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# FAILURE INVESTIGATION OF A ROOF TRUSS IN THE EASTERN BLACK SEA REGION DUE TO THE SNOW LOAD

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**Abstract**

The aim of this study is to analyze a 3d space truss under the snow loads calculated as specified in Turkish codes (TS 498; TS 7046), and also using GIS-based snow load map for the Eastern Black Sea region of Turkey. The differences between the stress and the displacement pattern and the service failure investigation of the truss due to snow loads are also shown. From the result of the study it is worthy saying that the danger may be serious for most steel structures designed under the snow loads calculated by using TS 498. The structures designed using the GIS-based snow load map is most durable against the imperfections of snow load in the region.

**Keywords:** Failures, snow loads, roofs, codes, mapping

## 1. Introduction

Many roof's collapses 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. For example, Transvaal Water Park in Russia and an exhibition hall in Poland collapsed because of the extreme snow loads accumulated on the roofs of the buildings. In these events, at least 84 people were killed and 247 were injured [1], Fig. 1a and 1b. In Turkey, almost 100 events have been reported since the beginning of 2008. These events resulted in at least 2 people to die, injuring 10 people and loss of goods and money. [2]

a) The failure of Transvaal Water Park Moscow, Russia.

b) The failure of the exhibition hall Katowice, Poland

Fig. 1. Roof failure examples from the Russian and Poland

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. These points tend to deflect increasingly allowing a deeper pond to form as snow, snow melt water, and rainwater accumulate. If the structure does not possess enough stiffness to resist this progression, partial or complete failure can take place by localized overloading. Besides, since steel roofs of which the dead loads are much less than the design gravity loads (dead load + snow load) are designed with low safety factor (mostly 1.2-1.7); they cannot resist overloads [3]. Thus, researchers, [4,5,6], 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 the roof snow load as the product of a design ground snow load and the conversion factors that depend on the roof properties.

A comparative study is performed here to analyze a 3d truss under the snow loads as specified in Turkish codes of TS 498 [7] and TS 7046 [8]. The same truss is also analyzed calculating the snow load according to the GIS-based snow load map which reflects the variation of ground snow load satisfactorily for the Eastern Black Sea region, and thus the differences between the stress and displacement pattern and the service failure investigation of the truss due to snow loads are presented in graphical forms.

## 2. Snow loads in Turkish codes

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 and TS 7046.

### *2.1 TS 498*

According to TS 498 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 Fig. 2.

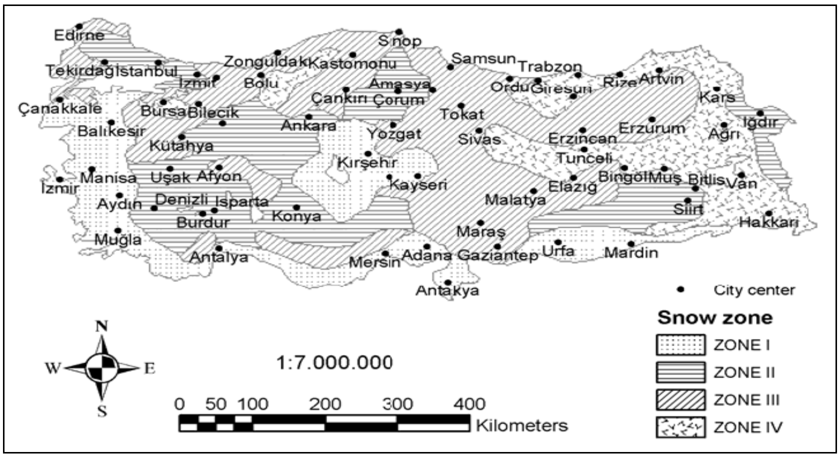



Fig. 2. Snow zone map of Turkey according to TS 498

Design ground snow load at any site is taken from Table 1 according to the zone number and the altitude of the site. Additionally 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.

*2.2 TS 7046*

In TS 7046, the characteristic ground snow load, $S_0$, at any location is determined by either measuring the snow load on the ground directly or usually analyzing the climatological data of the related site statistically. If the return period, $T_r$, is given, $S_0$ is simply calculated by the equation below which is derived from the Gumbel probability distribution function

$$S_0 = a - b\,ln\{-ln[F(S_0)]\} \tag{1}$$

where $a = (\bar{x} - \sigma)\cdot \bar{y}_N / \sigma_N$, $b = \sigma / \sigma_N$; and $F(S_0) = 1 - (1/T_r)$; $\bar{x}$ and $\sigma$ = mean and standard deviation of the extreme annual snow load data, $\bar{y}_N$ and $\sigma_N$ = reduced mean and reduced standard deviation which are depend on sample size and obtained from the related tables in TS 7046; and $T_r$= the return period.

