GEODETIC MEASURING METHODS AND SHAPE ESTIMATION OF CONCRETE THIN SHELL SURFACE

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ABSTRACT

The geodetic measurements of surface geometry can be performed with new laser scanning technologies.
This paper presents the results of such measurements of external surface of cooling tower using Leica TCRP 1201+ tacheometer and Image Station 03 video tacheometer. The overlapping data sets of consecutive scans were investigated in order to propose a method to compound partial surface scans. The data analysis included estimation of systematic errors in common sections of scans. The results of obtained surfaces were compared with precise point measurements using Leica TCRP 1201+.

1.INTRODUCTION

The thin shell structures require exceptionally high precision of designed shape construction. It is the shape that governs appropriate strain distribution and is responsible for appropriate stability and structural strength of the construction. It enables to use exceptionally thin shells. It is very important both from economical and ground load point of view.
The final shape of the construction as well as impact of ageing, mostly caused by weather conditions and corrosion, should be carefully controlled periodically. It is to guarantee the safety of the object and its surrounding.
The deformation evaluation require high precision and reliability. Due to the absence of distinctive points on the controlled surfaces the deformation calculation must be performed on the basis indirect comparison of surface measurements.
The advancement of the modern tacheometers brought us RMS (Remote Measuring Systems). It is a very precise measuring technique however time-consuming and expensive.
Reflector less distance measurements allowed using polar methods to determine the coordinates of arbitrary points of the controlled surface. It requires very narrow laser beam of distance meter with perfectly coupled angles and distance. Latest scanning tacheometers allow to acquire up to 20 measurement points per second. Due to a high volume of measurement data obtained in an automatic scanning procedure unique approach to measuring and data analysis is required.

This paper presents the results of investigations of the tacheometer laser scanning accuracy in practice. The analyses were made using data from experiments carried out on cooling tower of Belchatow Power Station (BPS).

2.MEASUREMENTS ON COOLING TOWER

In order to investigate the accuracy effects of the fast scanning measurements of the thin shell structure's shape and deformation calculation a scanning of a real 130 m high structure of cooling tower Belchatow was measured. The most precise tacheometer Leica TCRP 1201+ and video-tacheometer TOPCON Image Station IS03 were used.

The verification of the object's shape requires measuring an number of points in common coordinate system and calculating geometric imperfections in reference to the design. In order to have a common coordinate system independent from centering and instrument orientation error, a geodetic network was established. The observations were performed on 10 instrument stations bound to 7 connecting points and 3 points of basic network of power station (fig. 1). The positioning error of control network points was determined by mean error ellipse with semi-axis below 1 mm.
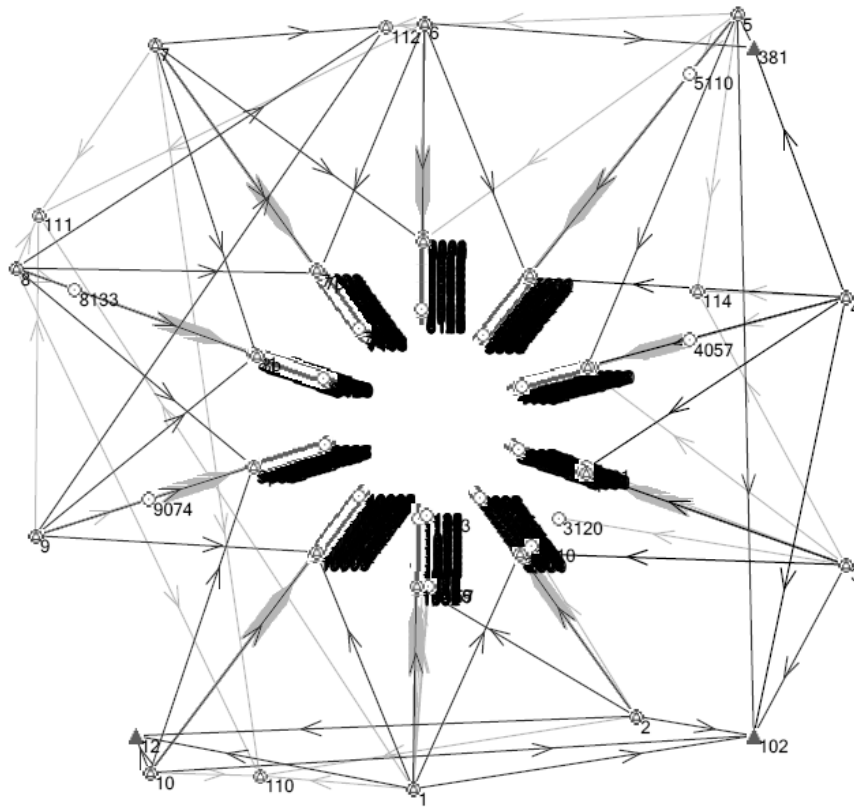

