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Research paper

Comparative analysis of guyed lattice mast computations in terms of American and European standard

Renata Pigoń[1]

Abstract: The paper presents an analysis of a 100-meter wind measurement guyed mast located in the north-western part of the United States, in the state of Oregon. Using the RFEM software [1], the influence of the wind on the mast was analyzed according to the guidelines of two standards: American TIA-222-H [2] and European EN 1993-3-1 [3]. The purpose of this work is to show the differences between the results of static computations of the mast in terms of the considered standards. Due to the limited content of the work, the icing load on the structure was ignored in the analysis and the focus was on determining the response of the mast only in terms of wind action. The author tried to describe the differences in this respect between the standard guidelines [2] and [3]. The comments and conclusions regarding the analysis of guyed masts presented in the article have some practical aspects and can be used in design practice.

Keywords: comparative analysis, guyed mast, wind loads

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1. Characteristics of a wind measurement mast

Since the 1980s, the inexhaustible wind resources have been used to generate electricity using wind turbines that form wind farms. One of the first stages of building such a wind farm is the selection of an appropriate location that meets not only environmental, but also spatial, economic, socio-cultural, political, legal and administrative, technical and technological requirements [4]. The most important factor determining the location of a wind farm is to ensure appropriate wind parameters. According to [5], in Poland these are areas where the mean annual wind speed at a height of 70 m above sea level is at least equal to 6.0 m/s. To measure the wind speed and direction, measurement masts in the form of light steel structures are used, usually erected for a period of several years. Measuring masts with lower heights (usually up to 100 m high) are made of a tubular telescopic mast shaft (Fig. 1b), and masts with higher heights – with a shaft in the form of a spatial truss (Fig. 1a).

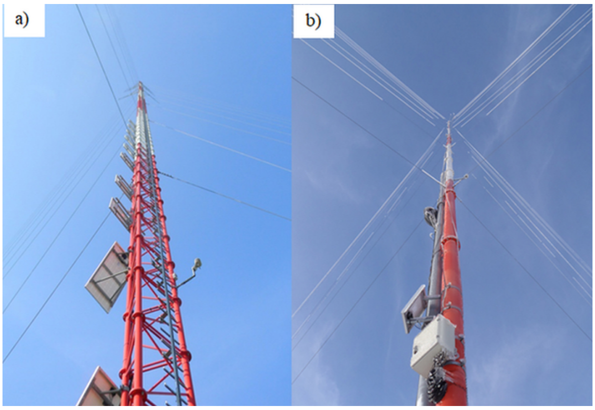


Fig. 1

2. Guidelines for the following analysis

Depending on the location of the guyed mast, the analysis of the structure should take into account various variable loads, i.e. the impact of wind, temperature, icing and accidental actions, such as rupture a single guy or uneven settlement of foundations. Due to the fact that the greatest differences in the approach of both standards occur in the case of wind influence on the mast, the following work focuses on the analysis of this load.

3. Wind action on the mast according to TIA-222-H standard

Guyed masts in the United States should be designed in accordance with standards TIA-222 guidelines, which are develop by the Telecommunications Industry Association (TIA), accredited by the American National Standards Institute (ANSI). The TIA-222-H [2] standard have been implemented since January the 1st 2018, replacing the highly appreciated

TIA-222-G [6] standard, which was released in 2005. An analysis of the differences in the calculation of the wind influence on the tower structure between these standards is presented in [7, 8]. The current TIA-222-H [2] standard defines the rules for the structural design and fabrication of new and the modification of existing structural antennas, antenna-supporting structures, small wind turbine supporting structures, appurtenance mounting systems, guy assemblies, insulators and foundations. This standard can be adapted for international use if the basic design parameters are defined, i.e.: risk category, environmental loads (wind load, icing and seismic shocks), site exposure category as well as the topography of the site. Determining such data is necessary for the correct design of the structure. According to the standard [2], four categories of structure risk are distinguished and they determine the degree of danger to human life, potential damage to the facility and its basic purpose (Table 1). In the further part of this article, the abbreviations of the TIA-222-H (TIA) and EC 3-3-1 (EC) standards are used.

Table 1. Risk categorization of structure according to [2]

Risk category	Danger degree	Application examples
I	low risk to human life and/or damage to surrounding facilities in the event of failure	low-power radio access nodes (small cell), single-appurtenance supporting structures that allow for rapid repair or replacement
II	moderate risk to human life and/or damage to surrounding facilities in the event of failure	commercial wireless antennas: (cellular, PCS, 3G, LTE, 4G, 5G, etc.); television and radio broadcasting; community access television (CATV)
III	substantial risk to human life and/or damage to surrounding facilities in the event of failure	non-redundant and hardened networks such as: civil or national defense: rescue or disaster operations; military and navigation facilities
IV	substantial hazard to the community in the event of failure	structures that in the event of failure would threaten the functionality or integrity of facilities that are designated as Risk Category IV facilities

It should be mentioned here that category II applies to all structures except those defined in risk categories I, III and IV.

