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LAYOUT OPTIMIZATION OF TRUSS STRUCTURES USING CENTER OF MASS OPTIMIZATION ALGORITHM

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ABSTRACT

The main objective of this paper is to optimize the size and layout of planar truss structures simultaneously. To deal with this challenging type of truss optimization problem, the center of mass optimization (CMO) metaheuristic algorithm is utilized, and an extensive parametric study is conducted to find the best setting of internal parameters of the algorithm. The CMO metaheuristic is based on the physical concept of the center of mass in space. The effectiveness of the CMO metaheuristic is demonstrated through the presentation of three benchmark truss layout optimization problems. The numerical results indicate that the CMO is competitive with other metaheuristics and, in some cases, outperforms them.

Keywords: seismic performance level; steel moment resisting frame; neural network; feed-forward back-propagation.

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1. INTRODUCTION

One of the complex and challenging areas of structural optimization is optimum design involving sizing and layout variables. In many cases, traditional gradient-based techniques may not be sufficient to handle the additional complexity of these design optimization problems. The problem's complexity arises from considering variables of different natures simultaneously. It is necessary to optimize structural cross-sections and geometry simultaneously for layout optimization of structures with fixed topology. In these cases, a design space with large dimensions is encountered due to the large number of design variables consisting of cross-sectional areas and nodal coordinates. The selection of the cross-sections of the structural members from a discrete list of available sections leads to a discrete design space. In such discrete layout optimization problems, constraints on member

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tensile-compressive stresses and nodal displacements increase the possibility of being trapped in local optima [1-3]. Therefore, to solve truss layout optimization problems, it is necessary to use powerful optimization algorithms.

Over the past few decades, numerous metaheuristic algorithms have been proposed for structural optimization. These algorithms were inspired by different natural metaphors (such as evolution theory, biology, and physics) and have proved to be more effective and reliable than traditional gradient-based methods in solving complex and challenging optimization problems [4-8]. One of the physics-based metaheuristic algorithms is the Center of Mass Optimization (CMO) algorithm [9]. The principle behind the CMO is that mass must be balanced around its center of mass in space. The effectiveness of CMO in solving benchmark sizing optimization problems of truss structures and seismic performance-based design optimization of steel moment-resisting frames has been demonstrated in recent years compared to some metaheuristics [9-11]. Therefore, the present paper uses the CMO to address the layout optimization problem of trusses.

This paper presents three design examples of layout optimization for trusses with 15, 18, and 47 bars. For each design example, a sensitivity analysis is conducted to determine the optimal values of an internal parameter of the CMO. The numerical results reveal that the CMO is a competitive metaheuristic algorithm that, in some cases, even outperforms other techniques proposed in the literature.

2. LAYOUT OPTIMIZATION PROBLEM FORMULATION

The objective of layout optimization of trusses is usually to minimize their weight while taking into account certain design constraints. The design variables include the cross-sectional areas of the members and the coordinates of nodes in the structure. These variables are chosen from a set of discrete and continuous available values respectively. Therefore, the optimization problem can be formulated as follows

$$\text{Minimize:} \quad w(X) = \sum_{i=1}^{ne} \rho_i A_i L_i \tag{1}$$

$$\text{Subject to:} \quad \begin{cases} g_{s,i}(X) = \left(\dfrac{\sigma}{\sigma_{all}}\right)_i - 1 \leq 0 \,, i = 1,2,\dots,ne \\ g_{d,j}(X) = \left(\dfrac{d}{d_{all}}\right)_j - 1 \leq 0 \,, j = 1,2,\dots,nj \end{cases} \tag{2}$$

$$X = \{X_A \quad X_G\}^{\mathrm{T}} \tag{3}$$

$$X_A = \{A_1 \ A_2 \ \dots \ A_{ne}\}^{\mathrm{T}} \in \Delta_A \tag{4}$$

$$X_G = \{G_1 \ G_2 \ \dots \ G_{ng}\}^{\mathrm{T}} \in \Delta_G \tag{5}$$

where w is the weight of the truss structure; X is the vector of design variables; ρ_i, A_i and L_i

are the weight density, cross-sectional area and the length of the ith member, respectively; g_s, σ and σ_{all} are the stress constraint, stress and allowable stress of the ith member, respectively; g_d, d and d_{all} are the displacement constraint, nodal displacement and allowable displacement of the jth node, respectively; ne and nj are the numbers of members and joints, respectively; X_A and X_G are the vectors of cross-sectional areas of members and joints coordinates related design variables, respectively; Δ_A and Δ_G are domains of cross-sectional areas and joints coordinates, respectively and ng is the number of joints coordinates.

In this paper, the constraints of the layout optimization problem are handled using the exterior penalty function method (EPFM) [12] in which the pseudo unconstrained objective function is expressed as follows

$$\Phi(X) = w(X)\left(1 + r_p \sum_{k=1}^{nc} (max\{0, g_k(X)\})\right) \tag{6}$$

where Φ is the pseudo unconstrained objective function; r_p is the penalty parameter and nc is the number of design constraints.

