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DEFINITION OF THE LATTICE MAST CONSTRUCTION DEFLECTIONS

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ABSTRACT

Architectural structures, like lattice mast, has often complicated spatial construction. There are several methods to perform such surveys. To compare precision and efficiency of the chosen measurement methods, the deviation of a mast was defined by methods using an electronic tachymeter: traditional – direction measurements, modified – which uses reflectorless measurement of distances and technique of laser scanning.

1. INTRODUCTION

Dynamic development of telemetric techniques requires necessity of building many slim objects with varied spatial construction. That is why, because of safety of these buildings, it is very important to perform measurements, which are to define the deviation from the location. Measures of spatial translation of such buildings achieved during such works should provide us with valid information, necessary for defining the possibilities of danger. Results of such work have a vital influence on decisions about current exploitation of this type of objects.

2. OBJECT DESCRIPTION

The mast which is the subject of the paper is situated in the neighbourhood of Wroclaw in the region of Trzebnicko-Ostrzeszowskie Hills (The Cats' Mountains). The construction of the mast constitutes a triangle lattice with a side length of 0,60 m, constructed with 30mm diameter round pipes. The height of the mast is 60,0m and it is secured with four sets of guy-ropes which are located at a height of 12, 24, 42 and 60 meters of the construction.

3. RESULT OF CONTROL NETWORK OBSERVATIONS

Control network for mast deformation measurements consist of 7 points, 6 of which are located around the mast and the seventh near the object to strengthen the construction of the network. A sketch of the control network is presented in fig. 1.

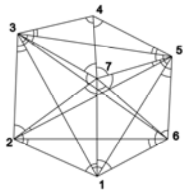
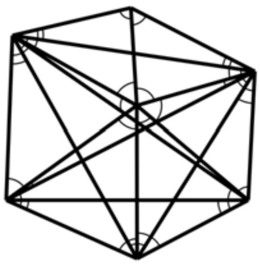


Fig. 1. A sketch of a control network.

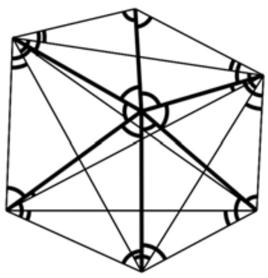
The control measurements as well as measurements of the mast construction were carried out by means of a tachymeter Leica TCRP 1203 with measurement parameters:
- precision of direction measurement: 3” – 10 ^{cc},
- precision of measurement with a mirror: 1mm+2mm/km
- precision of measurement without a mirror: 2mm+2mm/km

After performing field observations, calculations of a control network were run in a few ways. Each differ by the number and choice of observations. In the first method only distances measured to reflectors (linear network) were used. The following methods were situations where the number and choice of observations was limited. This would theoretically result from occurrence of terrain obstacles. Exemplary, schematic sets of measured observations and achieved results of equalization of control points were presented in fig. 2 – 7. The stablished set of measurements is shown by thicken lines. In tables, apart from adjusted coordinates values (X adj., Y adj.) and coordinates errors (mx, my, mp) which were achieved in particular cases, we have also presented differences of coordinates achieved in the following variation in comparison to coordinates from variation 1 (dx,dy).



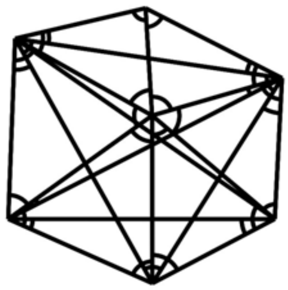
Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]
2	129.1390	37.6931	0.2	0.1	0.2
3	208.9867	40.4602	0.2	0.2	0.3
4	222.4355	97.3992	0.2	0.3	0.3
5	191.0073	156.9385	0.2	0.2	0.2
6	128.3436	153.5445	0.2	0.1	0.2
Average values			0.2	0.2	0.2

Fig. 2. Network control – full net, linear observations.



