

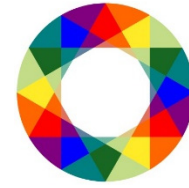
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WIND LOAD ASSESMENT OF STEEL LATTICE AND TUBULAR TOWERS

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ABSTRACT

Regarding the fact that the influence of wind is a dominant load case for the structural dimensioning and the structural stability of the towers, the paper aim is to assess the wind impact based on the structural design characteristics. In this paper two quite different structural designs are analyzed the aim was to gain data for variable structural characteristics and performances.

Mainly the paper is divided in two main parts that define the wind impact after which a conclusion for the structural performance is given.

The first part represents the approach to determine the wind loads according to the EN and the definition and variation of the parameters that mostly impact the wind loads with the change of the structural design characteristics, i.e. the load coefficient c_f and the structural factor $c_s c_d$.

The second part includes analysis of the two structural types, which basically is conducted for the same design requirements and the same load exposure levels in order to gain valid performance data for comparison of the results. After the gain performance data, comparison of the obtained wind load parameters is given i.e. the load coefficient c_f , the structural factor $c_s c_d$ and the reference area A_{ref} . additionally, presentation of the variation of the wind forces to the structural height and presentation of the static response due to wind forces.

After the definition of the wind impact and the structural design performances, conclusions are given for the characteristics of the two structural types. This conclusion can lead to an easier approach in defining and designing these structural systems in the future.

Keywords: *Wind load; Structural design; Dynamic characteristics; Static respons;*

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1. INTRODUCTION

Towers as structural systems are exposed to variable atmospheric influences and loads whose characteristics represent main inputs for ensuring the stability and the mechanical dimensioning of the structural part of these systems. As a dominant atmospheric influence on which the structures are exposed and influence on which the structural dimensions and characteristics are conditioned is the influence of wind.

The behavior of these structural systems exposed to wind loads mostly depends on the atmospheric parameters, terrain parameters and the characteristics of the structural system. That's why for a good designing approach, good knowledge of the structural design characteristics is needed. This paper focuses on the impact of the wind loads for two quite different structural systems based on their structural design characteristics.

For the wind load assessment, the following towers used for transmission systems are chosen:

- Steel lattice tower – referred as SD tower (traditional towers) used for transmission systems
- Steel tubular tower – referred as T shaped tower (new generation towers) used for transmission systems

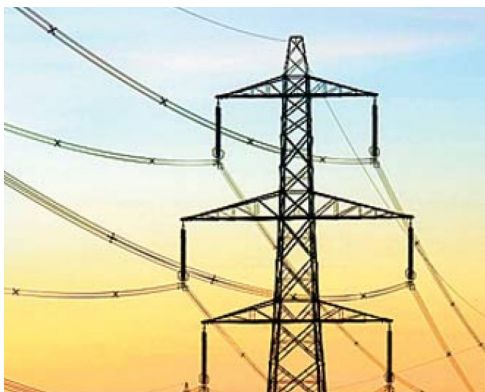


Fig. 1. Steel lattice tower



Fig. 2. Steel tubular tower

- Steel lattice tower – referred as SD tower

Traditional lattice tower, the design of this structure represent combination of interconnected axially stressed members that together form triangular shapes. The silhouette of the tower is characterized by a greater width at the base and a gradual or breach narrowing to the top, the conductors are fastened through insulators on cantilevered lattice segments, while the ground wire (protective wire) is fastened at the very top of the tower.

- Steel tubular tower – referred as T shaped tower

The T shaped tower represent a new generation of transmission towers commonly used in developed countries. These towers are characterized by a fairly simple silhouette configuration, usually of a full-length tube profile, which reduces the diameter from the base to the top. At the top, the tower breaks down into two cantilevered segments whose role is to provide the required safety distance to securing the insulators. Typical for this tower is the use of insulators that allow the connection of three conductors and the protective rope at one point in the structure.

2. WIND LOADS ACCORDING TO EN

$$F_w = c_s c_d c_f q_p(Z_e) A_{ref} - \text{wind load (force)}$$

$c_s c_d$ – structural factor
 c_f – load coefficient
 $q_p(Z_e)$ – peak velocity pressure
 A_{ref} – reference area

Most of the parameters that define the wind loads depend on the structural design characteristics, in this heading the definition and variation of the parameters that mostly impact the wind loads with the change of the structural design characteristics are presented, i.e. the load coefficient c_f and the structural factor $c_s c_d$.

