Paper 73

Proceedings of the Eleventh International Conference
on Computational Structures Technology,
B.H.V. Topping, (Editor),
Civil-Comp Press, Stirlingshire, Scotland

Discrete Design Optimization of Space Steel Frames using the Adaptive Firefly Algorithm

İ. Aydoğdu[1], A. Akın[2] and M.P. Saka[3]
[1] Civil Engineering Department, Akdeniz University, Antalya, Turkey
[2] Civil Engineering Department, Yüzüncuyıl University, Van, Turkey
[3] Civil Engineering Department, University of Bahrain, Isa Town, Bahrain

Abstract

Optimum design of steel frames is a complicated process because the designer has to consider a large number of nonlinear constraints which are imposed by steel design codes while also dealing with discrete design variables. Obtaining the optimum solution to discrete programming problems was never easy until the emergence of metaheuristic techniques. The firefly algorithm, one of the recent metaheuristic techniques that is based on the idealized behaviour of the flashing characteristics of fireflies. In this paper, the optimum design problem of steel space frames is formulated according to the provisions of LRFD-AISC (Load and Resistance Factor Design) [1]. The firefly optimization technique is used to obtain the solution to the design problem. A number of space frames is designed using the firefly algorithm developed in order to test the performance of the firefly algorithm for structural design problem.

Keywords: steel space frames; firefly algorithm, metaheuristic techniques, optimum structural design, load and resistance factor design, combinatorial optimization.

1 Introduction

Metaheuristic techniques attempt to find a solution to design problems by using special strategies that are generally inspired by the nature. These techniques search the design space by using certain rules in order to find out the optimal or near optimal solutions to the design problems [2-8]. These are usually named by natural phenomena they simulate. Genetic algorithm, Evolutionary Strategies, Simulating Annealing, Tabu Search, Ant Colony Optimization, Particle Swarm Optimization, Artificial Bee Colony, Harmony Search and Firefly algorithms are some of the Metaheuristic techniques that are used to develop structural optimization algorithms[9]. One of the recently developed Metaheuristic techniques is the Firefly algorithm [10]. This method is based on the idealized behavior of flashing characteristics of fireflies. Fireflies communicate, search for pray and breed using various flashing patterns. Firefly algorithm idealizes and simulates some of these flashing patterns in a numerical algorithm. Firefly algorithm is applied on many engineering fields such as solving nonlinear functions [11] and optimum design of truss system [12] problems. Satisfactory test results are obtained at the end of these studies.

In this study, the optimum design problem of steel space frames is formulated according to the provisions of LRFD-AISC (Load and Resistance Factor Design) [1]. Design constraints include the displacement limitations, inter-story drift restrictions of multi-story frames and strength requirements for beam-column members. Furthermore, additional constraints are used to satisfy practical requirements. These include three types of inequalities. The first type ensures that the flange width of the beam section at each beam-column connection of each story is less than or equal to the flange width or depth of column section. The second and third type of constraints make sure that the depth and the mass per meter of column at each column-column connection are less than or equal to the width and the mass of the column section at the lower story. The mathematical model of the design problem turns out to be discrete nonlinear programming problem. The Firefly optimization technique is used to find its optimum solution. Number of design examples is presented to demonstrate the performance of the Firefly algorithm.

2 Mathematical Modeling of Optimum Design of Space Frame Problems

Optimum design of space steel frame problems requires selection of steel sections for its columns and beams from available standard steel section tables so that the frame satisfies the serviceability and strength limitations specified by the code of practice. In this selection it is also necessary to consider the economy. This is achieved in the optimum design of steel frames by taken the overall or material cost of the frame as an objective function. The objective function of optimum design of space steel frame problems is formulated as minimization of weight of the frame which is expressed as:

$$\text{Minimize,}\quad W(x) = \sum_{r=1}^{NG} m_r \cdot \sum_{s=1}^{t_r} l_s \tag{1}$$

where; $W$is the weight of the frame, x is the vector which contains the sequence numbers of steel sections in the available list for the space frame which are described as design variables, m_r is the unit weight of the steel section selected from the standard steel sections table that is to be adopted for group r, t_r is the total number of members in group r and NG is the total number of groups in the frame, l_s is the of length of members which belongs to group r. These optimization problems are subjected to design constraints which are described in a formula as follows.

$$\sum_{i=1}^{NC} g_i(x) = \sum g_s(x) + \sum g_d(x) + \sum g_{td}(x) + \sum g_{id}(x) + \sum g_{cc}(x) + \sum g_{bc}(x) \geq 0 \tag{2}$$

where; g_s, g_d, g_{td}, g_{id}, g_{cc} and , g_{bc} are the constraints functions for strength, deflection, inter-story drift, top story drift, column-to-column geometric and beam-to-column geometric constraints functions according to design code LRFD-AISC [1] respectively. Strength constraint function is defined from inequalities given in Chapter H of LRFD-AISC as:

$$g_s(x) = \frac{P_u}{\emptyset P_n} + \frac{8}{9}\left(\frac{M_{ux}}{\emptyset_b M_{nx}} + \frac{M_{uy}}{\emptyset_b M_{ny}}\right) - 1.0 \leq 0 \; for \; \frac{P_u}{\emptyset P_n} \geq 0.2 \tag{3}$$

$$g_s(x) = \frac{P_u}{2\emptyset P_n} + \left(\frac{M_{ux}}{\emptyset_b M_{nx}} + \frac{M_{uy}}{\emptyset_b M_{ny}}\right) - 1.0 \leq 0 \; for \; \frac{P_u}{\emptyset P_n} < 0.2 \tag{4}$$

where, M_{nx} is the nominal flexural strength at strong axis (x axis), M_{ny} is the nominal flexural strength at weak axis (y axis), M_{ux} is the required flexural strength at strong axis (x axis) , M_{uy} is the required flexural strength at weak axis (y axis), P_n is the nominal axial strength (Tension or compression) and P_u is the required axial strength (Tension or compression) for member i. The values of M_{ux} and M_{uy} are to be obtained by carrying out $P - \Delta$ analysis of the steel frame. This is an iterative process which quite time consuming. In Chapter C of LRFD-AISC an alternative way is suggested for the computations of M_{uy} and M_{ux} values. In this way two first order elastic analyses are carried out. In the first, frame is analyzed under the gravity loads only where the sway of the frame is prevented to obtain M_{nt}values. In the second, the frame is analyzed only under the lateral loads to find M_{lt}values. These moment values are combined as given in the following.

