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Optimization of the braced dome structures by using Jaya algorithm with frequency constraints

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Abstract. The aim of this paper is to present new and an efficient optimization algorithm called Jaya for the optimum mass of braced dome structures with natural frequency constraints. Design variables of the bar cross-section area and coordinates of the structure nodes were used for size and shape optimization, respectively. The effectiveness of Jaya algorithm is demonstrated through three benchmark braced domes (52-bar, 120-bar, and 600-bar). The algorithm applied is an effective tool for finding the optimum design of structures with frequency constraints. The Jaya algorithm has been programmed in MATLAB to optimize braced dome.

Keywords: Jaya algorithm; size and shape optimization; frequency constraints; braced dome structure

1. Introduction

Optimizing the weight of a structure with frequency restrictions is considered a difficult problem. In most problems related to low-frequency vibrations, the reaction of a structure is primarily a function of its basic frequencies and shapes of modes. The natural frequency of the structure is key parameters that must be controlled to maintain the desired structural behavior. It is particularly important to impose certain restrictions on these parameters in order to avoid the phenomenon of resonance.

Mathematical programming techniques used to solve design optimization problems showed limited feasibility. Therefore, the use of optimization methods that are devoid of gradients and inspire natural or physical phenomena is attracting more and more attention. Various optimization approaches were tested and successfully applied to the optimal design of structures in recent years. Some of them are; optimal design of truss structures using harmony search and genetic algorithm by Artar (2016a), design of braced steel frames via TLBO by Artar (2016b) and optimum design of composite steel frames with semi-rigid connections by Artar and Daloğlu (2017).

The first problem of structural optimization with frequency constraints analyzed Bellagamba and Yang (1981). Then Lin *et al*. (1982) investigated the construction of the minimum mass of structures with simultaneous static and dynamic constraints. Lingyun *et al*. (2005) optimized the shape and size of a truss using the niche genetic hybrid algorithm (NGHA). Different versions of the particle swarm optimization (PSO) algorithm were analyzed by researchers. Gomes (2011) used (PSO) to study topology and sizing optimization of truss structures with frequency constraints. Kaveh and Zolghadr (2014a) presented a democratic particle swarm optimization algorithm (DPSO).

Kaveh and Zolghadr (2014b) studied a search for harmony, and a ray optimizer is used to improve the particle swarming optimization algorithm (PSRO). Kaveh and Javadi (2014) have developed a hybrid algorithm (HRPSO) to optimize the shape and size of trusses with frequency constraints. Kaveh and Zolghadr (2012) developed Big Bang-Big Crunch algorithms (CSS-BBBC) with the trap recognition function. Miguel and Miguel (2012) proposed a harmonics search algorithm (HS) and firefly (FA) to optimize the size and layout truss with frequency constraints. Kaveh and Mahdavi (2015) analysed an algorithm called (CBO) colliding bodies optimization for size and topology optimization of trusses. Kaveh and Ghazaan (2016) studied cascade sizing optimization utilizing a series of design variable configurations (DVCs). Kaveh and Ghazaan (2017) proposed the application of developed optimization algorithm (VPS) the vibrating particles system for optimization of truss with frequency constraints. Tejani *et al*. (2018) and (2016) proposed the algorithm Symbiotic Organisms Search (SOS) and Improved SOS (ISOS) to cope with the above-mentioned challenges. Teaching Learning Based Optimization (TLBO) were used by Baghlani and Makiabadi (2013), Dede and Togan (2015) as a mass optimizaton of the truss structures under frequency constraints. Farshchin et al. (2016) extends the concept of the education process from a single classroom to a school with multiple parallel classes and proposed algorithm MC-TLBO. By using TLBO a different study presented by Artar *et al*. (2017) for the optimal design of steel bridges. Non-dominated Sorting Genetic Algorithm II (NSGA II) approach is employed for multi-objective optimization of the dome structures the by Talaslioğlu

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(2012). Another sudy using PSO algorithm is also presented by Talaslioğlu (2013).

Kaveh and Zolghadr (2018) presented a review study related meta-heuristic methods for optimization of truss structures with frequencies constraints. This review study includes useful information obtain the natural frequencies in a fast and efficient manner for truss structures.

In this paper, a new optimization algorithm named as Jaya (a Sanskrit word meaning victory) is used to optimize braced dome structures. This new technique originally was developed by Rao (2016, 2018). The algorithm is based on the assumption that the solution obtained for a given problem should aim at the best solution and should avoid the worst solution. This algorithm requires only common control parameters and does not require any control parameters specific to the algorithm. Dede (2018) studied optimum design of steel grillage structure. Degertekin *et al.* (2018) solved minimization problems of truss structures including sizing and layout optimization problems.