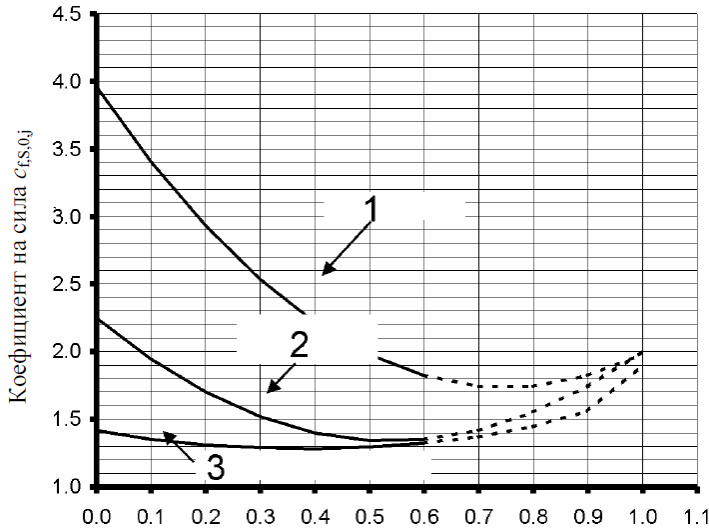
- Load coefficient c_f

$$c_f = K_\theta c_{f,s,0} (A_s / \Sigma A)$$

K_θ – wind inclination factor

If $K_\theta = 1.00$ and $A_s = \Sigma A = A_{ref}$ then $c_f = c_{f,s,0} = c_{f,s,0}(\varphi)$

- c_f for Lattice towers (the graph presents the change of the load coefficient for lattice towers)



1 – flat elements
 2 – circular elements $Re \leq 4 \times 10^5$
 3 – circular elements $Re \geq 4 \times 10^5$

Fig.3. c_f for lattice towers

- c_f for tubular towers (the graph presents the change of the load coefficient for tubular towers)

$$c_f = c_{f,0} \psi_{\lambda\alpha}, \quad c_{f,0} - \text{force coefficient without free - end flow}$$