Table 1. Design ground snow load ($P_{ko}$) values according to TS 498 (kPa)

| Elevation of the Location in meters | 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 | The values corresponding to 1000 m are increased by 10% | | | |
| >1500 | The values corresponding to 1000 m are increased by 15% | | | |

Snow load on the ground, $S_0$, is calculated by,

$$S_0 = r \cdot g \cdot d \tag{2}$$

where d= snow depth measured in meters g= acceleration of the gravity (9.81 m/sn$^2$), ρ= snow density (kg/m$^3$). According to TS 7046, ρ is calculated by,

$$r = 300 - 200 \cdot exp(-1.5 \cdot d) \tag{3}$$

Additionally, in TS 7046, the design roof snow load is calculated by multiplying the characteristic ground snow load with the conversion factors that depend on the roof geometries and exposure.

## 3. Snow load in the GIS-based snow load map

In recent works [9,2], the 50-year mean recurrence interval ground snow loads ($X_{50}$) were evaluated from a statistical analysis of the annual data collected from 32 Turkish State Meteorological Service (TSMS) weather stations located in the eastern Black Sea region and adjacent cities, Fig. 3. 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.

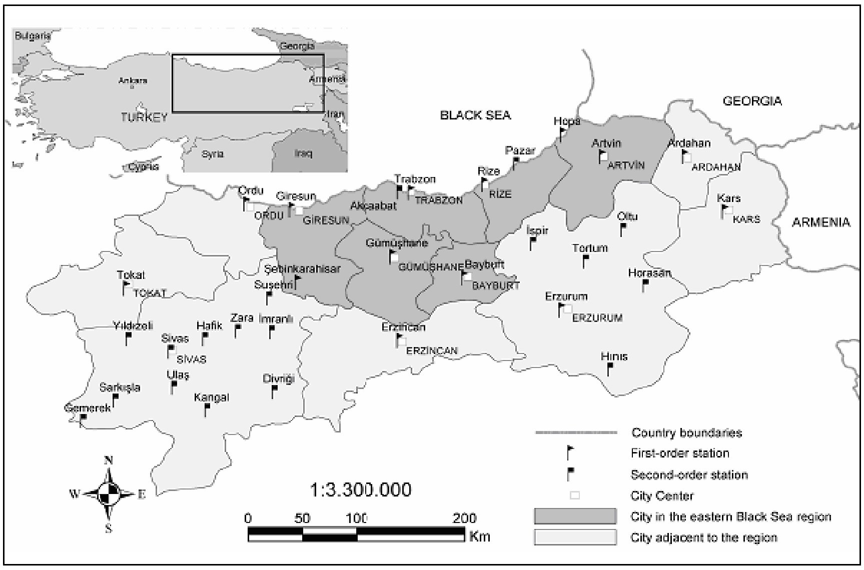



Fig. 3. Eastern Black Sea region and adjacent cities

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 analyze 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. 4 shows the $NX_{50}$ 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.

$$SL_{50} = NX_{50} + b \cdot Z \tag{4}$$

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).

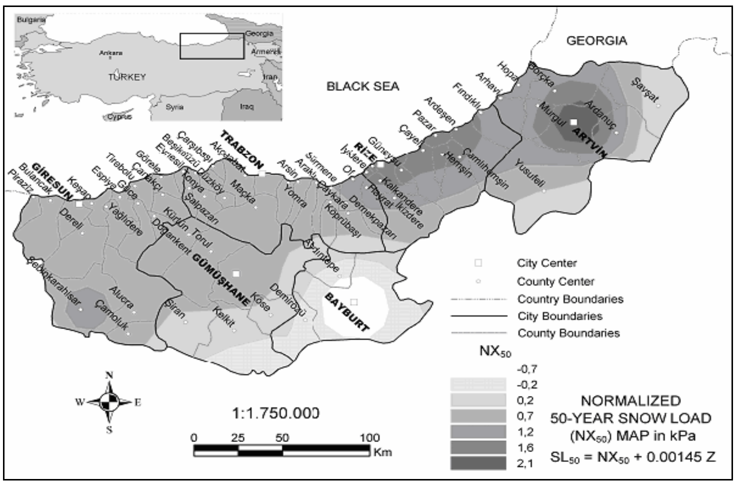



Fig. 4. Normalized 50-Year ground snow load map for the Eastern Black Sea region

## 4. The roof truss structures

It was the bridge builders of the early nineteenth century who first began systematically to explore and experiment with the potential of the truss. This was in response to the demands of rapidly expanding transportation systems of the time [10].

In architecture, to construct and to cover of areas or venues, which are as possible as high, large span, and without columns, was the most important seeking of all of ancient in doubt. The most brilliant examples of this seeking have been recently carrying out with the space trusses. It is possible to construct them with modular steel space systems in ways that are economic, esthetic, secure, and rapid. Thus, modern technology is put into service of architecture by means of modular steel space systems [11].

