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Size optimization of truss structures employing flower pollination algorithm without grouping structural members

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Abstract: - In the optimum design of the cross-sectional areas of the structural members, swarm intelligence based methods are effective in finding optimum designs. In order to increase the level of the feasibility of the approaches, the members of the structures are grouped. In that case, the computational cost decreases, but the exact optimum design of the structure cannot be found. In that case, the employed methodology must be sufficiently fast if the members are not grouped. In this paper, the truss structural systems are investigated without grouping. The methodology employs the flower pollination algorithm and an iterative constraint handling strategy is applied for design constraints about compression, tension and displacement limits. The method is effective in finding truss structure designs with smaller cross-sectional areas than those of the existing strategy using grouping of structural members.

Key-Words: Truss structures, Flower Pollination Algorithm, Structural member without grouping, Size optimization, Optimization, Nature inspired swarm intelligence.

1 Introduction

Nature-inspired methods and metaheuristic algorithms are commonly used in the design of structural members in civil engineering. The main purpose of the design is to find the design with the minimum material cost which is directly related to the total weight of the structure. To ensure the design constraints with an economical design, the engineering problem becomes highly non-linear. In that case, the only way is to use numerical iterations. In order to find a member with precise solutions and good computational cost, the studies on this subject is very active in employing swarm intelligence based methods.

The most popular optimization problem is the size optimization of three-dimensional truss structures. For this type of problems, Adeli and Kamal used a dual simplex algorithm [1]. Genetic algorithm has been also employed in optimum design of truss structures [2-3]. Camp and Bichon investigated truss structures by using ant colony optimization [4]. The big bang-big crunch (BB-BC) algorithm was another example of metaheuristic methods employed for truss structure optimization [5]. Li et al. developed hybrid method containing particle swarm optimizer with passive congregation and harmony search for truss structures [6]. Particle swarm optimization was used in the methodology developed by Perez and Behdinan [7]. In the sizing and layout optimization of truss structures, simulated annealing was used by Lamberti [8]. Kaveh and Talatahari employed BB-BC hybridized with particle swarm optimization and sub-optimization mechanism [9]. Sonmez combined artificial bee colony with adaptive penalty function for truss structure optimization [10]. Two variations of harmony search (efficient and self-adaptive) were used by Degertekin in truss system optimization [11]. Teaching learning based optimization (TLBO) was employed by Camp and Farshchin in the optimum design of truss structures [12]. Hybrid particle swallow swarm optimization was employed by Kaveh et al. for truss structure [13]. Kaveh et al. employed chaotic swarming of particles in size optimization of truss systems [14]. Colliding bodies optimization (CBO) was also employed for truss system optimization [15]. The enhanced version of CBO was used by Kaveh and Ilchi Ghazaan for the same types of problem [16]. Flower pollination algorithm (FPA) developed by Yang [17] was also used by Bekdaş et al. for sizing optimization of truss structures [18].

In the documented methods, the members of the truss structures are grouped and the members of different design variables are reduced. In that case, the optimization time is reduced, but the precise optimum results cannot be found. The FPA is effective in saving computation times and this algorithm can be also used if the members are not grouped. Another issue in grouping of members is how we group these members and if these groups are the best or not. For these reasons, the members are not grouped in this study. FPA is employed and the methodology is summarized in the second section. The detailed information and formulations about the method can be found in [17] including a good design constraint handling strategy.

2 The Design Methodology

The inspiration of FPA is the flow pollination process of flowering plants. Yang [17] developed FPA by using the four rules about biotic (cross) pollination, abiotic (self) pollination, flower constancy and a switch probability. The design methodology of the truss sizing optimization problem employing FPA can be explained in three steps.

As all structural optimization problems, the design constants, ranges of design variables and design constraints are defined in the first step. Also, the algorithm constraints of FPA such as flower number (n), switch probability (p) and maximum generation number (g_{max}) are entered.

In the second step, the initial values of design variables are randomly assigned before the iterative process. For all sets of design variables, structural analyses are done in order to control the design constraints. An iterative constraint handling strategy defined in [18] is applied.