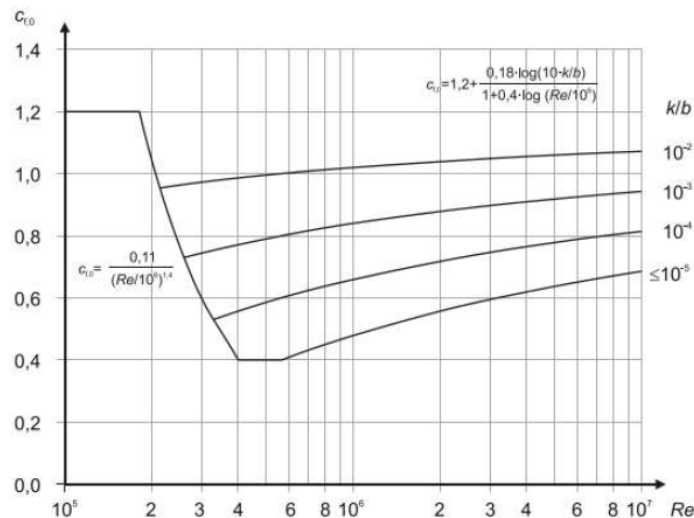


Fig.4. c_f for tubular towers

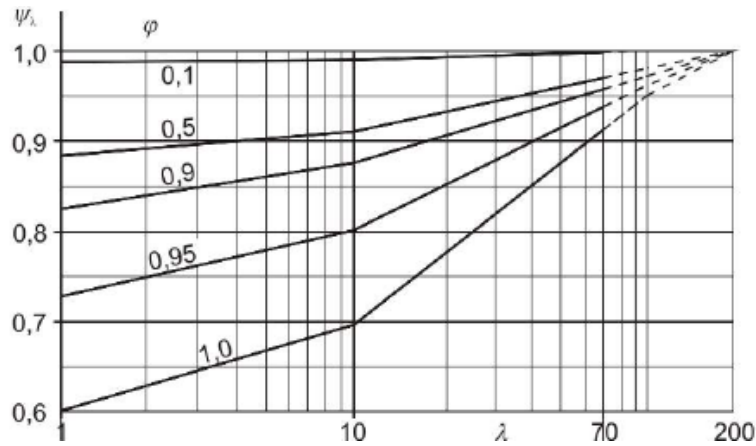


Fig.5. $\psi_{\lambda\alpha}$ for tubular towers

- Structural factor $c_s c_d$

$$c_s c_d = \frac{1 + 2k_p I_v(Z_e) \sqrt{B^2 + R^2}}{1 + 7I_v(Z_e)}$$

In terms of the structural factor $c_s c_d$

Mainly the size factor c_s takes into account the impact of wind action reduction as a result of the non-simultaneous occurrence of maximum surface pressures and mostly, this parameter depends on the atmospheric and field conditions, i.e. the wind impact parameters. While the dynamic factor c_d takes into account the effects of the vibration of the structure as a consequence of the wind turbulence in resonance with the structure and mostly this parameter depends on the dynamic characteristics of the structures i.e. the structural height, the structural stiffness, the mass of the structure, the height position of the mass and the logarithmic decrement of damping (structural characteristic).

From the above mentioned as structural characteristics that mostly impact the structural factor $c_s c_d$, are the dynamic characteristics of the structure. In addition, a graph is presented with the change of the structural factor for variable dynamic characteristics of the structure, i.e. frequencies of oscillations of the structure.

For the analysis the following wind parameters are selected:

basic wind speed $v_b = 27 \text{ m/s}$, orthographic coefficient $c_0(Z_e) = 1.0$, second category of terrain, structural height of $h = 20.0\text{m}$

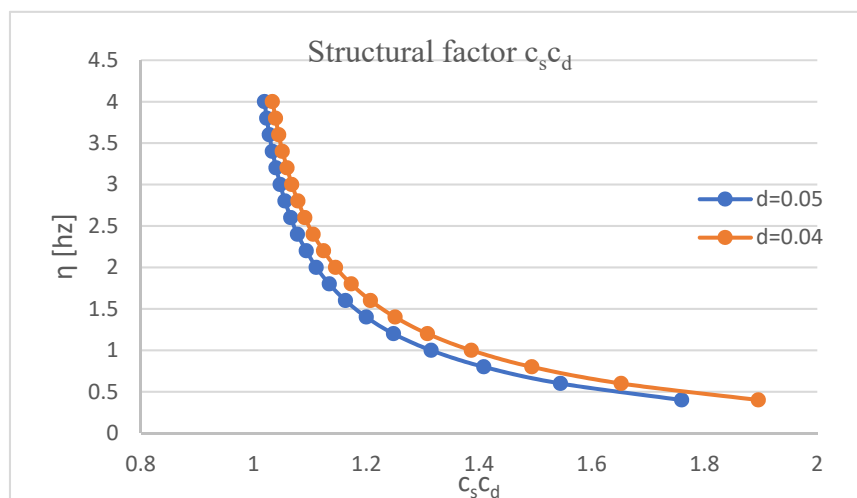


Fig.6. Structural factor $c_s c_d$

3. INPUT PARAMETERS FOR THE ANALYSIS

The analysis was conducted for the same design requirements and the same load exposure levels in order to gain valid performance data.

- Transmission system parameters

Double circuit transmission system of 110 kV

Intermediate range of conductors and protective rope: $L = 300\text{ m}$

Height difference between neighbor towers: $h = 7.00\text{ m}$ (on both sides)

Protective height to the lowest point of conductor bonding: $H = 15.5\text{ m}$

Conductor Type: ACSR 240/40

Protective rope type: OPGW - ALSH - D (S) b 24SMF (ST66-4.7)

- Wind impact parameters

$V_b = 27.00\text{ m/s}$ – Basic wind speed

II – terrain category

$c_0(Z_e) = 1$ – Orthographic coefficient

- Frost impact parameters

Glaze class $G2$ with density of $\rho = 900\text{ kg/m}^3$

Glaze thickness $t = 20\text{ mm}$, $k = 0.45$ – wind load reduction factor combined with ice

