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Structural analysis of tension tower subjected to exceptional loads during installation of line conductors

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Abstract

The paper presents results of study dealing with verification of the impact of different installation options (defined by the distance and tilt of anchoring cables from the tower axis and the distance and tilt of winch from the tower axis) to meet the limit state conditions for the tension tower subjected to exceptional loads during installation of overheads lines. 36 optional positions of anchor and winch have been considered. In current practice both the winch and the anchor are mounted at the distance from the axis of tower equal to 2 times H (where H - the distance above ground level on which an anchor or cable are fixed to the tower). It has been shown that the anchor as well as the winch can be fixed to the temporary foundations at the distance equal to H without any hazard to the safety of the structure.

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Keywords: tension transmission tower; installation of line conductors; anchoring cables

1. The scope of the paper

The subject of the work is the analysis of the limit state conditions of a strong tension tower during installation of line conductors.

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The demand to reduce the cost of temporary supporting structure and difficulties with space available during construction of power lines has led to the question: how short distance between tower and foundations of anchoring cables is safe with respect to all limit state condition. Different locations of winch and anchoring cables, important factors which may influence on safety of construction, have been considered.

2. Anchoring cables

Installation of line conductors depends on work of winch, which drag the conductors along of the new electrical line. In the last phase, tensioned conductor is pulled by 20 cm, what results in a significant increase not only in tension of the line but also extraordinary load is imposed on the tension tower, which is not included in service loads. To prevent destruction of the tower temporarily stays called anchor cables are applied [1].

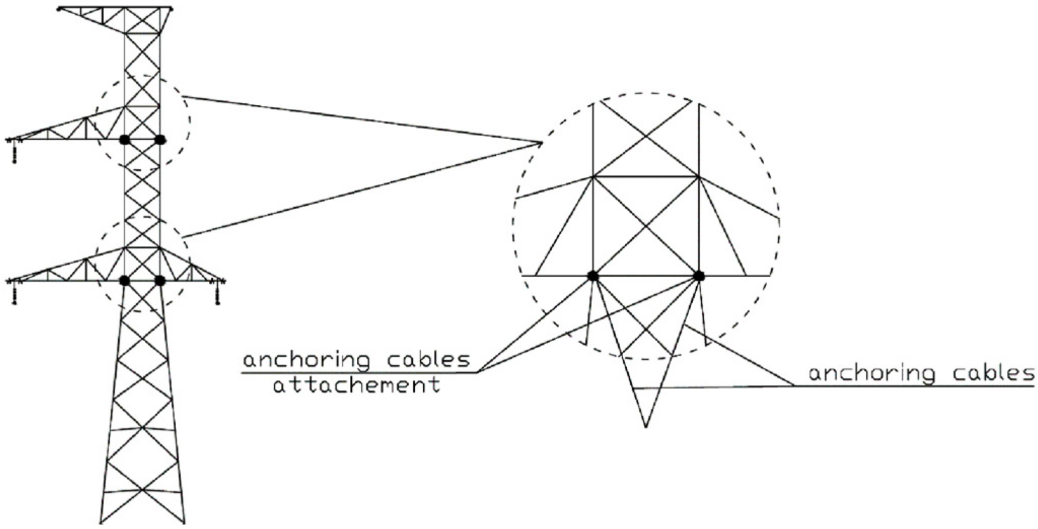

Fig. 1 Position of points at which anchoring cables are mounted to the tower

Fixing of anchoring cables takes place at the level of the bottom chord of cross arm. There are many possibilities for the location of the winch and anchor cables in reference to a power line (conductors) and a plane of symmetry of the tower. Fig. 1 shows the two fixing points to the tension tower, at height H and H '- respectively to the upper and lower cross arm, where H is the height from ground level to the bottom chord of the lower cross arm. (see Fig. 2). In this paper both levels H ' and H are treated in the same way.

