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THE EFFECT OF MEMBER GROUPING ON THE OPTIMUM DESIGN OF GRILLAGES VIA SEARCH TECHNIQUES

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Özet

Eleman guruplandırması çelik ızgara sistemlerin minimum ağırlık tasarımında önemli etkiye sahiptir. Mevcut çalışmada bu etki parçacık küme ve armoni arama isimleriyle bilinen iki farklı olasılığa dayalı optimizasyon metodu yardımıyla incelenmiştir. Izgara sistemin optimum tasarımı LRFD-AISC Amerikan şartnamesinde bulunan sınırlayıcıların dikkate alınması suretiyle gerçekleştirilmiştir. Her iki eksen doğrultusunda tasarlanacak olan elemanlar için aynı şartnamede bulunan 272 adet geniş başlıklı çelik profil kesiti kullanılmıştır. Optimum tasarım algoritması ızgara sistem elemanları için 272 adet çelik profilin bulunduğu tasarım havuzundan uygun profillerin seçilmesi suretiyle, sınılayıcıların sağlandığı ve ağırlığın minimum olduğu tasarımı belirleyecek şekilde oluşturulmuştur. Paçacık küme ve armoni arama yöntemlerinin kullanılmasıyla elde edilen tasarım algoritmaları yardımıyla sözkonusu kesikli optimizasyon probleminin çözümü gerçekleştirilmiştir. Bir tasarım örneği dikkate alınarak kiriş yerleşim aralıkları ile optimizasyon metodlarının performanslarının optimum tasarıma etkisi incelenmiştir.

Abstract

Member grouping of a steel grillage system has an important effect in the minimum weight design of these systems. In the present research, this effect is investigated using an optimum design algorithm which is based on two stochastic search techniques called particle swarm (PSO) and harmony search (HS) optimization methods. The optimum design problem of a grillage system is formulated by implementing LRFD-AISC (Load and Resistance Factor Design-American Institute of Steel Construction) limitations. It is decided that W-Sections are to be adapted for the longitudinal and transverse beams of the grillage system. 272 W-Section beams given in LRFD code are collected in a pool and the optimum design algorithm is expected to select the appropriate sections from this pool so that the weight of the grillage is the minimum correspondingly the design limitations implemented from the design code are satisfied. The solution for this discrete programming problem is determined by using the PSO and HS algorithms. Design example is presented to demonstrate the effect of beam spacing and performances of stochastic search techniques in the optimum design of grillage systems.

Keywords: Grillage optimization, discrete optimum design, member grouping, stochastic search techniques, particle swarm algorithm, harmony search algorithm.

1. Introduction

Grillage systems are used in structures to cover large spaces such as in bridge decks and in floors. They consist of crosswise longitudinal and transverse beams which constitute an orthogonal system. It is generally up to the designer to select the different member groupings between these beams unless some restrictions are imposed. It is apparent that the selection of varied numbers of member groupings between the longitudinal and transverse beams yields the adaptation of large or small steel sections for these beams. While a single member

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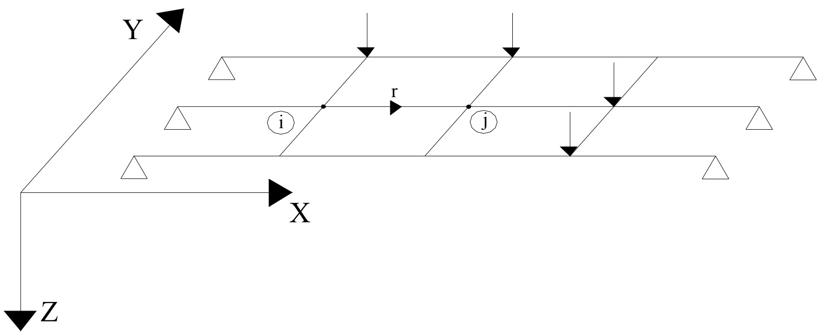
grouping increases the weight of the system to construct the grillage, an increase in the number of member grouping reduces the weight of the grillage system. Hence, there exist an optimum number of groups in both directions which provides a grillage system with the minimum weight. The number of beams in longitudinal and transverse directions is treated as design variables along with selecting the steel sections for the beams of both directions. The integrated design algorithm determines optimum number of beams in both directions as well as universal beam section designations required for these beams. In the present study, particle swarm and harmony search based design algorithms are used to investigate the effect of member grouping in the optimum design of grillage systems.