- Steel lattice tower – referred as SD tower

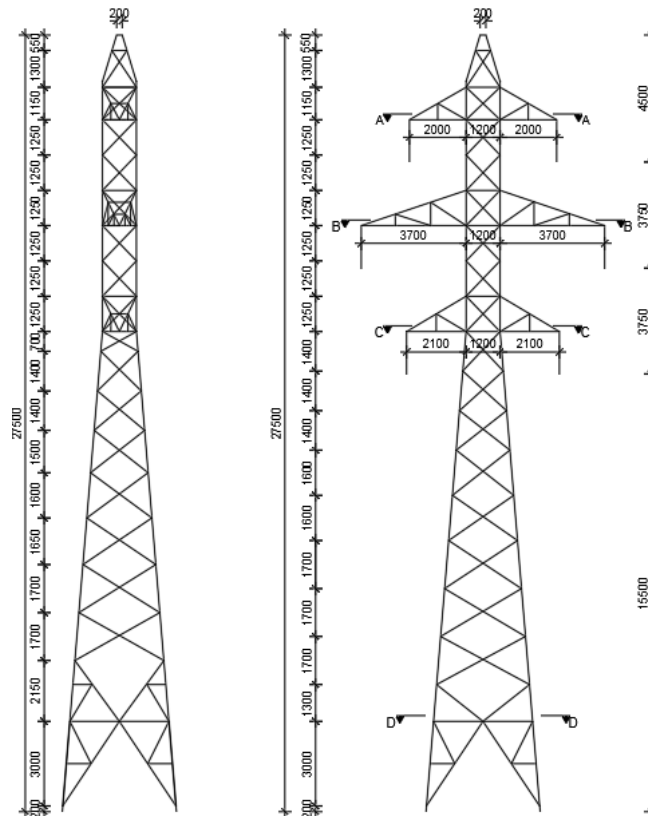


Fig.7. presentation of the analyzed Steel lattice tower

- Steel tubular tower – referred as T shaped tower

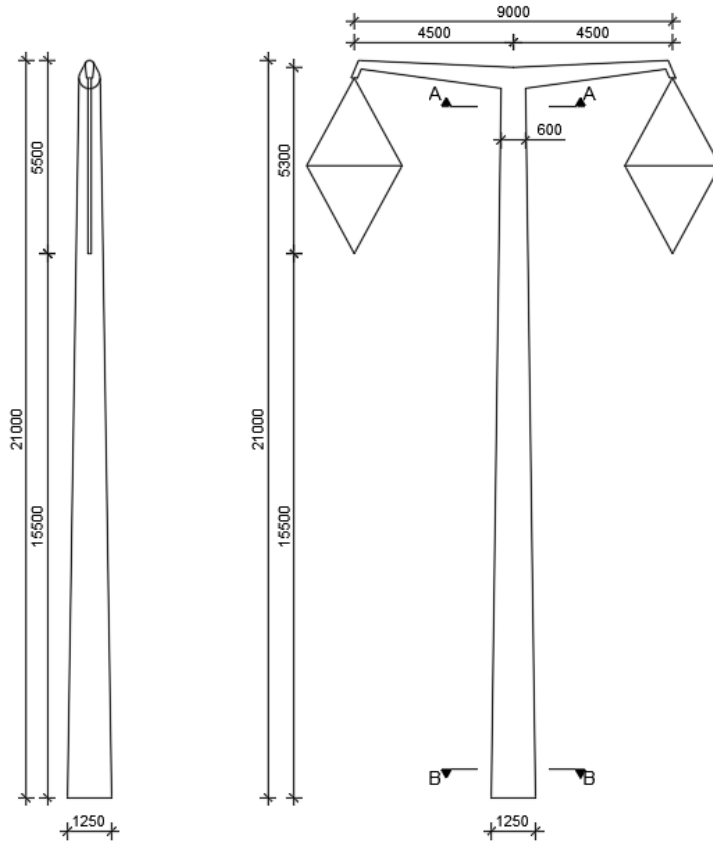


Fig.8. presentation of the analyzed Steel tubular tower

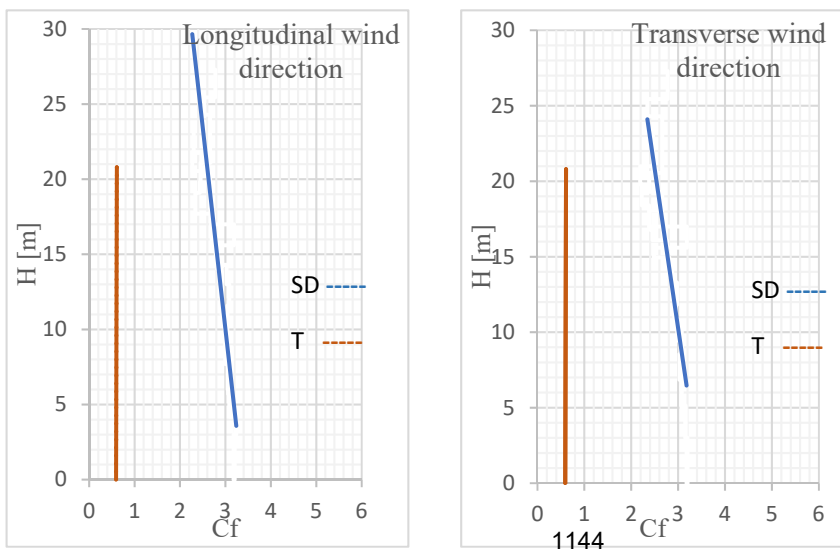
4. ANALYSIS RESULTS

In this heading, on the basis of the conducted analysis of the structural designs, a comparison of the obtained parameters that define the wind forces is made. Additionally, presentation of the variation of the wind forces to the structural height and presentation of the static response due to wind forces.

4.1. Wind force parameters

- Load coefficient c_f – referent to structural height

The load coefficient is presented by linear interpolated graphs of the precisely determined force coefficients for the sections of the towers in the analysis.



