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Optimization of Geometric Design of Retaining Wall by Differential Evolution Technique

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ABSTRACT
The retaining wall is generally employed for the construction of railways, highways, water front structures. Proper design of retaining wall is beneficial to retain earth at different levels on its either side to overcome the space scarcity. In this paper,Opposition based differential evolution (ODE) method being a global search technique is proposed to design the retaining wall maintaining the stability and geometry aspects.The opposition based learning strategy is applied to select the good candidates. To maintain the diversity in the population, migration strategy has been applied.The proposed ODE method enhances the capability to explore and exploit search space globally as well as locally.To design the retaining wall, the weight and cost of the retaining wall are minimized subject to feasible constraints.Exterior penalty method is applied to handle stability and geometry constraints. Sensitivity of the retaining wall design aspects with respect to height of wall, base soil friction, angle of shearing resistance and backfill slope have been investigated. The validity of proposed method is authenticated by considering three design proposals under diverse conditions. The obtained design of retaining wall gives better design than the traditional design by limit state method.

KEY WORDS: Retaining wall, Optimized design, Differential evolution (DE) method, Opposition based learning, Multi-parameter optimization. Meta-heuristic optimization algorithm

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I. INTRODUCTION

Retaining wall retains earth at different levels on its both faces and is provided at places where soil does not have sufficient space to attain stable slope. Retaining wall is generally employed for the construction of railways, highways, water front structures in cutting / filling. Retaining wall is also constructed to provide stability to the unstable soil mass in finite natural slope. The design of this important structure should be economical and safe against geotechnical and structural requirements. Presently, trial and error approach is followed by professionals for the design of retaining wall in accordance to the relevant codes.To initiate the design of retaining wall, the dimensions of retaining wall are fixed in accordance to the geotechnical requirements and then structural design of retaining was is completed. In casethe design fails structurally then dimensions are re-fixed as a next trial to achieve the successful design that may or may not be the economical design.

The load of retaining wall is transferred to the soil whose behavior depends on many parameters viz. type of soil, size of particles, degree of saturation, degree of compactness or consolidation, submergence of soil, direction of load (vertical, horizontal or inclined), type of load (dynamic or statics), type of retaining structure (rigid or flexible). The load carrying capacity of soil, earth pressure,friction between soil and concrete are the applications of geotechnical engineering which effect the design of retaining wall. Moreover, economics of retaining wall depends on change in load bearing capacity of soil, earth pressures, friction between soil and concrete [37].

Complex problems in various fields of science and technology need solution through Optimization techniques.Due to the actual and practical nature of the objective function or the model constraints,sometimes these problems become very complex. Optimization methods involved derivative-based techniques are outlined in[26,27]. These techniques are robust and have proven their effectiveness in handling many classes of optimization problems. Such techniques are sometime trapped in local minima, increasing computational complexity, and not being applicable to certain classes of objective functions. To overcome these shortcomingsnew optimization techniques are required to be developed. Heuristic optimization techniques are fast growing tools that can overcome most of the limitations found in derivative-based techniques.Metaheuristic algorithms are based on computational methods which uses iterative improvement of a candidate solution by some predetermined rules to optimize a problem. Metaheuristics are generally inspired by nature like bio-inspired [28]or ant colony [29]techniques. Metaheuristic optimization algorithms are classified into two categories: evolutionary algorithms and swarm intelligence algorithms [30].

Till date, many studies have been carried out for the optimization of design of retaining wall. To reach an optimal design, optimization procedures are followed whereby a mathematical modeling of design procedure is undertaken as objective function [1-5]. Metaheuristic optimization techniqueshave been utilized by many researchers for the optimal design of retaining wall because heuristics techniques are suitable to achieve global solution despite of the objective function(s) are of multimodal or discontinuous or non-differential nature.Ahmadi-Nedushan and Varaee [6]has implemented swarm intelligence techniquefor design of retaining wall.Particle swarm optimizationis used for design of reinforced concrete retaining wall by Khajehzadeh et al. [7].Modified particle swarm optimizationhas been applied byKhajehzadeh et al. [8] for the design of retaining wall. Gravitational search algorithmfor the optimization of retaining structures is used by Khajehzadeh and Eslami [9].Ceranic et al. [10]and Yepes et al. [11]utilized simulated annealing technique for optimum earth retaining structure. CO_2 optimization, ant colony optimization,harmony search,charged system search algorithm, hybrid firefly algorithmBig Bang Crunch were applied by Villalba et al. [12], Ghazavi and Bonab [13], Kaveh and Abadi [14], Kaveh and Behnam [15], Sheikholeslami et al. [16], Camp and Akin [17], respectively for the optimum design of concrete retaining wall.Sahab et al. [18], Pezeshk and Camp [19], Gholizadeh and Barati [20], Bekdas [21] hasapplied optimization techniques for design of various structural members like beams, columns, trusses, concrete walls. Das [22], Kashani et al. [23] and Khajehzadeh et al. [24]haveapplied optimization techniques for slope stability in the field of geotechnical engineering. Das and Basudhar [25] used optimization solution in rock mechanics.To summarize, a quality global solution procedure able to solve the design of retaining wall with better computational efficiency is a wide-open research field. It is better to use a solution procedure that is able to generate single solution as a final solution, which meets the design aspirations. Further, to support such procedure a search algorithm having balanced exploration and exploitation capability is needed, which ensures useful diversity in the population.