Fig. 1. Sketch of the geodetic control network

According to the civil engineering specialist the cooling tower should be controlled in at least 10 vertical profiles. In our experiment we performed a standard precise profile measurements with Leica TCRP 1201+ and scanning measurements with TOPCON Image Station IS03. Scanning on each station included both vertical line scan (1.5k points) as well as area scan (8.5k points).

The instrument TCRP 1201+ was testing. The images (see fig.2) present the systematic error and standard deviation of multiple measurements against the vertical and

horizontal incidence angle. The image sets were prepared for the distance of 42 m (upper) and 8 m (lower). In comparison to other tacheometers the results were superior. In our work we used this equipment as a reference measuring method.
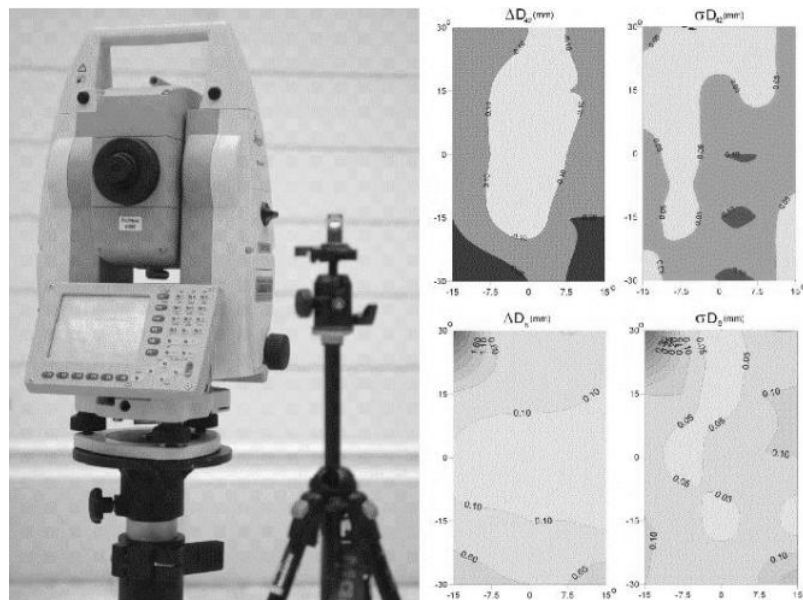

Fig. 2. Tacheometer TCRP 1201+ and results of testing an influence of an incidence angle on accuracy of distance measurements [2].

3.MEASUREMENT ANALYSIS

Data from three sources were analyzed:
- tacheometric measurements preformed in STOP mode using precise instrument Leica TCRP 1201+,
- automatic measurements preformed in LINE mode using TOPCON IS03,
- automatic measurements preformed in SCAN mode using TOPCON IS03.

Those observations allowed to build a 3D model of cooling tower shell. All data were analyzed in a local coordinate system with origin in the center of cooling tower basis. The position of the origin was approximated from the shape of the lowest part of the measured object.
Since the design describe the shape of the cooling tower as a body of revolution close to hyperboloid we presented all data in cylindrical coordinate system. The geometrical imperfections were described by radius difference.