2. Optimum Design Problem to LRFD-AISC

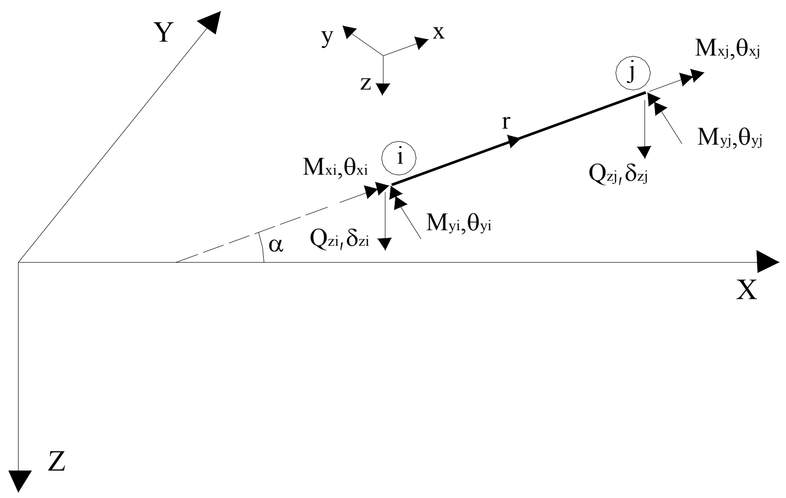
The optimum design problem of a typical grillage system shown in Figure 1 where the behavioral and performance limitations are implemented from LRFD-AISC [1] and the design variables which are selected as the sequence number of W sections given in the W steel profile list of LRFD-AISC can be expressed as follows.



a) Steel grillage system

$$\{D_i\} = \begin{Bmatrix} \theta_{xi} \\ \theta_{yi} \\ \delta_{zi} \end{Bmatrix} , \quad \{P_i\} = \begin{Bmatrix} M_{xi} \\ M_{yi} \\ Q_{zi} \end{Bmatrix}$$

b) Displacements and forces at joint i



c) End forces and end displacements of a grillage member

Figure 1 Typical grillage structure

$$\min \quad W = \sum_{k=1}^{ng} m_k \sum_{i=1}^{n_k} l_i \tag{1}$$

Subject to

$$\delta_j / \delta_{ju} \leq 1 \quad , j = 1,2,........, p \tag{2}$$

$$M_{ur} /(\phi_b M_{nr}) \leq 1 \, , r = 1,2,......., nm \tag{3}$$

$$V_{ur} /(\phi_v V_{nr}) \leq 1 \quad , r = 1,2,........, nm \tag{4}$$

Where m_k in Eq. 1 is the unit weight of the W-section selected from the list of LRFD-AISC for the grillage element belonging to group k, n_k is the total number of members in group k, and n_g is the total number of groups in the grillage system. l_i is the length of member *i*. δ_j in Eq. 2 is the displacement of joint j and δ_{ju} is its upper bound. The joint displacements are computed using the matrix displacement method for grillage systems. Eq. 3 represents the strength requirement for laterally supported beam in load and resistance factor design according to LRFD-F2. In this inequality $Ø_b$ is the resistance factor for flexure which is given as 0.9, M_{nr} is the nominal moment strength and M_{ur} is the factored service load moment for member r. Eq. 4 represents the shear strength requirement in load and resistance factor design according to LRFD-F2. In this inequality $Ø_v$ represents the resistance factor for shear given as 0.9, V_{nr} is the nominal strength in shear and V_{ur} is the factored service load shear for member r. The details of obtaining nominal moment strength and nominal shear strength of a W-section according to LRFD are given in the following.

2.1 Load and Resistance Factor Design for Laterally Supported Rolled Beams

The computation of the nominal moment strength M_n of a laterally supported beam, it is necessary first to determine whether the beam is compact, non-compact or slender. In compact sections, local buckling of the compression flange and the web does not occur before the plastic hinge develops in the cross section. On the other hand in practically compact sections, the local buckling of compression flange or web may occur after the first yield is reacted at the outer fiber of the flanges. The computation of M_n is given in the following as defined in LRFD-AISC.

a) If $\lambda \leq \lambda_p$ for both the compression flange and the web, then the section is compact;

$$M_n = M_p \text{ (Plastic moment capacity)} \tag{5}$$

b) If $\lambda_p < \lambda \leq \lambda_r$ for the compression flange or web, then the section is partially compact;

$$M_n = M_p - (M_p - M_r)\frac{\lambda - \lambda_r}{\lambda_r - \lambda_p} \tag{6}$$

c) If $\lambda \succ \lambda_r$ for the compression flange or the web, then the section is slender;

$$M_n = M_{cr} = S_x F_{cr} \tag{7}$$

where $\lambda = b_f/(2t_f)$ for I-shaped member flanges and the thickness in which b_f and t_f are the width and the thickness of the flange, and $\lambda = h/t_w$ for beam web, in which $h=d-2k$ plus allowance for undersize inside fillet at compression flange for rolled I-shaped sections. d is the depth of the section and k is the distance from outer face of flange to web toe of fillet. t_w is the web thickness. h/t_w values are readily available in W-section properties table. λ_p and λ_r are given in table LRFD-B5.1 of the code as

$$\left.\begin{aligned} \lambda_p &= 0.38\sqrt{\frac{E}{F_y}} \\ \lambda_r &= 0.83\sqrt{\frac{E}{F_y - F_r}} \end{aligned}\right\} \textit{for compression flange} \tag{8}$$

$$\left.\begin{aligned} \lambda_p &= 3.76\sqrt{\frac{E}{F_y}} \\ \lambda_r &= 5.70\sqrt{\frac{E}{F_y}} \end{aligned}\right\} \textit{for the web} \tag{9}$$

in which E is the modulus of elasticity and F_y is the yield stress of steel. F_r is the compressive residual stress in flange which is given as 69 MPa for rolled shapes in the code. It is apparent that M_n is computed for the flange and for the web separately by using corresponding λ values. The smallest among all is taken as the nominal moment strength of the *W* section under consideration.