The intent of this paper is to focus on the applications of opposition based differential evolution algorithmsto design the retaining wall that minimizes the weight and cost subject to feasible stability and geometry constraints. Capacity constraints of the design of retaining wall are out of scope of this paper. Three design cases are considered to check the efficiency of the proposed algorithm. Moreover, sensitivity of the proposed algorithm to design retaining with respect to height of wall, base soil friction, angle shearing resistance and backfill slope has been investigated.In this study, continuous variables areundertaken for wall geometry used for optimal design of retaining wall.

II. DESIGN OF RETAINING WALL

Retaining wall depicted in Figure 1 has been modeled considering geometry variables such that width of base, X_1, toe width, X_2, base of stem, X_3, thickness of top of stem, X_4, thickness of base, X_5, distance of the face of stem from the face of heel, X_6, width of shear key, X_7 and depth of shear key, X_8.

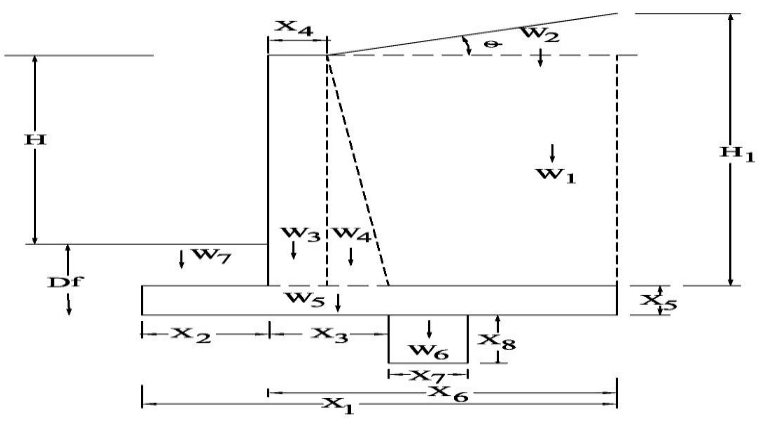


Figure 1: Retaining wall geometry

The focus of this research work is mainly on geotechnical design of retaining wall.The main characteristics of geotechnical design of retaining wall are its safety against overturning, sliding and load carrying capacity of soil. Figure 2 shows the disturbing as well as resisting forces acting on the retaining wall. Horizontal component of active earth pressure,P_{ah} is disturbing force whereas passive earth,P_p is resisting force. Vertical component of active earth pressure P_{av}, Weights, W_1 to W_7 of concrete and soil are resisting force for overturning and sliding failures whereas disturbing force for bearing capacity failure.

Coefficient of active, C_a earth pressure is defined mathematically as below [37]:

$$C_a = cos\theta \frac{cos\theta - \sqrt{\cos^2\theta - \cos^2\emptyset}}{cos\theta + \sqrt{(\cos^2\theta - \cos^2\emptyset)}} \ldots (1)$$

whereθ (degree) is slope of retained soil. $\emptyset$isan angle of shearing resistance of soil in degrees.

