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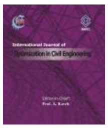

# OPTIMUM DESIGN OF THE BRACED DOME WITH FREQUENCY CONSTRAINT USING THE IMPROVED SHUFFLED BASED JAYA ALGORITHM

A. Kaveh*, † and A. Zaerreza
*School of Civil Engineering, Iran University of Science and Technology, PO Box 16846-13114, Iran*

## ABSTRACT

In this paper, the improved shuffled-based Jaya algorithm (IS-Jaya) is applied to the size optimization of the braced dome with the frequency constraints. IS-Jaya is the enhanced version of the Jaya algorithm that the shuffling process and escaping from local optima are added for it. These two modifications increase the population diversity and ability the escape from the local optima of the Jaya. The robustness and performance of the IS-Jaya are evaluated by the three design examples. The results show that the IS-Jaya algorithm outperforms other state-of-the-art optimization techniques considered in the literature.

**Keywords:** improved shuffled based Jaya algorithm; metaheuristic; structural optimization; braced dome structures; frequency constraints.

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## 1. INTRODUCTION

Optimization has grown in popularity as a research topic over the last four decades. Optimization is the process of determining the function's minimal or maximum value while satisfying all constraints [1, 2]. Gradient-based methods and meta-heuristic algorithms are two types of optimization methods. Meta-heuristic algorithms are more frequently employed than gradient-based methods due to their ease of implementation and lack of reliance on gradient information [3, 4].

Not all optimization can efficiently be solved with a single meta-heuristic solution [5]. As a result, researchers develop new meta-heuristic algorithms that draw inspiration from a

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[*] Corresponding author: School of Civil Engineering, Iran University of Science and Technology, PO Box 16846-13114, Iran

[†] E-mail address: alikaveh@iust.ac.ir (A. Kaveh)

variety of sources. Meta-heuristic algorithms can be classified into four classes based on their source of inspiration [6]. The first group is the evolutionary-based algorithms such as Genetic Algorithm (GA) [7], Genetic Programming (GP) [8], Biogeography-Based Optimizer (BBO)[9], Artificial Algae Algorithm (AAA) [10], Monkey King Evolutionary (MKE) [11], and Sunflower Optimization (SFO) algorithm [12] imitate the natural evolution. The second category of algorithms is the human-based algorithms that mimic or stimulate the human behavior, such as Harmony Search Algorithm (HS) [13], Tabu Search (TS) [14], Social-Emotional Optimization (SEO) [15], Tiki-Taka Algorithm (TTA) [16], Volleyball Premier League Algorithm (VPL) [17], Shuffled Shepherd Optimization algorithm (SSOA) [18], and Past Present Future Algorithm (PPF) [19]. The third type of algorithm is swarm-based, which mimics the social behavior of various animals. Particle Swarm Optimization (PSO) [20], Glowworm Swarm Optimization (GSO) [21], Dragonfly algorithm (DA) [22], Dolphin echolocation (DE) [23],Bird Mating Optimizer (BMO) [24], Cyclical Parthenogenesis Algorithm (CPA) [25], Harris Hawks Optimization (HHO) [26], and Fruit Fly Optimization (FFO) algorithm [27] are the example of this group. The final class of algorithms is physics-based algorithms, which employ physical laws to generate a new solution in each iteration, such as Big Bang–Big Crunch (BB–BC) [28], Electimize optimization algorithm [29], Charged System Search (CSS) [30], Heat Transfer Search Algorithm (HTS) [31], Ray Optimization [32], Henry Gas Solubility Optimization (HGSO) [33], Water Evaporation Optimization (WEO) [34], Flow Regime Algorithm (FRA), Tug of War Optimization (TWO) [35], Lichtenberg Algorithm (LA) [36], and Doppler Effect-Mean Euclidian Distance Threshold (DE-MEDT) [37].

Structural optimization has become a popular research subject for civil engineers in recent decades. Structural optimization is the process of reducing the weight of structures while also meeting all of the requirements such as stress, reliability, and story drift. Researchers evaluated the performance of the different optimization algorithms for the optimum design of structures. For example, Saka and Erdal [38] applied the harmony search algorithm for optimum design of the grillage system. Kaveh, et al. [39] tested the performance of four metaheuristic algorithms for the optimum design of castellated beams. Kumar, et al. [40] introduced modified symbiotic organisms for designing optimal structures with frequency constraints. Kaveh, and Malakoutirad [41] developed a hybrid method for analysis and design. Kazemzadeh Azad, et al. [42] developed the upper bound strategy framework for optimum design of structures using the meta-heuristic algorithms. Kaveh and Talatahri [43] charged system search with a fly to boundary method for discrete optimum design of truss structures. Azad and Hasançebi [44] applied the guided stochastic search for the optimum design of the steel truss. Kaveh, et al. [45] applied the metaheuristic algorithms for the optimum design of the portal frame. Jahangiri, et al. [46] proposed a new meta-heuristic algorithm for the optimum design of the seven benchmark structures. Artar and Carbas [47] applied two meta-heuristic algorithms for the optimum design of the steel truss bridges. Kaveh and Zaerreza [48] present the enhanced Rao's algorithms for optimum structural design with deterministic and probabilistic constraints.