2.2 Load and Resistance Factor Design for Shear in Rolled Beams

Nominal shear strength of a rolled compact and non-compact W section is computed as follows as given in LRFD-AISC-F2.2

$$\text{For } \frac{h}{t_w} \le 2.45\sqrt{\frac{E}{F_{yw}}}, V_n = 0.6F_{yw}A_w \tag{10}$$

$$\text{For } 2.45\sqrt{\frac{E}{F_{yw}}} < \frac{h}{t_w} \le 3.07\sqrt{\frac{E}{F_{yw}}}, V_n = 0.6F_{yw}A_w\left(\frac{2.45\sqrt{\frac{E}{F_{yw}}}}{\frac{h}{t_w}}\right) \tag{11}$$

$$\text{For } 3.07\sqrt{\frac{E}{F_{yw}}} < \frac{h}{t_w} \le 260 \;, \quad V_n = A_w\frac{4.52Et_w^{\,2}}{h^2} \tag{12}$$

where **E** is the modulus of elasticity and F_{yw} is the yield stress of web steel. V_n is computed from one of the expressions of (10)-(12) depending upon the value of h/t_w of the **W**-section under consideration.

3 Particle Swarm Method

Particle swarm optimizer (PSO) is based on the social behavior of animals such as fish schooling, insect swarming and birds flocking. This behavior is concerned with grouping by social forces that depend on both the memory of each individual as well as the knowledge gained by the swarm [2-5]. The procedure involves a number of particles which represent the swarm being initialized randomly in the search space of an objective function. Each particle in the swarm represents a candidate solution of the optimum design problem. The particles fly through the search space and their positions are updated using the current position, a velocity vector and a time step. The steps of the algorithm are outlined in the following as given in [6-8]:

I - *Initializing Particles:* A swarm consists of a predefined number of particles referred to as swarm size (μ). Each particle ($\mathbf{P}$) incorporates two sets of components; a position vector **I** and a velocity vector **V** (Eqn. 13). The position vector **I** retains the positions of design variables, while the velocity vector **V** is used to vary these positions during the search. Each particle in the swarm is constructed by a random initialization such that all initial positions $I_i^{(0)}$ and velocities $v_i^{(0)}$ are assigned from Eqns. (14-15):

$$\mathbf{P} = (\mathbf{I}, \mathbf{v}), \quad \mathbf{I} = \left[I_1, I_2, ..., I_{N_d}\right] \quad , \quad \mathbf{v} = \left[v_1, v_2, ..., v_{N_d}\right] \tag{13}$$

$$I_i^{(0)} = I_{\min} + r\left(I_{\max} - I_{\min}\right), \quad i = 1,..,N_d \tag{14}$$

$$v_i^{(0)} = \frac{I_{\min} + r(I_{\max} - I_{\min})}{\Delta t}, \quad i = 1,..,N_d \tag{15}$$

Where, r is a random number sampled between 0 and 1; Δt is the time step; and $I_{\min}$ and $I_{\max}$ are the sequence numbers of the first and last standard steel sections in the profile list, respectively.

II - *Evaluating Particles:* All the particles are analyzed, and their objective function values are calculated using design space positions.

III - *Updating the Particles' Best and the Global Best:* A particle's best position (the best design with minimum objective function) thus far is referred to as particle's best and is stored separately for each particle in a vector $\mathbf{B}$. On the other hand, the best feasible position located by any particle since the beginning of the process is called the global best position, and it is stored in a vector $\mathbf{G}$. At the current iteration *k*, both the particles' bests and the global best are updated (15).

$$\mathbf{B}^{(k)} = \left[B_1^{(k)}, ...B_i^{(k)} .., B_{N_d}^{(k)}\right] \qquad \mathbf{G}^{(k)} = \left[G_1^{(k)}, ...G_i^{(k)} .., G_{N_d}^{(k)}\right] \tag{16}$$

IV **-** Updating a Particle's Velocity Vector: The velocity vector of each particle is updated considering the particle's current position, the particle's best position and global best position, as follows:

$$v_i^{(k+1)} = wv_i^{(k)} + c_1 r_1 \left(\frac{G_i^{(k)} - I_i^{(k)}}{\Delta t} \right) + c_2 r_2 \left(\frac{B_i^{(k)} - I_i^{(k)}}{\Delta t} \right) \qquad (17)$$

Where, r_1 and r_2 are random numbers between 0 and 1; w is the inertia of the particle which controls the exploration properties of the algorithm; and c_1 and c_2 are the trust parameters, indicating how much confidence the particle has in itself and in the swarm, respectively.

V **-** Updating a Particle's Position Vector: Next, the position vector of each particle is updated with the updated velocity vector (Eqn. 18), which is rounded to nearest integer value for discrete variables.

$$I_i^{(k+1)} = I_i^{(k)} + v_i^{(k+1)} \Delta t \qquad (18)$$

VI **-** Termination: The steps 2 through 5 are repeated in the same way for a predefined number of iterations N_{ite} .