Coefficient of passive earth pressureC_p is stated below [37]:

$$C_p = \frac{1 + sin\theta}{1 - sin\theta} \ldots (2)$$

Height of retained soil above heal, H_1in m is computed from Figure 1 and given below:

$$H_1 = H + X_6 \tan\theta \qquad ..(3)$$

WhereH is the height of retaining wall (m)

$$P_{ah} = \frac{C_a \gamma_1 \mathrm{H_1}^2 cos\theta}{2} \ldots (4)$$

$$P_{av} = \frac{C_a \gamma_1 \mathrm{H_1}^2 sin\theta}{2} \ldots (5)$$

where $P_{ah}$and P_{av} are the horizontal and vertical active earth pressures forces per meter length in kN,respectively and γ_1 is unit weight of soil in kN/m^3(retained soil as well as soil below foundation)

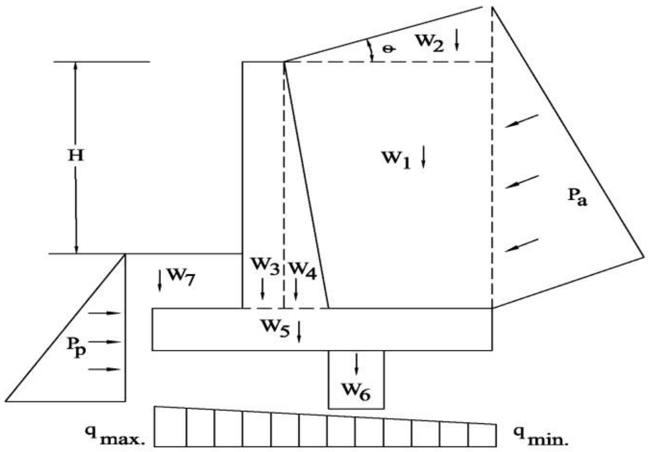


Figure 2: Forces acting on retaining

Factor of safety, FS_O against overturning is given below:

$$FS_O = \frac{M_r}{M_O} \ldots \ (6)$$

$$M_o = \frac{C_a \gamma_1 \mathrm{H_1}^3 sin\theta}{6} \ldots \ (7)$$

WhereM_o is the overturning moment (kNm) and M_r is the resisting moment (kNm)

$$M_r = W_w \left(X_1 - \frac{M}{W_w} \right) \ldots \ (8)$$

$$W_w = \sum_{i=1}^{8} W_i \ldots (9)$$

$$\mathrm{M} = \sum_{i=1}^{7} M_i \ldots \ (10)$$

$X_1$is the width of base slab in m, W_w is sum of all the weights (kN) and M is sum of all the moments (kNm).

Factor of safety, FSs against sliding of retaining wall is given below:

$$FSs = \frac{Fr}{Fd} \ (11)$$

F_r isa resisting force (kN) and is given below:

$$F_r = \mu W_w + P_P \ ... \ (12)$$

where, μ is coefficient of friction between soil and base of retaining wall and P_P is passive earth pressure force per meter length of retaining wall in kN

F_d isa sliding forces (kN) and is stated below:

$$F_d = P_{ah} \ ... \ (13)$$

Factor of safety, FSb against bearing capacity of soil is defined as:

$$FS_b = \frac{q_{max}}{qa} \ ... \ (14)$$

Where q_a is net allowable bearing capacity of soil in KM/m^2, and q_{max} is maximum pressure in kM/m^2 which stated below:

$$q_{max} = \frac{W_w}{L_r}\left(1 + \frac{6e}{X_1}\right) ... \ (15)$$

with

$$Lr = \frac{M + Mo}{W_w} ... (16)$$

$$e = Lr + \frac{X_1}{2} ... \ (17)$$

q_{max} is maximum pressure in kM/m^2, q_a is net allowable bearing capacity of soil in KM/m^2, e is eccentricity.

III. OBJECTIVE FUNCTIONS

To formulate optimization problem to design the retaining wall by using differential evolution technique, it is required to define objective function(s). In this research work cost, F_{cost} and weight per meter length, F_{weight} of retaining wall are considered as two objective functions.

The first objective function is to minimize the cost per meter length, F_{cost} of retaining wall and is defined below:

$$F_{cost} = C_c\left(V_{stem} + V_{heel} + V_{toe} + V_{sheerkey}\right) ... \ (18)$$

Where C_c is cost of one cubic meter of concrete, V_{stem}, V_{heel}, V_{toe} and $V_{sheerkey}$ are the volumes of stem, heel, toe and shear key, respectively in m^3.

The second objective function is to minimize the weight per meter length, F_{weight} of retaining wall and is defined below:

$$F_{weight} = \gamma_c\left(V_{stem} + V_{heel} + V_{toe} + V_{sheerkey}\right) ... \ (19)$$

Where γ_c is unit weight of concrete in kN/m^{3}Variable X is searched using differential evolution method minimize the above mention objectives.

3.2 Constraints

According to IS 456, the design of retaining wall should be stable, safe and economical. This design is required to satisfy the conditions related to capacity, stability and geometry of retaining wall.

