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Cost optimization of a composite floor system, one-way waffle slab, and concrete slab formwork using a charged system search algorithm

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Abstract In this paper, the optimum design of some floor systems, including composite slab, one way waffle slab, and the formwork of a concrete slab, is performed via recently developed meta-heuristic algorithms, namely, the Charged System Search (CSS) and the Enhanced Charged System Search (E-CSS). The CSS is a multi-agent approach based on some principles of physics and mechanics. Each agent, called a Charged Particle (CP), is a sphere with uniform charge density that can attract other CPs by considering the fitness of the CP. Here, optimum designs are based on LRFD-AISC and ACI 318-05. The objective function for each structure is the cost function. This function includes materials used and the construction cost of the structure. The considered structures are also optimized by the Improved Harmony Search (IHS) algorithm and the results are compared to those of the CSS.

1. Introduction

The composite slab is one of the most common types of slab in buildings. This type of slab is formed from a composition of steel and concrete systems. Steel beams stand under the concrete slab and shear connectors are used to produce the integrity of the system. These shear connectors are welded from one side to the upper flange of the beam, and are drowned from the other side to the concrete. The stiffness of a composite slab is simply more than a concrete slab and a steel beam when considered independently. By considering the premium of this type of system, and the increasing application of such systems in structures, optimization of the composite slab can help constructors considerably.

The one way waffle slab system contains a hollow slab with a height more than the height of the full slabs. This system is desirable for structures with large spans and small live load. Since the capability of concrete under tension is low, practically, utilization of concrete in tensional zones is inefficient. Therefore, in waffle slabs, the areas between joists are kept empty or filled with lightweight material, which results in a reduction in the weight and cost of the slab.

The formwork of a concrete slab is generally designed for the creation of proper support for fresh concrete before it can withstand itself. The formwork of concrete slabs typically includes sheathings, joists, stringers and shores. Sheathings are in the form of sheets of plywood, and joists, stringers and shores act like beams and columns. Sheathings retain both concrete and applied loads by supporting the members, including joists, stringers and shores. Stringers are supported on the shores, and joists are supported on the stringers.

In this paper, the charged system search method, developed by Kaveh and Talatahari [1,2], is used for the optimal design of these three types of structure. This method is based on Coulomb and Gauss laws from physics and Newton laws from mechanics. A number of charged particles are considered that have coordinates equivalent to variables of the structures, and which have the shape of a sphere with a uniform volume charge. The values assumed for these variables create the coordinate of each particle. Each of these particles has a charge

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proportional to the fitness of the particle. In other words, the better the fitness, the more the charge of the particle. These particles attract each other in such a way that a better particle certainly attracts a worse particle, but, a worse particle probably attracts a better particle. The forces generated between each pair of particles, and the paths of particle motion, are obtained from Coulomb and Gauss laws and Newton laws, respectively. Therefore, a force is applied to each particle and, thus, the particles move to new locations. In this way, the process of optimization is performed in the CSS.

For comparison of the results of the CSS algorithm with those of the IHS method, a short introduction is presented for the harmony search algorithm [3,4]. When a musician searches for a better state of harmony, the musical performance process occurs. The harmony search method is based on this idea. Jazz improvisation searches for musically enjoyable harmony, just like the optimization which seeks optimum solutions. A musicians select the pitch of each piece of music, brings together a number of different notes from all the notes, and then plays these with a musical instrument to find out whether it gives a pleasing harmony. The musician then tunes some of these notes to achieve a better harmony. It is then checked whether this candidate solution improves the objective function or not, similar to the process of finding out whether an euphonic music is obtained or not.

