ДГКМ
ДРУШТВО НА ГРАДЕЖНИТЕ КОНСТРУКТОРИ НА МАКЕДОНИЈА
Партизански одреди 24, П.Фах 560, 1001 Скопје
Северна Македонија

MASE
MACEDONIAN ASSOCIATION OF STRUCTURAL ENGINEERS
Partizanski odredi 24, P. Box 560, 1001 Skopje
North Macedonia

SS - 15
mase@gf.ukim.edu.mk
http://www.mase.org.mk

DESIGN ASSESMENT OF STEEL LATTICE AND TUBULAR TOWERS

Gjoko PASKALOVSKI[1], Denis POPOVSKI[2]

ABSTRACT

Towers as structural systems are characterized by a complex structural concept, with large number of elements and variable behavior characteristics. Regarding the design complexities and uncertainties, this paper focus is to assess the designs of two quite different structural types. The aim was to gain information about the efficiency of the designs from variable aspects like load bearing characteristics, stability characteristics, montage characteristics and economy.

Mainly this paper is divided in two parts that define the design characteristics after which a conclusion is given.

The first part represents the approach and definition of the basic characteristics of the structural designs, starts with the definition of the load bearing capacities and stability characteristics, and followed by the ways of assembling the structural designs in montage segments and their montage characteristics.

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 acquisition of performance data, comparison of the obtained results is given from aspects like material quantity, cost-effectiveness for variable structural parts and installation speed and benefits.

After the obtained 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: *Structural design; Load bearing; Stability*; Montage; *Economy;*

[1] MSc in Structural engineering, Ohrid, Republic of North Macedonia, gjoko.paskalovski@gmail.com

[2] Assistant professor, PhD, Faculty of Civil Engineering, University “Ss. Cyril and Methodius”, Skopje, Republic of North Macedonia, popovski@gf.ukim.edu.mk

1. INTRODUCTION

Towers as structural systems are quite complex, and they require a serious design approach followed from their efficiency and functionality requirements, as well as the need for material and economy savings. This paper focus is assessment of the designs of two quite different structural concepts, the idea is to acquisite information about the efficiency of the towers from variable aspects like load bearing characteristics, stability characteristics, montage characteristics and economy.

For the 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

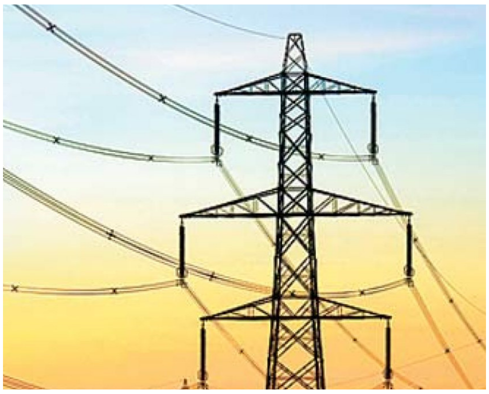


Fig. 1. Steel lattice tower

Fig. 2. Steel tubular tower

2. LOAD BEARING AND STABILITY CHARACTERISTICS

One of the main constructive features of any structural design, primarily in terms of functionality and also in terms of size, dimensions and cost-effectiveness, are the load bearing and stability characteristics. As a characteristic, the stability of a structural design depends largely on the conception of the structural design itself, i.e. its shape and dimensions, while the load bearing capacity in addition to the conceptual design depends on the material characteristics and the detailing. At this point, attention is paid to the concept of the structural design, as well as the way of their control, on the basis of which a description of the possibilities for manipulation are given.

2.1. Steel lattice towers

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

- Load bearing characteristics

When dealing with lattice towers, the structural design and the concept of interconnection of the members has a major role in the distribution of the loads and the load characteristics. By changing the interconnection concept of the members, we have changes in the static values in those members as well as the load parameters i.e. the bearing capacity. For example, by increasing the distance between the outer members, the axial forces in those members decrease, but on the other hand, the lengths of the inner members are increasing, so they become slender and critical to buckling. From the above mentioned we can say that it is a concept of features that significantly changes and depends on a large number of parameters. In the following, the definition of the resistance criteria and the bearing capacity of the members.

