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Research Article

Optimum design of a vaulted roof steel structure using grey wolf and backtracking search optimization algorithms through application programming interface

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ABSTRACT

In present study, structural formation identification of a vaulted roof steel structure is taken as optimization problem. The cost of a steel structure is directly related to the weight of the structure. Weight minimization of the vaulted roof steel structure is considered as objective function of the design problem. The design problem is intended to be as realistic as possible. Wind loads and snow loads are calculated in direction of TS EN 1991-1-4 and TS EN1991-1-3practice code specifications, respectively. And dead loads reobtained in terms of gravity. The structural design constraints of the optimization problem are determined according to American Institute of Steel Construction-Allowable Stress Design (AISC-ASD). In the design, W-shaped steel profile sections to be selected for assigning to the structural elements are considered as discrete design variables. Grey Wolf Optimizer (GWO) and Backtracking Search Optimization (BSO) algorithms that are relatively recent metaheuristic algorithms are utilized as optimizer tools to obtain the minimum weighted structural design. The vaulted roof steel structure is initially modeled in a finite element packaged software (ANSYS Workbench v18.1). Then, using the application programming interface of the software, integration of finite element model with GWO and BSO optimization algorithms encoded in Microsoft Visual Basic for Application (MS VBA v7) programming language is provided. Thus, the performances of two new generation optimization algorithms in design optimization of a vaulted roof steel structure are compared and the benefits of the application programming interface are demonstrated.

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1. Introduction

Nowadays, it has become more significant to design long-span structure with low costs in the construction sector due to the scarcity of raw material resources. A vaulted roof steel structure stands out with its cost and construction speed (Wu et al., 2020). Additionally, this type of structure presents lightweight roof systems to reduce self-weight of the steel structure (Pavic et al. 2002). In the building sector, the vaulted roof steel structures are used various fields such as canopy roofs (Natalini et al. 2013), greenhouses (Demetres et al. 2016), factory buildings, etc. and they are also used in the most of long-span structures (Hamdy et al. 2018).

The structural engineers are currently faced with many complicated engineering design problems and that means confrontation a lot of mathematical operations. This becomes more complex when the material and geometric non-linearity and the many details of the practice provisions are added to the operations. Finite element analysis (FEA) packaged software are often used to overcome this complexity. These software shave developed considerably in recent years. They are used for simulation of the designing structures. So, these FEA packaged softwares help the structural engineers before site construction. But, in the pre-design phase, the trial-and-error method is commonly used by structural design engineers to decide the sizes of load carrying structural ele-

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ments. This is not enough for yielding an optimum structure in such a complex design problem since the decided variables affect each other in a structural design.

An optimum design is to find the most suitable design simultaneously considering design variables and design constraints. It consists of three main parts such as objective function, design variables, and design constraints. In a steel structure design, the objective of the design problem is generally cost of the structure. And this is directly related to weight of the steel structure. The design variables may be any dimension of the structure and/or cross sections of the structural members. The design constraints of such a design problem come from the provisions of code specifications and practicality.

There are various kinds of optimization methods. These are basically divided into two main groups such as deterministic and probabilistic (stochastic) optimization methods. The deterministic methods contain many complex mathematical operations such as gradients. Since a structural optimization problem to be solved is already quite complex, the probabilistic methods come to the forefront in this case. But it cannot be claimed that the designs obtained from probabilistic optimization algorithms based on randomness are exact optimum. But there is a great variety of design problems in which they cannot be solved via deterministic methods (Carbas et al. 2021).

Stochastic optimization methods are developed day by day. Both existing optimization algorithms are developed, and new generation algorithms are emerged. In the literature, it is seen that these algorithms increase their popularity with classical algorithms such as particle swarm optimization algorithm (PSO) (Kennedy and Eberhart 1995), harmony search algorithm (HSA) (Woo et al. 2001) and genetic algorithm (GA) (Goldberg and Holland 1988). The new generation algorithms such as African vultures optimization algorithm (Abdollahzadeh et al. 2021), honey badger algorithm (Hashim et al. 2022), rain optimization algorithm (ROA) (Moazzeni and Khamehchi 2020), new caledonian crow learning algorithm (Al-Sorori and Mohsen 2020), etc. have been added to these in the last decades. In addition, new versions of old algorithms are also emerging (Ponz-Tienda et al. 2017; Huang and Chen 2020; Postolov and Iliev 2022; Chakraborty et al. 2021; Khan and Ling 2021).

