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OPTIMUM TRUSS DESIGN USING BIG BANG – BIG CRUNCH ALGORITHM

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Summary: *Big Bang – Big Crunch algorithm is relatively new optimization method inspired by one of the theories of the evolution of the universe. In this paper, the algorithm is presented for solving optimum design of spatial truss structure. Numerical results of solving a benchmark problem demonstrate the efficiency of the presented method compared with other authors' results.*

Keywords: *Big Bang – Big Crunch, optimization, truss structures*

1. INTRODUCTION

Truss optimization is one of the most active branches of the structural optimization. Size optimization of truss structures involves determining optimum values for member cross-sectional areas that would minimize the weight of a given truss structure. This minimum design should also satisfy the inequality constraints that limit design variable sizes and structural responses. In the last decades, different nature inspired evolutionary algorithms have been developed and employed for structural optimization, such as Genetic Algorithms, Bat Algorithm, Wolf Pack Search, Rats Herds Algorithm, Ant Colony Optimization, Particle Swarm Optimizer and many other heuristic procedures that incorporate random variation and selection mechanisms. Information obtained in each cycle are used for choosing new starting points in the subsequent cycles. These algorithms do not require for a given function to be derivable and an explicit relationship between the objective function and constraints is not needed.

Big Bang – Big Crunch (BB-BC) algorithm, introduced by Erol and Eksin [1], is relatively new optimization method that relies on one of the theories of the evolution of the universe namely, the Big Bang and Big Crunch theory and has a low computational time and high convergence speed.

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In this study, BB-BC algorithm is implemented for solving the truss optimization problem. Comparison of the results obtained in solving a benchmark problem (25-bar spatial truss) and the results proposed by other authors indicates that BB-BC method is efficient and reliable for optimum design of spatial truss structures.

2. OPTIMUM DESIGN OF TRUSS STRUCTURES

Mathematically, the optimal design of a truss can be formulated as finding:

$$\mathrm{A} = [A_1, A_2, ..., A_n], A_i \in D \tag{1}$$

where A is the set of design variables, A_i is the cross-sectional area of member i, ng is the number of groups of members and D denotes the allowable set of values for the design variable A_i, to minimize

$$\mathrm{W(A)} = \sum_{i=1}^{nm} \gamma_i A_i L_i \tag{2}$$

where $W(A)$ is weight of the structure; nm is the number of members of the structure; γ_i represents the material density of member i and L_i is the length of member i, subject to constraints:

$$g_j(A) \le 0, j = 1,2,...,n \tag{3}$$

Usual constraints for stress structures are stress nodal displacements limitations.

3. BIG BANG–BIG CRUNCH (BB-BC) ALGORITHM

The BB-BC method developed by Erol and Eksin [1] consists of two phases: a Big Bang phase and a Big Crunch phase. The authors associated the random nature of the Big Bang to energy dissipation or the transformation from an ordered state (a convergent solution) to a disorder or chaos state (new set of solution candidates). This method is basically similar to the Genetic Algorithms in respect to creating an initial population randomly. The creation of the initial population randomly is called the Big Bang phase. In this phase, the candidate solutions are spread all over the search space in a uniform manner.

The Big Bang phase is followed by the Big Crunch phase. The Big Crunch is a convergence operator that has many inputs but only one output, named as the *centre of mass*, since the only output has been derived by calculating the centre of mass, where the term *mass* refers to the inverse of the merit function value. The point representing the centre of mass that is denoted by x_c and can be calculated according to:

$$\vec{x}^{c} = \frac{\sum_{i=1}^{N} \frac{1}{f^{i}} \vec{x}^{i}}{\sum_{i=1}^{N} \frac{1}{f^{i}}} \tag{4}$$

where x_i is a point within an n-dimensional search space generated, f_i is a fitness function value of this point, and N is the population size in Big Bang phase.