In this study, the performance of the Improved Shuffled Jaya algorithm (IS-Jaya) in the size optimization of the braced dome structures with frequency constraints is investigated. Improved Shuffled Jaya algorithm (IS-Jaya) for the first time introduced by Kaveh, et al. [49] for size optimization of the structures with the discrete variables. In this study, for the first time, the performance of the IS-Jaya in the size optimization of the braced dome with continuous variables and frequency constraints. Three benchmark dome structure is considered, and two of them are large-scale structures. The result of the optimization in these structures shows that the IS-Jaya has good performance in the optimum design of the dome structures.

## 2. IMPROVED SHUFFLED JAYA ALGORITHM (IS-JAYA)

Jaya algorithm is developed by Rao [50]. Jaya algorithm has some shortcomings inducing the unwanted premature convergence and the possibility of being trapped in local minima. To alleviate these handicaps, first, the concept of shuffling is added to the Jaya algorithms. In the shuffling process, the population of the algorithm is divided into subpopulations. This dividing leads to an increase the population diversity of the algorithms and improves the ability of the escape from local optima. More detail about the shuffling process is available in Refs. [51, 52]. The escape from the local optima mechanism is added to the Jaya algorithms as a second modification. This mechanism helps the algorithms to get quickly out of the local optima. Also, it helps algorithms to find a better solution. the steps of the IS-Jaya algorithm are provided as follows.

Step 1: Initialization

Jaya algorithm starts with the population randomly generated in the search space.

Step 2: Shuffling

In the shuffling process, first, all of the solutions are sorted based on their objective function. Then, equal to the number of the subpopulation, the best solutions are selected and randomly added to each subpopulation. To place the second member of each subpopulation, the best solution of the rest of the solutions, and added randomly to each subpopulation. This process is repeated until all of the solutions are dived into the subpopulations.

Step 3: Main step size

After generating the subpopulations, the main step size of the algorithm is calculated as follows:

$$Stepsize_i = rand \times (X_{best} - X_i) - rand \times (X_{worst} - X_i) \tag{1}$$

where the $rand$ is the random vector generated between 0 and 1. $X_i$ is the considered solution. $X_{best}$ and $X_{worst}$ are the best and worst solution for the subpopulation to which $X_i$ belong.

Then, the new solution is calculated using Eq. (2).

$$X_i^{new} = X_i + Stepsize_i \tag{2}$$

Step 4: Escape from the local optima mechanism

One solution in each subpopulation is selected to increase the ability to escape from the local optima. Then, one variable of them is modified using the following equation:

$$X_i^{new} = X_i^{new} + 0.1 \times randn \times (X_{max} - X_{min}) \tag{3}$$

In which $randn$ is the normally distributed random number. $X_{max}$ is the upper bound of the search space. $X_{min}$ is the lower bound of the search space.

Step 5: Replacement strategy

First, the newly generated solutions are evaluated. Then, the new solution is compared with their old solution in the aspect of the objective function, and the worst of them are omitted.

Step 6: Checking the termination condition

If the iteration number reaches the maximum number of iterations, the algorithm terminates. Otherwise, it returns to Step 2 for the next round of iteration.

To further clarify, the flowchart of the IS-Jaya is given in Fig. 1.

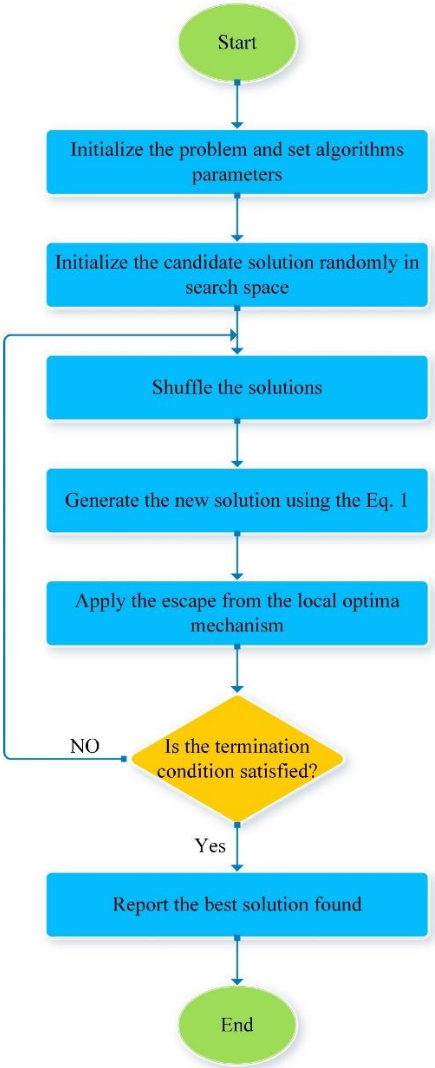

Figure 1. Flowchart of the IS-Jaya

## 3. DESIGN EXAMPLES

Three braced dome examples are considered to investigate the performance of the IS-Jaya. These examples include the 120-bar dome structure, 600-bar dome structure, and 1180-bar dome structure. The number of subpopulations is set to 4, and the number of solutions is set to 20 in all examples. Also, the maximum number of function evaluations is set to 20000 in these examples. To get the statistical results, 30 independent runs are performed.