As a metaheuristic algorithm, the design variables are updated in two ways and a switch probability controls the type of modification. In global search, biotic pollination is imitated. In that pollination, pollinators carry the pollens and they obey Lévy flight rules. For that reason, a new design variables (X_i^{t+1}) are calculated according to previous solution (X_i^t), Lévy distribution (L) and the best design variables with the maximum weight (g^*) as seen Eq. (1).

$$x_i^{t+1}= x_i^t+L(x_i^t-g_*) \quad (1)$$

In local optimization, abiotic pollinators is used. In that type of pollination, the pollinator is the different flowers of the same plant. As seen in Eq. (2), X_i^{t+1} is generated according to ∊ (a random number between 0 and 1) and the variables of jth (X_j^t) and kth (X_k^t) flowers which are randomly chosen.

$$x_i^{t+1}= x_i^t+\in(x_j^t- x_k^t) \quad (2)$$

The iterative process is carried out for maximum number of generations and the weight minimization is done as optimization objective.

3 Numerical Example

As numerical examples, 25 bar and 72 bar 3D truss structures are optimized without grouping design variables. The analyses are carried out by taking n=20, p=0.5 and g_{max}=100000, respectively as done in [18].

3.1 25 bar truss structure

The model of 25 bar structure is shown in Fig. 1 and loading cases are given in Table 1. In this example, the elasticity modulus and density are taken as 10 Msi and 0.1 lb/in^3. The ranges of cross sectional areas (design variables) are between 0.01 and 3.4 in^2. The compression and tension constraints are different for different members and these limits are shown in Table 2. The optimum results are given in Table 3. The best weight is 543.20 lb. This value is 545.159 lb if the members of truss are grouped [18].

3.2 72 bar truss structure

The FPA is effective to solve 72 bar truss structure (Fig. 2) optimization problem without grouping design variables. The loading case of 72 bar truss structure is shown in Table 4. The material properties are the same as the first example. The maximum displacement limits is ∓0.25 in for all nodes and stress limits ∓25 ksi for tension and compression of all members. The cross sectional areas are randomized between 0.1 and 3.0 in^2. The optimum results are presented in Table 5 and the optimum weight is 60.5180 lb. If the design variables are grouped, the optimum value is 379.534 lb [18].

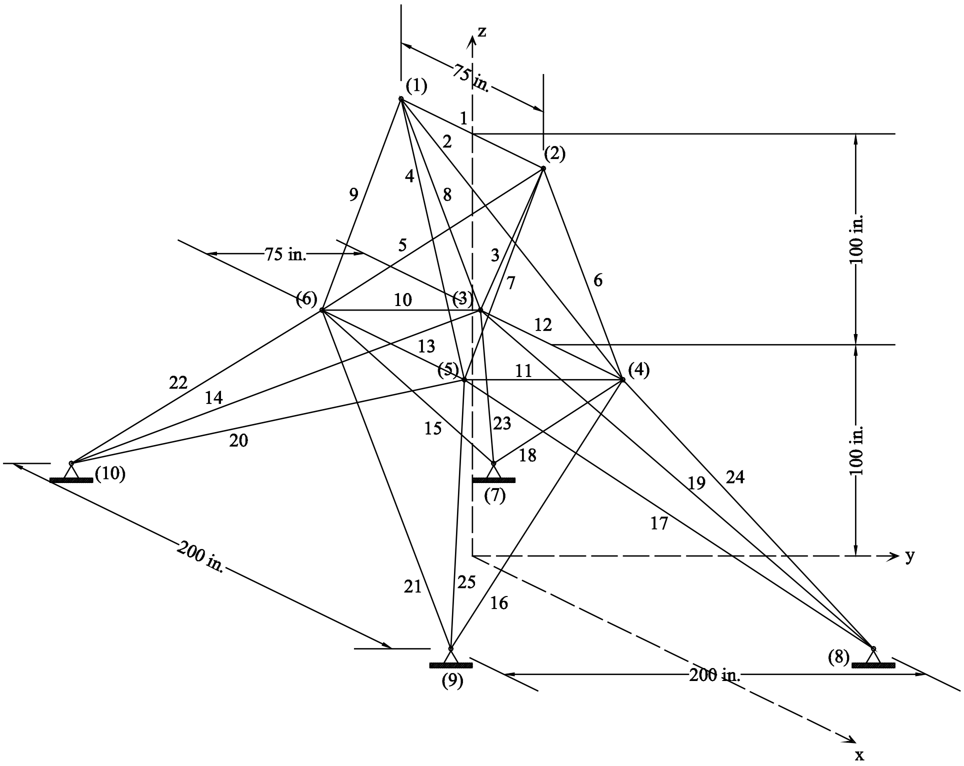

Figure 1 25-bar truss structure.

