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Research Article

Optimum design of purlin systems used in steel roofs

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ABSTRACT

In this study, one existing purlin system which is used in steel roof is optimized by taking into account less cost and bearing maximum load via developed software. This software runs with firefly algorithm which is one of the recent stochastic search techniques. One of the metaheuristic techniques, so-called firefly algorithm imitates behaviors of natural phenomena. Behaviors and communications of firefly are inspired by this algorithm. In optimization algorithm, steel sections, distance between purlins, tensional diagonal braces are determined as design variables. Design loads are taken into account by considering TS498-1997 (Turkish Code) in point of place where structure will be built, outside factors and used materials. Profile list in TS910 is used in selection stage of cross sections of profile. Constraints of optimization are identified in accordance with bending stress, deformation and shear stress in TS648. Design variables of optimization are selected as discrete variables so as to obtain applicable results. Developed software is tested on existing real sample so; it is evaluated with regard to design and performance of algorithm.

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1. Introduction

Approach of civil engineers to engineering problems inclines safety, economy and aesthetic. Among these, if anyone is ignored, solution of engineering problem will be insufficient. Therefore, it is not enough that a developed system has required functional conditions (Esen and Ülker, 2008). So, all systems which will be designed must require to be economic beside providing required functional conditions. Yet, it is quite difficult to do via traditional designs and solution methods when discussed engineering problems have complex structure which includes nonlinear material properties, multiple variables and est. properties. To analyze these complex problems, there are various software which include optimization tool. Çiftçioğlu et al. (2017) is investigated wind load design for hangar with different geometry via finite element method. Akpınar et al. (2017) optimize transportation system by using simulation software. Using optimization methods has been widespread for these problems. As a structural optimization example, Değertekin et al. (2007, 2008) optimize linear and nonlinear geometric steel frame systems by accepting minimum cost as objective function. Optimization is a method that can find suitable solutions in line with target or targets under specific conditions (Keleşoğlu and Ülker, 2005). Optimization is investigated in three main categories as topology optimization, shape optimization and size optimization according to the problem. (Erdal et al., 2011; Mooneghi and Kargarmoakhar, 2006; Rong et al., 2000). In the same way, optimization is investigated according to solution methods as deterministic and stochastic methods. Metaheuristic optimization techniques which are designed by inspiring natural phenomena are developed under randomness optimization methods. These methods become popular with based on probability effective solutions without need complex mathematical equations (Yang et al., 2003).

There are various metaheuristic search techniques available in the literature for structural optimization problems. Genetic algorithm, evolutionary algorithm, ant colony algorithm, particle swarm optimization and artificial bee colony algorithm etc. can be indicated as samples (Sonmez et al., 2013). In this study, an optimum

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design software is developed by using among them firefly algorithm that is one of the randomness optimization techniques. Sizes of purlin systems frequently used in steel roof structure are optimized to can carry snow load, earthquake load, wind load, dead load and to have minimum weight. Loading condition in problem, strength constrains and geometric constrains are considered from Turkish Standards (TS). In order to obtain applicable results, discrete variables are used in optimum design algorithm. In this way, option of steel profile used in solution is selected from profile table in TS910. Obtained results by using optimum design software which based on firefly algorithm are investigated with regarding to both of design and performance of algorithm.

2. Purlin Optimization Method

Purlins are one of the basic member of roof structure. Acting on the load to the structure such as live load, dead load and wind load is transmitted to other structural member by means of purlins. Additionally, they support to roof deck. These structural members are used commonly. Optimization of structural member which so often used in building sector is quite important in cost. Conception of optimization is essentially investigated in two main options as scholastic and deterministic. In stochastic method which is used in this study, randomness is utilized in the process of optimization. Firefly algorithm which is one of the stochastic optimization techniques is a metaheuristic method which is designed by inspiring natural phenomena. Firefly algorithm is developed by observing social behaviors of firefly which live in tropical regions and by imitating these behaviors.

