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A Comparative Study of the Hardness and Force Analysis Methods Used in Truss Optimization with Metaheuristic Algorithms and Under Dynamic Loading

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ABSTRACT

Increasing the scarcity of raw materials, and the tendency to have light, efficient and inexpensive structures demonstrates the importance of structural optimization. In the optimization process, truss structures are of particular interest due to their high performance in the construction of a variety of structures. The conducted research in this area has produced a great variety of optimization methods, and the researchers emphasize the effectiveness of their proposed method. Considering this issue, summarize and perform a comparative study between optimization methods (classical methods and Metaheuristic Algorithms), analysis methods used in optimization (hardness and force methods) and different optimization loads (static and dynamic loads) is needed to choose the right method and use them more effectively. By examining the research that has been done, it can be noted that the optimizations mentioned above should be compared from many perspectives. In this paper, a decision was made to make a general comparison of the analysis methods used to trusses optimization to provide the basis for further comparisons. In the present study, 19 articles (from 2003 to 2017) have been studied and compared using Metaheuristic algorithms and under dynamic loading in order to compare two methods (hardness and force methods) of analysis in the field of optimization of trusses in terms of optimization types, target function types, constraints and plane and space truss types, and Large-scale trusses, and finally, these two analysis methods were further scrutinized to optimize the 10-member truss plane. The results of this research can be a useful aid for optimization researchers to identify the gaps and deficiencies of truss optimization research.

1. INTRODUCTION

Optimization means achieving the best results for an operation while meeting certain constraints. The optimal design is therefore defined as the best design acceptable based on a predetermined qualitative criterion of competence. [21]. In aerospace, civil, mechanical and automotive industries, the cost is of the utmost importance and affects the weight, cost, and performance of the structure. The increasing scarcity of raw materials, the tendency to have lightweight, efficient and inexpensive structures demonstrates the importance of optimizing structures. Initially, mathematical (classical) methods were used to optimize the structures, and then the Metaheuristic algorithms entered the field of structures optimization. In the optimization process, truss structures are of particular interest due to their high performance in the construction of a variety of structures.

The conducted research in this area has produced a great variety of optimization methods, and the researchers emphasize the effectiveness of their proposed method. Considering this issue, summarize and perform a comparative study between optimization methods (classical methods and Metaheuristic Algorithms), analysis methods used in optimization (hardness and force methods) and different optimization loads (static and dynamic loads) is needed to choose the right method and use them more effectively [20]. By examining the research that has been done, it can be noted that the optimizations mentioned above should be compared from many perspectives.

In the field of truss optimization, researches have been made on optimization types, types of objective functions, constraints, plane and space trusses, large-scale trusses, fuzzy logic loading and combination types, neural networks and perturbation theory and structures reliability theory using Difficulty analysis method with Metaheuristic algorithms [18-1] and also researches conducted by using force method with Metaheuristic algorithms on types of optimization, types of objective functions, types of constraints, types of plane and space trusses, large-scale trusses, types of analysis methods, types of loading and fuzzy logic combination, neural networks and perturbation theory and structures reliability theory.

In this paper, a decision was made to make a general comparison of the analysis methods used to trusses optimization to provide the basis for further comparisons. These comparisons can help researchers in structures optimization obtain a more comprehensive understanding of structure optimization techniques, their strengths and weaknesses, and research deficiencies. In the present study, 19 articles have been studied and compared using Metaheuristic algorithms and under dynamic loading in order to compare two methods (hardness and force methods) of analysis. Next, the analysis methods used in truss optimization are first studied. Then a quantitative comparison is made between the two methods of analysis used in optimization and then a typical problem of truss structures is solved to compare two methods of analysis in

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optimization. Finally, the results of this study will be presented.