According to the standard [2], the following load combinations should be considered when designing guyed masts (3.1)–(3.3):

$$1.2D + 1.0D_g + 1.0W_o \tag{3.1}$$

$$1.2D + 1.0D_g + 1.0D_i + 1.0W_i + 1.0T_i \tag{3.2}$$

$$1.2D + 1.0D_g + 1.0E_v + 1.0E_h \tag{3.3}$$

in which: D – dead load of structure and appurtenances, excluding guy assemblies, D_g – dead load of guy assemblies, D_i – weight of ice due to factored ice thickness, W_o – wind load without ice, W_i – concurrent wind load with factored ice thickness, T_i – temperature load, E_h – earthquake load in the horizontal direction and E_v – earthquake load in the vertical direction.

Both ice and earthquake loads do not have to be considered for risk category I structures. Determination of the wind load on the mast should start with the assumption of the fundamental value of the basic wind velocity $v_{b,0}$ on the mast. Standard [2] requires assuming this speed on the basis of a 3-second gust wind speed, measured at a height of 10 m above ground level for a 50-year mean recurrence interval in exposure category C. Nowadays, determining this speed does not cause problems, because knowing the geographic coordinates of the designed structure, it is possible to use the ASCE 7 Hazard Tool website [9], which was created for free public access and is compliant with the ASCE/SEI 7-22 standard [10]. This standard provides up-to-date and coordinated design loading provisions such as flood, tsunami, snow, rain, atmospheric ice loads, seismic shocks, wind or fire. What is more, it defines how to evaluate load combinations. In order to precisely model the wind load for a particular location and structure, the appropriate exposure and terrain category must be adopted. The first one is determined on the basis of the ground surface roughness from natural topography, vegetation and locally constructed facilities. According to the recommendations of the standard [2], three categories of exposure are distinguished, presented in Table 2.

Table 2. Exposure category and surface roughness category [2]

Exposure category	Surface roughness category
B	urban and suburban areas, wooded areas, areas with closely spaced obstructions having the size of single-family dwellings or larger
C	– open terrain with scattered obstructions having heights generally less than 30 ft [9.1 m] – includes flat open country, grasslands and athletic fields – applies to locations where exposure B or D do not apply
D	– flat, unobstructed areas, shorelines and water surfaces – includes smooth mud flats, salt flats, and unbroken ice

In the process of designing masts or towers it is especially important that a proper site topography assessment is done. A structure, set on hills, ridges or escarpments that concern sudden changes in the general topography, is exposed to the effect of wind acceleration. Determination of the wind acceleration effect is possible using one of three methods [2]. Before selecting the calculation method, the first step is to determine and best match the topographical conditions of the area to one of the four positions given in the standard [2]. First of all, a height profile should also be created in the place of the designed mast, which will enable the correct assessment of the topography. For this purpose, the Google Earth Pro application [1] can be used. Determination of the above parameters (structure classification, exposure and terrain categories) allow accurate manner modeling of the wind impact for a given site and for a specific structure. In the case of constant values of these parameters, it is possible to calculate the design wind force F_{ST} acting on the mast shaft (3.4) and the design wind force F_G on the guys (3.5) from the formulas:

$$F_{ST} = q_z G_h (EPA)_s \tag{3.4}$$

$$F_G = C_d d L_G G_h q_z \sin^2(\theta_g) \tag{3.5}$$

where: F_{ST} – design wind force on the structure, F_G – design wind force on guys,q_z – velocity pressure, G_h – gust effect factor, $(EPA)_s$ – effective projected area of the structure, C_d – drag factor for a guy, d – guy diameter, L_G – length of guy, θ_g – angle of wind incidence to a guy chord.

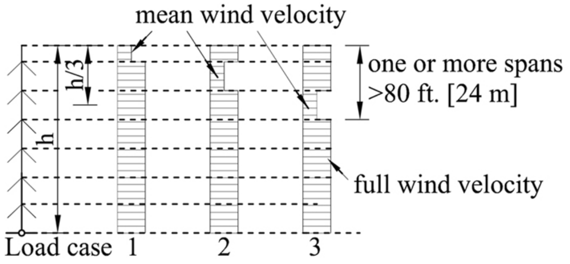
The equivalent wind load in the direction perpendicular to the chord of the guy was calculated on the basis of the formula (3.6) [12]:

$$W' = \sqrt{(W \sin\beta)^2 + (g\cos\alpha + W\sin^2\alpha\cos\beta)^2} \tag{3.6}$$

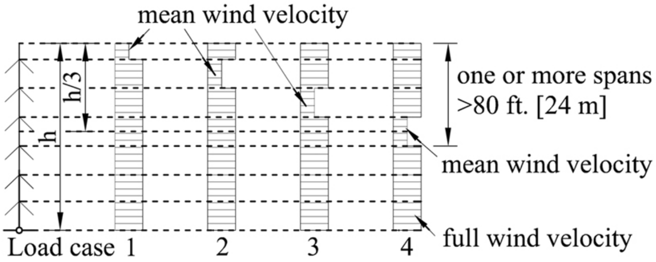
in which: W – horizontal wind load, g – dead weight of the guy, α – angle of inclination of the guy chord to the horizontal plane, β – angle of wind action in relation to the projection of the guy on a horizontal plane.