The trusses are very common structural forms in civil engineering to span long distances and they are mostly used in modern architectural designs of structures, such as airports, sport or multifunction centers, exhibition halls, and so on, Fig. 5a, 5b. Fig. 6 illustrates some examples of truss structures used as a roof of the auto showroom, the stadium, the exhibition hall, and the entrance of the airport in Trabzon, a city located in the center of Eastern Black Sea region.

a) Dome in Montreal, Quebec, Canada    b) Roof over Great Court, British Museum

Fig. 5. Modern architecture designs examples

All of these show that both 2d and 3d truss structures are being used as roof trusses in the Eastern Black Sea region which is in the fourth zone of the snow zone map according to Turkish code of TS 498, Fig. 2. This means that the cities in this region take the heaviest snowfalls during the winter season among the Turkey's regions. However, Durmaz and Daloğlu [2] have shown that the snow loads calculated according to design code TS 498, which is commonly used by the practical engineers in Turkey, are still underestimated for most locations. They have also stated that snow loads can be calculated more accurately using TS 7046 but sometimes the value of $S_0$ is overestimated since the statistical analysis is performed with exaggerated snow load data. However, most practicing engineers specify the snow loads for their designs using TS 498 because of its simplicity. Toğan et al. [12] show that a roof designed under the snow load calculated according to TS 498 does not have enough strength to meet the responses of the roof that arise from the snow load specified according to GIS-based snow map

a) Auto showroom

b) Stadium

c) Airport entrance

d) Exhibition hall

Fig. 6. Some roof truss examples from Trabzon

## 5. Sport hall in the eastern black sea region

Sport hall shown in Fig. 7 is a typical project accepted by General Directorate of Young and Sport of Turkey. Sport hall is used for the sport or social activities, such as basketball, volleyball, concert, and so on. The “Double storey Warren-shaped (without vertical)” main trusses with a spacing of 3.50 m have a span of 50.08 m. as shown in Fig. 7. A short IPE200 steel plinths resting on rigid connections on steel beams support the trusses. Seven different pipe sections listed in Table 2 are adopted for the roof members. The roof has 1520 joints and 6803 3d truss members. Table 2 also shows the sections properties and how much elements are in that section. Figure 8 shows the details of the upper chord nodes and geometrical properties only. The modulus of elasticity of the material is 210 kN/mm$^2$.

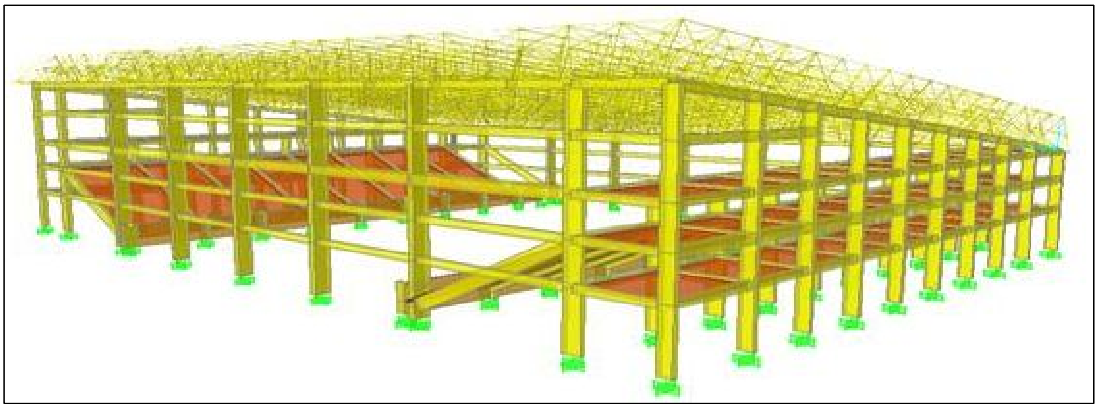
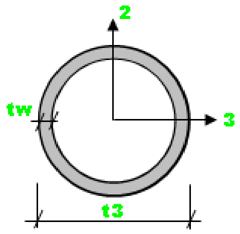
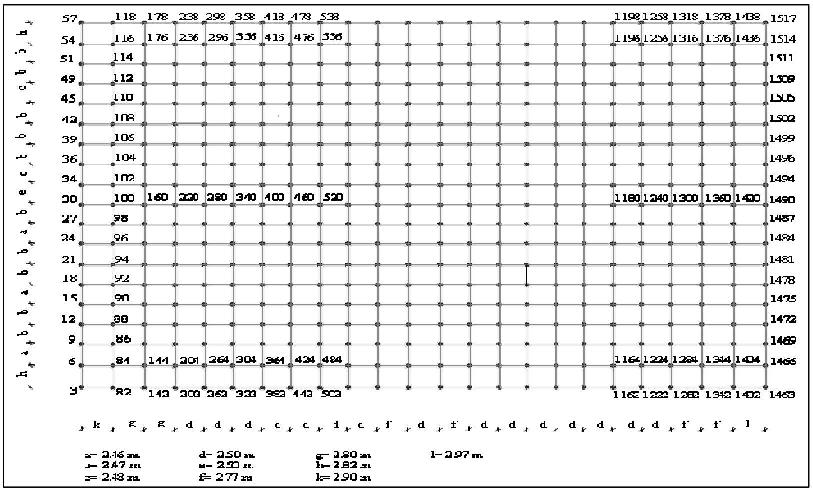


