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Comparison of LRFD with W Sections for the Optimization and Stress Ratio of Steel Frames Using Genetic Algorithm

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Abstract

Over the past several decades, algorithms have been employed to enhance structural designs, with a particular focus on the optimization of steel and concrete structures to achieve weight reduction. However, the optimization of metal structures with new analyses including LRFD analysis is one of the new challenges in this field. This research aimed to establish the structure's weight as the objective function, which was expected to be directly linked to its overall cost. The design models were individually optimized and subsequently analyzed and compared through the application of genetic algorithms (GA) and Load and Resistance Factor Design (LRFD) methodologies, utilizing W sections for the frames. The cross-section of beams and columns were studied as design variables, and the constraints specified in the Iranian National Building Code (Part 10) were considered design constraints. In conclusion, the graphs representing the GA and stress ratio under each LRFD condition for the W sections were generated and subsequently compared, leading to a thorough analysis.

Keywords: (Optimization, Steel structures, Genetic algorithm, LRFD analysis)
2022 MSC: O20, O10

1 Introduction

Optimization is defined as the systematic approach to enhancing a process or object to achieve superior outcomes. Engineers and scientists use optimization to improve and advance their new ideas. In other words, optimization means testing different modes on an initial idea and using the obtained information to improve that idea. Furthermore, given that the application of meta-exploratory algorithms for the optimization of steel structures has been relatively underutilized by researchers, it appears that there is a significant need for further studies and investigations in this area in the years ahead.

Optimizing structures by taking into account the existing conditions and limitations or the constraint functions has always been one of the concerns of engineers and designers. In general, the number of designs that provide acceptable design criteria is high, but choosing an economic design in such cases is not easily possible. Consequently,

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the design phase constitutes a decision-making process, in contrast to the structural analysis phase, where no options are available.

In a study conducted in 2010, Kaveh et al. were concerned with the optimal design of 2-D steel frames with the improved ant colony optimization algorithm (ACO) [8]. Elsewhere, Kaveh et al. [8] studied the optimal design of 2-D moment steel frames with ACO and GA [10]. Sadik et al. [2] worked with the harmony search algorithm (HSA) to minimize the costs of 3-D steel frames with semi-rigid connections [2].

In a study in 2010, Kripakaran et al. operated with GA to optimize steel frames with two different methods [14]. Togan [19] employed teaching-learning-based optimization (TLBO) algorithms to minimize the weight of 2-D steel frames [19]. Dogan and Saka [3] used PSO, GO, and HSA algorithms to optimize 2-D steel frames based on load and resistance factor design (LRFD) [3]. In a study in 2012, Kaveh et al. worked with the charged system search optimization algorithm (CSSOA) to minimize the weight of 2-D and 3-D frames [11].

Kaveh et al. [12] proposed an optimal design of 2-D frames using CSSOA and improved HAS algorithms [12]. Elsewhere, Gong et al. used GA to minimize the "weight of the frame" and "input seismic energy" and maximize the energy absorbed by the joint members in the braces. They further worked with the bee colony optimization algorithms (BCOA) to design the optimal capacity of a steel frame braced with divergent bracing [6].

Kociecki et al. [13] employed the two-phase GA to optimize 3-D free-form steel space-frame roof structures. These structures were two among all 13 train stations where the members were influenced by torsion and moment and axial loads. Using GA, they reduced the weight of these two structures by 12 and 7%, respectively [13]. Kaveh et al. [9] used CSSOA to optimize 2-D steel frames with semi-rigid connections [9]. Kao et al. [7] first designed several different buildings and then employed the obtained data to model a neural network that can predict the structure's behavior under design loads. Ultimately, they optimized the weight of this approximate model using evolutionary algorithms (EAs) [7]. In a study in 2014, Narimani et al. worked with optimization-based MHAs to minimize the weight of 2-D and 3-D steel frames [15]. Gholizadeh [5] optimized the study buildings using the modified firefly algorithm (MFA) [5]. Phan et al. [17] worked with GA to optimize cold-formed steel portal frames for stressed skin action. They reduced the weight of consumed materials by 53% with the help of GA [17].

Afzali et al. [1] operated optimization algorithms to minimize the weight of 2-D steel frames [1]. In a review research conducted in 2018, Ekichi et al. explored the use of collective and evolutionary intelligence algorithms in functional computing architecture. After the literature review, they proposed various statistical (e.g., the type of algorithms) and classified approaches in terms of sustainability, cost, performance, and structure. Ultimately, they reported sustainability as a factor that is at the attention center of most studies [4].

Reza Najafi, Reza Ansari, Abolfazl Darweizah, and Vahid Nuraifar [16] have worked on evolutionary optimization such as genetic algorithms. The research indicates that the optimization process begins with a predetermined initial shape, which gradually evolves towards its optimal configuration. The main emphasis of this research is to optimize the size, shape, and topology of the structure simultaneously. Considering design constraints including kinematic stability of the structure, tensile and compressive stresses in elements, displacement in nodes, buckling, Euler buckling for compression members, and natural frequency constraints, to optimize the size, shape, and topology of the two-dimensional truss and 3D has been used [16].