Depending on the height of the designed mast, in accordance with the guidelines of the standards [2], one of the three cases of wind effects should be assumed (Fig. 2).

a) Mast height > 450 ft. [137 m] and total length of top 3 spans > h/3



b) Mast height > 450 ft. [137 m] and total length of top 3 spans < h/3



c) Mast height less than or equal to 450 ft. [137 m]

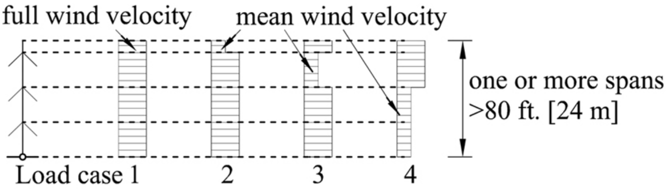


Fig. 2

To obtain the mean wind velocity pressure, the velocity pressure must be multiplied by the conversion factor, which for exposure categories B, C and D is 0.55, 0.60 and 0.65 respectively. As presented in the work [13], resultant load effects are obtained as maximum values from non-linear wind load analyzes for various combinations of wind directions and wind load patterns [2].

4. Differences in wind load computations for both standards

As mentioned in pt. 3, the American standard [2] defines the fundamental value of the basic wind speed $v_{b,0}$ based on the 3-second gust wind speed measured at a height of 10 m above ground level for a 50-year mean recurrence interval in exposure category C. In the case of the European standard [14], a 10-minute mean value is assumed with the probability of exceeding 0.02, which corresponds to the mean recurrence interval of 50 years. As in the case of the American standard [2], the fundamental value of the basic wind speed is determined at a height of 10 m, regardless of the direction of the wind. These wind speeds for both cases are shown in Fig. 3.

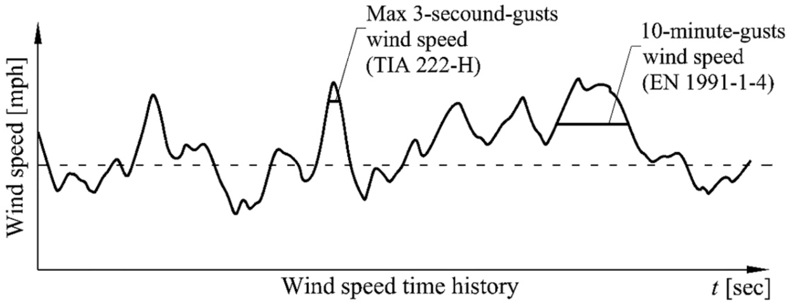


Fig. 3

According to [3], the wind action on the mast should be calculated with a division into the mean load over the entire height of the structure and patch loads, which are intended to represent the gusts of wind. The results of computations of the maximum internal forces in the mast should be calculated using the substitute static method. These forces are calculated as the sum of the forces N_m from the mean wind load $F_{m,W}(z)$ with the combined effects of patch loads $F_{PW}(z)$ (4.1):

$$N_{TM} = N_m + N_p \tag{4.1}$$

The total force from patch loads is obtained by adding geometrically the forces from independent patch loads in accordance with the Eq. (4.2):

$$N_p = \sqrt{\sum_{i=1}^{n} N_{PLi}^2} = \sqrt{\sum_{i=1}^{n} (N_i - N_m)^2} \tag{4.2}$$

where: N_{PLi} – load effect (response) from the i–th load pattern, N_m – forces from the mean wind load, N_i – forces from the mean wind load increased by the i-th patch load, n– total number of load patterns required.

In guyed masts, two combinations of icing and wind loads should be considered, both in the case of symmetrical and asymmetrical ice accretion [3]:

- for dominant ice and accompanying wind (4.3):

$$\gamma_G G_k + \gamma_{\mathrm{ice}} Q_{k,\mathrm{ice}} + \gamma_{\mathrm{w}} \psi_{\mathrm{w}} k Q_{k,\mathrm{w}} \tag{4.3}$$

- for dominant wind and accompanying ice (4.4):

$$\gamma_G G_k + \gamma_{\mathrm{w}} k Q_{k,\mathrm{w}} + \gamma_{\mathrm{ice}} \psi_{\mathrm{ice}} Q_{k,\mathrm{ice}} \tag{4.4}$$

where: γ_G, γ_{ice}, γ_{w} – respectively: factors for permanent actions, icing and wind action. The symbols G_k, $Q_{k,\mathrm{ice}}$, $Q_{k,\mathrm{w}}$ represent respectively the characteristic values of permanent actions (dead weight), icing and wind [15].