3.2.1 Stability Constraints

Stability against overturning is undertaken by satisfying the following equation

$$0.9Mr - 1.4Mo \geq 0 \quad ... \ (19)$$

Stability against sliding is limited by satisfying the following equation

$$\frac{0.9\ (\mu W + P_P)}{P_{ah}} \geq 1.4 \quad ... \ (20)$$

Stability against bearing capacity of soil is handled by fulfilling the following equation

$$\frac{W_w}{L_r}\left[1 + \frac{6e}{X_1}\right] - qa \leq 0 \quad ... (21)$$

3.2.2 Dimension Constraints

Bound on design variables is tackled by fulfilling the following equations.

$$X_1 - X_2 - X_6 = 0 \quad ... \ (22)$$

$$X_1 > X_2 + X_3 + X_7 \ ... (23)$$

3.3 Continuous Variables

Minimum dimensions of the components of retaining wall are dependent on the properties of soil and height of retaining wall. For fixing the dimensions of wall X_1 to X_{Nv} continuous variables are used. These variables can vary between the following limits

$$X_i^{min} \leq X_i \leq X_i^{max} \ (i = 1,2, \dots, Nv) \dots \ (24)$$

Aggregating the above equations constrained optimization problem is stated as below

Minimize F_{cost}

Minimize F_{wight}

Subject to

- Stability against overturning given by Eq.(19)
- Stability against slidinggiven by Eq.(20)
- Stability against bearing capacitygiven by Eq.(21)
- Design variable Constraints given by Eqs. (22) to (23).
- Bound on design variables given by Eq.(24)

Above optimization is redefined to club both the objectives having same nature as below

Minimize $F(X) = F_{cost} + \beta F_{weight} \dots \ (25)$

Subject to:

- Inequality and equality constraints given by Eqs. (19) to (24)

Whereβ is conversion faction having units (`/Kg)

Constrained problem is converted into unconstrained problem using exterior penalty function and defined below

$$A(X, r_k) = F(X) + r_k \left(\sum_{j=1}^{4} \langle G_j \rangle^2 + (X_1 - X - X)^2 + \left(X_2 - \frac{X_6}{3} \right)^2 \right) \dots (26)$$

where

$$\langle G_j \rangle = \begin{cases} 0 & ; G_j \geq 0 \\ G_j & otherwise \end{cases} \dots (27)$$

Penalty parameter $r_k$has large value.The main aim of optimization problem is to find X so that $A(X, r_k)$ is minimized while bound on variablesare taken care during applying differential evolution method.

IV. DIFFERENTIAL EVOLUTION METHOD

Differential evolution (DE) algorithm is a population based algorithm. It has mutation, crossover and selection operators. It is a parallel direct search method which utilizes $N_P$members as parameter vectors of N_V-dimensions.N_P remains same during optimization process. Initial vector population is selected randomlyout of the entire search space. The DE algorithm follows steps like mutation, crossover, selection and migration[31]. The steps are explained below one by one:

4.1 Parameter Setting

Parameters such as population size (N_P), boundary constraints of each dimension of population vector (N_V), mutation factor f_m, crossover, (CR) and maximum number of iterations (IT)are initially selected. Stopping criterion will be the maximum number of iterations. The set of real digital IIR filter coefficients is represented as the population. Thereare N_P members in the population and numbers of real IIR filter coefficients are N_V.The complete population is shown in a matrix form as below [32]:

$$\text{Population} = \begin{bmatrix} X_{11}^t X_{12}^t \cdots \cdots X_{1N_V}^t \\ X_{21}^t X_{22}^t \cdots \cdots X_{2N_V}^t \\ \vdots \vdots \ X_{ij}^t \ \cdots \vdots \\ \vdots \vdots \cdots \cdots \vdots \\ X_{N_P1}^t X_{N_P2}^t \cdots \cdots X_{N_PN_V}^t \end{bmatrix} \quad \dots(28)$$

4.2 Initialization of an Individual population

Individual population X_{ij}^t ($j=1,2, \dots, N_V; i=1,2, \dots, N_P$) is initialized with random value generated according to a uniform probability distribution in the N_V-dimensional problem space. With the given upper and lower limits of the search space, the population vector is described as below within the prescribed limits[35, 36]:

$$X_{ij}^t = X_j^{min} + rand(\ \ )\left(X_j^{max} - X_j^{min}\right)$$

$$(j = 1, 2, \dots, NV; \ i = 1, 2, \dots, NP) \dots (29)$$

Where*rand()* is anuniform random number between 0 and 1.X_j^{min} andX_j^{min} are minimum and maximum permissible limits of the j^{th}coefficients.