### *3.1 The 120-bar dome structure*

The first example considered is the 120-bar dome structure. Members of this example are divided into the 7 groups, as shown in Fig. 2. The modulus of elasticity and martial density are set to 210 GPa and 7971.81 kg/m$^3$, respectively. 3000 kg, 500kg, and 100 kg non-structural masses are added to node 1, nodes 2 through 13, and other remaining free nodes, respectively. The minimum value of the first and second frequencies of the structure is set to 9 and 11 as the constraint of the problem. The upper and lower boundary of the search space is set to 1 and 129.3 cm$^2$.

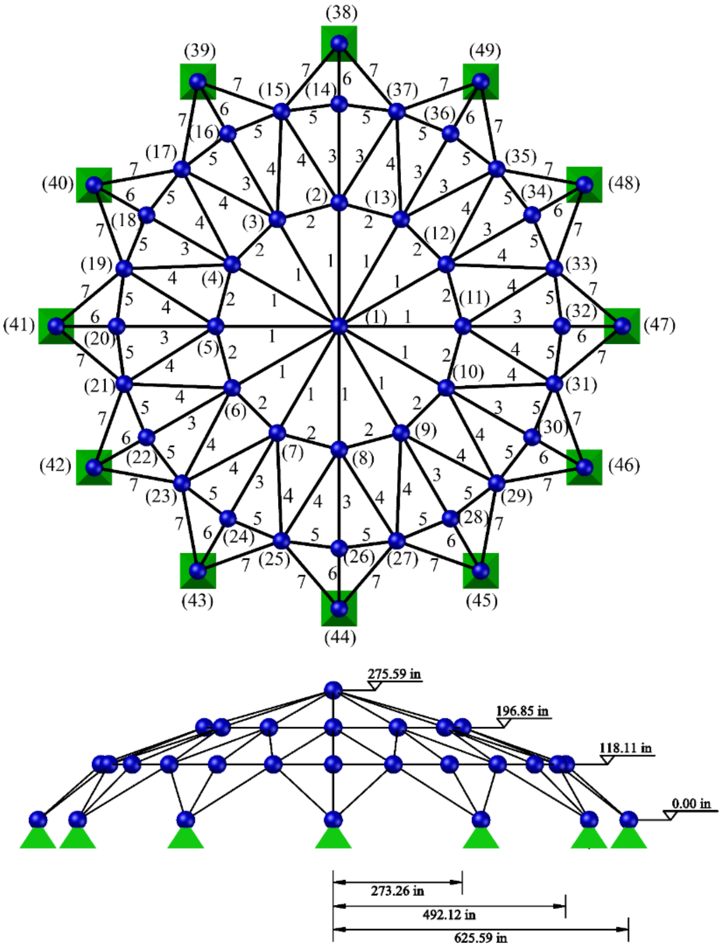

Figure 2. Schematic of the 120-bar dome structure

The result of the IS-Jaya and other methods are provided in Table 1. The optimum value found by the IS-Jaya (8707.62 kg) is better than Democratic PSO (8890.48 kg), ALC-PSO (8890.70kg), HALC-PSO (8889.96 kg), SOS- ABF1 (8712.11 kg), SOS- ABF2 (8710.33 kg), SOS- ABF1&2 (8716.94 kg), and Jaya (8709.35 kg). Also, the average of optimal weight found by IS-Jaya (8709.6428 kg) is much better than other optimization methods, and it is very close to the optimum weight found by IS-Jaya. Therefore, the IS-Jaya is more robust than other optimization methods. Table 1 shows that all of the constraint function in the best run of the IS-Jaya is satisfied. The convergence history for the best and average run of the IS-Jaya is provided in Fig. 3.