2.1. Firefly algorithm

The name of firefly algorithm, it is developed by Yang et al. (2009), come from firefly which live in tropical region and which is taken sample when selection stage of algorithm. Chemical is identified as "lusiferine" is used in organ which products light. "lusiferine" react with Oxygen and "lusiferase", that is name of other chemical. In this way, light is produced. Attraction of a firefly is directly proportional to its shine. There are several similarities about this algorithm and other metaheuristic based optimization methods. But, it is generally easier in applications. According to researchers, main purpose of producing light is to attract attention of other fireflies by sending signal. Among estimated other purpose, there are to find friends, to take potential prey and to protect itself from hunter. Genders of fireflies are not considered. Therefore, it is assumed that all of the fireflies have same gender. Because of there is not gender gap, the more fireflies are shiny, the more they have attractiveness. Distance between fireflies decreases light of fireflies. Thus, attraction between fireflies decreases. If a firefly sees brighter than itself, it moves to this seen. If most shiny firefly is itself, firefly will move randomly. In algorithm, each firefly is represented by a design variable. Objective function value is represented by light of fireflies. Design vector (value of design variable) is linked to position of fireflies. It is possible to summarize steps of firefly optimization algorithm as below (Değertekin et al., 2015);

<u>*First step: Initializing of parameter and generating positions of firefly:*</u> Firstly, parameters of optimization are defined such as number of firefly (n), randomness coefficient (α), brilliancy (β_0) and distance (γ). After the parameters of algorithm are defined, starting positions is randomly selected according to following equation.

$$\boldsymbol{x}_{i,j}^{0} = \boldsymbol{x}_{j,min} + rnd \cdot \left(\boldsymbol{x}_{j,max} - \boldsymbol{x}_{j,min}\right)\ . \qquad i = 1,2,\dots,n\ \ ;\ \ j = 1,2,\dots,td \tag{1}$$

In the above equation, *rnd* is a random value generated between 0 and 1, $\boldsymbol{x}^0_{i,j}$ is defined as value at number *i* firefly in the moment of initializing (*t*=0) and at number *j* dimensions, $\boldsymbol{x}_{j,max}$ is maximum limit of number *j* design value, $\boldsymbol{x}_{j,min}$ is limit of number j design value and *td* is total number of the design variables (dimension number of problem space). Performance of fire fly is investigated at current positions, after beginning position generate. In other words, values of objective functions ($f(\boldsymbol{x})$) are calculated by using assigned designs to firefly. After this process, designs and value of objective functions which is calculated by using design values are saved to algorithm memory.

<u>*Second step: Determination of light intensity of fireflies:*</u> In this step, light intensity of fireflies ($\boldsymbol{I}$) is determined as related to objective functions value of assigned design. In this study, cost minimization is purposed. Cost of purlin system which is used in steel roof is inversely proportional to their weight. So, light intensity is determined according to below equation.

$$\boldsymbol{I} = \frac{1}{f(x)}\ . \tag{2}$$

<u>*Third step: Updating position of fireflies:*</u> In this step, fireflies move to others which have more attractiveness. Modification of positions is updating design in firefly algorithm. Modification of position equation which is developed by depending on Levy flight theorem is formulized below.

$$\boldsymbol{x}_{i,j}^{t+1} = \boldsymbol{x}_{i,j}^{t} + \beta_0 \cdot e^{-\gamma r_{i,k}^2}\left(\boldsymbol{x}_{i,j}^{t} - \boldsymbol{x}_{k,j}^{t}\right) + \alpha \cdot \varepsilon_i^t\ . \qquad i,k = 1,2,\dots,n\ \ ;\ \ j = 1,2,\dots,td \tag{3}$$

In Eq. (3), *t* is number of steps, *k* index show fireflies which is determined to approach by number *i* firefly, ε is a weight coefficient which explains of new position of fireflies and $r_{i,k}$ distance between fireflies number *i* and number *j* respectively. Euclidean distance $r_{i,k}$ is calculated by Eq. (4).

$$r_{i,k} = \sqrt{\sum_{j=1}^{td}\left(x_{i,j} - x_{k,j}\right)^2}\ , \tag{4}$$

<u>*Fourth step: Revaluation of fireflies by considering updated positions:*</u> Objective function values of design of

fireflies which updated positions in previous stage are calculated similarly with end stage of first step and memory of algorithm is updated. Best firefly in the memory is saved and it is returned to second step. Processes between second and forth steps iterates until it reaches maximum number of cycle. Best solution in memory of algorithm at the end of iterative solutions is considered optimum result.

3. Mathematical Model of Purlin Optimization

In this study, software which has the capability of optimum design is developed. For this purpose, purlin design problem is converted to optimization problem and, mathematical model of problem is created. Generally, modeling of optimization problem consists of three main parts, objective function, design variables and design constrains. Objective function is identified as purpose which is converted to mathematical function. Main purpose in optimization problem of steel roof purlin systems is to minimize cost of purlin structure. Objective function can be identified for purlin systems design optimization as below.

$$M(\boldsymbol{x}) = M_k + M_a + M_p + M_g \,. \tag{5}$$

In objective function equation above, M is total cost of purlin in steel roof, M_k is total welding cost in production of purlin, M_a is total anchoring cost in production of purlin, M_p is total cost of profile which will be used and M_g is total cost of brace which will be used during construction phase.