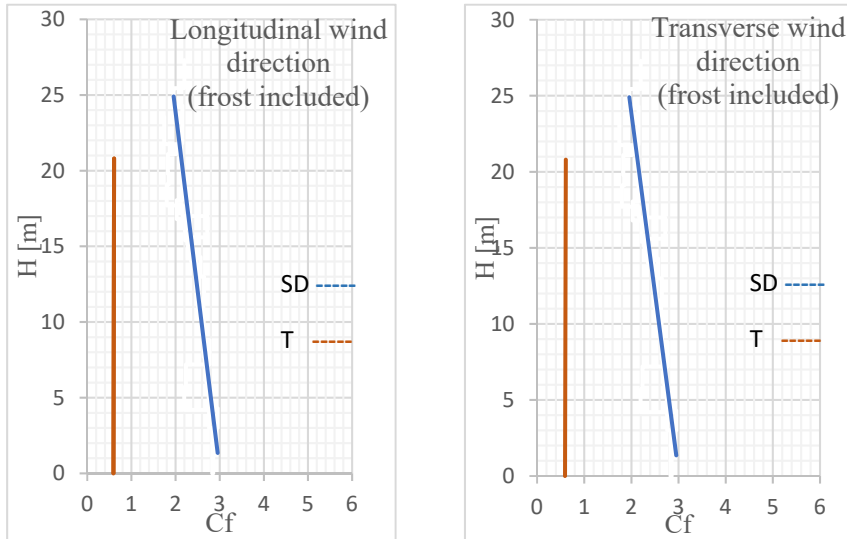


Fig.9,10,11,12. Load coefficients - referent to structural height

- Reference area A_{ref} – referent to structural height

The reference area A_{ref} is crucial for defining the wind forces i.e. the bigger the surface affected by wind pressure the bigger the wind force. Besides the importance in terms of the size of the surface, a crucial parameter that defines the static response of the structure is the pressure intensity to which the surface is exposed, or the surface position i.e. the higher the position, the higher the wind pressure and the greater the tendency for a greater bending moment or a less favorable static response. In the following presentation of the referent are to the structural height is presented.