In the optimization process, encoding of a complex optimization problem is time consuming. Stochastic optimization algorithms operate the objective function as it is. The derivatives of the function are not needed. Therefore, the full expression of the objective function is not required. It is sufficient to only get the outputs of the function for stochastic optimization. Many FEA-based packaged software present their users access opportunity to application programming interfaces (API). So, the outputs that express the design purpose and can be obtained from the FEA packaged software can be used directly.

In this study, a vaulted roof steel structure is modeled via ANSYS Workbench v18.1 which is a famous FEA-based packaged software. Here, the snow loads and wind loads are considered TS EN 1991-1-3 and TS EN 1991-1-4 (2007), respectively. Besides, the ground acceleration is assigned in finite element method (FEM). Thus, the dead loads are considered as weight of the vaulted roof steel structure. The cross-sections of the four frame member groups are treated as design variables. The cross-sections of the frame elements are selected from the available profile list in AISC. Then, the grey wolf optimizer (GWO) and the backtracking search optimization (BSO) algorithms are encoded in Microsoft Visual Basic for Application (MS VBA v7). After then, the optimization algorithms are integrated in interface of the ANSYS Workbench v18.1 by using IRONPYTHON script. Thereby, a new and complex optimization design problem can be optimized with two novel metaheuristics. Thus, the designing of a vaulted roof steel structure is handled in detail using the API, and the performances of the two new optimization algorithms in obtaining minimum weight of a vaulted roof steel structure are compared and evaluated.

2. Design of a Vaulted Roof Steel Structure

The design of a vaulted roof steel structure having minimum structural design weight is taken into account as the objective of the optimization problem. This can be explained in more detail as follows.

Here, the I^T vector consists of steel sections of the vaulted roof steel structure. It includes N_d different section groups (Eq. (1)). Each member of the vector is represented as a sequence number of the steel sections as in the profile list.

$$I^T = \left[I_1, I_2, I_3, .., I_{N_d}\right] \tag{1}$$

The weight of the structure can be calculated by multiplying the volume of the structure and the unit weight as shown in Eq. (2).

$$W = \sum_{i=1}^{N_d} \rho_i A_i \sum_{j=1}^{N_t} L_j \tag{2}$$

Here, ρ_i is unit weight of the steel, A_i is the cross-section area of the steel profiles, N_t is the total number of the member in a group, and L_j is the length of each member.

Each member of the structure exposes to mechanic and geometric restrictions in design process. The mechanic limits can be given as follows.

$$\frac{(\delta_j - \delta_{j-1})}{h_j} \leq \delta_{ju} \quad j = 1,2,3, .., ns \tag{3}$$

Here, the inter-story drift of the structure stories should be limited with Eq. (3). The δ_j and δ_{j-1} are two lateral deflections of respective story, h_j is the story height, and δ_{ju} is the ultimate limit of the story drift ratio and ns is number of stories. Additionally, other displacements on the structure are limited using Eq. (4).

$$\delta_i \leq \delta_{iu} \qquad i = 1,2,3, .., nd \tag{4}$$

Here, nd is the total number of limited displacements. δ_i is the occurred deflection, andδ_{iu} is the upper bound in the deflection. These may be horizontal column deflections or vertical beam deflections.

The shear capacities of the whole members of the structure are checked.

$$V_u \leq \varphi V_n \tag{5}$$

Here, V_u is the required shear strength, φ is resistance factor in shear, V_n is nominal shear strength. Furthermore, combined stresses on the structural members are considered.

$$\left(\frac{P_u}{\varphi_c P_n}\right) + \left(\frac{8}{9}\frac{M_{ux}}{\varphi_b M_{nx}}\right) \leq 1 \quad \text{for} \quad \frac{P_u}{\varphi_c P_n} \geq 0.2 \tag{6}$$

$$\left(\frac{P_u}{2\varphi_c P_n}\right) + \left(\frac{M_{ux}}{\varphi_b M_{nx}}\right) \leq 1 \quad \text{for} \quad \frac{P_u}{\varphi_c P_n} \leq 0.2 \tag{7}$$