- Resistance criteria

$$\frac{N_{Ed}}{N_{Rd}} \leq 1.00 - Resistance\ criteria$$

- Tension members

$$N_{t,Rd} = \min\left(N_{pl,Rd}, N_{u,Rd}\right)$$

$$N_{pl,Rd} = \frac{A\, f_y}{\gamma_{M0}} - Plastic\ resistance\ of\ gross - section$$

$$N_{u,Rd} = \frac{0.9 A_{net}\, f_u}{\gamma_{M2}} - Resistance\ of\ the\ net\ cross - section$$

- Compression members

$$N_{b,Rd} - \frac{\chi\, A_{eff}\, f_y}{\gamma_{M1}} - Resistance\ of\ the\ \ cross - section$$

$$\chi = \frac{1}{\phi + \sqrt{\phi^2 - \bar{\lambda}^2}} \leq 1{,}00 - Reduction\ factor\ for\ the\ relevant\ bucling\ mode$$

$$\phi = 0{,}50\left[1 + \alpha\left(\bar{\lambda}_{eff} - 0{,}20\right) + \bar{\lambda}_{eff}{}^2\right]$$

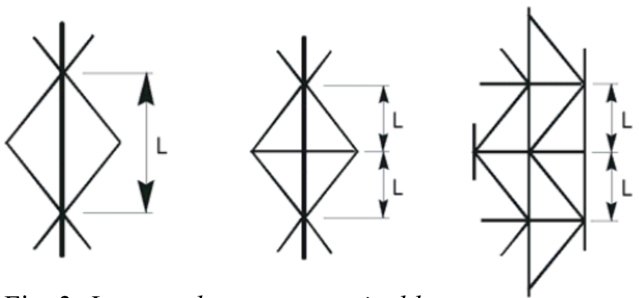
$$\bar{\lambda}_{eff} = k\,\bar{\lambda} - Effective\ slender\ ratio$$

Curvature length and slender parameters for variable ways of connecting the elements

(the parameters are presented for angular steel profiles i.e. the most commonly used profiles)

<u>*Leg members*</u> – buckling length and effective slender factor

Symmetrical bracing



$- axis\ v$ –v

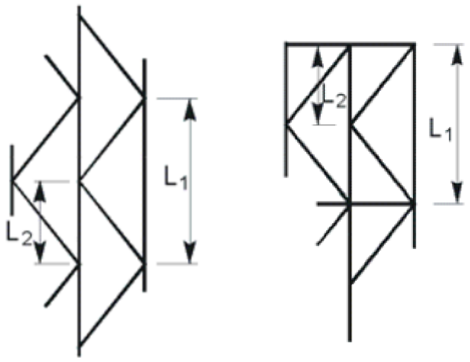
$k = 0.8 + \frac{\bar{\lambda}}{10};\ 0.9 \leq k \leq 1.00$

$L - buckling\ length$

Fig. 3. *Leg members -symmetrical bracıng*

Asymmetrical bracing

Case 1



$- axis\ v$ –v

$L_2 - buckling\ length$

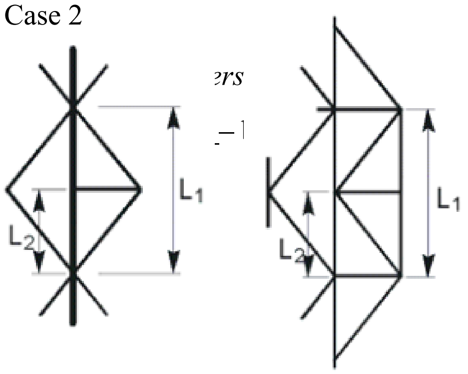
$k = 1.2\left(0{,}8 + \frac{\bar{\lambda}}{10}\right);\ 1.08 \leq k \leq 1.20$

