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# Optimizing the Weight of 3D Steel structures by spectrum dynamic analysis and soft computing algorithm

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**ABSTRACT:** Regarding the importance of the optimized and economical design of structures, reducing the total weight of structures has been considered. This approach leads to a decrease in the cost of building projects. In another point of view, reducing the weight of structures will be associated with decreasing the dimension of different elements so it can increase the likelihood of strength failure in the structures. This paper intends to apply the soft computing technique, firstly, to bring a new algorithm for minimizing the weight of structures with respect to satisfying different technical constraints and secondly, to improve the speed of answer. To achieve the second goal, various methods including the modified genetic algorithm, the modified ant colony, and artificial neural network, were applied and tested. Some performance indicators such as speed of answer, accuracy, etc. were selected to compare the output of those mentioned approaches with traditional calculations. The obtained results showed that the modified ant colony algorithm has better performance in terms of speed of answer and accuracy. While several previous investigations have been looked at the problem of structure weight optimization from a two-dimensional perspective, this paper developed three-dimensional modeling by applying the spectrum dynamic analysis. Four types of structures were examined to bring comprehensive results.

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## 1. INTRODUCTION

Optimization has become, over time, an essential part of design activity in all disciplines [1]. Optimization in structures is performed to minimize variables such as weight and cost, taking into account a set of constraints known as constraints [2]. In structural engineering, one of the areas of research is to optimize the design of buildings under load. Optimization techniques in structural engineering are generally classified into three ways: 1. a mathematical or gradient-based method; 2. Optimality criterion; and 3. Random search algorithms [3]. Soft computing techniques are used to optimize problems that are not solved by using mathematical methods or spending a lot of time and money. In principle, the soft computing technique refers to a set of methods used based on artificial intelligence and machine learning to solve complex optimization problems. A lot of research has also been done in this area, some of which are as follows:

In 2009, Nizar et al. [4] optimized the cost of building steel frames with the help of genetic algorithms and were able to some extent, contribute to its optimization. In 2012, Kaveh and Talat Ahari [5] used the CSS algorithm to design optimal 2D steel frames. The CSS algorithm searches for the problem space using the rules governing electrical physics and can get better answers than the previous algorithm. A year later, in 2013, Kaveh and Zakian [6] combined the CSS algorithm with an improved harmony search algorithm and were able to get better solutions than the previous one in the design of steel structures. In the same year, Cookie and Adley [7] used a two-phase genetic algorithm to optimize three-dimensional steel space frame roof structures. Van et al. in 2015, by optimizing a simple portal hot-rolled frame, was able to demonstrate the ability of a genetic algorithm. Using genetic algorithms, they were able to reduce up to 53% of the weight of expendable materials.

Considering the necessity of optimal and economical design of structures, it is important the final weight of the structure designed, which is directly related to the cost of construction. On the other hand, with the weight loss of the structure, the resistance parameter decreases, and also, the structural elements are displaced increasingly. Considering the issues studied by previous investigations and the position of the Moment frame system in steel buildings, it seems that the optimization of the Steel Moment-Frame system weight by developmental algorithms and the examination of other soft computing tools for more precise solutions at higher speeds are the controversial subject. Another major goal of this study was to compare the performance of different developmental algorithms in instrumental issues and algorithm classification in terms of the optimality of the solution, the speed of the algorithm, the number of iterations, and the number of the initial population. The paper explicitly

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examines the performance of soft computing tools including neural networks, ant colony optimization algorithm and unbalanced genetic algorithms in designing steel structures and comparing these with each other. The steps in this work will be to provide a mathematical model of the problem first, and then soft computing methods will be used through the API system by connecting MATLAB and SAP2000 software to the optimal combination of sections for the Moment-Frame system structures. Finally, the optimal responses provided will be compared in different ways, in addition to the response that the SAP2000 software offers as an optimal response.

## 2. MATERIALS AND METHODS

The buildings used in this paper as samples are steel moment-frame systems in both directions. The goal is to optimize the weight of these buildings by complying with the constraints set out in the valid regulations. It should be noted that this paper deals with a discrete optimization and the AISC360-2010 regulations and the ASCE7 loading rules have been used for designing. Since the purpose is to examine the strength of various soft calculating methods to optimize the structures, selecting the type of sections is not of utmost importance. In this regard, the probable sections of 32 W sections are selected.

