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STEEL TELECOMMUNICATION TOWER DISPLACEMENT STUDIES

The study of displacements of engineering structures using geodetic methods consists in determining the displacements of the structure in relation to the adopted reference system or in determining the geometry of individual structural elements or the entire structure. The geometry of tower objects is measured cyclically. In the case of telecommunications towers, the most common geometry research is the deviation of the tower axis and the turning angles of the tower at its individual levels. The article presents the methodology and results of the telecommunications tower geometry research obtained for a steel three-legged tower with a height of H = 32.11 m. It is a steel tower with a typical structure. The structure in the projection is described on the plan of an equilateral triangle. In the corners of the tower there are curbs in the form of solid round bars. Angular observations were made in two positions of the telescope to selected points on the legs of the tower. The heights of the points on the foundations of the tower were obtained from measurements using the geometric leveling method. The heights of the points at each level of connecting the segments were determined by the trigonometric leveling method based on the measured zenith angles. The measurement points were related to the geometric axes of the tower legs at the connection points of individual segments. The tower displacement parameters were determined from geodetic measurements with the Theo010A theodolite.

Keywords: tower structure, displacement measurement

1. Introduction

Observations of the deviations of the leg edge points from the vertical planes passing through the vertical geometric axis of the tower can be carried out by direct projection onto the horizontally positioned leveling staff in the vicinity of the ground level points. Another way is to observe the differences in horizontal angles with respect to the point at the foundation of the tower. The spatial indentation from the 3 theodolite sites is difficult to perform due to obstacles on the target lines to the characteristic points on the tower legs. Angular observations

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were made in two positions of the telescope to selected points on the legs of the tower. The heights of the points on the foundations of the tower were obtained from measurements using the geometric leveling method. The heights of the points at each level of connecting the segments were determined by the trigonometric leveling method based on the measured zenith angles. The measurement points were related to the geometric axes of the tower legs at the connection points of individual segments [1–3]. The tower displacement parameters were determined from geodetic measurements with the Theo010A theodolite.

2. Characteristics of the research object

The subject of the research is the tower of a mobile telephone station. It is a steel tower with a typical structure [4–5]. The structure in the projection is described on the plan of an equilateral triangle. In the corners of the tower there are curbs in the form of solid round bars. The walls of the tower consist of twelve mapped fields, counting from node to node, the view of the tower is shown in Fig. 1.