Mostafa Sepehari Menesh and colleagues used a genetic algorithm in 2019 to reduce the weight of astronaut structures by using reliability constraints [18].

A genetic algorithm is an evolutionary algorithm based on intelligent search. The purpose of this article is to find the minimum cost and minimum displacement of the structure with two sections I and W using the genetic algorithm, which will be obtained according to the limitations of the LRFD design method, the results of each of which are presented. It is worth mentioning that optimizing steel structures with different algorithms and using limit state analysis has been common, and we have used these methods in this article.

2 Optimizations

2.1 Definition of the objective function

In this research, the objective function was the weight of the structure, which is directly correlated with the structure's cost. Thus, the structure's cost was calculated based on the profile weight parameter.

The design variables intended in this research were the dimensions of the cross-section of the frame's beams and columns. Importantly, this study reflects constraints and items specified in Standard 2800 and the Iranian National

Building Code (Part 10), such as stress and displacement. The beams were subjected to the bending moment and the columns were under the synergistic effect of bending moment and axial force. The constraints of the optimization model were the design criteria based on the analytical criteria of LRFD and ASD.

$$\text{Minimize } F = f(\text{cost}) \tag{1}$$

$$f(\text{cost}) \propto \text{Weight} \tag{2}$$

2.2 Penalty function

The objective function should be defined to allow satisfying all constraints such as the stresses in each of the elements and lateral displacements. It further should cover constraints imposed on the deformation of the structure. For best functioning, the columns of the lower stories should be of larger dimensions than those of the upper stories. Other constraints specified in the building codes need to be further reflected. Failure to adhere to these constraints will result in penalties being imposed on the objective (cost) functions. This method simplifies the objective function and further allows to application of required constraints to increase the structure's cost or displacement, thereby automatically preventing the choice of penalized answers as the optimal solution. A multitude of methods have so far been proposed regarding the penalty function. However, the penalty function in this study is as follows:

$$C_i = \alpha_i V_i \tag{3}$$

$$\phi = \sum_{i=1}^{n} C_i \tag{4}$$

Where(C_i) is the penalty function for each constraint, (α_i) is the penalty factor for each constraint, (V_i) is the amount of penalty for each constraint, and (ϕ) is the total of penalties applied. The penalty factor is obtained by trial and error and according to the model and takes a unique for each structure.

$$\text{Penalty functions: } \begin{array}{lcl} \text{Tension} & & \text{if } \sigma > 1 \rightarrow \alpha_1 \times (1-\sigma) \\ \text{Shape} & \longrightarrow & \alpha_3 \times (\text{shape penalti}) \\ \text{Disp} & & \text{displacement} > 6.4 \rightarrow \alpha_4 \times (\text{displacement} - 6.4) \end{array}$$

3 GA

GAs are a group of search and optimization methods inspired by the principles of natural selection and genetics. These algorithms imitate the theory of natural evolution to find optimal solutions to complex problems. This evolutionary algorithm searches among a population of candidate solutions called chromosomes or individuals.

This algorithm randomly generates several solutions for the problem where each of these solutions is called a "chromosome" and the set of attempted (generated) solutions are called the "population". After the random population was generated, GA investigated all the chromosomes based on the merit function. Indeed, GA employs a variety of methods such as combination and mutation to select the most qualified individuals to make the next generation made up of better individuals. The combination operator selects some individuals in the population and combines them to integrate their characteristics and allow them to generate better offspring for the next generation. Likewise, the mutation operator selects several individuals and then alters some of their characteristics to upgrade the chosen individual to a better (improved) individual.

The number of individuals selected for combination and/or mutation will depend on the type of problem and the size of the population. Similarly, the method of choosing individuals for combination and mutation is a key factor to consider. The sought-after methods for choosing the best individuals are the roulette wheel, tournament selection, and random methods, which can be performed by trial and error according to the type of problem. For the problem concerned here, the roulette wheel outperforms other methods. GAs are usually run as a computer simulator in which the population of candidate solutions (i.e., chromosomes) for an optimization problem results in a better solution for the problem.

According to the regulatory constraints, this study introduces some cross-sections for beams and columns, where GA tries to possibly minimize the cost by choosing the best sections.

4 Regulatory constraints

The Iranian National Building Code (Part 10) has defined some constraints for the resistance of each of the elements, positioning of the elements, and examining the stress in each element.

