

TERRESTRIAL LASERSCANNING IN DEFORMATION MEASUREMENTS OF STRUCTURES

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ABSTRACT:

Terrestrial laserscanning broadens its application area in the civil engineering industry. This paper discusses the potential of the technology through the example of the deformation measurement of a new Hungarian bridge on the Danube during its load testing procedure. The paper discusses the complex procedure from the field measurement through primary data processing and the analysis of the laserscanned data. Comparison analysis between laserscanning and the traditional geodetic methods (such as high-precision leveling) is also described. For the accuracy analysis, laboratory deformation measurements have been carried out. During the controlled load testing of a full-scale steel portal frame each load phases were captured by terrestrial laserscanner. The displacements of dedicated points of the structure were measured by high-precision inductive transducers; thus the results of both methods can be directly compared. The paper is completed by a mathematical modeling of the error propagation of the measurement and the most relevant quality features are derived. By computing the accuracy measures of the terrestrial laserscanning the overall technology can be qualified and calibrated. Terrestrial laserscanning has proved its potential in such engineering projects. Data can be acquired about areas, not only about discrete points. In case of sizeable structures, such as bridges, information can be gathered about remote areas and points with limited accessibility.

1. INTRODUCTION

In engineering geodesy, especially in the field of deformation and displacement measurement of structures, mostly the traditional surveying methods are used. Vertical displacements and elevations are measured by high precision leveling whilst the spatial displacements and movements are derived by total stations and theodolites.

This paper deals with the potential of the terrestrial laserscanning in the field of deformation measurements of engineering structures. The paper reports the results of two measurement campaigns carried out in Hungary; a bridge load test measurement and a laboratory test. Accuracy analysis and evaluation of the particular data acquisition method also have been carried out and presented, the benefits as well as shortcomings of the method are also discussed.

The authors believe that this paper encourages experts working in the field of engineering geodesy to investigate the potential of terrestrial laserscanning in practice.

2. FIRST TEST: BRIDGE LOAD TEST MEASUREMENT

During the load tests of bridges the vertical movements of the bridge deck and the stresses (both in discrete points) are measured. The vertical displacements of the deck (and the girder) are measured by high-precision leveling, the 3D movements of predefined points of the structure are determined by total stations, whilst the stresses are measured by strain gauges.

The Pentele Bridge consists of 3 main parts: 2 parts over the flood plain, and the main part is over the river Danube. The focus of the current study is exclusively on this middle part of the bridge, which is a basket handle type tied arch bridge with a span of 307.8 m (world record in its category!) and height of 48 m. (Domanovszky, 2007; Horváth, 2007) The first static load test was performed in 28th of June, 2007, started at 9 p.m. and lasted 9 hours. In each phases the bridge was loaded for 20-30 minutes (minimum time needed for the geodetic measurements), that was the time limitation for the laserscanning (Figure 1).



Figure 1. Load test of the bridge

Since only one scanner was available, the selection of the measurement station was critical; the most characteristic points of the bridge should be captured. Moreover, since the objective of the current research is the investigation of the laserscanning

technology as an additional method in deformation measurements, both points that are measured by traditional techniques and points that cannot be measured traditionally should also be captured by the scanner.

Considering the available measurement time windows and the measurement range of the scanner, the station was selected at the left river bank (Dunavecse, where the bridge was assembled before floating) (Figure 2).



Figure 2. Laserscanning station

Since the load phases lasted for only a short period of time and cannot be repeated, only one laserscanning station was selected and the scanning resolution was reduced. Therefore the displacements of particular points of two structural parts (the northern arch and the bottom part of the girder) close to the scanner have been obtained. Applying only a single station during laserscanning caused sizeable shadowed areas in the data set. These problems could be bypassed by multistation scanning; the paper also contains recommendations for applying the technology for load test measurements of bridges. There was also no time for georeferencing the scanned points by measurements to ground control points, hence all the measurements were inserted in a local coordinate system. For the scaling, the zero point at the intersection of the arch and the deck (at the left river bank) was selected (Polgár, 2007).

The structural displacements derived from the laserscanned data sets are in strong correlation with those obtained from the traditional techniques. The computed maximum vertical displacement is ~35cm in both methods in the fourth load phase (Figure 3).

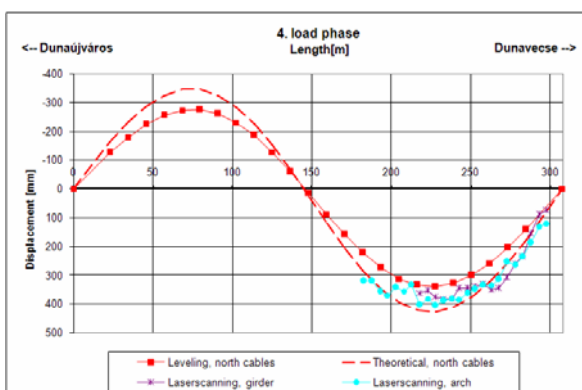


Figure 3. Displacements of the girder and arch derived by different techniques in the fourth load phase

Figure 3 shows the displacement values obtained from different methods: high-precision leveling (north cables), theoretical (computed/simulated) values and those of derived from laserscanning for both the girder and the arch.

