http://dx.doi.org/10.15576/GLL/2016.4.49

GLL

Geomatics, Landmanagement and Landscape No. 4 • 2016, 49–57

THE ASSESSMENT OF THE APPLICATION OF TERRESTRIAL LASER SCANNING FOR MEASURING THE GEOMETRICS OF COOLING TOWERS

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Summary

The investigation of technical condition of cooling towers is an important engineering issue. Regulations regarding safe operations of high structures force periodic measurements in order to determine technical state of such towers. This paper presents the processing methodology of laser scanning data and shows computation results of cooling tower W-1 shape changes. These results were referred to the designed shape of the tower in question. Tower surface displacements (deformations) are shown by plotting the deviations of the measured shape from the regular one. The determined changes in the surface shape are between –20 cm and 5 cm. This article presents the evaluation of the technical condition of the W-1 cooling tower.

Keywords

TLS • cooling towers • hyperboloidal towers • monitoring • displacements

1. Introduction

Cooling towers, which are large volume structures, constitute essential components of every major processing plant. Such towers may be found adjoining, for instance, steel mills, power plants, etc., and therefore they are a regular feature in the industrial landscape of Poland. Cooling towers play an indispensable part in the proper functioning of power plants - they cool water in a closed circuit. Among many types of cooling towers, hyperboloidal ones are the most common, allowing fair operability with low material and construction expenditure. Most of them are made of reinforced concrete with thin walls, whereas the wall thickness changes with height. The thickness of the tower mantle lowers with the height. Special construction and working conditions of such slender structures are the cause of the special treatment they require, in terms of thorough measurement for the purpose of finding any deviations of the standing structure from its construction plans. For buildings of this kind of shape, it is strictly necessary to achieve the designed, prescribed dimensions. Any deviation from the planned shape may be and had been the cause of major disasters [Seręga et al. 2013a, 2013b].

Geodetic measurements allow us to determine the actual shape of a hyperboloidal cooling tower. Among the surveying methods used, one can distinguish classical ones, based on distance and angle measurements, and photogrammetric ones, which use images taken from ground level by special cameras. The surrounding tangents method is the one that uses theodolite (or Total Station), and is based on measuring tangents of the contours of the tower surface. The standard approach is to measure the object from three sites located around the structure. This method does not require any marking of controlled points on the surface. It may be used for objects whose shapes can be approximated as second degree functions [Czaja 1984]. The extension of this kind of surveys is to use marked controlled points that are evenly distributed along the selected parallels around the structure.

Photogrammetric methods use ground level images that are taken from the base, thus they can be set up in a stereocomparator, and measured stereoscopically. In this case, it is possible to determine the course of the surface curves. The advantage of this approach is the capacity to store multiple images for documentation purposes during a structure's lifespan. On the other hand, the major drawback is the cost of such surveys, except for the scenario when the number of points measured with photogrammetric methods greatly exceeds the amount of measurements that need to be taken using classical methods [Gocał 1980].

The limitations in processing of the data are that the contours of the tower visible in the background are not contained on the vertical plane, and that they are slanted due to the field of view. Vertical cross section of the outside surface is not a mathematically designed hyperboloid, the one that is designed and constructed, but the inner surface of the cooling tower, therefore it is the latter that should match the planned shape [Kadaj 1973]. In accordance with the construction technique, the tower mantle is created by building one hundred 1.2 m high cut cones on top of one another.

The surveying results of selected points on the tower surface comes down to the calculation of XYZ coordinates. Typically, 10 mm accuracy level is the standard for this kind of surveying measurements [Gawałkiewicz 2007]. The processing of results, independently of the survey method used, provides the information about any deviations from the designed hyperboloid with perfectly vertical centric axis and the planned dimensions [Zdanowicz 2011].

For direct displacement detection, temporal pairs can be used. All the paperwork, that is numerical data, graphics, and plots of displacement should clearly and conveniently visualize anomalies of the cooling tower's shape. The subjects of such collations include radial deviations from the nominal circles in horizontal cross sections on certain heights, deviations from the nominal hyperbolas in vertical cross sections, displacements, and deformation components. The visualisation side includes plots and contour maps of the radial deformation components, axonometric views of the radial deviations or deformations, as well as axonometric views of the tower in its skeletal form.