5. Global analysis of mast

5.1. Mast characteristics

The subject of static computations is a lattice guyed mast 100 m high (Fig. 5), used to measure the necessary parameters of the wind, i.e. its direction and speed. The designed new structure will be located in the north-western part of the United States in the state of Oregon (Fig. 4a). The exact terrain conditions, i.e. the terrain relief at the location of the designed facility, were checked using the Google Earth Pro application [11] (Fig. 4b).

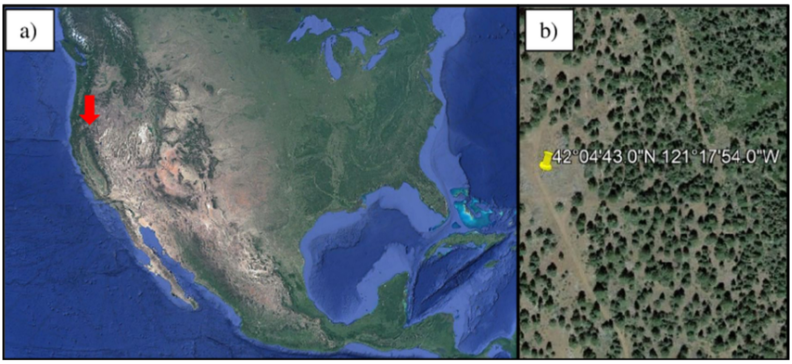


Fig. 4

The trihedral mast shaft in the form of a spatial truss with the axial spacing of legs equal to 0.9 m is made of the leg members with a tubular cross-section connected by the bracing members. For leg members, circular hollow sections Ø101.6/8.0mm were used, and for bracing

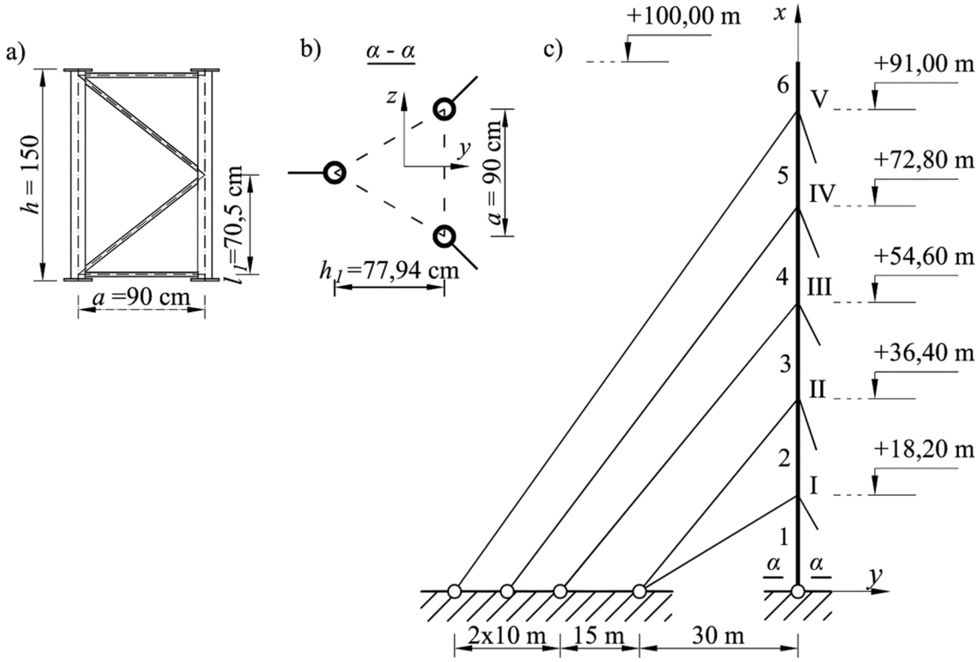


Fig. 5

members – circular hollow sections Ø30.0/4.0 mm of S355 steel grade. The mast shaft consists of 61 arctic type segments produced by WINDHUNTER company with a height of 1.5 m and a weight of 1.5 kN. The mast has five guys levels at the following heights: 18.2, 36.4, 54.6, 72.8 and 91.0 m. The mast guys were designed of spiral strand steel rope 1 × 37 structure, diameter Ø20.0 mm and minimum breaking force $N_{\text{min}} = 362.9$ kN. Wires for spiral strand ropes have a tensile strength of 1770 MPa. Initial guys forces realize as a result of shortening these elements, while the initial forces of the ropes were equal 30 kN (I level), 35 kN (II level), 40 kN (III level), 45 kN (IV level) i 40 kN (V level). The assumed values of the initial guys forces are 8–12.5% of the minimum breaking force of the rope (according to the recommendations given in the standard [2]), they are in the range of 7–15%.