4.3 Opposition Based Learning

Population based optimization techniques starts with some initial random values. Convergence time and optimized value depends upon the initial guesses of population. Since, there are sufficient (almost 50%) chances that the initial guess is right. So, there is an equal chance that opposite guess may be nearer to the optimal solution[33,34]. So, starting with the closer of the two guesses as judged by the objective function, better solution is attained with smaller convergence time. The opposite population is obtained using the following expressions.

$$X_{ij}^{t+1} = X_j^U + X_j^L - X_{ij}^t\,(j = 1, 2, \ldots, NV;\ i = 1, 2, \ldots, NP) \ldots (30)$$

Where

$$X_j^L = \begin{cases} X_j^{min} & ; \quad t = 0 \\ min\{X_{ij}^t\ ;\ (i = 1, 2, \ldots, N_P)\} & t > 0 \end{cases} \ldots (31)$$

$$X_j^U = \begin{cases} X_j^{max} & ; \quad t = 0 \\ max\{X_{ij}^t\ ;\ (i = 1, 2, \ldots, N_P)\} & t > 0 \end{cases} \ldots (32)$$

(j=1, 2, …, N_V)

The opposition strategy has also been applied during progressive iterations.

4.4 Mutation Operator:

Mutation is an operator where weighted difference of randomly selected population vectors is added to another vector to generate new vectorZ_{ij}. There are many variations of differential evolution algorithm strategies [35] that are being be used for optimizations. The mutation strategy used here is described below:

$Z_{ij3}^t = x_{ij}^t + f_B(x_{Bj}^t - x_{ij}^t) + f_m(x_{R_1j}^t - x_{R_2j}^t)$ *j=1,2, . . ., N_V; i=1,2, . . ., N_P)* …(33)

WhereR_{ij} is random index of population and f_m is the mutation factor ∈[0 2].Z_{ij}^t, x_{ij}^t , x_{Bj}^t and x_{Rj}^t are the mutated population vector, present populations vector, the best population vector and random population vector respectively. In these mutation strategies, the current population vector is modified by using the best population vector and few random population vectors.

4.5 Crossover Operation

In order to increase the diversity or the perturbed population vectors, crossover is introduced. In this operation, a trial vector is generated by replacing certain parameters of target vector by the corresponding parameters of a randomly generated donor vector[31].

By combining target vector $X_i^t = (x_{i1}^t, x_{i2}^t, \ldots, x_{iN_V}^t)$ with randomly selected vectorZ_i^{t+1}, Trial vector is produced as below

$$U_i^{t+1} = (U_{i1}^{t+1}, U_{i2}^{t+1}, \ldots, U_{iN_V}^{t+1}) \ldots (34)$$

where

$$U_{ij}^{t+1} = \begin{cases} Z_{ij}^{t+1} if(randb(j) \le CRorj = rnbr(i) \\ x_{ij}^t\, if(randb(j) > CRorj \ne rnbr(i) \end{cases} \ldots (35)$$

randb(j) is the j[th]evaluation of a uniform random number generator with outcome ∈[0 1]. CR is the crossover rate∈[0 1]. *rnbr(i)* is a randomly chosen index ∈{1,2, ... N_V} which ensures that U_i^{t+1} gets at least one parameter from Z_i^{t+1}.

4.6 Selection

To decide whether or not the newly produced offspring should become a member of next generation; the trial vector U_i^{t+1} is compared with the target vector x_i^t using greedy criterion[35]. If *f* denotes the objective function under minimization, then

$$x_{ij}^{t+1} = \begin{cases} U_{ij}^{t+1}(j = 1,2, \ldots, N_V):\ iff(U_{ij}^{t+1}) < f(x_{ij}^t) \\ x_{ij}^t\,(j = 1,2, \ldots, N_V):\ otherwise \end{cases} (i=1,2, \ldots, N_P) \ldots (36)$$

So, the objective function of each trial vector is compared with the objectivefunction of target vector. Incase the objective function of target vector improves than that of trial vector, the target vector advances to the next stage otherwise the trial vector replaces the target vector.