$- axis\ y - y$

$L_1 - buckling\ length$

$k = 1.2\left(0{,}8 + \frac{\bar{\lambda}}{10}\right); 1.08 \leq k \leq 1.20$

Case 2



$-$ *axis v* $-$v

$L_2 -$ *buckling length*

effective slender factor

$$k = 0.8 + \frac{\overline{\lambda}}{10};\ 0.90 \leq k \leq 1.00$$

$-$ *axis y* $-$ *y*

$L_1 -$ *buckling length*

$$k = 0.8 + \frac{\overline{\lambda}}{10};\ 0.90 \leq k \leq 1.00$$

Typical primary bracing patterns

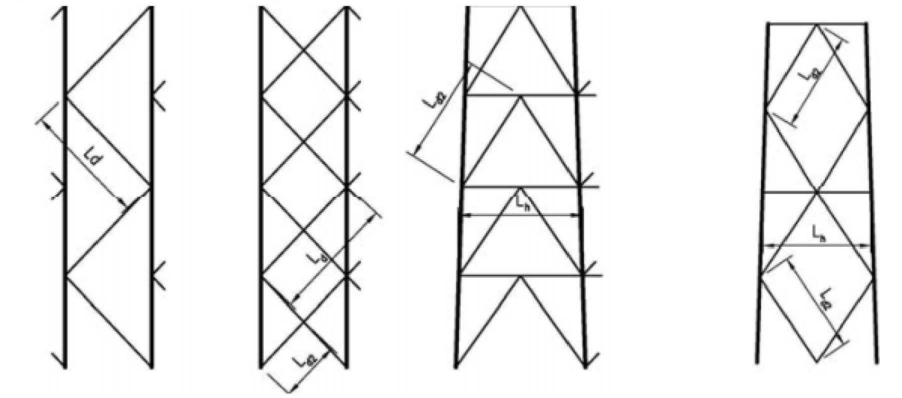


Fig. 5. *Bracing members – primary bracing pattern*

Single bracing	Cross bracing	K - bracing	Cross bracing with horizontal intersection

$$\lambda = \frac{L_{d2}}{i_{vv}} - For\ the\ maximal\ axial\ force$$

$$\lambda = \frac{L_d}{i_{xx}}\ or\ \frac{L_d}{i_{yy}} - For\ the\ algebric\ of\ the\ axial\ forces$$

Typical secondary bracing patterns

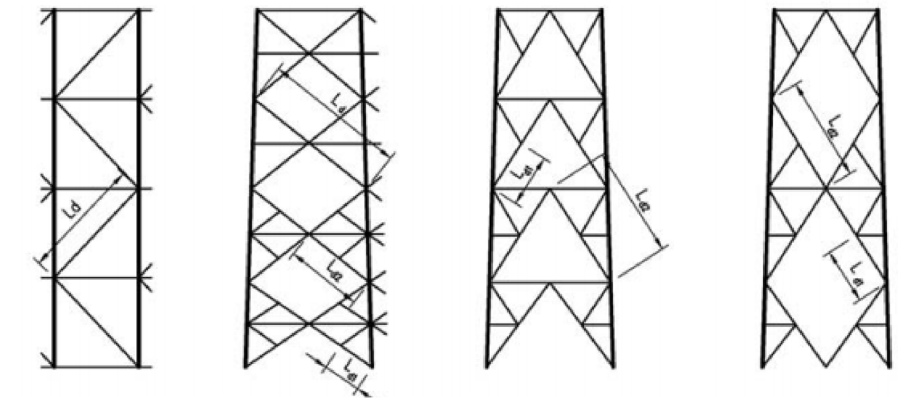


Fig. 6. *Bracing members – secondary bracing pattern*

Single bracing	Cross bracing	K - bracing	Cross bracing with horizontal intersection

$$\lambda = \frac{L_{d1}}{i_{vv}};\ \frac{L_{d_2}}{i_{xx}}\ or \frac{L_{d_2}}{i_{yy}} - For\ the\ maximal\ axial\ force$$

$$\lambda\ = \frac{L_d}{i_{xx}}\ or\ \frac{L_d}{i_{yy}} - For\ the\ algebric\ of\ the\ axial\ forces$$