3. CENTER OF MASS OPTIMIZATION

CMO was proposed in [9] based on the concept of center of mass in physics. In the CMO algorithm, a population including np randomly selected particles (X_i , $i \in [1,np]$) is generated in design space. The mass of ith particle m_i is determined as follows

$$m_i = \frac{1}{f(X_i)} \tag{7}$$

Particles are sorted based on their mass values in ascending order and then they are equally divided into two groups G1 and G2. The first half of the particles are put in G1 and the others in G2. The particles in G1 are paired with their corresponding ones in G2. The position of the center of mass and the distance between jth (j=1,..., $np/2$) pair of particles in iteration t are determined as follows

$$X_j^C(t) = \frac{m_j X_j(t) + m_{j+\frac{np}{2}} X_{j+\frac{np}{2}}(t)}{m_j + m_{j+\frac{np}{2}}} \tag{8}$$

$$d_j(t) = \left| X_j(t) - X_{j+\frac{np}{2}}(t) \right| \tag{9}$$

To switch between exploration and exploitation of the CMO algorithm, the following controlling parameter (CP) is computed in which t_{max} is the maximum number of iterations and α is a constant value.

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$$CP(t) = \exp\left(-\frac{\alpha t}{t_{max}}\right) \tag{10}$$

The position of jth couple of particles is updated using the following equations

$$if\ d_j(t) > CP(t) \tag{11}$$

$$X_j(t+1) = X_j(t) - R_1\left(X_j^C(t) - X_j(t)\right) + R_2\left(X_b - X_j(t)\right) \tag{12}$$

$$X_{j+\frac{np}{2}}(t+1) = X_{j+\frac{np}{2}}(t) - R_3\left(X_j^C(t) - X_{j+\frac{np}{2}}(t)\right) + R_4\left(X_b - X_{j+\frac{np}{2}}(t)\right) \tag{13}$$

$$if\ d_j(t) \le CP(t) \tag{14}$$

$$X_j(t+1) = X_j(t) + R_5\left(X_j^C(t) - X_{j+\frac{np}{2}}(t)\right) \tag{15}$$

$$X_{j+\frac{np}{2}}(t+1) = X_{j+\frac{np}{2}}(t) + R_6\left(X_j^C(t) - X_{j+\frac{np}{2}}(t)\right) \tag{16}$$

where R_1 to R_6 are vector of random numbers in [0,1]; and X_b is the best solution found.

There is a mutation operator in CMO to decrease the probability of local optima entrapment. A mutation rate $mr = 0.1$ is taken and in iteration t a number between 0 and 1 is randomly selected for each particle in group G1 (X_j , j=1,..., $np/2$).

$$r_j(t) \in [0, 1] \tag{17}$$

$$X_j(t) = \left\{x_{j1}(t) \quad x_{j2}(t) \quad \dots \quad x_{ji}(t) \quad \dots \quad x_{jm}(t)\right\}^{\mathrm{T}} \tag{18}$$

For jth particle, if the selected random number is less than the mutation rate, one randomly selected component will be regenerated in the design space as follows

$$if\ r_j(t) \le mr \rightarrow x_{ji}(t) = x_{ji}^L + \mu(t) \times \left(x_{ji}^U - x_{ji}^L\right) \tag{19}$$

where μ is a random number in the interval [0, 1] in iteration t; and x_{ij}^L and x_{ij}^U are lower and upper bounds of x_{ji} in design space.

The CMO metaheuristic consists of an internal parameter, namely α which plays a crucial role in the convergence of the algorithm. Determining the optimal value of this parameter requires performing a sensitivity analysis. As, in the original CMO algorithm $\alpha =$ 5.0, in this paper, different values of 5.0, 5.5, 6.0, 6.75, 7.5, 8.5, 10.0, 12.0, 15.0, and 20 are considered for α. Fig. 1 depicts CP over t for the different values of α.

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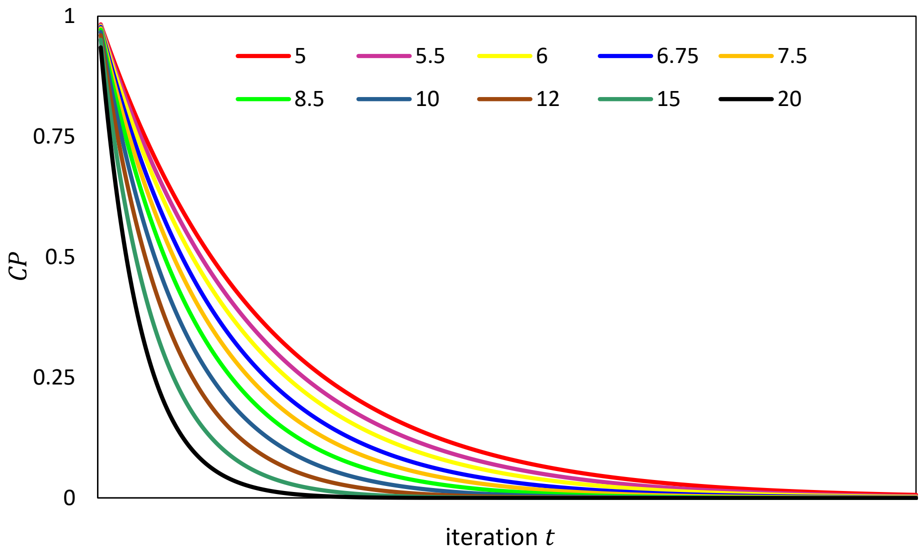

Figure 1. $CP - t$ graphs for different values of α

4. NUMERICAL EXAMPLES

Three truss sizing-layout benchmark optimization problems including discrete sizing variables and continuous configuration variables are presented to investigate the performance of the CMO metaheuristic algorithm. The presented design examples in this paper are a planar 15-bar truss, a planar 18-bar truss, and a planar 47-bar truss.