5.2. Loads and design assumptions

The self-weight load of the mast shaft structural elements was taken into account directly in the calculation program. The own weight of the equipment and connections (allowance 10%) was given as concentrated forces in the structure nodes. Own weight of guys was modeled as uniformly distributed load along the length of the cable element. The forces of initial tension of the guys at individual levels of fastening were assumed as a change in the length of the cable (shortening or lengthening). In the case of computations according to the standard [2], as shown in Fig. 6 (variant c), the wind load was taken into account in the form of four load cases for a height of less than 137 m, which are presented in Fig. 7a. The II risk category was adopted for the computations. On the basis of the geographical coordinates provided by the investor and the ASCE 7 Hazard Tool website [9], the necessary design parameters were checked, i.e. wind speed and icing thickness of the structure depending on the location and height above sea level. There is no need to take seismic effects into account in the area under consideration [1]. Due to the extensiveness of the issue, it was decided to omit the icing load of the structure and analyze the response of the mast only in terms of wind action. In the static computations included a higher value of the basic wind speed was included than that given in the ASCE 7 Hazard Tool [9] equal to 180 mph (80.5 m/s). The wind load on the mast structure according to the European standard [3] was carried out with a division into the mean load over the entire height of the structure and the patch load (13 load cases in one wind direction) (Fig. 7b). In this case, the first reliability class of structure was adopted, corresponding to sparsely populated, open rural areas with a very low probability of loss of life. Therefore, the recommended partial factor of load combination for permanent and variable actions were assumed to be 1.0 and 1.2, respectively [3]. Taking into account the definition of the fundamental value of the basic wind speed $v_{b,0}$ according to the TIA-222-H [2] standard (3-second wind speed in gusts – period of 50 years) (point 4), the basic wind speed was recalculated in accordance with the standard [3] (10-minute wind speed in gusts – period of 50 years) and a value of 57.5 m/s was obtained. The internal forces were calculated using the procedure of the equivalent static method discussed in point 4. An example of calculating the total force in a selected member according to the substitute static method is presented in Table 3.

Table 3. An example of calculating the total force in a 282 member according to the substitute static method [3] – wind direction W3

Combination	N_i [kN]	N_m [kN]	$(N_i - N_m)$ [kN]	$(N_i - N_m)^2$ [kN]
1+2	–332.44	–350.05	17.61	310.11
1+3	–392.99	–350.05	–42.94	1843.84
1+4	–455.63	–350.05	–105.58	11147.14
1+5	–399.06	–350.05	–49.01	2401.98
1+6	–357.03	–350.05	–7.25	52.56
1+7	–347.16	–350.05	2.89	8.35
1+8	–350.62	–350.05	–0.57	0.32
1+9	–328.34	–350.05	21.71	471.32
1+10	–450.77	–350.05	–100.72	10144.52
1+11	–430.64	–350.05	–80.59	6494.75
1+12	–374.39	–350.05	–24.34	592.44
1+13	–347.46	–350.05	2.59	6.71

Continued on next page

Table 3 – *Continued from previous page*

Combination	N_i [kN]	N_m [kN]	$(N_i - N_m)$ [kN]	$(N_i - N_m)^2$ [kN]
	N_m	350.05	$\sum_{i=1}^{n}(N_i - N_m)^2$	33474.05
			$\sqrt{\sum_{i=1}^{n}(N_i - N_m)^2}$	182.96
			$N_{TM} = N_m + N_p$	533.01

For both considered variants, three wind directions were assumed, according to Fig. 6.

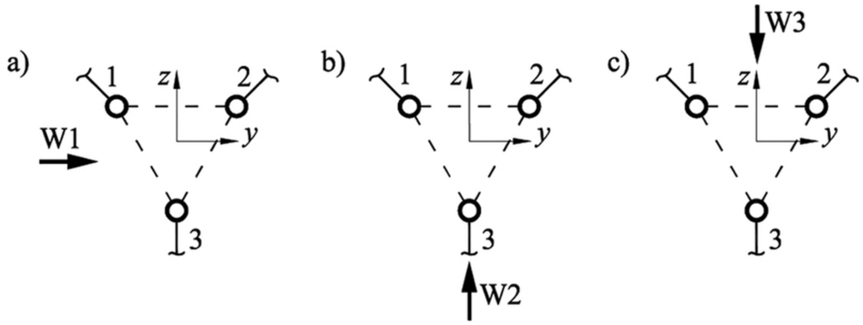
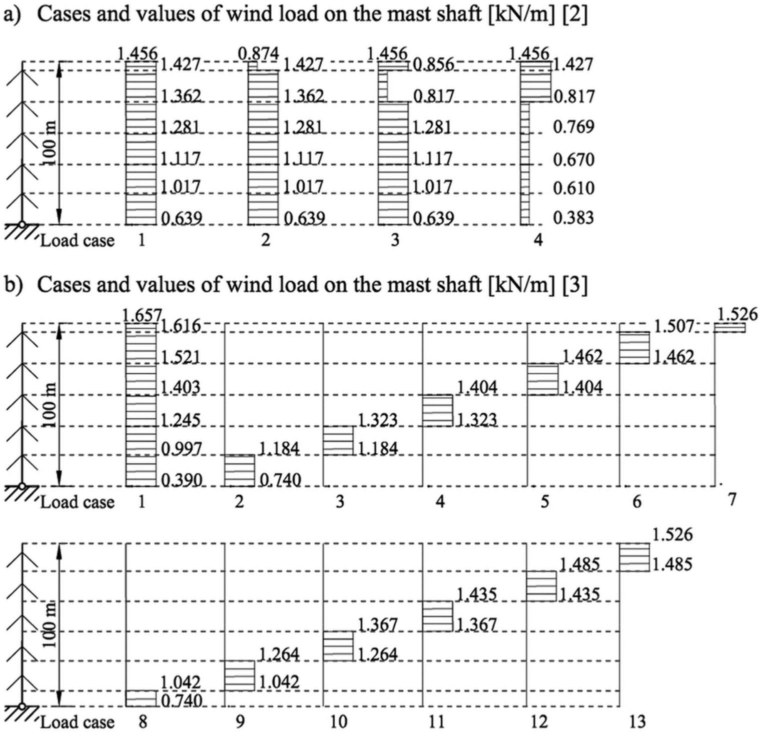


