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Analysis of guyed steel lattice mast subjected to environmental loads

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Professional paper

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Analysis of guyed steel lattice mast subjected to environmental loads

Steel lattice masts rank among the most efficient load-bearing structures in the field of high-rise construction. The non-linear analysis of a guyed steel lattice mast is conducted using the SAP 2000 finite-element program for different ice thickness values at 1500 m of altitude. After definition of the geometrical model and cross-section properties, various load combinations are analysed. Finally, the wind speed - ice thickness relationship is obtained, and the maximum wind speed that the structure can withstand is determined for varying ice thicknesses.

Key words:
mast, non-linear analysis, ice thickness, wind speed, finite elements

Stručni rad

R. Tugrul Erdem

Analiza čeličnog rešetkastog jarbola izloženog djelovanju vjetra i leda

Čelični rešetkasti jarboli ubrajaju se među najučinkovitije nosive konstrukcije u području visokogradnje. U ovom radu prikazana je nelinearna analiza čeličnog rešetkastog jarbola, koji je izložen različitim debljinama leda na nadmorskoj visini od 1500 m. Analiza je provedena pomoću programa konačnih elemenata SAP 2000. Nakon što su određeni geometrijski model i svojstva presjeka, primijenjene su različite kombinacije opterećenja. Provedenim analizama dobiven je odnos brzine vjetra i debljine leda te je određena maksimalna brzina vjetra koju konstrukcija može podnijeti s obzirom na različite debljine leda.

Ključne riječi:
jarbol, nelinearna analiza, debljina leda, brzina vjetra, konačni elementi

Fachbericht

R. Tugrul Erdem

Analyse abgespannter Stahlfachwerktürme unter Umgebungseinwirkungen

Stahlfachwerktürme zählen bei außerordentlich hohen Konstruktionen zu den effizientesten Tragwerken. In dieser Arbeit ist die nichtlineare Analyse eines abgespannten Stahlfachwerkturmes für verschiedene Werte der Eisstärke auf einer Höhenlage von 1500 m mittels finiter Elemente im Programm SAP 2000 durchgeführt. Der Festlegung von Geometrie und Querschnittseigenschaften des Modells folgend sind verschiedene Lastkombinationen aufgebracht. Letztlich ist ein Verhältnis von Windgeschwindigkeiten und Eisstärken aufgestellt und die entsprechenden maximalen Windgeschwindigkeiten, die das Tragwerk nicht gefährden, sind bestimmt.

Schlüsselwörter:
Fachwerkturm, nichtlineare Analyse, Eisstärke, Windgeschwindigkeit, finite Elemente

1. Introduction

Lattice mast is a general name for different kinds of steel masts. A lattice mast or truss mast is a freestanding framework mast. These structures can be used as transmission masts especially for voltages of more than 100 kilovolts, as radio masts (self-radiating masts or carriers for aerials), or as observation masts for safety purposes. Big and heavy frame sections are not required in these masts. This is why they are lighter than other mast types, and the modules can easily be connected to one another [1, 2].

Steel lattice masts have been used for many years in the countries where the ice and wind loads are considerable. This is due to increasing demands of modern industry with regard to communication and energy [3-7]. There are different styles of masts on which small wind generators are mounted: freestanding, guyed lattice, and tilt-up. Freestanding masts are relatively heavy duty, and they stay upright without the help of guy cables.

Guyed lattice masts use guy cables to anchor the mast and keep it upright using a relatively small quantity of concrete. Cables stretch from three points near the top of the mast to the ground at some distance from the base of the mast. These constructions are quite light compared to freestanding masts, and therefore constitute the least expensive means for supporting a wind turbine. However, they require a larger area to accommodate the guy cables.

The technical efficiency and durability of steel lattice masts have increased in recent years. The behaviour of steel lattice masts has been investigated in literature [8, 9]. As the design procedure is significant in these masts, the structural analysis is related to the geometrical model and section properties. Thus, the module production and assembly steps, and economic costs, are directly related to the design of masts.

Steel lattice masts on land are vulnerable structures. They are mostly affected by environmental loading. Wind loads are the most effective design criteria for these structures. However, the ice effect must also be taken into consideration, especially at high elevations. In cold regions, these two effects are combined. Therefore, the relationship between the wind and ice must be investigated by conducting proper finite-element analyses to avoid the collapse of such structures.

