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AN ENHANCED IMPERIALIST COMPETITIVE ALGORITHM FOR OPTIMUM DESIGN OF STEEL FRAMES

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Development of efficient and robust optimization methods for structural design is one of the most active research fields in structural engineering. Imperialist Competitive Algorithm (ICA) is one of the recent meta-heuristic algorithms proposed to solve optimization problems. In this paper, an Enhanced Imperialist Competitive Algorithm (EICA) is proposed which increases the search space and enables the ICA algorithm to escape from local optima in a fast time. In this algorithm added value is given to a slightly unfeasible solution, based on its distance from the relative imperialist. The performance of the proposed EICA algorithm in optimum design of side sway frames is investigated by comparing the EICA optimum designs of two benchmark side sway frames with the best designs obtained using a number of other meta-heuristic solutions. Results indicate that, in terms of both the design quality and the solution speed, EICA compares favorably with a number of other meta-heuristic optimizers, including the basic ICA.

Keywords: Design optimization, Metaheuristic optimization algorithms, Skeletal structures, Global optima, Search space.

1 INTRODUCTION

In recent years development of efficient meta-heuristic optimization, algorithms for structural design has received much attention. Meta-heuristic algorithms are most suited for structural optimization problems having many design variables and large design spaces. The imperialist competitive algorithm (ICA) is one of the most recent developments in meta-heuristic optimization techniques. This socio-politically motivated optimization algorithm was first proposed by Atashpaz-Gargari and co-workers (2007, 2008). Later, Eskandar *et al.* (2010) applied the ICA method to the truss optimization problems and showed that the algorithm can be effectively used to solve structural optimization problems with discrete variables. Kaveh and Talatahari (2010a) also used this algorithm to solve skeletal structures optimization problems. They applied the ICA method to some trusses and frames and compared their results with some well-known meta-heuristic algorithms. In 2011, Sabour *et al.* (2011) combined the ICA method with ACO algorithm and applied the hybrid algorithm (ICACO) to the structural optimization problems. In this algorithm, ACO does the local search and the global search is carried out by the ICA search engine. They showed that the hybrid ICACO method produced results very similar to the ICA algorithm but at a higher rate of convergence.

Despite recent improvements made to the ICA algorithm, it still suffers from the possibility of getting trapped in local optima. In the present paper, the concept adopted by Maheri and Narimani (2014) to enhance the harmony search method is used to improve on the global search characteristic of the ICA algorithm. In the proposed algorithm, termed the Enhanced Imperialist Competitive Algorithm (EICA), the imperialistic competition phase of the ICA is modified by giving weight to distant designs resulting in enhanced global search capacity and increased rate of convergence. In the following, after presenting an overview of the basic ICA method, the proposed EICA algorithm is first described and then applied to optimum design of a number of sway frames. The results are then compared with those obtained from some other meta-heuristic optimization solutions.

2 PROPOSED ENHANCED IMPERIALIST COMPETITIVE ALGORITHM

In the proposed improvement to the ICA, the rules of imperialist competition are modified with the aim of enhancing the ability to search for global optima. Other stages of the original ICA remain unchanged (Atashpaz-Gargari and Lucas 2007, Atashpaz-Gargari *et al.* 2008). As it was mentioned earlier, during the competition stage of the original imperialist competitive algorithm, in the weakest empire, the colony which has the lowest objective function value will be selected and transferred to another empire. In other words, the competition process is carried out based only on the value of the objective function. In the proposed Enhanced Imperialist Competitive Algorithm (EICA), transferring colonies in the competition process is carried out based not only on the objective function value of the colonies, but also on their distance from their respective imperialists. In other words, if the objective function value of the weakest colony is slightly worse than the next weakest colony, but it is located at a large distance away from the imperialist, we may keep that colony in the empire and the slightly better colony which is closer to the imperialist will be transferred. In this way, a colony can search within a larger area in the search space with a good chance to locate the global optima.

In order to import this idea into the ICA algorithm, we propose to base the selection process in the weakest empire on the value of the objective function of each colony divided by its distance to the imperialist in that empire. For controlling this occurrence, we also propose to add a new parameter to the algorithm called compatibility factor (CF). The role of this factor is to match the algorithm with the type of the optimization problem at hand. In the weakest empire, the objective function of each colony is multiplied by the CF and the result is then divided by the distance. This factor may range in value from very small to very large. It completely depends on the nature of the search space, i.e. on the type of optimization problem. The smaller the compatibility factor, the more similar the proposed algorithm is to the basic ICA. On the other hand, if a large value is selected for the CF the algorithm may transfer the best colonies of the empire hence reducing algorithm efficiency. In continuous problems, the colonies can stay close to their imperialists with no restrictions. In such problems the CF factor can help to find the weakest colony with the shortest distance from the imperialist to be removed from the empire. This factor is, however, less effective in weight optimization problems with discrete variables such as those discussed in this paper.

