

OPTIMIZATION OF ROOF TRUSSES UNDER THE SNOW LOADS GIVEN IN TURKISH CODE AND THE GIS-BASED SNOW LOAD MAP

Vedat TOĞAN^{1†}, Mustafa DURMAZ¹, Ayşe DALOĞLU²

¹ Research Assistant, Karadeniz Technical University, Civil Engineering Department

² Professor, PhD., Karadeniz Technical University, Civil Engineering Department

Abstract

Many roofs collapse or damages have been reported due to heavy snowfalls in various regions of the world during winter season. Due to this, researchers have been trying to create maps to give the variation of ground snow loads precisely, and to estimate the snow loads more accurately than the existing standards which calculate roof snow loads as the product of a design ground snow load and the conversion factors that depend on the roof properties. The aim of this study is to optimize the 2D and 3D roof trusses under the snow loads specified according to current Turkish code, TS 498, and the GIS-based snow load map which reflects the variation of ground snow load satisfactorily for the Eastern Black Sea region and to show the differences between the optimum designs of roof trusses. Genetic Algorithm (GA), coded in MATLAB and one of the stochastic optimization methods, is used for the optimization. It can be concluded that the design obtained by the GIS-based snow load map is most durable than the design obtained by Turkish code against the imperfections of snow load in the region.

Keywords: Structural optimization, Genetic Algorithm, TS 498, Snow load, Roof trusses

Çatı Makaslarının Türk Standardı ve GIS-tabanlı Kar Yüğü Haritası'nda Verilen Kar Yüğü Altında Optimizasyonu

Özet: Kış mevsimi süresince dünyanın farklı bölgelerinde aşırı kar yağışı nedeniyle pek çok çatının göçtüğü veya zarar gördüğü bildirilmektedir. Bundan dolayı, araştırmacılar zemin kar yüklerinin değişimlerini daha kesin veren haritalar oluşturmak ve kar yüklerini çatının geometrik özelliklerine bağlı dönüşüm faktörü ile tasarım zemin kar yükünün çarpımıyla hesaplayan mevcut standartlardan daha doğru biçimde kar yüklerini tahmin etmeye çalışmaktadırlar. Bu çalışmanın amacı, 2 ve 3 boyutlu çatı makaslarının, TS 498' de ve zemin kar yüklerini Doğu Karadeniz Bölgesi için daha gerçekçi veren GIS-tabanlı Kar Yüğü Haritasında belirtilen kar yükleri altında optimize etmek ve optimum tasarımlar arasındaki farklılıkları göstermektir. Optimizasyon için MATLAB'de kodlanmış ve stokastik bir optimizasyon yöntemi olan Genetik Algoritma kullanılmaktadır. Sonuç olarak GIS-tabanlı Kar Yüğü Haritasından alınan yüklerle elde edilen tasarımlar kar yükündeki belirsizlikleri de dikkate alması nedeniyle TS 498 ile elde edilen tasarımlardan daha güvenlidir.

Anahtar Kelimeler: Yapısal Optimizasyon, Genetik Algoritma, TS 498, Kar yükü, Çatı Makasları

[†] Karadeniz Technical University, Civil Engineering Department, 61080 Trabzon/Turkey
e-mail: togan@ktu.edu.tr

INTRODUCTION

Many roofs collapse or damages have been reported due to heavy snowfalls in various regions of the world during winter season. These snow-related failures usually result in collapse of the roofs only, but sometimes complete structural failures occur causing tens of people to die and injuring hundreds. According to the disaster survey conducted from 1940 to 2002 in Turkey, every year, in average, eight events that are relevant to extreme snow loads result in loss of goods and/or lives [1]. The last one of the most terrible examples of these failures is the collapse of the roof Transvaal Water Park in Moscow, Russia. In this event, at least 24 people were killed and 106 injured.