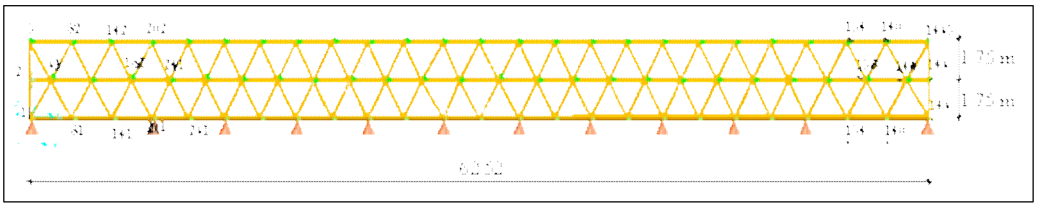
Fig. 7. Sport hall modeled in SAP2000

Table 2. Pipe sections details

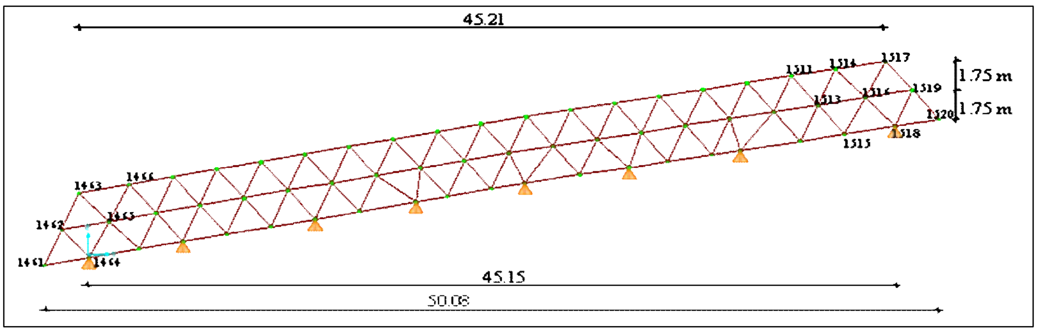
| | Section types | Outside diameter, t3 (mm) | Wall thickness, tw (mm) | Area ($mm^2$) | Number of elements |
|---|---|---|---|---|---|
|   | 1 | 48.30 | 3.25 | 460.00 | 5482 |
| | 2 | 76.10 | 3.65 | 830.80 | 642 |
| | 3 | 88.90 | 4.05 | 1080.00 | 214 |
| | 4 | 114.30 | 4.50 | 1552.00 | 164 |
| | 5 | 139.70 | 4.85 | 2055.00 | 84 |
| | 6 | 165.10 | 6.00 | 3000.00 | 100 |
| | 7 | 168.00 | 12.00 | 5881.00 | 117 |



a) Plan of upper chord



b) Plan of space roof truss in x-z plane




c) Plan of space roof truss in y-z plane

Fig. 8. Details of the upper chord nodes and geometrical properties of the roof

## 6. Service failure analysis of sport hall

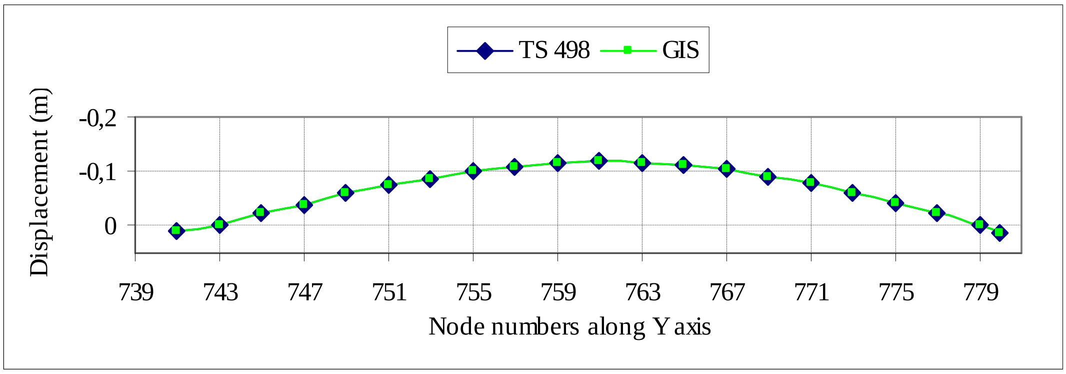
Three cities, Trabzon, Rize and Artvin, with different altitudes are chosen from Eastern Black Sea region to carry out the service failure investigation of the sport hall due to the snow loads. The three cities reflect the fluctuation of snow load depending on the altitude of cities and the serious of the service failure under the snow loads.