4.1 15-bar truss

The first design problem is a planar 15-bar truss shown in Fig. 2. A concentrated 10 kips load is applied to node 8 as shown in Fig. 2. The material density and the modulus of elasticity are 0.1 lb/in^3 is 10^4 ksi, respectively.

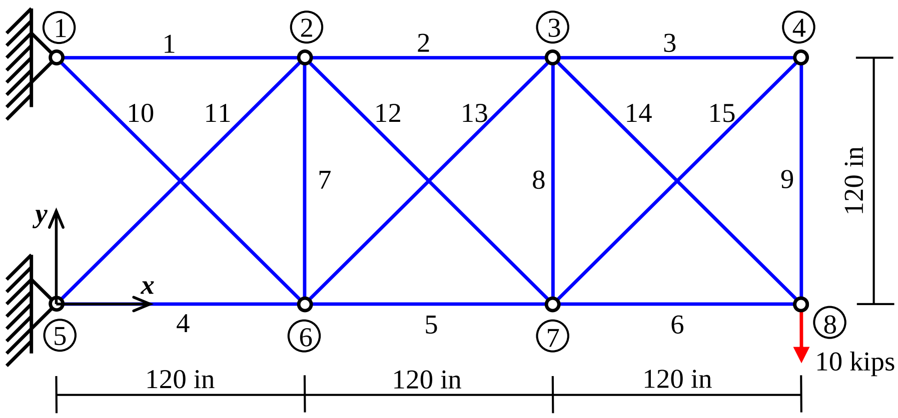

Figure 2. 15-bar planar truss structure

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There are 23 design variables in this benchmark optimization including 15 sizing variables (A_i, i=1,2,…,15) and 8 configuration variables ($x_2 = x_6$; $x_3 = x_7$; y_2; y_3; y_4; y_6; y_7; y_8). The allowable stress for all elements is $\pm 25\,\text{ksi}$. Sizing variables are selected from the following discrete set during the optimization process:

D = { 0.111, 0.141, 0.174, 0.220, 0.270, 0.287, 0.347, 0.440, 0.539, 0.954, 1.081, 1.174, 1.333, 1.488, 1.764, 2.142, 2.697, 2.800, 3.131, 3.565, 3.813, 4.805, 5.952, 6.572, 7.192, 8.525, 9.300, 10.850, 13.330, 14.290, 17.170, 19.180} (in.^{2}). In addition, side constraints for configuration variables are as follows:

100 in. $\leq x_2 \leq$ 140 in.; 220 in. $\leq x_3 \leq$ 260 in.; 100 in. $\leq y_2 \leq$ 140 in.; 100 in. $\leq y_3 \leq$ 140 in.;
50 in. $\leq y_4 \leq$ 90 in.; −20 in. $\leq y_6 \leq$ 20 in.; −20 in. $\leq y_7 \leq$ 20 in.; 20 in. $\leq y_8 \leq$ 60 in.;

In the literature, this benchmark truss optimization problem has been dealt with genetic algorithm (GA) [13], Firefly algorithm (FA) [14], modified harmony search algorithm (MHSA) [15], and artificial bee colony algorithm (ABCA) [3].

In this example, 50 independent optimization runs are conducted using CMO for each value of α, and the best results are obtained when $\alpha = 6.75$. The number of particles and the maximum number of iterations are 50 and 200, respectively. The best results obtained by CMO are compared with those of other algorithms in Table 1. In addition, the best layout found by the CMO is shown in Fig. 3.

Table 1: Optimal designs of 15-bar planar truss

No.	Design Variable	GA [13]	FA [14]	MHSA [15]	ABCA [3]	CMO
1	A_1	1.081	0.954	0.954	0.954	0.954
2	A_2	0.539	0.539	0.539	0.539	0.539
3	A_3	0.287	0.220	0.220	0.347	0.174
4	A_4	0.954	0.954	0.954	0.954	0.954
5	A_5	0.539	0.539	0.539	0.539	0.539
6	A_6	0.141	0.220	0.220	0.111	0.270
7	A_7	0.111	0.111	0.111	0.111	0.111
8	A_8	0.111	0.111	0.111	0.111	0.111
9	A_9	0.539	0.287	0.440	0.539	0.174
10	A_{10}	0.440	0.440	0.347	0.440	0.347
11	A_{11}	0.539	0.440	0.347	0.440	0.347
12	A_{12}	0.270	0.220	0.270	0.174	0.220
13	A_{13}	0.220	0.220	0.270	0.174	0.220
14	A_{14}	0.141	0.270	0.220	0.111	0.270
15	A_{15}	0.287	0.220	0.220	0.347	0.174
16	x_2	101.5775	114.967	135.5676	110.2086	135.2451
17	x_3	227.9112	247.040	245.5421	249.8193	257.1279
18	y_2	134.7986	125.919	123.1303	133.5991	120.3808
19	y_3	128.2206	111.067	120.6957	111.6235	107.8293
20	y_4	54.86300	58.298	57.9313	55.1278	50.8612
21	y_6	-16.4484	-17.564	-5.9742	-18.9505	-9.5547
22	y_7	-13.3007	-5.821	-2.9125	3.3411	-0.1707
23	y_8	54.8572	31.465	56.3256	55.1423	50.8125
Best weight (lb)		76.68	75.55	73.887	72.715	72.267
Analyses		8,000	8,000	5,000	18,000	10,000