2. Description of the object of study

The test object was a hyperboloidal cooling tower, 60 m in height, and 45.5 meters in diameter at the base. The tower was constructed in 1970s (Figure 1). The survey took place in October 2014. The measurements of geometric condition of the outer surface was taken with a laser scanner with EDM capability. In the course of the survey process, most of the old reference points, marked in 2005 and 2009, had been identified, and any damaged points were reestablished. The modernized reference network constituted the angle and distance grid that resembled the shape of closed polygons, located around the test object.

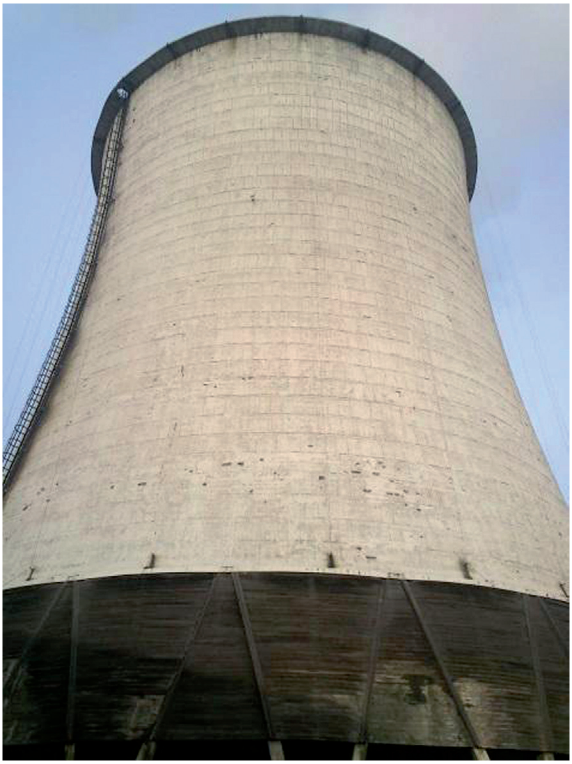


Photo by J. Wajs (2.10.2014)

Fig. 1. The view of the hyperboloidal cooling tower

The entire network was measured in reference to the centers of benchmark's head side faces, which were located on the cantilevers of the tower. As those benchmark coordinate centers had been previously determined, they served as reference points. DTMs were used on each point of the network to take two series of measurements on every visible point. Each series constituted measurements in two faces of the DTM, and additionally a dual distance measurement was conducted for each DTM face. Vertical tie was made using trigonometric levelling with reference to the benchmark heads on cantilevers. Vertical points gained new heights from the adjustment of precise geometric levelling with the accuracy of ± 0.2 mm. For the horizontal network, a precise servo operated DTM was used with accuracy properties of ±2' of angle determination and (±2 + 2 ppm) distance to the reflector measurement. Subsequently, all survey results have been adjusted using the least squares method [Wiśniewski 2005]. The coordinate adjustment analysis revealed that the maximum error did not exceed ±0.8 mm with the average value of ±0.6 mm, while the vertical position error was not higher than ±0.4 mm with average of ±0.4 mm.

Surveying of the tower mantle was performed with laser scanning placed over network points or on free stations situated in convenient locations around each tower. Points that were not marked were observed; they were distributed evenly on all the external surfaces. Mean error of 3D position measured on the tower (with the attribute of zero error for control points) did not exceed ±5mm.

Points surveyed with laser scanner represented the external side surface of the tower's mantle. Mathematical model for the cooling tower is a hyperboloid that can be described as:

$$\frac{r^2}{a^2} - \frac{z^2}{b^2} = 1 \tag{1}$$

Assuming that:

$$r^2 = x^2 + y^2 \tag{2}$$

where:

a, b – are the hyperboloid's semi axis;

x, y, z – are the hyperboloid's coordinates in the system where its beginning is the center of the hyperboloid's symmetry.

The parameters of the cooling tower hyperboloid model, provided by the owners, can be viewed in Table 1. The actual parameters of the real object were determined from the results of a survey performed using classical methods, examining the surrounding tangent during the measurement of reference points. Process results are available in the Report by the Wrocław University of Science and Technology [Głowacki et al. 2014].