When the roof components such as trusses, purlins, etc. are subject to overloads due to snow related reasons, i.e. extreme snow fall, surcharge load due to drifting by wind, a collecting point takes form on the roof because of the deflection of the structural components. If the structure does not possess enough stiffness to resist this progression, partial or complete failure can take place by localized overloading. Thus, , researchers have been trying to create maps to give the variation of ground snow loads precisely, and to estimate the snow loads more accurately than the existing standards which calculate roof snow loads as the product of a design ground snow load and the conversion factors that depend on the roof properties.

The aim of this study is to optimize the 2D and 3D roof trusses under the snow loads specified according to current Turkish code, TS 498 [2], and the GIS-based snow load map [3, 4] which reflects the variation of ground snow load satisfactorily for the Eastern Black Sea region and to show the differences between the optimum designs of roof trusses. A computer program coded in MATLAB is used for the optimization with Genetic Algorithm (GA) which is one of the stochastic optimization methods.

SNOW LOAD IN TURKISH CODE, TS 498

The rules to evaluate design ground snow loads to be used in the structural design in Turkey are given in Turkish codes of TS 498 [2].

According to TS 498 [2], the design ground snow load, P_{ko} , depends on the geographical location and the altitude of the site being considered. The return period of the P_{ko} is not expressed explicitly in the code. TS 498 presents a map in which Turkey is subdivided into four zones of snow as shown in Figure 1. Design ground snow load at any site is taken from Table 1 according to the zone number and the altitude of the site. Additionally, in TS 498 [2], the design roof snow load is calculated as the product of the design ground snow load and a conversion factor that depends on the roof slope.

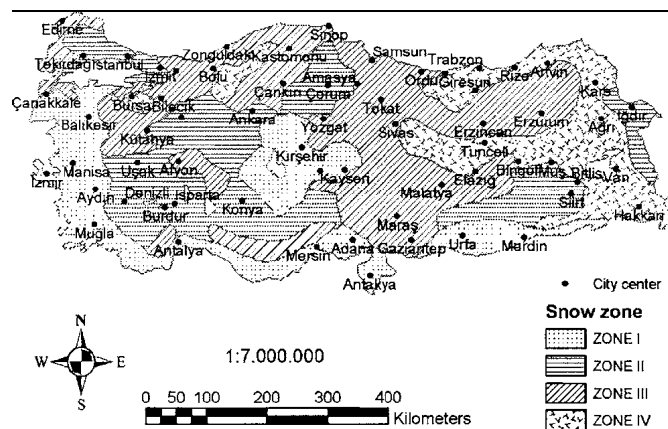


Figure 1. Snow zone map of Turkey according to TS 948

Table 1. Design Ground Snow Load (P_{k0}) Values according to TS 498 [2] (kPa)

Elevation of the location (m)	Zones			
	I	II	III	IV
≤200	0.75	0.75	0.75	0.75
300	0.75	0.75	0.75	0.80
400	0.75	0.75	0.75	0.80
500	0.75	0.75	0.75	0.85
600	0.75	0.75	0.80	0.90
700	0.75	0.75	0.85	0.95
800	0.80	0.85	1.25	1.40
900	0.80	0.95	1.30	1.50
1000	0.80	1.05	1.35	1.60
>1000 and <1500	a	a	a	a
>1500	b	b	b	b

a The values corresponding to 1000 m are increased by 10%.
 b The values corresponding to 1000 m are increased by 15%.

SNOW LOAD IN THE GIS-BASED SNOW LOAD MAP

In [3, 4], the 50-year mean recurrence interval (MRI) ground snow loads (X_{50}) were evaluated from a statistical analysis of the annual maximum ground snow data collected from 32 Turkish State Meteorological Service (TSMS) weather stations located in the eastern Black Sea region and adjacent cities. Probability Plot Correlation Coefficient (PPCC) test was examined with three different cumulative distribution functions (Gumbel, Lognormal and Weibull) to determine the best fit of the theoretical probability distribution with the snow data of the stations. A GIS was utilized to produce a map that visually represents the geographic distribution of the normalized X_{50} values (NX_{50}) for the region. In order to analyse the NX_{50} data spatially to produce the normalized snow load map, the spatial analyst was conducted. In spatial analysis, of spatial interpolation techniques, Inverse Distance Weighting (IDW) was used. Fig. 2 shows the normalized 50 year ground snow load map for the eastern Black Sea region. With NX_{50} , and the elevation of the location above mean sea level, a code value SL_{50} can be obtained using the equation below.

$$SL_{50} = NX_{50} + b \cdot Z \quad (1)$$

where $NX_{50} = X_{50}$ normalized to mean sea level (kPa); Z = location elevation above mean sea level (m); and b = change of X_{50} with elevation (kPa/m) [3,4].

