

Step 4. Evolve each complex. Evolve each complex A^k, k=1,…,p according to the competitive complex evolution (CCE) algorithm.

Step 5. Shuffle complexes. Replace $A_1,\dots,A_p$ into D, such that $D=\{A^k, k=1,\dots,p\}$. Sort D in order of increasing function value.

Step 6. Check convergence. If the convergence criteria are satisfied, stop; otherwise, return to Step 3.

The CCE algorithm is required for the evolution of each complex in Step 4 of the SCE method is presented below (Duan et al., 1993).

Step 0. Initialize. Select q, a, and b, where $2 \leq q \leq m$, $\alpha \geq 1$, and$\beta \geq 1$.

Step 1. Assign weights. Assign a triangular probability distribution to A^k; i.e.,

$P_i = 2(m+1-i) / m (m+1)$, i = 1,...,m

The point x_i^k has the highest probability,ρ_l=2/m+1. The point x_m^k has the lowest probability, ρ_m=2/m(m+1).

Step 2. Select parents. Randomly choose q distinct points $u_1,...,u_q$ from A^k according to the probability distribution specified above. Store them in array B ={u_i ,v_i ,i = 1,...,q}, where $v_j$is the function value associated with point u_j. Store in L locations of A^k which are used to construct B.

Step 3. Generate offspring. Sort B and L so that the q points are arranged in order of increasing function value. Compute the centroidg using the expression

g =[1/(q-1)$\sum_{j=1}^{q-1} u_j$]. Compute the new point r =2g-u_q .

Step 4. Replace parents by offspring. Replace B into A^k using the original locations stored in L. Sort A^k in order of increasing function value.

Step 5. Iterate. Repeat steps (1) through (4) b times, where $b \geq 1$ s a user- specified parameter which determines how many offspring should be generated (β can be generated by each independently evolving complex between two consecutive shuffles).

According to the suggestions of Duan *et al*, (1993 [7]), tuning parameters of the SCE algorithm are set as follows in this study: the size of a complex m and the number of offspring β are all chosen to be equal to 2n+1, where n is the dimension of the problem. The size of each sub complex selected for generation of an offspring is n+1. The value of the parameter α is set equal to 1 (only one step evolution of each simplex is permitted). The primary tuning parameter to be selected in this method is the number of complexes p, which is set equal to n.

The philosophy behind the SCE approach is to treat the global search as a process of natural evolution [7]. The sampled points constitute a population. The population is partitioned into several communities (complexes), each of which is permitted to evolve independently (i.e., search the space in different directions). After a certain number of generations, the communities are forced to mix, and new communities are formed through a process of shuffling. This procedure enhances survivability by a sharing of the information (about the search space) n gained independently by each community.

The SCE method is designed to improve on the best features of the CRS method (i.e., global sampling, complex evolution), by incorporating within it the powerful concepts of competitive evolution and complex shuffling. Both competitive evolution and complex shuffling help to ensure that the information contained in the sample is efficiently and thoroughly exploited. They also help to ensure that the information set does not become degenerate. These properties enable the SCE approach to have better global convergence features over a broader range of global optimization problems [7]. Also, SCE flow chart was presented in Figure 2.

Modeling

In this study, a new model is proposed to predict seepage rate, slope stability, hydraulic gradient in non-homogeneous earth dams using Geo-Studio software. Thorough this model, seepage, slope stability, and hydraulic gradient are formulated by different factors which are related to material properties and geometric dimensions of dam. It should be noted that permeability in shell for the non-homogeneous earth dams is more than core. Hence, the seepage rate for shell can be ignored because existing remarkable difference between shell and core dam. Therefore, the core can be considered as a homogeneous dam [10]. In the research, 150 assumed sections with different materials and dimensions are designed. Ranges of effective parameters for optimization problem are given in Table 1.