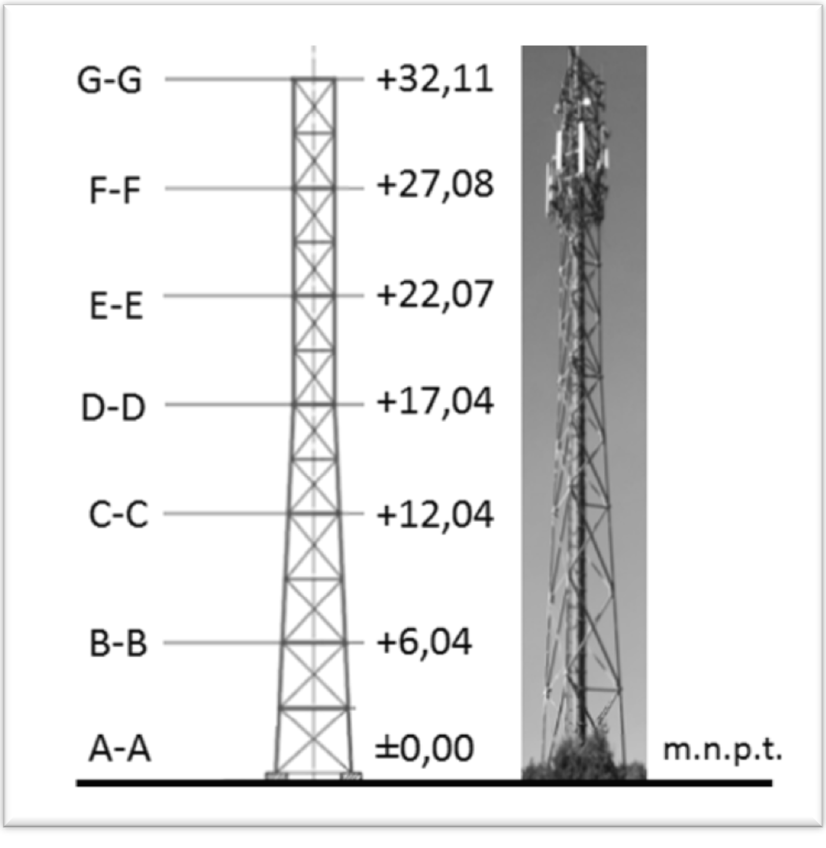

Fig. 1. View and scheme of arrangement telecommunication tower segments

3. Research method and calculations

3.1. Research method

Observations of the deviations of the leg edge points from the vertical planes passing through the vertical geometric axis of the tower can be carried out by direct projection onto the horizontally positioned leveling staff in the vicinity of the ground level points. Another way is to observe the differences in horizontal angles with respect to the point at the foundation of the tower. The spatial indentation from the 3 theodolite sites is difficult to perform due to obstacles on the target lines to the characteristic points on the tower legs. Angular observations were made in two positions of the telescope to selected points on the legs of the tower. The heights of the points on the foundations of the tower were obtained from measurements using the geometric leveling method. The heights of the points at each level of connecting the segments were determined by the trigonometric leveling method based on the measured zenith angles. The measurement points were related to the geometric axes of the tower legs at the connection points of individual segments [6–8]. The tower displacement parameters were determined from geodetic measurements with the Theo010A theodolite.

It should be remembered that depending on the type of structure, the measurement method should be selected [9–14].

3.2. Calculations

The auxiliary measurements were performed to calculate the point heights and the spans at each level of joining the tower segments. At the first stand, horizontal and vertical angles were observed to determine the height of the segments and the spacing of the legs (span) (Fig. 2).

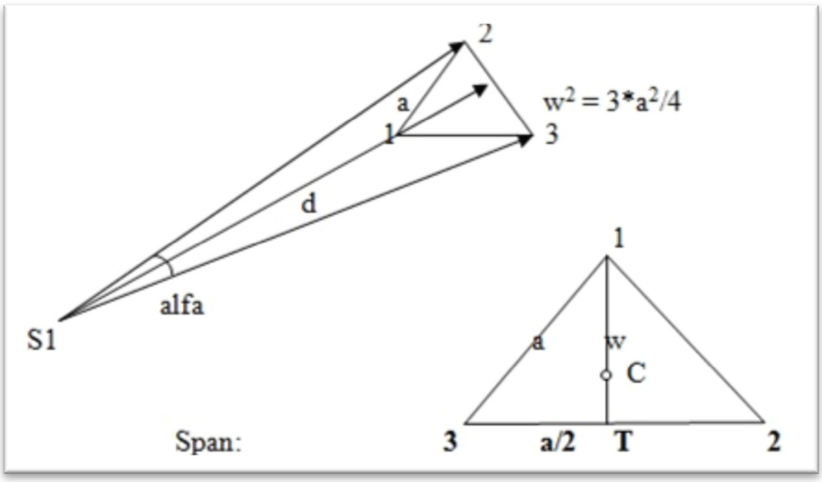

Fig. 2. Schematic drawing for calculations

In order to carry out the calculations and analyzes, the following formulas were used (1)÷ (2):

$$a_i = 2 \cdot d_{2i} \cdot \tan\left(\frac{\alpha_i}{2}\right) \tag{1}$$

where:
α_i – the of the i-th level,
d_i – distance state S1 from point 1,
d_1 – state distance S1 from point C - calculated as: $d_o + (2/3) \cdot w_{o,}$
d_{2i} – state distance S1 from the point Ti - calculated as: $d_o + (1/3) \cdot w_i$
and height:

$$h_i = d_i \,/\, \tan\left(\frac{z_i}{y}\right) + i \cdot w_s \tag{2}$$

where:
i – line of sight level (z = 100g),
w_s – signal height, (most often w_s= 0).