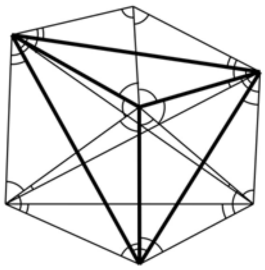
Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]	dx [mm]	dy [mm]
2	129.1397	37.6926	1.0	0.8	1.3	0.7	-0.5
3	208.9872	40.4605	1.3	0.8	1.5	0.5	0.3
4	222.4354	97.3981	0.2	1.1	1.2	-0.1	-0.9
5	191.0074	156.9379	1.2	0.6	1.3	0.0	-0.6
6	128.3445	153.5449	1.0	0.9	1.3	0.9	0.4
Average values			1.1	0.8	1.3	0.4	0.5

Fig. 3. Network control – full net, angle observations.



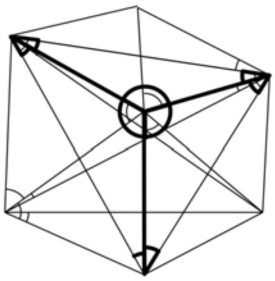
Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]	dx [mm]	dy [mm]
2	129.1390	37.6931	0.2	0.1	0.2	0.0	0.0
3	208.9867	40.4602	0.2	0.2	0.3	0.0	0.0
4	222.4355	97.3990	0.2	0.2	0.3	0.0	-0.2
5	191.0074	156.9385	0.2	0.1	0.2	0.1	0.0
6	128.3437	153.5445	0.2	0.1	0.2	0.1	0.0
Average values			0.2	0.1	0.2	0.0	0.0

Fig. 4. Network control – full net, linear and angle observations.



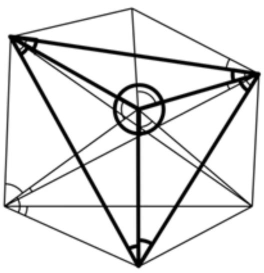
Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]	dx [mm]	dy [mm]
3	208.9866	40.4601	0.5	0.3	0.6	-0.1	-0.1
5	191.0073	156.9385	0.3	0.2	0.3	-0.1	0.0
Average values			0.4	0.2	0.4	0.1	0.1

Fig. 5. Network control – triangle with a central point, linear observations.



Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]	dx [mm]	dy [mm]
3	208.9865	40.4601	1.0	06	1.2	-0.2	-0.1
5	191.0086	156.9377	0.9	0.5	1.0	1.2	-0.8
Average values			1.0	0.6	1.1	0.7	0.4

Fig.6. Network control – triangle with a central point, angle observations.



Point number	X adj. [m]	Y adj. [m]	mx [mm]	my [mm]	mp [mm]	dx [mm]	dy [mm]
3	208.9866	40.4601	0.4	0.3	0.5	-0.1	-0.1
5	191.0074	156.9385	0.3	0.2	0.3	0.0	0.0
Average values			0.3	0.2	0.4	0.0	0.0

Fig. 7. Network control – triangle with a central point, linear and angle observations.

Apart from methods of control measurement presented above, calculations of other possibilities were also performed: for the control in rosette shape (without additional diagonal elements) and for a control in triangle shape (without a central point).

To conclude results of control network solution it is possible to state that much better results are achieved by using length observations for calculations. In such cases errors of location of the points are within the range of 0,2mm to 0,4mm, while for an angle network within the range of 0,6mm to 1,0mm. Including measured angles into linear network does not increase but also does not decrease the precision of calculation of coordinates of control network. Comparing the values of coordinates, control points which were defined in different ways it is concluded that maximal differences of those coordinates (dx, dy) does not exceed 0,7mm.

4. A MEASUREMENT OF DEVIATIONS OF THE MAST BY THE TRIGONOMETRIC METHOD

Measurements of a mast were made on 5 levels – at the base, on the three middle levels and on the top . The top was defined as the middle of the construction pipe of the mast. For measurements by trigonometric method, as mentioned before, we used an electronic tachymeter Leica TCRP 1203. Apart from observations of directions, distances were also determined with aid of reflectorless measurements. After performing field observations, calculations of coordinates of the mast were also run in a few ways. The best results were achieved while using for calculations only distance observations from all 6 points of control network (fig. 8). Such calculated coordinates of the controlled points were compared with coordinates calculated from linear observations and angle-linear.