2. INTRODUCING STRUCTURAL OPTIMIZATION METHODS AND ANALYTICAL METHODS

The current methods of structural optimization are divided into two categories: classic methods (mathematical optimization) and metaheuristic algorithms. Mathematical methods perform optimization using the principles of mathematical differentiation. However, as the problems of optimization and optimization of mathematical methods became more complex, more efficient tools were needed to solve these problems. In addition to problems such as the need for assurances of differentiation and continuity, and the convergence possibility to local optimum, the time to solve these methods exponentially grows in many problems. In response to this need, Metaheuristic algorithms have emerged. These algorithms were inspired by the nature. These algorithms do not need information from derivative of the problem.

They are able to escape from local optimization and discover general optimization with their operators, and also the time required for computation increases with increasing linear or polynomial dimensions of the problem [20]. In this way, many metaheuristic algorithms have been introduced to the optimization world over the years, which despite their ability to solve structural optimization problems have weaknesses compared to mathematical methods. It is necessary to address the weaknesses of each of these algorithms and even the weaknesses of each of the mathematical methods to increase the ability of researchers in the field of structural optimization. Even optimization methods can be improved by combining different algorithms or by combining algorithms with mathematical methods.

In this paper, 28 metaheuristic algorithms were investigated, which are presented in Tables 2. For more information on these methods, see References 1-19. Table 1 also presents the number of Persian and English articles reviewed in the given time frame.

Table 1. Number of articles reviewed from 2003 to 2017 by hardness and force analysis methods using metaheuristic algorithms under dynamic loading.

Total reviewed Persian articles: 6
Total reviewed English articles: 13
Total reviewed articles: 19

* It should be noted that several algorithms have been used for optimization in some articles.

Table 2. Metaheuristic algorithms used in Trusses optimization in the reviewed articles

Abbreviation	**known as**	**Name (English)**	Row
GA	Genetic Algorithm	Genetic Algorithm	1
PSO	Particles Swarm Algorithm	Particles Swarm Optimization	2
ACO	Ant Colony Algorithm	Ant Colony Optimization	3
HS	Harmony Search Algorithm	Harmony Search	4
BCO	Bee Colony Algorithm	Bee Colony Optimization	5
CSS	Charged Particles Algorithm	Charged System Search	6
DE	Differential Evolution Algorithm	Differential Evolution	7
ES	Evolution Strategy Algorithm	Evolution Strategy	8
FA	Firefly Algorithm	Firefly Algorithm	9
BB-BC	Big Bang–Big Algorithm	Big Bang–Big Crunch	10
CA	Cellular Automata	Cellular Automata	11
COA	Cuckoo Algorithm	Cuckoo Optimization Algorithm	12
BA	Bat Algorithm	Bat-inspired Algorithm	13
ICA	Imperialist Competitive Algorithm	Imperialist Competitive Algorithm	14
SA	Simulated Annealing Algorithm	Simulated Annealing	15
TLBO	Teaching-Learning Algorithm	Teaching-Learning-Based Optimization	16
CBO	Colliding Bodies Algorithm	Colliding Bodies Optimization	17
GSA	Gravitational Search Algorithm	Gravitational Search Algorithm	18
IA	Immune Algorithm	Immune Algorithm	19
RO	Ray Algorithm	Ray Optimization	20
CGA	Cellular Growth Algorithm	Cellular Growth Algorithm	21
FPA	Flower Pollination Algorithm	Flower Pollination Algorithm	22
GCDMM	Garbage Can Decision-Making Algorithm	Garbage Can Decision-Making Model	23
HTS	Heat Transfer Algorithm	Heat Transfer Search	24
MBA	Mine Blast Algorithm	Mine Blast Algorithm	25
PVS	Passing Vehicle Algorithm	Passing Vehicle Search	26
WCA	Water Cycle Algorithm	Water Cycle Algorithm	27
WWO	Water Wave Algorithm	Water Wave Optimization	28

Table 3. Number and Percentage of Hardness and Force Analysis Methods in the Articles Using Metaheuristic Algorithms and Under Dynamic Loading