2. Charged system search

The charged system search is based on electrostatic and Newtonian mechanics laws [1]. The Coulomb and Gauss laws provide the magnitude of the electric field (E_{ij}) at a point inside and outside a charged insulating solid sphere, respectively, as follows:

$$E_{ij} = \begin{cases} \dfrac{k_e q_i}{a^3} r_{ij} & \text{if } r_{ij} < a \\ \dfrac{k_e q_i}{r_{ij}^2} & \text{if } r_{ij} > a \end{cases} \quad (1)$$

where k_e is the Coulomb constant, r_{ij} is the separation of the center of the sphere and the selected point, q_i is the magnitude of the charge, and a is the radius of the charged sphere. Using the principle of superposition, the resulting electric force, due to N charged spheres (F_j), is equal to:

$$F_j = k_e q_j \sum_{i, i \neq j} \left(\frac{q_i}{a^3} r_{ij} . i_1 + \frac{q_i}{r_{ij}^2} . i_2 \right) \frac{r_i - r_j}{\| r_i - r_j \|}$$
$$\langle \begin{cases} i_1 = 1, & i_2 = 0 \Leftrightarrow r_{ij} < a \\ i_1 = 0, & i_2 = 1 \Leftrightarrow r_{ij} \geq a. \end{cases} \quad (2)$$

Also, according to Newtonian mechanics, we have:

$$\Delta r = r_{new} - r_{old}, \quad (3)$$

$$v = \frac{r_{new} - r_{old}}{\Delta t}, \quad (4)$$

$$a = \frac{v_{new} - v_{old}}{\Delta t}, \quad (5)$$

where r_{old} and r_{new} are the initial and final positions of a particle, respectively, v is the velocity of the particle, and a is the acceleration of the particle. Combining the above equations and using Newton's second law, the displacement of any object as a function of time is obtained as:

$$r_{new} = \frac{1}{2} \frac{F}{m} \cdot \Delta t^2 + v_{old} \cdot \Delta t + r_{old}. \quad (6)$$

Inspired by the above electrostatic and Newtonian mechanics laws, the pseudo-code of the CSS algorithm can be presented as follows [1,2]:

Level 1: *Initialization*

Step 1. Initialization. Initialize the parameters of the CSS algorithm. Initialize an array of Charged Particles (CPs) with random positions. The initial velocities of the CPs are taken as zero. Each CP has a charge of magnitude (q) defined considering the quality of its solution as

$$q_i = \frac{fit(i) - fit_{worst}}{fit_{best} - fit_{worst}} \quad i = 1, 2, \ldots, N, \quad (7)$$

where fit_{best} and fit_{worst} are the best and worst fitness of all particles, respectively, and $fit(i)$ represents the fitness of agent i. The separation distance, r_{ij}, between two charged particles is defined as:

$$r_{ij} = \frac{\| x_i - x_j \|}{\| (x_i + x_j)_{/2} - x_{best} \| + \varepsilon}, \quad (8)$$

where x_i and x_j are the positions of the ith and jth CPs, respectively, x_{best} is the position of the best current CP, and ε is a small positive number to avoid singularity.

Step 2. CP ranking. Evaluate the values of the fitness function for the CPs, compare them with each other and sort them in an increasing order.

Step 3. CM creation. Store the number of the first CPs equal to Charged Memory Size (CMS) and their related values of fitness functions in the charged memory (CM).

Level 2: *Search*

Step 1. Attracting force determination. Determine the probability of moving each CP toward the others, considering the following probability function:

$$P_{ij} = \begin{cases} 1 & \dfrac{fit(i) - fit_{best}}{fit(j) - fit(i)} > rand \vee fit(j) > fit(i) \\ 0 & \text{else} \end{cases} \quad (9)$$

and calculate the attracting force vector for each CP as follows:

$$F_j = q_j \sum_{i, i \neq j} \left(\frac{q_i}{a^3} \cdot i_1 + \frac{q_i}{r_{ij}^2} i_2 \right) \cdot P_{ij}(x_i - x_j)$$
$$\langle \begin{cases} j = 1, 2, \ldots, N \\ i_1 = 1, & i_2 = 0 \Leftrightarrow r_{ij} < a \\ i_1 = 0, & i_2 = 1 \Leftrightarrow r_{ij} \geq a \end{cases} \quad (10)$$

where F_j is the resultant force affecting the jth CP.