In this study, the constraints set to the resistance of the columns are investigated based on the synergistic effect of the axial force and flexural moment of the same column. Indeed, when tensile or compressive axial force and the flexural moment in the study column exceed the values specified in the building codes and the stress ratio is greater than one, the column will be penalized. The equations are as follows:

A) If $\frac{P_r}{\phi_c P_n} \geq 0.2$
Then,

$$\frac{P_r}{\phi_c P_n} + \frac{8}{9}\left(\frac{M_{rx}}{\phi_D M_{nx}} + \frac{M_{ry}}{\phi_D M_{ny}}\right) \leq 1.0 \tag{1}$$

B) If $\frac{P_r}{\phi_c P_n} \geq 0.2$
Then,

$$\frac{P_r}{2\phi_c P_n} + \left(\frac{M_{rx}}{\phi_D M_{nx}} + \frac{M_{ry}}{\phi_D M_{ny}}\right) \leq 1.0 \tag{2}$$

Where P_r is the compressive strength required, P_n is the nominal compressive strength for the given section, (ϕ_c) is the compressive strength coefficient that takes a value of 0.9, M_{rx} and M_{ry} are the required flexural strength around strong and weak axes (respectively), M_{nx} and M_{ny} are the nominal flexural strength around the strong and weak axes (respectively), and (ϕ_D) is flexural strength coefficient taking a value of 0.9 [6].

The regulatory constraints set columns are also applied to beams, but the difference is that there is no interaction between axial and flexural forces in the beams and the only determinant factor will be "flexural moment". Here, according to the calculated reduction coefficients of the allowable flexural strength, and when the above condition is not satisfied, the cost function will be penalized to some values.

4.2. In the allowable stress design (ASD) method, the reliability coefficients are applied such that the material's strength is divided into the reliability coefficients and, in calculations, smaller values are assigned to strength.

Further, according to the ASD method, the sections are chosen such that the stress generated under the service loads in any member does not exceed a given allowable stress. This method was first devised according to the theory of elasticity to allow quantifying stress created in the members under the service load.

Thus, the constraints set for the strength of columns are studied according to the synergistic effect of axial and flexural forces of the same column. In turn, when the tensile or compressive axial force and the flexural moment in the intended column exceed the values set in the building code and the stress ratio is greater than one, the column will be penalized. According to the building codes, these equations will be as follows:

A) If $\left(\frac{f_0}{FA} > 0.15\right)$
Then,

$$\frac{f_0}{FA} + \frac{C_m \cdot fb}{\left(1 - \frac{fa}{F'_{ex}}\right) FB} \leq 1 \tag{3}$$

$$F'_e = \frac{12}{23} \times \frac{\pi^2 E}{\lambda_b^2} \tag{4}$$

$$\frac{f_a}{0.6 f_y} + \frac{f_b}{FB} \leq 1 \tag{5}$$

Where (λ_b) refers to the slenderness of the free length of the element in the plane of bending.

B) If $\left(\frac{f_0}{FA} < 0.15\right)$
Then,

$$\frac{f_0}{FA} + \frac{fb}{FB} \leq 1 \tag{6}$$

Where (C_m) is a coefficient its value depends on the condition of the frame and lateral forces.

B-1) In rigid frames (where the ends of the frame have zero rotation), C_m is obtained from the equation below:

$$C_m = 0.6 - 0.4\frac{M1}{M2} \geq 0.4 \tag{7}$$

Where $(\frac{M1}{M2})$ is the ratio of the small-to-larger anchor of the free ends of the column and takes a positive value.

Importantly, besides the constraints mentioned above, some other constraints have also been regarded in this research. In turn, the cross-section of the columns of the lower stories should be larger than that of the columns of the upper stories. Therefore, if these conditions are not satisfied, or if the cross-section of columns of the lower stories is smaller than that of the columns of the upper stories, the model under consideration will be further penalized beyond the penalty set on the stress ratio. Accordingly, such problems will be automatically omitted from the optimization cycle [6].

5 The study samples

This research investigated two distinct samples to evaluate the performance of the algorithm. For this, two structures were studied. These were two-bay structures, one with three stories and the other with six stories, where the former represents a short-height and the latter represents a medium-height structure. The height of the stories was 3 m and the length of the bays was 4 m. The live and dead loads of the stories were widely applied to the beams of the stories. Similarly, the lateral point loads were applied to the joints of the beams and columns. According to the building codes, the loads were synergistically applied as follows:

$$U = D + 1.2L + 1.2E \tag{1}$$

$$U = 0.85D + 1.2E \tag{2}$$

Furthermore, uniform dead and live loads were equal to $Dl = 550\ kg/cm^2$ and $Ll = 200\ kg/m^2$, respectively. For the roof, these values were 500 kg/m^2 and 150 kg/m^2, respectively. The compressive strength of steel was equal to $F_y = 2400\ kg/cm^2$

We can apply various conditions to stop the algorithm, including the “condition of convergence” or “the number of iterations”. By examining various “trials and errors” and choosing the best stopping strategy, we selected the condition of “the number of iterations” for this algorithm. To find the best population and number of iterations, we evaluated various populations with different iterations and ultimately picked up a population with 45 members and 250 iterations.

5.1 Study samples

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In this article, two different samples have been examined to measure the performance of the algorithm. The two investigated models of two-bay structures with three and six floors are considered so that each of the samples is representative of low and medium-height structures. The height of the floors is 3 meters and the length of the openings is 4 meters.