- Stability characteristics

The structural design of the lattice towers has a rather easy concept of manipulation based on the manipulation of the forces in the outer members derived from the global turning moment. The magnitude of these forces in the outer members depends on the size of the loading and the perpendicular distance between its line of action, with increasing the distance between the line of action i.e. the width of the structure, the forces in the outer members are reducing, and thus the forces to which the foundations are exposed. lattice towers have the capacity to reach quite large widths, which means that the foundations will be exposed to acceptable forces, and the structural design offers good stability characteristics.

2.2. Steel tubular towers

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 wire at one point in the structure.

- Load bearing characteristics

The load bearing capacity of these structural design mostly depends on the characteristics of the tube i.e. its diameter and its thickness, additionally in more detail calculations parameters of the used stiffeners are used. From the above mentioned these structural designs can be easily manipulated to reach desired performance. In the following, the definition of the resistance criteria and the bearing capacity of the structures exposed to variable loading situations.

First order resistance criteria

$$\frac{N_b}{N_{crit}} \leq 0.10 - requred\ condition$$

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} \leq 1.00$$

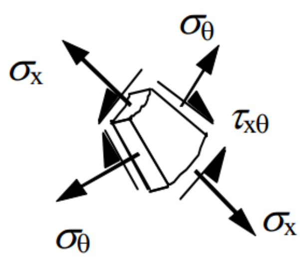
Second order resistance criteria

$$\frac{N_{Ed}}{\chi\, N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,ED}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zy}\frac{M_{z,ED}}{M_{z,Rk}/\gamma_{M1}} \leq 1.00$$

If the cross section of the design is of class 4, further control is required according to EN1993-1-6

Local buckling control according to membrane theory

$$\left(\frac{\sigma_{x,Ed}}{\sigma_{x,Rd}}\right)^{kx} - ki\left(\frac{\sigma_{x,Ed}}{\sigma_{x,Rd}}\right)\left(\frac{\sigma_{\theta,Ed}}{\sigma_{\theta,Rd}}\right) + \left(\frac{\sigma_{\theta,Ed}}{\sigma_{\theta,Rd}}\right)^{k\theta} + \left(\frac{\tau_{x\theta,Ed}}{\tau_{x\theta,Rd}}\right)^{k_\tau} \leq 1.00$$