To check precision of coordinates definition of the controlled points in conditions of the limited access to the object, we have concluded calculations of coordinates using observations of directions from only three chosen locations and distance observations of three different points of network. Also calculations for angle-linear intersections were run from two different locations. Results of calculations were presented in fig. 9 - 14, where average values of errors and average values of coordinates differences of measured controlled points which were calculated in respect to the initial version, were given. Established set of measurements is shown by thicken lines. To simplify schematic drawings illustrating the rules of the measurement, observations performed for three "vertical" pipes of the mast (marked A, B, C) were presented as single lines, and the spatial object construction was marked as one point.

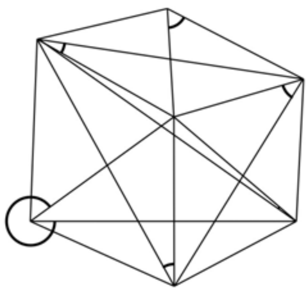
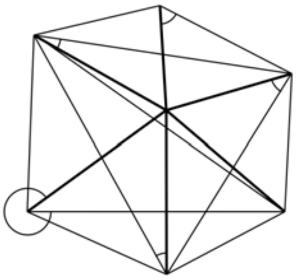


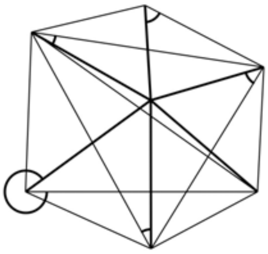
Fig. 8. The mast construction measurement, locations 1, 2, 3, 4, 5, 6 - direction observations.

Point number	Xadj. [m]	Yadj. [m]	mx [mm]	my [mm]	mp [mm]
1A	164.0358	106.3311	0.8	0.7	1.1
1B	164.0612	105.7351	06	0.6	0.9
1C	164.5643	106.0584	0.8	0.6	1.0
2A	163.9777	106.2176	0.7	0.7	1.0
2B	164.0378	105.6218	0.6	0.7	1.0
2C	164.5217	105.9707	1.0	0.9	1.4
3A	163.9343	106.0885	0.7	0.7	1.0
3B	164.0185	105.4932	0.8	0.8	1.1
3C	164.4861	105.8621	0.9	0.7	1.1
4A	163.8668	105.9995	0.9	1.0	1.4
4B	163.9806	105.4112	0.8	0.8	1.1
4C	164.4325	105.8084	1.0	0.9	1.3
5A	163.8045	105.9194	0.8	0.6	1.0
5B	163.9341	105.3391	0.7	0.8	1.0
5C	164.3725	105.7372	0.8	0.8	1.2
Average values			0.8	0.8	1.1



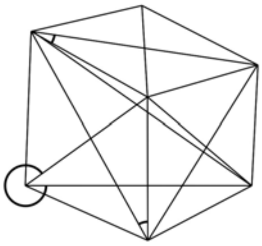
Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	3.3	3.9	5.2	3.4	4.0

Fig. 9. The mast construction measurement, locations 1, 2, 3, 4, 5, 6 – distance observations.



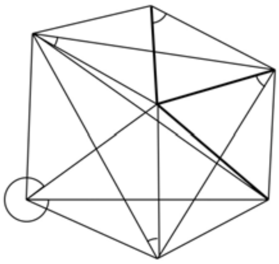
Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	1.1	1.2	1.8	1.3	1.0

Fig. 10. The mast construction measurement, locations 1, 2, 3, 4, 5, 6 – direction and distance observations.



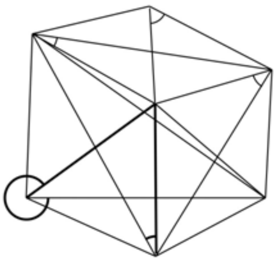
Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	1.0	0.8	1.3	1.3	0.8

Fig. 11. The mast construction measurement, locations 1, 2, 3 – direction observations.



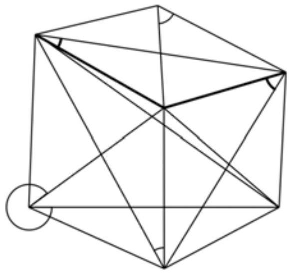
Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	3.2	3.1	4.4	3.7	6.5

Fig. 12. The mast construction measurement, locations 3, 4, 5 – distance observations.



Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	1.8	2.0	3.0	2.2	2.3

Fig. 13. The mast construction measurement, locations 1, 2 – direction and distance observations.