The constraints governing optimization are all the provisions contained in the AISC360-2010 Regulations for steel moment frame structures. The soil of the construction project site is of type 3 and buildings are considered to be of great importance. The roof of the structures is regarded as Rib and Block. The spectral and dynamical analysis is used to apply the earthquake force to the structure. Given that the moment-frame system was used, assuming there are at least two openings resistant to lateral loads on each side of the center of mass, the indeterminate coefficient for both directions is considered to be 1. Optimization is done for four types of buildings, including regular, irregular in-plane, irregular in height, irregular in height and plan. The optimization was based on three methods: improved genetic algorithm improved ant colony optimization algorithm and neural network algorithm in this paper.

In the present paper, by applying modifications to the genetic algorithm process, an algorithm has been proposed that merely examines the constraints for responses that are the best in the population of the current generation. This is important by proposing a criterion function for the objective function and incorporating the problem constraints. In fact, the problem constraints are eliminated and indirectly raised in the objective function, and a new issue is raised for optimization. The new problem is presented in such a way that there is no constraint for evaluation and consists only of the objective function so that if the objective function of the new problem is optimized, both the objective function for the initial problem will be optimized and the constraints governing the initial problem will be satisfied.

In the improved ant colony optimization algorithm, the method will be such that the weight of all the selected structures of ant colonies is determined initially, then the procedural constraints for the least costly structure are checked by the SAP2000 software. Next, if the procedural constraints are established, the algorithm will transfer to the next step; otherwise, the cost of the ant colony will be penalized, and this process will be repeated to the second ant colony (which currently has the lowest cost) to reach an ant colony that has the lowest cost and satisfies the procedural constraints or all existing ant colonies are examined in terms of procedural constraints, then the algorithm will go to the next level. In the next step, ant colonies that are not subject to procedural checks will suffer a degree of fines to retreat from the ant colony with the lowest cost and procedural constraints. It should be noted that ants that do not satisfy the procedural constraints would increase the maximum possible weight for the structure after the fines are imposed.

Indeed, the main objective in the neural network algorithm method is to obtain a neural network algorithm that can estimate the elements of the structure with the least degree of error, with the characteristics of the structure and loading specifications for a certain degree of certainty. The existence of basic information is required to build and train a neural network algorithm. For this purpose, MATLAB and SAP2000 software have been used. In this way, MATLAB software randomly specifies the thickness of the floor ceiling, the project ground acceleration, the building importance factor, other parameters related to earthquake loading, wall load, floor and roof dead load, live loads, and eventually the sections of each element. It actually builds information about the structure and introduces it to the SAP2000 software. SAP2000 software, after analyzing and checking design constraints, introduces the information of each of the elements, which is, in fact, their ratio, to the MATLAB software to save this information. This process is repeated to a thousand times for each of the structures, thus providing the basic information for training the neural network algorithm.

## 3. RESULTS

The structure reviewed in this section is a 9-story building with a height of 3 meters each floor. The use of the intended structure is considered residential. Each floor area is 500 square meters. All floors are type, and the structure is implemented in four types of buildings, including regular, irregular in plan, irregular in height, irregular in height and plan. The construction system is moderate in both directions of the moment-frame and with clamp connections. Tables 1, 2, 3, and 4 have compared the results of soft computing techniques along with the results of the SAP2000 automated design.

As seen in all building modes, improved ant colony optimization algorithm provides better results. According to the results, the more complicated the algorithms are the more developmental algorithms than the SAP2000 automated selection will be revealed, and the difference in its further results.