The convergence operator in the Big Crunch phase is different from 'exaggerated' selection since the output term may contain additional information (new candidate or member having different parameters than others) than the participating ones, hence differing from the population members. This one-step convergence is superior compared to selecting two members and finding their centre of gravity. This method takes the population members as a whole in the Big-Crunch phase that acts as a contraction operator.

After the Big Crunch phase, the algorithm creates the new solutions to be used as the Big Bang of the next iteration step, by using the previous result (centre of mass). This can be accomplished by spreading new off-springs around the centre of mass using a normal distribution operation in every direction, where the standard deviation of this normal distribution function decreases as the number of iterations of the algorithm increases:

$$x^{new} = x^{c} + \frac{l \cdot r}{k} \tag{5}$$

where x^c stands for centre of mass, l is the upper limit of the parameter, r is a normal random number and k is the iteration step. Then new point x^{new} is both upper and lower bounded.

After the second explosion, the new centre of mass is calculated and successive explosion-contraction steps are carried repeatedly until a stopping criterion has been met.

The BB–BC approach takes the following steps [1]:

- *Step 1*: Form an initial generation of N candidates in a random manner. Respect the limits of the search space.
- *Step 2*: Calculate the fitness function values of all the candidate solutions.
- *Step 3*: Find the centre of mass according to (10). Best fitness individual can be chosen as the centre of mass.

- *Step 4*: Calculate new candidates around the centre of mass by adding or subtracting a normal random number whose value decreases as the iterations elapse of using (11).
- *Step 5*: Return to Step 2 until stopping criteria has been met.

4. NUMERICAL EXAMPLE

The topology and nodal numbers of a 25-bar spatial truss structure are shown in Figure 1. In this example, designs for two load cases (Case 1 – discrete variables, Case 2 – continuous variables, Table 1) are performed and the results are compared to those of other optimization techniques employed by different authors [2–10]. In these studies, the material density is considered as 2767.990 kg/m^3 and the modulus of elasticity is taken as 68.950 MPa. Twenty five members are categorized into eight groups, and the design variables are the areas of each truss group. The design variable A_1 is the member that connects node 1 to node 2; A_2 are members 1-4, 2-3, 1-5 and 2-6; A_3 are members 2-5, 2-4, 1-3 and 1-6; A_4 are members 3-6 and 4-5; A_5 are members 3-4 and 5-6; A_6 are members 3-10, 6-7, 4-9 and 5-8; A_7 are members 3-8, 4-7, 6-9 and 5-10; and A_8 are members 3-7, 4-8, 5-9 and 6-10. The range of cross-sectional areas varies from 0.6452–21.94 cm^2. Maximum allowable node displacement are ± 8.89 mm in every direction, while the axial stress constraints and loading conditions are presented in Table 1.