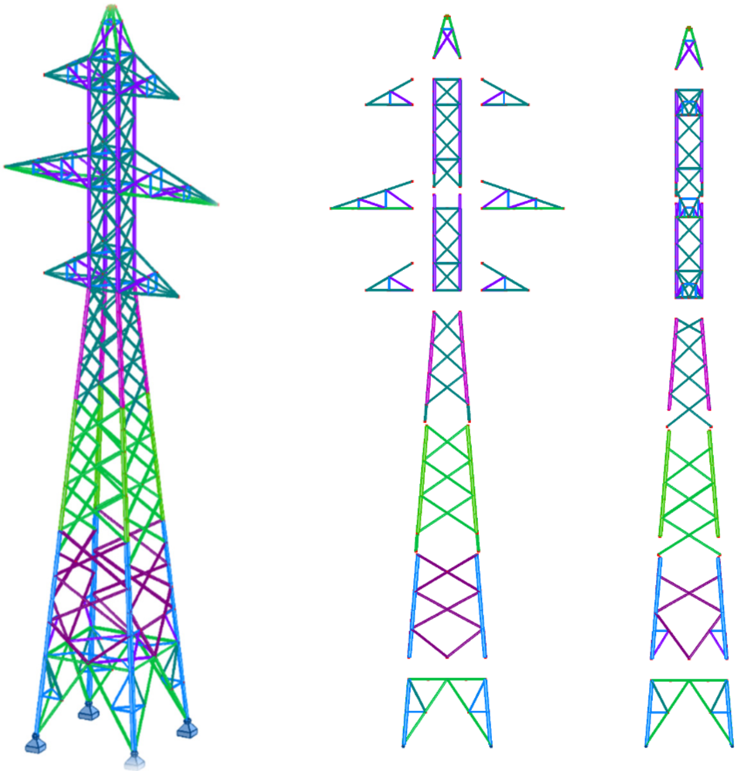


- Stability characteristics

When considering the stability characteristic, it can be said that this structural design does not offer good features, i.e. the concept of the design doesn't offer possibilities to manipulate with the global forces (global turning moment), so basically this forces are transferred to a fairly small base width, and the overall stability is provided by the foundation.

3. MONTAGE CHARACHTERISTICS

- Steel lattice towers

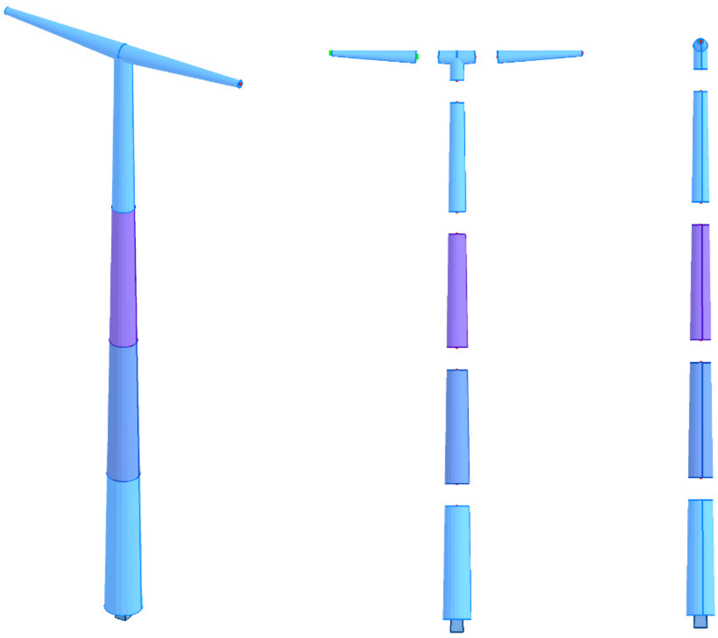


The assembly of the structures is given for light weight machinery and minimal transportation opportunities.

Segment type	number
body	7
cantilever	6
Sum:	13

Fig. 7. *Montage characteristics – steel lattice tower*

- Steel tubular towers



The assembly of the structures is given for light weight machinery and minimal transportation opportunities.

Segment type	number
body	7
cantilever	6
Sum:	13

Fig. 8. *Montage characteristics – steel tubular tower*

4. 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: $L = 300\ m$

Height difference between neighbor towers: h = 7.00 m (on both sides)