3 DESIGN OPTIMIZATION EXAMPLES

Utilizing the developed algorithm, optimal design of two benchmark steel frame problems is performed and the results are compared with those reported in the literature for these problems using other meta-heuristic optimization solutions. In line with assumptions made by others in solving these problems, the shear deformations are ignored.

3.1 Three-Bay, Fifteen-Story Frame

The first benchmark example is a three-bay, fifteen-story frame. This frame was originally designed by Kaveh and Talatahari (2009) with PSO and hybrid PSO, HS and AC algorithms (PSOPC and HPSACO) and later by Kaveh and Talatahari (2010b) using the Big Bang–Big Crunch (HBB–BC) algorithm. The configuration of the frame, material properties and the applied loads are given in the above reference. The AISC strength constraints are the performance constraints considered for this frame.

The optimum design of the frame using the EICA is obtained after 3,300 analyses, giving a minimum weight of 407.44 kN. By comparing the result of the six different algorithms listed in Table 1, it can be seen that the optimum solution given by the EICA method is the lightest solution; it is also obtained using the minimum number of analyses. The EICA design has improved on designs of the PSO by 17.9%, the PSOPC by 9.9%, the HPSACO by 4.4%, the HBB-BC by 6.2% and the basic ICA by 2.4%.

The convergence history of the best design obtained from the EICA solution is compared with that from the basic ICA in Figure 1. Convergence histories shown in Fig. 1 and the number of analyses given in Table 1 show the remarkable convergence speed of the EICA method compared to other algorithms.

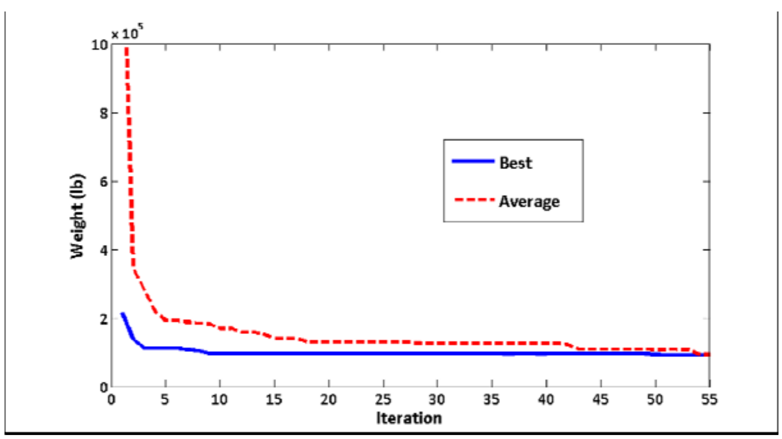

Figure 1. Comparison of best design convergence curves of the basic ICA and the EICA for the three-bay, fifteen-story frame.

Table 1. Optimization results of the three-bay, fifteen-story frame problem.

Group No.	PSO (Kaveh, Talatahari, 2009)	PSOPC (Kaveh, Talatahari, 2009)	HPSACO (Kaveh, Talatahari, 2009)	HBB-BC (Kaveh, Talatahari, 2010b)	ICA (Kaveh, Talatahari, 2010c)	EICA (This Study)
1	W33x118	W26x129	W21x111	W24x117	W24x117	W18x71
2	W33x263	W24x131	W18x158	W21x132	W21x147	W30x235
3	W24x76	W24x103	W10x88	W12x95	W27x84	W18x46
4	W36x256	W33x141	W30x116	W18x119	W27x114	W30x132
5	W21x73	W24x104	W2x83	W21x93	W14x74	W12x40
6	W18x86	W10x88	W24x103	W18x97	W18x86	W14x120
7	W18x65	W14x74	W21x55	W18x76	W12x96	W10x22
8	W21x68	W26x94	W26x114	W18x65	W24x68	W12x53
9	W18x60	W21x57	W10x33	W18x60	W10x39	W8x28
10	W18x65	W18x71	W18x46	W10x39	W12x40	W12x50
11	W21x44	W21x44	W21x44	W21x48	W21x44	W21x44
Weight (kN)	**496.68**	**452.34**	**426.36**	**434.54**	**417.46**	**407.44**
Number of analyses	**50,000**	**50,000**	**6,800**	**9,900**	**6,000**	**3,300**

3.2 Three-bay, Twenty Four-story Frame

The second benchmark example is the three-bay, twenty four-story steel frame, consisting of 168 members and undergoing a single load case. This frame was originally designed by Davison and Adams (1974) and later by Camp *et al.* (2005) using an ACO algorithm, by Değertekin (2008) using a HS algorithm, by Kaveh and Talatahari (2010) using an improved ACO (IACO) algorithm, by Kaveh and Talatahari (2010c) using an imperialist competitive algorithm (ICA) and by Maheri and Narimani (2014) using the enhanced harmony search algorithm (EHS). Details of the frame and the applied loads are given by Davison and Adams (1974). All beams and columns were considered unbraced along their lengths. The element groups could be chosen from all the W-shapes listed in the AISC standard list, while the column element groups were limited to the W14 sections only.