In nowadays practice, the anchoring cables are mounted at a distance of 1.5 H - 2 H from the axis of the tower body. Due to the field difficulties (river, forest, lakes, and mountains) or buildings, the desired solution is to reduce the distance of foundation of anchoring cables to H

From variety of possible angles of fixing the anchoring cable three cases of the horizontal angle to the axis of the tower have been considered: -30 °, 0 °, + 30 ° (see Fig. 2).

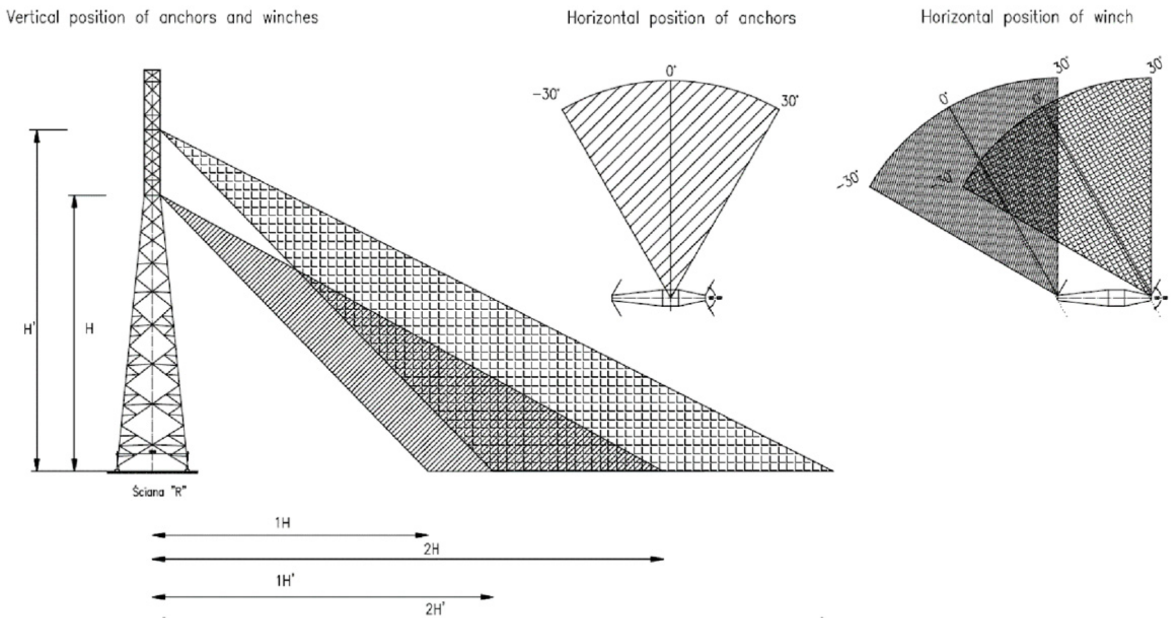

Fig. 2 Ranges of considered positions of anchoring cables and winch

3. The location of the winch

The winch usually is mounted on the extension of the power line and on the opposite side of the tension tower in reference to the installed conductors. However, the position of winch can vary from the direction of the power line section. In order to the most optimal angle describing in horizontal plane position of winch three cases of the horizontal angle to the axis of the line: -30°, 0°, + 30° have been considered (see Fig. 2).
The vertical angle depends on the location of winch with respect to axis of tower varies. Two limiting values have been considered: + 45° for distance H and + 64° for distance 2H (see Fig. 2)

M6z towers often is applied at deviation points of the power line, where angle between two adjacent power line sections "α"varies from 120° to 150°. The presented analysis has been carried out for the smallest angle $\alpha = 120°$, since the bending forces are the largest in this case (see Fig. 3)

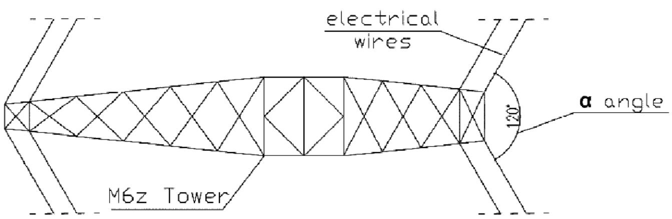

Fig. 3 Definition of angle α

4. Schemes of line conductors assembly

Below are listed the basic phases how conductors are installed.