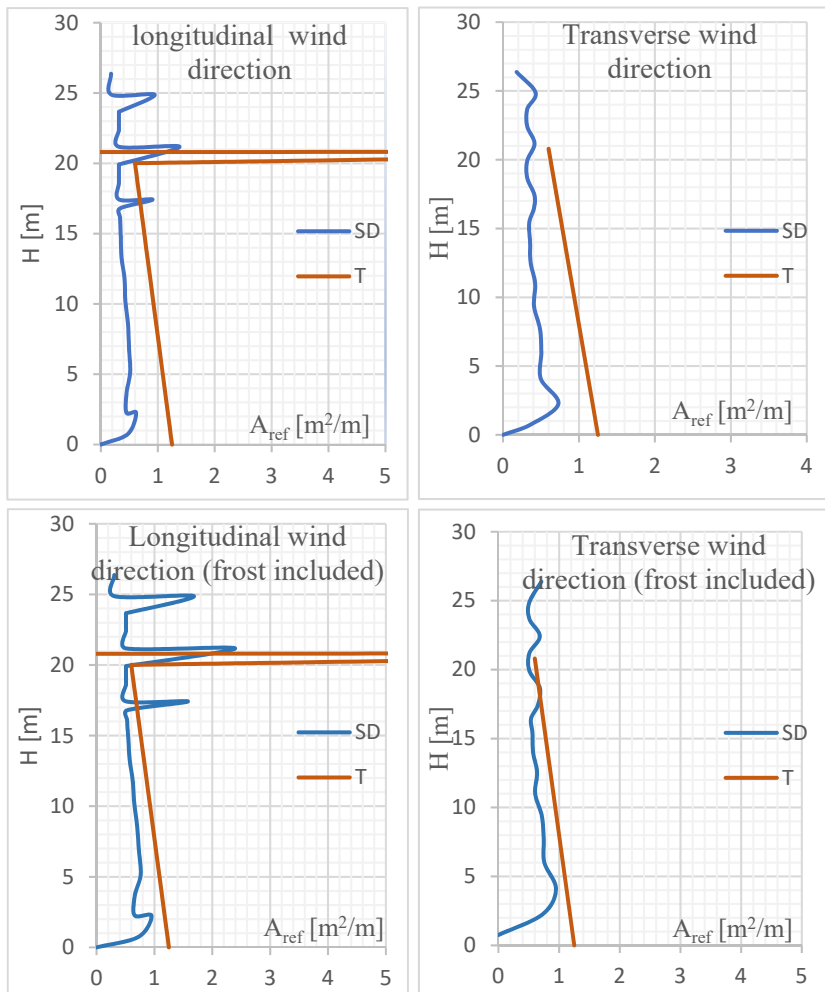
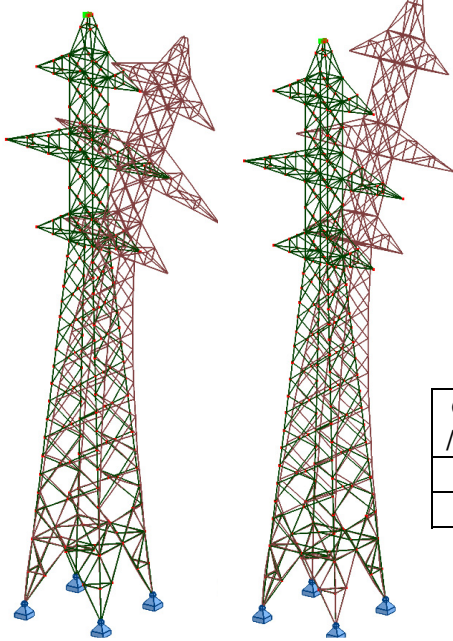


Fig.13, 14, 15, 16. Reference area - referent to structural height

- Structural factor $c_s c_d$
- Steel lattice tower – referred as SD tower



Dynamic characteristics

$\delta = 0.05$ – logarithmic decrement of damping

Case- /Mode	Frequency (Hz)	Period (sec)	Rel.m- as.UX (%)	Rel.m- as.UY (%)	Total mass (kg)
49/ 1	2.04	0.49	58.31	0.00	6267.85
49/ 2	2.11	0.47	58.31	64.87	6267.85