Details of the best design obtained using the proposed EICA optimization method are given in Table 2. For comparison, details of the best designs obtained for this frame using other optimization algorithms are also presented in Table 2. This table shows that the proposed EICA has produced the lightest design among all different optimization algorithm solutions available for this problem. The EICA algorithm has improved on designs of the ACO method by 13.9%, basic HS algorithm by 11.7%, IACO algorithm by 12.7%, EHS method by 2.4% and the basic ICA by 10.8%. The convergence history of the best design obtained from the EICA solution for this problem is compared with its counterpart from the basic ICA solution in Figure 2. The available total number of analyses performed using different solutions reported are also compared in Table 2. Fig. 2 and Table 2 indicate that the proposed EICA is remarkably faster than the basic ICA in locating the global optima. It is also faster than other algorithms except for the EHS algorithm.

Table 2. Optimization results of the three-bay, twenty four-story frame problem.

Group No.	ACO (Camp *et al.*, 2005)	HS (Değertekin, 2008)	IACO (Kaveh, Talatahari, 2010b)	EHS (Maheri, Narimani, 2014)	ICA (Kaveh, Talatahari, 2010c)	EICA (This Study)
1	W30x90	W30x90	W30x99	W10x19	W30x90	W16x31
2	W8x18	W10x22	W16x26	W12x190	W21x50	W12x210
3	W24x55	W18x40	W18x35	W6x8.5	W24x55	W21x44
4	W8x21	W12x16	W14x22	W24x370	W8x28	W10x12
5	W14x145	W14x176	W14x145	W14x132	W14x109	W14x426
6	W14x132	W14x176	W14x132	W14x30	W14x159	W14x22
7	W14x132	W14x132	W14x120	W14x99	W14x120	W14x132
8	W14x132	W14x109	W14x109	W14x53	W14x90	W14x22
9	W14x68	W14x82	W14x48	W14x74	W14x74	W14x26
10	W14x53	W14x74	W14x48	W14x26	W14x68	W14x82
11	W14x43	W14x34	W14x34	W14x68	W14x30	W14x370
12	W14x43	W14x22	W14x30	W14x193	W14x38	W14x26
13	W14x145	W14x145	W14x159	W14x145	W14x159	W14x455
14	W14x145	W14x132	W14x120	W14x26	W14x132	W14x22
15	W14x120	W14x109	W14x109	W14x26	W14x99	W14x132
16	W14x90	W14x82	W14x99	W14x43``	W14x82	W14x30
17	W14x90	W14x61	W14x82	W14x26	W14x68	W14x22
18	W14x61	W14x48	W14x53	W14x120	W14x48	W14x22
19	W14x30	W14x30	W14x38	W14x426	W14x34	W14x38
20	W14x26	W14x22	W14x26	W14x68	W14x22	W14x22
Weight (lb)	**220,465**	**214,860**	**217,464**	**194,400**	**212,725**	**189,720**
Number of analyses	**----**	**----**	**3,500**	**1,259**	**7,500**	**3,640**

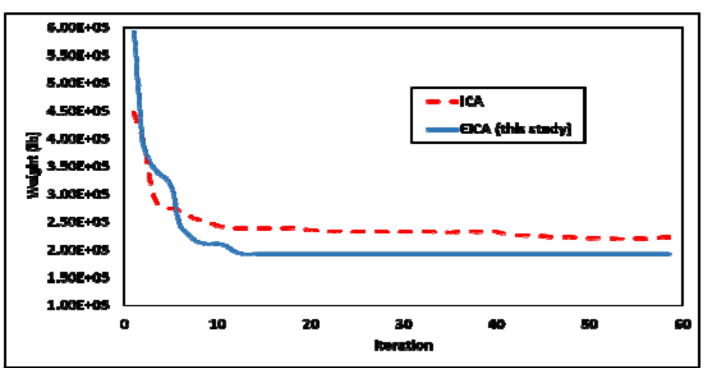

Figure 2. Comparison of best design convergence curves of the basic ICA and the EICA for the three-bay, twenty four-story frame.

4 CONCLUSIONS

Based on the results presented above, it can be concluded that the proposed EICA outperforms all the other meta-heuristic algorithms including the basic ICA and EHS in both benchmark problems. The EICA performs best on design quality in larger structures, indicating its superiority in solving practical structural engineering problems. Regarding the solution cost, the EICA also performed remarkably better than other meta-heuristic solutions except the EHS algorithm. This indicates that the proposed enhancement to the ICA algorithm is very effective in algorithm's speedy escape from local optima trapping.

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