4 Harmony Search Method

The solution of the optimum design problem described from Eq. 1 to Eq. 4 is obtained by HS algorithm [9-12]. The method consists of five basic steps as listed below.

I **-** Harmony search parameters are initialized: A possible value range for each design variable of the optimum design problem is specified. A pool is constructed by collecting these values together from which the algorithm selects values for the design variables. Furthermore the number of solution vectors in harmony memory (HMS) that is the size of the harmony memory matrix, harmony considering rate (HMCR), pitch adjusting rate (PAR) and the maximum number of searches are also selected in this step.

II **-** Harmony memory matrix (HM) is initialized: Harmony memory matrix is initialized. Each row of harmony memory matrix contains the values of design variables which are randomly selected feasible solutions from the design pool for that particular design variable. Hence, this matrix has n columns where N is the total number of design variables and HMS rows which is selected in the first step. HMS is similar to the total number of individuals in the population matrix of the genetic algorithm. The harmony memory matrix has the following form:

$$[H] = \begin{bmatrix} x_{1,1} & x_{2,1} & .. & .. & x_{n-1,1} & x_{n,1} \\ x_{1,2} & x_{2,2} & .. & .. & x_{n-1,2} & x_{n,2} \\ .. & .. & .. & .. & .. & .. \\ .. & .. & .. & .. & .. & .. \\ x_{1,hms-1} & x_{2,hms-1} & .. & .. & x_{n-1,hms-1} & x_{n,hms-1} \\ x_{1,hms} & x_{2,hms} & .. & .. & x_{n-1,hms} & x_{n,hms} \end{bmatrix} \qquad (19)$$

$x_{i,j}$ is the value of the i^{th} design variable in the j^{th} randomly selected feasible or near feasible solution. $x_{i,j}$ represents the sequence number of a steel section in the design pool. These candidate designs are sorted such that the objective function value corresponding to the first solution vector is the minimum. In other words, the feasible solutions in the harmony memory matrix are sorted in descending order according to their objective function value. It is worthwhile to mention that not only the feasible designs that are those which satisfy the constraints 1-4 are inserted into the harmony memory matrix. Those designs having a small infeasibility are also included in the harmony memory matrix as explained in the next step.

III **-** *New harmony memory matrix is improvised:* In generating a new harmony matrix the new value of the i^{th} design variable can be chosen from any discrete value within the range of i^{th} column of the harmony memory matrix with the probability of *HMCR* which varies between 0 and 1. In other words, the new value of x_i can be one of the discrete values of the vector $\{x_{i,1}, x_{i,2}, \ldots\ldots\ldots, x_{i,hms}\}^T$ with the probability of *HMCR*. The same is applied to all other design variables. In the random selection, the new value of the i^{th} design variable can also be chosen randomly from the entire pool with the probability of *1-HMCR*. That is

$$x_i^{new} = \begin{cases} x_i \in \{x_{i,1}, x_{i,2}, \ldots\ldots\ldots x_{i,hms}\}^T & with\ probability\ HMCR \\ x_i \in \{x_1, x_2, \ldots\ldots\ldots, x_{ns}\}^T & with\ probability\ (1-HMCR) \end{cases} \quad (20)$$

where *ns* is the total number of values for the design variables in the pool. If the new value of the design variable is selected among those of the harmony memory matrix, this value is then checked whether it should be pitch-adjusted. This operation uses pitch adjustment parameter *PAR* that sets the rate of adjustment for the pitch chosen from the harmony memory matrix as follows:

$$Is\ \ x_i^{new}\ to\ be\ pitch-adjusted\ ? \begin{Bmatrix} Yes & with\ probability\ of\ PAR \\ No & with\ probability\ of\ (1-PAR) \end{Bmatrix} \quad (21)$$

Supposing that the new pitch-adjustment decision for x_i^{new} came out to be *yes* from the test and if the value selected for x_i^{new} from the harmony memory is the k^{th} element in the general discrete set, then the neighboring value k+1 or k-1 is taken for new x_i^{new}. This operation prevents stagnation and improves the harmony memory for diversity with a greater change of reaching the global optimum. Once the new harmony vector x_i^{new} is obtained using the above-mentioned rules, it is then checked whether it violates problem constraints. If the new harmony vector is severely infeasible, it is discarded. If it is slightly infeasible, there are two ways to follow. One is to include them in the harmony memory matrix by imposing a penalty on their objective function value. In this way the violated harmony vector which may be infeasible slightly in one or more constraints, is used as a base in the pitch adjustment operation to provide a new harmony vector that may be feasible. The other way is to use larger error values such as 0.08 initially for the acceptability of the new design vectors and reduce this value gradually during the design cycles and use finally an error value of 0.001 towards the end of the iterations. This adaptive error strategy is found quite effective in handling the design constraints in large design problems.

IV **-** *Harmony Memory matrix is updated:* After selecting the new values for each design variable the objective function value is calculated for the new harmony vector. If this value is better than the worst harmony vector in the harmony matrix, it is then included in the matrix while the worst one is taken out of the matrix. The harmony memory matrix is then sorted in descending order by the objective function value.