4.7 Migration:

With the progress of iterations, the population diversity decreases rapidly, which causes the decrease in exploration of search space. Due to this, clustered individuals are unable to reproduce newly better solution by mutation and crossover. To increase the exploration of search space, the migration operation is applied. It also decreases the selection pressure for a small population. The j^{th} gene of i^{th} individual is randomly regenerated as below [38]:

$$X_{ij}^{t+1} = \begin{cases} X_{bj}^{t+1} + R_i\left(X_j^{min} - X_{bj}^{t+1}\right) if \delta < \dfrac{X_{bj}^{t+1} - X_j^{min}}{X_j^{max} - X_j^{min}} \\ X_{bj}^{t+1} + R_i\left(X_j^{max} - X_{bj}^{t+1}\right) if otherwise \end{cases} \quad \ldots (37)$$

Where x_{bj}^{t+1} is the best individual, R_i and δ are uniform random numbers.

V. DESIGN PARAMETERS

The lower and upper bondsof continuous variablesof three cases are given Table 1 in which the variables are searched by implementing differential evolution algorithm.

Table 1 Lower and upper limits of continuous variables

Variable, X_i	Case-1		Case-2		Case-3	
	X_i^{min}	X_i^{max}	X_i^{min}	X_i^{max}	X_i^{min}	X_i^{max}
X_1	1.25	3.5	1.25	3.5	1.25	4.0
X_2	0.5	1.0	0.5	1.25	0.5	1.75
X_3	0.3	0.45	0.3	0.45	0.3	0.45
X_4	0.15	0.2	0.15	0.2	0.15	0.2
X_5	0.3	0.5	0.3	0.5	0.3	0.5
X_6	1.0	2.5	1.0	2.5	1.0	2.5
X_7	0.25	0.5	0.25	0.5	0.25	0.5
X_8	0.25	0.5	0.25	0.5	0.25	0.75

Design input parameters for the undertaken three cases are given in Table 2.

Table 2: Values of input variables

Input variables	Description	Case		
		1	2	3
H	Height of retaining wall (m)	4	5	6
θ	Angle of retained soil with horizontal in degree	15	15	15
Φ	Angle of shearing resistance in degree	30	30	30
γ_1	Unit Weight of soil (kN/m^3)	16	16	16
γ_c	Unit Weight of concrete (kN/m^3)	25	25	25
μ	Co-efficient of friction	0.5	0.5	0.5
D_f	Depth of base of foundation wrt NSL in m	1.25	1.25	1.25
C_s	Cost of Retaining Concrete (□/m^3)	6000	6000	6000
q_a	Net allowable bearing capacity of soil in (kN/m^2)	160	160	160
c	Cohesion intercept (kN/m$^{2)}$	0	0	0

VI. Results

Differential evolution technique has been applied for the design of retaining wall. Three design cases of retaining wallof different heights are undertaken for optimized design to investigate the effect on cost and weight of retaining wall with respect to traditional design. Population size, N_P is taken as 100. Maximum generations (T_{max}) are evolved are 50. Crossover rate, CR and mutation factor, f_m are set to 0.2 and 0.85, respectively. Penalty parameter, r_k is taken as10^7. 100 independent trial runs are performed to validate the global solution. Best, mean, worst and standard deviation (SD) of cost and weight per length are given in Table 3 by applying differential evolution method for all three design cases of retaining wall. Obtained design of retaining wall by traditional limit state method is also depicted in Table 3.

Table 3: Results of retaining wall design.

Parameter	Case-1	Case-2	Case-3
Best Cost, (□/m)	9208.99	11888.68	14160.4
Best Weight, (Kg/m)	3837.08	4953.61	5900.58
Mean Cost, (□/m)	9354.32	12045.4	14397.40
Mean Weight, (Kg/m)	3897.63	5018.91	5998.91
Worst Cost, (□/m)	10995.54	12679.72	16765.53
Worst Weight, (Kg/m)	4331.47	5283.22	6985.64
SD, Cost (□/m)	228.2	188.6	407.99
SD, Weight (Kg/m)	0.951	0. 786	1.70
Cost (□/m),(Traditional Method)	16740	21420	26820
Weight(Kg/m), (Traditional Method)	6975	8925	11175

Table 4: Comparison of optimized design with traditional design for Case 1

Parameter	Traditional Design	Optimized design with DE	
		Best Design	Worst Design
Cost (□/m)	16740	9208.99	10995.54
Weight (Kg/m)	6975	3837.08	4331.47
X_1(m)	3.0000	2.4319	2.8082
X_2 (m)	1.0000	1.0000	0.6609
X_3 (m)	0.4500	0.3000	0.3000
X_4 (m)	0.1500	0.1500	0.1804
X_5 (m)	0.4200	0.3000	0.3007
X_6 (m)	2.0000	1.4327	2.1467
X_7 (m)	0.3000	0.2500	0.3528
X_8 (m)	0.3000	0.25000	0.2548

The result of traditional limit state design of retaining wall has been compared with the optimized design by differential evolution optimization technique. Tables 4, 5 and 6 show the design parameters of retaining wall obtained by traditional limit state method along with best worst design parameters obtained by differential evolution method.