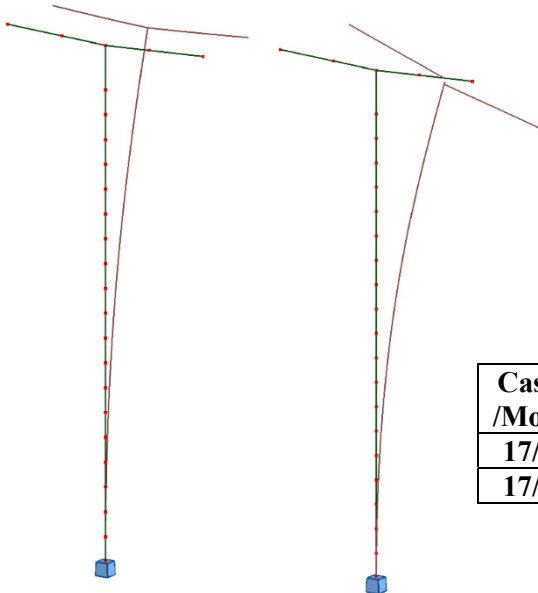
Table 1. Modal properties – Steel lattice tower

Fig.17. Mode shapes 1 and 2 - Steel lattice tower

Direction	η (Hz)	L(Z) [m]	fL (Z, η)	SL (Z, η)	η_h	η_b	B ²	R ²	ν	k_p	$c_s c_d$
T	2.04	112.43	7.085	0.038	7.972	0.754	0.718	0.279	1.079	3.765	1.039
L	2.11	112.43	7.328	0.037	8.246	0.780	0.718	0.261	1.090	3.767	1.034

Table 2. Structural factor – Steel lattice tower

- Steel tubular tower – referred as T shaped tower



Dynamic characteristics

$\delta = 0.04$ – logarithmic decrement of damping

Case- /Mode	Frequency (Hz)	Period (sec)	Rel.m- as.UX (%)	Rel.m- as.UY (%)	Total mass (kg)
17/ 1	1.21	0.83	0.00	67.12	9549.14
17/ 2	1.23	0.81	67.65	67.12	9549.14

Table 3. Modal properties – Steel lattice tower

Fig.18. Mode shapes 1 and 2 - Steel tubular tower

Direction	η (Hz)	L(Z) [m]	fL (Z, η)	SL (Z, η)	η_h	η_b	B ²	R ²	ν	k_p	$c_s c_d$
L	1.21	87.32	3.55	0.058	3.892	0.168	0.754	1.440	0.980	3.739	1.313
T	1.23	87.32	3.61	0.058	3.956	0.171	0.754	1.403	0.992	3.742	1.307

Table 4. Structural factor – Steel lattice tower

4.2. Wind forces

In the following presentation we can see the change of the wind forces regarding the structural height and structural design characteristics. Comment: The wind forces with the frost included conditions are reduced by a reduction coefficient $k = 0.4$, defined by the EN.