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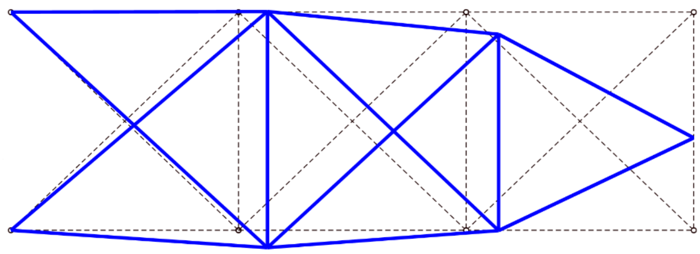


Figure 3. Optimum layout of 15-bar planar truss found by CMO

Based on the results given in Table 1, it can be concluded that the CMO algorithm is more effective than all other algorithms in finding the best solution. Additionally, the 50 independent optimization runs produced the best weight of 72.267 kg, the worst weight of 83.937 kg, the average weight of 79.007 kg, and a corresponding standard deviation of 2.006 kg. Furthermore, Fig. 4 presents the optimum weights obtained by the CMO algorithm in 50 independent optimization runs.

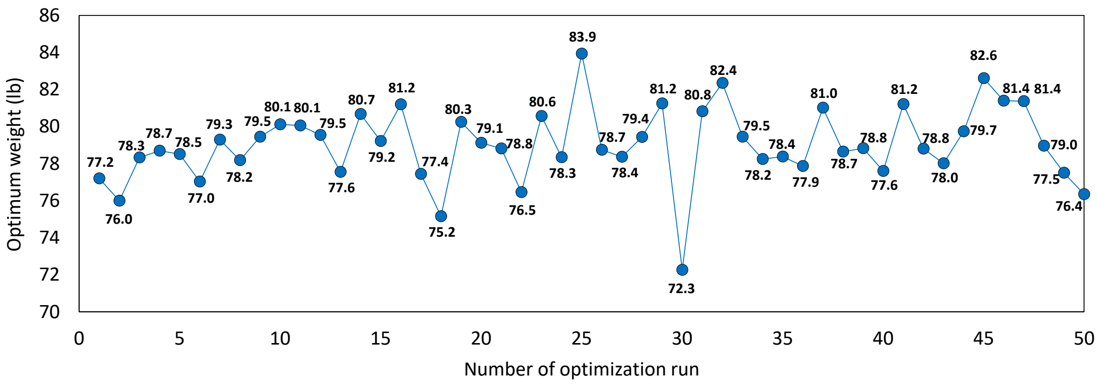
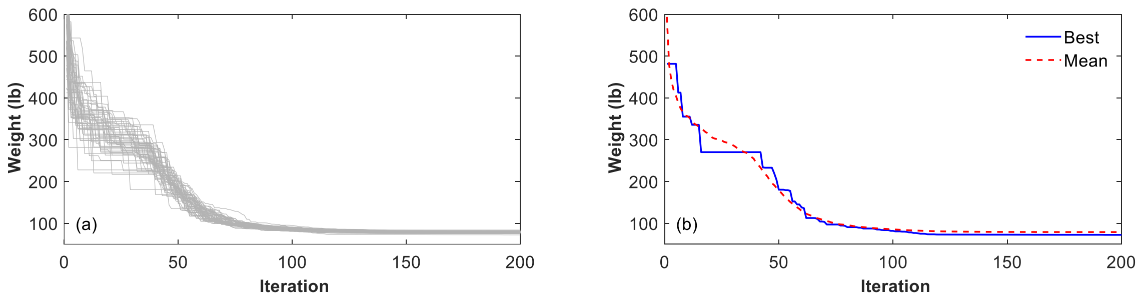


Figure 4. Optimum weights obtained by CMO for 15-bar planar truss

Fig. 5 presents the convergence curves of all optimization runs, along with the best and mean convergence curves. It can be seen that the mean convergence curve is very close to the best convergence curve indicating the good performance of the CMO in all the independent optimization runs.



(a) (b)

Figure 5. (a) All convergence curves and (b) the best and mean convergence curves of CMO in layout optimization of 15-bar planar truss

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4.2 18-bar truss

The second design problem is a planar 18-bar truss shown in Fig. 6. The material density and the modulus of elasticity are 0.1 lb/in^3 is 10^4 ksi, respectively.