In this paper, the non-linear analysis of a guyed steel lattice mast 80 m in height is performed using the SAP 2000 program [10]. While the model is constituted according to TS 648 [11], load conditions are taken from TS 498 [12]. The altitude of the structure is taken to be 1500 m, and the snow region IV is adopted, which is the most conservative option. In this way, the analysis can also be used for other snow regions. The structure was first analysed without any ice effect. Afterwards, the ice thickness was gradually increased, and the relationship between the wind speed and ice thickness was determined.

2. Material and method

Proper sections and angles of the steel lattice mast are first determined. Afterwards, the three dimensional finite element model is given in Figure 1. Top view of the model is presented in Figure 2. Face sections of the model, showing the distances with angles, are shown in Figure 3 and Figure 4.

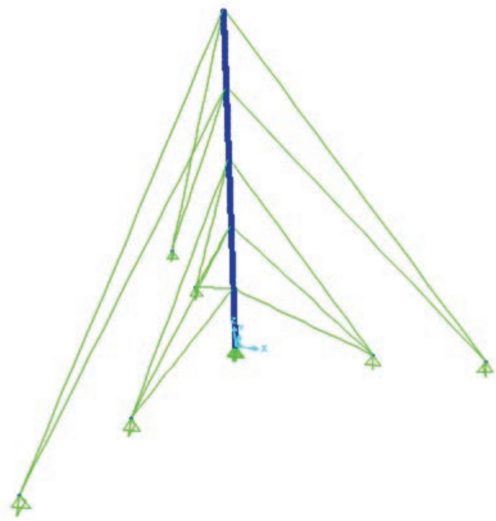

Figure 1. 3-D model

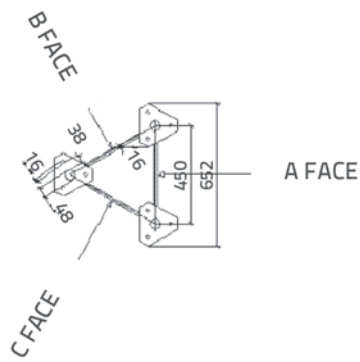

Figure 2. Top view

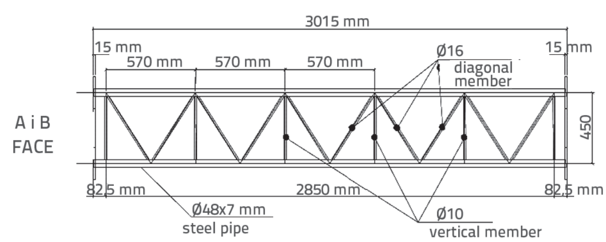

Figure 3. A and B face sections

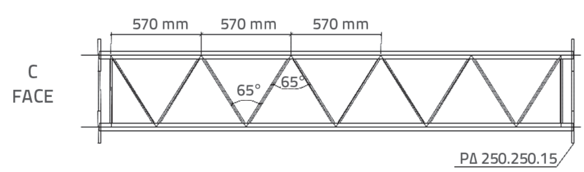

Figure 4. C face section

A module 3015 mm in length is made of steel members. Columns are placed at an angle of 90° to the ground. Vertical steel members connect columns to one another, and are placed vertically with respect to the columns. Diagonal members are placed by definite angles to the columns, and they also connect the columns to one another. A column with diagonal and vertical members that constitute the module, are shown in Figure 5.

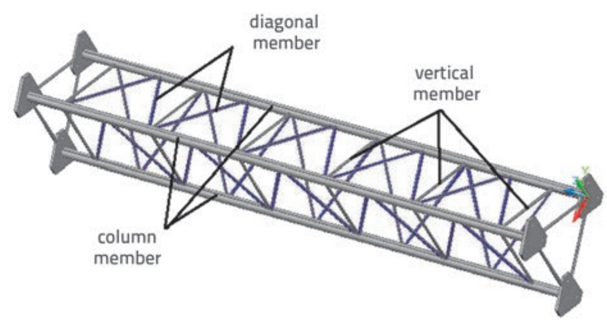

Figure 5. Module members

Guy members and modules are named according to the total height from the ground level. The guy and section numbers, with related heights, are presented in Figure 6.