The roof snow loads of the sports hall are calculated by multiplying both the ground snow loads determined from the snow load zone map in TS 498 and the GIS-based snow load map by the conversion factor taken from the relevant table in TS 498. Table 3 presents the related design ground snow loads for the three cities, Trabzon, Rize and Artvin. The linear static analysis of the truss is performed under dead and snow (dead + snow) loads using SAP2000 commercial program for three cities, respectively. The results of analysis are used to investigate the service failure condition of the truss.

Table 3. Design ground snow loads for Trabzon, Rize, Artvin, and Kalkandere

| Design ground snow load ($kN/m^2$) | Residential area | | | |
|---|---|---|---|---|
| | Trabzon | Rize | Artvin | Kalkandere |
| TS 498 ($P_{ko}$) | 0.75 | 0.75 | 0.90 | 1.84 |
| GIS ($SL_{50}$) | 0.75 | 1.61 | 2.90 | 5.08 |

Figs. 9, 10, and 11 show the responses of the roof truss depending on the snow loads for three cities, Trabzon, Rize and Artvin, respectively.



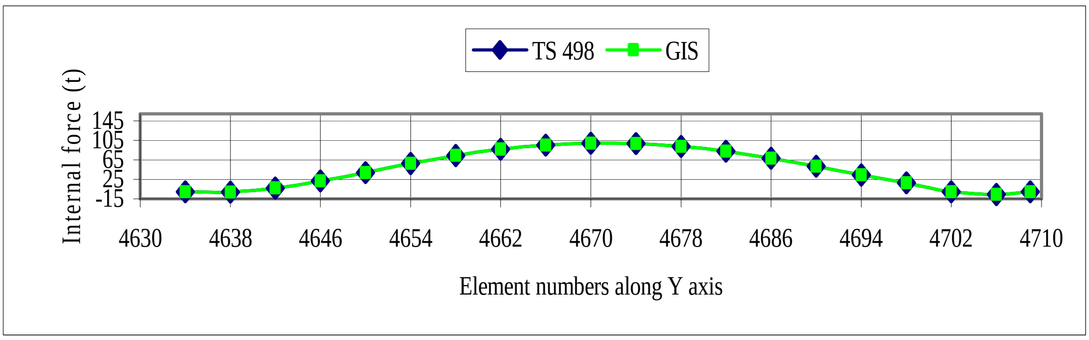




Fig. 9. Response of the sport hall roof under the snow loads in Trabzon

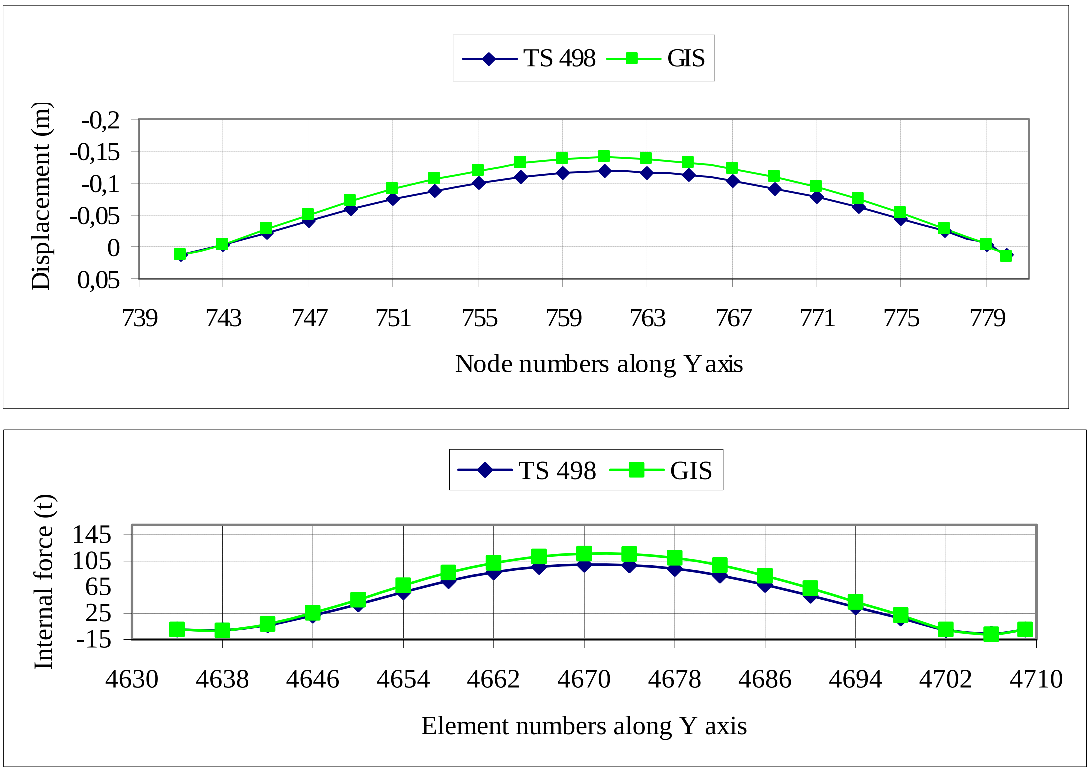



Fig. 10. Response of the sport hall roof under the snow loads in Rize

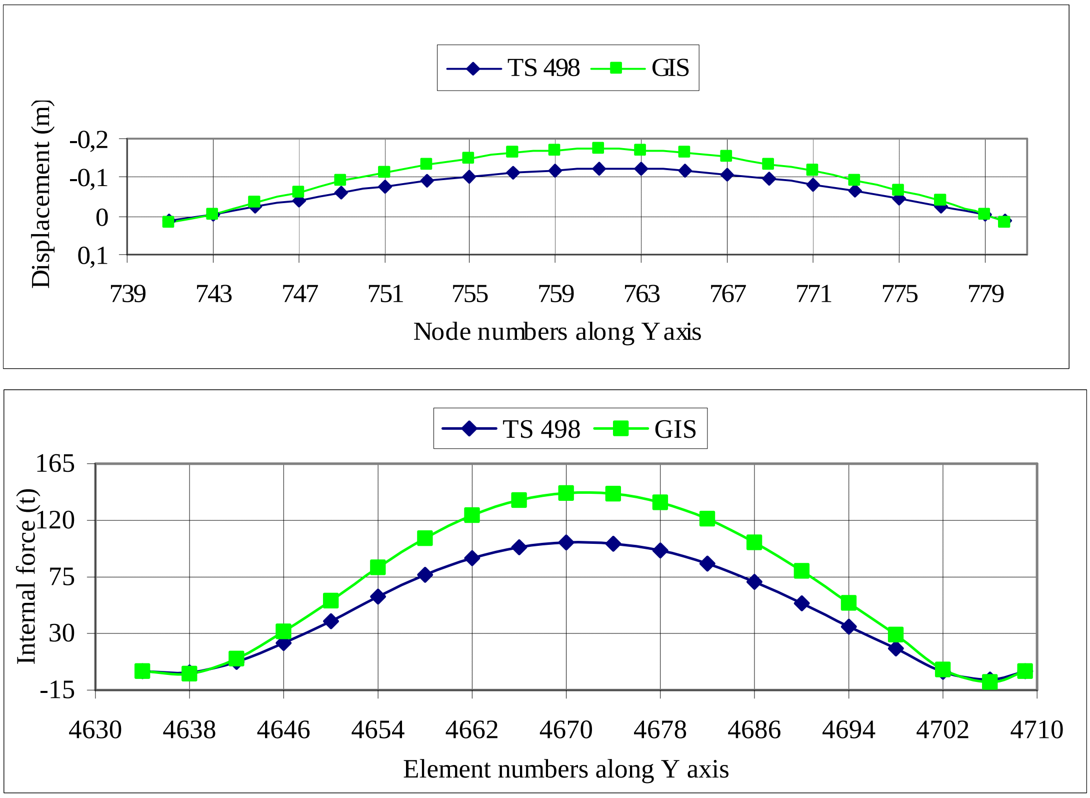



Fig. 11. Response of the sport hall roof under the snow loads in Artvin

As seen in figures the analysis performed under the snow loads calculated according to the specifications in TS 498 is not causing any service failure on the roof truss for all three cities. Maximum allowable vertical displacement for steel structures according to the Building Code for Steel Design, TS 648 [13], is L/300 in which L is the span length. Therefore, maximum allowable displacement for this example can be calculated as 50.08/300 = 0.1667 m. Even if it has been shown that there is not any service failure of the truss as long as the snow load is being calculated according to TS 498, the snow loads calculated using the GIS based snow load map show that this is not true especially for cities like Rize, Artvin having higher elevation than Trabzon. Maximum displacement of the roof under the roof snow load using the GIS based snow load map is calculated as 0.1729 m assuming the roof is being erected in Artvin, and it is not acceptable from the service failure point of view. Therefore it can be said that the roof trusses erected in Eastern Blacksea region can be in danger and may face local or complete failure under extreme snow loads. A complete failure of these kinds of roofs will be a real disaster causing huge losses.