The comparison of line measurements shows that the automatic line measurements have saw shaped plot. We observe two states separated with a distance of several centimeters (Fig. 3). This divergence increase with the measuring range. Both LINE and SCAN measurements are leaning away from the line of precise measurements as the distance and vertical angle increase (Fig. 4).
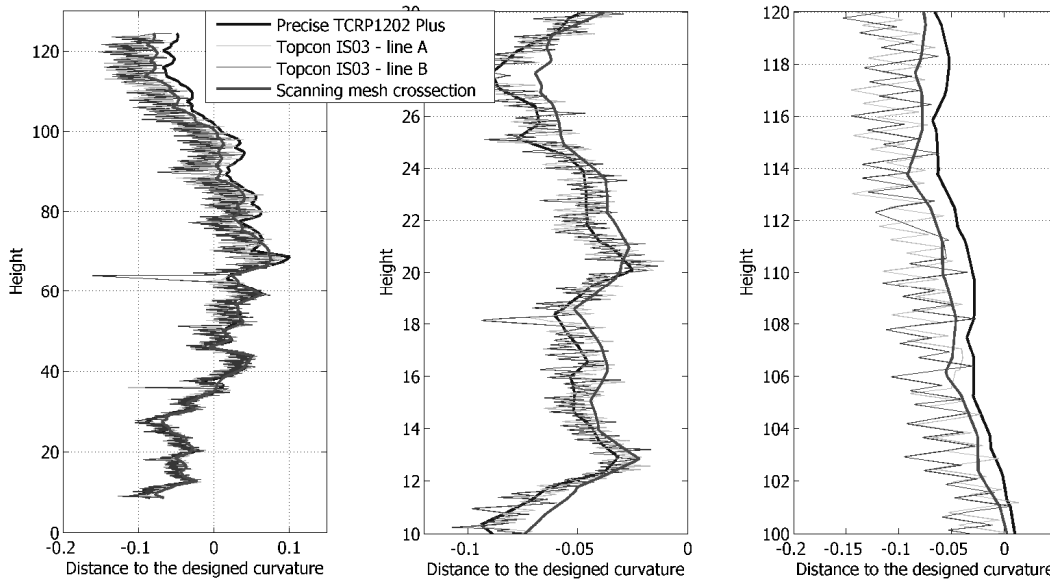
Fig. 3. Difference of the measured and designed curvature of the cooling tower vertical cross-sections. Left plot shows the full range of the measurements. The centre and right plots show a detailed view of a lower and upper part of the scanning range.
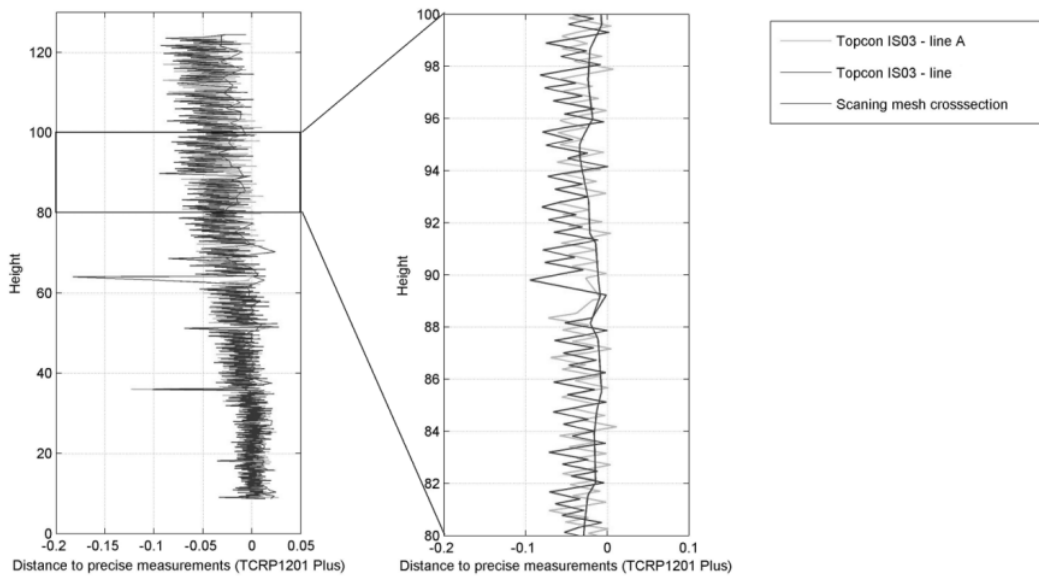
Fig. 4. The comparison of two measuring methods against the reference precise measurements. Measurements plotted in red and green were performed in "Line Mode" of Topcon IS03. Purple line shows a cross-section of the reconstructed surface obtained in "Scan Mode".