***V* -** *Termination:* Steps 3 and 4 are repeated until the termination criterion which is the pre-selected maximum number of cycles is reached. This number is selected large enough such that within this number of design cycles no further improvement is observed in the objective function.

5 Optimum Design Algorithms

The optimum design algorithm is based on the PSO and HS methods, steps of which are given previous sections. The discrete set from which the design algorithm selects the sectional designations for grillage members is considered to be the complete set of 272 W-sections which start from W100×19.3mm to W1100×499mm as given in LRFD-AISC [1]. The design variables are the sequence numbers of W-sections that are to be selected for member groups in the grillage system. These sequence numbers are integer numbers which can take any value between 1 and 272. PSO and HS methods then randomly select integer number for each member group within the bounds. Once these numbers are decided, then the sectional designation and cross sectional properties of that section becomes available for the algorithm. The grillage system is then analyzed with these sections under the external loads and the response of the system is obtained. If the design constraints given in Eqs. 2-4 are satisfied this set of sections are placed in the solution vector, if not the selection is discarded. This process is continued until the search algorithms find the optimum solution for grillage system.

6 Design Example

The optimum design algorithm presented in the previous sections is used to demonstrate the effect of member grouping in the design of grillages. In order to demonstrate this effect, 40-member grillage system shown in Figure 2 is designed several times by considering different member groupings. For this purpose, 12.5m×10m square area is considered. The design problem is to set up a grillage system that is supposed to carry 25.6kN/m^2 uniformly distributed load total of which is 3200kN. The total external loading is distributed to the joints as 200kN point load. The grillage system that can be used to cover the area will have 12.5m long longitudinal beams and 10m long transverse beams. The total external load is distributed to joints of the grillage system as a point load value of which is calculated according to beam spacing. A36 mild steel is selected for the design, which has the yield stress of 250MPa, the modulus of elasticity of 205 kN/mm^2 and shear modulus of 81 kN/mm^2 respectively. The vertical displacements of joints 6, 7, 10 and 11 are restricted to 25 mm. The result of the sensitivity analysis carried out to determine the appropriate value ranges of the PSO and HS parameters is given in [13]. It is noticed that particle swarm parameter values of 10 for number of particles (μ), 1.0 for the self-confidence parameter of particles ($c1$) and swarm confidence parameter ($c2$), 0.08 for the inertia weight (w) and 2 for maximum velocity of particles (V_{max}) and velocity time increment (Δt) and harmony search parameters; harmony memory size (*HMS*) is taken as 10, harmony memory considering rate (*HMCR*) is selected as 0.7 while pitch adjusting rate (*PAR*) is considered as 0.5 after carrying out several trials in the design of all grillage systems. When the optimum design problem is carried out considering only single group shown in Figure 2, the minimum weight of the system turns out to be

14499.8kg. The optimum design of the grillage system is carried out by both algorithms presented and the optimum results obtained are given in Table 1.

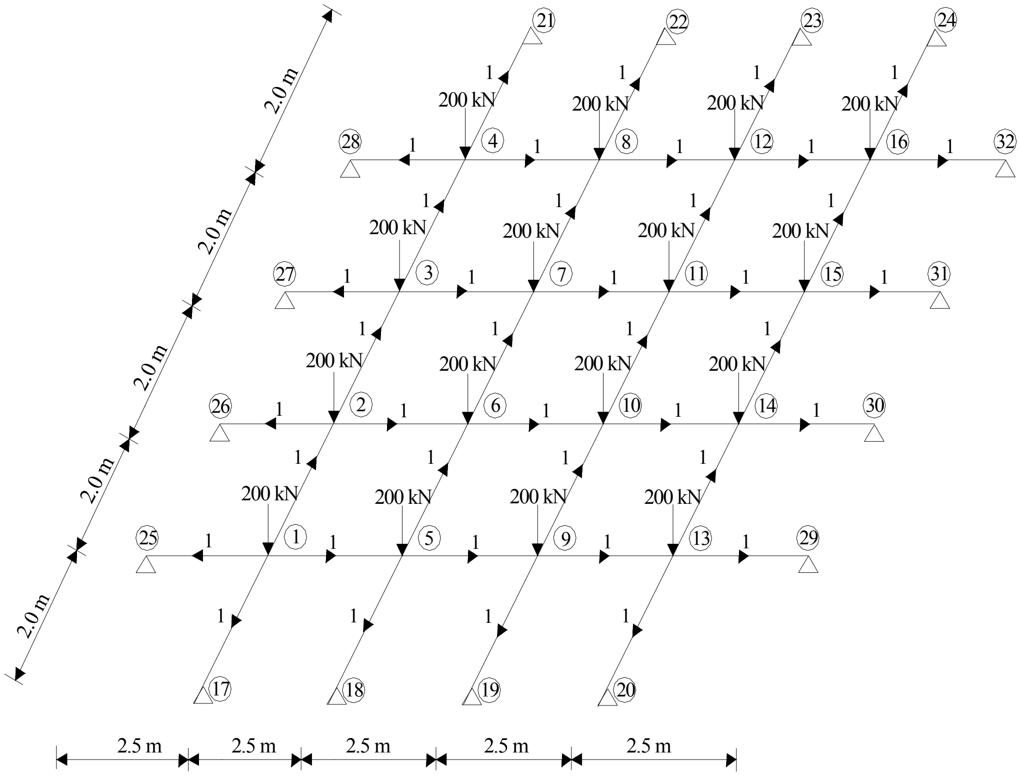


Figure 2 40-member grillage system with single grouping

Table 1. Optimum design for 40-member grillage system with one group

Method	Optimum W-Section Designations		δ_{max} (mm)	Maximum Strength Ratio	Minimum Weight (kg)
	Group No.	Designation			
Particle Swarm	1	W410×46.1	24.2	0.73	14499.8
Harmony Search	1	W410×46.1	24.2	0.73	14499.8