Table 1: Comparative results of the IS-Jaya with other methods in the 120-bar dome truss

| Design variable | Democratic PSO [53] | ALC-PSO [54] | HALC-PSO [54] | SOS-ABF1 [55] | SOS-ABF2 [55] | SOS-ABF1&2 [55] | Jaya [56] | IS-Jaya |
|---|---|---|---|---|---|---|---|---|
| A1 | 19.607 | 19.5316 | 19.309 | 19.5449 | 19.5715 | 19.3806 | 19.309 | 19.5231 |
| A2 | 41.290 | 41.5725 | 40.763 | 40.9483 | 39.8327 | 40.4230 | 40.763 | 40.2601 |
| A3 | 11.136 | 11.3712 | 10.791 | 10.4482 | 10.5879 | 11.1095 | 10.791 | 10.5795 |
| A4 | 21.025 | 21.6754 | 21.272 | 21.0465 | 21.2194 | 21.2086 | 21.272 | 21.1117 |
| A5 | 10.060 | 9.8078 | 9.943 | 9.5043 | 10.0571 | 9.9200 | 9.943 | 9.8825 |
| A6 | 12.758 | 12.7670 | 11.695 | 11.9362 | 11.8322 | 11.3161 | 11.695 | 11.8025 |
| A7 | 15.414 | 14.7140 | 14.579 | 14.9424 | 14.7503 | 14.7820 | 14.579 | 14.8471 |
| Best weight (kg) | 8890.48 | 8890.70 | 8889.96 | 8712.11 | 8710.33 | 8716.94 | 8709.35 | 8707.62 |
| Worst weight (kg) | N/A | N/A | N/A | N/A | N/A | N/A | N/A | 8722.3824 |
| Average weight (kg) | 8895.99 | 8900.68 | 8900.39 | 8727.42 | 8725.307 | 8790.69 | 8713.21 | 8709.6428 |
| Standard deviation (kg) | 4.26 | 8.81 | 6.38 | 16.5503 | 10.6402 | 55.7294 | 2.97 | 2.6029 |

Table 2: Natural frequencies evaluated at the optimum designs of the 120-bar dome truss

| Frequency number | Natural frequencies (Hz) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Democratic PSO [53] | ALC-PSO [54] | HALC-PSO [54] | SOS-ABF1 [55] | SOS-ABF2 [55] | SOS-ABF1&2 [55] | Jaya [56] | IS-Jaya |
| 1 | 9.0001 | 9.000 | 9.000 | 9.0011 | 9.0006 | 9.0012 | 9.0000 | 9.0000 |
| 2 | 11.00007 | 11.000 | 11.000 | 11.0003 | 11.0002 | 11.0023 | 11.0002 | 11.0002 |
| 3 | 11.0053 | 11.000 | 11.000 | 11.0003 | 11.0010 | 11.0023 | 11.0002 | 11.0002 |
| 4 | 11.0129 | 11.009 | 11.010 | 11.0015 | 11.0010 | 11.0056 | 11.0008 | 11.0002 |
| 5 | 11.0471 | 11.048 | 11.050 | 11.0674 | 11.0679 | 11.0720 | 11.0674 | 11.0674 |

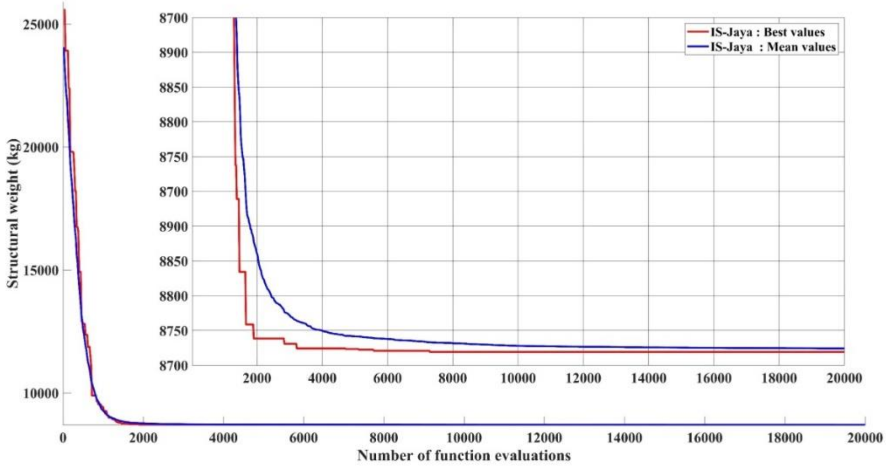

Figure 3. Convergence histories of the IS-Jaya for the 120-bar dome structure

### *3.2 600-bar dome structure*

The 600-bar dome structure is the second example investigated, as shown in Fig. 4. This structure is composed of 24 substructures; each substructure has 25 members, as shown in Fig. 5. Each member of the substructures is considered as the group of the design variables; thus, this problem has 25 design variables. The modulus of elasticity and martial density are set to 200 GPa and 7850 kg/m3, respectively. A non-structural mass of 100 kg is attached to all 192 free nodes of the structure. The minimum value of the first and third frequencies of the structure is set to 5 and 7 as the constraint of the problem. The upper and lower boundary of the search space is set to 1 and 100 cm2.