Step 2. Solution construction. Move each CP to the new position and find its velocity using the following equations:

$$x_{j,new} = rand_{j_1} \cdot k_a \cdot \frac{F_j}{m_j} \cdot \Delta t^2 + rand_{j_2} \cdot k_v \cdot v_{j,old} \cdot \Delta t + x_{j,old}, \quad (11)$$

$$v_{j,new} = \frac{x_{j,new} - x_{j,old}}{\Delta t}, \quad (12)$$

where $rand_{j1}$ and $rand_{j2}$ are two random numbers uniformly distributed in the range (0, 1). m_j is the mass of the ith CP, which is equal to q_j in this paper. Δt is the time step, and it is set to 1. k_a is the acceleration coefficient, k_v is the velocity coefficient to control the influence of the previous velocity. Here, k_a and k_v are taken as:

$$k_v = 0.5(1 - iter/iter \max), \; k_a = 0.5(1 + iter/iter \max). \quad (13)$$

Step 3. CP position correction. If each CP exits from the allowable search space, correct its position using the harmony search based handling approach.

$$x_{i,j} = \begin{cases} \text{w.p. CMCR} \implies \text{select a new value} \\ \quad \text{for a variable from CM} \\ \implies \text{w.p. } (1 - \text{PAR}) \text{ do nothing} \\ \implies \text{w.p. PAR choose a neighboring value} \\ \text{w.p. } (1 - \text{CMCR}) \implies \\ \quad \text{select a new value randomly} \end{cases} \quad (14)$$

where "w.p." is the abbreviation for "with the probability", $x_{i,j}$ is the *i*th component of the CP *j*. The CMCR (the Charged Memory Considering Rate), varying between 0 and 1, sets the rate of choosing a value in the new vector from the historic values stored in the CM, and (1 - CMCR) sets the rate of randomly choosing one value from the possible range of values. The pitch adjusting process is performed only after a value is chosen from CM. The value (1-PAR) sets the rate of doing nothing, and PAR sets the rate of choosing a value from the best neighboring CP. For more details, the reader may refer to [2].

Step 4. CP ranking. Evaluate and compare the values of the fitness function for the new CPs, and sort them in an increasing order.

Step 5. CM updating. If some new CP vectors are better than the worst ones in the CM, in terms of their objective function values, include the better vectors in the CM and exclude the worst ones from the CM.

Level 3. Controlling the terminating criterion. Repeat the search level steps until a terminating criterion is satisfied.

3. Enhanced charged system search

One assumption of meta-heuristic algorithms is that the time alters discretely. This means that all alterations in space–time are performed when all agents have created their solutions. For example, in the CSS algorithm, when calculations of the amount of forces are completed for all CPs, the new locations of agents are determined. Also, CM updating is fulfilled after moving all CPs to their new locations. All these conform to a discrete time concept. In optimization problems, this is known as iteration. In other words, the modification of space–time for the multi-agent algorithms is often performed when iteration is completed and the new iteration is not started yet. This assumption is ignored in the enhanced CSS algorithm [5]. In the enhanced CSS, time changes continuously, and after creating just one solution, all updating processes are performed. Using this enhanced CSS, the new position of each agent can affect the moving process of the subsequent CPs, while in the standard CSS, unless an iteration is completed, the new positions are not utilized.

4. Design variables

For the three types of structure studied in this paper, the design variables selected for the optimization are as follows:

1. For the composite floor, the thickness of the slab and the dimensions of the steel beam are considered as variables (Table 1).
2. For the one way waffle slab, the design variables are provided in Table 2.
3. For the formwork of a concrete slab, the design variables are given in Table 3.