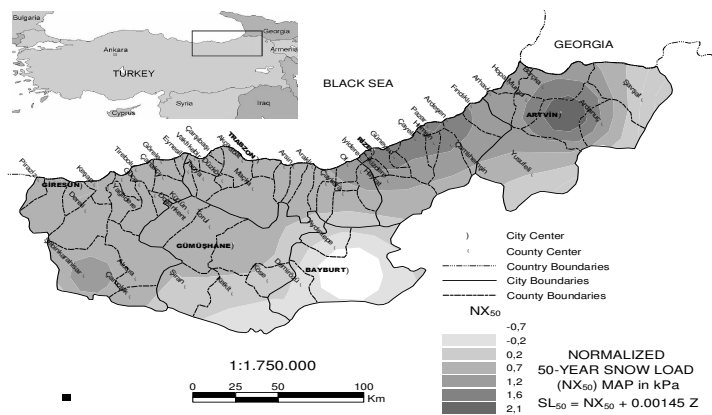


Figure 2. Normalized 50-Year Ground Snow Load Map for the Eastern Black Sea Region

GENETIC ALGORITHMS (GA)

The GA is a stochastic global search method that mimics the metaphor of natural biological evolution. GAs operate on a population of potential solutions applying the principle of survival of the fittest to produce better approximations to a solution. At each generation, a new set of approximation is created by the process of selecting individuals according to their level of fitness in the problem domain and reproducing them together using operators taken from nature. This process leads to the evolution of populations of individuals that are better suited previously.

The improved versions of GAs have new adaptive penalty schemes and adaptive mutation and cross-over operators in order to protect the optimization process from getting stuck on a local optimum, and to get close to the global optimum instead [5, 6].

APPLICATION EXAMPLES

The optimum design of 2D and 3D trusses are analyzed by improvement in GA under the snow loads given in TS 498 [2] and GIS based snow load map [3, 4], respectively. Hemşin in Rize is picked as the location for the structures. A 49-bar 2D roof truss is selected as the first example. Then a 3D roof of 200-bar is optimized to show the differences between the optimum designs of roof trusses as indicated in two different snow loads specifications as mentioned above. The value of material density for the examples is taken as $\rho=7.85E-08$ kN/mm³.

Example 1-49-bar 2D roof truss

The genetic algorithm based optimum design method as presented in [5, 6] is used to minimize the weight of a roof truss by selecting the appropriate steel sections from the standard tables of cross sections while satisfying the design limitation obeying TS 648 [7]. The geometry and the loading of the truss are shown in Figure 3. The modulus of elasticity for the example is 210 N/mm². The design strength is specified as 144 N/mm² and the mid-span deflection of the truss is limited to 65 mm. The members of the truss are collected into four groups. The upper chord and lower chord members are collected in group 1 and group 2 respectively and assumed to be made out of equal leg double angle sections. The equal leg single angle sections are adopted for the vertical and diagonal members and they are collected in groups 3 and 4 respectively.