2. The structural optimization problem

In a frequency constraint dome shape and size optimization problem the aim is to minimize the weight of the structure while constraints are satisfied. The optimization problem can be presented in a mathematical form

$$W = \sum_{i=1}^{n} \rho_i \, L_i A_i \qquad i = 1, 2, \dots, n$$

subject to:

$$\begin{array}{ll} \omega_j \geq \omega_j^* & \text{for some natural frequencies "}j\text{"} \\ \omega_k \geq \omega_k^* & \text{for some natural frequencies "}k\text{"} \\ A_l^{low} \leq A_l \leq A_l^{up} & \text{for some bar cross-section areas} \\ x_m^{low} \leq x_m \leq x_m^{up} & \text{for some nodal coordinates} \end{array} \tag{1}$$

where "A" (bar cross-sectional areas) and "x" (nodal coordinates) are the design variable, respectively; "W" is the weight of the truss; "ρ" and "L" is the material density and the length of the i-th element, respectively; "n" is numbers of bars in the truss; "ω_j" is the *j-th* natural frequency of the structure, and "ω_j*" is minimum value; "ω_k" is the *k-th* natural frequency of the structure and "ω_k*" is its maximum value; "A_{low}" and "A_{up}" are minimum and maximum value of the design cross-sectional area, respectively; "x_{low}" and "x_{up}" are minimum and maximum value of the design coordinate variables, respectively.

To take into the constraints, the objective function must the changed as a penalty function "ϕ" including the constraint. The penalized objective function can be written in a basic form as

$$\phi = W * (1 + P * C) \qquad (2$$

where "C" is the sum of the violations of the constraints and "P" is a constant value. For example, the frequency constraint "ω_j", a violation (c_i) can be calculated as

$$g_i = \frac{\omega_j}{\omega_j^*} - 1 \geq 0 \quad \text{if} \quad g_i < 0 \quad \text{then} \quad c_i = gi \qquad (3$$

3. Jaya algorithm

Like the other many population based algorithms, the Jaya algorithms stars with a randomly created initial population. The main principle of this algorithm is getting close the best individual (solution) and moving away the worst individual. The best solution is defined as the combination of the design variables which gives the minimum or the maximum score of the fitness function. The advantage of this method is that only the general control parameters are required. To explain the general process of the Jaya algorithms a simple computer codes and a flowchart are given in Table 1 and Fig. 1, respectively.

In this Table, "*dim*" is the number of design variables, "*Pop*" is the all solutions, "*Pn*" is the size of population, "*lb*" is the lower bound for design variables, "*ub*" is the upper of the design variables, "*Gn*" is the total number of generation, "*Fx*" is the value of fitness function, "Pop_{best}" is the best solutions, "Pop_{worst}" is the worst solutions, "Pop_{new}" is the updated new solutions, "Fx_{new}" is the value of fitness function for updated solution and "*rand*(*1*,*dim*)" is a random vector whose length is equal to dim.

Table 1 The simple computer codes for the Jaya algorithm

```
% Generate initial population randomly

Loop   j = 1 → dim
    Pop(:,j) = rand(Pn,j).*(ub(j)-lb(j))+lb(j);
End Loop

Gn = 1;
While (the termination criterion can be written here)

   % Calculate objective function Fx for all population
   FOR   i = 1 → Pn
      Fx(i) = objective_function(Pop(i,:));
   END FOR

% Define the best and the worst solutions
% (for minimization problem)
Pop_best = min(Fx);
Pop_worst = max(Fx);

   % Update the population
   Loop i = 1:Pn
   Pop_new(i,:) = Pop(i,:) + rand(1,dim)*[Pop_best-Pop(i,:)]
                  - rand(1,dim)*[Pop_worst- (Pop(i,:)];

% Calculate objective function for all population
Fx_new(i) = objective_function(Pop_new (i,:));

                 if Fx_new(i) < Fx(i)
            Pop(i,:) = Pop_new(i,:)
                 End if

    End Loop
Gn = Gn + 1;
End While
```