3. Non-linear analysis

Various investigations have been conducted by researchers about the design and analysis rules. In this respect, simplifications have been recently introduced in Part 3.1 of Eurocode-3 [13]. The wind load is determined by analytical statements together with the wind direction. The wind velocity is different for each country, and it is dependent on both directional and seasonal factors. The snow load is distributed along lateral structural members. On the other hand, all surfaces of members are considered to be covered by ice thickness between 0 and 3 cm. Unit weight of ice is 7 kN/m^3 according to [12]. Ice load effects all structural members. SAP 2000 analysis program is used in the solutions. The non-linearity is determined from geometry. Load requirements are taken from [12]. Material properties are given in Table 1. St52 steel material is similar to European standard steel grade S355.
Section properties and load cases with wind speed and ice properties are given in Tables 2-5. Snow load values are given in [12] for various altitude and snow region values. The values are stated for duration of snowing and elevation from sea level. Snow load effecting the lattice mast is determined for 1500 m altitude in snow region IV in the analysis.

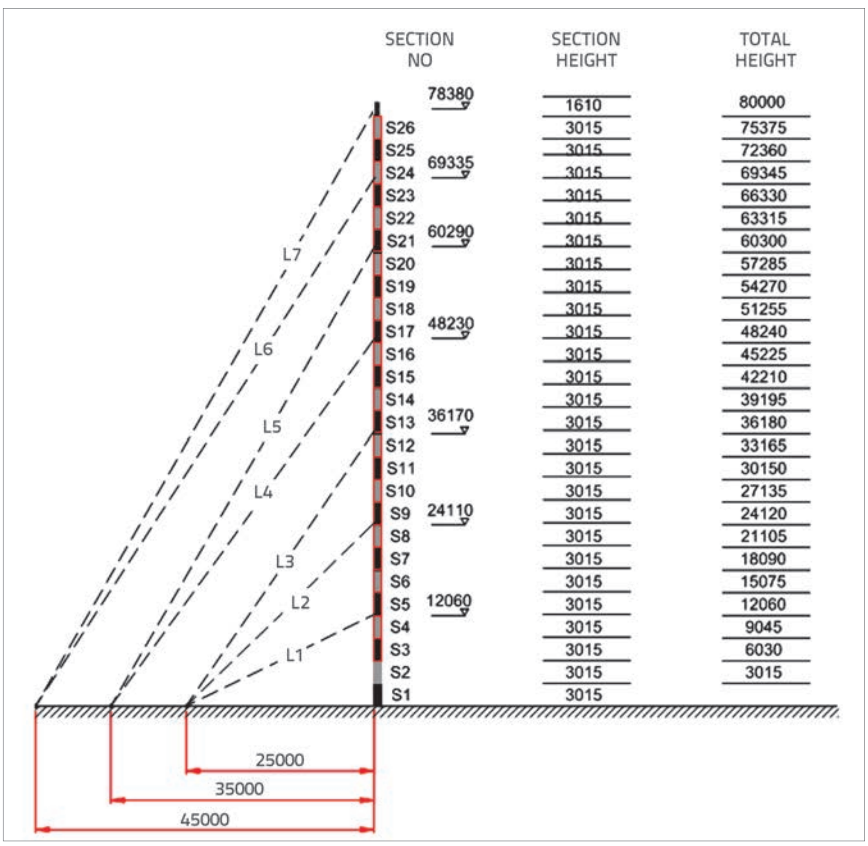

Figure 6. Guy members and modules

Table 1. Material properties

Material type	Tensile strength [MPa]	Yield strength [MPa]
St52 (S355)	510	360

Table 2. Section properties

Member type	Section type	Size [mm]
Column members	Pipe	48x7
Vertical members	Circular	16
Diagonal members	Circular	16
Guy members	Circular	16

Table 3. Wind speed and loads according to height

Height [m]	Wind speed "v" [m/s]	Wind load "q" [kg/m^2]
0-8	28	50
8-20	36	80
20-80	46	130

Table 4. Height and snow properties

Altitude [m]	Snow region	Snow load q_s [kg/m²]
1500	IV	176

Table 5. Ice properties

Weight of unit volume [kN/m³]
7

There are 26 modules in the lattice mast. The column, vertical, and diagonal members in each face of the module are shown in Figure 7. Positive and negative wind directions affecting the module are also presented in the figure.