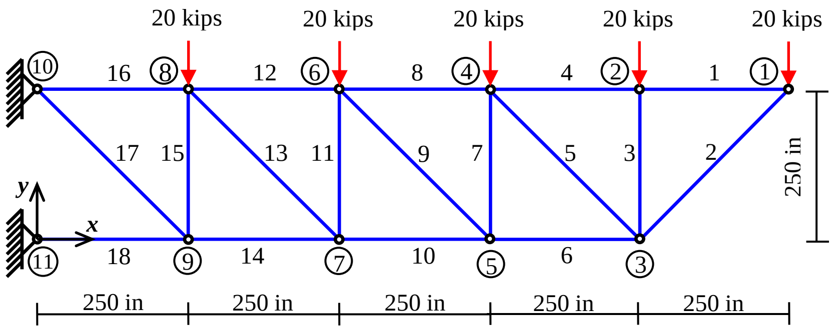

Figure 6. 18-bar planar truss structure

The members of this truss structure are divided into four design groups including (1) $A_1 = A_4 = A_8 = A_{12} = A_{16}$; (2) $A_2 = A_6 = A_{10} = A_{14} = A_{18}$; (3) $A_3 = A_7 = A_{11} = A_{15}$; and (4) $A_5 = A_9 = A_{13} = A_{17}$. Additionally, there are eight layout design variables including x_3; y_3; x_5; y_5; x_7; y_7; x_9; y_9; As a result, the layout optimization problem of the 18-bar planar truss has 12 design variables. The allowable stresses for all elements are ± 25 ksi and $4EA/L^2$ (Euler buckling stress). Sizing design variables are selected from the following discrete set during the optimization process: D = {2.00, 2.25,…,21.50, 21.75} (in.^{2}). In addition, side constraints for configuration variables are as follows: 775 in. $\leq x_3 \leq$ 1225 in.; 525 in. $\leq x_5 \leq$ 975 in.; 275 in. $\leq x_7 \leq$ 725 in.; 25 in. $\leq x_9 \leq$ 475 in.; -225 in. $\leq y_3, y_5, y_7, y_9 \leq$ 245 in.;

In the literature, researchers have solved this benchmark truss layout optimization problem using simulated annealing (SA) [16], GA [13], group search optimization (GSO) [17], and ABCA [3].

Table 2: Optimal designs of 18-bar planar truss

No.	Design Variable	SA [16]	GA [13]	GSO [17]	ABCA [3]	CMO
1	A_1	12.25	12.75	12.25	12.50	12.00
2	A_2	17.50	18.50	18.25	17.75	18.00
3	A_3	5.75	4.75	4.75	5.75	5.00
4	A_5	4.25	3.25	4.25	3.75	4.50
5	x_3	910.0	917.4475	916.9	912.9974	915.0135
6	y_3	179.0	193.7899	191.971	183.6806	188.9937
7	x_5	638.0	654.3243	654.224	642.7143	648.7662
8	y_5	141.0	159.9436	156.1	143.8920	150.9643
9	x_7	408.0	424.4821	423.5	411.6918	418.3478
10	y_7	91.0	108.5779	102.571	97.14763	97.3077
11	x_9	198.0	208.4691	207.519	200.9087	205.5284
12	y_9	24.0	37.6349	28.579	30.21906	23.0166
Best weight (lb)		4533.24	4530.68	4538.7676	4537.064	4525.864
Analyses		-	8,000	-	18,000	10,000

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The CMO is used to conduct 50 independent optimization runs for each value of α. It is observed that the best results are obtained when α is set to 6.75. For the layout optimization, 50 particles and 200 iterations are considered. Table 2 compares the best results obtained by CMO with other algorithms. Additionally, Fig. 7 shows the best layout found by the CMO.

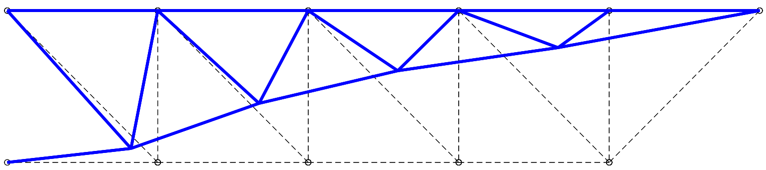


Figure 7. Optimum layout of 18-bar planar truss found by CMO

The optimization results indicate that the CMO algorithm outperforms all other algorithms in finding the best solution. Fig. 8 displays optimum weights obtained by the CMO algorithm in 50 independent optimization runs. The best, worst, average weights and their standard deviation are 4525.864, 4714.999, 4586.438, and 37.6838 kg, respectively.

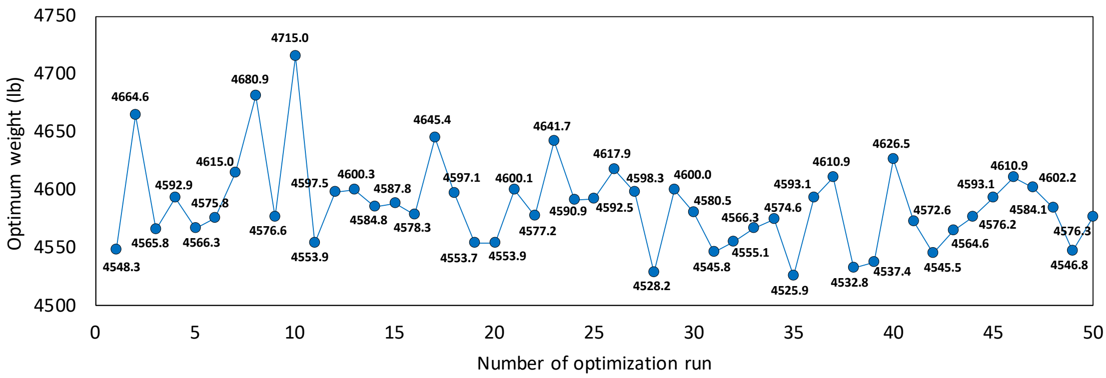
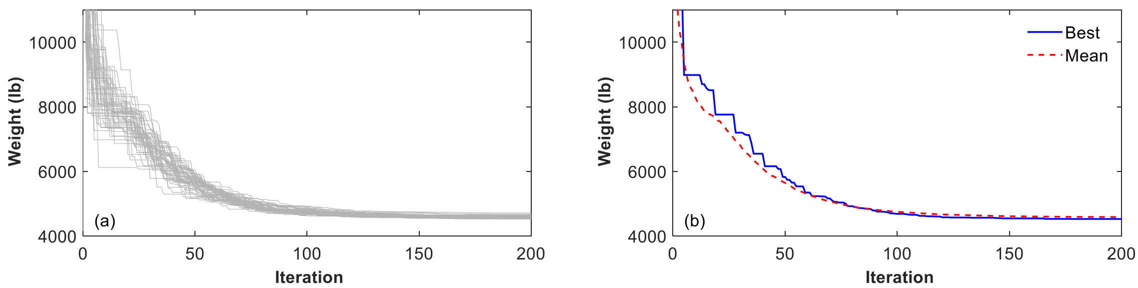