Number of Hardness Analysis and Force Analysis methods using Metaheuristic Algorithms in reviewed Articles		
Total Uses in Persian Articles: 6	Number of Force method used in the Persian articles: 0	Number of Hardness method used in the Persian articles: 6
Total Uses in English Articles: 13	Number of Force method used in the English articles: 1	Number of Hardness method used in the English articles: 12
Total Uses in all Articles: 19	Number of Force method used in total articles: 1	Number of Hardness method used in total articles: 18
The Percentage of using Hardness Analysis and Force Analysis methods with Metaheuristic Algorithms		
Total Percentage of Usage in Persian Articles: 100	Percentage of using Force method in Persian Articles: 0	Percentage of using Hardness method in Persian Articles: 100
Total Percentage of Usage in English Articles: 100	Percentage of using Force method in English Articles: 7/7	Percentage of using Hardness method in English Articles: 92/3
Total Percentage of Usage in total Articles: 100	Percentage of using Force method in total Articles: 5/3	Percentage of using Hardness method in total Articles: 94/7
Percentage usage of hardness analysis and force analysis methods using metaheuristic algorithms in studied articles compared to total usage (19)		
Total Percentage of Usage in total Articles: 100	Percentage of using Force method in Persian Articles: 0	Percentage of using Hardness method in Persian Articles: 31/6
Total Percentage of Usage in total Articles: 100	Percentage of using Force method in English Articles: 5/3	Percentage of using Hardness method in English Articles: 63/1

As shown in Tables 1 and 3, there has been no research on force method under dynamic loading in Persian articles. In English articles, 92.3% used the hardness method and 7.7% the force method. As can be seen from Table 3, 94.7% of the articles used the hard method and only 5.3% of the articles used the force method. From these results, it is well known that the hardness method is more common in all cases. This is, of course, because of the ease of work with the hardness analysis method in solving optimization problems. However, much more research is needed to develop structural optimization on the force method.

Table 4. Comparison of the type of optimization in using the hardness and force analysis methods in the investigated articles using metaheuristic algorithms under dynamic loading

Numbers of analysis methods used in the reviewed articles			
Total	Force method	Hardness Method	Optimization Type / Algorithm Type
Total use: 36	1	35	Size
Total use: 13	1	12	the shape
Total use: 1	0	1	Topology
Total: 50	2	48	Total
Percentage usage of each algorithm in the reviewed articles			
Total percentage	Force method	Hardness Method	Optimization Type / Algorithm Type
Total use: 100	8/2	2/97	Size
Total use: 100	7/7	3/92	the shape
Total use: 100	0	100	Topology
Total: 100	4	96	Total
Percentage usage of each algorithm in the studied articles, relative to the total articles (50)			
Total percentage	Force method	Hardness Method	Optimization Type / Algorithm Type
Total: 100	2	70	Size
Total: 100	2	24	the shape
Total: 100	0	2	Topology

Table 5. Comparison of Objective Function Types in Using Hardness and Force Analysis Methods in studied Articles Considered Using Metaheuristic Algorithms and under Dynamic Loading

The number of uses of each algorithm in the studied articles			
Total number	Force method	Hardness Method	Objective Function Type / Algorithm Type
Total use: 19	1	18	Single-objective function
Total use: 0	0	0	Multi-objective function
Total use: 19	1	18	Total
Percentage of use of each algorithm in the studied articles			
Total percentage	Force method	Hardness Method	Objective Function Type / Algorithm Type

Total use: 100	5/3	94/7	Single-objective function
Total use: 100	0	0	Multi-objective function
Total use: 100	5/3	94/7	Total
Percentage of use of each algorithm in the studied articles relative to the total (19)			
Total percentage	Force method	Hardness Method	Objective Function Type / Algorithm Type
Total: 100	5/3	94/7	Single-objective function
Total: 100	0	0	Multi-objective function

Table 6. Comparison of types of constraints in applying hardness and force analysis methods in the studied articles using Metaheuristic algorithms under static and dynamic loading