Deviation of actual shape of the shell from the nominal (designed) curvature is the basis for any evaluation of static properties of the structure. Precise measurement data taken by TCRP tacheometer were worked out for the whole cooling tower in a cylindrical coordinate system. This model of cooling tower surface was build on the basis of 10 vertical profiles of around 140 points each. The discussed difference in surface shape was analyzed as a change of radius coordinate. Magnitude of the local imperfections were as high as 150 mm. The location and magnitude of the deformation is presented on the fig. 5.
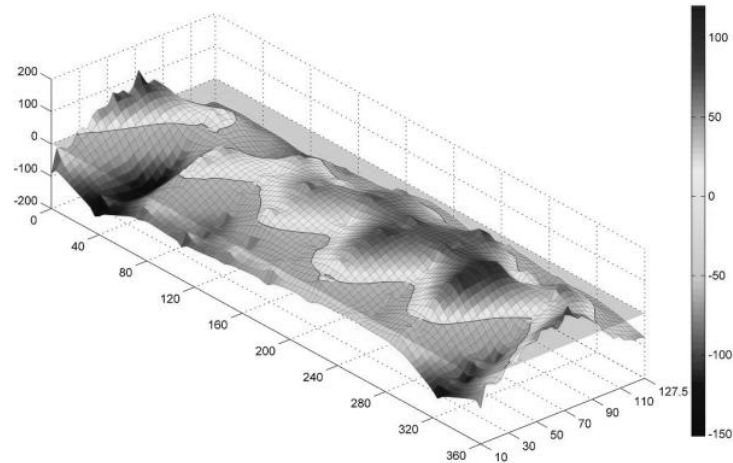
Fig. 5. The deformation of the cooling tower in reference to the designed surface curvature obtained from the single point precise measurements. The model contains 1400 control points.

4.ANALYSES OF SCANS

The scanned data sets show distinct loss of measurement precision on the edges of the scanning area. These are the regions where both incidence angle and distance rises. In such cases any mistuning of the measuring device will cause an error increase. The magnitude can exceed 10 centimeters. Because of that it is very important to eliminate those distorted measurement observations in further analysis. In order to avoid those high error regions it is necessary to limit the scan area in horizontal direction thus increase the number of stations.

Detailed observation of the reconstructed surface reveals the zigzagging character of scanning mode similar to the one observed in line measurements. This will create the coat of data that is several centimeter thick. It is possible to reduce this effect by appropriate low pass filtering but it may significantly reduce the measurement precision in case of complicated shapes.
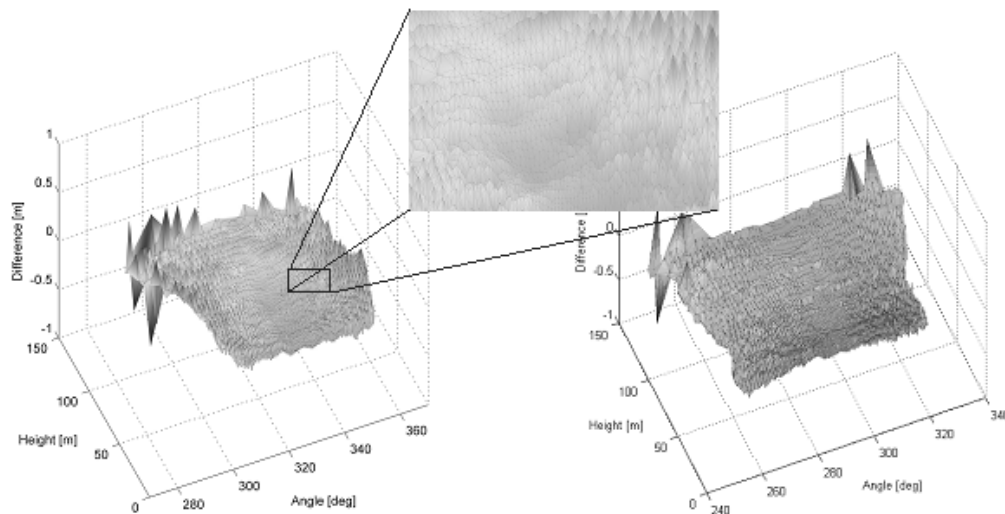
Fig. 6. The difference of the designed curvature and measurements done in SCAN mode. The highest difference is visible on the edges of the scanning area where the incidence angle was highest. The close-up shows that the obtained surface is highly spicular.

5.MERGING SCANS INTO SINGLE DATA SET

The main goal of the inventory measurements is to build a detailed 3D model of the investigated structure. In most cases it requires a number of scans that only merged together give a complete view of the object. In our case we were interested in achieving high precision data set. The overlapping parts of the surface had to be connected. Due to the particular shape of the cooling tower it was decided to build a uniform grid of surface deformation in cylindrical coordinate system. Two methods were used.

The first one was calculating the theoretical radius for each measured point. Than the whole region of interest (theta = 0 - 360 degrees, Z = 0 : 130 m) was divided into small rectangles. The value for each of the rectangles was calculated as a mean value of all the points within the region. This method was not able to evaluate the deformations for all regions. On the fig. 7 we can see an aliasing effect connected with the distribution of the measurement points on the surface.