Table 1. Cooling tower W-1 parameters

Cooling tower	Mantle height	Radius at the bottom (at intake)	Radius at the top (at exhaust)	Theoretical parameters		Actual parameters	
				a	*b*	*a*	*b*
	[m]	[m]	[m]	[m]	[m]	[m]	[m]
1(W)	59.0	22.500	13.665	13.000	33.975	12.990	34.049

Theoretical model location is at the middle of the tower wall, and therefore all measured points on the surface had to be recalculated in such a way that it would represent exactly the middle part of the mantle, while taking into account that the mantle is narrowing as the height increases. The reductions of the locations of points were carried out along the normal to inner surface, with respect to the design documentation, corrections of *dr* (point location radial correction) and of *dz* (corrections from the measured height). Because the design parameters of the hyperboloid were not accurate enough, for reliability reasons all comparisons of deviations between the current and the previous surveys were made according to the actual hyperboloid's semi axis (Table 1).

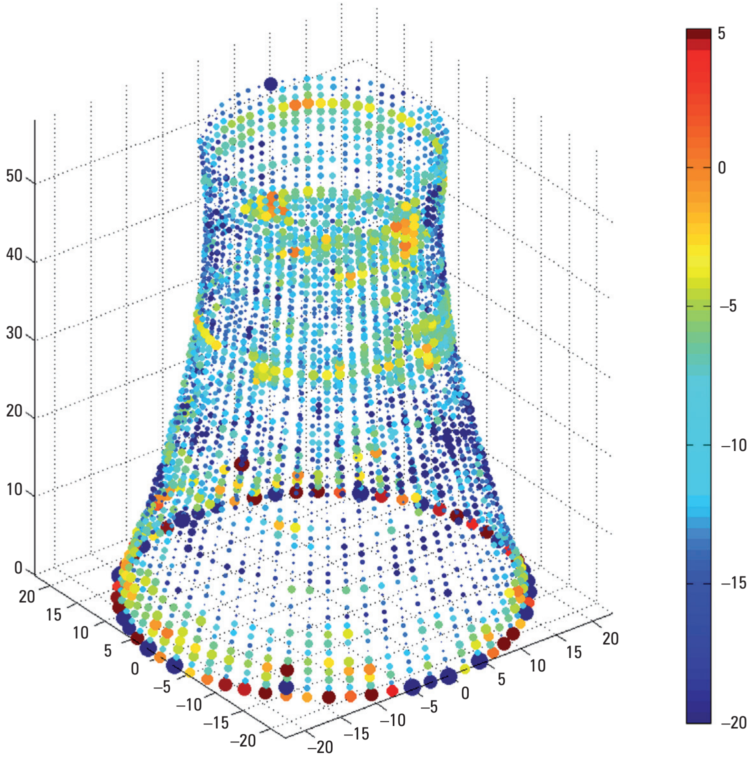
The test object was measured using Leica C10 laser scanner. In total, 34 thousand points have been collected, evenly distributed on the tower surface. For this purpose, nine survey sites located around tower were used. The coordinate system was established in a way that it is cartesian, homogeneous, and its origin is in the theoretic center of the tower. All coordinates were calculated in this system. The measured points that constitute the theoretical surface of the tower mantle were used for calculating imperfections. The points placed on both the theoretical and the actual surfaces do match in local coordinate system, but they differ according to the value of the radius.

3. Processing of the measured data

The values of the imperfections were calculated as a difference between the radius of the measured point (that represents the middle of the tower wall thickness) and its theoretical counterpart at a certain height. These radiuses were calculated from the theoretical main vertical axis of the hyperboloid. The negative value of the imperfection signals the inward bending direction of the mantle, whereas the positive value signals the outward bending direction. The distribution of the controlled points with imperfection values are shown in Figures 2 and 3. Imperfection values are represented as sizes of points in respect to their theoretical counterparts (in the scale of 0 to 1). Colors from brown to green represent outward bending (negative values) while green to blue show inward bending (positive values of the imperfections). Imperfection values at point locations were calculated as differences between the real and the theoretical radius lengths. In some places, high imperfection values are shown, and this is due to modelling specific conditions, and serves to achieve a clearer visualization. Extreme imperfection values are mildly reduced in comparison to the actual values.

4. Analysis of results

The calculated values of the imperfections of tower mantle surface fall within the –205 mm to +50 mm range. Most of the deviations are negative (87%). This means that the actual surface of the cooling tower is bent inwards compared to the theoretical one. The highest differences can be found at the base of the tower, while most of the imperfection values are greater than 100 mm. No pattern of difference locations can be found, and they are not evenly distributed, which may indicate that they are caused by an imperfect assembly and faulty construction methods. Most of the positive imperfection values can be found at the exhaust, and they too are distributed unevenly. Also on the remaining surface of the tower, the deviation values are not distributed evenly, instead, we observe that the deviation values decrease from the bottom (where they are negative) to the neck (where they reach zero value), and that they increase towards the top with the most of positive values.