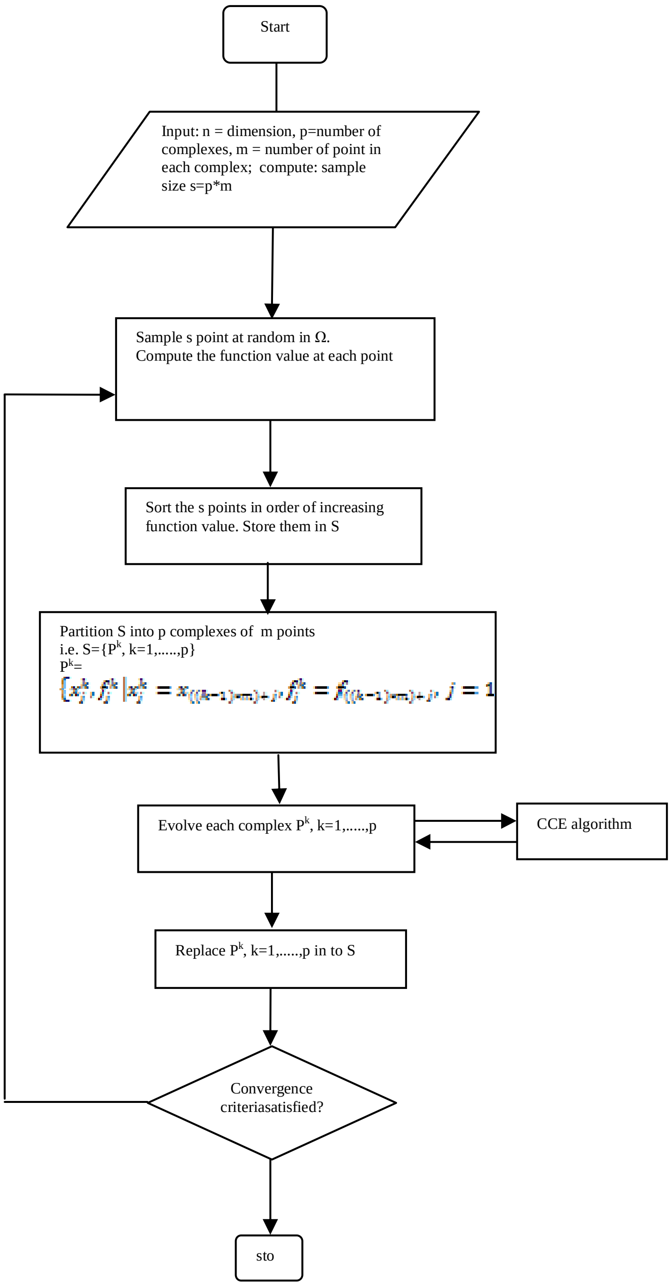

Figure 2. SCE flowchart

Table 1. Up and down limit of effective parameters

Effective Parameter	Low Bound	Up Bound
Dam Height (meter)	15	40
Crest Width of core (m)	3	6
Up-stream Slope of Shell	1(Vertical):2(Horizontal)	1(V):5(H)
Down Stream Slope of Shell	1(V):2(H)	1(V):4(H)
Up Slope of Core	1(V):0.15(H)	1(V):0.53(H)
Down Slope of Core	1(V):0.15(H)	1(V):0.53(H)

Performances of FEM-software for assumptive dam models were analyzed using non-linear regression model. Correlation coefficient (r^2) and standard error were considered in order to determine the model validity. For accessing the objective, a consolidated model consisted of a simple model obtained using linear regression and SA, SCE and GA algorithms. In addition, evolutionary algorithms were coded using the MATLAB package.

Seepage Model

In present study, 150 sections with different materials and dimensions were molded using SEEP/W. Geometric parameters and materials characteristics are independent variables and seepage rate is dependent variable. Independent variables are recognized as a partial regression coefficient. It indicates increasing in dependent variables against adding a one unit to independent variables. Performance of linear regression model provided high accuracy (R=0.93 and Std=0.067). The regression model for predicting the of seepage rate was expressed as follows:

$$q=(2.167-0.958\,\frac{d}{h})\times k\times l \qquad (3)$$

Where q = Seepage in unit of dam length (m^3 / s /m) ; k = Permeability coefficient of core (m/ s) ; l = Water height in dam reservoir (m) ; h = Dam height (m) ; d = Core width on foundation (m).