1. Dragging assembly cable between assembly rollers, done by hand due to the low weight assembly line
2. The installation of the assembly line to the winch .
3. The winch begins to pull the assembly line to which at another end the conductor is fixed.
4. When the line conductor reaches the opposite tension tower, is attached to final destination points with help of the insulator chain.
5. Next, break starts to work as winch and pulls the conductors until the desired overhang (measuring tension force) is reached.
6. The anchoring cables attached to cross arm are used to reduce deformations and stresses of supporting structure.
7. To attach the conductor is necessary to drag it further with smaller overhang than it is planned during operation.
8. Dragging causes temporary shortening the conductor, what results in extreme horizontal forces imposed to tower.

In case of the tension tower M6z 5 conductors are to be mounted (3 power conductors and 2 ground conductors). Generally conductors are mounted one after another. The mounting of the second conductor is started after the first one is at the proper position. Order of conductors is strictly specified and shown in Fig. 3.

5. The analyzed tower M6z

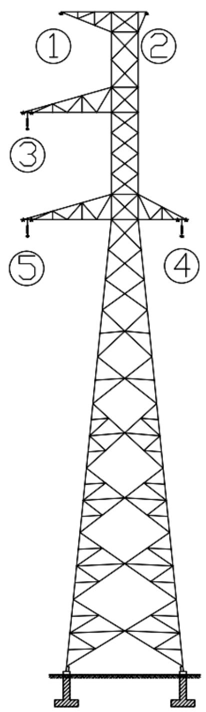

Fig. 4. M6z with positions of ground conductors (1, 2) and transmission conductors (3, 4, 5).

The analysis has been carried out for the tower M6z designed by ELBUD Projekt Warszawa sp. z o.o.

This is a typical lattice structures made of bars with angle cross section which are joined by the screw connections.
The tower M6z jest made of
- columns (vertical bars at corners of cage and tower body called also "curbs"): sections from L90x7 until L160x15
- cross arms: sections from L60x5 until L100x10
- bracing: sections from L40x4 until L80x8

Ground conductors (points 1, 2 in Fig. 3) are mounted to the peak cross arm.

The tower has been designed according to Polish codes PN-EN 50341-1:2005 [3], PN-EN 50341-3-22:2010 [5] and PSE Standard technical specification [6].

Two types of steel has been used: steel S235 for cross-sections smaller or equal to L90x7 and steel S355 for cross-sections greater than L90x7.

The analytical model of the tower takes into account the different behavior of a member depending on the type of joint. Those elements connected by one screw at both ends are assumed as pure tension/compression members. Others members joined with help of two or three screws have been assumed as ordinary frame elements with rigid connections at both ends.

6. Method of analysis and applied software

Autodesk Robot Structural Analysis Professional 2012 and 2014 have been used to construct the models and carry out the analysis. Analytical model consists of 816 elements and 378 joints. The loads cases and combinations of loads have been assumed in accordance with the code PN-EN 50341-3-22 [5] and [2].
The analytical model contains cable elements, which stiffness depend on the displacements imposed to them. An iterative method of structural analysis has to be applied in order to solve the non-linear equations.
P-delta analysis together with iterative Newton-Raphson method (part of Solver in program Autodesk Robot Structural Analysis Professional) have been applied.

7. Design options

18 design options considered for the distance between tower axis and foundation of anchoring cable equal to 2H is presented in Table 1. Similar 18 design options have been taken into account for the distance between tower axis and foundation of anchoring cable equal to H.