Table 5: Comparison of optimized design with traditional design for Case 2

Parameter	Traditional Design	Optimized design with DE	
		Best Design	Worst Design
Cost (□/m)	21420	11888.68	12679.72
Weight (Kg/m)	8925	4953.61	5283.22
X_1(m)	3.5200	3.1689	3.4938
X_2 (m)	1.1700	1.2500	1.2364
X_3 (m)	0.4500	0.3000	0.3000
X_4 (m)	0.1500	0.1500	0.1500
X_5 (m)	0.5000	0.30000	0.3000
X_6 (m)	2.3500	1.9192	2.2587
X_7 (m)	0.3000	0.2500	0.3810
X_8 (m)	0.3000	0.2519	0.2552

It is observed from the results that optimized method given better cost and weight per meter length of retaining wall better than traditional design by limit state method. Even the worst optimal design results in term of cost and weight obtained after performing independent 100 trail runs, are better that the traditional design by limit state method. 81.77%, 80.17 and 89.4% is saving of cost and weight per meter length for case 1,2 and 3 respectively.

Table 6: Comparison of optimized design with traditional design for Case 3

Parameter	Traditional Design	Optimized design with DE	
		Best Design	Worst Design
Cost (□/m)	26820	14160.4	16765.53
Weight (Kg/m)	11175	5900.58	6985.64
X_1(m)	4.1000	3.6864	3.7507
X_2 (m)	1.4000	1.7500	1.7303
X_3 (m)	0.4500	0.3000	0.4257
X_4 (m)	0.1500	0.1500	0.1513
X_5 (m)	0.6000	0.3000	0.3031
X_6 (m)	2.7000	1.9335	2.0183
X_7 (m)	0.3000	0.2503	0.2500
X_8 (m)	0.3000	0.2507	0.5717

Table 7: Variation of cost (□/m) with the variation of backfill slope

θ^o	Design Cases of retaining wall		
	1	2	3
0	9192.71	11369.34	13645.13
5	9171.21	11402.47	13666.72
10	9173.52	11581.06	13856.97
15	9208.99	11888.68	14160.40
20	9533.64	12391.83	14724.53
25	10224.28	12923.46	15074.03
Variation %	11.22	13.67	10.47

Table 8: Variation of weight (kg/m) with the variation of backfill slope

θ^o	Cases		
	1	2	3
0	3830.29	4737.22	5685.47
5	3821.44	4751.05	5694.46
10	3822.30	4825.44	5773.73
15	3837.08	4953.61	5900.58
20	3972.35	5163.26	6135.22
25	4260.11	4968.10	6280.84
Variation %	11.22	13.67	10.47

Variation of cost with respect to backfill slope, θ^o is observed by varying the value from 0 to 25 degrees with step of 5 degree and results are given Table 7 for all the three-design case of retaining wall undertaken for study. It is observed that the cost increases with the increase of backfill slope, θ^o. Variation of weight with respect to backfill slope, θ^o is observed by varying the value from 0 to 25 degrees with a step of 5 degree and results are given Table 8 for all the three-design case of retaining wall. It is observed that the weight of material increases with the increase of backfill slope, θ^o hence causing increase in the cost.

Table 9: Variation of Cost (□/m) with the variation of angle of shearing resistance

Φ°	Design Cases of retaining wall		
	1	2	3
26	9794.10	12288.52	14582.69
28	9460.30	1230.21	14671.48
30	9208.99	11888.68	14160.40
32	9010.83	11508.60	13717.34
34	8819.45	11151.89	13273.79
36	8633.19	10811.92	12898.90
38	8445.99	10516.87	12620.50
Variation %	15.96	16.84	15.54

Variation of cost with respect to angle of shearing resistance Φ° is observed by varying the value from 26 to 38 degrees with a step of 2 degrees and results are given Table 9 for all the three-design case of retaining wall. It is observed that the cost of material decreases with the increase of angle of shearing resistance, Φ°. Similarly, variation of weight of material with respect to angle of shearing resistance, Φ° is observed by varying the value from 26 to 38 degrees with a step of 2 degrees and results are given Table 10 for all the three-design case of retaining wall. It is observed that the weight

Table 10: Variation of Weight (kg/m) with the variation of angle of shearing resistance

Φ°	Design Cases		
	1	2	3
26	4080.87	5120.02	6067.12
28	3941.79	5125.86	6113.12
30	3837.08	4953.61	5900.58
32	3754.81	4795.24	5715.55
34	3674.77	4646.62	5530.74
36	3597.16	4504.96	5374.54
38	3519.17	4382.03	5258.54
Variation %	15.96	16.84	15.54

Of material decreases with the increase of angle of shearing resistance, Φ°.

