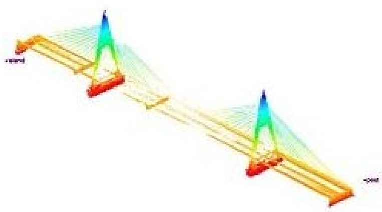
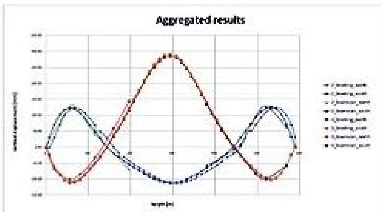
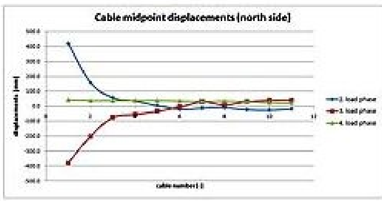
ACQUIRING 3D SPATIAL DATA OF BRIDGES

Laser Scanning in Deformation Measurements







State-of-the-art geodetic and remote sensing techniques can prove their potential through particular engineering applications. Here we discuss load test measurements of bridges over the Danube. Prior to the particular bridge surveying projects, accuracy analysis was carried out in the laboratory. We describe the shortcomings and limitations of remote sensing and propose the joint application of traditional and remote sensing technologies. We also provide recommendations for further applications of laser scanning in deformation measurement of structures.

View Larger Map

Terrestrial laser scanning is a state-of-the-art remote sensing technology that can rapidly acquire accurate three-dimensional (3D) spatial data. The primary engineering applications include architectural surveying, mining volume analysis and measuring complex mechanical systems for modelling. We discuss the potential of laser scanning in engineering geodesy, i.e. displacement and deformation measurement. The technological capabilities are validated by laboratory measurements including comparative analysis. The outdoor potential of laser scanning is shown by load test measurements of two Danube bridges. The results demonstrate the potential of terrestrial laser scanning in such engineering projects.

The Technology

The result of a laser scanning measurement is an accurate 3D point cloud describing the surveyed object. The range of the applied laser scanners is currently 2-800m; they can therefore be applied indoors (e.g. laboratory test of portal frame) and on site (e.g. load test of a bridge). The concept of laser scanning is based on measuring the time for an emitted beam of light to be reflected from the target, allowing the distance between the scanner and object to be calculated. For accurate point location in space, the reflection angle is also recorded.

Lab Measurements

In order to validate the accuracy of the terrestrial laser scanners used in the surveying projects, laboratory measurements were carried out. To investigate the root-mean-square error (RMSE) of the laser scanner ranging, the deformation of a steel plate was measured. The

displacements were also measured by high-precision digital calliper. The results confirmed the scanner manufacturer's claim of ±5mm ranging accuracy. In the second phase of the laboratory tests, laser scanning of the load test of a Lindab small building systems (SBS) portal frame was carried out. The displacement of particular points of the structure was measured by inductive transducers, while the stresses were measured by strain gauges. The primary objective was to measure each of the load cases by laser scanner and to derive the particular displacements.
Additionally, comparing the results with values obtained from traditional high-precision equipment enabled the accuracy of the laser scanning to be analysed and its potential for such projects to be evaluated.
As well as comparing the 3D models of each state, direct measurements of the point clouds were also validated.

Bridge Tests

During the load tests of the bridges, the vertical movements of the bridge deck and the stresses (both in discrete points) were measured. The vertical displacements of the deck (and the main girder) were measured by high-precision levelling. The 3D movements of predefined points of the structure were determined by total station s, while the stresses were measured by strain gauges.

Pentele Bridge

The Pentele Bridge consists of three main parts: two parts over the flood plain and the main part over the river Danube. The focus of the study is exclusively on the middle part of the bridge, which is over the river. It is a basket-handle tied-arch bridge with a span of 307.8m (the world record in this category) and height of 48m. Since the load cases lasted for only a short period of time (20-30 minutes, the minimum time needed for the geodetic measurements) and cannot be repeated, only one laser scanning station was selected (Figure 2) and the scanning resolution was reduced. The displacements of particular points of two structural features (the northern arch and the bottom part of the girder) close to the scanner were therefore obtained. The structural displacements derived from the laser-scanned data sets are very similar to those derived by traditional techniques. The computed maximum vertical displacement is about 35cm with both methods in the fourth load case. The reason for the oscillation of the curves derived from laser-scanned data is the reduced point density. The trend of the curves and the displacement values validate the laser scanning measurements.