Table 1. Design options (18) for the distance between tower axis and foundation of anchoring cables equal to 2H

Distance of anchoring cables fixing	**Tilt of anchoring cables from tower axis**	**Distance of winch fixing**	**Tilt of winch from cable axis**	**Designation of design option**
Anchoring cable base 2H	Tilt of anchoring cables +30°	Winch base 2H	Tilt of winch +30°	**A2H_+30, W2H_+30**
			Tilt of winch 0°	**A2H_+30, W2H_0**
			Tilt of winch -30°	**A2H_+30, W2H_-30**
		Winch base 1H	Tilt of winch +30°	**A2H_+30, W1H_+30**
			Tilt of winch 0°	**A2H_+30, W1H_0**
			Tilt of winch -30°	**A2H_+30, W1H_-30**
	Tilt of anchoring cables 0°	Winch base 2H	Tilt of winch +30°	**A2H_+0, W2H_+30**
			Tilt of winch 0°	**A2H_+0, W2H_0**
			Tilt of winch -30°	**A2H_+0, W2H_-30**
		Winch base 1H	Tilt of winch +30°	**A2H_+0, W1H_+30**
			Tilt of winch 0°	**A2H_+0, W1H_0**
			Tilt of winch -30°	**A2H_+0, W1H_-30**
	Tilt of anchoring cables -30°	Winch base 2H	Tilt of winch +30°	**A2H_-30, W2H_+30**
			Tilt of winch 0°	**A2H_-30, W2H_0**
			Tilt of winch -30°	**A2H_-30, W2H_-30**
		Winch base 1H	Tilt of winch +30°	**A2H_-30, W1H_+30**
			Tilt of winch 0°	**A2H_-30, W1H_0**
			Tilt of winch -30°	**A2H_-30, W1H_-30**

8. Results of the analysis - displacements

Both absolute and relative displacements should be considered. They are defined as follows:

1) the absolute displacement, measured with respect to deformation of structure just before applying loads induced by installing conductors;
2) the relative displacements, measured with respect to deformation of structure just before applying loads induced by installing one specific conductor;

First case is important for the safety of structure in the phase when conductor is pulled by extra 20 cm (just before it is mounted to insulators chain and horizontal force in a conductors increases significantly.

Second case is very important for safety of the whole procedure, since excessive displacement during mounting could be dangerous for a worker operating at height H (standing on the platform hanging from the cross arm).

8.1. Absolute displacements

The main results are as follows:

1. Maximal absolute displacement of at the left end of the peak cross arm (point 1 in Fig. 3)) is equal to 8,1 cm. Ratio of the maximal absolute displacement to the height from the ground level is equal to 8,1/3910=1/483=0,0021
2. Maximal absolute displacement of the right end of the peak cross arm (point 2 in Fig. 3) is equal to 6,1 cm. Ratio of the maximal absolute displacement to the height from the ground level is equal to 6,1/3910=1/641=0,0016
3. Maximal absolute displacement of the cross arm PR1 (point 3 in Fig. 3) is equal to 7,9 cm. Ratio of the maximal absolute displacement to the height from the ground level is equal to 7,9/3319=1/420=0,0024
4. Maximal absolute displacement of the cross arm PR2 (point 4 in Fig. 3) is equal to 2,8 cm. Ratio of the maximal absolute displacement to the height from the ground level is equal to 2,8/2670=1/953=0,0010
5. Maximal absolute displacement of the cross arm PR1 (point 5 in Fig. 3) is equal to 4,0 cm. Ratio of the maximal absolute displacement to the height from the ground level is equal to 4,0/2670=1/668=0,0015
6. The maximum absolute displacement of the cross arms occurs for design options: winch and anchoring cables are mounted at a distance 1H from the column.
7. Tilt of anchoring cables and winch at an angle of + 30 ° results in the biggest absolute displacements of cross arms.
8. Tilt of anchoring cables an angle of -30 ° does not increase the absolute displacements.
9. The tower is subjected to strong torsion. Cross arms PR1, PR3 and left end of peak cross arm are turned towards the conductors to be installed. This fact should be taken into account assessing the risks for workers.
10. The smallest displacement occurs for the cross arm PR2 for mounting options A2H_-30 W2H_ + 30. The cross arm is rotated in the opposite direction than the direction of the assembly phase conductors.