Table 1: The variables defined for modeling the composite slab.

Variable	Defined variables
X1	Slab thickness
X2	Height of beam
X3	Flange width
X4	Flange thickness
X5	Web thickness
X6	Beam spacing

Table 2: The variables defined for modeling the one way waffle slab.

Variable	Defined variables
X1	Slab thickness
X2	Ribs spacing
X3	Rib width at lower end
X4	Rib width at taper end
X5	Bar diameter
X6	Depth of rib

Table 3: The variables defined for modeling the concrete slab formwork.

Variable	Defined variables
X1	Joist height
X2	Joist width
X3	Stringer height
X4	Stringer width

5. Objective function

1. In composite floor, the objective function can consist of the cost of materials, labor and construction. But, research shows that labor and construction costs do not noticeably alter by changing the type of beam or slab thickness, and are approximately constant. Thus, in this paper, we consider the utilized material costs for the objective function. For this purpose, the costs of the steel beam, concrete slab and shear connectors are combined and the cost function is obtained as follows:

$$\text{MinQ} = W_s \times L \times N \times C_s + L \times w \times t_c \times \rho \times C_b + N_s.C_{st}. \quad (15)$$

By considering the function proportional to the length and cost of the steel beam, we have:

$$\text{Min}\bar{Q} = W_s \times N + w \times t_c \times \rho \times \left(\frac{C_b}{C_s}\right) + \frac{N_s}{L} \times \left(\frac{C_{st}}{C_s}\right), \quad (16)$$

where W_s is the weight of the steel beam per unit length, L is the length of the beam, N is the total number of steel beams in the composite floor, C_s is the cost of the steel beam in weight units, W_c is the total weight of concrete, C_c is the cost of concrete in weight units, W is the length of the bay, t_c is the thickness of the concrete slab, ρ is the density of the concrete, N_s is the total number of studs, and C_{st} is the cost of each stud.

For a composite beam satisfying the following conditions, the cost function can be calculated from the Relationship (16), otherwise this function will be penalized.

$$\delta/\delta_u \leq 1, \tag{17}$$

$$M_u/(\phi_b M_n) \leq 1, \tag{18}$$

$$V_u/(\phi_b V_n) \leq 1, \tag{19}$$

where δ is the maximum displacement of the steel beam and δ_u is its upper bound. ϕ_b is the resistance factor for flexure, given as 0.9, M_n is the nominal moment strength and M_u is the factored service load moment for a steel beam. ϕ_v represents the resistance factor for shear, given as 0.9, V_n is the nominal strength in shear, and V_u is the factored service load shear for the steel beam. For more details about the design of a composite slab, the reader may refer to [6–8].

2. In the one-way waffle slab, the cost function includes the cost of materials, such as concrete and reinforcement, and the cost of construction of each unit. Therefore, the cost function can be defined as:

$$Q = V_{conc} \times (C_1 + C_2) + W_{steel}(C_3 + C_4), \tag{20}$$

$$\text{Min}\overline{Q} = V_{conc} + W_{steel}\left(\frac{C_3 + C_4}{C_1 + C_2}\right). \tag{21}$$

Subjected to:

$$M_u/(\phi_b M_n) \leq 1, \tag{22}$$

$$V_u/(\phi_b V_n) \leq 1. \tag{23}$$

3. The objective function for the formwork of a concrete slab can be formulated as:

$$C = N_1 \times C_1 + N_2 \times C_2 + N_3 \times C_3 + N_4 \times C_4 + A \times t \times C_5, \tag{24}$$

where:

N_1 = No. of sheathing.	C_1 = Unit cost of sheathing.
N_2 = No. of joist.	C_2 = Unit cost of joist.
N_3 = No. of stringers.	C_3 = Unit cost of stringers.
N_4 = No. of shores.	C_4 = Unit cost of shores.
A = Area of slab.	C_5 = Unit labor cost for unit volume of concrete.

t = thickness of slab.