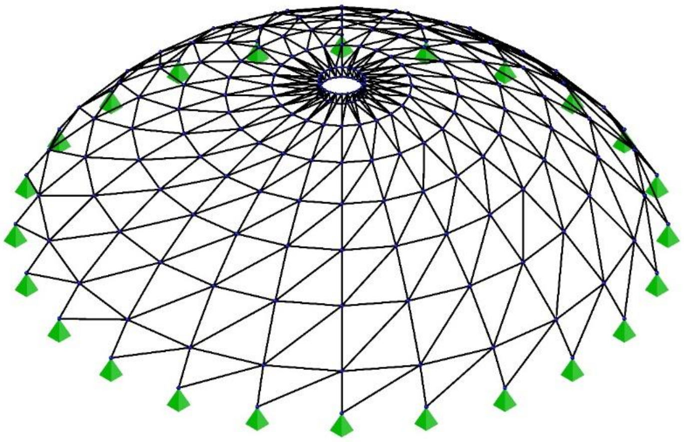

Figure 4. Schematic of the 600-bar dome structure

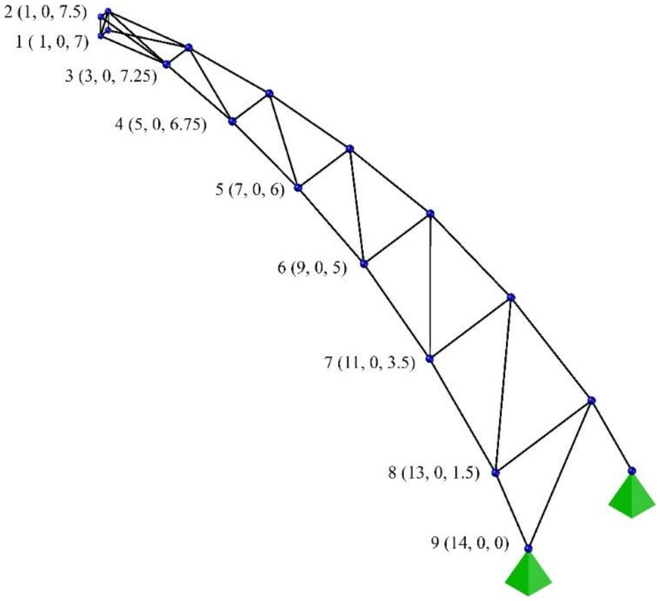

Figure 5. Details of a sub-structure of the 600-bar dome structure

Table 3 provides the comparison results of IS-Jaya with other available results acquired by Craziness based Particle Swarm Optimization (CRPSO) [57], Quantum-based Jellyfish Search (QJS) [58], Parameter Free Jaya Algorithm (PFJA) [59], and Jaya [60]. The optimum weight obtained by IS-Jaya is 6063.6003, which is the smallest weight among the other methods. Also, the average of the optimum weight of the present method is 6074.1263, which is the lightest weight in comparison to the other methods. The first five natural frequencies of the considered methods are given in Table 4. The convergence history for the best and average run of the IS-Jaya is provided in Fig. 6.

Table 3: Comparative results of the IS-Jaya with other methods in the 600-bar dome truss

| Design variable | CRPSO [57] | QJS [58] | PFJA [59] | Jaya [60] | IS-Jaya |
|---|---|---|---|---|---|
| 1 (1–2) | 1.5000 | 1.2623 | 1.1867 | 1.7518 | 1.1596 |
| 2 (1–3) | 1.5000 | 1.4105 | 1.2967 | 1.1811 | 1.4122 |
| 3 (1–10) | 7.0000 | 5.1157 | 4.5771 | 4.8878 | 5.5829 |
| 4 (1–11) | 1.0000 | 1.3939 | 1.3356 | 1.5162 | 1.1723 |
| 5 (2–3) | 16.5000 | 17.5568 | 18.3157 | 18.1659 | 16.8962 |
| 6 (2–11) | 34.5000 | 34.5863 | 38.5097 | 36.0764 | 36.7215 |
| 7 (3–4) | 12.0000 | 13.0500 | 13.5917 | 12.6571 | 12.7631 |
| 8 (3–11) | 15.5000 | 14.9897 | 16.8824 | 14.6113 | 15.4603 |
| 9 (3–12) | 10.5000 | 11.3361 | 13.8766 | 11.3198 | 11.4343 |
| 10 (4–5) | 10.0000 | 9.1993 | 9.5286 | 8.4580 | 9.3386 |
| 11 (4–12) | 8.5000 | 8.3409 | 9.4218 | 8.4285 | 8.5046 |
| 12 (4–13) | 9.0000 | 9.2362 | 9.7643 | 9.7321 | 9.5695 |
| 13 (5–6) | 7.5000 | 7.5831 | 7.2431 | 7.2947 | 7.4455 |
| 14 (5–13) | 5.5000 | 5.3152 | 5.3913 | 6.1922 | 5.2852 |
| 15 (5–14) | 6.5000 | 6.5682 | 6.7468 | 6.4395 | 6.1294 |
| 16 (6–7) | 5.5000 | 4.8128 | 5.1493 | 5.4760 | 5.0411 |