Protective height to the lowest point of conductor bonding: H = 15.5m

Conductor Type: ACSR 240/40

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

- Structural material

Structural steel S235

Concrete C25/30

- Wind impact parameters

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

II – terrain category, $c_0(Z_e) = 1$ – Orthographic coefficient

- Frost impact parameters

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

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

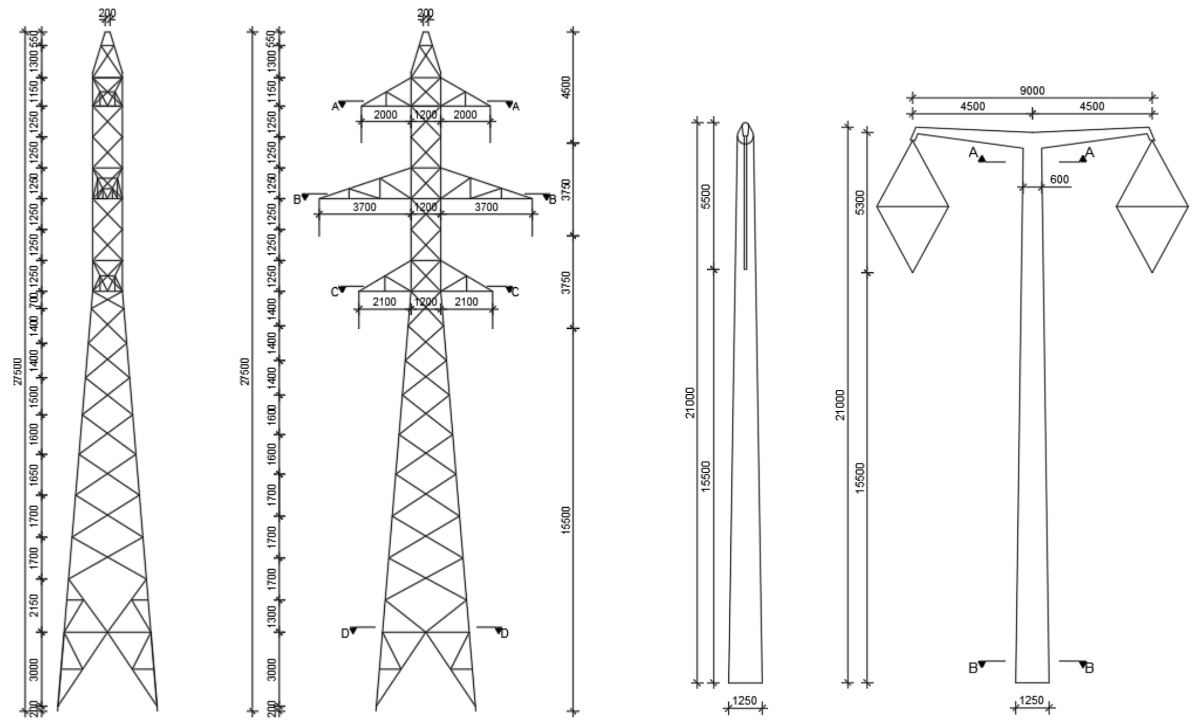


Fig. 9. *Presentation of the analyzed towers*

5. ANALYSIS RESULTS

In this heading, on the basis of the conducted analysis, comparison of the obtained parameters is given.

5.1. Structural material costs

Table 1. Material quantity – lattice tower

Type	Length (m)	Unit weight (kg/m)	Bar weight (kg)	Total weight (kg)	Painting area (m^2)
S 235					
L 40x4	67.2300	2.47	165.75	166	10.76
L 50x4	55.0200	3.11	171.32	171	11.00
L 50x5	248.6300	3.84	955.31	955	49.73
L 60x5	136.0400	4.67	634.87	635	32.65
L 65x6	60.6400	6.02	365.03	365	15.77
L 90x6	34.6000	8.49	293.86	294	12.46
L 100x8	17.0400	12.49	212.79	213	6.82
L 110x8	19.8400	13.77	273.16	273	8.73
L 120x8	31.0800	15.05	467.72	468	14.92
Total				3540	162.82

Table 2. *Material quantity – tubular tower*

Type	Length (m)	Unit weight (kG/m)	Bar weight (kG)	Total weight (kG)	Painting area (m2)
S 235					
t=8mm	9.0200	83.89	756.71	757	12.04
t=9mm	5.8000	152.66	885.42	885	12.45
t=10mm	5.0000	209.61	1048.03	1048	13.25
t=11mm	5.0000	274.83	1374.14	1374	15.78
t=12mm	5.0000	349.30	1746.51	1747	18.37
Total				5811	71.90

The graph presents the following costs: Structural material costs, foundation costs and material costs for the connection details.