When the longitudinal members are considered as a group and the transverse ones are collected in another group shown in Figure 3, the minimum weight drops down almost by half to 7729.5kg and the particle swarm optimization method finds again the same optimum designs with harmony search algorithm. Optimum sectional designations of the 40-member grillage system under the external loading, obtained by design method presented, are given in Table 2.

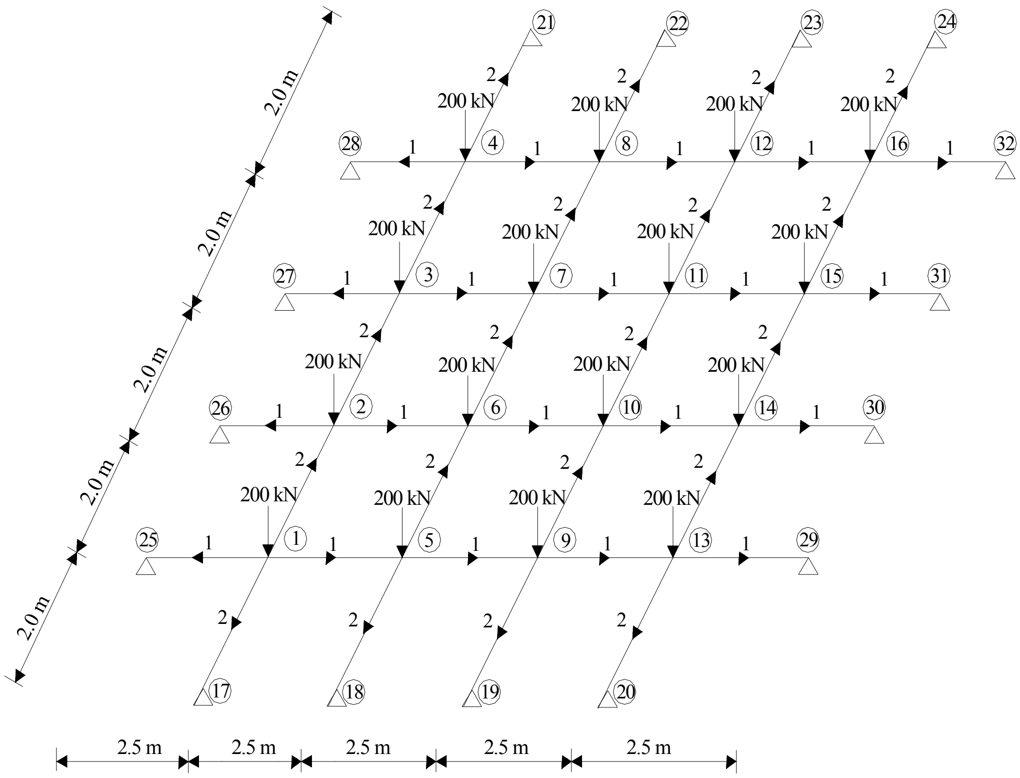


Figure 3 40-member grillage system with two groups

Table 2 Optimum design for 40-member grillage system with two groups

Method	Optimum W-Section Designations		δ_{max} (mm)	Maximum Strength Ratio	Minimum Weight (kg)
	Group No.	Designation			
Particle Swarm	1 2	W150×13.5 W840×176	24.2	0.80	7729.5
Harmony Search	1 2	W150×13.5 W840×176	24.2	0.80	7729.5

Further reduction is possible if longitudinal members are collected in two groups and transverse members are considered as another two groups. It is apparent from Figure 4 that consideration of four member groups represents the optimum grouping for 40-member grillage system and the optimum grillage system obtained by the PSO are 25.5 kg lighter than the one determined by the HS algorithm. The optimum design of this grillage system with four groups is carried out by the algorithm presented and the optimum results obtained are given in Table 3.