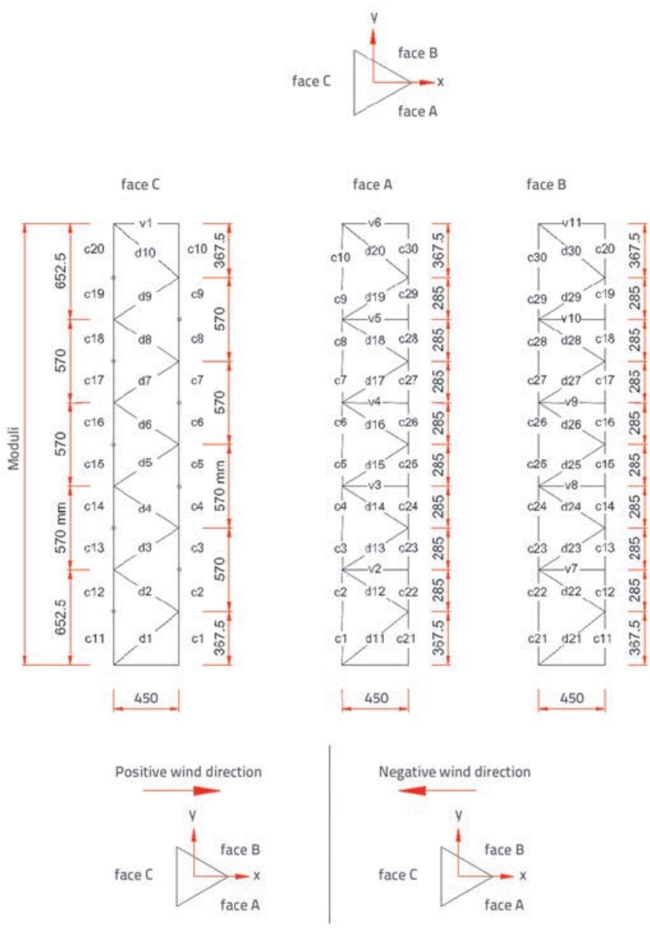

Figure 7. Face views of one module

Load combinations used in the analysis are given in Eqn (1) and Eqn (2) as follows. The combinations are constituted by considering wind direction while both snow and ice loads exist according to TS-498.

$$C_1 = G + S + W + I \quad (1)$$

$$C_2 = G + S - W + I \quad (2)$$

Load names in the combinations are explained below:
G - Self weight
S - Snow load
W - Wind load
I - Ice load

Types and geometrical properties of the structural members in the lattice mast are given in Table 6.

Table 6. Section properties

Member	Section type	Section size [mm]	Section circumference [cm]	Section area [cm²]
Column	Pipe	48x7	15.08	9.02
Vertical	Circular	16	5.03	2.01
Diagonal	Circular	16	5.03	2.01
Guy	Circular	16	5.03	2.01
Column	Pipe	48x7	15.08	9.02
Vertical	Circular	16	5.03	2.01
Diagonal	Circular	16	5.03	2.01
Guy	Circular	16	5.03	2.01
Column	Pipe	48x7	15.08	9.02
Vertical	Circular	16	5.03	2.01
Diagonal	Circular	16	5.03	2.01
Guy	Circular	16	5.03	2.01
Column	Pipe	48x7	15.08	9.02
Vertical	Circular	16	5.03	2.01
Diagonal	Circular	16	5.03	2.01
Guy	Circular	16	5.03	2.01

Snow loads, ice loads according to ice thickness values, and wind loads effecting different heights of the lattice mast with wind speeds are given in Table 7. Snow