Comment: The costs for 1km line length are estimated for five towers

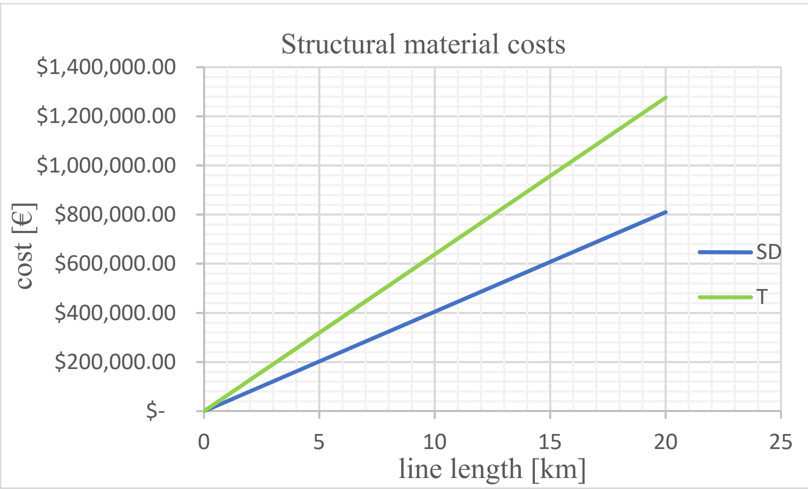


Fig. 10. *Structural material costs*

5.2. Equipment costs

The graph presents the following costs: conductors costs, insulator costs and protective wire costs. Comment: The costs for 1km line length are estimated for five towers

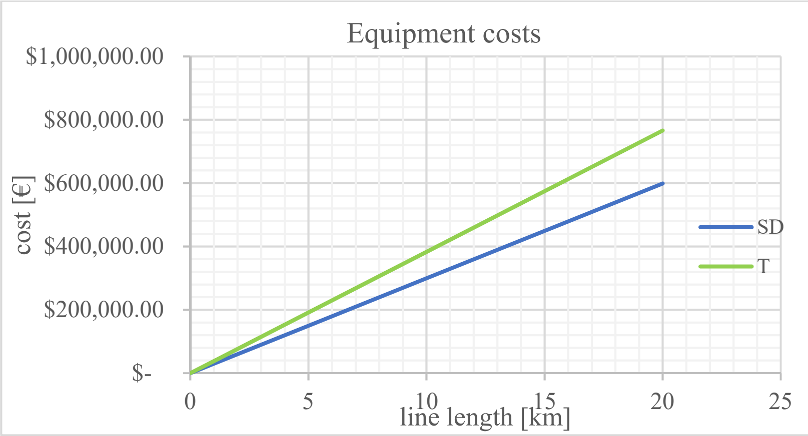


Fig. 11. Equipment *costs*

5.3. Installation costs

Comment: The costs for 1km line length are estimated for five towers

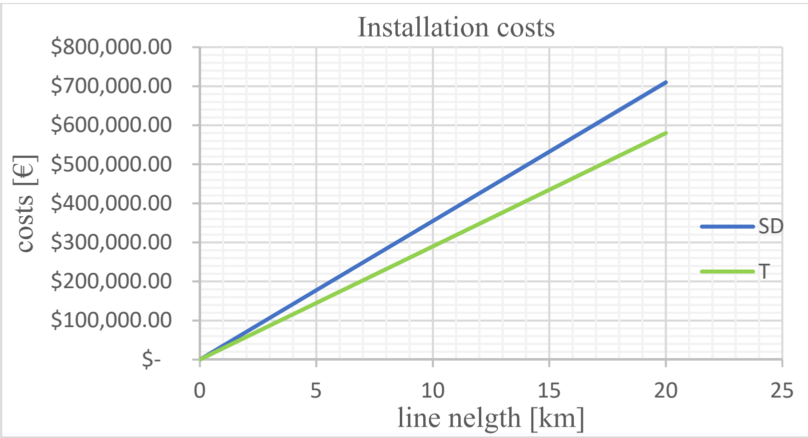


Fig. 12. Installation *costs*

5.4. Installation speed

Comment: The costs for 1km line length are estimated for five towers
The graph presents the installation speed capacity of one team