Table 11: Variation of Cost (□/m) with the variation of base friction

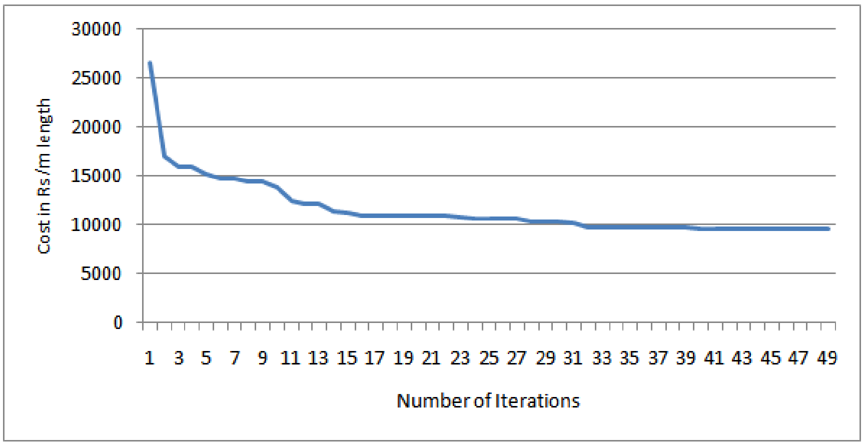
μ	Design Cases		
	1	2	3
0	9502.53	12725.51	15198.55
0.1	9282.41	12424.92	14922.38
0.2	9232.92	12147.94	14637.23
0.3	9208.99	11888.68	14291.55
0.4	9208.99	11888.68	14160.40
0.5	9208.99	11888.68	14160.40
0.6	9208.99	11888.68	14160.40
Variation %	3.18	7.03	7.33

Variation of cost with respect to base friction, μ is observed by varying the value from 0 to 0.6with a step of 0.1 and results are given Table 11 for all the three-design undertaken. It is observed that the cost of material decreases with the increase of base friction, μ. Similarly, variation of weight of material with respect to base friction, μ is observed by varying the value from 0 to 0.6with a step of 0.1 and obtained results are given Table 12 for all the three-design case of retaining wall. It is observed that the weight of material decreases with the increase of base friction, μ.

Table 12: Variation of Weight (kg/m) with the variation of base friction

μ	Design Cases		
	1	2	3
0	3959.38	5302.14	6332.72
0.1	3867.67	5177.05	6217.66
0.2	3844.55	5061.64	6098.84
0.3	3837.08	4953.61	5954.99
0.4	3837.08	4953.61	5900.58
0.5	3837.08	4953.61	5900.58
0.6	3837.08	4953.61	5900.58
Variation %	3.18	7.03	7.33

Covergence graph of cost with respect to interations given to differential evolution method is shown in Figure 3. After 35 iteration, result does not improve.



100 trial run give result significant results when t-test is applied with p-value approximately equal to zero for α =0.05. It is true when Wilcoxon signed rank test for one sample also gives significant result with p-value =0 for α =0.05. So obtained results are optimal.

VII. CONCLUSION

This paper proposes the design of retaining wall using meta-heuristic search technique having opposition baseddifferential evolution algorithm for global search optimization. To maintain the diversity migration is applied. Opposition helps to start with good solutions. The design of retaining wall has been compared with the traditional design limit state method. Three cases with different design conditions are untaken. In this paper, a large variation in the cost and weight per meter length has been observed. Both the cost and weight per meter length of wall decrease with the increase in angle of shearing resistance. The effect of increase in angle of back slope has adverse effect on the cost and weight. The cost and weight of retaining wall become constant for higher values of base friction. The results reveal that the proposed method with new proposed strategies works well with arbitrary random initialization and satisfies the stability and geometry constraint. Further, it has been concluded that the proposed heuristic search technique gives better results when compared with traditional method of design of retaining wall.

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