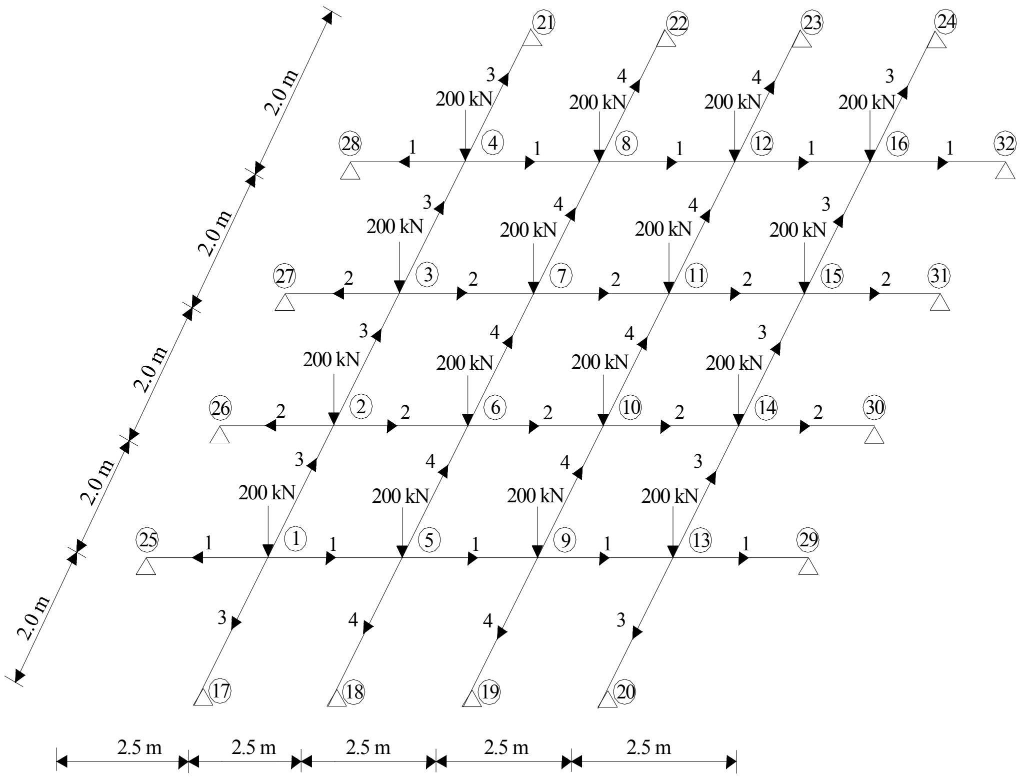


Figure 4 40-member grillage systems with four groups

Table 3 Optimum design for 40-member grillage system with four group

Method	Optimum W-Section Designations		δ_{max} (*mm*)	Maximum Strength Ratio	Minimum Weight (kg)
	Group No.	Designation			
Particle Swarm Algorithm	1	W410X46.1	23.2	0.99	7198.2
	2	W460X52			
	3	W200X15			
	4	W1000X222			
Harmony Search Algorithm	1	W410X46.1	22.3	1.00	7223.7
	2	W410X53			
	3	W200X15			
	4	W1000X222			

Finally, the number of groups is increased from 4 to 8 in both directions. It is interesting to notice that when all the members are allowed to have separate groups, shown in Figure 5, the minimum weight of the grillage system also increases from 7198.2kg to 9403.1kg for PSO and 9231.3kg for HS algorithm. The optimum sectional designations obtained for the 40-member grillage system with 8 groups is given in Table 4. Furthermore, it is clear from the same table that for the larger number of groups, the strength constraints becomes dominant in the design problem, while for the cases where less number of groups is considered, the displacement constraints become dominant.