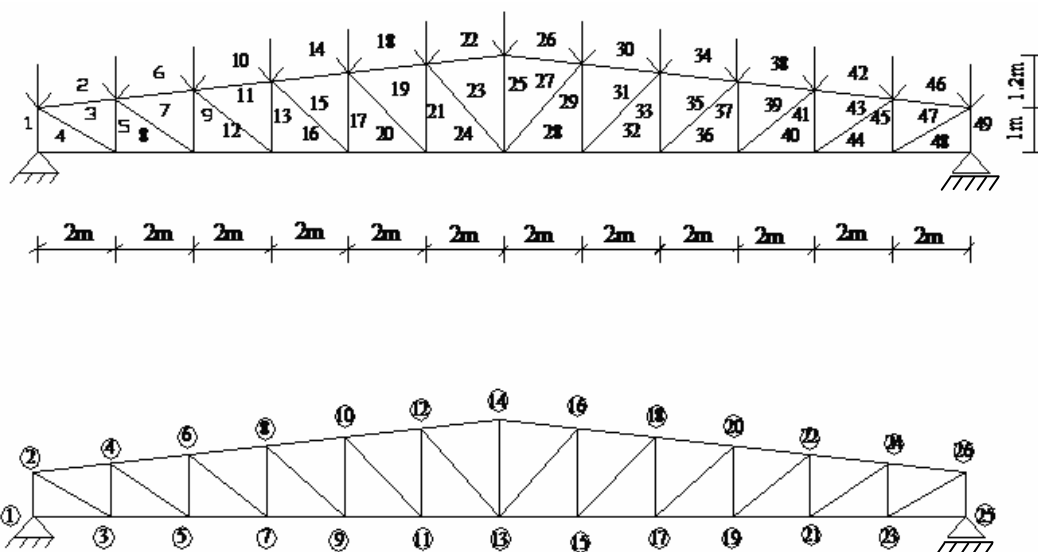


Figure 3. 49-bar roof truss of the industrial building

The total of 32 equal leg angle sections selected from TS 908 [8] are used as an available discrete list. The spacing between trusses is 3800 mm.

Two different designs are carried out for the roof truss considered. In the first design, the roof truss is optimized by GA under the snow load specified according to TS 498 [2] and snow map given in TS 498 [2], Table 2. In the second, the results obtained from first case are checked under the snow load determined depending on GIS-based snow load map [3, 4]. Then the truss is optimized by GA under the related snow load for the second case.

Table 2. Snow loads specified according to snow map given in TS 498 [2]

Loaded nodes	Load area (a*b)			P_{ks} (kN/m ²)	P_k (kN)
	a (m)	b (m)	m		
2	3.80	1.00	1.00	1.76	6.69
4	3.80	2.00	1.00	1.76	13.38
6	3.80	2.00	1.00	1.76	13.38
8	3.80	2.00	1.00	1.76	13.38
10	3.80	2.00	1.00	1.76	13.38
12	3.80	2.00	1.00	1.76	13.38
14	3.80	2.00	1.00	1.76	13.38
16	3.80	2.00	1.00	1.76	13.38
18	3.80	2.00	1.00	1.76	13.38
20	3.80	2.00	1.00	1.76	13.38
22	3.80	2.00	1.00	1.76	13.38
24	3.80	2.00	1.00	1.76	13.38
26	3.80	1.00	1.00	1.76	6.69

m represents a conversion factor that depends on the roof slope. The altitude of Hemşin is 1200 m. Table 3 and Figure 4 show the results and the graphical representation of genetic process for the 49-bar roof truss.