Fig. 6

For the analyzed example, the values of the mean wind load on the mast guys in the wind direction W2 are presented in Table 4, and the values of the wind load on the mast shaft according to the TIA-222-H and EC-3-3-1 standards are presented in Fig. 7a and 7b, respectively.

Table 4. The values of the mean wind load on the mast guys [kN/m] – wind direction W2

Standard	TIA-222-H						EC 1993-3-1					
Guy level	Guy 1		Guy 2		Guy 3		Guy 1		Guy 2		Guy 3	
	W_y	W_z	W_y	W_z	W_y	W_z	W_y	W_z	W_y	W_z	W_y	W_z
I	0.025	0.008	0.025	0.008	0.000	0.015	0.027	0.008	0.027	0.008	0.000	0.016
II	0.042	0.019	0.042	0.019	0.000	0.038	0.050	0.022	0.050	0.022	0.000	0.045
III	0.046	0.021	0.046	0.021	0.000	0.041	0.057	0.025	0.057	0.025	0.000	0.051
IV	0.050	0.023	0.050	0.023	0.000	0.047	0.064	0.029	0.064	0.029	0.000	0.059
V	0.054	0.025	0.054	0.025	0.000	0.051	0.069	0.033	0.069	0.033	0.000	0.065


a) Cases and values of wind load on the mast shaft [kN/m] [2]

b) Cases and values of wind load on the mast shaft [kN/m] [3]

Fig. 7

The numerical analysis of the structure was carried out in the RFEM program, using an elastic frame-truss model of the shaft [2], with continuous legs and lattice bars hinged connected to them was used. Mast shaft models are discussed, among others, in work [16]. Each of the mast guys was modeled as a cable element, carrying only tensile forces, divided into 6-10 finite elements, proportionally to their length. Static computations of the mast were carried out taking into account the analysis of large deformations called the 3rd order theory or large deformation theory, which takes into account both longitudinal and shear forces. To solve the geometrically non-linear problem, the Newton-Raphson method is used, in which the tangent stiffness matrix is defined as a function of the current strain state and it is reversed in each iteration cycle.

5.3. Computation results

The values of the mast shaft internal forces and the normal forces in the guys were read directly from RFEM. The results of the mast static computations in the form of maximum computational values of internal forces in the mast shaft leg members on the W3 direction for the most heavily loaded bars are summarized in Table 5, while the degree of use of these elements in terms of standards [2] and [3] are shown in Fig. 8.

Table 5. Maximum design values of internal forces in mast shaft leg members – wind direction W3

Mast span	Number of leg member	Design ratio EC 3-3-1	Design ratio TIA-222-H	Standard	Forces [kN]			Moments [kNm]	
					N	V_y	V_z	M_y	M_z
1	282	0.59	0.35	TIA-222-H	–271.20	–2.00	–1.27	0.50	–0.60
				EC 3-3-1	–533.01	–3.25	–2.08	0.86	–0.84
2	309	0.59	0.34	TIA-222-H	–263.55	1.92	1.31	–0.43	0.82
				EC 3-3-1	–526.32	2.86	2.49	–0.99	1.68
3	606	0.49	0.28	TIA-222-H	–212.06	1.62	1.13	–0.39	0.70
				EC 3-3-1	–468.92	2.50	2.29	–0.95	1.42
4	903	0.44	0.25	TIA-222-H	–191.09	1.36	1.00	–0.36	0.67
				EC 3-3-1	–455.42	2.18	2.09	–0.91	1.43
5	1197	0.31	0.13	TIA-222-H	–46.20	0.42	0.27	–0.12	0.34
				EC 3-3-1	–147.05	1.85	0.49	–0.19	1.00
6	1497	0.10	0.04	TIA-222-H	–31.47	0.36	0.26	–0.11	0.29
				EC 3-3-1	–93.21	0.99	0.79	–0.36	0.74