Note that the vertical deflection of the deck is measured directly at the cables whilst the laserscanner captured the edge of the girder, however these structural elements are solidly coupled to each other.

The reason of the oscillation on the curves derived from laserscanned data is the reduced point density; in the resulted data set it is difficult to fit regular edges and planes on the point cloud. After all, the trend of the curves and the displacement values validate the laserscanning measurements. Similarly to the fourth load phase, the comparative analysis can be made for the seventh phase, which is an unloaded state, showing the residual deformations (Figure 4). Figure xxx also contains the results of the leveling and the theoretical values as references. The displacement curves obtained from the laserscanning are oscillating, but the trends of the curves are correlating to that of the leveling (note the different vertical scaling in Figure 4!).

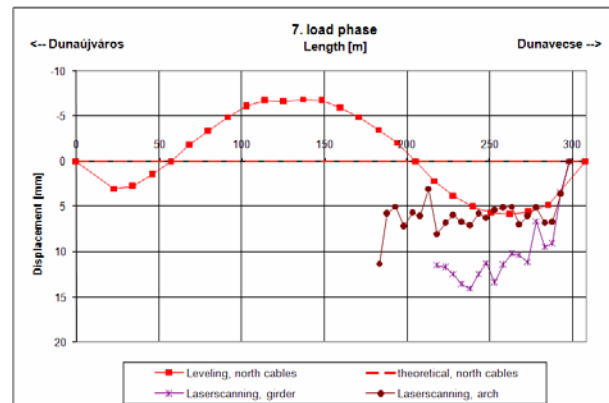


Figure 4. Residual displacements of the girder derived by different techniques in the seventh load phase

As opposed to traditional geodetic methods, laserscanning provides data from any points of the structure visible from the station. The displacements of the arch, the girder, the cables and other parts of the structure can be investigated in a single dataset. The points to be measured are not required to be defined prior to the scanning, these can be selected in the post-processing phase. However, careful planning is required (e.g. the location of the station), since the relevant points have to be in the range of the scanner. Comparing to traditional data acquisition methods the main shortcomings of the laserscanning in displacement measurement are the 5 mm (1 sigma) accuracy (high precision leveling: below 1 mm) and the difficult matching, i.e. it is hard to select the same structural points in two datasets.

As additional benefit the point cloud can be the base of 3D model generation for the better representation (Figure 5).

In case of multistation scanning data can be gathered from the whole structure, including the inner parts of the arches, cables and structures. Detailed measurements can be carried out and more sophisticated comparative analysis become available, e.g.

measurements in the cross sections (Figure 6) (Lovas et al, 2007).

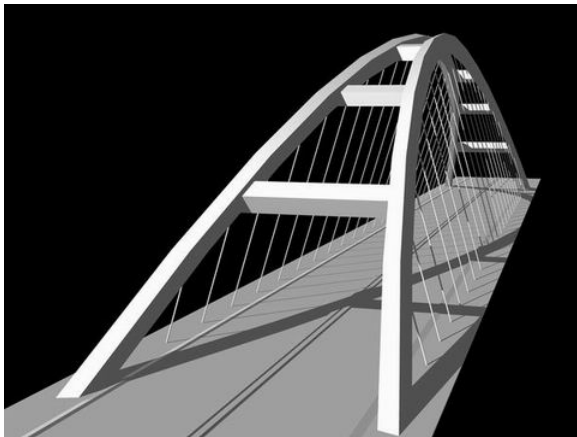


Figure 5. 3D model generated from the laserscanned point cloud

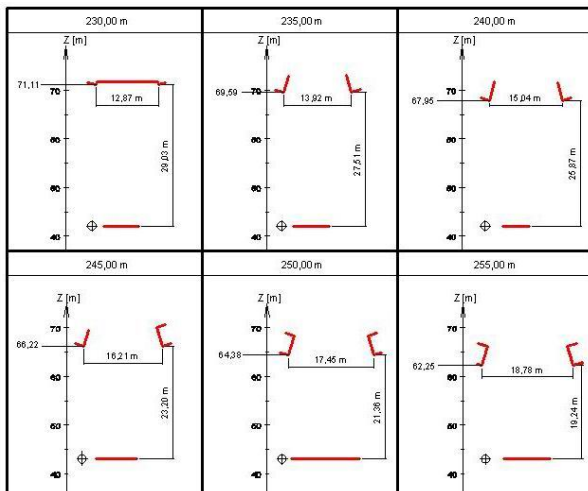


Figure 6. Measurements in the cross sections

As a conclusion, laserscanning is recommended as supplementary measurement method in load tests and displacement measurements; it cannot replace, however, the traditional techniques but can provide useful additional information.