In Eqs. (6) and (7), P_u is applied axial load, P_n is nominal axial strength, φ_c is resistance factor in compression, φ_b is resistance factor in bending, M_{ux} is applied moment, and M_{nx} is nominal flexural strength. The two W-shaped steel sections are intertwined in some connections of the frame. Finally, the flange width of the beam section (B_{jb}) should be equal or less than the flange width of column section (B_{jc}).

$$B_{jb} \leq B_{jc}, \quad j = 1,2,3,\ldots,n \tag{8}$$

3. Calculation of Wind and Snow Loads

In this study, in order to determine the wind and snow loads, the TS EN 1991-1-4 and TS EN-1991-1-3 are considered, respectively.

3.1. Wind loads

The basic wind velocity is calculated considering directional factor C_{dir} and season factor C_{season}. The values of both are recommended as 1.0.

$$V_b = C_{dir} C_{season} V_{b,0} \tag{9}$$

The mean wind velocity $V_m(z)$ is obtained using the basic wind velocity V_b as Eq. (10).

$$V_m(z) = C_r(z) C_0(z) V_b \tag{10}$$

In here, $C_o(z)$ is the orography factor. Recommended value of this factor is 1.0. $C_r(z)$ is roughness factor. It can be calculated using Eq. (11).

$$C_r(z) = k_r \, ln\left(\frac{z}{z_0}\right) \quad \text{for} \quad z_{min} \leq z \leq z_{max}$$

$$C_r(z) = C_r(z_{min}) \quad \text{for} \quad z \leq z_{min} \tag{11}$$

In Eqs. (11) and (12), z is the height of the structure. Here, four different terrain categories are considered. The value of z_0 and $z_{\min}$ are determined using Table 1. $z_{\max}$ is taken as 200m for all terrain categories. k_r is terrain factor depending on z_0. It can be calculated as follow.

$$k_r = 0.19 \left(\frac{z_0}{z_{0,II}}\right)^{0.07} \tag{12}$$

The standard deviation of the turbulence σ_v is obtained via Eq. (13).

$$\sigma_v = k_r V_b k_l \tag{13}$$

Here, it is recommended to take the turbulence factor k_l as 1.0. The turbulence intensity $I_v(z)$ can be calculated using Eq. (14).

$$I_v(z) = \frac{\sigma_v}{V_m(z)} = \frac{k_l}{C_0(z) \, ln\left(\frac{z}{z_0}\right)} \quad \text{for} \quad z_{min} \leq z \leq z_{max}$$

$$I_v(z) = I_v(z_{min}) \quad \text{for} \quad z \leq z_{min} \tag{14}$$

Then, the peak velocity pressure $q_p(z)$ is determined via Eq. (15).

$$q_p(z) = [1 + 7 I_v(z)] \frac{1}{2} \rho V_m^2 \tag{15}$$

Finally, wind pressure on the surface $\mathrm{w_e}$ depending on the pressure coefficient C_{pe} is calculated using Eq. (16). The wind pressure acting on the internal surfaces w_i of the structure can also be calculated by Eqs. (16) and (17).

$$w_e = q_p(z_e) C_{pe} \tag{16}$$

$$w_i = q_p(z_i) C_{pi} \tag{17}$$

Table 1. Terrain categories and terrain parameters (EN 1991-1-4).

Terrain category	Descriptions	z_0 (m)	$z_{\min}$ (m)
0	Sea or coastal area exposed to the open sea	0.003	1
1	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0.01	1
2	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0.05	2
3	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0.3	5
4	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1	10

The calculation on the wind load of the circular cylindrical roof and domes is given in TS EN 1991-1-4, in section 7. Here, the roof is divided into four equal surfaces. The first of these parts is called A, the second and third surfaces are called B, and the last is called C. Wind loads on all parts are calculated using $C_{\mathrm{pe,10}}$ coefficients from the Fig. 1. In here, f is height of the roof, h is the height of the columns and d is the span of the roof.