At the connection level of the zero tower segment (terrain), do was obtained from direct measurement. Successive values of di were calculated according to the formulas (3)÷(5):

$$d_1 = d_0 + 2 \cdot w_0/3 \tag{3}$$

$$d_1 = d_1 + 2 \cdot w_i/3 \tag{4}$$

$$2d_i = d_i + w_i \tag{5}$$

Angles (α_i) calculated from the difference of readings (horizontal circle) from the observations of points (*2i*) and (*3i*), where *i*-th is the tower segment.

Based on the measurement results, the coordinates of the characteristic points on the tower legs and the deviations of the edge points from the vertical planes passing through the vertical geometric axis of the tower were calculated. The coordinates of the tower axis points at the segment connection levels were calculated based on the formulas (6)÷(9):

$$x_s = \frac{\sqrt{3}}{3} \cdot (k_2 - k_3) \tag{6}$$

$$y_s = \frac{1}{3} \cdot (-2k_1 + k_2 + k_3) \tag{7}$$

$$w = \sqrt{{x_s}^2 + {y_s}^2} \tag{8}$$

$$\varphi = arctg\left(\frac{y_s}{x_s}\right) \tag{9}$$

where:
x_s, y_s – deviation components (coordinates of the tower axis points at each segment level),
k_1, k_2, k_3 – deviations of the edge points (legs) from the vertical plane passing through the lowest point of the edge (level 0),
w – resultant deviation,
φ – resultant direction (with respect to the *OX* axis.

The origin of the coordinate system was assumed in the geometric center of the triangle connecting the points of the tower base. The *OX* axis passes through the edge marked with number *1*, the *OY* axis is directed to the right of the origin of the system (geodetic system).

The changes in the position of the points were determined on the basis of the geometric interpretation of the tower movement in the horizontal plane (translation) and rotation (twisting) as the second phase of the movement. This analysis does not take into account deformations of the elements, assuming the triangles in the segment connections as isosceles.The heights of the indicated levels of segment connections were calculated on the basis of the formula (10):

$$H_i = d_i \cdot (ctg(z_i) - ctg(z_0)) \tag{10}$$

Depending on the zenith angle measurement plan.

From the geometric analysis of the triangle (*1'2'3'*) after a parallel shift along the vector w. Point S' will be coincide with point *S*, points (*1'2'3'*) will take the position (*1'2'3''*). Point *1''* will have the *Y* coordinate equal to *k. Z* in the drawing.

$$k = k_1 + y_s \tag{11}$$

$$y_s = (-2k_1 + k_2 + k_3)/3 \tag{12}$$

$$y_s = (-2k_1 + k_2 + k_3)/3 = (k_1 + k_2 + k_3) \tag{13}$$

in the triangle (1'2'3 ''), k will be equal to 1/3 * w, where w is the height of this triangle. The section S-1 '' in relation to the section S-1 will turn by the angle α (turning angle of the tower segment) (14) ÷(18)::

$$(k/(S - 1'') = \sin(\alpha) \tag{14}$$

$$\sin(\alpha) = k(\frac{2w}{3})) \tag{15}$$

$$w = \sqrt{w} \cdot \alpha/2 \tag{16}$$

$$\sin(\alpha) = 3k/(\sqrt{3} \cdot \alpha) \tag{17}$$

$$\alpha = \arcsin(\frac{c}{100}) \tag{18}$$

4. Calculation results

The calculations performed are presented below in tabular form. Tables 1 to 3 and figure 2 and 3.