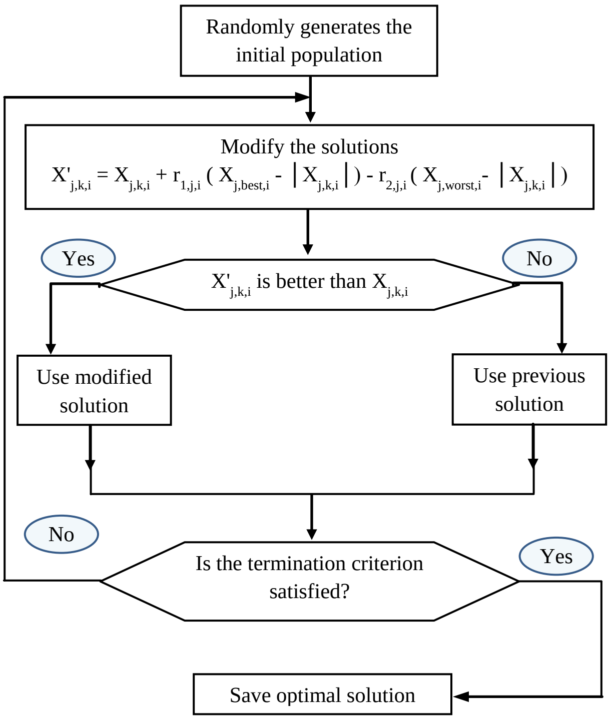


Fig. 1 Flow chart for Jaya algorithm

4. Examples

For the application of the proposed optimization method, three 3D dome structures are considered. These structures have been solved by the researchers before considering the different constraint such as displacement and Euler buckling. In this study, only frequency constraint is taking into account. As a first example, 52-bar dome structure is optimized for size and shape parameters and the others are optimized with only size parameters. The last example is examined for two cases by considering different groups including the design variables. The design variables are selected as continuous by taking into account the lower and upper bounds for all dome structures. 20 independent runs are taken into account for all domes. The best solution, mean solutions and standard deviation are also given to show the statistical results of the proposed algorithm.

4.1 Example 1 (size and shape optimization)

52-bar dome structure is given in the Fig. 2 with initial shape as a first example. To obtain the geometry of this structure, initial nodal coordinates, grouping of the elements and grouping of the nodal points can be seen from the Fig. 1 and the first column of Table 3. This dome structure was investigated by Kaveh and Zolghadr (2012) with Charged System Search and Big Bang-Big Crunch (CSS-BBBC), Lingyum *et al*. (2005) with a Niche Hybrid Genetic Algorithm (NHGA), Miguel and Miguel (2012) with Harmony Search (HS) and Firefly Algorithm (FA), Kaveh and Javadi (2014) with an enhanced particle swarm optimization technique (HRPSO), Gomes (2011) with particle swarm optimization technique (PSO), Lin *et al*. (1982) with mathematical programming technique (MPT),

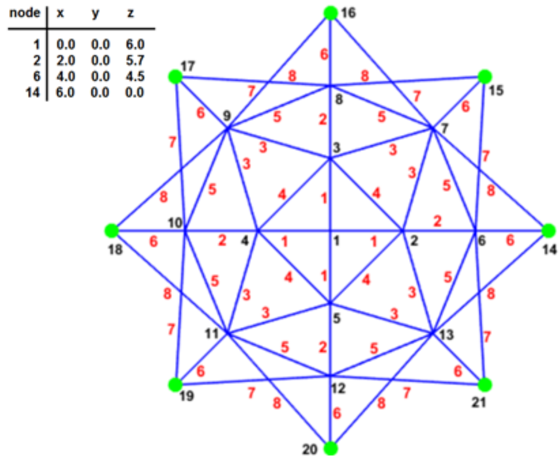


Fig. 2 Plan view and element grouping of the example 1

Table 2 Structural constraints and material properties for example 1

Properties / constraints	Unit	Value / notes
Modulus of elasticity	E (N/m^2)	2.1×10^{11}
Material density	ρ (kg/m^3)	7800
Non-structural mass	m (kg)	50 for all free nodes (1:13)
Lower and upper bounds	A (m^2)	$0.0001 \le A \le 0.001$
Frequency constraints	ω (Hz)	$\omega_1 \le 15.916$, $\omega_{2,3} \ge 28.648$
Permitted movements	Δ (m)	± 2 for all free nodes in each directions

Kaveh and Zolghadr (2014b) with hybridized Particle Swarm Ray Optimization (PSRO), Baghlani and Makiabadi (2013) with Teaching-Learning-Based Optimization technique (TLBO) and Farshchin *et al*. (2016) with multi-class TLBO.

The structural element of this example is classified 8 groups for the size optimization and nodal points are classified 5 groups for the shape optimization by preserving the structural symmetry. Thus, the cross-sections and the coordinates are the design variables for the size and shape optimization, respectively. The material properties, frequency constraints and the non-structural masses are given in the Table 2. The size of population is 30 and the number of generation is 600 for this example.