Point	mx	my	mp	dx	dy
	[mm]	[mm]	[mm]	[mm]	[mm]
Average	1.3	1.8	2.2	1.7	2.3

Fig. 14. The mast construction measurement, locations 3, 5, – direction and distance observations.

From performed coordinates analysis of controlled points, can be concluded that better results are achieved using bearing observations (from 0,8 mm – 1,2mm) than distances measured without using reflector (from 3,3mm -3,9mm). In case of difficulties in control network measurements, proper results of measurements of the mast (from 1,3mm – 2,0mm) can also be achieved from the polar measurements performed from two locations. The polar type of measurements can also be used while performing rectification (Wichtowski, 2007) of spatial location of slim objects, using only one tachymeter which carries out refrectorless distance measurement.

It is obvious that for other constructions of slim objects there will be different results. In the case of pipe made objects, precision depends on the diameter of the pipes. For the construction made of angle bars it depends on precision of aiming onto edges. To asses precision of achieved results, an analysis based on the formulas (1) (2) was performed: (1) (Instrukcja techniczna G-3) and (2) (Norma PN-B-03204:2002, Norma BN 69/2940-01).

$$M_p = r \times m_p \leq R \times P \tag{1}$$

Where:

Mp – a threshold error of displacement definition,

P - threshold displacement defined for a certain object in a technical project or in appropriate technical – exploitation regulations,

R - parameter defining which part of threshold displacement (P) can be threshold error of its definition (Mp),

Mp – average error of definition of displacement,

r - coefficient which value depends on required probability level for results and degree of measurements random error.

$$a \leq h/1000 \tag{2}$$

Where:

a - is a approved deflection of the mast (border displacement),

h - measured mast level.

Taking exemplary data: h = 60,00m, R = 0,1, r = 3 we get a value of the average error of displacement definition, and in this case average error of deflection definition equals 1,8mm. Taking into consideration achieved results, we can state that the precision criteria is completed only in the case of carrying out direction measurements. In the case of angle – linear incisions, random errors obtained exceed twice investigated threshold. In case of linear measurements the error is three times higher. It is to be noticed, though, that an exemplary analysis was run allowing huge probability of correctness of achieved results, on the level of P = 0,997 (r = 3). It is thus possible that in cases of huge difficulties in appropriate location of control network, we can use, also measurements of distances made in a reflectorless way.

5. THE MAST DEFLECTIONS MEASUREMENT BY SCANNING LASER METHOD

The laser scanning technique was also used to measure mast deflections. In measurements we used a Leica instrument, ScanStation HDS 3000 with precision parameters of:

- **precision of direction measurements: 60 micro radians – 40^{cc},**
- **precision of distance measurements: 4mm**
- **precision of measurement of a single point in three dimension space 6mm.**

The measurements were carried out from three locations with assumed resolution of 2mm in horizontal plane and 4mm in vertical plane. The session time at one location was about 2 hours. Totally about 3 000 000 points were measured.

Terrain measurements was processed by using specialist software from Leica company which allows building a 3D model and obtain any dimension of the construction element.

6. THE MAST CONSTRUCTION DEFLECTIONS PROCESSING

To asses the efficiency of using both carried out measurement methods, a comparison of the values of defections was performed. The values were directly compared basing on coordinates of controlled points, without usage of the controversial formulas which can be found in the instruction ER-1 (Jankowska , 2001, Wichtowski, 2002) Deflections of the vertical axis of the mast were calculated, both in the side views (fig. 15) and in the top view (fig. 16). On the chart (fig. 15), the axis of the mast was presented as a single line, taking into consideration that the value of differences of deflections which were achieved from both methods of measurements cannot be presented in the scale of drawing. The maximal differences in values of deflections on particular levels are 8mm which, to a large degree, exceeds the value of earlier calculated criteria of precision. However, in the case of the allowed deflection of the mast (a = 60mm) and stated deflections of the object (fig. 15) it is a low value. The information achieved from the laser scanning could be useful in taking decisions about rectification of researched slim objects.