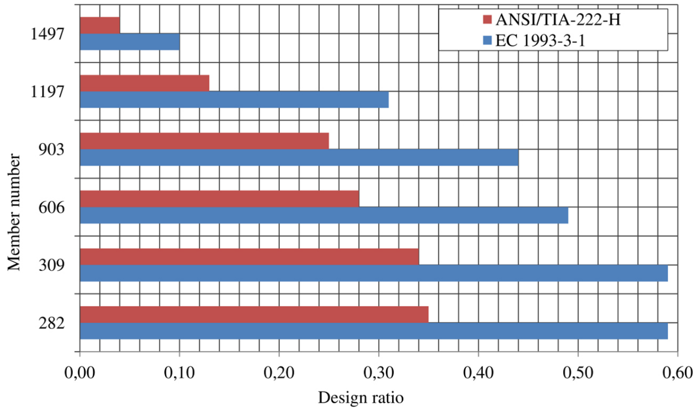


Fig. 8

As it was shown in the work [16], in the case of trihedral masts, the highest values of compressive forces in the mast shaft leg members were obtained on the direction of the wind pressure acting on the bisector of the angle (wind W3). Comparing the use of load capacity conditions of leg members (Table 5), it can be seen that the design ratio of the most strenuous bar (No. 282) according to the standard [3] is nearly 69% higher than in the case of computations according to the standard [2] (stability analysis results – buckling about the y and z axes, read from RFEM [1]). In the case of the most strenuous bracing member of the mast shaft (bar No. 17), the effort of the element according to [2] and [3] was obtained – 26% and 48%, respectively. The design buckling resistance condition of compression members of mast was checked in accordance with formula (5.1) [17]:

$$\frac{N_{Ed}}{N_{b,Rd}} \leq 1.0 \tag{5.1}$$

wherein the design buckling resistance of a compression member of mast was calculated according to the formula (5.2) [3]:

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} \tag{5.2}$$

in which: A – cross-section area, f_y – yield strength of steel, χ – reduction factor for the relevant buckling mode, γ_{M1} – partial safety factor.

Static calculations of the mast – in accordance with EN 1993-3-1 – were carried out taking into account the second-order non-linear elastic analysis, disregarding the initial imperfections of the mast shaft. In the work [18] it was shown that, indeed, the influence of geometrical imperfections of the mast shaft on the values of forces and displacements of the mast structure is small and can be neglected in practical calculations. It should be noted that the consideration of geometric imperfections in the mast structure analysis is very laborious and complicated.

The values of the maximum design forces in the mast guys for three wind directions according to the standards [2] and [3] are presented in Table 6.

Table 6. Maximum mast guy forces [kN]

Guy level	Guy number	TIA-222-H			EC 1993-3-1		
		W1	W2	W3	W1	W2	W3
I	1	42.22	23.09	35.92	74.70	27.09	61.76
	2	19.43	23.09	35.92	21.37	27.09	61.76
	3	28.45	44.49	17.87	39.07	75.22	15.46
II	1	58.64	25.65	48.88	115.23	30.00	97.12
	2	19.79	25.65	48.88	20.89	30.00	97.12
	3	35.65	61.78	17.32	58.89	113.59	16.88
III	1	73.98	32.72	62.55	140.02	39.37	119.21
	2	23.94	32.72	62.55	27.37	39.37	119.21
	3	46.05	77.64	20.15	73.99	138.78	22.13
IV	1	86.21	38.41	73.33	156.33	48.75	132.89
	2	27.20	38.41	73.33	35.70	48.75	132.89
	3	55.15	90.60	23.00	85.05	157.06	29.88
V	1	86.72	42.97	74.63	163.97	56.20	142.07
	2	32.52	42.97	74.63	44.44	56.20	142.07
	3	57.91	91.06	28.29	93.24	164.42	38.36

The highest values of tensile forces in the mast guys according to both standards were obtained on the direction of the wind in the plane of guy No. 3 (wind W2). The maximum differences of these forces for the most strenuous guys are nearly 50% higher according to the European standard [3] than in the case of the American standard [2]. The results of these analyzes were confronted with the results of calculations from the SOFiSTiK program [19]. Guys modelling and computation method in this program are described in [20].

5.4. Summary and conclusions

Comparative analysis of computations of wind action on the mast according to American [2] and European [3] standard leads to interesting observations. Comparing the mast computations using the European [3] and American [2] standards, it can be seen that the differences between the results of normal forces in the mast shaft leg members are immense. In the case of the most strenuous bar (No. 282), the differences between the values of normal forces are about 46%. Similar differences can be observed when comparing the tensile forces in the mast guys. For the most strenuous guy (V level, No. 3), on the W2 wind direction, these differences do not exceed 45.5%. It is important to mention here that higher values of normal forces refer to mast computations according to the European standard [3]. According to table 5, it can be seen that the design ratio of the mast shaft leg members determined according to the European standard [3] is always higher than in the case of the American standard [2], reaching values even over 69% higher for the most strenuous bar (No. 282). Based on the above conclusions, it can be noticed that according to [3] – compared to [2] – much higher internal forces in the mast shaft and guys (and larger nodal displacements) are obtained. Designing according to [3] requires therefore the use of larger cross-sections of the mast structure elements.