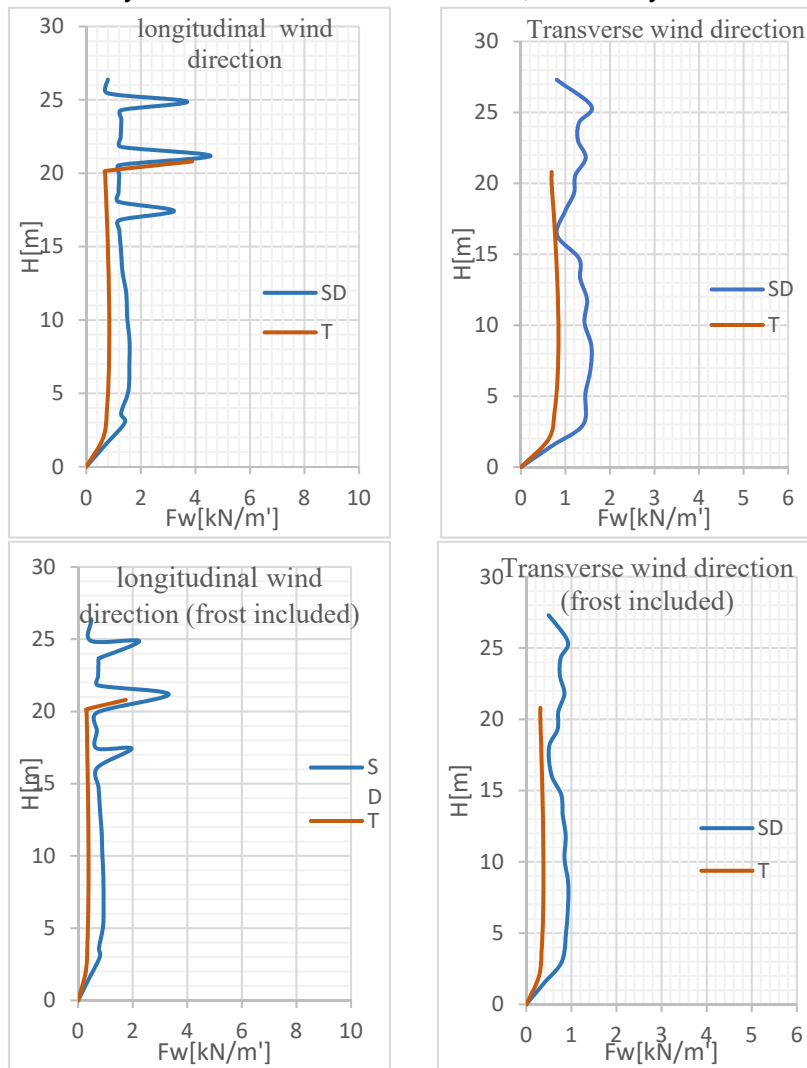


Fig.19, 20, 21, 22. Wind forces - referent to structural height

4.3. Global wind force reactions

Comment: In the global wind force reactions, among the wind forces on the structure, additionally wind forces of the conductors are included, which are quite large, especially in the transverse direction.

- Steel lattice tower – referred as SD tower

Node/Case	FX (kN)	FY (kN)	MX (kNm)	MY (kNm)
Case 4	WL			
Sum of reac.	-0.00	-45.64	673.95	0.00
Case 5	WT			
Sum of reac.	-86.45	0.00	-0.00	-1586.81

Table 5. Global reactions – Steel lattice tower

- Steel tubular tower – referred as T shaped tower

Node/Case	FX (kN)	FY (kN)	MX (kNm)	MY (kNm)
Case 3	WL			
Sum of reac.	0.0	-12.35	192.13	0.00
Case 4	WT			
Sum of reac.	-71.47	0.0	-0.00	-1434.98

Table 6. Global reactions – Steel tubular tower

5. CONCLUSIONS

- In terms of the force coefficient c_f

The lattice tower is characterized by drastically greater coefficients than those for the tubular tower.

- In terms to the reference area A_{ref}

The structural design of the tubular tower is characterized with larger surfaces exposed to wind pressure compared to the structural design of the lattice tower, although the lattice tower has a wider surface. In terms of the position of the exposed surfaces the lattice tower is characterized to have the most exposed surfaces, but those surfaces are quite small.

- In terms of the structural factor $c_s c_d$

While considering the stiffness characteristics of the structural designs, the lattice tower is characterized with a good structural concept that can achieve fairly large stiffness parameters, dramatically larger than the structural design of the tubular tower.

While considering the mass as a parameter for the dynamic characteristics, it can be said that the structural design of the lattice tower has a much smaller mass than that of the structural design of the tubular tower, although the overall dimensions are generally larger.

While considering the logarithmic decrement of damping, the structural design of the lattice tower is characterized by a fairly large coefficient $\delta = 0.05$, while the coefficient of the tubular tower is $\delta = 0.04$.

Followed by the concept of structural designs and their dynamic characteristics, comparatively, it can be said the structural design of the lattice tower has good dynamic characteristics, resulting in a rather low value of the structural factor, lower than the one of the structural design for the tubular tower.

- In terms of the wind forces F_w

The advantages and disadvantages of the structural designs that define the wind forces, can be roughly guessed from the previously discussed features. Where it can be said that the structural design of the lattice towers is characterized with a greater wind forces compared to the ones of the T tower.

- In term of the static response

Regarding the static response of the towers, the lattice tower has greater static values compared to the tubular tower, especially in longitudinal wind direction, while the quite small difference in the static values in the transverse wind direction comes from the quite large wind forces of the conductors and the use the additional protective wire for the tubular tower.

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