$$M_u = B_1 M_{nt} + B_2 M_{lt} \tag{5}$$

where, B_1 is the moment magnifier coefficient and B_2 is the sway moment magnifier coefficient. The details of how these coefficients are calculated are given in Chapter C of LRFD-AISC [1].

Deflection, top story drift and inter story drift constraints functions are given in the following equations (6), (7) and (8) respectively [13].

$$g_d(x) = \frac{\delta_{jl}}{L/Ratio} - 1.0 \leq 0 \quad j = 1,2,\dots,n_{sm} \quad l = 1,2,\dots,n_{lc} \tag{6}$$

$$g_{td} = \frac{\Delta_{jl}^{top}}{H/Ratio} - 1.0 \leq 0 \quad j = 1,2,\dots,n_{jtop} \quad l = 1,2,\dots,n_{lc} \tag{7}$$

$$g_{id} = \frac{\Delta_{jl}^{oh}}{h_{sx}/Ratio} - 1.0 \leq 0 \quad j = 1,2,\dots,n_{st} \quad l = 1,2,\dots,n_{lc} \tag{8}$$

where, δ_{jl} is the maximum deflection of j^{th} member under the l^{th} load case, L is the length of member, n_{sm} is the total number of members where deflections limitations are to be imposed, n_{lc} is the number of load cases, H is the height of the frame, n_{jtop} is the number of joints on the top story, Δ_{jl}^{top} is the top story displacement of the j^{th} joint under l^{th} load case, n_{st} is the number of story, n_{lc} is the number of load cases and Δ_{jl}^{oh} is the story drift of the j^{th} story under l^{th} load case, h_{sx} is the story height and $Ratio$ is limitation ratio for lateral displacements described in ASCE Ad Hoc Committee report [14] .According to the ASCE Ad Hoc Committee report, the accepted range of drift limits by first-order analysis is 1/750 to 1/250 times the building height H with a recommended value of H/400.The typical limits on the inter-story drift are 1/500 to 1/200 times the story height. Based on this report the deflection limits recommended are proposed in [15, 16] for general use which is repeated in Table 1.

	Item	Deflection Limit
1	Floor girder deflection for service live load	L/360
2	Roof girder deflection	L/240
3	Lateral drift for service wind load	H/400
4	Inter story drift for service wind load	H/300

Table 1: Displacement limitations for steel frames

Geometric limitations functions are included in the design problem as in the equations (9) and (10).

$$g_{cc}(x) = \sum_{i=1}^{n_{ccj}} \left(\frac{D_i^a}{D_i^b} - 1.0 \right) + \sum_{i=1}^{n_{ccj}} \left(\frac{m_i^a}{m_i^b} - 1.0 \right) \leq 0 \tag{9}$$

$$g_{bc}(x) = \sum_{i=1}^{n_{j1}} \left(\frac{B_f^{bi}}{D^{ci} - 2t_b^{ci}} - 1.0 \right) \leq 0 \; or \; \sum_{i=1}^{n_{j2}} \left(\frac{B_f^{bi}}{B_f^{ci}} - 1.0 \right) \leq 0 \tag{10}$$

where; n_{ccj} is the number of column-to-column geometric constraints defined in the problem , m_i^a is the unit weight of W section selected for above story, m_i^b is the unit weight of W section selected for below story, D_i^a is the depth of W section selected for above story, D_i^b is the depth of W section selected for below story, n_{j1} is the number of joints where beams are connected to the web of a column, n_{j2} is the number of joints where beams connected to the flange of a column, D^{ci} is the depth of W section selected for the column at joint i, t_b^{ci} is the flange thickness of W section selected for the column at joint i, B_f^{ci} is the flange width of W section selected for the column at joint i and B_f^{bi} is the flange width of W section selected for the beam at joint i.

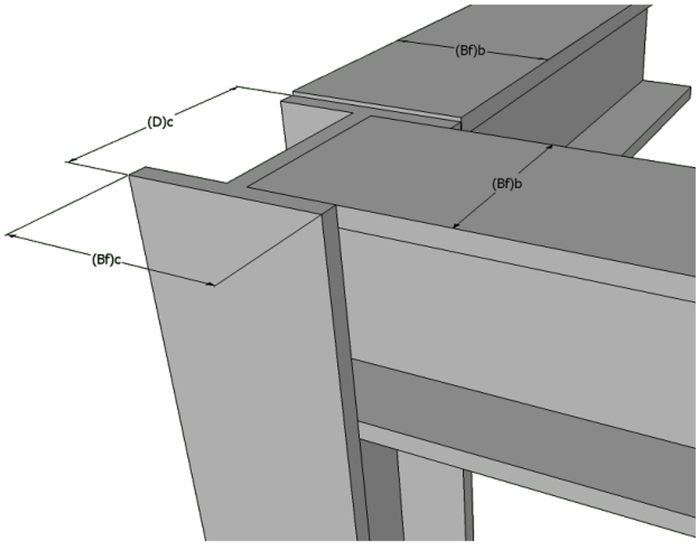

Figure 1: Beam column geometric constraints

3 The Firefly Algorithm for Optimum Design of Frame Problems

The Firefly algorithm introduced by Yang [9, 10] is one of the very recent Metaheuristic techniques. This optimization algorithm is improved by adopting idealized behavior of the characteristic of the fireflies. This natural behavior can be defined by using three rules described as:

1. All fireflies will be attracted to other fireflies due to fact that they are unisex.
2. Attractiveness of all fireflies is determined to be proportionate with their brightness.
3. The brightness of a firefly is assumed to be related to the objective function.