We further considered 150 and 78 distinct cross-sections for “columns” and “beams”, respectively. We further considered 267 distinct cross-sections for “W sections” according to the building codes for both the beam and column.

Sample 1

In this frame, the stories are each 3 m in height and the length of the bays is 4 m. The values of gravity loads have been reported previously, and the values of lateral loads are depicted in Figure 1. There are two types of beams and four types of columns.

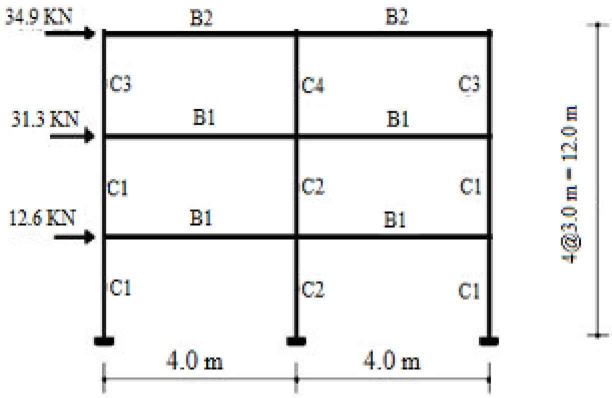


Figure 1: Sample 1

Information		
$DL = 550\ kg/m$	$LL = 200\ kg/m$	$E = 2E6$
$F = 2400\ kg/cm2$	LL for roof $= 250\ kg/m$	
Combination of loads $= 1.2D + 1.0E + 1.0L$		
Loads on beams $= 1.2 \times 550 + 200 = 860\frac{kg}{m} = 8.6\ kg/cm$		
Loads on the beams of the roof $= 1.2 \times 500 + 150 = 750\frac{kg}{m} = 7.5\ kg/cm$		

Model 1: Two-bay, three-story structure

In this model, each story is 3 m in height and the length of each bay is 4 m. The seismic load is calculated as follows:

$H = 9m$: $T = 0.08H^{0.75} = 0.08 \times 9^{0.75} = 0.4157\ s$

$A = 0.3,\ I = 1$, II Type of ground

$T_0 = 0.1,\ T_S = 0.5,\ S = 1.5,\ S_0 = 1$

$B_1 = 2.5,\ N = 1\ B = B.N = 2.5\ R_U = 5$

$C = \frac{ABI}{R} = \frac{0.3\times 2.5\times 1}{5} = 0.15$

$W = (0.2 \times 200 + 550) \times 2 \times 8 \times 8 + (0.2 \times 150 + 550) \times 8 \times 8 + (3 \times (3 - 1)) \times 4 \times 8 \times 250 = 157.44\ ton$

$K = 1,\ V = C.W = 0.15 \times 157.44 = 23.616$

$f_i = \frac{w_i \cdot h_i}{\Sigma w_i \cdot h_i},\ F = f_i \cdot V$ Since the optimization method is an MHA, we cannot consider the answers obtained after

Table 1: Lateral loads on the structure

Story	Load applied to the story	Load applied to the frame	Load applied to the node
1	3.73	1.26	0.42
2	9.38	3.13	1.64
3	10.46	3.46	1.16

the first optimization as the best solutions. Thus, to achieve the best solution, the optimization needs to be repeated in several iterations. In this research, each model was optimized within 11 separate iterations. Figure 2 illustrates the values obtained for the best answer and the average value of answers.

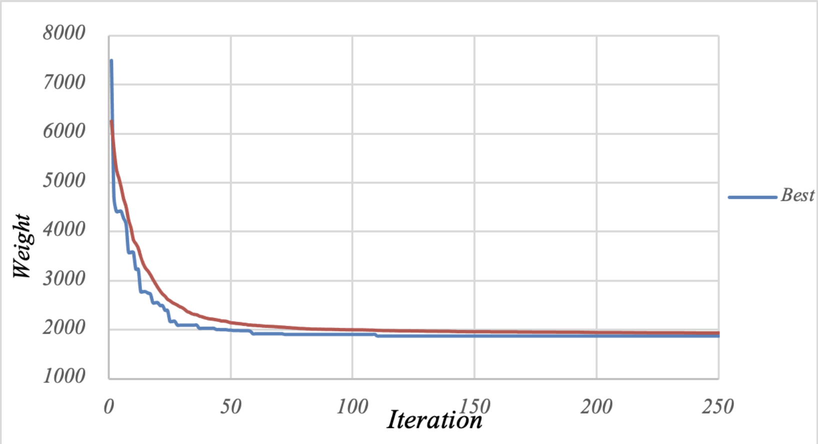


Figure 2: The optimization process for sample 1 based on the method of ultimate strength (W sections)

Regarding ultimate strength, the weight of a 3-story structure is reduced from 7491.80 kg to 1868.40 kg at best, and its average weight is reduced from 6250.9 kg to 1930.2 kg.