To emphasize how serious it is, the values of the ground snow loads obtained using TS 498 and the GIS based map of Eastern Blacksea region are presented in graphical forms in Fig. 12. It can be said that the ground snow loads calculated using the two methods differentiates quite a lot. The difference is very big in some provinces like Hemşin, İkizdere, Kalkandere.

A steel roof truss is analyzed under the snow loads obtained both using TS 498 and GIS based snow load map of the region to show how reliable the designs obtained or to be obtained according to TS 498 for the Eastern Black Sea region of Turkey. Kalkandere is picked for the location of the truss since the difference on the ground snow load from both the approaches is noticeable as seen in Figure 12. The ground snow loads are calculated obeying TS 498 and then using GIS based snow load map for the region. The truss is analyzed under the self weight + snow load from both the cases and the result is presented in graphical forms in Fig. 13. As presented in figures, the design under the snow load calculated obeying TS 498 looks fine both for the stresses and the displacement point of view since the maximum displacement is obtained as 0.132 m being less than the maximum allowable displacement, 0.1667 m. But the roof truss does not look promising under the snow load obtained using GIS based snow load map and the maximum displacement of the truss is calculated as 0.1962 m that is higher than the maximum allowable displacement for the truss, 0.1667 m. This means that the truss fails and can not achieve the limit case for serviceability conditions according to design rules of TS 648.

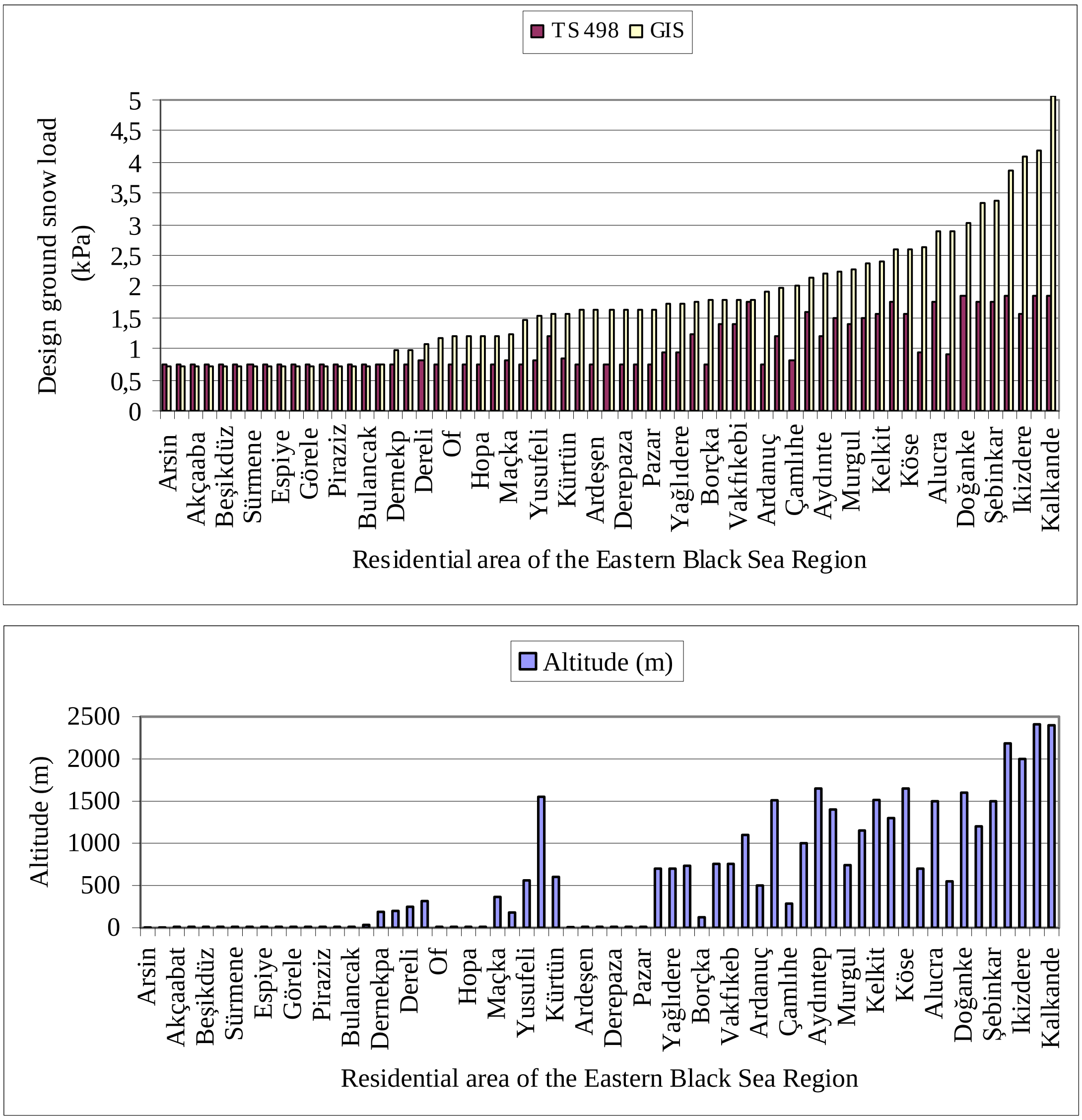
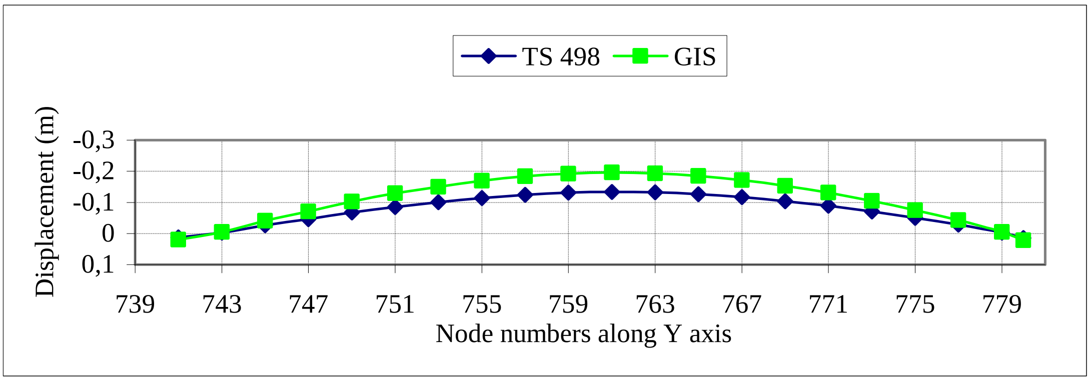