Table 7. Load properties

Member	Snow load [kg/m²]	Distributed snow load [kg/m]	Ice thickness [mm]	Distributed ice load [kg/m]	Wind speed [km/h]	Wind load according to height [kg/m]		
						0-8 m	8-20 m	20-80 m
Column	176	–	30	5.15	209	12.18	19.49	26.81
Vertical member		4.42		3.03		4.06	6.50	8.94
Diagonal member		4.42		3.03		4.06	6.50	8.94
Guy		4.42		3.03		4.06	6.50	8.94
Column	176	–	20	2.99	217	12.63	20.21	27.79
Vertical member		4.42		1.58		4.21	6.74	9.26
Diagonal member		4.42		1.58		4.21	6.74	9.26
Guy		4.42		1.58		4.21	6.74	9.26
Column	176	–	10	1.28	223	12.96	20.73	28.50
Vertical member		4.42		0.57		4.32	6.91	9.50
Diagonal member		4.42		0.57		4.32	6.91	9.50
Guy		4.42		0.57		4.32	6.91	9.50
Column	176	–	0	–	226	13.14	21.03	28.92
Vertical member		4.42		–		4.38	7.01	9.64
Diagonal member		4.42		–		4.38	7.01	9.64
Guy		4.42		–		4.38	7.01	9.64

load effects lateral members. Distributed snow load is calculated by considering top surface area of the members.

3.1. Stress analyses

Tensile and compression values of structural members are determined in the analysis. Tensile and compression capacities are calculated according to TS-648 in stress analyses.

3.1.1. Tensile capacities of members

Tensile capacities are calculated according to Eqn (3).

$$N_t = \sigma_{tsafety} \times A_s \quad (3)$$

where A_s is the section area of the steel member, $\sigma_{tsafety}$ is the maximum limit tensile stress, and N_t is the maximum limit design tensile force for the section. The values according to structural members are shown in Table 8

Table 8. Maximum allowable design tensile forces

Member	Section	A_s [cm²]	Material	F_y [MPa]	$\sigma_{tsafety}$ [MPa]	N_t [kN]
Column	Pipe, 48x7 mm	9.02	St52 (S355)	360	216	224
Vertical Member	Circular,16 mm	2.01	St52 (S355)	360	216	50
Diagonal Member	Circular, 16 mm	2.01	St52 (S355)	360	216	50

Table 9. Control of slenderness ratio

Member	Section	A_s [cm²]	Length L [cm]	K Factor	r [cm]	KL/r	Slenderness control
Column	pipe, 48x7 mm	9.02	57	1	1.47	39	< 250 √
Vertical	circular, 16 mm	2.01	45	1	0.40	113	< 250 √
Diagonal	circular, 16 mm	2.01	58	1	0.40	145	< 250 √

Table 10. Design compression forces according to slenderness ratio

Member	Section	A_s [cm²]	KL/r	Material	F_y [MPa]	σ_{tl} [MPa]	N_c [kN]
Column	pipe, 48x7 mm	9.02	39	St52	360	196	204
Vertical	circular, 16 mm	2.01	113	St52	360	68	16
Diagonal	circular, 16 mm	2.01	145	St52	360	49	11

Table 11. Capacity ratios of section 1 without any ice effect

Section	Section type	Section	max.	Combination 1 (C1)		Combination 2 (C2)		N_d [kN]	Capacity ratio	Capacity check
			min.	Pt [kN]	Pc [kN]	Pt [kN]	Pc [kN]			
S1	column	pipe, 48x7 mm	max.	-	-197.25	-	-	-203.61	0.969	< 1.0 √
S1	column	pipe, 48x7 mm	min.	-	-143.31	-	-	-203.61	0.704	< 1.0 √
S1	column	pipe, 48x7 mm	max.	-	-	-	-108.36	-203.61	0.532	< 1.0 √
S1	column	pipe, 48x7 mm	min.	-	-	-	-64.65	-203.61	0.318	< 1.0 √
S1	diagonal	circular, 16 mm	maks.	-	-3.86	-	-	-11.33	0.340	< 1.0 √
S1	diagonal	circular, 16 mm	min.	1.59	-	-	-	49.94	0.032	< 1.0 √
S1	diagonal	circular, 16 mm	max.	-	-	-	-3.39	-11.33	0.299	< 1.0 √
S1	diagonal	circular, 16 mm	min.	-	-	2.40	-	49.94	0.048	< 1.0 √
S1	vertical	circular, 16 mm	max.	2.00	-	-	-	49.94	0.040	< 1.0 √
S1	vertical	circular, 16 mm	min.	3.38	-	-	-	49.94	0.068	< 1.0 √
S1	vertical	circular, 16 mm	max.	-	-	1.24	-	49.94	0.025	< 1.0 √
S1	vertical	circular, 16 mm	min.	-	-	1.89	-	49.94	0.038	< 1.0 √