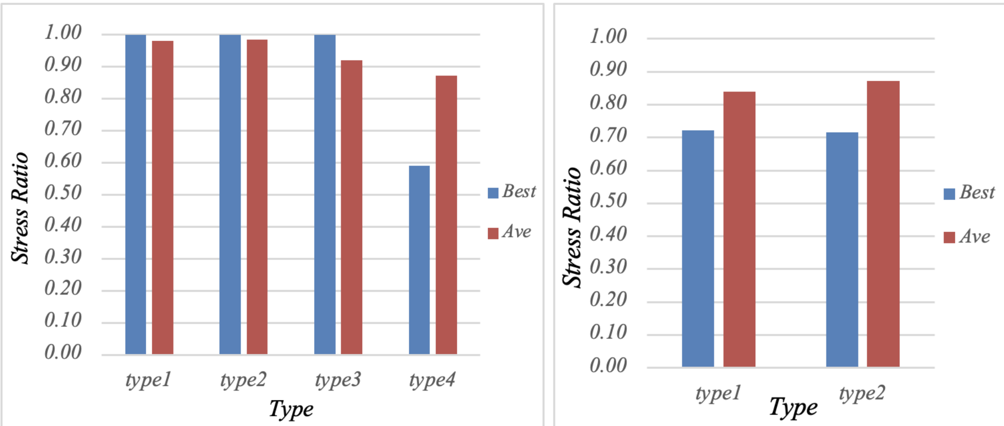


Figure 3: The ratio of stresses generated in beams and columns for sample 1 at ultimate strength (I section)

To determine the efficiency of the algorithm, we can pay attention to the values of the ratio of the stresses in the sections to their tolerable stress. Considering that six beams with two different types are considered in this model, the average amount of the existing stress ratio to the tolerable stress of the beams is shown in Figure 3.

Also, the maximum stresses created in the columns of four different types are shown in Figure 3. The remarkable thing is the very good performance of the algorithm in finding the right sections of the columns. The stress ratio created in the columns confirms the maximum use of the capacity of these sections, which is desirable for any optimization operation.

Table 2: Specifications of beam type (3-story) - ultimate strength

Type	I section	Stress ratio
1	IPE 240	0.86
2	IPE 160	0.95

Table 3: Specifications of columns type (3-story) - ultimate strength

Type	I section	Stress ratio
1	IPB 220	0.90
2	IPB 220	1.00
3	IPB 140	0.98
4	IPB 180	0.88
Best Weight		**2260.30 kg**
Worst Weight		**5687.80 kg**
Ave Best Weigh		**2318.90 kg**
Displacement		**4.01 cm**

Table 4: Specifications of the beams (3-story) – ultimate strength

Type	**W section**	**Stress ratio**
1	W14×22	0.72
2	W12×14	0.72

Table 5: Specifications of the columns (3-story) – ultimate strength

Type	**W section**	**Stress ratio**
1	W16×26	1.00
2	W18×50	1.00
3	W12×16	1.00
4	W16×26	0.59
Best Weight		1868.40 kg
Worst Weight		7491.80 kg
Ave Best Weight		1930.21 kg
Displacement		1.61 cm

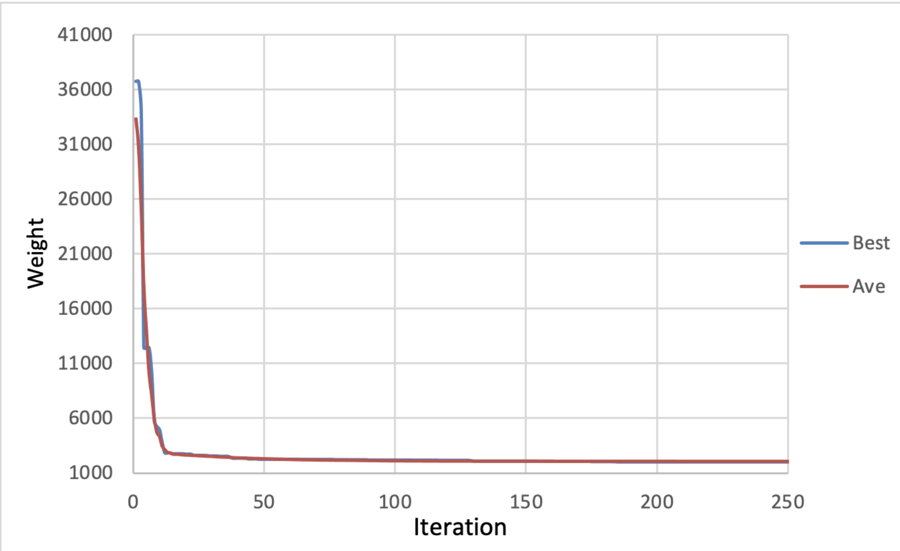


Figure 4: Optimization of the first model with the method of ultimate strength (W section)

The weight comparison of sections I and W in LRFD mode is as follows:

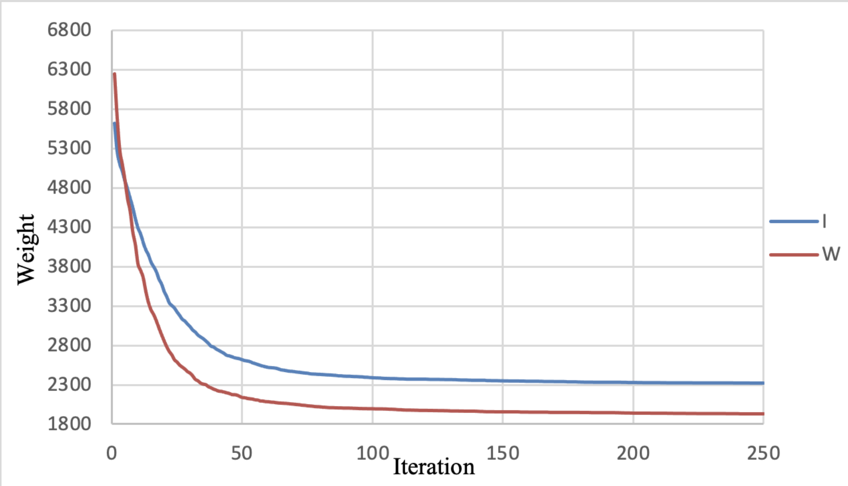


Figure 5: Showing the comparison of the optimization process of the first model for sections I and W (ultimate strength)

Also, for better performance of the algorithm, only one of the beam sections, which has a stress ratio of 0.86, is replaced with a point of a smaller number. In this case, the amount of stress ratio of beams and columns increases, but the amount of increase of the stress ratio is such that the beams are in the allowed range and show better performance, but the columns are out of range. They are allowed to leave. Therefore, even by shrinking one of the sections that has a lower stress ratio than the other sections, it is not possible to reduce the weight values of the first model.

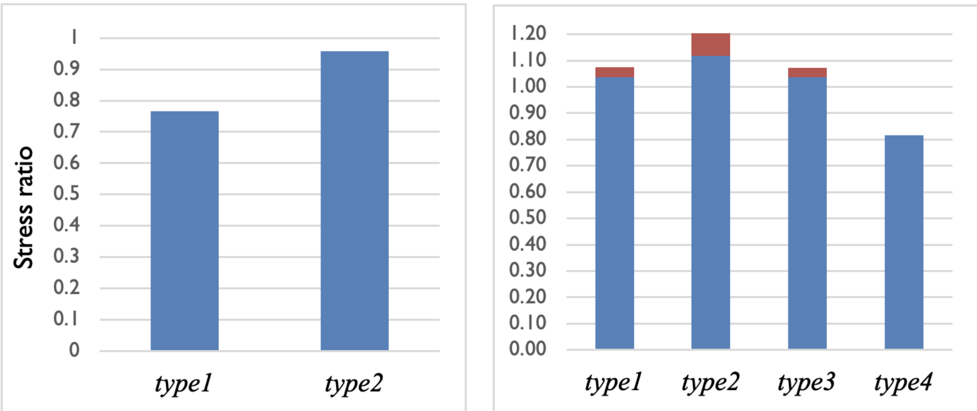


Figure 6: the ratio of stresses created for the first model in case of shrinking one of the sections (ultimate strength)

Table 6: specifications of beam type (3 layers) - final strength

Type	I section	Stress ratio
1	IPE 180-70*10	0.77
2	IPE 160	0.96

Table 7: column type specifications (3 floors) - final strength

Type	I section	Stress ratio
1	IPB 220	1.04
2	IPB 220	1.12
3	IPB 140	1.04
4	IPB 180	0.82

Sample 2

As in the first example, the length of the openings is 4 meters and the height of the floors is 3 meters for this example as well. According to the number of beams and columns, four types of beams and eight types of columns have been considered. Gravity loads including live load and dead load are the same like the previous example and there is no difference. The values of lateral loads and the type of beams and columns are given in Figure 8. To clarify the issue better, the values of the stress on the beams and columns are also given separately and in different forms. Allowable displacement values are calculated as follows.

$$\begin{cases} \Delta m = 0.7R\Delta w \\ \Delta w < 0.02\ h \end{cases} \longrightarrow \delta w < \frac{0.02 \times 3600}{0.7 \times 5} = 20.57\ cm$$

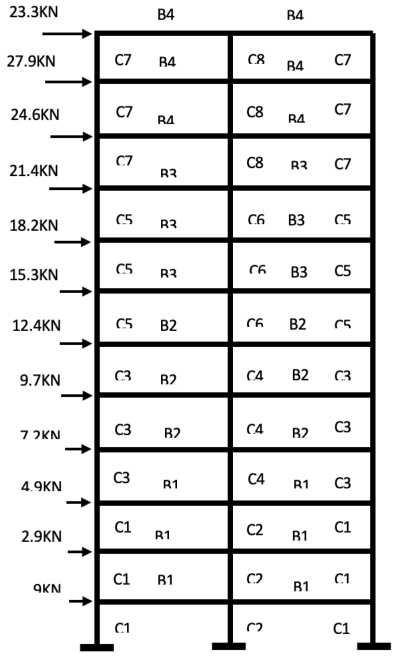


Figure 7: Show the second model under review

- **The second model (two openings, twelve floors)**
  Earthquake load calculations:

$H = 36m:\ T = 0.08H^{0.75} = 0.08 \times 36^{0.75} = 1.176\ s$

$A = 0.3,\ I = 1$, II Type of ground

$T_0 = 0.1,\ T_S = 0.5,\ S = 1.5,\ S_0 = 1$

$B_1 = (S+1)\left(\frac{T_S}{T}\right) = 1.06,\ N = 1\ B = B.N = 1.06 R_U = 5$

$C = \frac{ABI}{R} = \frac{0.3\times1.06\times1}{5} = 0.0636$

$W = (0.2 \times 200 + 550) \times 5 \times 8 \times 8 + (0.2 \times 150 + 500) \times 8 \times 8 + (3 \times (6-1)) \times 4 \times 8 \times 250 = 713.28$

$K = 0.5T + 0.75 = 1.388\ V = C.W = 0.107 \times 342.72 = 36.67$

$f_i = \frac{w_i.h_i}{\sum w_i.h_i},\ F = fi.V$

Table 8: Lateral forces acting on the structure

Load applied to the node	Load applied to the frame	Load applied to the story	Story
1	0.27	0.09	0.03
2	0.86	0.29	0.1
3	1.47	0.49	0.16
4	2.17	0.72	0.24
5	2.92	0.97	0.32
6	3.73	1.24	0.41
7	4.58	1.53	0.51
8	5.48	1.82	0.61
9	6.41	2.14	0.72
10	7.38	2.46	0.82
11	8.38	2.79	0.93
12	7.2	2.33	0.78

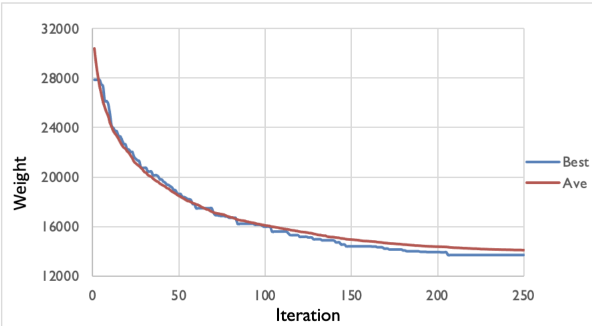
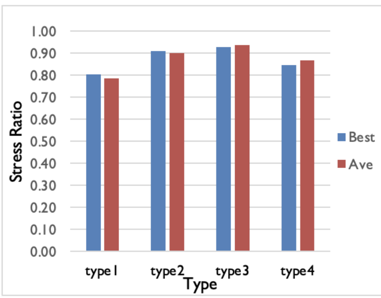


Figure 8: Showing the process of optimization of the second ultimate resistance sample (I section)

In the state of final strength with the I section in the 12-story structure, the weight has been reduced from 28,000 kg to 14,000 kg in the best case.

Figure 10 shows the average stress values of beams and columns for the first example of the LRFD method. The ratio of stresses obtained in both cases were favorable values in such a way that almost all the capacity of columns and beams was used.

The presented figure shows the highest stress in the beams of the seventh, eighth, and ninth floors, for which the calculated stress is 0.93 Meanwhile, the lowest stress is related to the beams of the first and second floors, which have a stress equal to 0.80. For the columns, the maximum and minimum stress values are 1.00 and 0.89.



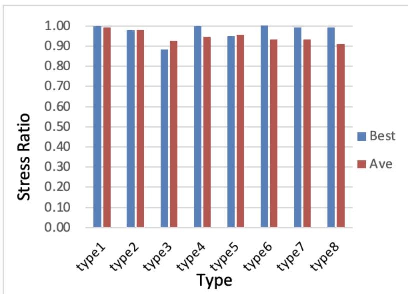


Figure 9: The ratio of stresses created in beams and columns of the third model (ultimate strength)

Table 9: Specifications of columns type (12-Story) – LRFD

Type	I section	Stress ratio
1	IPB 300	1.00
2	IPB 260-230*18	0.98
3	IPB 260	0.88
4	IPB 300	1.00
5	IPB 220	0.95
6	IPB 280	1.00
7	IPB 180	0.99
8	IPB 220	0.99

Table 10: Specifications of the beam type (12 floors) – LRFD

Type	I section	Stress ratio
1	IPE 330	0.80
2	IPE 300	0.91
3	IPE 270	0.93
4	IPE 220	0.85

Best Weight	13682 kg
Worst Weight	27881 kg
Ave Best Weight	14078 kg
Displacement	19.29 cm