Table 3 gives the comparison of the best results given by researchers by using different optimization algorithms. As seen from this comparison, the best solutions are obtained by using the proposed algorithm. Also, in this study, when a high iteration number is selected as 1500 with the 20 population size the weight of the structure can be obtained as 193.1864 kg (for shape optimization, nodal coordinates: [5.94855 2.26454 3.72567 3.97181 2.50000] m and for the size optimization, cross-sectional areas: [1.00000 1.11396 1.21257 1.45494 1.40569 1.00008 1.59111 1.37042] cm^2). This solution is also not violates the constraints. The optimal results given by Baghlani and Makiabadi (2013) and Farshchin *et al*. (2016) are seen the best, but they

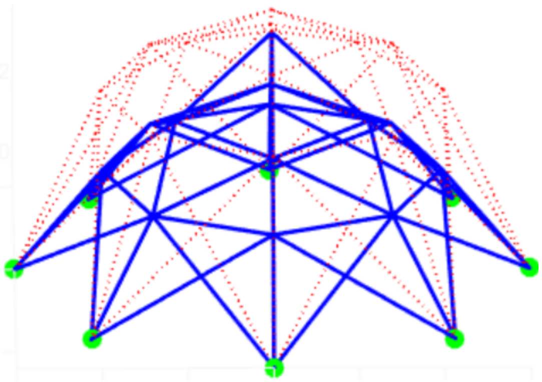


Fig. 3 Optimized shape of the example 1

violates the frequency constraint of the structure. This may result from taking 4 digits after point or unit conversion (Hz to rad/s) for the value of frequency constraints given in Table 2. The constraints are calculated by using the optimal solutions given in the Table 3. Also, the natural frequencies for best solution obtained by the researchers are given in this table. The optimized shape obtained by using Jaya algorithm is given in the Fig. 3. In this figure, the dotted lines are the initial shape and the others are the optimized shape. As seen from this figure and the optimal solution given in Table 3, the optimized weight for dome structure is lighter than initial configuration.

As seen from Table 3, the values of the mean solution and the standard deviation are smaller than the results given by other researchers. The convergence graph for example 1 with the best solution, mean solution and the standard deviation is given in Fig. 4. To show convergence history