3.1.2. Compression capacities of members

Compression capacities of the members are determined according to Eqn (4).

$$N_c = \sigma_{csafety} \times A_s \quad (4)$$

The maximum limit compression stress is represented by $\sigma_{ccsafety}$ in the equation. A_s is the section area and N_c is the maximum limit design compression force for the section. The compression safety stress changes according to slenderness. The section compression capacities are calculated according to the geometry of members. The slenderness value of any member for compression can not amount to more than 250. The control of slenderness ratios for all sections is presented in Table 9. Design compression forces for slenderness ratios are given in Table 10.

The radius of gyration is represented with r in the preceding tables. Capacities of the sections for combinations are calculated according to four different ice thicknesses for the compression and tensile values. The results for the first most conservative section are presented in Table 11.

Global displacement values for different mast heights and for different ice thicknesses are given in Table 12.

Table 12. Global mast displacement values

Height [m]	Combination 1 (ice = 0 mm)	Combination 1 (ice = 30 mm)	Combination 2 (ice = 0 mm)	Combination 2 (ice = 30 mm)
24	3.08 cm	2.92 cm	-1.44 cm	-1.36 cm
48	10.34 cm	9.78 cm	-4.54 cm	4.28 cm
78	9.76 cm	9.28 cm	-4.32 cm	4.12 cm

Table 13. Ground forces for 10 mm and 0 mm ice thickness values

Joint	Combination	For 30 mm ice thickness			For 20 mm ice thickness		
		Horizontal force X [kN]	Horizontal force Y [kN]	Vertical force Z [kN]	Horizontal force X [kN]	Horizontal force Y [kN]	Vertical force Z [kN]
GndA0	C1	-2.20	0.85	202.58	-2.26	0.89	201.02
GndA0	C2	1.10	-1.03	76.05	1.20	-1.07	70.08
GndA1	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA1	C2	52.97	0.00	-54.86	54.94	0.00	-56.90
GndA2	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA2	C2	47.49	0.00	-72.63	49.20	0.00	-75.25
GndA3	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA3	C2	39.66	0.00	-64.00	41.09	0.00	-66.30
GndB0	C1	0.55	-0.45	150.75	0.055	-0.45	147.739
GndB0	C2	0.22	-0.31	118.34	0.21	-0.30	113.80
GndB1	C1	50.85	0.23	-53.41	52.75	0.24	-55.38
GndB1	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndB2	C1	48.47	0.45	-73.81	50.18	0.47	-76.42
GndB2	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndB3	C1	39.85	0.35	-64.24	41.26	0.37	-66.51
GndB3	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC0	C1	-0.87	-0.40	150.70	-0.94	-0.45	147.33
GndC0	C2	2.03	1.34	118.20	2.09	1.37	113.70
GndC1	C1	50.85	-0.23	-53.41	52.75	-0.24	-55.38
GndC1	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC2	C1	48.48	-0.45	-73.82	50.19	-0.47	-76.43
GndC2	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC3	C1	39.84	-0.35	-64.24	41.25	-0.37	-66.50
GndC3	C2	0.00	0.00	0.00	0.00	0.00	0.00

Ground joint numbers are shown in Figure 8. A0, B0 and C0 ground joints constitute the supports of the lattice mast. These joints take place in the middle of the figure. Forces occurring under the effect of different ice thickness values are given in Table 12 and Table 13. When structural members are covered by ice, increase in surface area effected by wind is considered in the analysis.

The maximum guy force adopted amounts to 48.8 kN. After the end of analyses, the relationship between the wind speed and ice thickness is presented in Figure 9 for the 80 m lattice mast. Ice thickness is gradually increased to 30 mm and change in wind speed is obtained while providing structural safety of the lattice mast. Section capacities are ensured according to both load combinations for all values under the curve given in Figure 9.