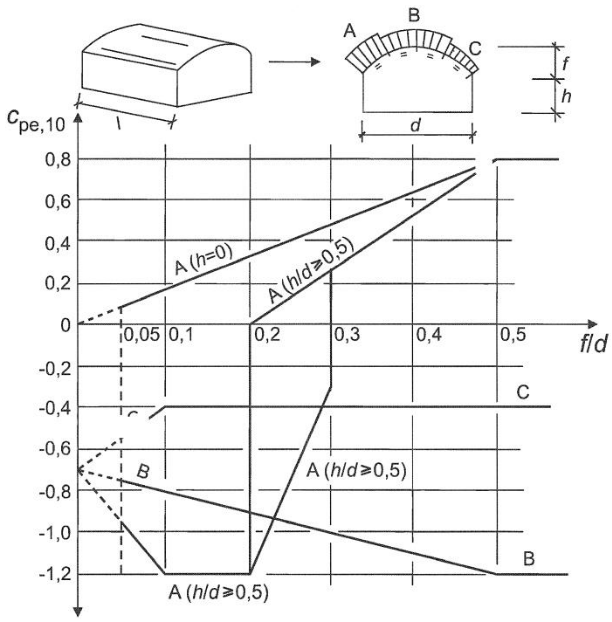

Fig. 1. The external pressure coefficients of $C_{\mathrm{pe,10}}$ recommended for rectangular based vaults (EN 1991-1-4).

The wind pressure on the vertical wall of rectangular plan buildings is considering as given in section 7 in TS EN-1991-1-4.

3.2. Snow loads

In Eurocode (EN 1991-1-3), snow loads on the roof are calculated using Eq. (18).

$$S = \mu_i C_e C_t S_k \tag{18}$$

Here, S is snow load, μ_i is shape coefficient, C_e is exposure coefficient and C_t is thermal coefficient. S_k is the characteristic value of snow load on the ground. For some glass covered roofs, the snow load is reduced because of melting caused by heat loss. For other cases C_t is considered as 1.0. C_e can be specified depending on topology or, it can be taken as 1.0. To determine snow load on the cylindrical roof, drift case is considered. In Fig. 2, case (i) and case (ii) represent the undrifted and drifted load arrangement, respectively. In this study, undrifted load arrangement is considered. Finally, S_k can be determined via Attachment-E.

4. Stochastic Optimization Techniques

In this study, to design vaulted roof steel structure two novel optimization algorithms are used. Thus, the performance of grey wolf optimizer (GWO) and backtracking search optimization algorithm (BSOA) on a vaulted roof steel structure are investigated. Additionally, obtained performances in finding the minimum structural weight are compared and evaluated.

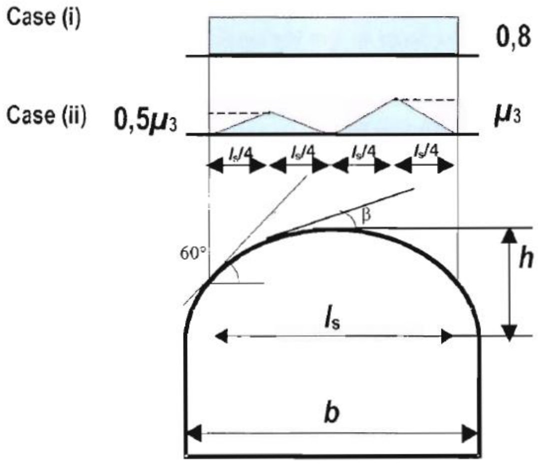

Fig. 2. The shape coefficients of the cylindrical roof.

4.1. Grey wolf optimizer (GWO)

Grey wolf optimizer was developed by Mirjalili et al. (2014) inspiring behaviors of grey wolves (Canis lupus). They hunt the preys as a group and, these animals have a hierarchy. There are three dominant grey wolf named alpha (α), beta (β) and omega (ω) in the hierarchical structure. The most dominant one is the alpha.