Details of the design of a concrete slab formwork can be found in [9,10].

6. Optimum design process

In this study, the design process begins by inputting the data, including structural input, such as slab width and length, material input, such as yield stress of steel, concrete compressive characteristic strength, and loading input, consisting of the excess dead and live load. The design process using the CSS algorithm consists of three levels as follows:

Level 1: *Initialization*.

Step 1. Select the random values for particles. In this paper, the number of CPs is set to 20. The number of variables in the first and second problems is taken as 6, and in the third problem, is set to 4; variables are selected randomly between the lower and upper limits in each problem. In this way, the initial positions of CPs are defined.

Step 2. In this step, for each CP, conditional inequalities for each cost function are checked and, if all conditions are satisfied, the value of the cost function is calculated, and CPs are sorted increasingly. Otherwise, that cost function is penalized.

Step 3. Store the CMS number of the first CPs and their related cost function values in the Charged Memory (CM). The CMS is chosen as 5 in this article.

Level 2: *Search*.

Step 1. In this step, the distance between the CPs, and the charge of the CPs, are calculated. Then, the probability of moving the CPs toward others, and attracting forces for the CPs, is determined.

Step 2. After determination of attracting forces, the new position and velocity of each CP are determined.

Step 3. When some of the particles' new positions violate the boundaries, then, the CSS corrects their position using the harmony search based handling approach [1,3,4].

Step 4. This step is similar to step 2 of level 1, with the new position of the CPs.

Step 5. If some CPs are better than the particles saved in the CM, replace them.

Level 3: *Termination Criterion*.

Repeat level 2 until the termination criterion is satisfied.

7. Design examples

The CSS, enhanced CSS, and IHS algorithms are programmed in MatLab software. The analysis and design stages and the cost function are created in a function file, which is called from the main code of each algorithm.

For optimum design of each floor system, we consider spans that have 6, 7 and 8 m length and 5 m width. The 28 days concrete cylinder strength is 21 MPa, steel yield stress is 240 MPa and rebar yield stress is 420 MPa. Live load is set to be 2 kN/m^2 and excess dead load is 3 kN/m^2 (steel and reinforced concrete weight is calculated in the program. The base diameter of the stud is 20 mm and the overall height is 50 mm. Figures 1 and 2 present a schematic view of a composite slab and a one-way waffle slab, respectively. Also, Tables 4 and 5 present the design bounds of each structure, respectively.

For optimum design of the formwork, we consider a concrete slab with horizontal dimensions of 27 × 18 m and a vertical dimension of 3 meters. The thickness of the slab is set to 40, 50 and 60 cm. A schematic view of a concrete slab formwork is presented in Figure 3. Tables 6 and 7 present the input data of sheathing, and joist and stringer, respectively. The design bounds of the formwork are presented in Table 8.

The result for a composite slab optimum design is as follows:

1. For a 6 m span size steel beam, spacing is 1500 mm, concrete slab thickness is 80 mm, and the steel beam size is taken as INP 14.
2. For a 7 m span size steel beam, spacing is 1750 mm, concrete slab thickness is 80 mm, and the steel beam size is selected as IPE 16.
3. For an 8 m span size steel beam, spacing is 1330 mm, concrete slab thickness is 80 mm, and the steel beam size is selected as IPE 16.

Tables 9 and 10 present the results of a one-way waffle slab and the formwork of a concrete slab optimum design, respectively. The design histories for three structures are shown in Figures 4–6, respectively.

For the composite flooring system, it is obvious that, as the span size becomes larger, the beam spacing decreases and the

Table 4: Bounds of design variables for the composite slab.

Bounds	Beam spacing (mm)	Slab thickness (mm)	Steel beam size[a]
Lower bound	500	80	1
Upper Bound	2500	160	29

[a] The steel beam consists of 29 steel I-beams (IPE12 to 30, INP12 to 30 and IPB12 to 30).