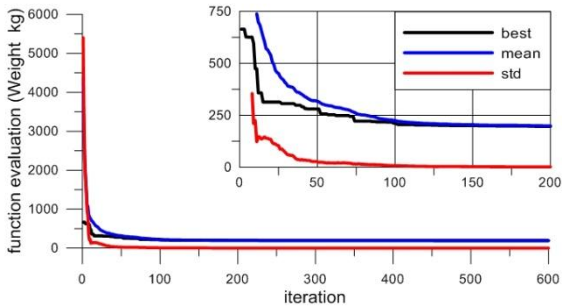


Fig. 4 Convergence graph for example 1

Table 3 Optimal solutions for example 1

Design variables		Initial shape/ Size	Kaveh and Zolghadr (2012)	Miguel and Miguel (2012)	Kaveh and Javadi (2014)	Lingyum *et al.* (2005)	Gomes (2011)	Lin *et al.* (1982)	Kaveh and Zolghadr (2014b)	Baghlani and Makiabadi (2013)	Farshchin *et al.* (2016)	This study
			CSS-BBBC	FA	HRPSO	NHGA	PSO	MPT	PSRO	TLBO	MC-TLBO	Jaya
Shape opt. coordinate (m)	Z_1	6.00	5.3310	6.4332	5.8285	5.8851	5.5344	4.3201	6.2520	5.9749	5.95310	5.94930
	X_2	2.00	2.1340	2.2208	2.2436	1.7623	2.0885	1.3153	2.4560	2.2801	2.29078	2.30600
	$Z_{2:5}$	5.70	3.7190	3.9202	3.7206	4.4091	3.9283	4.1740	3.8260	3.7241	3.70365	3.71420
	X_6	4.00	3.9350	4.0296	3.9566	3.4406	4.0255	2.9169	4.1790	3.9734	3.96604	3.98550
	$Z_{6:13}$	4.50	2.5000	2.5200	2.5000	3.1874	2.4575	3.2676	2.5010	2.5000	2.50010	2.50000
Size optimization cross-sec. area (cm^2)	A_1	2.00	1.0000	1.0050	1.0000	1.0000	0.3696	1.0000	1.0007	1.0000	1.00016	1.00000
	A_2	2.00	1.3056	1.3823	1.1365	2.1417	4.1912	1.3300	1.0312	1.0982	1.09615	1.08219
	A_3	2.00	1.4230	1.2295	1.2218	1.4858	1.5123	1.5800	1.2403	1.1993	1.22522	1.19599
	A_4	2.00	1.3851	1.2662	1.4866	1.4018	1.5620	1.0000	1.3355	1.4621	1.45553	1.47996
	A_5	2.00	1.4226	1.4478	1.3954	1.9116	1.9154	1.7100	1.5713	1.4041	1.41723	1.41009
	A_6	2.00	1.0000	1.0000	1.0000	1.0109	1.1315	1.5400	1.0021	1.0000	1.00031	1.00001
	A_7	2.00	1.5562	1.5728	1.5515	1.4693	1.8233	2.6500	1.3267	1.5958	1.62036	1.57885
	A_8	2.00	1.4485	1.4153	1.4182	2.1411	1.0904	2.8700	1.5653	1.3701	1.32958	1.38031
First five frequency ω, (Hz)			12.987	11.3119	11.6853	12.8050	12.751	15.22	12.311	11.5580	11.5924	11.7039
			28.648	28.6529	28.6486	28.6488	28.649	29.28	28.648	28.6479	28.6480	28.6485
			28.679	28.6529	28.6486	28.6488	28.649	29.28	28.649	28.6479	28.6481	28.6485
			28.713	28.8030	28.6509	29.5398	28.803	31.68	28.715	28.6482	28.6481	28.6523
			30.262	28.8030	29.1298	30.2442	29.230	33.15	28.744	28.6500	28.6642	28.7083
Weight (kg)			197.309	197.53	193.361	236.045	228.381	298.0	197.186	193.141*	193.185*	193.223
Mean (kg)			-	212.80	-	274.164	234.3	-	213.42	196.43	197.876	195.144
std (kg)			-	17.980	17.637	37.4620	5.22	-	10.11	2.38	5.7905	2.87430
n.f.e or Pn/Gn			20/200	1000	90/300	20/400	70/161	-	30/200	12500	15000	30/600
Run			20	5	10	10	5	-	20	5	100	20
Violation			0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	6.093e-6	3.960e-6	0.0000

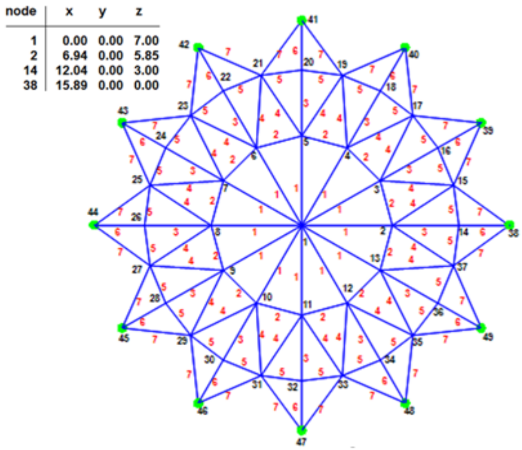


Fig. 5 Plan view and grouping for example 2

Table 4 Structural constraints and material properties for example 2

Properties / constraints	Unit	Value / notes
Modulus of elasticity	E (N/m^2)	2.1×10^{11}
Material density	ρ (kg/m^3)	7971.81
Non-structural mass at nodes	m (kg)	3000 for 1 500 for 2:13 100 for 14:37
Lower and upper bounds	A (m^2)	$0.0001 \leq A \leq 0.01293$
Frequency constraints	ω (Hz)	$\omega_1 \geq 9$, $\omega_{2,3} \geq 11$

more clearly, the first parts of the graph is drawn with a large scale.

4.2 Example 2 (size optimization)

The second example illustrated in Fig. 5 has 120-bar. Size optimization is taken into account for this example with the frequency constraints. To obtain the geometry of this structure, initial nodal coordinates and grouping of the elements can be seen from this figure. Example 2 was investigated by Kaveh and Zolghadr (2012) using (CSS-BBBC), Kaveh and Zolghadr (2014b) with (PSRO), Tejani *et al.* (2018) using improved symbiotic organisms search (ISOS), Tejani *et al.* (2016) using symbiotic organisms search (SOS-ABF2), Kaveh and Mahdavi (2015) with Colliding-Bodies Optimization (CBO) and Kaveh and Zolghadr (2014a) with Democratic Particle Swarm Optimization (DPSO).