Figure 8. Optimum weights obtained by CMO for 18-bar planar truss

In this example, the convergence curves of all optimization runs, along with the best and mean convergence curves are displayed in Fig. 9. It can be observed that the CMO performed well in all independent optimization runs, as the mean convergence curve is very close to the best convergence curve.



(a) (b)

Figure 9. (a) All convergence curves and (b) the best and mean convergence curves of CMO in layout optimization of 18-bar planar truss

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4.3 47-bar truss

The third design problem of this paper involves a planar 47-bar tower shown in Fig. 10. The material density and the modulus of elasticity are 0.3 lb/in^3 is 3×10^5 ksi, respectively.

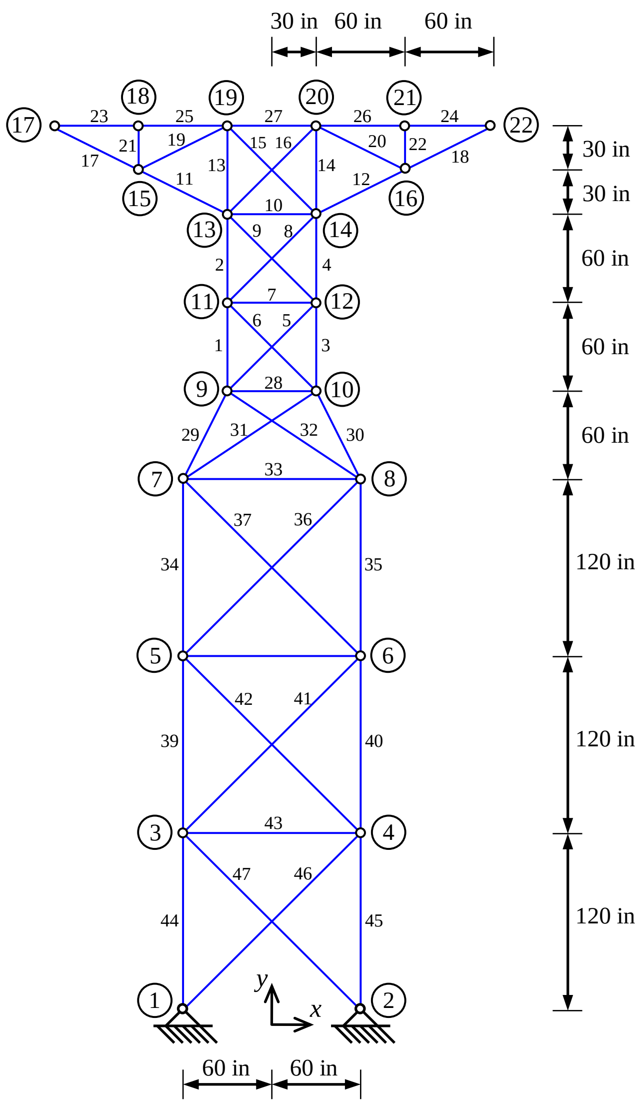

Figure 10. 47-bar planar truss structure

Three different loading conditions are applied independently to the tower. The first condition is a concentrated load of 6000 lbf in the positive *x*-direction and another 14,000 lbf in the negative *y*-direction applied to nodes 17 and 22. The second condition is a concentrated load of 6000 lbf in the positive *x*-direction and 14,000 lbf in the negative *y*-direction applied to node 17. The third condition is a concentrated load of 6000 lbf in the positive *x*-direction and a concentrated force of 14,000 lbf in the negative *y*-direction applied to node 22.

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Table 3: Optimal designs of 47-bar planar truss