Megyeri Bridge

This cable-stayed bridge is the longest river bridge in Hungary (1,861m) and consists of five bridges (nine bridge structures). We focused on the largest bridge structure that spans the Danube with a length of 591m (Figure 3). In this load test, two terrestrial laser scanners simultaneously scanned each load case. A Riegl Z420i was deployed at the Pest riverbank (Figure 4, Pest - right of the image) and a Riegl Z390i was located on the side of Szentendrei Island (Figure 4, island, left of the image). During the load test, the laser scanners operated with the parameters listed in Table 1. The resolution determining the number of points and point density was set by the time required by the high-precision levelling in each load case.

Evaluating Results

The result of laser scanning is a raw 3D point cloud. Geometric elements can be fitted during the post-processing and analysis, and the planar or spatial model of the object can therefore be generated. Because of the great number of points and the high point density, the visualisation of the raw point clouds enables basic displacement and deformation tendencies to be defined. To exploit the full potential and high accuracy of the technology, measurements of the point cloud were made. No predefined discrete points were captured during laser scanning, but a particular segment of the space including all objects in the range of the scanner was measured. The identification of particular points in the case of displacement is extremely difficult. To overcome this problem, planar or spatial objects were fitted to the point cloud (e.g. lines or cylinders to the cables), and the movement and deformation of these elements was investigated. In the evaluation procedure, the results of the high-precision levelling (RMSE is less than 1mm) were used as a reference. The clear correlation of the laser scanning results compared to those from the levelling is depicted in Figure 5 (left, below).

Application Issues

The reasons for the differences at particular points include the following:

- Displacements of discrete points were measured during the levelling, while the displacements of the fitted lines and arcs were measured in the case of laser scanning.

- The measurements were made from the deck during the levelling. However, from the laser scanning stations, the lower part of the bridge is seen from below, and lines and arcs are fitted onto the cross structures (which move with the deck).

- The bridge also moved during the load cases. That means the laser scanner did not capture a snapshot, but the point cloud also describes the (minor) displacements that occurred during the load case.

The effect described in the latter point can be observed in Figure 5: the displacement values are more correlated on the side of the bridge from which the scanning measurements were acquired. Considering all the circumstances of the measurement (dark environment, movements during the measurements and the size of displacements), the ±5mm accuracy of the laser scanner can be considered adequate for describing the displacements of the deck. Note that due to the lower point density, the investigation of the middle segment of the bridge is omitted from the evaluation.

Cable Movements

The main advantage of laser scanning can be observed in measurements that cannot be executed by traditional methods or would make the evaluation unaffordable. The point density of the laser-scanned point cloud enables the modelling of the cables and hence the evaluation of their movements. Such analyses are not supported by traditional geodetic measurement. The displacements (with respect to the unloaded state) of the northern cables of the Pest riverbank pylon are depicted in Figure 6 (right). It can clearly be seen that the greatest displacements occur at the longest cables. These cables are fixed close to the pier supports and are unable to share the load with the deck. Due to the A-shape of the pylons, the cables are not located in a plane. The spatial movements of the cables are therefore represented in the figure.

Scanning Potential

Based on the presented results, terrestrial laser scanning has demonstrated its potential in deformation and load test measurements. The laser-scanned point cloud holds information about the whole visible part of the structure. It enables the displacement and deformations to be measured during the post-processing, without the use of previously highlighted control points. Analysing the structure's displacements and distortions in 3D provides reasonable information for engineers in the investigation of structural behaviour. The evaluation of the displacements of the cables and pylons clearly demonstrates how laser scanning can allow measurements not possible by traditional methods. However, since laser scanning cannot be evaluated on the same accuracy level as the traditional high-precision equipment, it should only be considered as a useful additional measurement method.

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