Summing up, the results obtained based on the American standard are more similar to the real response of a guyed mast structure to the dynamic effects of wind. European standards are more conservative. This is not surprising, because as described in [21] and [22], comparing the dynamic component of the mast response under turbulent wind action, about half of the value of this component calculated according to the procedures in Eurocode 3 was obtained. It should be emphasized that the results of analyzes according to the American standard [2] are obtained in a typical manner on the basis of the maximum values of initial forces from the most unfavorable load combinations [13]. In turn, computations done according to the European standard [3] are quite complicated and have approximate and indirect character, because the maximum values of internal forces of the structure are determined as the algebraic sum of the effects of the mean load and patch loads according to the formula (4.2 of the standard [3]. On this basis, it can be concluded that the computation procedures in accordance with the standard [2] are simpler in practical applications and more suitable for the analysis of a guyed mast, while the European procedures [3] are more difficult and, due to the approximate approach of the dynamic response of the mast, overestimate the final results of the analysis.

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Analiza wpływu oddziaływania wiatru na maszt według TIA-222-H I EN 1993-3-1

Słowa kluczowe: analiza porównawcza, maszt z odciągami, obciążenie wiatrem

Streszczenie:

Praca dotyczy statycznej analizy pomiarowego masztu z odciągami wysokości 100 m zlokalizowanego w północno-zachodniej części Stanów Zjednoczonych w stanie Oregon. W obliczeniach wykonanych programem RFEM [1] rozpatrzono oddziaływanie wiatru na maszt według wytycznych dwóch norm: amerykańskiej TIA-222-H [2] i europejskiej EN 1993-3-1 [3]. W artykule wykazano różnice między wynikami obliczeń statycznych rozważanego masztu oraz porównano podejścia i wytyczne normowe [2]

i [3]. Dynamiczną odpowiedź masztu na działanie wiatru uwzględniono z podziałem na obciążenie średnie na całej wysokości konstrukcji i obciążenia odcinkowe [3]. Według normy amerykańskiej [2], o liczbie przypadków obciążenia wiatrem na maszt decyduje wysokość konstrukcji. W przeprowadzonej analizie na podstawie wytycznych rozważanych norm [2] i [3] uwzględniono odpowiednio 4 i 13 odmiennych przypadków obciążenia wiatrem. Różnica w podejściu normy amerykańskiej [2] w stosunku do normy europejskiej [3] jest widoczna również przy przyjmowaniu wartości podstawowej bazowej prędkości wiatru Norma [2] nakazujeprzyjęcie tej prędkości na podstawie 3-sekundowej prędkości wiatru w porywach, mierzonej na wysokości 10 m nad poziomem gruntu przez 50 lat średniego okresu powtarzalności w kategorii narażenia C. Z kolei norma europejska [3] zaleca uwzględnienie tej prędkości jako wartość średnią 10-minutową o prawdopodobieństwie przewyższenia 0,02 co odpowiada średniemu okresowi powrotu 50 lat. Kolejną różnicę między [2] i [3] stanowi uzyskanie końcowych wartości siłwewnętrznych do wymiarowania elementów. W przypadku normy amerykańskiej [2] są to maksymalne wartości siłwewnętrznych jako efekt najbardziej niekorzystnych kombinacji obciążeń odczytane bezpośrednio jako wyniki analizy statycznej masztu. Natomiast w przypadku normy europejskiej [3] ostateczne wyniki analizy należy wyznaczyć jako algebraiczną sumę efektów od obciążenia średniego i obciążeń odcinkowych. Do analizy użyto ramowo-kratowy model obliczeniowego trzonu masztu [2]. Obliczenia prowadzono z uwzględnieniem nieliniowej analizy sprężystej II rzędu, z pominięciem wstępnych imperfekcji trzonu masztu. Z przeprowadzonej analizy można zauważyć, że różnice pomiędzy wynikami siłwewnętrznych w krawężnikach trzonu i siłnormalnych w odciągach masztu według obu rozważanych norm [2] i [3] są bardzo duże. Różnice te w przypadku najbardziej obciążonych elementów są blisko 46% większe w przypadku normy europejskiej [3] w stosunku do normy amerykańskiej [2]. Przy projektowaniu według [3] należy zatem stosować większe przekroje poprzeczne elementów konstrukcyjnych masztu. W związku z powyższym można stwierdzić, że procedury amerykańskie [2] są znacznie prostsze i mniej rygorystyczne w porównaniu z normą europejską [3], a zastępcza metoda statyczna przedstawiona w Eurokodzie pozwala na wyznaczenie dynamicznej odpowiedzi masztu z dużym zapasem bezpieczeństwa. Wyniki analiz numerycznych w programie RFEM zostały skonfrontowane z wynikami uzyskanymi w programie SOFiSTiK.

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