8.2. Relative displacements

The main results with respect to absolute displacements are as follows:

1. Maximal relative displacement of point 1 at peak cross arm (see Fig. 3) is equal to 8,5 cm.
2. Maximal relative displacement of point 2 at peak cross arm (see Fig. 3) is equal to 6,8 cm.
3. Maximal relative displacement of point 3 at cross arm PR3 (see Fig. 3) is equal to 8,2 cm.
4. Maximal relative displacement of point 4 at cross arm PR2 (see Fig. 3) is equal to 3,3 cm.
5. Maximal relative displacement of point 5 at cross arm PR1 (see Fig. 3) is equal to 4,6 cm.
6. Maximum relative displacement of cross arm has been noticed for anchoring cables were mounted in 2H distance. It is worth noting that when they are mounted anchoring cables within 1H distance, the structure of the tower is stiffened by vertical forces. This prevents stronger torsion due to the impact of the winch.
7. Changes in angles of anchoring cables do not influence on the relative displacement, eg. for the angle of +30° relative displacements decrease by 5%.
8. The distance from the winch to the tower is as short as 1H results in increased relative displacements. Compared to the case of 2H displacement of cross arms increased by 10%. The same as in the case of absolute

displacements.

9. Tilt winch +30 ° from the axis of power line results in an increase of the relative displacement, an average of 19%.

9. Results of the analysis - load capacity factors

9.1. Load capacity factor estimated for columns of tower body

1. Load capacity factors are smaller with increase of distances between tower and foundations of winch and anchoring cables from H to 2H. However, the load capacity factors are between 0.3 and 0.4, i.e. in both cases they much less than critical value 1.
2. Anchoring cables tilt from the axis of tension tower and changes in the location of winches has low impact on elements load capacity factors.

9.2. Load capacity factor estimated for truss elements

1. Distance of anchoring cables foundation and theirs detailed position have influence on the level of the tension of truss elements.
2. Depending on position of the winch the load capacity factors varies by 30%, from 0.5 to 0.65.
3. All truss elements are sensitive to changes in the fixing position of anchoring cables and winches.

9.3. Load capacity factor estimated for cross arm elements

1. For cross arm PR2 change the distance of foundation for the winch from 2H to 1H results in greater load capacity factors by 35%. However, the later load capacity factors remain small, app. 0.4.
2. The highest load capacity factor equal to 0.98 were determined in the cross arm PR1 and it is not dependent on the position of anchoring cables and winches.
3. This is only cross arm PR2 on the right side of the tower is more sensitive to than other three on the other side of the axis of the tower to torsional forces. Load capacity factors for elements of cross arm PR2 significantly depend on the distance of foundation of anchoring cables and winches.

10. Final conclusions

The most tensioned parts of the supporting structures are bars in the lower cross arm zone, where anchoring cables are mounted. Load capacity factors for these elements depend on the winch position and anchoring cables.

Installation of individual conductors is unusual event, generating loads which do not occur during normal operation of the tension tower. In special extreme cases, it is advisable to use temporary reinforcements of the specific elements.

Reduction of the distance between tower axis and foundations of anchoring cables from 2 H to H results in insignificant changes, both in displacements of nodes and levels of load capacity factors.

Columns at four edges of the tower body are the most sensitive to changes in the anchoring cable angle in reference to the plane of tension tower.

Considered transmission tower, designed according to current standards, turned out to be significantly overdesigned with respect to extraordinary loads induced while installing line conductors. This means that the change of anchoring cable foundation position in the range of 1 H to 2H, and angle from -30 ° to + 30 ° does not have a negative impact on the safety columns.

The displacements have not reached the extremely high values which could be dangerous for people working at height. The highest values were obtained for option mounting A1H_+ 30, W1H_ + 30) (see Table 1).

It has been found out that the safest option is A2H_-30 W2H_0 (see Table 1).

In current practice anchoring cable and winches are mounted to foundation block at a distance of 2H from the tension tower and the tower axes and power line. This study demonstrates that smaller distance (H) to foundation of the anchoring cable and winches does not threaten the safety of the structure. Distance of mounting anchoring cables and theirs detailed position have influence on the level of the tension of truss.

Acknowledgements

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