The steps of the optimum design algorithm developed for space steel frames which is based on Firefly algorithm are given in the following:

Step 1: n fireflies start selecting steel sections randomly from the steel sections list where, n represents the number of Fireflies in the swarm. At the end of this random selection process n frame designs are obtained. The objective function values of these designs are also calculated.

Step 2: The n frame designs obtained in step 1 are analyzed and designed. At the end of this process constraint violations are obtained. Summing these violations, total constraint violation value is calculated for each frame design. These values are used for penalizing weights of designed frames. At the end of this process, n penalized frame weights are obtained by using following function.

$$W_p(i) = W(i)\left(1 + C(i)\right)^{\varepsilon} \quad i = 1,2,\ldots,n \tag{11}$$

where, W_p is the penalized weight of frame generated by i^{th} firefly and ε is penalty coefficient.

Step 3: Original light intensities (I_0) of all fireflies which are inverse proportional to penalized weight are calculated by using the following equation.

$$I_0(i) = \frac{W_{\min}}{W_p(i)} \qquad i = 1,2,\ldots,n \tag{12}$$

where, W_{min} is minimum weight of the structure obtained in step 1. After these calculations, original light intensities and steel sections of frame designs are sorted in descending order of penalized weights.

Step 4: In the last step, all fireflies in the algorithm starts moving to the better location. These movements are depended on their attractiveness and attractiveness is proportional to the light density, which also varies with distance(d). Attractiveness of each firefly is calculated by following function.

$$\beta(d) = \beta_0 e^{-\gamma d^2} \tag{13}$$

where, β_0 is attractiveness of the Firefly at original location, γ is the absorption coefficient and d is the distance calculated by following function.

$$d_{ij} = \sqrt{\sum_{k=1}^{NG} (Sect_i^k - Sect_j^k)^2} \tag{14}$$

where, NG is the number of groups in the frame system, $Sect$ is section number of section profiles in the profile list (all sections are sorted ascending order of their unit weight). Then, all fireflies select new sections and generate new designs by using the formula given as :

$$\begin{gathered} Sect_i^k = Sect_i^k + \beta(d) \cdot \left(Sect_j^k - Sect_i^k\right) + \alpha \cdot \left(rand - \frac{1}{2}\right) \\ i = 1,2,\ldots,n \qquad j = 1,2,\ldots,n \qquad k = 1,2,\ldots,NG \end{gathered} \tag{15}$$

where, $Sect_i^k$ section number of profile selected by Firefly i for k^{th} Firefly, α is the randomness parameter and $rand$ is a random number generator uniformly distributed in [0,1]. After movements of all fireflies, one cycle is completed. The algorithm then goes back to the step 2 and evaluates these new n frame designs that are obtained due to movements. The steps 2 and 4 are repeated until a pre-assigned maximum number of cycle is reached.

4 Adaptive randomness parameter stage

In classical Firefly algorithm, randomness parameter α is taken as static. Selecting randomness parameter as lower value, stagnation and local convergence can be seen in the large scale optimization problems. On the contrary, selecting randomness parameter as higher value, convergence problems can be seen in the optimization problems. In order to resolve these problems, adaptive randomness parameter strategy is improved. In this strategy, randomness parameter (α) changes dynamically as expressed in following equation.

$$\alpha^i = \alpha_{max} - (\alpha_{max} - \alpha_{min}) \cdot \left(\frac{I^i_{max} - I^i_{mean}}{I^i_{max} - I^i_{min}} \right) \tag{16}$$

Equation (6) is adopted from Coello [17]. In this equation α^i represents randomness parameters at cycle i, α_{max} and α_{min} represent maximum and minimum randomness parameters defined in the algorithm respectively. I^i_{max}, I^i_{min} and I^i_{mean} represent maximum light density, minimum light density and mean value of light densities of all fireflies at cycle i respectively.

5 Design Examples

Two steel space frames are designed by the proposed optimum design algorithm. These are four story, 132 member steel space frame and eight story, 1024 member steel space frame.

5.1 Four-story, three bay 132 members space frame

In the first example, three dimensional irregular steel frame which is previously designed in [17] is considered. 3-D, side and plan side views of this frame are shown in Figures 2, 3 and 4 respectively. This space frame consists of 70 joints and 132 members that are grouped into 30 independent design groups. The frame is subjected to gravity loads and lateral loads, which are computed per ASCE 7-05 [18] based on the following design values: a design dead load of 2.88kN/m^2, a design live load of 2.39kN/m^2, a ground snow load of 0.755kN/m^2. The basic wind speed is considered as 85mph (38 m/s) [17]. The factored distributed gravity loads on the beams of the roof and floors are tabulated in Table 2 and the unfactored earthquake loads are given in Table 3. The load and combination factors are applied according to code specification [1, 15] as: Load case1: 1.4D, Load Case 2: 1.2D+1.6L+0.5S; Load Case 3: 1.2D+0.5L+1.6S; Load Case 4: 1.2D+1.0EX+0.5L+0.2S; Load Case 5: 1.2D+1.0EZ+0.5L+0.2S; Case 6 1.2D+1.6WX+L+0.5S and Case 7 : 1.2D+1.6WZ+L+0.5S where D represents dead load, L is live load, S is snow load, EX and EZ represent earthquakes loads applied on X and Z global directions respectively and WX and WZ are the wind loads applied on X and Z global direction respectively. In addition, the top story drift constraints in x and y directions are restricted as the 3.9 cm. Inter-story drift is applied as the 1.14 cm to first story 0.915 cm to other story. Maximum deflection of beam members is restricted as 2.03 cm.