Table 3. Optimization details for the first optimization strategy

Weight (kN)	Design variables (mm ²)			
	A_1	A_2	A_3	A_4
12.88	3020	1740	940	1010

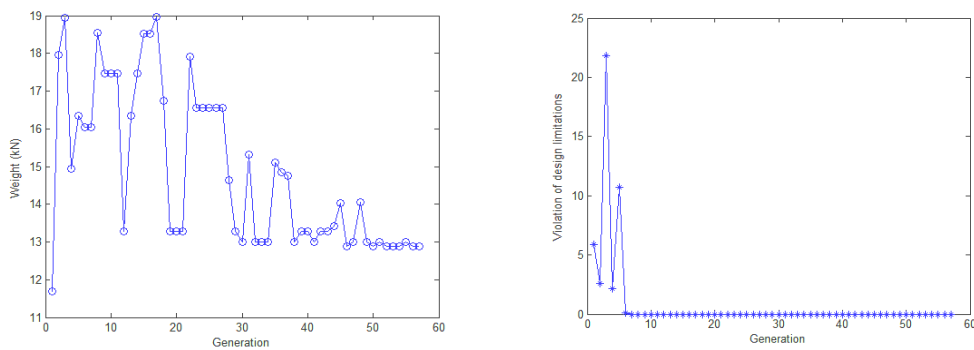


Figure 4. Histories of genetic process for the first optimization strategy

The results given in Table 3 are used to check whether they have enough strength against snow load given Table 4 or not. The results show that the roof truss violates the design limitation adopted, Figure 5.

Table 4. Snow loads specified according to GIS-based snow map [3, 4] and TS 498 [2]

Loaded nodes	Load area (a*b)			P_{k0} (kN/m ²)	P_k (kN)
	a (m)	b (m)	m		
2	3.80	1.00	1.00	3.34	12.69
4	3.80	2.00	1.00	3.34	25.38
6	3.80	2.00	1.00	3.34	25.38
8	3.80	2.00	1.00	3.34	25.38
10	3.80	2.00	1.00	3.34	25.38
12	3.80	2.00	1.00	3.34	25.38
14	3.80	2.00	1.00	3.34	25.38
16	3.80	2.00	1.00	3.34	25.38
18	3.80	2.00	1.00	3.34	25.38
20	3.80	2.00	1.00	3.34	25.38
22	3.80	2.00	1.00	3.34	25.38
24	3.80	2.00	1.00	3.34	25.38
26	3.80	1.00	1.00	3.34	12.69

Table 5 shows the results obtained from optimization under the load given in Table 4 for the 49-bar roof truss.

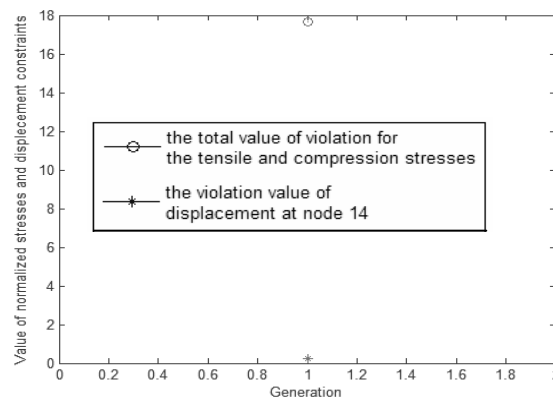


Figure 5. Strength representation of 49-bar roof truss against snow load given in Table 4

Table 5. Optimization details for the second optimization strategy

Weight (kN)	Design variables (mm ²)			
	A_1	A_2	A_3	A_4
21.713	4540	3340	1510	1870

Studying both Table 3 and Table 5, it can be said that the results presented in Table 3 is lighter than the results given in Table 5. However, Table 5 shows the more realistic and durable results than Table 3 for the roof truss erected in Hemşin against the snow load. The design histories for the last optimization case are illustrated in Figure 6.