Table 14. Ground forces for 10 mm and 0 mm ice thickness values

Joint	Combination	For 10 mm ice thickness			For 0 mm ice thickness		
		Horizontal force X [kN]	Horizontal force Y [kN]	Vertical force Z [kN]	Horizontal force X [kN]	Horizontal force Y [kN]	Vertical force Z [kN]
GndA0	C1	-2.31	0.92	199.95	-2.33	0.94	199.14
GndA0	C2	1.27	-110	65.80	1.31	-1.12	63.14
GndA1	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA1	C2	56.38	0.00	-58.38	57.21	0.00	-59.23
GndA2	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA2	C2	50.44	0.00	-77.16	51.16	0.00	-78.25
GndA3	C1	0.00	0.00	0.00	0.00	0.00	0.00
GndA3	C2	42.13	0.00	-67.98	42.73	0.00	-68.95
GndB0	C1	0.55	-0.45	145.01	0.55	-0.45	143.45
GndB0	C2	0.20	-0.29	110.57	0.19	-0.29	108.51
GndB1	C1	54.14	0.25	-56.81	54.94	0.26	-57.63
GndB1	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndB2	C1	51.43	0.49	-78.32	52.14	0.50	-79.40
GndB2	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndB3	C1	42.29	0.39	-68.17	42.88	0.40	-69.12
GndB3	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC0	C1	-1.00	-0.48	144.96	-1.03	-0.50	143.39
GndC0	C2	2.14	1.39	110.49	2.16	1.41	108.45
GndC1	C1	54.14	-0.25	-56.81	54.94	-0.26	-57.63
GndC1	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC2	C1	51.43	-0.49	-78.33	52.15	-0.50	-79.42
GndC2	C2	0.00	0.00	0.00	0.00	0.00	0.00
GndC3	C1	42.28	-0.39	-68.16	42.87	-0.40	-69.11
GndC3	C2	0.00	0.00	0.00	0.00	0.00	0.00

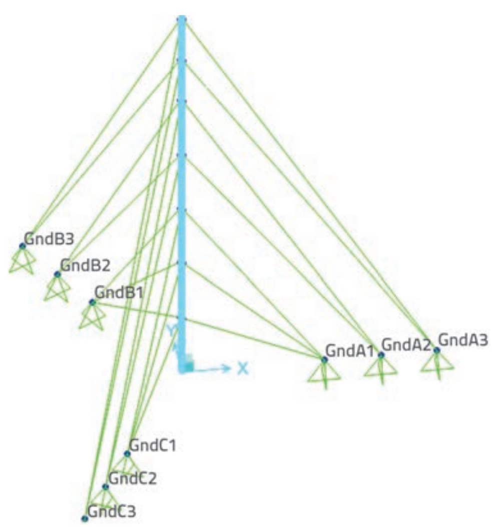

Figure 8. Ground joint numbers

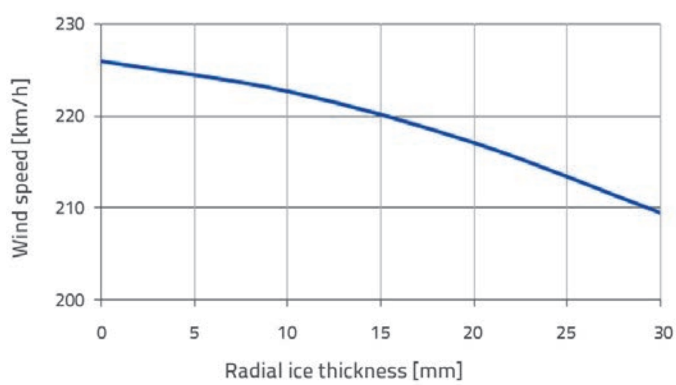

Figure 9. Relationship between wind speed and ice thickness

4. Conclusions

The need for high structures has been steadily growing in line with advancements in modern technology. As steel lattice masts have many advantages, they are used in many different fields. They are mostly used in the following areas: offshore structures, energy transmission lines, telecommunication facilities, radio or television broadcasting facilities, and safety enhancing structures. Many lattice masts have been used for quite a long time. These structures do not require big sections and are therefore easy to construct at low cost.