	Beam Type	**Uniformly distributed load,(KN/m)**	
		Outer Span	Inner Span
Load Case 1	Roof Beams	-7.012182404	-14.02436481
	Floor Beams	-8.180879472	-16.36175894
Load Case 2	Roof Beams	-7.932531345	-15.86506269
	Floor Beams	-18.25598315	-36.5119663
Load Case 3	Roof Beams	-9.957299014	-19.91459803
	Floor Beams	-10.52587014	-21.05174027
Load Case 4	Roof Beams	-7.012182404	-14.02436481
	Floor Beams	-10.52587014	-21.05174027
Load Case 5	Roof Beams	-7.012182404	-14.02436481
	Floor Beams	-10.52587014	-21.05174027
Load Case 6	Roof Beams	-6.763834278	-13.52766856
	Floor Beams	-14.2763359	-28.55267179
Load Case 7	Roof Beams	-6.763834278	-13.52766856
	Floor Beams	-14.2763359	-28.55267179

Table 2 : Gravity loading on the beams of 132-member space frame

Floor Number	Earthquake Design Load (kN)	Floor Number	Earthquake Design Load (kN)
1	29.23	3	82.35
2	55.28	4	110.15

Table 3: Earthquake loading on the beams of 132-member space frame

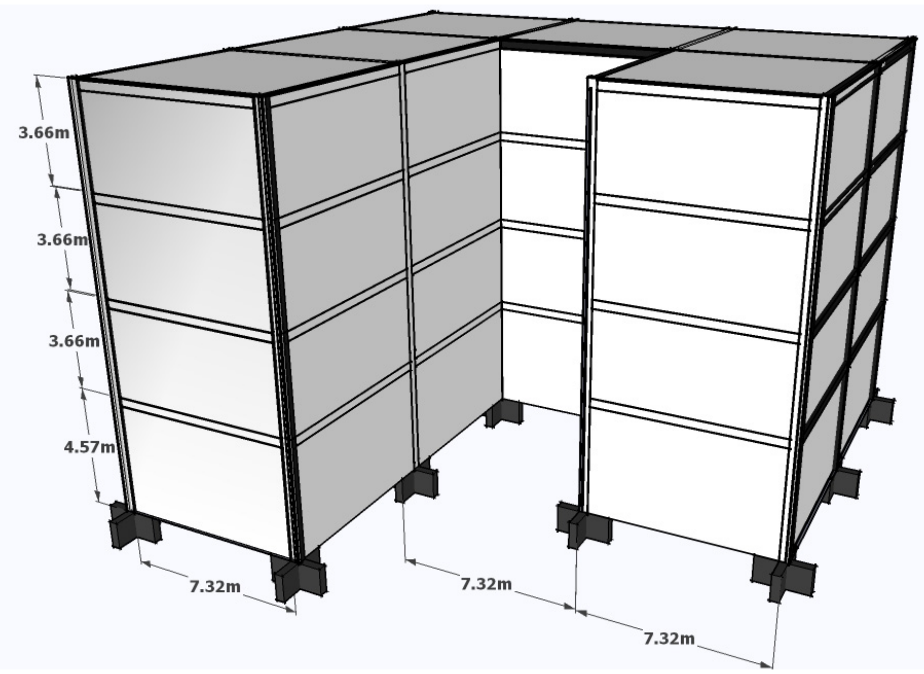

Figure 2 : 3D view of four-story, 132 member space frame

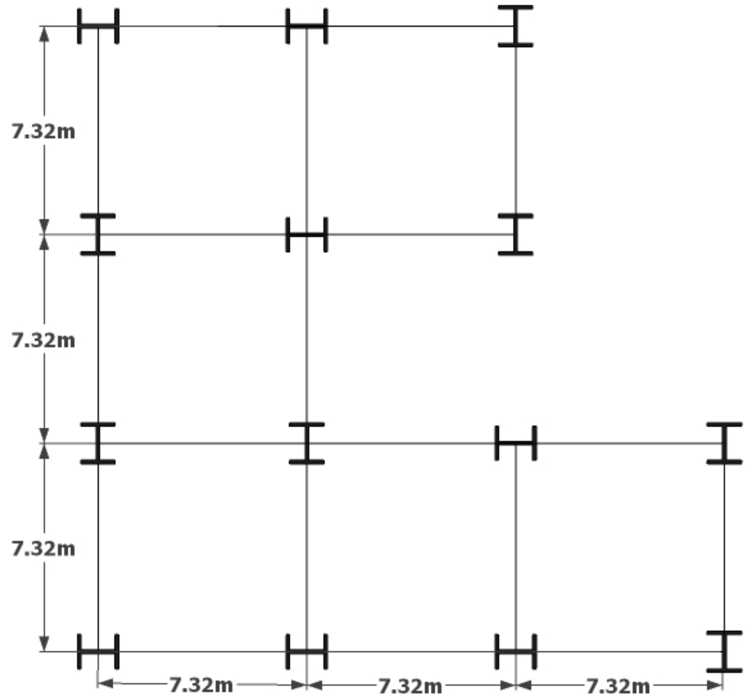

Figure 3 : Plan view of four-story, 132 member space frame

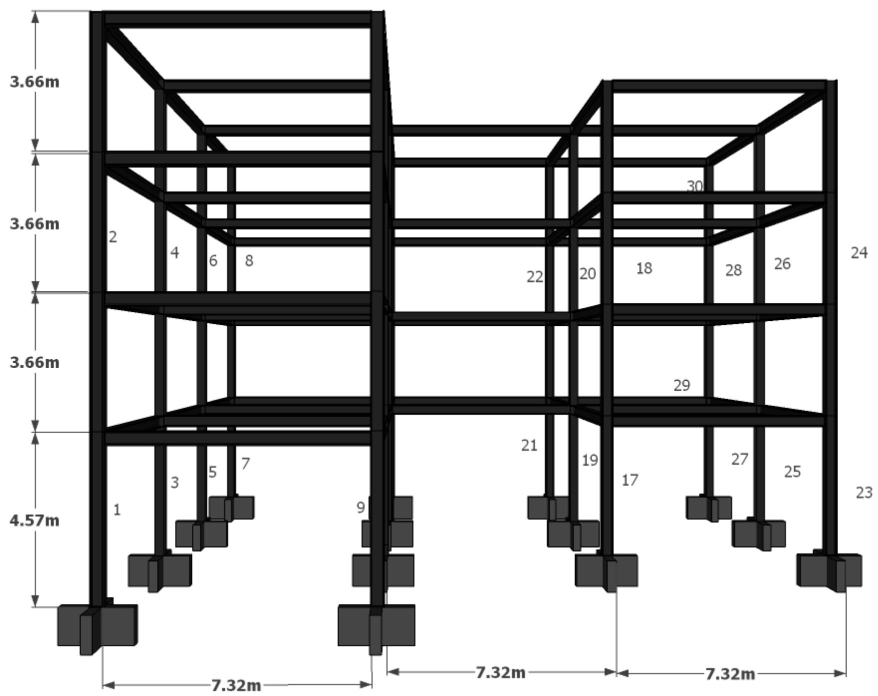

Figure 4 : Side view of four-story, 132 member space frame

This steel frame is designed by the algorithm developed 20 times using different seed values in each design. For Firefly algorithm, the following search parameters are used: Number of fireflies = 50, maximum randomness parameter (α_{max}) =0.8, minimum randomness parameter (α_{min}) =0.1, attractiveness at original location (β_0) =0.5, absorption coefficient (γ) =10 and maximum iteration number = 50,000 . The average weight and standard deviation of the 20 best designs of each run are obtained as 620.61 and 12.10 respectively. The weight of best design having the smallest weight between 20 best designs is 609.86 kN. This value is compared to the best designs obtained by using Dynamic Harmony Search [12] and