The number of uses of each algorithm in the studied articles			
Total number	Force method	Hardness Method	Constraint type / Algorithm type
Total use: 157	6	151	Static constraints
Total use: 44	2	42	Dynamic constraints
Total use: 201	8	193	Total
Percentage of use of each algorithm in the studied articles			
Total percentage	Force method	Hardness Method	Constraint type / Algorithm type
Total use: 100	3/8	96/2	Static constraints
Total use: 100	4/5	95/5	Dynamic constraints
Total use: 100	4	96	Total
Percentage of use of each algorithm in the studied articles relative to the total (201)			
Total percentage	Force method	Hardness Method	Constraint type / Algorithm type
Total: 100	3	75/1	Static constraints
Total: 100	1	20/9	Dynamic constraints

The hardness method was used in size, shape and topology optimization of 96% and force method of only 4%. The hardness method in single-objective and multi-objective functions was 94.7% and the force method was 5.3%. The hardness method was used 96% in optimizations with static and dynamic constraints and force method 4% was used. The percentage of the total for size, shape, and topology optimization using the percent hardness method is 70, 24 and 2, respectively, indicating that more research should be done on shape and topology optimization using the hardness method. In terms of total percentages, the percentages for optimization, size, shape, and topology using the force method are 2, 2, and zero, respectively, and it indicates that much more research needs to be done on shape and topology optimizations using the force method. Regarding the percentage of total, optimization with single-objective and multi-objective functions using percent hardness method is 94.7 and zero percent, which indicates that much more research should be done on multi-objective optimization using hardness method. Percentage of total percentage for single-objective and multi-objective optimization using force percentile is 5.3 and zero, respectively, indicating that much more research should be done on multi-objective optimization using force method. Total Percentage for static and dynamic constraint optimization using hardness method is 75.1 and 20.9, respectively, indicating that dynamic constraint optimization using hardness method should be more investigated. Total Percentage for static and dynamic constraint optimization using the force method is 3 and 1 respectively, which indicates that optimization with static and dynamic constraint and especially dynamic constraint method is necessary and much more research is needed.

It can be concluded from the above percentages that much more research needs to be done on the force method in terms of optimization types (size, shape and topology) and single-objective and multi-objective functions as well as static and dynamic constraints. From the percentages to the total, it can be concluded that better research was done on size optimization, single-objective optimization and static constraint optimization using the hardness method, but the shape and topology optimization, multi-objective optimization and optimization with Dynamic constraints should be further investigated using the hardness method. From percentages to total, it can be concluded that size optimization, single-objective optimization and static constraint optimization using force method have not been well researched and shape and topology optimization, multi-objective optimization and dynamic constraint optimization should be further investigated using the Force method.

Finally, in order to develop structural optimization in both hardness and force methods, much more research is needed on shape and topology optimization, multi-objective functions, dynamic constraints; in particular, these cases require further consideration of the force method.

Tables 7 and 8, show specimens of plane and space trusses used for optimization in both hardness and force methods and Table 9, shows the number and percentage of types of trusses used in the hardness and force methods under dynamic loading. The results of these tables are as follows:

Table 7. Samples of Trusses Used for Optimization Using Hardness Analysis methods in Articles Using Metaheuristic Algorithms under Dynamic Loading

Plane truss	2	3	4	6	8	9	10	11	12	13	15	17

Number of use	1	0	0	0	1	0	34	0	1	0	0	0
Plane truss	18	20	21	23	24	25	26	28	31	32	36	37
Number of use	0	0	0	0	0	0	0	0	0	0	0	28
Plane truss	39	41	42	45	47	50	52	54	60	68	77	110
Number of use	0	0	0	0	0	0	1	0	0	0	0	0
Plane truss	113	120	131	137	200	224	392	940				
Number of use	0	0	0	0	7	0	0	0				
Space Truss	4	9	18	22	24	25	30	35	36	39	40	47
Number of use	0	0	0	0	0	1	0	0	0	3	0	0
Space Truss	52	56	62	68	72	110	112	117	120	130	132	160
Number of use	13	20	0	0	31	0	0	0	24	0	0	0
Space Truss	200	224	244	330	354	582	693	942	1262	1700	4666	17
Number of use	0	0	0	0	0	0	0	0	0	0	0	