The structural element of this example is classified 7 groups for the size optimization. The input data for this example are given in the Table 4. The size of population is 30 and the number of generation is 600 for this example.

Table 5 shows the best results by using different optimization algorithms. As seen from this comparison the best results are obtained by using the proposed algorithm. Also, in this table, the first five frequencies of the optimal solution given by the researchers. As seen from this table, the optimal results given by Tejani *et al.* (2018) violates the frequency constraints.

The history of the best solution, mean solution and the standard deviation are given in Fig. 6. To show the first part

Table 5 Best results and comparison for example 2

Design variables		Kaveh and Zolghadr (2012)		Kaveh and Zolghadr (2014b)	Tejani *et al.* (2018)	Tejani *et al.* (2016)		Kaveh and Mahdavi (2015)	Kaveh and Zolghadr (2014a)	This study	
		CSS	CSS-BBBC	PSRO	ISOS	SOS-ABF1	SOS-ABF2	CBO	DPSO	Pn = 20	Pn = 30
Cross-sectional area (cm^2)	A_1	21.710	17.478	19.972	19.6662	19.5449	19.5715	19.6917	19.607	19.300	19.309
	A_2	40.862	49.076	39.701	39.8539	40.9483	39.8327	41.1421	41.290	40.861	40.763
	A_3	9.0480	12.365	11.323	10.6127	10.4482	10.5879	11.1550	11.136	10.697	10.791
	A_4	19.673	21.979	21.808	21.2901	21.0465	21.2194	21.3207	21.025	21.107	21.272
	A_5	8.3360	11.190	10.179	9.79110	9.5043	10.0571	9.8330	10.060	9.989	9.943
	A_6	16.120	12.590	12.739	11.7899	11.9362	11.8322	12.8520	12.758	11.779	11.695
	A_7	18.976	13.585	14.731	14.7437	14.9424	14.7503	15.1602	15.414	14.743	14.579
First five frequency ω, (Hz)		9.002	9.000	9.000	9.0001	9.0011	9.0012	9.0000	9.0000	9.0016	9.0000
		11.002	11.007	11.000	10.9998	11.0003	11.0023	11.0000	11.0000	11.0013	11.0002
		11.006	11.018	11.005	-	11.0003	11.0023	11.0000	11.0052	11.0013	11.0002
		11.015	11.026	11.012	-	11.0015	11.0056	11.0096	11.0134	11.0044	11.0008
		11.045	11.048	11.045	-	11.0674	11.0720	11.0494	11.0428	11.0716	11.0674
Weight (kg)		9204.51	9046.34	8892.33	8710.062*	8712.110	8710.330	8889.130	8890.48	8712.677	8709.353
Mean (kg)		-	-	8921.30	8728.5951	8727.426	8725.307	8891.254	8895.99	8730.174	8713.215
std (kg)		-	-	18.54	14.2296	16.5503	10.6402	1.7926	4.26	12.7829	2.969
nfe or Pn/Gn		20/200	20/200	20/200	4000	4000	4000	6000	30/200	20/200	30/600
Run		20	20	20	-	-	-	20	30	20	20

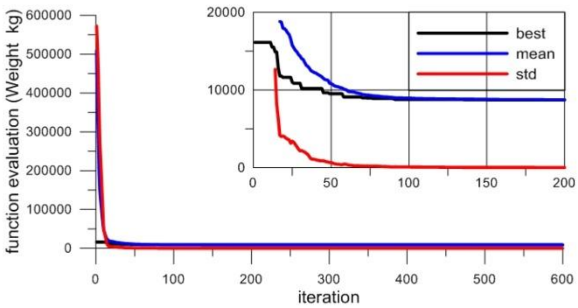
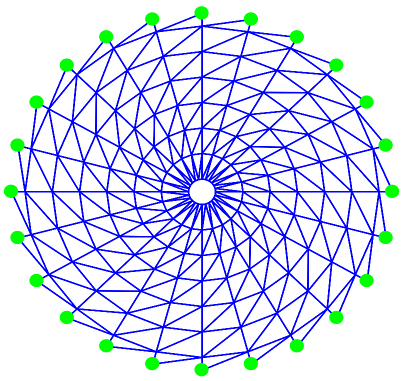


Fig. 6 Convergence graph of solutions for example 2

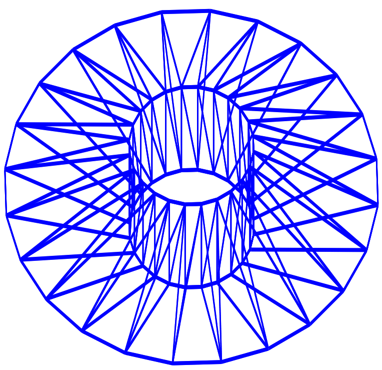
of the convergence more details, a large scaled graphic is added to the same figure.