Ant Colony algorithms [20]. W sections of the optimum designs and corresponding maximum constraints values for each algorithm are illustrated in Table 4. It is apparent from the Table 4 that the best design having the lightest weight is obtained by the Firefly algorithm (609.86kN). Value of this minimum weight is 6.3% lighter than the weight of the best design obtained by the Dynamic Harmony Search algorithm and 13.44 % lighter than the weight of the best design obtained by the Ant Colony Optimization method. Search histories of these solutions are illustrated in Figure 5.

#	Group Type	Firefly	AHS	ACO	#	Group Type	Firefly	AHS	ACO
1	Column	W250X49.1	W410X60	W250X58	16	Column	W530X92	W250X58	W460X82
2	Column	W250X49.1	W250X49.1	W920X223	17	Column	W200X46.1	W410X67	W610X262
3	Column	W310X79	W310X86	W760X185	18	Column	W250X58	W410X60	W920X313
4	Column	W310X117	W250X73	W760X220	19	Column	W410X100	W410X75	W410X132
5	Column	W310X97	W310X97	W530X300	20	Column	W530X101	W310X67	W760X147
6	Column	W360X147	W200X46.1	W920X365	21	Column	W250X80	W310X60	W690X125
7	Column	W200X46.1	W310X74	W310X60	22	Column	W250X80	W250X58	W690X265
8	Column	W200X46.1	W250X73	W690X384	23	Column	W310X67	W200X59	W310X107
9	Column	W460X74	W410X60	W530X92	24	Column	W310X67	W200X46.1	W360X179
10	Column	W460X74	W410X53	W610X92	25	Column	W310X79	W310X86	W460X158
11	Column	W360X179	W760X147	W760X314	26	Column	W310X117	W310X79	W920X253
12	Column	W360X179	W460X144	W1000X321	27	Column	W410X60	W250X49.1	W200X59
13	Column	W460X113	W410X75	W690X140	28	Column	W410X60	W200X46.1	W310X60
14	Column	W460X113	W360X72	W920X313	29	Beam	W530X74	W610X82	W460X60
15	Column	W530X92	W310X60	W410X75	30	Beam	W410X46.1	W410X53	W460X52
						Minimum weight(KN)	609.86	650.77	703.55
						Maximum top story drift (cm)	2.95	2.83	2.99
						Maximum Inter-story drift (cm)	1.05	1.05	0.88
						Maximum strength constraint ratio	0.974	0.999	0.895
						Maximum number of iterations	50000	50000	50000