Hunters who hunt in groups surround their prey at the beginning of the hunt. The encircling behavior of grey wolves is represented by Eqs. (19) and (20).

$$\vec{D} = \left|\vec{C}\vec{X}_p(t) - \vec{X}(t)\right| \tag{19}$$

$$\vec{X}(t+1) = \vec{X}_p(t) - \vec{A}\vec{D} \tag{20}$$

Here, t is the number of iterations. $\vec{X}$ and $\vec{X}_p$ are the positions of grey wolves and prey, respectively. $\vec{A}$ and $\vec{C}$ are the coefficient vectors given in following equations.

$$\vec{A} = 2\,\vec{a}\vec{r}_1 - \vec{a} \tag{21}$$

$$\vec{C} = 2\,\vec{r}_2 \tag{22}$$

In Eqs. (21) and (22), $\vec{r}_1$ and $\vec{r}_2$ are randomly generated vectors. They are between 0 and 1. $\vec{a}$ is linearly reduced 2 to 0 during the iterative process.

The hunting begins after the prey or preys encircled. The alpha, most dominant gray wolf, leads the hunt. But sometimes beta and gamma also have an effect. So, the locations of all grey wolves are repositioned according to the top three best results. For this purpose, following equations are operated.

$$\vec{D}_\alpha = \vec{C}_1\vec{X}_\alpha - \vec{X},\ \vec{D}_\beta = \vec{C}_2\vec{X}_\beta - \vec{X},\ \vec{D}_\delta = \vec{C}_3\vec{X}_\delta - \vec{X} \tag{23}$$

$$\vec{X}_1 = \vec{X}_\alpha - \vec{A}_1(\vec{D}_\alpha),\ \vec{X}_2 = \vec{X}_\beta - \vec{A}_2(\vec{D}_\beta),\ \vec{X}_3 = \vec{X}_\delta - \vec{A}_3(\vec{D}_\delta) \qquad (24)$$

$$\vec{X}(t+1) = \frac{\vec{X}_1+\vec{X}_2+\vec{X}_3}{3} \qquad (25)$$

The grey wolves complete the hunt by attacking after they stop the repositioning. Here, the $\vec{A}$ starts to decrease due to the decrease in $\vec{a}$. This forces the gray wolves to attack.

4.2. Backtracking search optimization algorithm (BSOA)

Civicioglu (2013) studied on a novel metaheuristic algorithm named backtracking search optimization (BSO) algorithm. BSOA consists of five main processes named initialization, selection-I, mutation, crossover, and selection-II. In initialization, initial parameters are entered into the algorithm such as population size, number of dimensions of problem, lower and upper bounds of search spaces est. Then, initial population is generated as in Eq. (26).

$$P_{i,j} \sim U(\mathrm{low}_j, \mathrm{up}_j) \qquad (26)$$

Here, U represents uniform probability distribution and, each $P_{i,j}$ in the population P is possible solution value.

In the selection-I, historical population P_{old} is determined. When P_{old} is first defined, it is randomly generated, as in P. Then, Eq. (27) is used for the following iterations.

$$\text{if } a < b \ \text{ then } \ \mathrm{old}P := P|a, b \sim U(0,1)| \qquad (27)$$

In Eq. (27), a and b are random value between 0 and 1. If a is smaller than b, member of P_{old} is changed with member of P. Else, value of P_{old} is saved as memory of BSOA. Then, the order of the individuals in P_{old} is randomly changed via Eq. (28).

$$\mathrm{old}P := \mathrm{Permuting}(\mathrm{old}P) \qquad (28)$$

In the mutation process, first form of the trial population Mutant is determined using Eq. (29).

$$\mathrm{Mutant} = P + F\ (\mathrm{old}P - P) \qquad (29)$$

Here, F is a coefficient that adjusts the amplitude of the search direction. It may be generated randomly in each iteration. The final form of the trial population T is generated in crossover stage. The crossover process consists of two main stages. In the first, the binary integer-valued matrix (map) is randomly generated. Its elements are the values 0 and 1. The matrix dimensions of the *map* are same as T and P. If the member of *map* is equal to 1.0, the member of T is manipulated via the relevant member of P in same numbered row and column. After that, each member of T is checked to ensure that its value between upper and lower boundaries. In case the values exceed the limits, boundary values are assigned instead of these values.

In selection-II, global minimum value is checked. If the *global minimum value* that saved is worse than the fitness of best individual of P (P_{best}). The best fitness value of the P is assigned to the *global minimum value* in memory.

5. Application Programming Interface (API)

Many structural optimization problems can be modeled by the matrix-displacement method. In structural design problems, it is very important that the obtained designs are as realistic and practicable as possible. The structural design problems become so complex when material nonlinearity, geometric nonlinearity, specification provisions, and serviceability are considered.