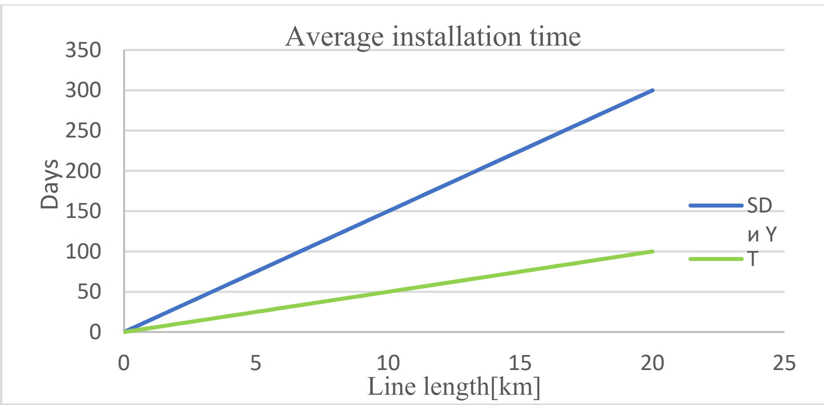


Fig. 13. Average installation time

6. CONCLUSION

- Functionality and size of the structure

The lattice towers offer an easy concept to manipulate in terms of functionality requirements and size, it has a small width between the conductors, followed from their height positioning and the design is easy to adapt to the surrounding. While the tubular tower has a quite width positioning of the conductors and in high voltage systems these width increase and the tower is hard to adapt to the surrounding, while in terms of manipulation to fulfill the functionality requirements the concept of the design is quite good.

- Mechanical characteristics

In terms of mechanical characteristics both of the tower can handle quite big loading situations, regarding the material saving, the lattice tower offers better performances so usually for the same load situations the material costs for the tubular towers are higher.

- Stability characteristics

In terms of stability the lattice tower offers a good structural design, easy to manipulate and able to handle quite high loading situations, while the stability characteristics for the tubular tower are not so good, so in terms of stability the lattice tower is quite better than the tubular tower.

- Installation speed

In terms of installation speed for the same design requirements of the towers, the tubular tower offers a much smaller amount of structural segments and quite easy details for their attachment, so the installation procedure goes really quick without any unpredicted problems. Regarding the graph in heading 5 we can visually see the average time difference in the installation speed between the two structural designs, so in terms of installation speed the tubular tower is better.

- Cost – effectiveness

In terms of cost – effectiveness, regarding the material and the equipment costs the tubular tower is much pricier, in terms of installation usually the lattice tower has a higher price, but with no significant difference. As conclusion the overall costs are much bigger for the tubular tower, but the earnings with the fast release of the system, regarding the installation speed differences can be significant and most of the time the earning are bigger than the saving with the costs of the towers, so in some situation the tubular tower present a better cost – effective solution.

REFERENCES

[1] Paskalovski Gj. (2019), Comparative analysis of structural designs for double circuit transmission towers (master thesis)

[2] Eurocode 3: Design of steel structures – Part 1-1: General rules and rules for buildings

[3] Eurocode 3:Design of steel structures - 1-6: General rules – Strength and stability of shell structures.

[4] Eurocode 3: Design of steel structures – Part 3-1: Tower, mast and chimneys – Tower and masts

[5] Eurocode 3: Design of steel structures – Part 3-1: Tower, mast and chimneys – Chimneys

[6] Eurocode 3: Design of steel structures – Part 1-8: Design of joints

[7] J.G.S.da Silva, P.C.G. da S.Vellasco, S.A.L.de Andrade, M.I.R.de Oliveira (2005), Structural assessment of current steel design models for transmission and telecommunication towers