Table 4 : Design results for four-story, 132 member space frame

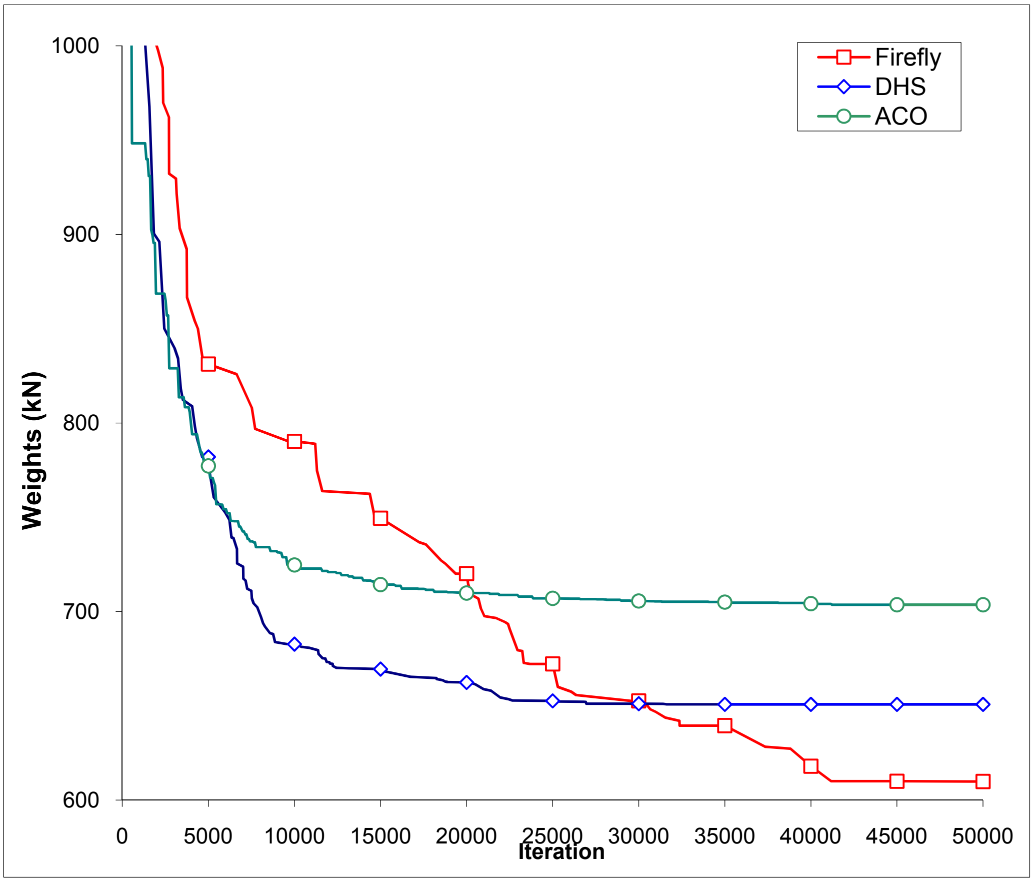

Figure 5 : Search histories of four-story, 132 member space frame

5.2 Eight-story, 1024-member space frame

The three dimensional, plan and side views of eight-story, 1024-member steel space frame are illustrated in Figures 6, 7 and 8 respectively. The frame has 384 joints and 1024 members which are collected in 40 independent design variables. The member grouping of frame is illustrated Table 4. The frame is subjected to gravity loads as well as lateral loads that are computed according to ASCE 7-05 [18]. The design dead and live loads are taken as 2.88kN/m^2 and 2.39kN/m^2 respectively. Basic wind speed is considered as 85mph (38 m/s). The following load combinations are considered in the design of the frame according to the code specification [1]: 1.2D+1.6L+0.5S, 1.2D+0.5L+1.6S, 1.2D+1.6WX+L+0.5S and 1.2D+1.6WX+L+0.5S where D is the dead load, L represents the live load, S is the snow load and WX, WZ are the wind loads in the global X and Z axis respectively. Drift ratio limits for this example are taken as 0.875 cm for inter story drift and 7 cm for top storey drift. Maximum deflection of beam members is restricted as 2.0 cm.