Design variables are one of the three main parts of optimization which can change objective function value. In problem of purlin system optimization, distance between purlins, slope of roof, cross section of profile, type of roof covering are design variables which directly affect cost of purlin structure.

Obtained results from optimization problem must provide necessary certain conditions. Constrains of purlin system optimization problem are strength constrains, displacement constrains and geometric (application) constrains. Obtained design must provide conditions of TS (Turkish Standards) which is shown below. These are limiters of optimization problem. There are three main verifications of TS to investigate purlin system design. These are classified as strength verification, displacement verification and shear verification.

Strength behavior constrain:

$$\sigma_{max} = \frac{M_x}{W_x} + \frac{M_y}{W_y} \le \sigma_{em} \,. \tag{6}$$

In Eq. (6), M_x and M_y are moment values which occur on the profile in x and y dimensions respectively. W_x and W_y are static moment value which can be changed regard to cross section of profile and are imported from table of considered standard.

Displacement behavior constraints:

$$f = \sqrt{f_x^2 + f_y^2} < \left(\frac{l_k}{300}\right) cm \,,$$

$$f_x = \frac{2.48 q_x l_k^4}{I_x} \;\;,\;\; f_y = \frac{2.48 q_x l_k^4}{I_y} \;\;. \tag{7}$$

In Eq. (7), f_x and f_y are displacement of purlin in x and y dimensions, l_k is purlin span and I_x and I_y are moment of inertia in x and y axis respectively.

Shear behavior constrains:

$$T_x = q_y * \frac{L_0}{2},$$

$$\tau_x = \frac{T_x}{\frac{5}{3} * (F_{başlık})} \le \tau_{em} \;\;,\;\; \tau_y = \frac{T_y}{F_g} \;\le\; \tau_{em} \;\;. \tag{8}$$

Used in Eq. (8), T_x is shear force on the purlin, τ_x and τ_y are shear stress which will occur on the purlin, F_b is cross section area of flans in compression, F_g is cross section area of web and q_y is value of distributed load.

4. Created Software for Design Optimization of Purlin Systems Used in Steel Roofs

A software is edited by using firefly algorithm which is mentioned above to be used optimum design of purlin systems in steel roofs. This software which splash screen is showed in Fig. 1, is edited at Windows environment by using Visual Basic programing language. Usage of software and visual properties is indicated below.

1. Windows which will be entered desired data is displayed to enter parameter of structure systems which will be optimized by running dimensions command that is "*Boyutlar*" in splash screen windows "*Ana Sayfa*" under the menu of optimize "*Optimize Et*". In this screen, there are entry box listed below;

- Span of frame system (m)
- Total length of structure (m)
- Slop of roof (degree)
- Type of roof covering
- Steel grade
- Snow region (by regarding to TS)
- Altitude (m)
- Elevation from ground (m)
- Brace price per unit (TL/kg)
- Profile price per unit (TL/kg)
- Maximum load that 1m roof covering can carry (kg/m^2) (optionally)
- Type of steel sections (IPN or IPE)

2. After that, windows which will be entered optimization parameters of firefly algorithm is displayed by clicking optimization parameters "*Optimizasyon Parametreleri*" under also optimize button "*Optimize Et*". (Figs. 2 and 3). This window provides to enter parameter of firefly algorithm which will be used for solution by user. Desired optimization algorithm parameters to run this software are listed below.

- Number of fireflies
- Randomness

- β coefficient
- γ coefficient
- Number of design variables
- Number of maximum cycle
- Tolerance

3. Location of text file which will be saved optimum results is selected to initialize optimization process by clicking main page command "*Ana Sayfa*" that is placed under the optimize menu "*Optimize Et*". Optimum design process is begun with start command "*Başla*". When optimization process is finished, the passing time for optimization, beginning and finishing times, average passing time for per iteration, number of iteration until optimum result is obtained and optimum design results can be seen in "*Optimum/Best Design*" box (Fig. 4).

Fig. 1. Splash screen of optimum purlin design software.