The second method of building the uniform grid was calculating the intersection of sampling lines with the reconstructed scan surfaces. The sampling lines were created for angles and height ranges the same as in the first method. For the sampling lines that were intersecting more than one scan surface a mean value was collected.
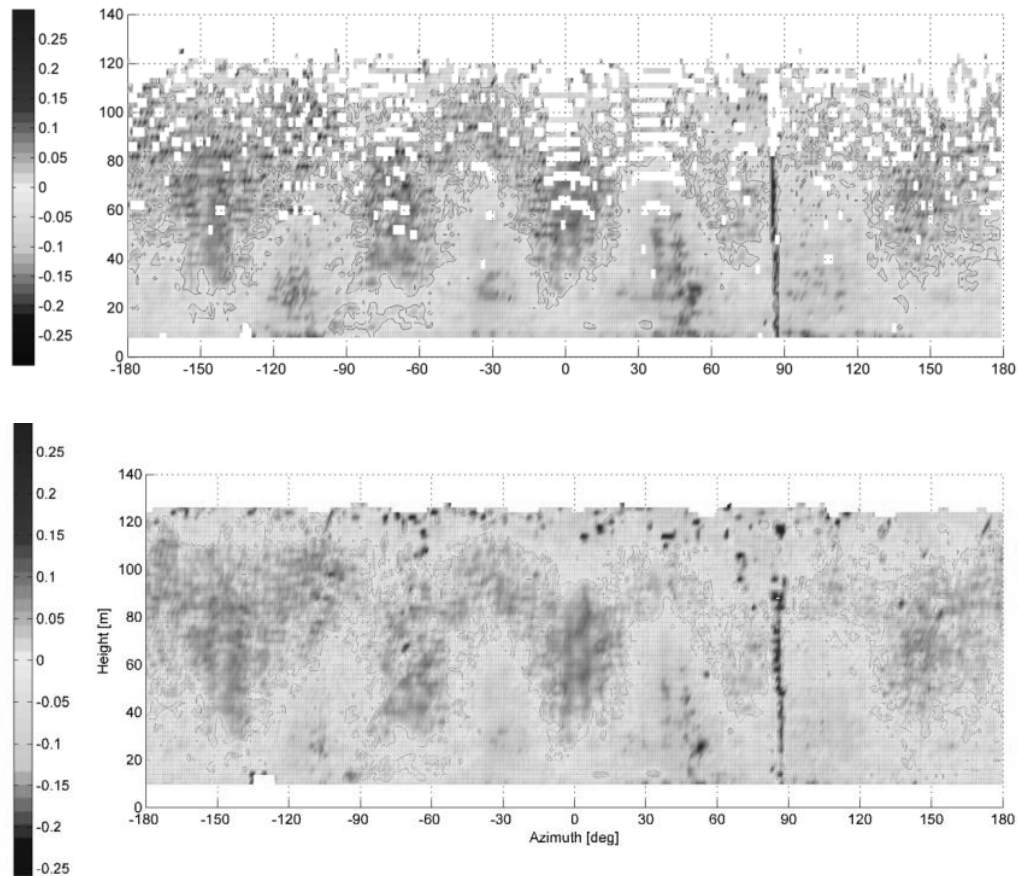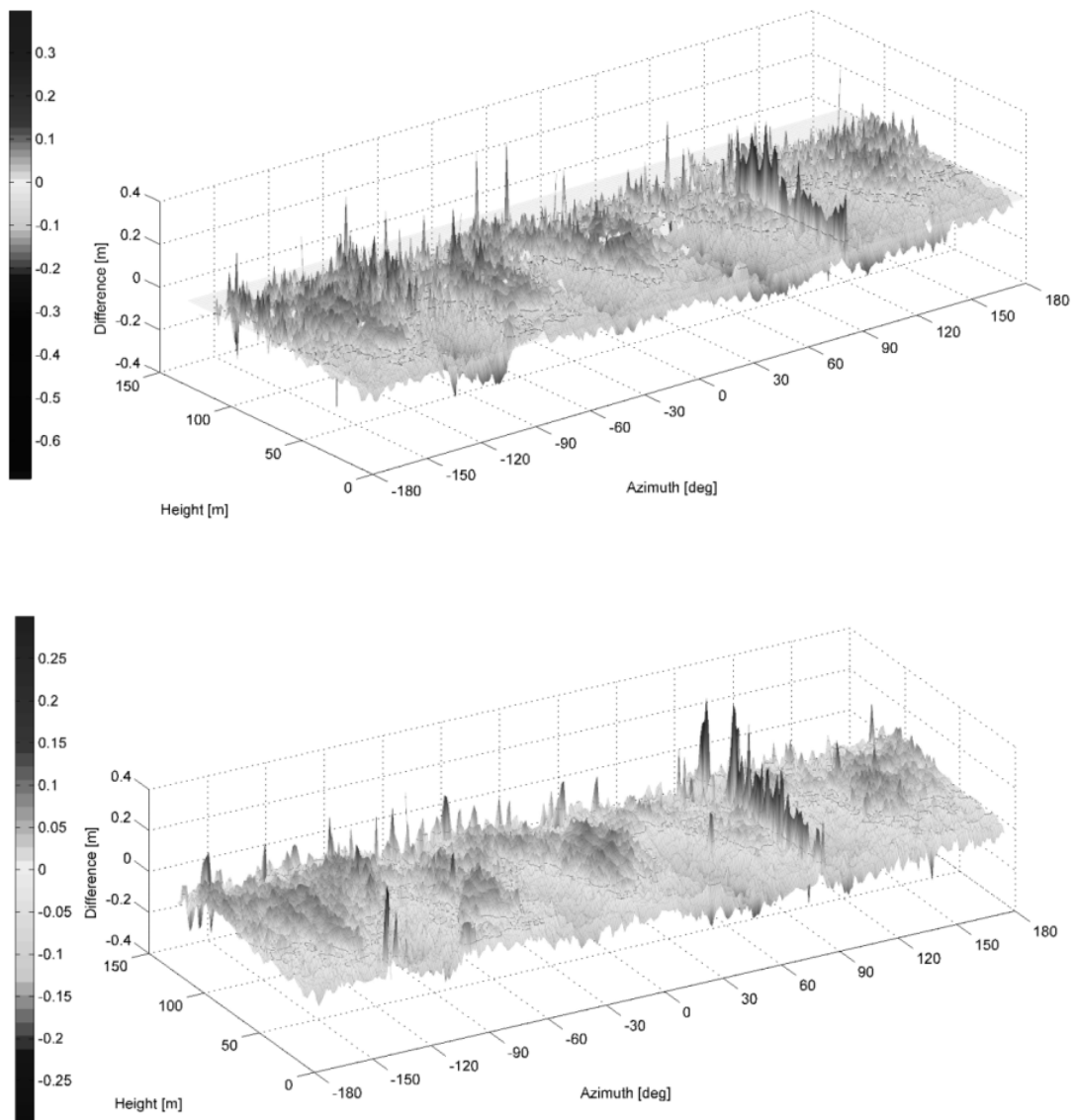
Fig. 7. The deformation maps achieved with averaging algorithm (upper image) and resampling algorithm (bottom image). The data are presented in cylindrical coordinates. The colour describes the distance of the measured data to the designed surface of the cooling tower.