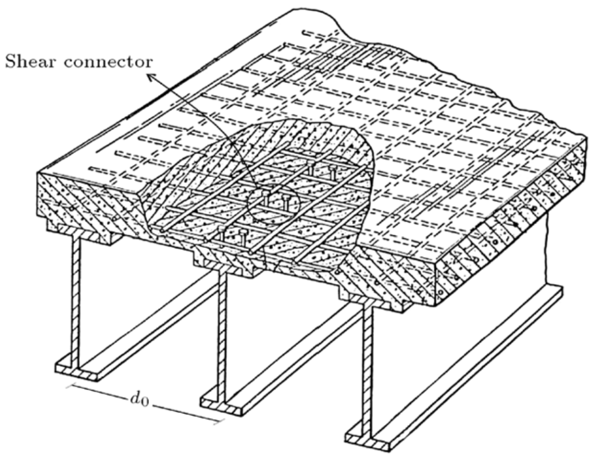

Figure 1: Schematic view of a simple composite slab.

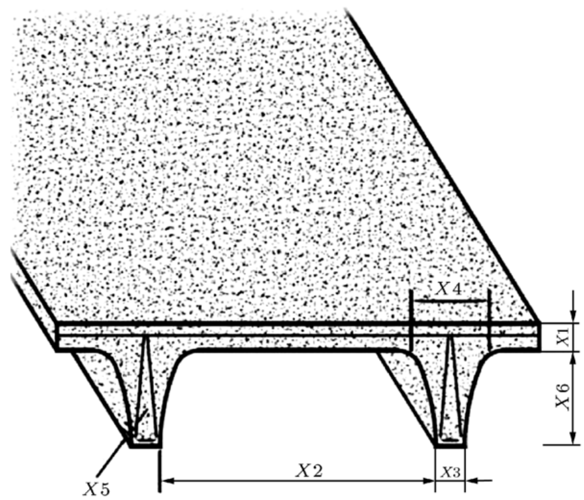

Figure 2: Schematic view of a one-way waffle slab.

Table 5: Design variables bounds for the one-way waffle slab.

Design variables	Value (cm)
Slab thickness	2.5, 5, 7.5, 10
Ribs spacing	40, 42.5, 45, . . . ,72.5, 75
Rib width at lower end	10, 12.5, . . . ,22.5,25
Rib width at taper end	10, 12.5, . . . ,27.5, 30
Bar diameter	1, 1.2, 1.4, 1.6, 1.8,2
Depth of rib	15, 17.5, . . . ,72.5,75

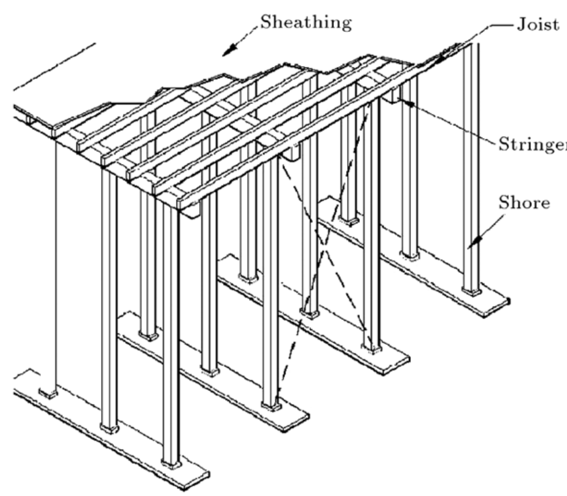

Figure 3: Schematic view of a concrete slab formwork.

steel beam size increases. However, the thickness of the slab does not change. Also, for the waffle slab, by increasing the span size, the rib spacing decreases and rebar diameters are increased. However, other variables remain almost constant and equal to the minimum value of their bounds.