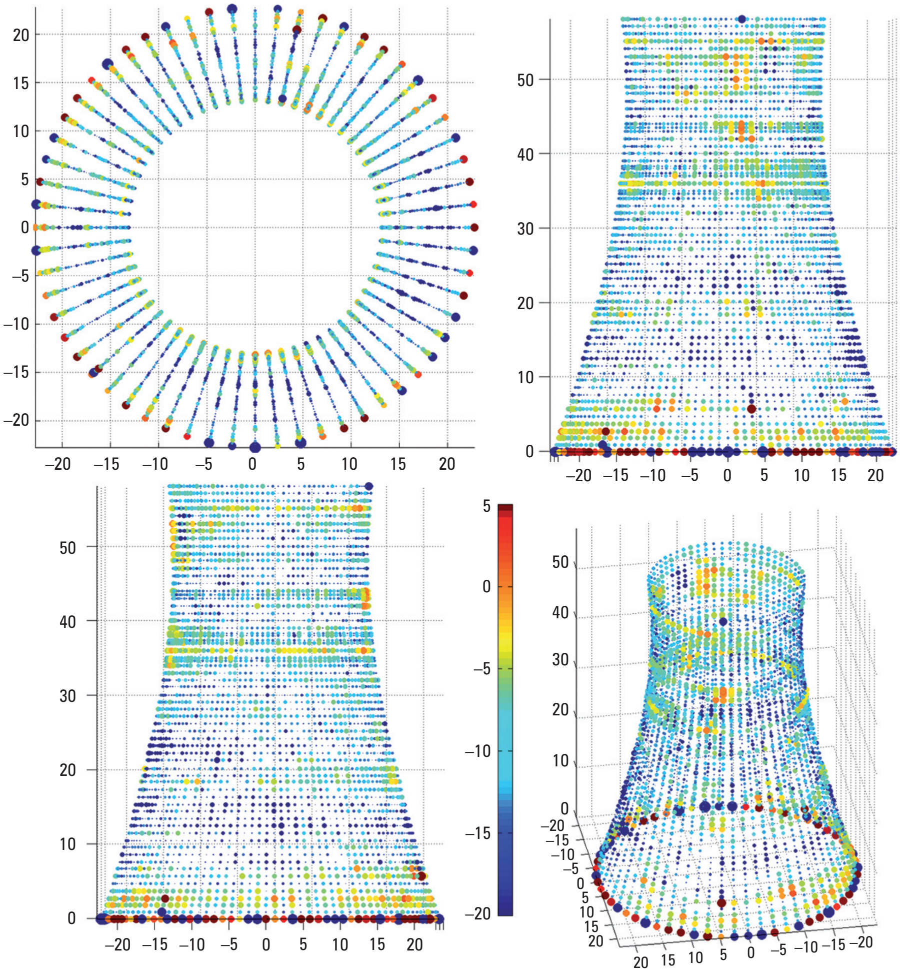


Source: authors' study

Fig. 2. A 3D model of the tower's mantle imperfections

5. Conclusions

The tested cooling tower was measured using two independent techniques, first: radial surveying conducted with distance, horizontal and vertical angle measurements of 28 hyperboloid parallels distributed evenly on the circumference of the tower; and second: automatic laser scanning, where points were distributed evenly on the tower's side surface. All surveys were referred to the same control points, the characteristics of which had been described in the previous chapter. All survey data were collected on the same day, with the same weather conditions. Results of both survey methods match closely for repeatable points, while the differences reach just couple of millimeters in value, which is consistent with the equipment's measurement errors. The classical survey took 24 hours and 420 observations were gathered, while the laser scanning took only 6 hours and 34,000 points were measured. The laser scanning method is obviously faster and gives a full picture of the tower's mantle condition for further analysis, but only an expert in the field of reinforced concrete construction can determine the real condition of the structure. The results of this analysis are consistent with other laser scanning measurements performed by other authors [Gawałkiewicz 2007]. Comparison with previous records, available at Eurtokods, shows that the described structure is stable and there is no threat of catastrophic failure.



Source: authors' study

Fig. 3. Imperfections shown in three planes and an axonometric view

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