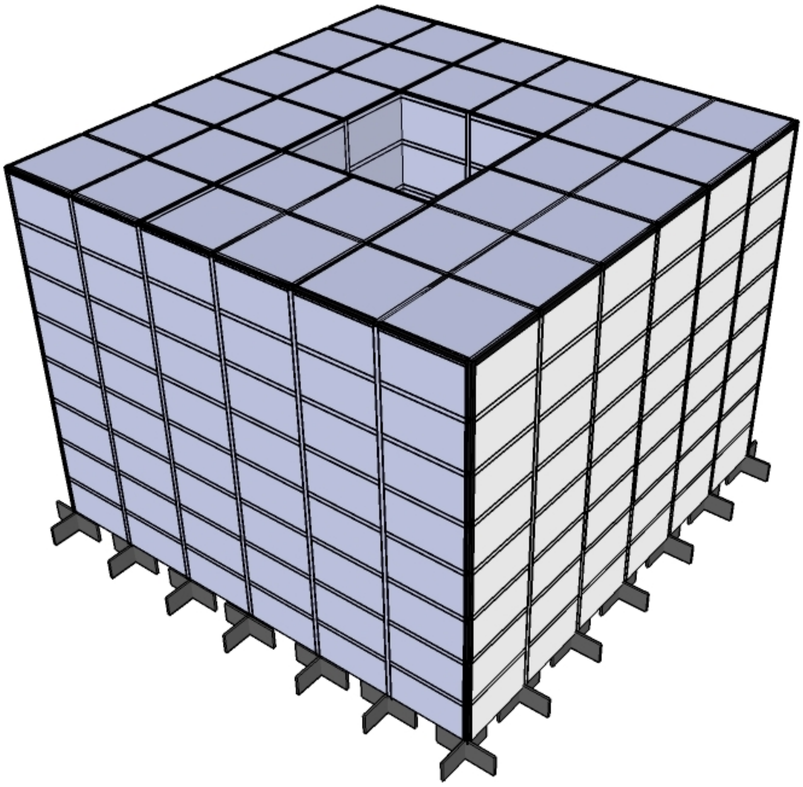

Figure 6 : 3D view of eight-story, 1024-member space frame

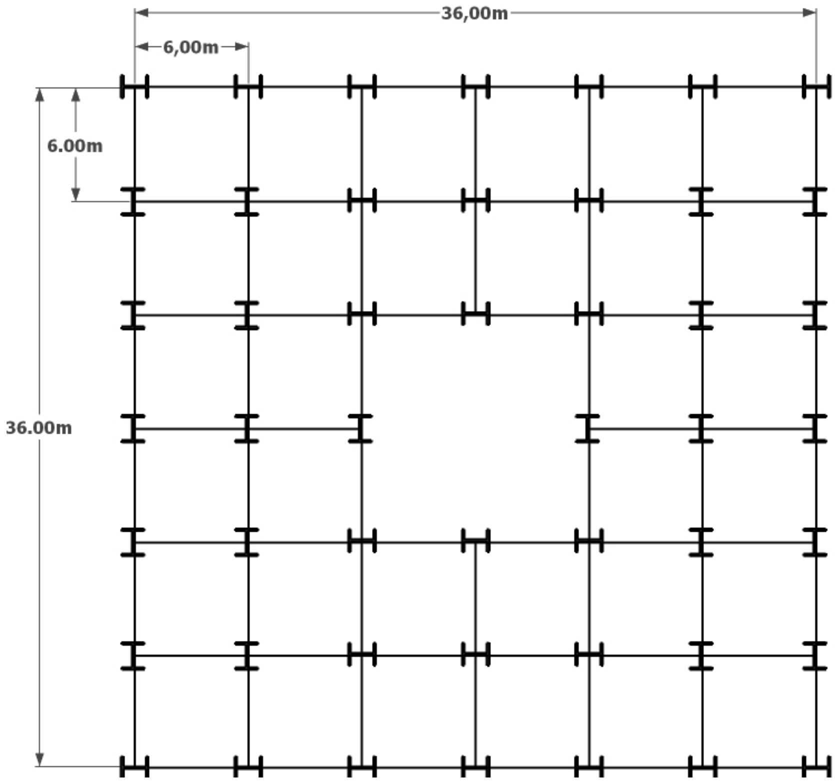

Figure 7 : Plan view of eight-story, 1024-member space frame

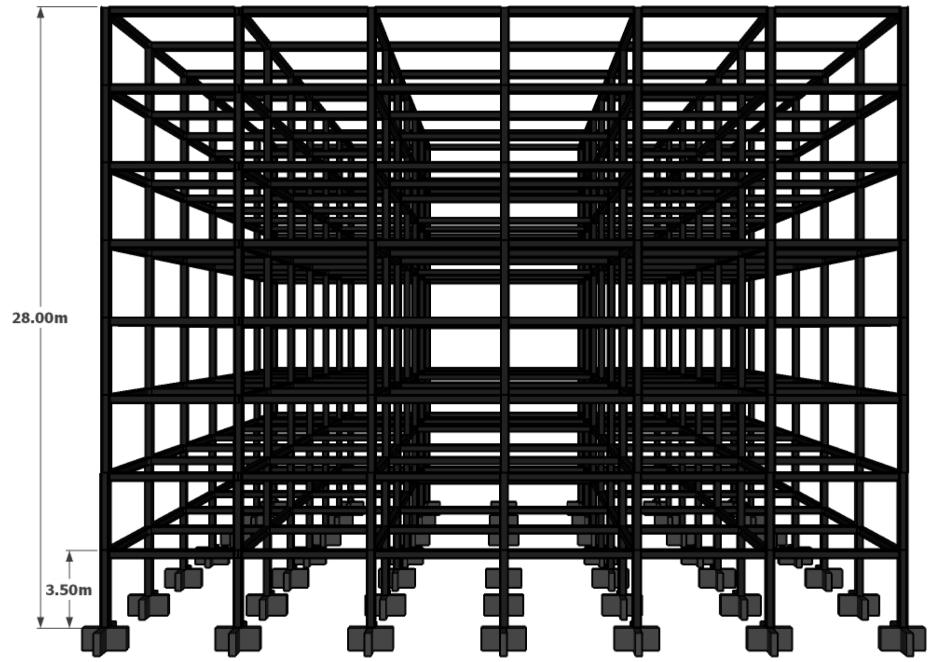

Figure 8: Side view of eight-story, 1024-member space frame

Story	Side beam	Inner Beam	Corner Column	Side Column	Inner Column
1	1	2	17	18	19
2	3	4	20	21	22
3	5	6	23	24	25
4	7	8	26	27	28
5	9	10	29	30	31
6	11	12	32	33	34
7	13	14	35	36	37
8	15	16	38	39	40

Table 5: The member grouping of eight-story 1024 member space frame

The eight-story 1024 member space frame problem is designed 10 times by the optimum design algorithm presented using different seed values. In this problem following Firefly algorithm search parameters are used: Number of Fireflies =50, maximum randomness parameter (α_{max}) =1.0, minimum randomness parameter (α_{min}) =0.1, attractiveness at original location (β_0) =0.5, absorption coefficient (γ) =10 and maximum iteration number = 75,000. At the end of 10 tests, average weight and standard deviation of optimum weights are obtained as 6776.31 and 38.14

respectively. This space frame is also designed by Dynamic Harmony Search [12] and Ant Colony Optimization algorithms [20]. The minimum weights, maximum constraints values and W-section designations of the optimum designs obtained from each of these algorithms are illustrated in Table 6. It is apparent from the table that the Firefly algorithm optimum solution having the lightest weight among these optimization algorithms. The Weight obtained by Firefly algorithm result is 6.4 % lighter than the Dynamic Harmony Search and 12.23 % lighter than the Ant Colony Optimization solutions. Search histories of optimum designs are shown in Figure 9.