Fig. 8. 3D view of achieved deformation maps. The azimuth 90 deg shows local heightened error. It is caused by the service ladder installed on the cooling tower. Such additional installations as well as any object that partially obscure the measured structure may cause a significant error.

In scanning mode the distribution of the measurement points is regular and may be additionally distorted by any small objects that obscure the construction surface (fig.9). It is not possible for the user of the device to avoid any obstacles in the way of the measuring beam. Large error can be easily removed from the data set but the smaller ones may turn out to be difficult to identify and compensate. In the case of the cooling tower that was investigated the main source of such errors were electrical cables, ladder on the side of the tower and lighting elements. Even thou it was possible to remove the distortion caused by cables an identify the position of the ladder it was not possible to identify any of the lighting infrastructure.

Fig. 9. View of cooling tower.

6. CONCLUDING REMARKS

The following conclusions can be drawn from the above experiments:
- **line and area scanning modes have characteristic zigzagging effect,**
- **area scanning is susceptible to incidence angle measuring laser beam and it should be taken into account in designing the geometry of measurements,**
- **merging overlapping data sets should take into account the density of the measurements,**
- **automatic measurement point selection is susceptible to any objects on the line of the measuring laser beam. Only large errors can be filtered out. Small distortions are difficult to eliminate,**
- **the general deformation maps obtained from scanning data set are similar to precise measurements of the geometrical imperfections. However they contain spicular noise caused by measuring errors.**

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