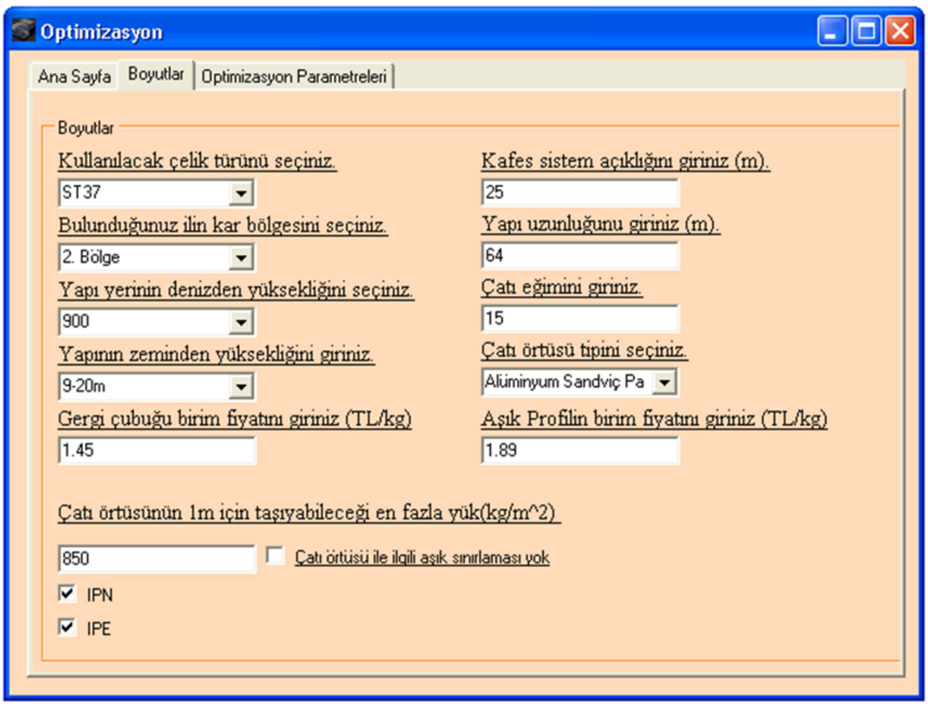

Fig. 2. Entries are requested from users by optimum purlin design software.

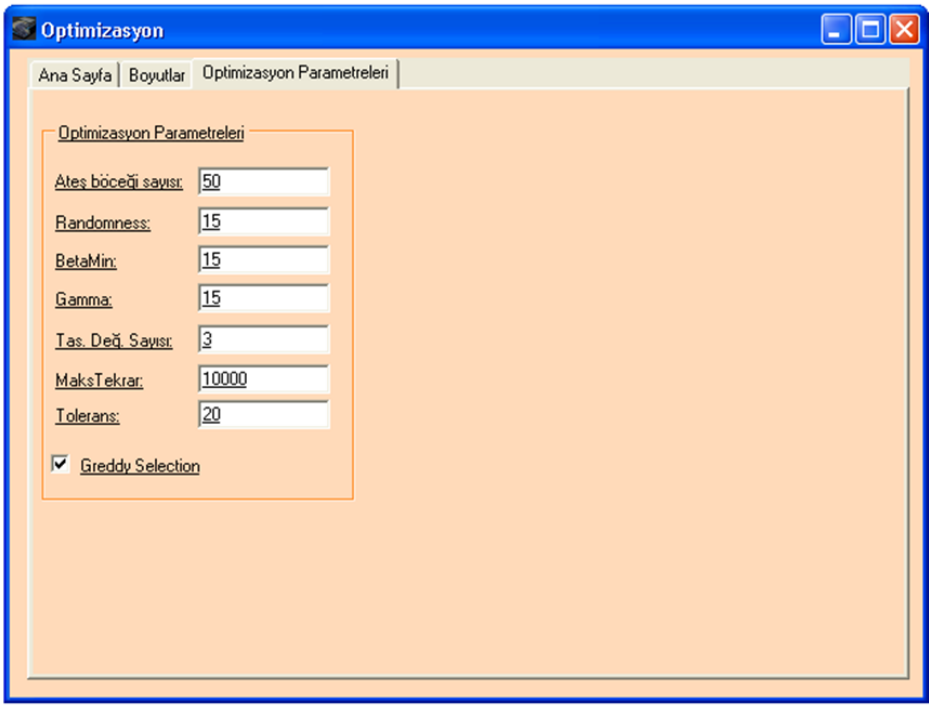

Fig. 3. Window, in which algorithm parameters of firefly method are entered.