#	Group Type	Firefly	DHS	ACO	#	Group Type	Firefly	DHS	ACO
1	Beam	W310X38.7	W310X158	W200X35.9	21	Column	W460X128	W360X216	W690X265
2	Beam	W200X46.1	W610X195	W200X46.1	22	Column	W530X165	W360X162	W760X147
3	Beam	W310X79	W760X134	W410X75	23	Column	W690X240	W360X216	W1100X390
4	Beam	W310X117	W760X134	W360X32.9	24	Column	W1000X258	W690X217	W1100X343
5	Beam	W460X82	W460X82	W360X110	25	Column	W530X165	W840X299	W1000X321
6	Beam	W460X82	W460X106	W310X107	26	Column	W690X240	W1100X390	W1100X390
7	Beam	W360X110	W610X101	W460X106	27	Column	W1000X321	W840X299	W1100X390
8	Beam	W360X110	W760X134	W460X68	28	Column	W690X170	W840X299	W1000X321
9	Beam	W610X125	W360X162	W610X113	29	Column	W760X284	W1100X390	W1100X390
10	Beam	W460X52	W760X220	W360X39	30	Column	W1000X477	W920X365	W1100X499
11	Beam	W610X82	W530X182	W690X125	31	Column	W760X173	W840X299	W1100X390
12	Beam	W460X68	W920X223	W460X52	32	Column	W1000X412	W1100X390	W1100X390
13	Beam	W840X176	W310X86	W690X170	33	Column	W1100X499	W1000X412	W1100X499
14	Beam	W360X32.9	W690X125	W310X32.7	34	Column	W760X173	W1100X343	W1100X433
15	Beam	W760X147	W310X74	W840X176	35	Column	W1100X433	W1100X499	W1100X499
16	Beam	W310X32.7	W460X82	W310X28.3	36	Column	W1100X499	W1100X499	W1100X499
17	Column	W200X35.9	W410X149	W410X100	37	Column	W1000X296	W1100X343	W1100X433
18	Column	W360X101	W760X161	W250X149	38	Column	W1100X433	W1100X499	W1100X499
19	Column	W360X64	W610X155	W250X89	39	Column	W1100X499	W1100X499	W1100X499
20	Column	W530X165	W610X155	W1100X390	40	Column	W1100X343	W1100X343	W1100X499
						Minimum weight(KN)	6748.99	7210.12	7689.51
						Maximum top story drift (cm)	6.675	6.577	6.239
						Maximum Inter-story drift (cm)	0.875	0.874	0.871
						Maximum strength cons. ratio	0.993	0.986	0.989
						Maximum number of iterations	75000	75000	75000

Table 6 : Design results for eight-story, 1024-member space frame

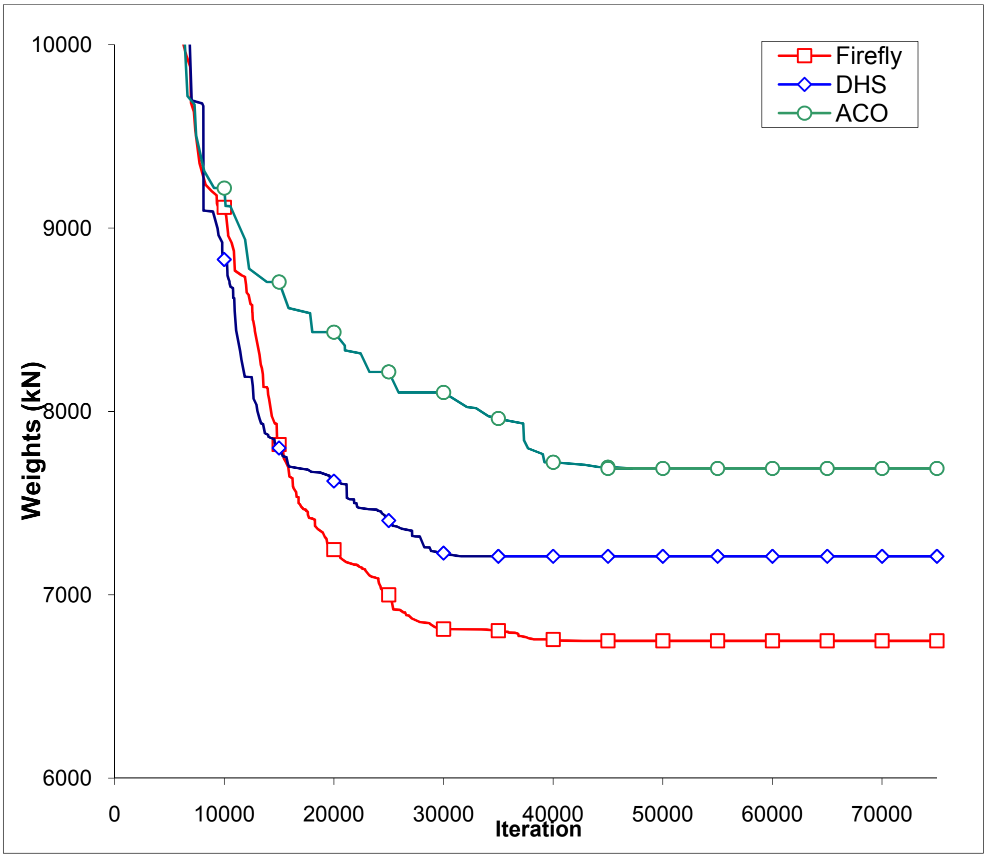

Figure 9 : Search histories of eight-story, 1024-member space frame

6 Conclusion

An optimum design algorithm is developed for steel space frames is based on one of the very recent metaheuristic technique called the firefly algorithm. The firefly algorithm is enhanced by introducing adaptive randomness parameter which is taken as fixed value in the standard firefly algorithm. Two large real size steel space frames are designed by the algorithm presented. Results obtained from the firefly algorithm are compared to those attained by the dynamic harmony search and ant colony optimization algorithms. The optimum frames obtained using the firefly algorithm is lighter than both of the optimum designs determined by the other two metaheuristic algorithms. The inspection of the design histories of both design examples clearly indicates that the performance of firefly algorithm is better than the dynamic harmony search and ant colony optimization algorithms. It is also noticed that the enhancement suggested for the firefly algorithm has increased the efficiency of the technique. Therefore it can be concluded that, the firefly algorithm is a robust and efficient approach that can be effectively used to determine the optimum designs of large scale, real size steel space frames

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