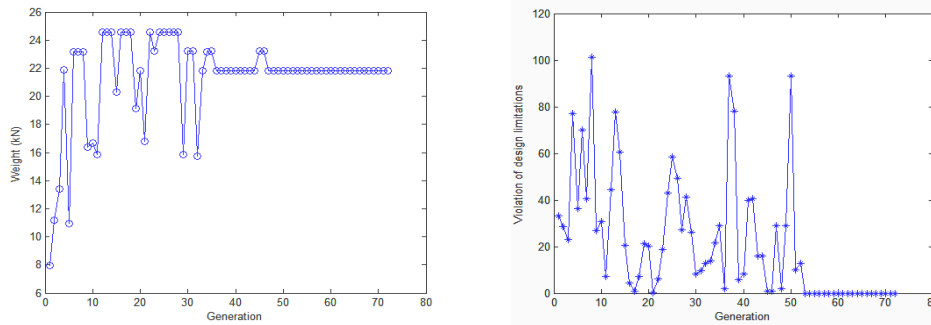


Figure 6. Histories of genetic process for the second optimization strategy

Example 2-200-bar 3D roof truss

The space truss in Figure 7 has 200 bars. The cross sections of members are collected into three groups. One of the groups contains the bottom chord members. Diagonals are grouped together as another one, and finally top chord members are collected in the third group. Circular hollow sections given in Turkish specification are adopted for the members of the space truss in the study. The allowable compressive stress for each member is computed depending on the Turkish design code [7]. The top chord joints of space truss are subjected to snow loads given in Table 6 and Table 7. As Table 6 is formed according to map given in TS 498 and TS 498 [2], Table 7 according to GIS-based snow map [3, 4] and TS 498 [2], like previously examined example.

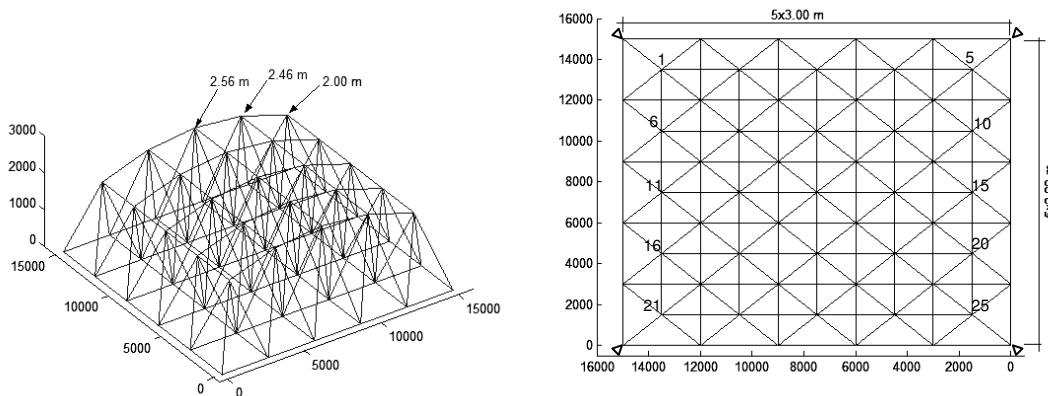


Figure 7. Topology of 200-bar 3D roof truss

Table 6. Snow loads specified according to snow map given in TS 498 and TS 498 [2]

Loaded nodes	Load area (a*b)			P_{ko} (kN/m ²)	P_k (kN)
	a (m)	b (m)	m		
1, 5, 21, 25	1.50	1.50	1.00	1.76	3.96
2, 3, 4, 6, 10	1.50	3.00	1.00	1.76	7.92
11, 15, 16, 20					
22, 23, 24					
The others	3.00	3.00	1.00	1.76	15.84

The displacements of the top chord joints are restricted to 20 mm. The allowable tensile stress is taken as 150 N/mm² and the modulus of elasticity is 210 kN/mm². In this example, the optimization of space truss is first performed by using snow load given in Table 6. Then the optimal weight of the truss is obtained with snow load given in Table 7 after checking the results obtained from former optimization case.

Table 7. Snow loads specified according to GIS-based snow map [3, 4] and TS 498 [2]

Loaded nodes	Load area (a*b)				
	a (m)	b (m)	m	P _{ko} (kN/m ²)	P _k (kN)
1, 5, 21, 25	1.50	1.50	1.00	3.34	7.515
2, 3, 4, 6, 10 11, 15, 16, 20 22, 23, 24	1.50	3.00	1.00	3.34	15.03
The others	3.00	3.00	1.00	3.34	30.06

The optimum designations of pipe sections obtained for first case are summarized in Table 8. The design histories for the 200-bar roof truss are shown in Figure 8. The analysis performed by using the results obtained from first optimization case under the snow load given in Table 7 shown that the design obtained for the first case don't satisfy the design limitation, Figure 9.