4.3 Example 3 (size optimization with large structure)

The configuration of 600-bar dome is shown in the Fig. 7. For this structure, 600 elements are categorized into two cases. There are 8 groups for the first one and 25 groups for the second. The nodal coordinates and the grouping for the all cases are given on the substructure in Fig. 8. This example tested previously by the Kaveh and Ghazaan (2016) using Multi-DVC cascade optimization. Kaveh and Zolghadra (2016) presented another study including large dome structures such as 1180-bar and 1410-



(a)



(b)

Fig. 7 (a) Plan view; and (b) large scaled 3D view of the inner two ring of the example 3

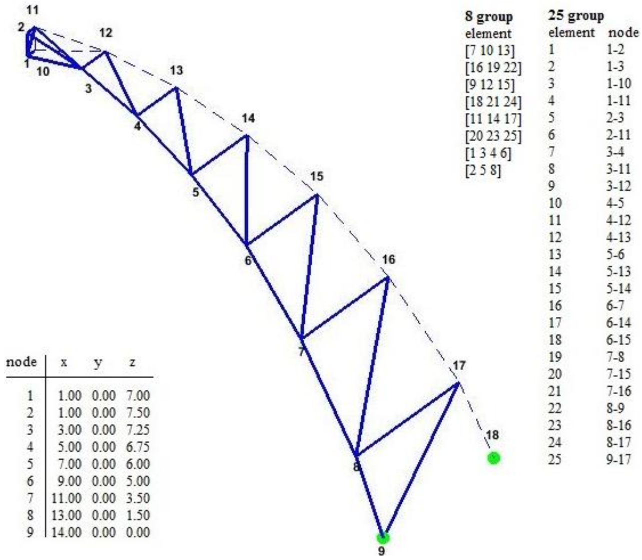


Fig. 8 A symmetrical substructure of 3D 600-bar dome

Table 6 Structural constraints and material properties for example 3

Properties / constraints	Unit	Value / notes
Modulus of elasticity	E (N/m^2)	2.0×10^{11}
Material density	ρ (kg/m^3)	7850
Non-structural mass	m (kg)	100 for all free nodes
Lower and upper bounds	A (m^2)	$0.0001 \leq A \leq 0.001$
Frequency constraints	ω (Hz)	$\omega_1 \geq 5$, $\omega_{2,3} \geq 7$

bar dome trusses. For the 600 bar dome structure, the material properties, non-structural added mass, frequency constraints, lower and upper bounds for design variables are given in the Table 6.

The optimal solutions and frequency of the optimal results for this structure are summarized in the Table 7 for the case I and case II, respectively. As seen from this table, the best results are obtained from this study. The solution does not violate the frequency constraints.

To show the performance of the used algorithm the best solution, mean solution, standard deviation, number of independent runs and the number of function evaluation are given in the same tables. The history of the best solution,