There are many finite elements (FE) based packaged software based on the matrix-displacement method that are frequently used in the construction industry. This is why the building simulations through these are easy. Additionally, some FE-based packaged software allow to connect interface of the software via commonly used programming languages.

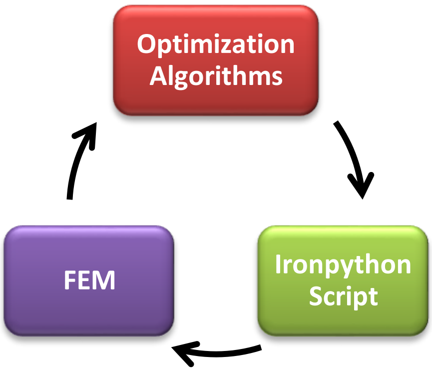

Fig. 3. Interaction between finite element model (FEM) and optimization algorithms via IRONPYTHON script.

In this study, the API functions of ANSYS Workbench v18.1 is used to connect it with the BSOA and GWO algorithms which are encoded in MS VBA 7. To make this, IRONPYTHON script is utilized as seen Fig. 3. Thus, optimum design information is transferred to FEM-based ANSYS as inputs and, the results of FEM analysis obtained from ANSYS are given as outputs.

6. Design Example

The minimum weighted design of a vaulted roof steel structure is considered as design example of this study. The heights of the column elements are 10m and the total height of the structure is 12m. The spans of the beams are 20m and the total length of the structure is 40m. The spans of the roof purlins and the wall purlins are 10m. The design variables of the optimization problem are the cross-sections of the structural members. All members are divided in to four different member groups. These are the columns, the beams, the wall purlins, and the roof purlins. In Fig. 4(a), each of these is depicted by different colors. The thicknesses of the roof and sidewall panels shown in Fig. 4(b) are considered as 1mm steel sheet. The maximum mesh size is taken as 80cm. The quadrilateral method is used for surface meshing of the steel sheet. The finite element model of vaulted roof steel structure consists of totally 6410 nodes and 487 elements. In Fig. 4(c), the mesh distribution is seen.