No.	Design Variable	BB [18]	GA [1]	SA [16]	ABCA [3]	CMO
1	A_1	2.61	2.50	2.50	2.4	2.8
2	A_2	2.56	2.20	2.50	2.2	2.6
3	A_5	0.69	0.70	0.80	1.1	0.6
4	A_7	0.47	0.10	0.10	0.1	0.1
5	A_8	0.80	1.30	0.70	1.2	0.8
6	A_{10}	1.13	1.30	1.30	1.3	1.0
7	A_{12}	1.71	1.80	1.80	1.7	1.6
8	A_{14}	0.77	0.50	0.70	0.6	0.9
9	A_{15}	1.09	0.80	0.90	0.8	1.0
10	A_{18}	1.34	1.20	1.20	1.6	1.2
11	A_{20}	0.36	0.40	0.40	0.3	0.3
12	A_{22}	0.97	1.20	1.30	0.9	1.0
13	A_{24}	1.00	0.90	0.90	1.2	0.9
14	A_{26}	1.03	1.00	0.90	1.0	0.9
15	A_{27}	0.88	3.60	0.70	1.0	0.9
16	A_{28}	0.55	0.10	0.10	0.6	0.1
17	A_{30}	2.59	2.40	2.50	2.8	2.7
18	A_{31}	0.84	1.10	1.00	0.4	1.0
19	A_{33}	0.25	0.10	0.10	0.1	0.1
20	A_{35}	2.86	2.70	2.90	2.9	2.9
21	A_{36}	0.92	0.80	0.80	1.5	1.1
22	A_{38}	0.67	0.10	0.10	0.6	0.1
23	A_{40}	3.06	2.80	3.00	3.1	3.1
24	A_{41}	1.04	1.30	1.20	0.9	0.9
25	A_{43}	0.10	0.20	0.10	0.1	0.1
26	A_{45}	3.13	3.00	3.20	3.3	3.2
27	A_{46}	1.12	1.20	1.10	0.8	1.2
28	x_2	107.76	114.0	104.0	103.6063	102.4999
29	x_4	89.15	97.0	87.0	81.5008	84.0721
30	y_4	137.98	125.0	128.0	143.0525	141.7668
31	x_6	66.75	76.0	70.0	67.0169	70.8394
32	y_6	254.47	261.0	259.0	252.8466	234.1873
33	x_8	57.38	69.0	62.0	54.5203	54.3291
34	y_8	342.16	316.0	326.0	374.0126	347.9126
35	x_{10}	49.85	56.0	53.0	39.8226	44.8092
36	y_{10}	417.17	414.0	412.0	443.9461	441.7606
37	x_{12}	44.66	50.0	47.0	30.9474	41.0135
38	y_{12}	475.35	463.0	486.0	491.9941	487.9129
39	x_{14}	41.09	54.0	45.0	36.7597	41.6433
40	y_{14}	513.15	524.0	504.0	510.000	518.0844
41	x_{20}	17.90	1.0	2.0	17.6763	1.0137
42	y_{20}	597.92	587.0	584.0	598.8911	603.1467
43	x_{21}	93.54	99.0	89.0	77.6661	98.0282
44	y_{21}	623.94	631.0	637.0	619.8911	631.3745
	Best weight(lb)	1900.00	1925.79	1871.70	1871.843	1871.96
	Analyses	-	100,000	-	18,000	15,000

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The structural elements are divided into 27 sizing design variables as follows: $A_3 = A_1$; $A_4 = A_2$; $A_5 = A_6$; A_7; $A_8 = A_9$; A_{10}; $A_{12} = A_{11}$; $A_{14} = A_{13}$; $A_{15} = A_{16}$; $A_{18} = A_{17}$; $A_{20} = A_{19}$; $A_{22} = A_{21}$; $A_{24} = A_{23}$; $A_{26} = A_{25}$; A_{27}; A_{28}; $A_{30} = A_{29}$; $A_{31} = A_{32}$; A_{33}; $A_{35} = A_{34}$; $A_{36} = A_{37}$; A_{38}; $A_{40} = A_{39}$; $A_{41} = A_{42}$; A_{43}; $A_{45} = A_{44}$; $A_{46} = A_{47}$; Sizing design variables are selected from the following discrete set: D={0.1,0.2,0.3,…,4.8, 4.9, 5.0} (in.^{2}). Nodes 15, 16, 17 and 22 are fixed while only x-coordinates of nodes 1 and 2 can be changed. Therefore, 17 layout design variables are: $x_2 = - x_1$; $x_4 = - x_3$; $y_4 = y_3$; $x_6 = - x_5$; $y_6 = y_5$; $x_8 = - x_7$; $y_8 = y_7$; $x_{10} = - x_9$; $y_{10} = y_9$; $x_{12} = - x_{11}$; $y_{12} = y_{11}$; $x_{14} = - x_{13}$; $y_{14} = y_{13}$; $x_{20} = - x_{19}$; $y_{20} = y_{19}$; $x_{21} = - x_{18}$; $y_{21} = y_{18}$; x_i, $y_i \in R$. The tension and compression allowable stresses of members are 20 and 15 ksi, respectively. in addition, Euler buckling stress for each member is $3.96EA/L^2$.

In the literature, researchers have solved this benchmark truss layout optimization problem using the branch and bound (BB) method [18], GA [1], SA [16], and ABCA [3].

The CMO is utilized to perform 50 independent optimization runs for each value of α, and α=6.75 gives the best results, similar to the other examples. In this example, 50 particles and 300 iterations are used. Table 3 presents the best solution for CMO and other algorithms in the literature. Additionally, the best layout found for the tower is displayed in Fig. 11.