3. LABORATORY TEST

Motivated by the promising results of the bridge load test measurement, a decision has been made to carry out a more detailed accuracy analysis based on laboratory measurements. The Department of Structural Engineering at the Budapest University of Technology and Economics executed the load test of a Lindab SBS “Small Building Systems” portal frame in the fall of 2007. The displacements of specified points of the structure have been measured by inductive transducers (Figure 7) whilst the stresses were measured by strain gauges.

The primary objective was to capture each of the load phases by laserscanner and derive the particular displacements. Additionally, comparing the results with the values provided

by the traditional high precision equipments enable to analyze the accuracy of the laserscanning and therefore helps in evaluating its potential for such projects.



Figure 7. The portal frame equipped with the measurement devices

3.1 Measurement planning issues

The frame to be tested was located in a busy and crowded engineering laboratory and the hydraulic loading equipment was operated manually, therefore the location of the scanner had to be planned carefully. Finally the scanner was deployed closed to the corner of the frame where the characteristic displacements and structural damages were expected and the field of view was set with tilted scanner head. Before the measurement, magnetic reflector spots have been put on the characteristic points of the structure (Figure 8).



Figure 8. Laserscanning station, note the tilted scanner head and the reflectors on the portal frame

3.2 Measurement

The measurement, as regularly, started with panorama scanning in order to narrow the scanning area to the parts of interest. Before the test, the unloaded state has been captured as future reference. The load test consisted of separate load phases with static phases, the load levels were 2.4, 4.6, 5, 9.4, 13.7kN respectively. The 8-10 minutes static phases enabled the laserscanning of each phases.

The table below contains the main parameters of the scanning:

MEASUREMENT PARAMETERS			
	Horizontal and vertical angular resolution (deg)	No. of points	Measurement time (min)
Panorama scan	0.120	1.998.000	4
Zero measurement	0.050	815.366	3
Control measurement	0.070	21.098	0.5
Control measurement	0.050	56.445	1
Regular measurement	0.040	1.300.000 _{mean}	5 _{mean}

Table 1. Measurement parameters

3.3 Post-processing

Due to the general demands of such load tests, three different approaches were applied for measuring displacements and deformations:

- measuring reflectors,
- comparing TIN models,
- measurements on the point cloud.

The laserscanner's primary processing software (RiscanPro) is able to automatically detect and compute the coordinates of each reflectors in all data sets. The coordinates have been exported in DXF format and the spatial measurements have been made in CAD environment.

Comparing the polygon models is done by built-in algorithms of the processing software (Geomagic8). The main advantage of this method that information can be gathered from all (the visible part) of the structure, whilst the traditional methods provide data only about the predefined, dedicated points. The resulted figures of each load phases provide reasonable information about the deformation of the whole frame, the colors are changing according to the displacement values compared to the reference state (Figure 9).

The shortcoming of this method that it is done by commercial software, the algorithm is a "black box", the parameterization is limited.

The most exciting part of the post processing is measurement on the point cloud. Since the previously mentioned methods are based on full or semi-automatic processing methods, the visual detection and manual fitting and its accuracy can be interesting compared to the built in techniques.