Table 8. Sample Trusses Used to Optimize in using Force Analysis Methods in studied Articles Using Metaheuristic Algorithms and Under Dynamic Loading

Plane truss	2	3	4	7	9	10	11	12	13	15	17	18
Number of use	0	0	0	0	0	1	0	0	0	0	0	0
Plane truss	20	21	23	24	25	26	28	31	32	36	37	39
Number of use	0	0	0	1	0	0	0	0	0	0	1	0
Plane truss	41	42	45	47	50	52	54	60	68	77	110	113
Number of use	0	0	0	0	0	0	0	0	0	0	0	0
Plane truss	120	131	137	200	224	392	940					
Number of use	0	0	0		0	0	0					
Space Truss	4	9	18	22	24	25	30	35	36	39	40	47
Number of use	0	0	0	0	0	0	0	0	0	0	0	0
Space Truss	52	56	62	68	72	110	112	117	120	130	132	160
Number of use	1	0	0	0	1	0	0	0	0	0	0	0
Space Truss	200	224	244	330	354	582	693	942	1262	1700	4666	18
Number of use	0	0	0	0	0	0	0	0	0	0	0	0

Table 9. Number and Percentage of Trusses Used for Optimization Using Hardness and Force Analysis Methods in studied Articles using Metaheuristic and Dynamic Loading Algorithms

	Number	Percentages to sums	Percentages to Total
Number of plane trusses used in optimization by hardness method	7	63/6	46/7
Number of space trusses used in optimization by hardness method	4	36/4	26/7
Total	11	100	73/3
Number of plane trusses used in optimization by Force method	2	50	13/3
Number of space trusses used in optimization by Force method	2	50	13/3
Total	4	100	26/7
Total	15 = 4 + 11		100

The percentage of the type of trusses used in optimization by hardness and force method were 63.6 and 50%, respectively, and the percentage of space trusses used in optimization by hardness and force method were 36.4 and 50, respectively. This indicates that the use of space trusses in the hardness method is less than that of plane trusses, but in force method the number and percentage of the type of space and plane trusses are equal. The percentages of plane trusses in the hardness and force method were 46.7 and 13.3, respectively. The percentages of the type of space trusses in the hardness and force method were 26.7 and 13.3, respectively. Finally, the percentages of the types of plane and space trusses were 73.3% and 26.7%, respectively. From the percentages survey relative to the total, it can be concluded that there is a need for more research on the types of plane and space trusses in the force method.

Table 10 presents the number of studies on optimized trusses in optimization methods using the methods of hardness and force analysis in the investigated articles using mathematical methods under dynamic loading.

Table 10. The number of studies on optimized trusses in optimization methods using the methods of hardness and force analysis using Metaheuristic algorithms and under dynamic loading.

Percentage relative to Total	Percentage relative to Sums	Study	
50	51/4	73	The number of studies on plane trusses used in optimization using the Hardness method
47/2	48/6	69	The number of studies on space trusses used in optimization using the Hardness method
97/3	100	142	Sum
1/4	50	2	The number of studies on plane trusses used in optimization using the Force method
1/4	50	2	The number of studies on space trusses used in optimization using the Force method
2/7	100	4	Sum
100		146 = 4 + 142	Total

The survey Percentage of plane and space trusses used in optimization by hardness method relative to total percentage were 51.4 and 48.6, respectively and the survey Percentage of plane and space trusses used in optimization by hardness method relative to total percentage were 50 and 50, respectively. This indicates that the review percentage of plane trusses in the hardness method is slightly higher than the space trusses percentage, and the review percentage of plane trusses in the force method is equal to the review percentage of space trusses. The survey percentage of plane trusses in comparison to the total percentage in hardness and force method were 50 and 1.4, respectively. The survey percentages of space trusses compared to total percentages in hardness and force methods were 47.2 and 1.4, respectively. The percentage of trusses in hardness and force method were 97.3 and 2.7, respectively. High percentages indicate that much more research is needed on the types of trusses using force method. Tables 11 and 12 show the large-scale trusses and the results are as follows:

Table 11. Investigation of large-scale trusses (from 200 members or more) for the optimization of trusses using Hardness analysis using Metaheuristic algorithms under dynamic loading

		940	392	224	200	Plane truss
		0	0	0	7	Number of use
582	354	330	244	224	200	Space Truss
0	0	0	0	0	0	Number of use
	4666	1700	1262	942	693	Space Truss
	0	0	0	0	0	Number of use

Table 12. Investigation of large-scale trusses (from 200 members or more) for the optimization of trusses using Force analysis using Metaheuristic algorithms under dynamic loading

		940	392	224	200	Plane truss
		0	0	0	0	Number of use
582	354	330	244	224	200	Space Truss
0	0	0	0	0	0	Number of use
	4666	1700	1262	942	693	Space Truss
	0	0	0	0	0	Number of use

In large plane-scale trusses, only 200-member trusses were studied using the Hardness method. The large-scale space trusses have not been investigated using the hardness method and no large scale trusses have been investigated using the force method. It is concluded from the above studies that much more research should be done on large-scale trusses in the force method. However, for the Hardness method, further research needs to be done. Table 13 shows the numbers and percentages of large scale trusses used in hardness and force methods, and the results are presented below:

Table 13. The numbers and percentage of large-scale trusses used in optimization by hardness and force analysis methods using Metaheuristic algorithms under dynamic loading

Percentages compared to Total	Percentages compared to sums	Number	
100	100	1	The number of large-scale plane trusses using the Hardness method
0	0	0	The number of large-scale space trusses using the Hardness method
100	100	1	Sum
0	0	0	The number of large-scale plane trusses using the Force method

0	0	0	The number of large-scale space trusses using the Force method
0	100	0	Sum
100		1	Total

The Hardness method on spatial large-scale trusses has been studied more than large-scale plane trusses, but the research was little in this field. In the force analysis method, no research has been carried out on both large-scale plane and space trusses. Therefore, it is necessary to conduct extensive research on large scale trusses in both hardness and force methods using mathematical methods under dynamic loading. Table 14 shows the number and percentage of surveys carried out on large-scale trusses and the results of the table are as follows:

Table 14. Number and Percentage of conducted studies on Large Scale Trusses Used in Optimization by Hardness and Force Analysis Methods Using Metaheuristic Algorithms and under Static Loading

Percentages compared to Total	Percentages compared to sums	Study	
100	100	7	The number of studies on large-scale plane trusses using metaheuristic algorithms
0	0	0	The number of studies on large-scale space trusses using metaheuristic algorithms
100	100	7	Sum
0	0	0	The number of studies on large-scale plane trusses using mathematical algorithms
0	0	0	The number of studies on large-scale space trusses using mathematical algorithms
0	100	0	Sum
100		7	Total

In terms of large scale trusses investigations, large-scale space trusses have not been investigated using the hardness method. Unfortunately, no large-scale trusses have been investigated using the force method. Therefore, considering the presented percentages, further research is needed to be done on large-scale trusses using force method. However, further research on large-scale trusses is essential in both methods. Tables 15 and 16 show the most consumed trusses and the results are presented below:

Table 15. The most consumed trusses for optimization by hardness analysis method using Metaheuristic algorithms under static loading

200	37	10	Plane trusses
7	28	34	Number of use
120	72	25	space trusses
15	45	63	Number of use

Table 16. The most consumed trusses for optimization by Force analysis method using Mathematical methods under static loading

37	10	Plane trusses
1	1	Number of study
72	25	space trusses
1	1	Number of study

In the Hardness method, the most consumed trusses are 10, 37, 200-member plane trusses and 25, 72, and 120-member space trusses. In the force method, the most consumed trusses are 10, 37-member plane trusses and 25, 72-member space trusses. In general, the most widely used trusses are 10-member plane trusses and 25-member space trusses. However, research on the types of trusses under static loading in both hardness and force methods is scarce and much more research needs to be done.