Slope Stability Model

Modeling of slope stability for 150 assumed sections with different materials and dimensions performed using SLOPE/W. Geometric parameters and materials characteristics were considered as independent variables. Also, the seepage rate is dependent variable. Performance of linear regression model provided high accuracy and appropriate correlation (R=0.909 and Std=0.0098). The regression model for predicting the stability was expressed as follows:

$$SF=0.354+1.548\tan\emptyset+0.033\,\frac{d}{x}+2.194\,\frac{c^{'}}{\gamma h} \qquad (4)$$

Where SF = Slope stability; x = Dam width on foundation (m); $\emptyset$= Angel of internal friction; $c^{`}$ = Effective cohesion (kg/cm^2) ; γ= Specific weight (kg/m^3).

Hydraulic Gradient Model

Modeling of slope stability for 150 assumed sections with different materials and dimensions was carried out using SEEP/W. Geometric parameters and materials characteristics were considered as independent variables. Also, the seepage rate is dependent variable. Basis on assumptions mentioned in modeling section, the core dam was considered as a homogeneous media [10]. Furthermore, it should be noted that the seepage curve was linearized.

linear regression model provided good performances (R=0.92 and Std=0.0098). The regression model for prediction of hydraulic gradient was expressed as follows:

$$i=0.76-1.625\frac{l}{s} \qquad (5)$$

$$s=(l^2+(d*l-0.35(d-b).l)^2)^{0.5} \qquad (6)$$

Where i = hydraulic gradient; s = leak line length (m); b =crest width of core (m).

Optimization

With regarding the preventing seepage from the dam body, the stability safety factor and hydraulic gradient were considered as constrains problem for minimizing the dimensions of the clay core dam. In this section, descriptions of design variables and objective function would be discussed.

Variables design

Generally, two types of variables are available dam cross designing. At the first, environmental variables which are functions of the location of the plan such as bond sources and material properties are defined as parametric variable. Another type is geometrical variables which some of them are fixed such as the core axis angle . Also, the reminding parametric variables are included those of the height and width of the dam crest which integrated as design variables in the objective function. In this study, vector of design variables is expressed as follows:

$X = \{X_1, X_2, X_3\}$

Which X_1 , X_2, and X_3 are the core crown width, core width on foundation, and dam width on foundation, respectively. The parametric variables include *h* (total height of the dam), *l* (water level upstream of the dam), and *w* (width of the dam crest).

Objective Function

Estimation of effective cost involves the use of data derived from the most current pricing for materials, appropriate wages and salaries, accepted productivity standards, and customary construction practices, procurement methods, equipment needs, and site conditions. Cost estimation is determined with regarding the inherent levels of risk and uncertainties.

Typically, each new cost estimation for a specific project is based on increasing levels of project refinement and more detailed levels of design data. Cost estimation are developed based on the best available information at the time, the cost estimating based on mentioned information should be considered remarkably in terms of high accuracy and confidence.

The purpose of this study is to reduce seepage through dam and volume of earth dam materials is defined as a function of cost. Hence, the objective function is expressed for cost estimation in form of:

$$T = C_S + C_C + C_W \quad (7)$$

Where T, C_S, C_C and C_W are Total cost, construction shell cost, construction core cost and costs of water waste from a leaking dam respectively.

Cost of the Shell

Total materials volume used to construct the shell of the earth dam is calculated by following equation:

$$F_1 = \left(\frac{1}{2}[(x_3 + w) \times h] - \frac{1}{2}[(x_2 + x_1) \times h]\right) \times b \quad (8)$$

Where $F_1$is the materials volume (m^3/ m) and b is the length of the crest.