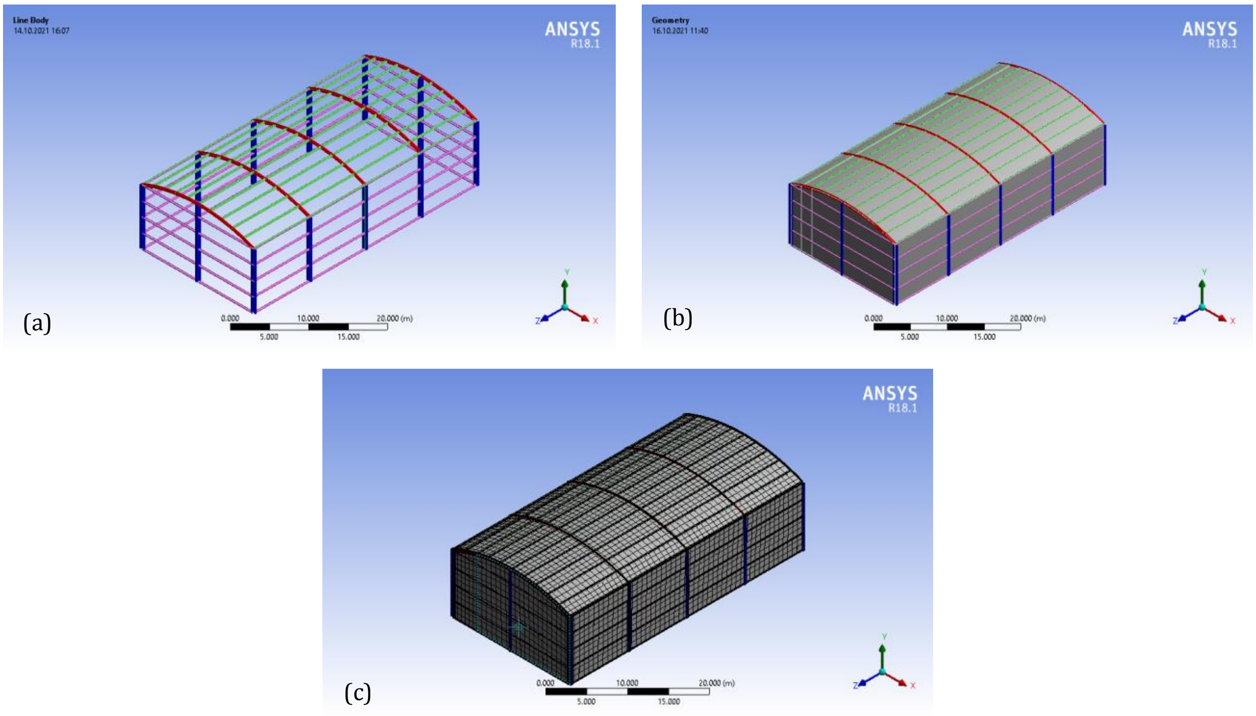

Fig. 4. The geometry, member groups and mesh distribution of the vaulted roof steel structure.

The snow and wind loads are subjected to the structure directly over the panels as in reality. The vaulted roof steel structure is modeled in ANSYS Workbenchv18.1. The entire structure is under the influence of gravity. So, the dead loads vary depending on the structural weight for each proposed design. The snow load acting on the roofis924 Pa according to provisions of TS EN 1991-1-3. The wind loads are determined considering the provisions of TS EN 1991-1-4. Thus, outer surface of the structure is divided into nine regions as shown in Fig. 5. All the wind loads acting on these regions are tabulated in Table 2.

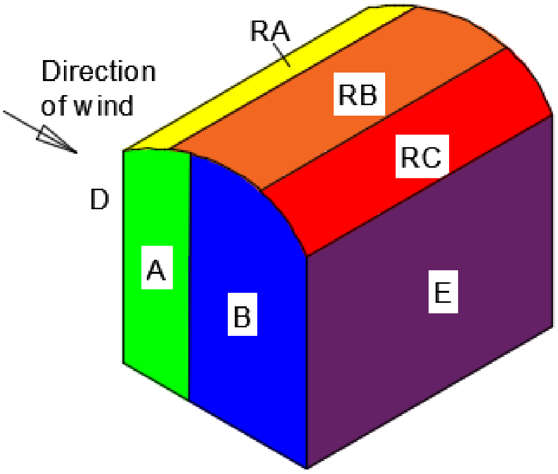

Fig. 5. Wind load regions of the vaulted roof steel structure.

Table 2. Wind loads acting on the regions of the vaulted roof steel structure.

Wind loads on side		Wind loads on the roof	
Name	Wind load	Name	Wind load
A	1452 Pa	RA	1742 Pa
B	871 Pa	RB	1162 Pa
D	649 Pa	RC	581 Pa
E	281 Pa		

In the optimization process, the GWO and BSO algorithms are used as optimizer tools of this study abovementioned in Section 4. The population sizes of both metaheuristic algorithms are considered as 7. The obtained optimal design results are presented in Table 3. Additionally, integer number of the W-sections are given in parenthesis. It is clear from this table that the BSO algorithm yields the minimum weighted structure with design weight of 78.604 ton. The GWO acquires slightly heavier structural design than BSO with design weight of 78.77 ton. The difference between optimal structural design weights yielded via GWO and BSO algorithms is only 0.21%. This proves that the algorithmic performances of both algorithms are almost similar for this design example. Additionally, it is seen from the Table 3 that the stress constraints are not effective for this structural design problem, instead the vaulted roof steel structure is sized according to the displacement limiters.

Table 3. The obtained optimum results.