Table 8. Optimization details of the first optimization strategy for 200-bar truss

Weight (kN)	Design variables (mm ²)		
	A ₁	A ₂	A ₃
57.13	641.26	1552.26	1066.89

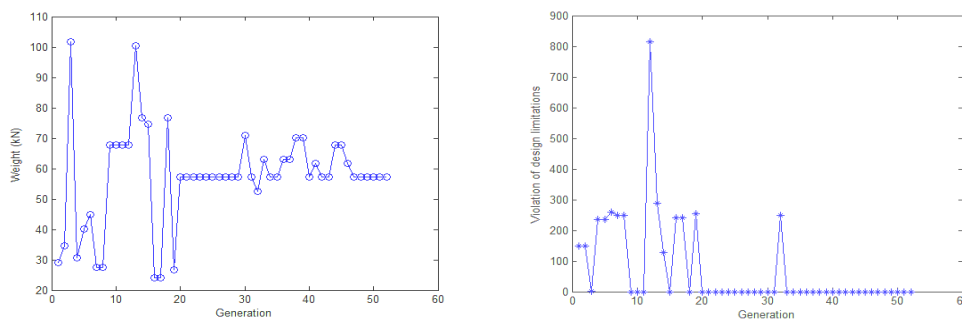


Figure 8. Histories of genetic process of the first strategy for 200-bar truss

Table 9 shows the results obtained from optimization under the load given in Table 7 for the 200-bar roof truss.

Table 9. Optimization details of the second optimization strategy for the 200-bar truss

Weight (kN)	Design variables (mm ²)		
	A ₁	A ₂	A ₃
78.043	819.96	2115.87	1552.26

Studying both Table 8 and Table 9, the results presented in Table 8 is lighter than the results given in Table 9. However, the 3D roof truss designed according to the results given in Table 9 is more durable against snow fall imperfection in Hemşin. The design histories for the last optimization case are illustrated in Figure 10.

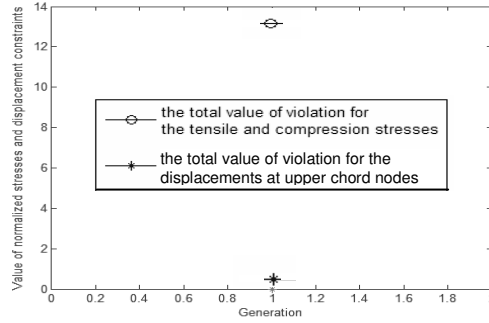


Figure 9. Strength of 200-bar roof truss against the snow load given in Table 7

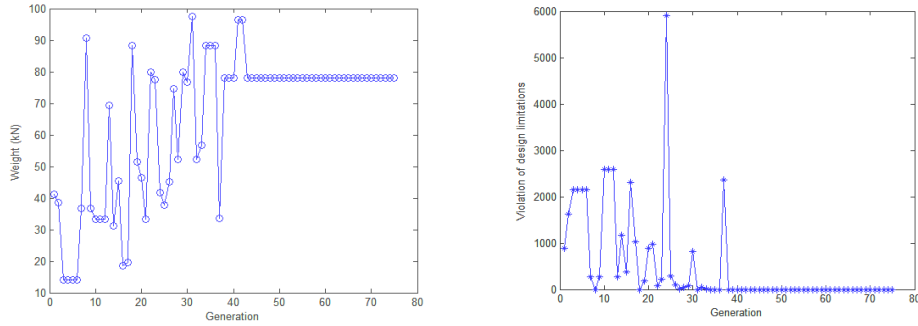


Figure 10. Histories of genetic process of the second strategy for the 200-bar truss

CONCLUSIONS

The results from the optimization of 2D and 3D roof trusses using genetic algorithms show that TS 498 propose unsafe design ground snow load. So, most steel structures to be erected in the Eastern Black Sea region may be unsafe due to underestimating of snow load given in TS 498 [2]. The GIS-based snow map proposed by [3, 4] reflects the variation of ground snow load more satisfactorily than TS 498 [2] for the Eastern Black Sea region. The designs obtained by GA under the snow load specified depending on GIS-based snow map [3, 4] are more durable against snow fall imperfection in the region.

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