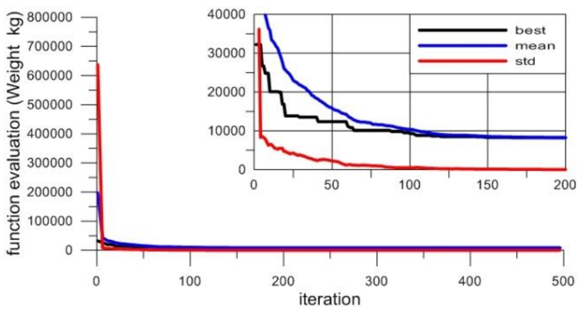


Fig. 9 Convergence history of solutions for the 600-bar (8 group) dome structure

Table 7 Optimal solutions for example 3

	Design variables (cm^2)	Kaveh and Ghazaan (2016)	This study Jaya	Design variables (cm^2) cont.	Kaveh and Ghazaan (2016)	This study Jaya
Case I 8 group	1	-	12.7774	5	-	8.12486
	2	-	5.13015	6	-	1.75396
	3	-	11.8198	7	-	16.24721
	4	-	6.63288	8	-	16.28953
	First five frequency ω, (Hz)	-	5.0041	Weight (kg)	8472	8153.7646
		-	5.0041	Mean (kg)	-	8160.5211
		-	7.0006	Sdt (kg)	-	3.8249
		-	7.0006	n.f.e	-	15030
		-	7.0015	Run	-	10
Case II 25 group	1	1.0299	1.75176	14	5.2917	6.19220
	2	1.3664	1.18111	15	6.2750	6.43952
	3	5.1095	4.88782	16	5.4305	5.47595
	4	1.3011	1.51622	17	3.6414	3.26953
	5	17.0572	18.16588	18	7.2827	8.37244
	6	34.0764	36.07637	19	4.4912	4.49865
	7	13.0985	12.65709	20	1.9275	2.21967
	8	15.5882	14.61127	21	4.6958	4.61615
	9	12.6889	11.31977	22	3.3595	3.06674
	10	10.3314	8.45802	23	1.7067	1.85490
	11	8.5313	8.42854	24	4.8372	4.79602
	12	9.8308	9.73211	25	2.0253	1.60290
	13	7.0101	7.29467	-	-	-
	First five frequency ω, (Hz)	5.001	5.0804	Weight (kg)	6140.51	6112.6438
		5.001	5.0804	Mean (kg)	6175.33	6146.1936
		7.001	7.0001	Sdt (kg)	39.08	17.2355
		7.001	7.0001	n.f.e	19020	15030
		7.002	7.0006	Run	5	10

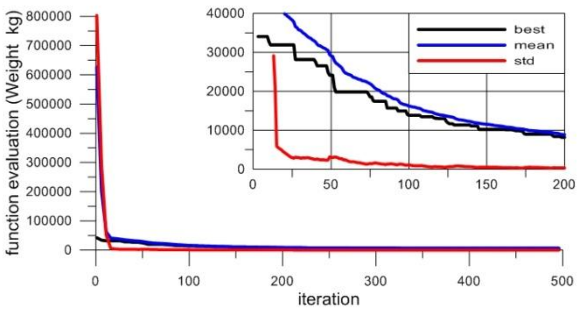


Fig. 10 Convergence history of solutions for the 600-bar (25 group) dome structure

mean solution and the standard deviation obtained using the Jaya algorithm for the case I and case II are given the Fig. 9 and Fig. 10, respectively. The population size and maximum generation number are 30 and 500 for this example.

To show the diversity of the independent runs for the all examples the weight of the related structure are given in the Table 8. The elapsed mean times to solve each example are given in this table. The computer used to solve these examples has the properties as; Intel(R) Core(TM) i5-3470 CPU @ 3.20Hz 8,00 GB, Windows 10 Enterprise.

5. Conclusions

Size and shape optimization with the frequency constraints of 3D dome structure are investigated in this study. To optimize the dome structures a new and efficient algorithm called Jaya is coded in the Matlab. The results obtained from the optimization process of the examples taken from the literature as benchmark problem are compared the other results given in previous studies. The results of this study show that Jaya algorithm has the best solution among the other algorithms. As a result, it can be concluded that the Jaya algorithm can be used as an

Table 8 Diversity of the run for all dome structure

Run no	Weight (kg)			
	52 bar	120 bar	600 bar, Case I	600 bar, Case II
1	193.4331	8709.3539	6112.9373	8157.3212
2	193.4372	8715.9286	6783.4848	8156.3640
3	193.2229	8711.9890	6401.4122	8158.0960
4	193.6924	8709.5981	6160.0375	8157.9533
5	193.4243	8710.2483	6217.0690	8160.8536
6	193.7176	8710.9132	6175.6752	8164.8832
7	200.4245	8711.6594	6155.6403	8157.5666
8	194.9921	8713.1122	6165.5573	8153.7646
9	193.5917	8711.6286	6112.6438	8161.0008
10	193.6830	8710.0645	6148.4103	8156.3290
11	201.7807	8714.4637	6163.4892	8194.5151
12	193.7251	8715.7458	6430.3657	8158.1589
13	193.7234	8712.5166	6173.0347	8155.7006
14	200.5723	8715.1362	6125.7295	8157.7951
15	194.0887	8713.9430	6172.2255	8158.6338
16	193.4686	8719.6570	6251.6208	8387.6109
17	193.4955	8719.5643	6136.4168	8171.6543
18	193.5493	8713.9493	6173.2871	8159.5760
19	194.3601	8715.0774	6186.5439	8154.2743
20	200.5117	8709.7543	6113.3473	8160.2273
Best	193.2229	8709.3539	6112.6438	8153.7646
Pn/Gn	30/600	30/600	30/500	30/500
CPU time	371.2813	1237.9688	16072.8906	16205.4844

effective algorithm to find best solution for the 3D dome structures.

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