Cost of the shell (C_S) is equivalent to:

$$C_S = F_1 \times K_1 \quad (9)$$

where K_1 is the cost per cubic meter of earth shell dam.

Cost of the Core

Total materials volume used for the construction of the core of the earth dam is calculated by following equation:

$$F_2 = \left(\frac{1}{2}[(x_2 + x_1) \times h]\right) \times b \quad (10)$$

Where F_2 is the volume of the earth material (m^3 / m)

Costs of the core (C_C) is equivalent to:

$$C_C = F_2 \times K_2 \quad (11)$$

Where K_2 is the cost per cubic meter of the earth core.

the stability constraint is a function of the parameters of the dam body. In addition, an appropriate slope is obtained through optimizing the core dimensions and dam embankment shell.

Amount of Leakage from the Dam Body

As it mentioned before, Eq.(12) is applied to predict amount of leakage from the dam. Through the optimization problem, Eq.(12) entered the problem by following equation:

$$q = \left(2.167 - 0.958\ \frac{x_2}{h}\right) \times k \times l \times b \tag{12}$$

Where q is the term of cubic meters of waste water in a year

The cost of wasted water per cubic meter from the body of the dam is 1000 Rials. Considering the actual life of 30 years, an interest rate of 15 percent of the cost of wasted water has been calculated over the actual life of the dam.

Constrains Design

Here for reduction of objective function based on designing variables, constraints presented as follows:

For considering static stability of the dam in the steady seepage conditions, a factor is presented as Stability Safety Factor (SF) that should not be less than 1.5 (U.S Army, 2003).

leakage from the dam body caused un stability of dam so, the methods for reduction of seepage through dam body is essential. Therefore, hydraulic gradient (*i*) is presented as constraint that must be less than the critical value (i_{cr}). Here, since the critical hydraulic gradient is calculated for the materials equal to 1. the constraint is defined in front of:

$$i=0.76-1.625\frac{1}{s} \tag{13}$$

Where *s* is the length of the phreatic line that is calculated using Eq.(6).

Figure 3. illustrated the result of convergence of the SCE, SA and GA algorithms for the optimization problem.

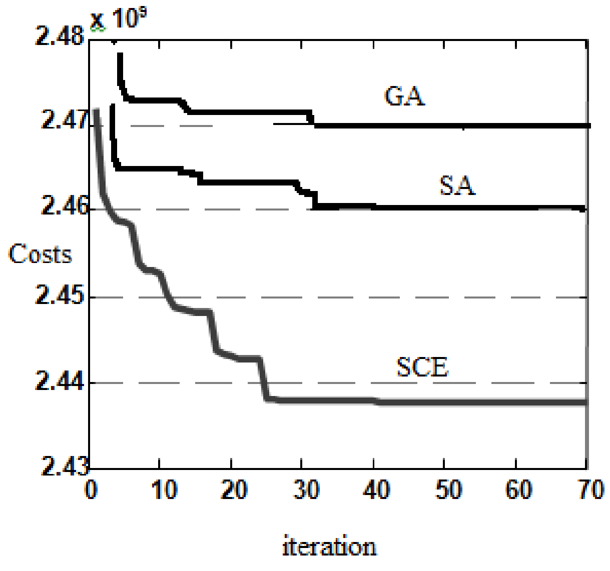

Figure 3. Result of convergence for the used evolutionary algorithms

From the Figure 3, it is clear that SCE algorithm accesses to the optimal value the optimal values were met for the two other algorithms in more than 30 iterations. That indicated the higher performance of SCE algorithm, compared to the SA and GA algorithms.

Case Study

The Hesar Sangi dam is a earth dam with vertical clay core as a nutrition –storage in Birjand. It has with storage capacity of two million cubic meters of water that was constructed in 2003. Also, it is located 120 kilometers northern of Birjand and five kilometers up of the Hesar Sangi village (latitude $32^0 53^{'}$, longitude $59^0 13^{'}$), across the Dahaneh river. Figure 4. shows the location of this earth dam. Dam material properties and geometries are presented in Table 2 and 3, respectively.