| | | | | | |
|---|---|---|---|---|---|
| 17 (6–14) | 5.0000 | 3.5015 | 3.8342 | 3.2695 | 3.5434 |
| 18 (6–15) | 7.5000 | 7.6773 | 8.0665 | 8.3724 | 7.7381 |
| 19 (7–8) | 4.5000 | 4.2587 | 4.2800 | 4.4987 | 4.3076 |
| 20 (7–15) | 2.0000 | 2.1748 | 2.2509 | 2.2197 | 2.1404 |
| 21 (7–16) | 4.5000 | 4.7066 | 4.5372 | 4.6162 | 4.4964 |
| 22 (8–9) | 4.0000 | 3.8047 | 3.5615 | 3.0667 | 3.6230 |
| 23 (8–16) | 2.0000 | 1.9187 | 1.7744 | 1.8549 | 1.8495 |
| 24 (8–17) | 4.5000 | 4.7502 | 4.6445 | 4.7960 | 4.8509 |
| 25 (9–17) | 1.5000 | 1.5567 | 1.6141 | 1.6029 | 1.6506 |
| Best weight (kg) | 6132.296 | 6065.503 | 6333.251 | 6112.644 | 6063.6003 |
| Worst weight (kg) | N/A | 6094.435 | N/A | N/A | 6104.2034 |
| Average weight (kg) | 6682.319 | 6077.634 | 6380.31 | 6146.1936 | 6074.1263 |
| Standard deviation (kg) | 999.246 | 9.356 | 47.396 | 17.2355 | 7.9698 |

Table 4: Natural frequencies evaluated at the optimum designs of the 600-bar dome truss

| Frequency number | Natural frequencies (Hz) | | | | |
|---|---|---|---|---|---|
| | CRPSO [57] | QJS [58] | PFJA [59] | Jaya [60] | IS-Jaya |
| 1 | 5.0231 | 5.0008 | 5.0011 | 5.0804 | 5.0003 |
| 2 | 5.0231 | 5.0008 | 5.0011 | 5.0804 | 5.0003 |
| 3 | 7.0013 | 7.0001 | 7.0000 | 7.0001 | 7.0001 |
| 4 | 7.0013 | 7.0001 | 7.0000 | 7.0001 | 7.0001 |
| 5 | 7.0013 | 7.0003 | 7.0000 | 7.0006 | 7.0001 |

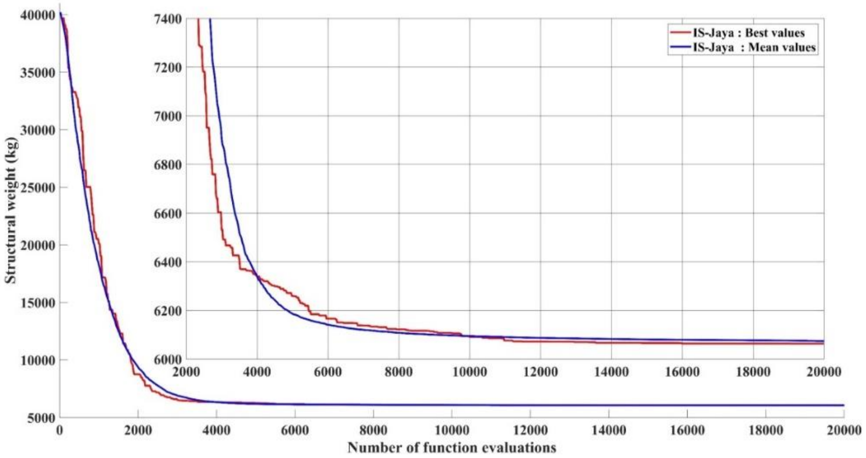

Figure 6. Convergence histories of the IS-Jaya for the 600-bar dome structure

### *3.3 The 1180-bar dome structure*

The last example is the 1180-bar dome structure, as given in Fig. 7. This structure is composed of 20 substructures; each substructure has 59 members, as shown in Fig. 8. The structure members are categorized into the 59 sizing variables as given in Table 5. The modulus elasticity, martial density, and boundary of the search space of this problem are the same as in the second example. The minimum value of the first and third frequencies of the structure is set to 7 and 9 as the constraint of the problem.