For the reinforced concrete formwork, by increasing the concrete thickness, a balanced decrease of joist, stringer and shore spacing is observed. A balanced decrease refers to a case where an increase in the thickness of concrete results in an increase in the stringer spacing, but a double decrease in shore spacing. Also joist and stringer heights are increased by increasing the thickness of the concrete.

The results show that mostly the CSS finds better fitness values for the design of these three types of structure. The number of iterations to obtain the minimum answer for the CSS method is considerably lower. Downfall of the CSS curve, in initial steps, demonstrates the power of the method in exploration. This occurs in the first 10 iterations. This search is in the global space and Coulomb's law provides the magnitude of the electric forces between each pair of CPs. Then, a local search is started and, in 50 iterations, the minimum solution is found. In the local search stage, the magnitude of the electric force is obtained using the Gauss law. This part is the exploitation of the algorithm. In each of the global and local search spaces, the force is attractive and its magnitude for the CP located inside the sphere of the CP is proportional to the separation distance between the CPs. For the CP located outside, the sphere is inversely proportional to the square of the separation distance between the charged particles. The

Table 6: Sheathing input data — formwork.

Thickness (cm)	Moment of inertia (cm^4/m)	Elastic modulus (MPa)	Allowable bending stress (MPa)	Allowable shear stress (MPa)
1.59	17.8	11,601	13.57	0.51

Table 7: Joist and stringer input data — formwork.

Elastic modulus (MPa)	Allowable bending stress (MPa)	Allowable shear stress (MPa)
10546.2	8.79	0.615

Table 8: Design variables bounds for formwork.

No	Limiting values	Joist		Stringer	
		Height (cm)	Width (cm)	Height (cm)	Width (cm)
1	Lower bound	5	5	5	5
2	Upper bound	25	10	35	15

Table 9: Results for the one-way waffle slab.

Waffle slab	Span size (m)	Thickness of top slab (cm)	Ribs spacing (cm)	Rib width at bottom (cm)	Rib width at top (cm)	Rebar diameter (cm)	Rib depth (cm)
E-CSS	6	5	59	10	10	1.6	15
	7	5	56	10	10	1.9	15
	8	5	50	10	10	2	15
CSS	6	5	57	10	10	1.6	15
	7	5	54	10	10	1.8	17
	8	5	51	10	10	1.9	16
IHS	6	2.5	55	10	10	1.4	15
	7	2.5	57	10	10	1.7	15
	8	2.5	47	10	10	1.8	15

Table 10: Results for the concrete slab formwork.

Formwork	Slab thickness (cm)	Joist width (cm)	Stringer width (cm)	Joist height (cm)	Stringer height (cm)	Joist spacing (cm)	Stringer spacing (cm)	Shore spacing (cm)
E-CSS	40	5	5	15	30	40	227	132
	50	5	5	15	30	40	178	152
	60	5	5	18	30	36	192	117
CSS	40	5	5	18	29	40	215	132
	50	5	5	20	29	38	229	117
	60	5	5	20	30	36	168	133
IHS	40	5	5	15	25	40	187	146
	50	5	5	19	26	38	214	107
	60	5	5	20	28	36	188	116

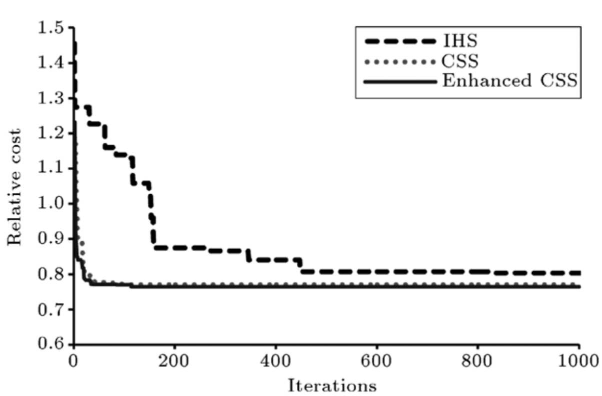

Figure 4: Design history for the composite floor system.