Figure 4. Location of Hesar Sangi Dam

Table 2. Dam material properties

Parameters	Shell	Core
Ø	40	30
$\gamma(\frac{kg}{m^3})$	2260	2080
$\gamma_w(\frac{kg}{m^3})$	10000	10000
$c^{'}(kg/cm^2)$	0.05	0.3
K(m/year)	182.28	0.06

Table 3. geometries properties

Crest length(*m*)	250
Crest width(*m*)	6
Dam height (*m*)	15
core crest width (*m*)	4
Core width on foundation (*m*)	9.8
Slope of Shell	1:2.5
Slope of Core	1: 0.21
Dam width on foundation (*m*)	75

RESULTS AND DISCUSSION

In modeling the material properties of Hesar Sangi earth dam, a grouped known parameters such as the height and the width of the dam crest are used (Table 4). the values of the core dimensions, coefficient of stability, leakage from the body and hydraulic gradient obtained from a models development were compared with actual values of the dam. The cost of Hesar Sangi dam construction with actual dimensions is 2.82×10^9 Rials. While the costs of the dam construction using the SCE, SA ,and GA algorithms were 2.43×10^9, 2.46×10^9 and 2.4762×10^9 Rials, respectively. In the other hand, the results of performances indicated that SCE, SA, and GA algorithms produced 14, 12.8,and 12.4

percent reduction of the dam cost, respectively. Development of SCE algorithm was proven remarkably prosperous capability in form of 24 percent reduction for material type in dam core and 8.5 percent in shell dam.

Table 4. Comparison of actual dimension by optimal dimension of clay core

	actual dimensions of clay core	optimal dimensions of clay core (SA)	optimal dimensions of clay core (SCE)	optimal dimensions of clay core (GA)
core crest width (*m*)	4	3.4	3	3.42
Core width on foundation (*m*)	9.8	7.58	7.5	7.55
Slope of Shell	1:2.5	1: 2	1:2	1: 2.02
Slope of Core	1: 0.21	0.139	1:0.15	1:0.138
Dam width on foundation (*m*)	75	66.2	66	66.71
hydraulic gradient	-	0.46	0.45	0.46
Slope stability	-	1.69	1.79	1.69
Seepage	-	1.33	1.3	1.5

As indicated from the Table 4, core crest width, core width on foundation, slope of shell, slope of core, and dam width on foundation decreased actual dimensions. The SCE algorithm yielded relatively higher reduction values for the supply stability and hydraulic gradient constraints than those obtained by using the other algorithms. For instance, reduction values for the core crest width were obtained 25, 15, and 14.5 percent using the SCE, SA and GA algorithms, respectively. Result indicated that the SCE algorithm provided higher performance for optimization of clay core dimension in comparison with other algorithms.

CONCLUSION

In this paper, new regression models including leaking from dam body model ,hydraulic gradient model , and stability safety factor model were developed to calculate the designing variables. The results indicated the high performance of new regression models for determining coefficient of stability, leakage from the body, and hydraulic gradient. For developing the necessary model, hydraulic gradient and stability safety factor were considered as constraints Also, the objective function was expressed as costs of dam structure and waste water from the reservoir. This problem was optimized using the SCE, SA, and GA. The results of modeling were compared with actual geometry of Birjand Hesar Sangi earth fill dam. The values of the core dimensions, coefficient of stability, leakage from the body, and hydraulic gradient obtained from a models development were compared with actual values of the dam. The results of performances indicated that SCE, SA, and GA algorithms produced 14, 12.8, 12.4 percent reduction of the dam cost, respectively. Development of SCE algorithm was proven remarkably prosperous capability in form of 24 percent reduction for material type in dam core and 8.5 percent in shell dam.

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