Table 1. Edge deviation from the vertical plane

Level	Height [m]	Distance [m]	Components of deviations		
			k_1 [mm]	k_2 [mm]	k_3 [mm]
A-A	0.00	4.55	0	0	0
B-B	6.04	3.83	0	0	0
C-C	12.04	3.11	1	7	2
D-D	17.04	2.50	10	13	3
E-E	22.07	2.51	2	1	-5
F-F	27.08	2.50	-7	-8	-25
G-G	32.11	2.52	-10	-10	-15

Table 2. Deviations of the tower axis from the vertical

Level	Height [m]	Distance [m]	Components of deviations		Total deviation	Direction [g]	Deviation Δ_{dop}
			X_s [mm]	Y_s [mm]			
A-A	0.00	4,55	0	0	0	0,00	0
B-B	6.04	3,83	3	2	4	43.28	18
C-C	12.04	3,11	6	-1	6	385,55	36
D-D	17.04	2,50	3	-3	4	358,23	51
E-E	22.07	2,51	10	-6	12	363,52	66
F-F	27.08	2,50	3	-2	3	366,67	81
G-G	32.11	2,52	8	5	10	37,13	96

The measured axis deviations from the vertical do not exceed the permissible value $\Delta_{dop} = 0.003 \cdot h$. The tower meets the requirements in this respect set out in the "Instructions for the use of base stations, part B, p. 4.1.

Table 3. Calculation of the twist angles

Level	Sprains		
	d [mm]	c [mm/m]	α [g]
A-A	0	0,0	0,00
B-B	-9	-4.1	-0.26
C-C	-16	-9.1	-0.58
D-D	-26	-18,1	-1,15
E-E	-30	-21.0	-1.34
F-F	-29	-20.3	-1.29
G-G	-24	-16.7	-1.06

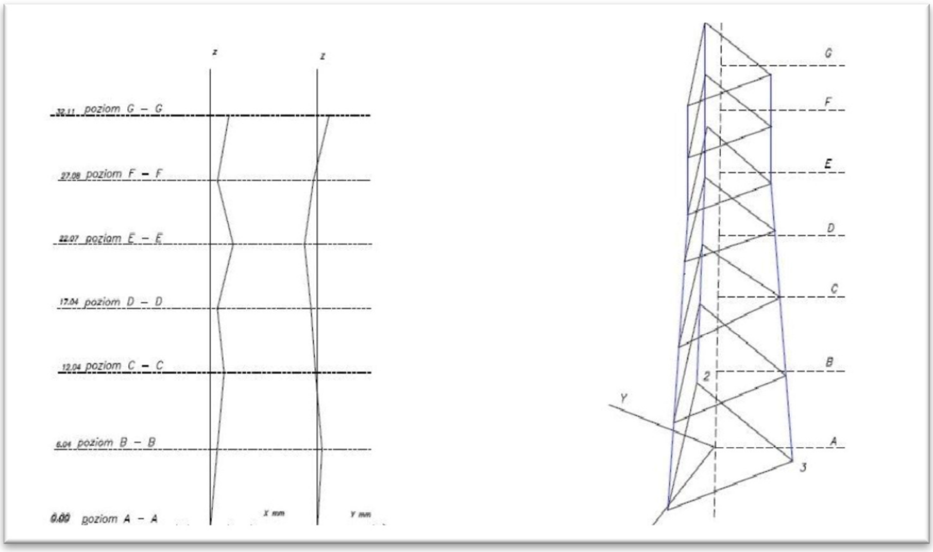

Fig 3. Graphs of the deviations of the tower axis from the vertical

Fig. 4. Graph of differences in the height of the tower foundation

5. Summary

The following conclusions can be drawn from the research of the telecomunications tower:

1) With moderate sunlight and no wind, the displacements of the top section of the tower do not exceed the limit values recommended for this type of structure,
2) The obtained values of the resultant deflections for the analyzed tower are close acceptable values (assuming the *L / 1000* criterion),
3) The limit value of displacements proposed by PN-B-03204 (PN-B-03204: *L / 1000*) for the analyzed case is met,
4) The currently recommended Eurocode 3 standard does not provide limit values for apex displacements, making them dependent on the requirements of the tower user. According to this standard, the user is obliged to carry out rectification and meet the standard requirements,
5) From the measurements, axis deviations from the vertical do not exceed the permissible value $\Delta_{lim} = 0.003 \cdot h$. The tower meets the requirements in this respect set out in the "Instructions for the use of base stations.

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