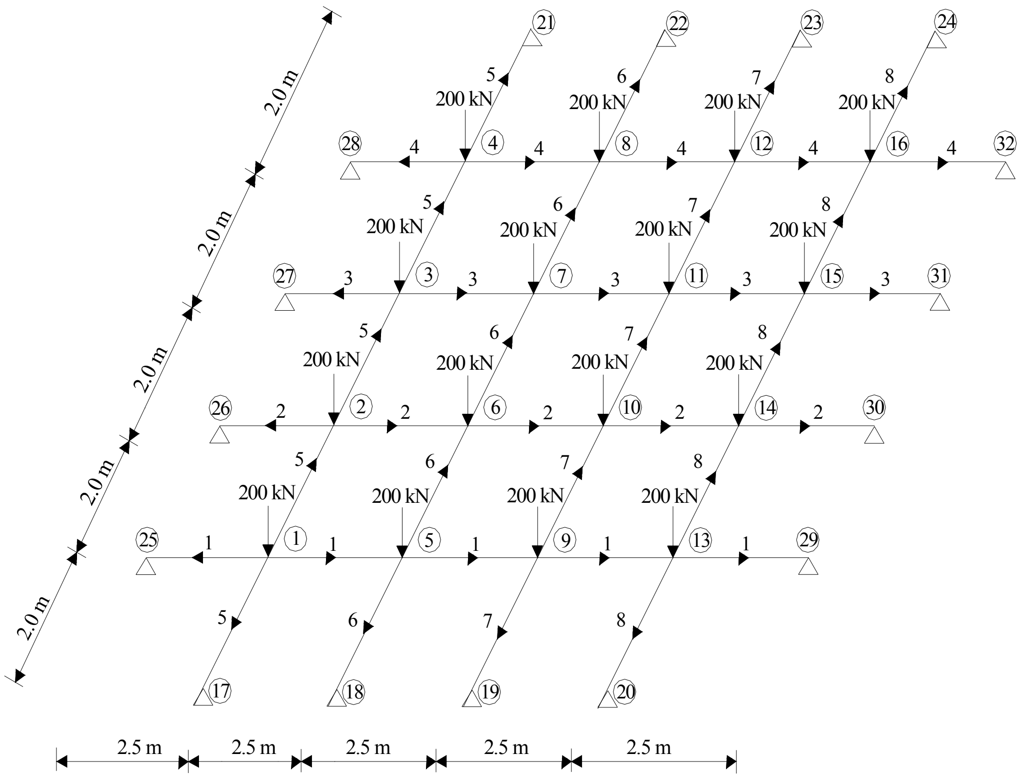


Figure 5 40-member grillage system with eight groups

Table 3 Optimum design for 40-member grillage system with four group

Method	Optimum W-Section Designations		δ_{max} (mm)	Maximum Strength Ratio	Minimum Weight (kg)
	Group No.	Designation			
Particle Swarm Algorithm	1	W150×13.5	24.9	0.99	9403.1
	2	W760×147			
	3	W150×13.5			
	4	W1000×272			
	5	W410×46.1			
	6	W610×101			
	7	W460×52			
	8	W760×134			
Harmony Search Algorithm	1	W310×32.7	24.7	1.00	9231.3
	2	W460×52			
	3	W460×89			
	4	W250×22.3			
	5	W200×59			
	6	W1000×321			
	7	W760×185			
	8	W460×113			

The variation of the minimum weight with the member grouping of PSO and HS algorithms is shown in Figure 6. In the present study, the member grouping is selected as numbers that are practically preferred. It is apparent from the figure that 4-member grouping is the optimum grouping among the values considered. It should be pointed out that in the design of grillage systems member grouping should be taken as design variable in addition to steel section designations to be selected for the beam spacing.

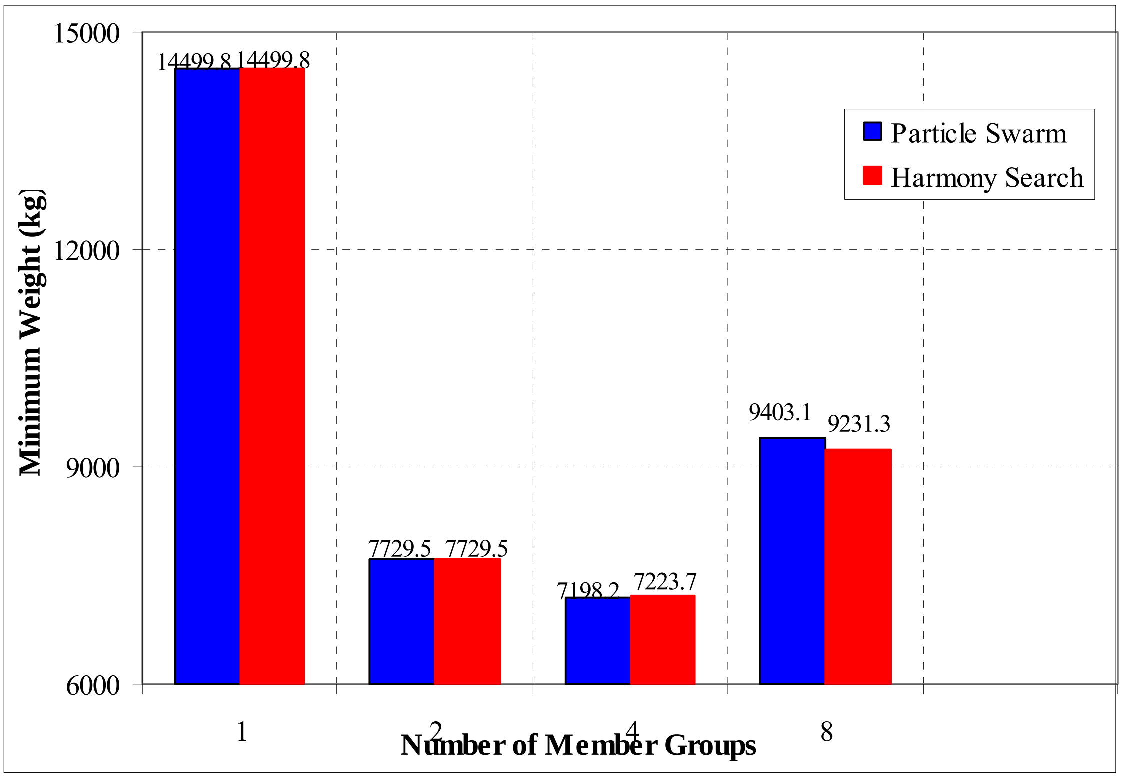


Figure 6 Variation of weight versus member groups

6. Conclusions

It is shown that the particle swarm and harmony search methods which are two of the recent additions to metaheuristic algorithms can successfully be used in the optimum design of grillage systems. These stochastic search techniques have some parameters that are required to be determined prior to its use in determining the optimum solution. These parameters are problem dependent and some trials are necessary to determine their appropriate values for the problem under consideration. It is also shown that member grouping in the optimum design of grillage systems has a considerable effect on the minimum weight and it is more appropriate to consider this parameter as a design variable if a better design is looked for. It is also interesting to notice that while for the larger values of member grouping the optimum design problem is strength dominant, for the smaller values of member grouping the problem becomes displacement dominant.

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