	Number of cycle	Assigned section to columns	Assigned section to beams	Assigned section to roof purlins	Assigned section to wall purlins	Weight (ton)	Stress ratios	*X*-def$_{max}$ (m)	*Z*-def$_{max}$ (m)	*Y*-def$_{max}$ (m)
BSO	159	W530x82 (137)	W410X100 (168)	W310x21 (242)	W310x28.3 (240)	78.604	0.587	0.020	0.011	0.049
GWO	424	W530x72 (138)	W460x89 (159)	W310x21 (242)	W310x500 (213)	78.766	0.596	0.020	0.012	0.050

The maximum iteration number which can be identified as the maximum needed structural analysis is taken as 1000 for both algorithms. But the BSO and GWO algorithms accomplished the optimum designs in 159th and 424th iterations, respectively. So, it can be concluded that the BSO algorithm needs less computational effort. In design history graph as shown in Fig. 6, it is enough to present feasible design weights obtain in the first 500 iterations. Furthermore, it is obviously seen from this figure that although the BSO algorithm revealed worse performance in the earliest phases of the optimization process, it ended with lighter design as final.

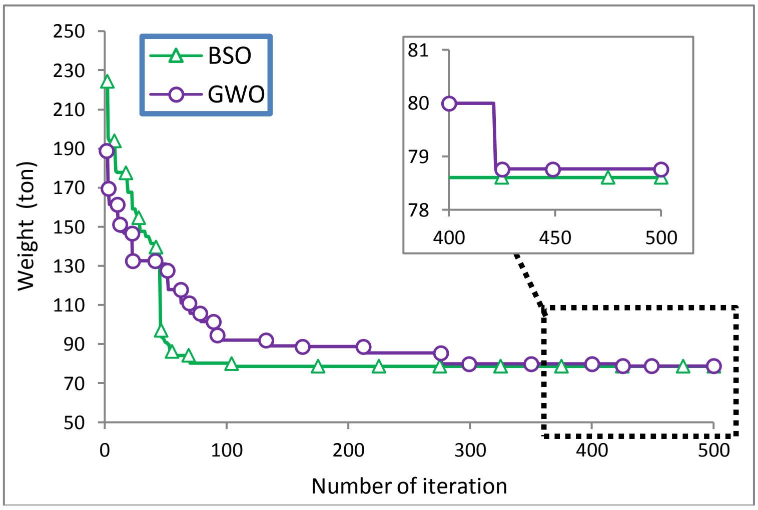

Fig. 6. The minimization performance of the BSO and GWO.

7. Conclusions

In this study, the design optimization of a vaulted roof steel structure to obtain minimum structural weight is considered as an optimization problem. The cross-sections of the roof purlins, the wall purlins, the beams and the columns are treated as design variables of this problem. They are taken into account as discrete design variables and, The W-shaped steel profiles are selected from available list of American Institute of Steel Construction (AISC). The encoded optimization algorithms are supplied with structural responses in virtue of a finite element method (FEM) based software integrated through application programming interface. (API). Thus, the vaulted roof steel structure is modelled in ANSYS Workbench v18.1. It is subjected to wind and snow loads as well as the dead loads. The TS EN 1991-1-4 and TS EN.1991-1-3 provisions are used to determine the wind and snow loads, respectively. The gravity is directly assigned to FEM for defining the dead load. The structural design constraints of optimization problem are considered using the limitations of AISC-ASD. The Grey Wolf Optimization (GWO) and Backtracking Search Optimization (BSO) algorithms, which are two novel metaheuristics, are encoded via Microsoft Visual Basic programming language to obtain the minimum weighted designs. The FEMs integrated to these algorithms utilizing the IRONPYTHON script file which are so-called the API functions.

This study leads to the following chief concluding remarks;

- The vaulted roof steel structures have an important role in the construction sector, especially in long-span structures.
- The GWO and BSO algorithms are primary used as design optimizer of such a structure in this study.
- Even the maximum number of structural analyses are taken as 1000, the BSO and GWO reaches the optimum designs in the 159th and 424th iterations, respectively. These verify that the BSO algorithms displays the most advantageous with respect to computational effort. Also, the BSO algorithm acquires the lightest vaulted roof steel structure, the those designed with the GWO algorithm has only 0.21% heavier design.
- The present findings confirm that thanks to the application programming interface (API), the optimum design problems can be handled in a very detailed way especially in having structural behavior responses more accurately.

Eventually, this study gives researchers an idea about how complex engineering design optimization problems can structurally be dealt by integrating optimization algorithms with the finite element method based software with aid of the application programming interface ability. As a future work, it is aimed to add the roof slope among the design variables. In this way, the structure can dynamically behave under acting loads, so the more realistic structural characteristics are taken into account in the design.

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Conflict of Interest

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