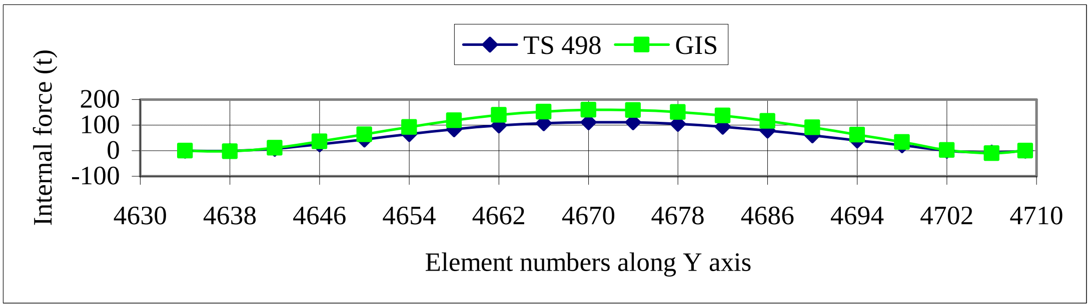

Fig. 12. Design ground snow loads and altitude of each residential area in the Eastern Black Sea region

## 7. What can be done to prevent the failure of the roofs due to snow load?

It is obvious that some measures must be taken into consideration to prevent roof failures because of excessive snow loads on steel roofs in the Eastern Black Sea region. Following precautions can be advised to be taken in the short term. The roof trusses already in use should be redesigned and strengthened if necessary under the snow load calculated using the criteria given in TS 7046 or GIS based snow load maps. The practicing engineers should be encouraged to use TS 7046 or GIS based maps for their new designs since snow loads calculated using TS 498 become insufficient for the region. The snow load map of Turkey given in TS 498 should be redeveloped and therefore TS 498 must be updated as a long term precaution. So the studies should focus on to develop more reliable ways to estimate the values of the snow loads more precisely considering climate changes also as a result of global warming.




a) Maximum displacements of the roof in Kalkandere




b) Maximum internal forces of the roof in Kalkandere

Fig. 13. Response of the sport hall roof under the snow loads in Kalkandere

## 8. Conclusions

A roof truss of a sport facility is analyzed statically under dead and snow load to show that the designs obeying TS 498 might end up with unsafe dimensions in the Eastern Black Sea region. Various provinces having different elevations are considered in the study. The most significant results emerging from this study are as follows.

TS 498 propose unsafe design ground snow loads for most of residential centers (76.2%) in the Eastern Black Sea region. Design ground snow loads proposed by TS 498 for some residential centers, (12.7%) are about 2.28-3.22 times smaller than those proposed by GIS-based snow map. So, most steel structures erected or to be erected in the Eastern Black Sea region may be unsafe because the snow loads given in TS 498 are underestimated. The danger can be serious for most steel structures that the possible error of TS 498 can not even be tolerated by a factor of safety of 1.67 as given in TS 648. Even more serious occasions might be unavoidable in the region in near future if the excessive snow loads are experienced as a result of the climate change and global warming.

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