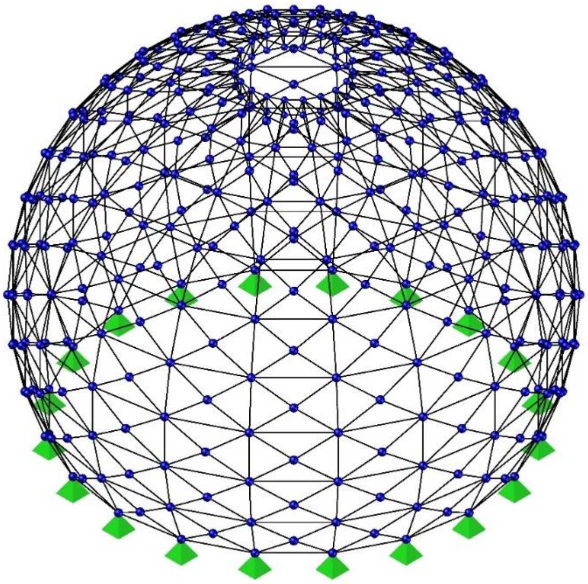

Figure 7. Schematic of the 1180-bar dome structure

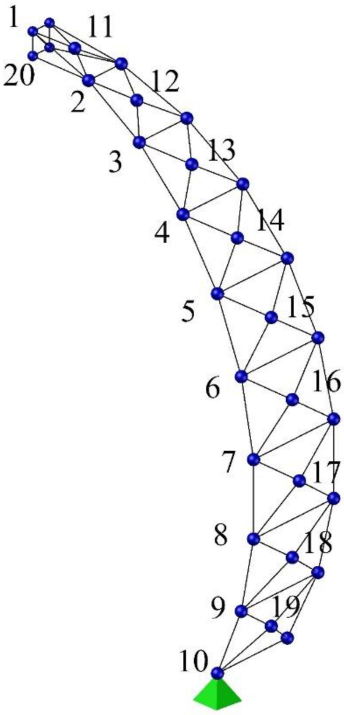

Figure 8. Details of a sub-structure of the 1180-bar dome structure

The result obtained by IS-Jaya and other methods are given in Table 5. As shown in Table 5, the IS-Jaya algorithm achieved the best weight of the 37463.0955 kg, which is the lightest weight among the other methods, namely ECBO [61] with the weight of 37984.39 kg, and PFJA [59] with the weight of 37695.59 kg. Furthermore, the average of the optimum weight of IS-Jaya acquired in the 30 independent runs is the lowest average weight (37723.0320 kg). Table 6 shows that all of the constraint function in the best run of the IS-Jaya is satisfied. The convergence history for the best and average run of the IS-Jaya is provided in Fig. 9.

Table 5: Comparative results of the IS-Jaya with other methods in the 1180-bar dome truss

| Design variable | ECBO [61] | PFJA [59] | IS-Jaya |
|---|---|---|---|
| 1 (1–2) | 7.6678 | 7.952 | 7.3001 |
| 2 (1–11) | 11.1437 | 10.466 | 9.6455 |
| 3 (1–20) | 1.8520 | 2.089 | 2.0368 |
| 4 (1–21) | 14.5563 | 14.219 | 14.3985 |
| 5 (1–40) | 4.9499 | 3.944 | 4.4610 |
| 6 (2–3) | 6.8095 | 5.979 | 5.9427 |
| 7 (2–11) | 6.6803 | 7.775 | 7.2721 |
| 8 (2–12) | 6.7889 | 6.351 | 6.3176 |
| 9 (2–20) | 1.0630 | 1.896 | 2.0442 |
| 10 (2–22) | 9.1602 | 11.908 | 12.3579 |
| 11 (3–4) | 6.9891 | 7.241 | 6.8076 |
| 12 (3–12) | 6.9881 | 5.647 | 6.0854 |
| 13 (3–13) | 6.9555 | 6.700 | 6.7160 |
| 14 (3–23) | 7.5443 | 7.799 | 7.4693 |
| 15 (4–5) | 9.5431 | 9.198 | 8.7578 |
| 16 (4–13) | 6.9123 | 6.282 | 6.0298 |
| 17 (4–14) | 8.9891 | 7.695 | 8.3957 |
| 18 (4–24) | 6.8926 | 7.520 | 7.8206 |
| 19 (5–6) | 12.6128 | 11.840 | 11.4506 |
| 20 (5–14) | 8.1983 | 7.230 | 8.2123 |
| 21 (5–15) | 11.8358 | 10.211 | 10.8735 |
| 22 (5–25) | 9.7321 | 9.252 | 9.5121 |
| 23 (6–7) | 19.1650 | 17.222 | 16.7036 |
| 24 (6–15) | 10.4682 | 11.417 | 9.3909 |
| 25 (6–16) | 14.1178 | 14.196 | 14.0410 |
| 26 (6–26) | 11.14567 | 11.639 | 11.4703 |
| 27 (7–8) | 23.4125 | 24.065 | 24.5147 |
| 28 (7–16) | 15.5167 | 13.377 | 14.0221 |
| 29 (7–17) | 16.6613 | 16.469 | 17.7860 |
| 30 (7–27) | 15.9631 | 16.057 | 16.3183 |
| 31 (8–9) | 37.0532 | 34.125 | 32.1375 |
| 32 (8–17) | 22.2937 | 18.866 | 19.6740 |
| 33 (8–18) | 22.7409 | 24.600 | 24.5431 |
| 34 (8–28) | 23.5624 | 21.103 | 21.2025 |
| 35 (9–10) | 47.7652 | 47.696 | 48.6303 |
| 36 (9–18) | 22.5066 | 27.760 | 27.8856 |
| 37 (9–19) | 34.6418 | 33.518 | 33.7737 |