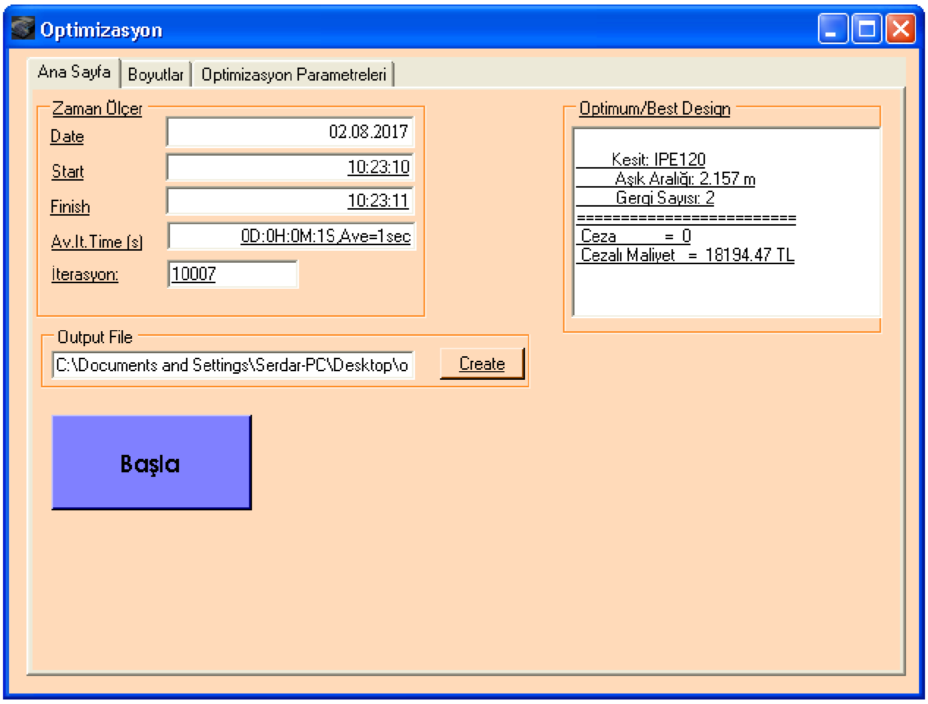

Fig. 4. Window, in which output of optimum results is displayed.

5. Design Sample

Developed software is tested on the sample which is recently projected. Detail of the project is shown in Table 1. Sample problem is calculated with optimization software. Obtained results from this solution are compared in cost of structure. This comparison is demonstrated in Table 2. When obtained result is investigated, developed optimization software obtains optimum purlin design which has about %32 less cost.

6. Conclusions

In this study, a software was developed to obtain optimum design of purlin systems of steel roofs by using firefly algorithm which inspires life style of fireflies. The main objective of this software is to minimize cost of steel purlin system in steel roof purlin system problem. Constraint functions of optimization problem were obtained by importing from verifications of TS-648 code. Results, which were obtained from optimization process, must satisfy criterions of the Turkish Standards. Three different verifications were provided at the same time in order to design purlin systems which are used in steel roofs according to the Turkish Standards. These are axial stress verification, deformation verification and shear verification. Most important characteristic specifications of the software, which is used to design purlin system in steel roof, are ability of entry data and, ability to give result rapid and easily. Finding optimum solution of these structural systems, which is calculation of design, is quite complex and so easy owing to the structure of this software.

Table 1. Details of project.

Span of roof: 12 m	Height: 8 m
Length of roof: 51.6 m (10 span)	Slope of roof: 5°
Province: Kastamonu (3rd region)	Weight of roof covering: 50 N/m^2
Altitude: 800 m	Unit cost of steel (Brace/Profile): 1.9/2 TL/kg

Table 2. Comparison of purlin designs.

	Project Results	Optimum Results
Profile type of purlin	IPN140	IPE140
Distance between purlins (Horizontal Distance)	2m	3m
Type of brace (diameter of brace)	Single (ϕ8)	Double (ϕ8)
Max. Displacement / Limit	0.906cm / 1.72cm	1.384 / 1.72cm
Max. Stress / Limit	1011 / 1440 kgf/cm^2	1413 / 1440 kgf/cm^2
Cost of brace	158 TL	194 TL
Cost of profile	11806 TL	7997 TL
Total cost	11964 TL	8181 TL

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