5.2 The second sample with W sections:

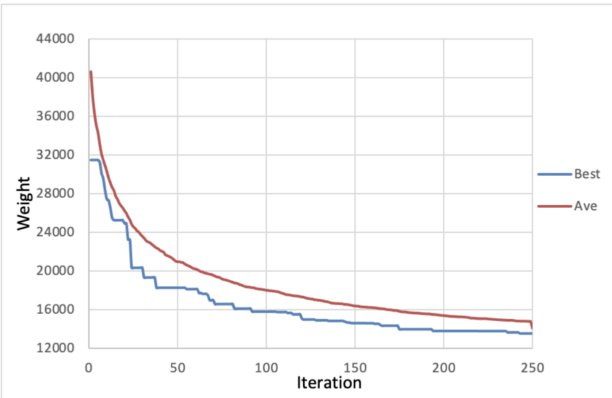
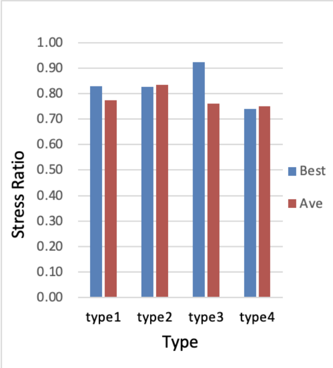


Figure 10: Showing the optimization process of the second sample in the state of ultimate strength (W section)

In the state of ultimate strength with W sections in a 12-story structure, the weight was found to be from 31483 kg to 13567 kg in the best condition, and also on average, the weight of the structure decreased from 40636 kg to 5648 kg



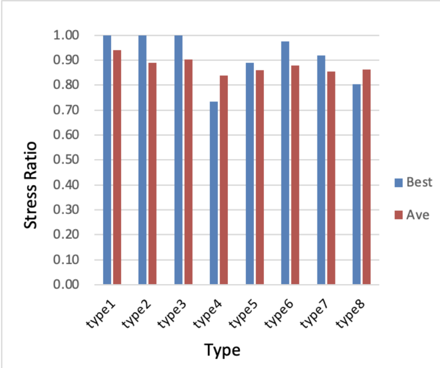


Figure 11: The ratio of stresses created in beams and columns (W section)

Table 11: Specifications of the type of beams (12 floors) - final strength

Type	I section	Stress ratio
1	W16X26	0.83
2	W16X26	0.83
3	W10X22	0.92
4	W8X21	0.74

Table 12: Specifications of columns type (12 floors) – LRFD

Type	I section	Stress ratio
1	W10X68	1.00
2	W14X109	0.98
3	W12X58	0.88
4	W10X100	1.00
5	W10X54	0.95
6	W12X79	1.00
7	W8X31	0.99
8	W10X49	0.99

Best Weight	13682 kg
Worst Weight	27881 kg
Ave Best Weight	14078 kg
Displacement	19.29 cm

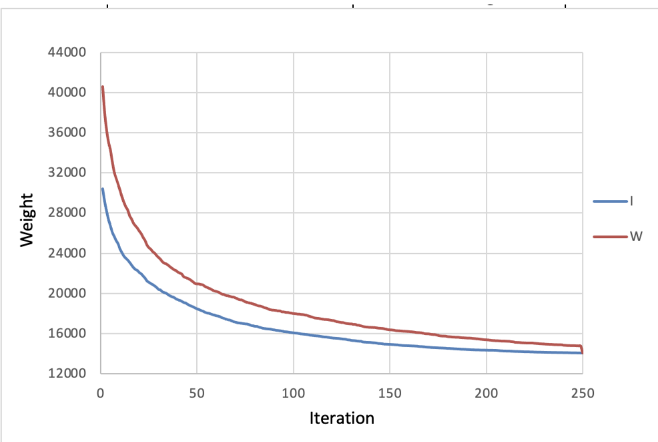


Figure 12: Showing the comparison of the optimization process of the second model for sections I and W (ultimate strength)

6 Conclusion

To analyze the operational mechanics of the algorithm for each model, graphs have been compiled that depict the correlation between the weight of the structure, the count of repetitions, and the number of times the objective function is collected. In addition, the stress ratio of each type of beam and column is given separately for each model.

Finally, the cost of the structure, the ratio of stresses, and the change of location show the optimal performance of the algorithm. Through a range of analyses, it has been determined that the algorithm demonstrates a low level of dependence on the initial population, a factor that can be viewed as a significant benefit of this algorithm. Generally, the results acquired from the optimization activities can be presented as follows:

1. The values of the stresses in the beams and columns confirm that in the LRFD method, all the capacity of the section has been used, which is considered the final goal of the algorithm.

2. According to the graphs presented concerning how the algorithm works, it can be concluded that the algorithm did not stop at the local optimum and achieved the overall optimum.

3. In the comparison of optimization using the I section and W section by LRFD method, we can see that in the first example including the structure with low height, the W section showed better performance than the I section and provided a lighter structure. However, in the high-height structure, the I section showed better performance than the W section section.

4. It can be concluded that the W section for low-height structure and the I section for high-height structure have better performance.

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