In this paper, design calculations were performed for a guyed steel lattice mast 80 m in height. The non-linear analysis was conducted by the SAP 2000 finite-element program for different ice thicknesses. The altitude of the structure was taken to be 1500 m, and the snow region IV was adopted according to TS 498. The loads were calculated for these cases.

Most lattice masts are designed by taking wind loads into consideration. However, the ice effect is a major design criterion for tall structures, especially in high and cold regions where masts are affected by ice. Wind loads increase with ice effects in these regions. For this reason, the lattice mast was first analyzed without any ice effect. Afterwards, the ice thickness was gradually increased to determine the relationship between the wind speed and ice thickness, which is a significant parameter for lattice masts. It was demonstrated that the lattice mast safely stands at lower wind speeds as the ice thickness values increase.

This analysis is applicable for all snow regions up to 1500 m in altitude. Guy members are taken to be 16 mm in diameter. The maximum guy force of 48.8 kN was adopted after analysis. The minimum safety coefficient of at least 5 was accepted for guy members. This coefficient was taken into account when deciding the size of guy members.

Capacity ratios and ground forces were calculated for the modules. The most conservative results for the critical section are given, and the capacity control is provided for the steel lattice mast. Finally, it is stated that the safety of the whole system is provided under the effect of design forces due to capacity control. This study can be additionally extended by investigating different lattice-mast sections at higher altitudes, according to other codes.

REFERENCES

[1] Jiang, W., Wang, Z., McClure, G., Wang, G., Geng, J.: Accurate Modeling of Joint Effects in Lattice Transmission Towers, *Engineering Structures*, 33 (2011), pp. 1817-1827, http://dx.doi.org/10.1016/j.engstruct.2011.02.022

[2] Zhuge, Y., Mills, J., Ma, X.: Modelling of Steel Lattice Tower Angle Legs Reinforced for Increased Load Capacity, *Engineering Structures*, 43 (2012), pp.160-168, http://dx.doi.org/10.1016/j.engstruct.2012.05.017

[3] Jones, K., Peabody, A.: The Application of A Uniform Radial Ice Thickness to Structural Sections, *Cold Regions Science and Technology*, 44 (2006), pp. 145-148, http://dx.doi.org/10.1016/j.coldregions.2005.10.002

[4] Makkonen, L., Lehtonen, P., Hirviniemi, M.: Determining Ice/ Loads for Tower Structure Design, Engineering Structures, 74 (2014) 1, pp. 229-232.

[5] Terziev, A., Antonov, I., Velichkova, R.: Wind Data Analysis and Wind Flow Simulation over Large Areas, *Mathematical Modelling in Civil Engineering*, 10 (2014) 1, pp. 38-48.

[6] Mara, T., Hong, H.: Effect of Wind Direction on The Response and Capacity Surface of A Transmission Tower, Engineering Structures, 57 (2013), pp. 439-501, http://dx.doi.org/10.1016/j.engstruct.2013.10.004

[7] Adhikari, R., Wood, D., Sudak, L.: Design Procedure for Tubular Lattice Towers for Small Wind Turbines, Wind Engineering, 38 (2014) 4, pp. 359-376.

[8] Phill-Seung, L., Ghyslaine, M.: Elastoplastic Large Deformation Analysis of a Lattice Steel Tower Structure and Comparision with Full Scale Tests, *Journal of Constructional Steel Research*, 63 (2007) 5, pp. 709-717.

[9] Eltaly, B., Saka, A., Kandil, K.: FE Simulation of Transmission Tower, *Advances in Civil Engineering*, (2014), pp. 1-13, http://dx.doi.org/10.1155/2014/258148

[10] SAP2000, Integrated Finite Element Analysis and Design of Structures Basic Analysis Reference Manual, *Computers and Structures Inc*. Berkeley, 1995.

[11] TS 648, Building Code for Steel Structures, *Turkish Standard Institutes*, Ankara, 1997.

[12] TS 498, Building Loads for Buildings, *Turkish Standard Institutes*, Ankara, 1980.

[13] Eurocode 3, Design of Steel Structures - Part 3.1: Towers and Masts, *European Committee for Standardization*, 2006.