TABLE I. THE LOADING CASES OF 25-BAR STRUCTURE

Case	Node	P_x (kips)	P_y (kips)	P_z (kips)
1	1	1.0	10.0	-5.0
	2	0.0	10.0	-5.0
	3	0.5	0.0	0.0
	6	0.0	0.0	0.0
2	1	0.0	20.0	-5.0
	2	0.0	-20.0	-5.0

TABLE II. THE DESIGN CONSTRAINT LIMITS OF 25-BAR STRUCTURE.

Members	Compression (ksi)	Tension (ksi)
1	35.092	35
2-5	11.590	35
6-9	17.305	35
10,11	35.092	35
12,13	35.092	35
14-17	6.759	35
18-21	6.959	35
22-25	11.082	35

TABLE III. THE OPTIMUM RESULTS OF 25-BAR STRUCTURE

Member No	Area (in^2)	Member No	Area (in^2)	Member No	Area (in^2)
1	0.0100	11	0.0104	21	1.3793
2	2.3903	12	0.0100	22	2.3446
3	1.8524	13	0.0100	23	2.5744
4	2.0935	14	0.7058	24	3.1464
5	1.9749	15	0.5950	25	2.5920
6	2.9549	16	0.8043		
7	2.9379	17	0.6149		
8	3.0085	18	1.7011		
9	2.4974	19	1.7259		
10	0.0100	20	1.8375		
Best Weight (lb)		543.20			

TABLE IV. THE LOADING CASES OF 72-BAR STRUCTURE

Case	Node	Px (kips)	Py (kips)	Pz (kips)
1	17-20	-5.0	-5.0	-5.0
2	17	5.0	5.0	-5.0

TABLE V. THE OPTIMUM RESULTS OF 72-BAR STRUCTURE.

Member No	Area (in^2)	Member No	Area (in^2)	Member No	Area (in^2)
1	2.3656	25	0.4861	49	0.1125
2	0.5654	26	0.7112	50	0.2167
3	2.9571	27	0.7178	51	0.1000
4	0.1570	28	0.4372	52	0.3199
5	0.4829	29	0.4478	53	0.1936
6	0.1626	30	0.2355	54	0.1000
7	0.8478	31	0.1018	55	0.5265
8	0.2821	32	0.1415	56	0.8380
9	0.8694	33	0.1263	57	0.8082
10	0.5814	34	0.1031	58	0.3976
11	0.1918	35	0.1018	59	0.1530
12	0.5212	36	0.1606	60	1.2308
13	0.1004	37	0.2796	61	0.6596
14	0.1000	38	0.9654	62	0.2411
15	0.1393	39	2.1531	63	0.1087
16	0.1225	40	0.5820	64	0.5861
17	0.1679	41	0.5124	65	1.0083
18	0.1000	42	0.1039	66	0.1378
19	1.5037	43	0.5328	67	0.2458
20	0.1000	44	0.4544	68	0.1202
21	2.5814	45	0.6972	69	0.1040
22	0.2401	46	0.6018	70	0.1233
23	0.2092	47	0.2437	71	0.5579
24	0.4181	48	0.4370	72	0.1296
Best Weight (lb) 360.5180					

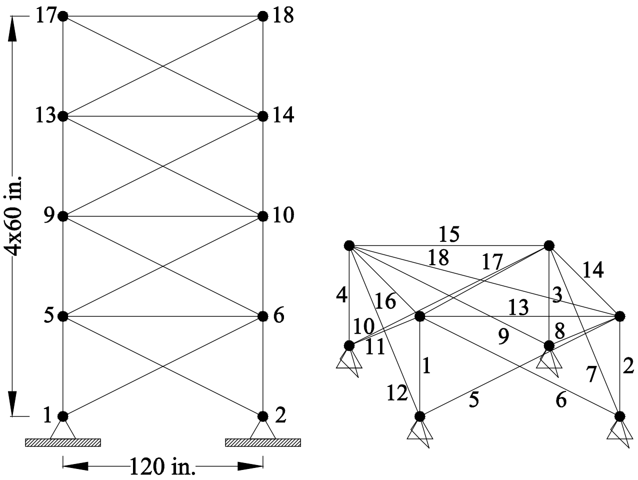

Figure 2 72-bar truss structure.

4 Conclusions

As a conclusion, FPA is also effective if the members of truss structures are not grouped. In that case, precise optimum results can be found. The results of the optimization problems are updated by 3.6% and 5% for the first and second examples. Future studies will focus on the extension of the current method and results to more complicated real-world design applications.

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