## 4. CONCLUSION

The results showed that improved genetic algorithm and improved ant colony optimization algorithm reduced the structural weight from 14 to 33 percent based on the type of structure in question compared to the automated design of the software. The results of the proposed perceptron neural network algorithm in this study also led to the weight loss of the structure but could not satisfy all the procedural

**Table 1. Results of four methods for structure as regular in plan and height**

| | Total weight of the structure (tons) | Weight per unit area (kg / m $^2$) | Weight relative to SAP | Number of selected sections | Mean Ratio | Standard Deviation Ratio | Maximum Ratio | Minimu m Ratio | Most used section |
|---|---|---|---|---|---|---|---|---|---|
| **SAP2000** | 352 | 78.2 | 0 | 20 | 0.72 | 0.15 | 0.95 | 0.39 | **W18x50** |
| **improved genetic algorithm** | 342 | 75.92 | -2.9 | 21 | 0.65 | 0.14 | 0.98 | 0.2 | **W18x50** |
| **improved ant colony optimization algorithm** | 300 | 66.69 | -14.7 | 21 | 0.83 | 0.07 | 0.95 | 0.62 | **W8X48** |
| **neural network algorithm** | 349 | 77.67 | -0.8 | 11 | 0.66 | 0.2 | 1.19 | 0.2 | **W18x50** |

**Table 2. Results of four methods for structure as irregular in plan and regular in height**

| | Total weight of the structure (tons) | Weight per unit area (kg / m $^2$) | Weight relative to SAP | Number of selected sections | Mean Ratio | Standard Deviation Ratio | Maximum Ratio | Minimum Ratio | Most used section |
|---|---|---|---|---|---|---|---|---|---|
| SAP2000 | 621 | 143.9 | 0 | 16 | 0.62 | 0.17 | 0.96 | 0.2 | W18x50 |
| improved genetic algorithm | 598 | 137.6 | -3.7 | 21 | 0.67 | 0.08 | 0.91 | 0.42 | W10X100 |
| improved ant colony optimization algorithm | 414 | 96.03 | -33.3 | 22 | 0.74 | 0.12 | 0.96 | 0.33 | W18x50 |
| neural network algorithm | 344 | 79.2 | -44.6 | 11 | 0.65 | 0.2 | 1.2 | 0.2 | W18x50 |

**Table 3. Results of four methods for structure as regular in plan and irregular in height**

| | Total weight of the structure (tons) | Weight per unit area (kg / m $^2$) | Weight relative to SAP | Number of selected sections | Mean Ratio | Standard Deviation Ratio | Maximum Ratio | Minimum Ratio | Most used section |
|---|---|---|---|---|---|---|---|---|---|
| SAP2000 | 499 | 110.8 | 0 | 32 | 0.64 | 0.17 | 0.96 | 0.2 | W12X40 |
| improved genetic algorithm | 450 | 134.34 | -9.8 | 23 | 0.59 | 0.17 | 0.97 | 0.12 | W21X55 |
| improved ant colony optimization algorithm | 381 | 88.26 | -20.34 | 15 | 0.77 | 0.12 | 0.95 | 0.4 | W18X50 |
| neural network algorithm | 382 | 89.08 | -19.6 | 19 | 0.6 | 0.23 | 1.25 | 0.18 | W8X48 |

**Table 4. Results of four methods for structure as irregular in plan and height**

| | Total weight of the structure (tons) | Weight per unit area (kg / m $^{2}$) | Weight relative to SAP | Number of selected sections | Mean Ratio | Standard Deviation Ratio | Maximum Ratio | Minimum Ratio | Most used section |
|---|---|---|---|---|---|---|---|---|---|
| SAP2000 | 473 | 109.5 | 0 | 11 | 0.43 | 0.3 | 0.96 | 0.09 | W8X10 |
| improved genetic algorithm | 406 | 94.09 | -14.11 | 21 | 0.75 | 0.13 | 0.94 | 0.3 | W16X57 |
| improved ant colony optimization algorithm | 377 | 87.22 | -20.38 | 15 | 0.76 | 0.12 | 0.94 | 0.35 | W18X50 |
| neural network algorithm | 383 | 85.08 | -22.33 | 11 | 0.66 | 0.2 | 1.98 | 0.2 | W18X50 |

constraints. As a result, it cannot be used as a separate method for optimization, but due to its high speed, it can be used in combination with other optimization methods. It is suggested that future researchers consider the topic of the present study at the special moment frames, taking into account the strength of the beam, a weak pillar. Also, the study of concrete structures and their optimization mechanism using soft computing can be considered as a subject for future research.

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