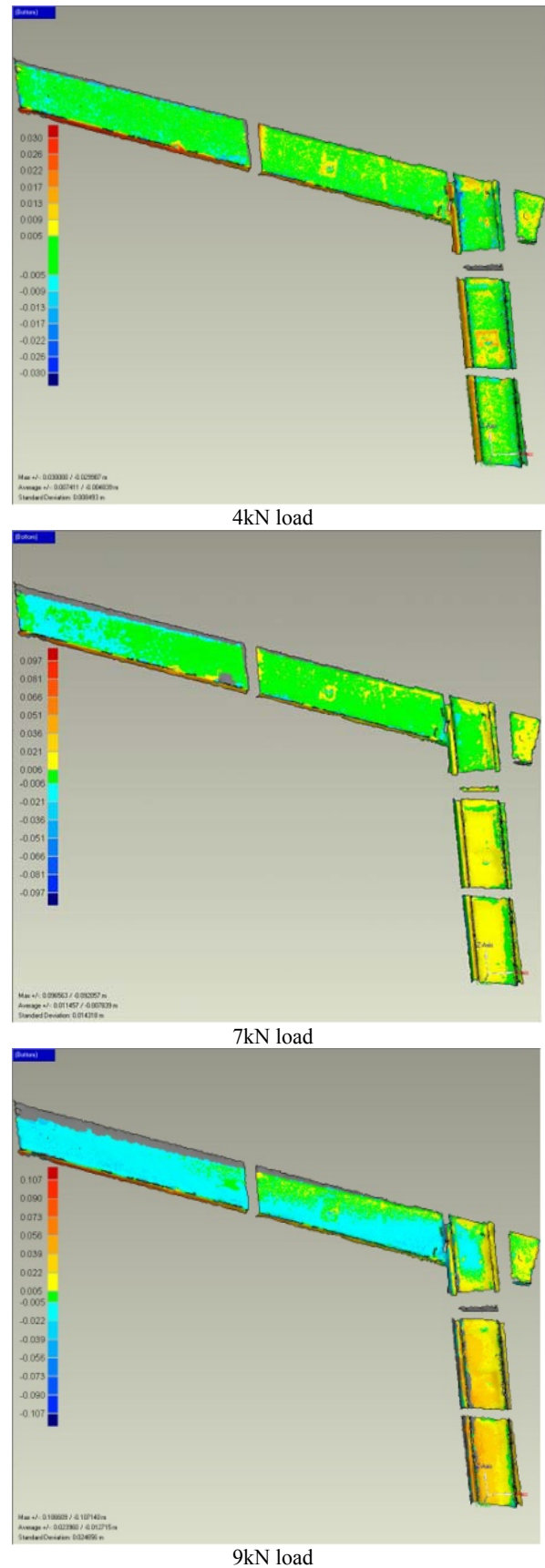


Figure 9. Deformations under different loads

Initially, the manual fitting based on visual interpretation was tested. The edges in the point cloud are nicely detectable, that gave the idea to fit lines onto the edges manually and evaluate the fitting's precision. The method is the following. Fit lines on the unloaded and loaded phase onto a dedicated edge and measure the distance between them. This was repeated by 20 times, and the particular edge was selected in an area where traditional high precision measurement was available. The reference value provided by the transducer was 58 mm, the result from the manually fitting was 60 mm with 3 mm deviation (Figure 10).

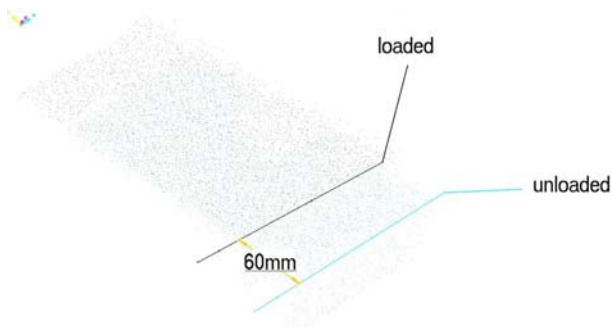


Figure 10. Edge fitting on the point cloud

Note, that the factory provided laserscanning accuracy is $\pm 5\text{mm}$ (RMS of the laser range measurement), which was validated by our department in a previous project (Maksó, 2006).

Another method was the measurement in the cross-sections. Lines were fitted to the points of the cross sections and were compared in all load phases. The figures of the cross sections regarding the particular load phases are representing how the structure acts under load; displacements, cross-section distortion (Figure 11) (Csák, 2007).

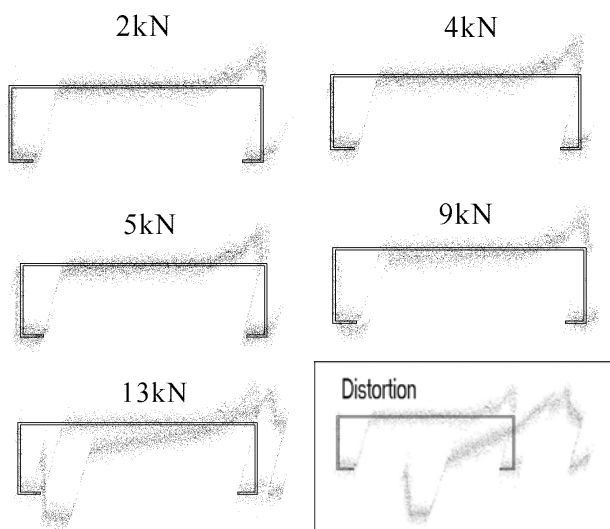


Figure 11. Analysis of the cross sections

4. CONCLUSION

Based on the presented results, terrestrial laserscanning proved its potential in deformation and load test measurements. The

laserscanned point cloud hold information about the whole visible part of the structure and enable measuring the displacement and deformations during the post-processing, without previously marked, dedicated points.

Analyzing the structure's displacements and distortions in 3D provides reasonable additional information for the engineers in the investigation of structural behavior. Our investigations show that analyzing laserscanned data is available even with widely used CAD environment.

The authors note that laserscanning is to be considered as a useful additional measurement method, since it cannot be evaluated on the same accuracy level as the traditional high-precision equipments.

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