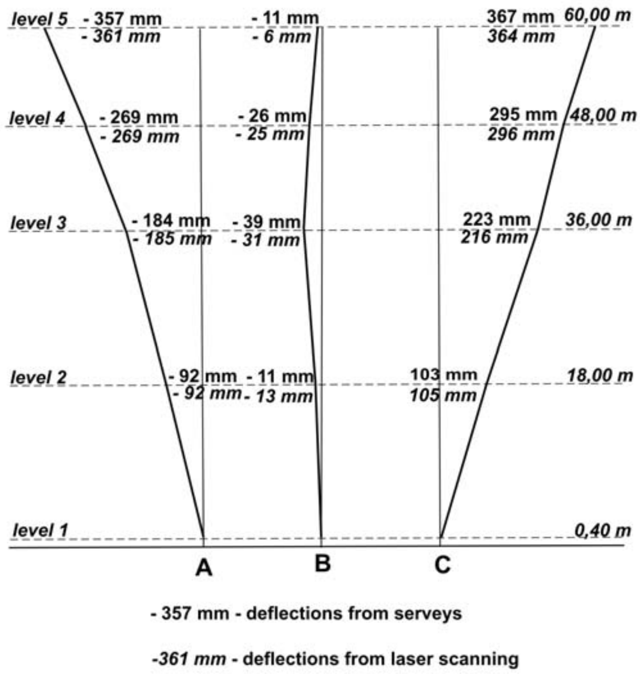


Fig. 15. Deflections of the axis of the mast – views from the side from particular edges of the mast.

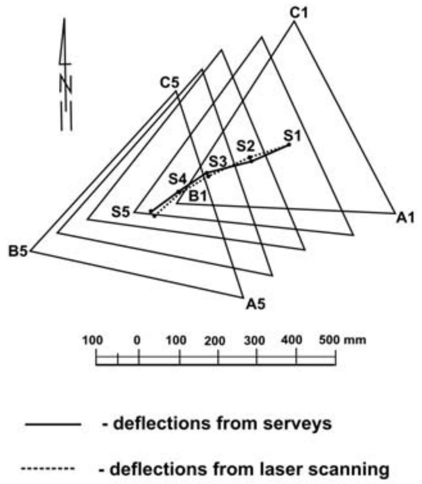


Fig. 16. Deflections of the axis of the mast – a view from the top.

CONCLUSIONS

1. **Using suitable electronic tachymeters which carry out reflectorless measurements we can make observations of slim objects with limited possibilities of locating controls and limited accessibility of construction elements of the mast .**
2. **These instruments can be used to supervise slim objects "rectification". All required measurements are possible to perform with one instrument exclusively.**
3. **Using the laser scanning method for observation of slim objects deflections we achieve comparable results to these made with the land surveying methods. The laser scanning method has the advantage of achieving information about the whole construction, not only about its chosen elements.**

4. **The results of measurements achieved by the method of laser scanning are precise enough to take decisions about the further exploitation of researched objects.**

REFERENCES

Jankowska B., 2001 – Błąd wzoru na wyznaczanie przemieszczeń masztu 3-ściennego wg instrukcji ER-01, Zeszyty Naukowe, Budownictwo, Politechnika Zielonogórska, z.127(35), s. 111 – 119.

Wichtowski B., 2002 – Geometria stalowych wież i masztów radiowo-telewizyjnych na podstawie inspekcji okresowych, Budownictwo PN PS, nr 561/2002, s. 37-51.

Wichtowski B., 2007 – Rektyfikacja stalowych wież antenowych na podstawie inspekcji okresowych, XXII Konferencja naukowo – techniczna, Szczecin – Międzyzdroje, 23 – 26 maja 2007, s. 665 – 672.

Instrukcja techniczna G-3 – Geodezyjna obsługa inwestycji, Główny Urząd Geodezji i Kartografii, wyd. 3, Warszawa 1981.

Instrukcja ER – 01, 1994 – Eksploatacja wież i masztów, Telekomunikacja Polska S.A., Warszawa 1994.

Norma BN-692940-01 – Konstrukcje stalowe. Maszty oraz wieże radiowe i telewizyjne. Wymagania i badania.

Norma PN-B-03204:2002 – Konstrukcje stalowe, wieże i maszty, projektowanie i wykonanie, Polski Komitet Normalizacyjny, wyd. Ars Boni sp. z o.o., Warszawa 2002.