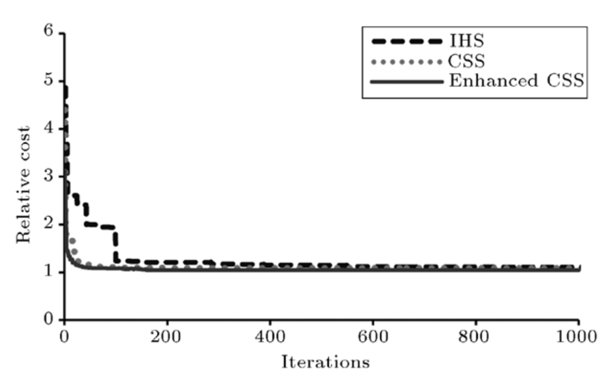

Figure 5: Design history for the one-way waffle system.

superposed forces and the laws for the motion determine the new location of the CPs. At this stage, each CP moves in the direction of the resultant forces and its previous velocity. From an optimization point of view, this process provides a good balance between the exploration and the exploitation paradigms of the algorithm, which can considerably improve its efficiency. The effect of the previous velocity and the resultant

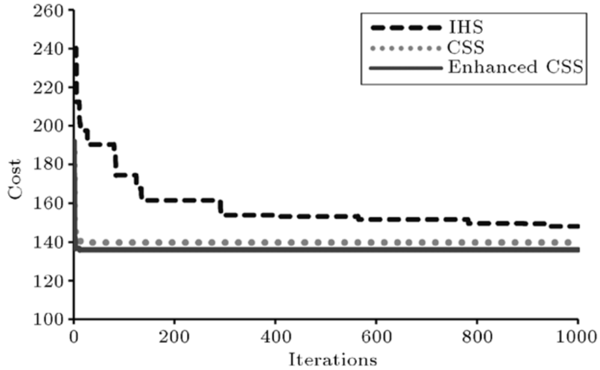

Figure 6: Design history for the concrete slab formwork.

force acting on a CP can be decreased or increased, by adjusting the values of the k_v and k_a, respectively. Excessive search in the early iterations may improve the exploration ability, however, it must be decreased gradually. Since k_a is the parameter related to the attracting forces, selecting a large value for this parameter may cause a fast convergence, and, vice versa, a small value can increase the computational time. In fact, k_a is a control parameter of the exploitation. Also, it is clear that the enhanced version of the CSS algorithm has a better minimum solution, obtained in fewer steps, because of using continuous time in every iteration. For future research of CSS, one may improve this algorithm, such that it does not require a parameter-value-setting, similar to other meta-heuristics [11–13].

8. Concluding remarks

In this article, the CSS and enhanced CSS algorithms are utilized for optimal design of three types of structure including composite slab, one-way waffle slab, and concrete slab formwork. These designs are based on the Load and Resistance Factor Design (LRFD) specification of the AISC and ACI 318-05 [14]. Also, these optimum designs are performed by the improved harmony search method, and the results are compared to demonstrate the efficiency of the CSS algorithm.

The charged system search is a meta-heuristic method for optimization of any kinds of problem. This method has three levels. The first level is initialization. In this level, the initial positions of charged particles are randomly selected in the search space. In the second level, the search for an optimum solution begins. Attracting forces, the probability of moving each particle towards others, and the new position and velocity of each particle, are determined in this level. The third level is the termination criterion. In this level, the algorithm checks if the best fitness satisfies the criterion set by the operator or not.

Three essential concepts, namely, the self-adaptation step, cooperation step, and competition step, are considered in this algorithm. Moving towards good CPs fulfills the self-adaptation step. Cooperating CPs, to determine the resultant force acting on each CP, provides the cooperation step. Comparison of the CPs and saving good ones in the charged memory corresponds to the competition step.

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