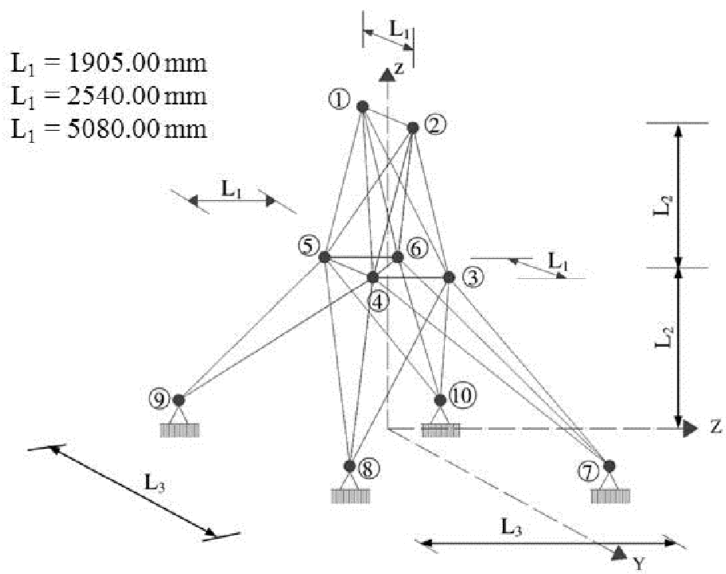

Figure 1. 25-bar spatial truss

Table 1. Loading conditions and stress limitations for 25-bar truss

Loading conditions (kN)							Stress limitations (MPa)		
	Node	1	2	3	6		Group	Compression	Tension
Case 1	Px	0.0	0.0	0.0	0.0		1,4,5	241.96	275.80
	Py	89	89	0.0	0.0		2	79.913	275.80
	Pz	22.25	22.25	0.0	0.0		3	119.31	275.80
Case 2	Px	4.45	0.0	2.22	0.5		6	46.603	275.80
	Py	44.5	44.5	0.0	0.0		7	47.982	275.80
	Pz	22.25	22.25	0.0	0.0		8	76.410	275.80

Obtained results and comparison with results of other authors are presented in Table 2. It can be concluded that the final results are very satisfactory because proposed algorithm reaches a satisfying solution for the discrete design variables (Case 1) and an excellent solution for the continuous variables (Case 2). Besides that, BB–BC has low computational time and high convergence speed compared to the Genetic Algorithms.

Table 2. Performance comparison for 25-bar truss

Case 1						
A_i	Rajeev [2]	Erbatur [3]	Coello [4]	Togan [5]	Lemonge [6]	This study
A_1	0,645	0,645	0,645	0,645	0,645	0,645
A_2	11,614	7,742	4,516	1,936	1,936	4,516
A_3	14,840	20,646	20,646	21,937	21,937	21,937
A_4	1,290	0,645	0,645	0,645	0,645	0,645
A_5	0,645	7,097	9,033	12,904	13,549	11,614
A_6	5,162	5,807	7,097	6,452	6,452	6,452
A_7	11,614	2,581	3,226	3,226	3,226	1,936
A_8	19,356	21,937	21,937	21,937	21,937	21,937
W (kg)	**247,67**	**223,99**	**224,05**	**219,25**	**219,93**	**220,78**
Case 2						
A_i	Venkayya [7]	Lee [8]	Saka [9]	Adeli [10]	Togan [5]	This study
A_1	0,181	0,303	0,065	0,065	0,645	0,065
A_2	12,671	13,046	13,278	12,814	13,549	12,827
A_3	19,879	19,033	19,279	19,104	18,066	19,298
A_4	0,065	0,645	0,065	0,065	0,645	0,065
A_5	0,065	0,090	0,065	0,065	0,645	0,065
A_6	4,471	4,439	4,491	5,200	4,516	4,413
A_7	10,827	10,690	10,775	10,839	10,968	10,820
A_8	16,949	17,182	16,724	16,324	17,40	17,182
W (kg)	**247,43**	**246,93**	**247,32**	**247,51**	**249,95**	**247,28**

5. CONCLUSION

In this paper a heuristic population-based search inspired by the Big Bang and Big Crunch theory (BB–BC) of the evolution of the universe is implemented for solving the spatial truss optimization problem. Comparison of numerical results for the benchmark problem with the solutions obtained by other heuristic approaches indicates that proposed method is efficient and sufficiently reliable for solving complex problems in the field of optimum structural design.

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ОПТИМИЗАЦИЈА РЕШЕТКЕ АЛГОРИТМОМ ВЕЛИКИ ПРАСАК - ВЕЛИКО САЖИМАЊЕ

Rezime: *Алгоритам Велики прасак – велико сажимање је релативно нова метода оптимизације инспирисана једном од теорија о еволуцији космоса. У раду је приказан примена овог алгоритма за решавање проблема оптималног димензионисања просторне решеткасте конструкције. Нумерички резултати добијени решавањем стандардног проблема за тестирање показују ефикасност алгоритма у поређењу с резултатима других аутора.*

Кључне речи: *Велики прасак - велико сажимање, оптимизација, решеткасте конструкције*