| | | | |
|---|---|---|---|
| 38 (9–29) | 31.6492 | 31.773 | 30.4383 |
| 39 (10–19) | 32.7268 | 33.592 | 35.9067 |
| 40 (10–30) | 1.05206 | 1.000 | 1.0842 |
| 41 (11–21) | 11.3681 | 9.455 | 8.4624 |
| 42 (11–22) | 6.5512 | 7.189 | 7.0956 |
| 43 (12–22) | 6.3619 | 6.767 | 6.3814 |
| 44 (12–23) | 5.9296 | 6.322 | 5.9853 |
| 45 (13–23) | 7.8739 | 6.720 | 6.2996 |
| 46 (13–24) | 6.2794 | 6.425 | 6.1165 |
| 47 (14–24) | 7.6206 | 8.451 | 8.3440 |
| 48 (14–25) | 7.2937 | 8.176 | 8.0963 |
| 49 (15–25) | 10.5783 | 10.069 | 10.5493 |
| 50 (15–26) | 10.1173 | 12.219 | 10.8258 |
| 51 (16–26) | 15.1088 | 13.257 | 13.9404 |
| 52 (16–27) | 12.8251 | 13.782 | 15.9261 |
| 53 (17–27) | 17.4375 | 17.573 | 20.2339 |
| 54 (17–28) | 20.1153 | 19.909 | 17.9468 |
| 55 (18–28) | 24.2121 | 24.019 | 24.6328 |
| 56 (18–29) | 23.3175 | 27.701 | 24.2340 |
| 57 (19–29) | 34.6196 | 32.918 | 31.2279 |
| 58 (19–30) | 35.2970 | 37.001 | 34.4086 |
| 59 (20–40) | 8.8569 | 3.864 | 4.4601 |
| Best weight (kg) | 37984.39 | 37695.59 | 37463.0955 |
| Worst weight (kg) | | | 38286.5945 |
| Average weight (kg) | 38042.15 | 37755.05 | 37723.0320 |
| Standard deviation (kg) | 101.43 | 58.025 | 203.2727 |

Table 6: Natural frequencies evaluated at the optimum designs of the 1180-bar dome truss

| Frequency number | Natural frequencies (Hz) | | |
|---|---|---|---|
| | ECBO [61] | PFJA [59] | IS-Jaya |
| 1 | 7.000 | 7.0000 | 7.0005 |
| 2 | 7.001 | 7.0000 | 7.0005 |
| 3 | 9.000 | 9.0024 | 9.0005 |
| 4 | 9.000 | 9.0024 | 9.0005 |
| 5 | 9.064 | 9.0129 | 9.0161 |

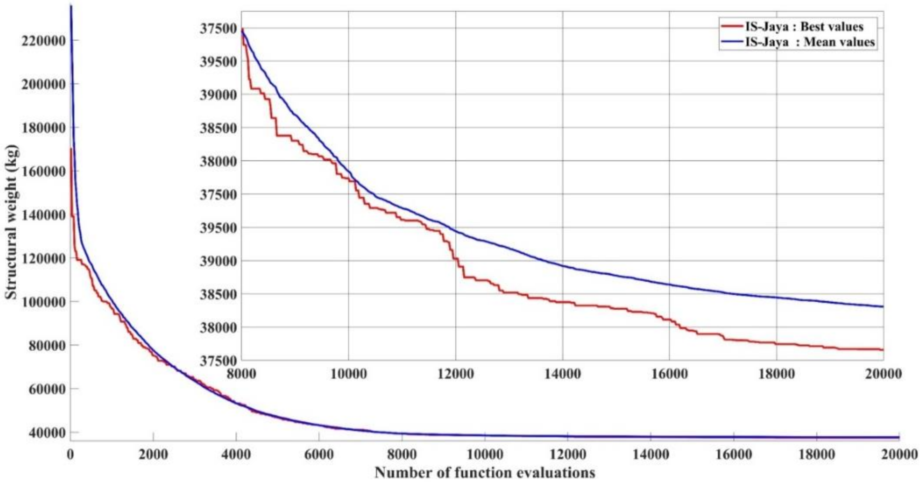

Figure 9. Convergence histories of the IS-Jaya for the 1180-bar dome structure

## 4. CONCLUDING REMARKS

The improved shuffled-based Jaya algorithm (IS-Jaya) is employed for the size optimization of the braced dome structures in this study. In this method, the shuffling process is added to the main algorithm to increase the diversity of the population. In the shuffling prosses, the entire of population is divided into the subpopulation, then the main step size of the algorithm is calculated in each subpopulation. Also, escape from the local optima mechanism is added to increase the algorithm's ability to escape from the local optima.

Three braced dome examples with frequency constraints are considered in this study. These examples include the 120-bar dome structure, 600-bar dome structure, and 1180-bar dome structure. The result of the optimization. The IS-Jaya finds the best in these examples in the comparison of the considered methods. Also, the average weight obtained by IS-Jaya is less than other considered state-of-the-art optimization methods.

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