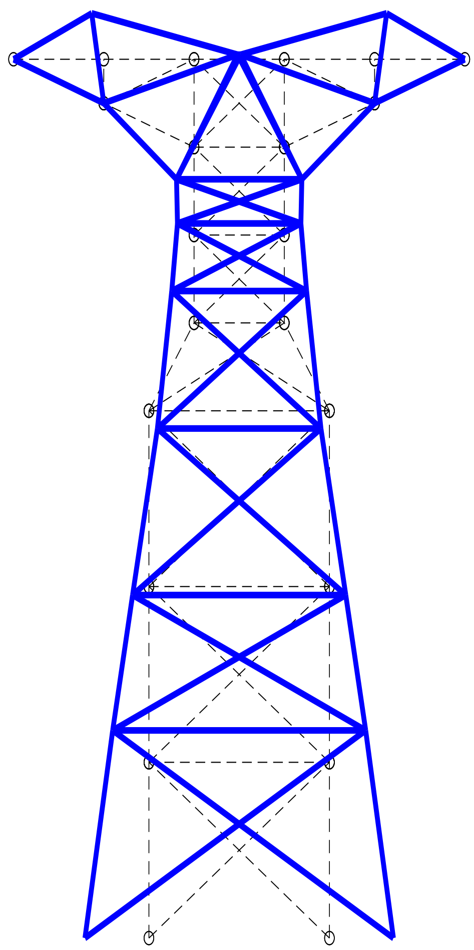

Figure 11. Optimum layout of 47-bar tower found by CMO

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The optimization results indicate that the CMO algorithm outperforms GA [1] and BB [18] and is competitive with ABCA [3] and SA [16] in finding the best solution. The weights of all the optimal solutions found are presented in Fig. 12. The best, worst, average weights and their standard deviation are 1871.964, 1996.998, 1934.032, and 22.451 kg, respectively.

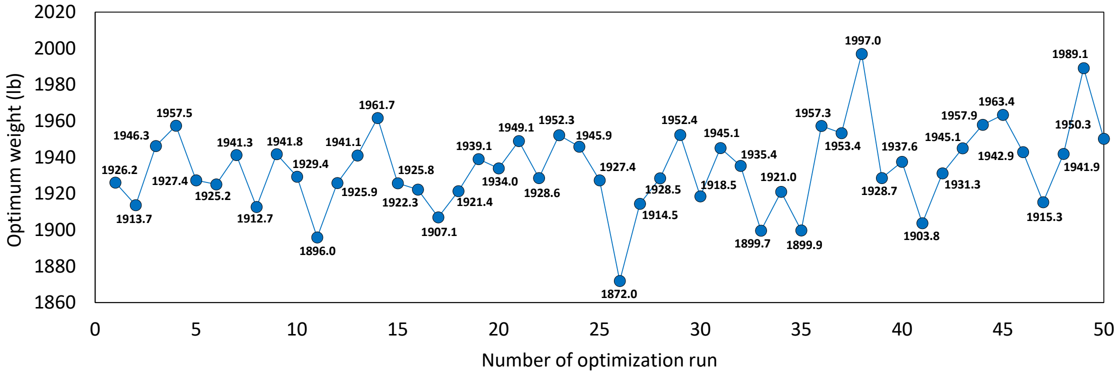
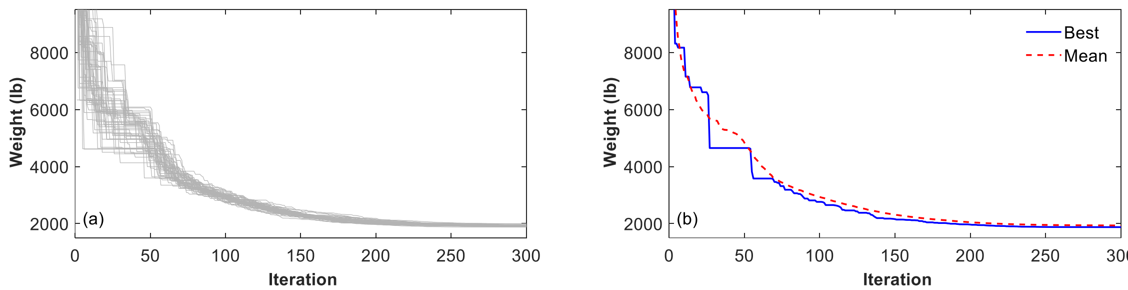


Figure 12. Optimum weights obtained by CMO for 47-bar tower

Fig. 13 shows the convergence curves of all optimization runs, along with the best and mean convergence curves are displayed. Obviously, the CMO performed well in all the optimization runs, because the mean convergence curve is very close to the best convergence curve.



(a) (b)

Figure 13. (a) All convergence curves and (b) the best and mean convergence curves of CMO in layout optimization of 47-bar tower

5. CONCLUSIONS

This paper presented a center of mass optimization (CMO) metaheuristic algorithm for sizing-layout optimization of planar truss structures. The CMO metaheuristic is based on the physical concept of the center of mass in space. Recent studies have shown that CMO is highly effective in solving various types of structural optimization problems compared to other metaheuristics. This paper applies the CMO to deal with the layout optimization problem of planar truss structures. The optimization process takes into account both discrete

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and continuous design variables. The cross-sectional areas of the truss are considered discrete design variables, while the coordinates of structural joints are treated as continuous design variables.

This paper presents three benchmark design examples of truss layout optimization including 15, 18, and 47-bar trusses. The optimization results for the truss layout obtained by the CMO algorithm are compared with those obtained by other optimization techniques in the literature. The numerical analysis shows that for 15-bar and 18-bar trusses, the CMO outperforms the artificial bee colony algorithm (ABCA) [3], genetic algorithm (GA) [13], firefly algorithm (FA) [14], modified harmony search algorithm (MHSA) [15], simulated annealing (SA) [16], and group search optimization (GSO) [17]. On the other hand, for the 47-bar truss, the CMO outperforms a genetic algorithm (GA) [1] and branch and bound (BB) [18] method, and is competitive with ABCA and SA in finding the best solution. These findings indicate that the CMO is an effective optimization algorithm for truss layout optimization.

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