3. RESULTS

In this section, a sample of 10-member plane truss is examined to better compare the analysis methods. Figure (1) illustrates the schematic of the investigated truss for size optimization and Table 17 shows the data and information required for the analysis and optimization of the 10-member plane truss.

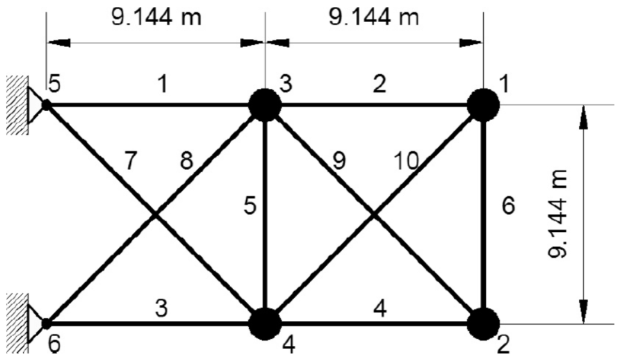

Figure 1. Schematic of the 10-member plane truss for size optimization by hardness and force analysis using Metaheuristic algorithms under dynamic loading

Table 17. Material Properties, Variable Boundaries, and Frequency Constraints for the 10-member plane Truss Problem by Hardness and Force Analysis Methods under Dynamic Loading (for Size Optimization)

Quantity	Properties, units
6.89×10^{10}	E) Modulus of elasticity ‹(N/m^2
2770.0	ρ) Density of material ‹(kg/m^3
454.0	Added Mass ‹kg
0.645×10^4	Bottom border of variable design ‹m^2
50×10^4	Top border of variable design ‹ m^2
9.144	L) Main rod dimension ‹(m
$\omega_1 \geq 7, \omega_2 \geq 15, \omega_3 \geq 20$	Constraints in the first three frequencies ‹Hz

Table 18. presents the best results for the size optimization of the 10-membered plane truss plate using the hardness and force analysis methods with Metaheuristic algorithms under dynamic loading.

Row	Dynamic loading (Hardness method)	Dynamic loading (Force method)
Minimum Weight (lbs)	454/9008(kg)	537/98
Algorithm used	(Evolutionary Strategy Algorithm, Genetic (ES, GA, HS) Algorithm and Harmony Search Algorithm)	(Particles Swarm (PSO) Algorithm)
Variable type	Continuous	Continuous
Target function type	Single Objective: Minimum Weight	Single Objective: Minimum Weight
Type of constraints	Dynamic	Dynamic
Type of penalty function	Kaveh-Zolghadr function	Yes
Type of programming language or software	MATLAB	------
Authors	Nantiwat Pholde, Sujin Bureerat	Herbert Martins Gomes
Year of authoring the article	2014	2011

It can be seen from Table 18 that research has only been done on size optimization and the research should be done on shape and topology optimization in both methods. It is clear from the tables that the results of the hardness method are better than the force method. Although the difference is small, but further research is needed, especially on the method of force analysis to develop and strengthen these two methods.

4. CONCLUSION AND SUGGESTIONS

These results can be deduced from the present study: In the studied articles, the hardness method was much more than the force method. Most optimization research has been done on size optimization, optimization with single-objective function and optimization with static constraints. Also, most optimization research has been done on plane trusses and the least amount of research carried out on large scale trusses. In investigating the sample problem in the case of 10-member plane truss optimization with both methods, the best results in size optimization belong to (ES, GA, HS) (evolutionary strategy algorithm, genetic algorithm and harmony search algorithm) and PSO (particle swarm algorithm), respectively.

Therefore, in order to develop structural optimization, it is necessary to do more research on both hardness and force methods. In particular, more research is needed on the force method. In both hardness and force analysis methods, much more research should be done on Shape and topology optimization, optimization by multi-objective function, optimization by dynamic constraints, space trusses and large-scale trusses optimization.

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