DETERMINATION OF BRIDGE STRUCTURE DEFORMATION USING TLS

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ABSTRACT
This paper deals with determination of deformation of the No. M 137 bridge at Bojnická Street in Bratislava (Slovak Republic). The structure of the bridge consists of eleven concrete beams positioned in longitudinal direction. The atmospheric conditions and the traffic are causing deformation of the bridge structure. In this paper is described the procedure of initial measurement of displacements using Terrestrial Laser Scanner (TLS). Heights of 196 measured points were determined in local coordinate system. The points were situated in profiles (11 in each profile) on the beginning, the centre and the end of each bridge section.

KEYWORDS
Bridge Structure, Concrete Beam, Deformation, Terrestrial Laser Scanner

1. INTRODUCTION
The method of terrestrial laser scanning is one of the most effective spatial data collecting methods in the present. For this feature was the method of Terrestrial Laser Scanning (TLS) choosen for determining the displacements and deformation of the structure of the No. M 137 bridge at Bojnická Street in Bratislava (Slovak Republic).

The construction of the bridge consists of reinforced concrete beams shaped like letter “I”. The traditional method for determining the vertical displacements is precise leveling. Leveled are points stabilized on the sidewalks, situated on the both sides of the deck, but the displacements of these points correspond only to displacements of side beams. Technology of TLS allows the determination of deformation at any point of construction, where is impossible to stabilize measured points for leveling due to the traffic. The paper deals with the procedure of initial measurement of vertical displacements of measured points.
2. CHARACTERISTICS OF THE BRIDGE STRUCTURE

The No. M 137 bridge allows crossing a local route in Bratislava with railway line Bratislava-Galanta. It consists of reinforced concrete construction with two traffic lanes with cross slope ± 1.5 % and sidewalks on both sides of the deck. The length of the construction is 110.0 m with longitudinal slope 3.7 %. The deck is divided into six sections, each section consists of eleven “I” shaped reinforced concrete beams with dimensions 1.0 m x 0.8 m x 18.0 m positioned in longitudinal direction. The sections are separated by dilatations. The beams are placed on traverse girders with dimensions 1.2 m x 1.0 m x 11.0 m, which are placed on a foursome of reinforced concrete pillars with dimensions 0.7 m x 0.7 m. The substructure consist of 20 pillars and supports on both ends of the construction.

3. PRECISE LEVELING

The traditional method of determination of bridge structure deformation is precise leveling. There are four reference points (VB1 – VB4) for the leveling, stabilized by wall benchmark on the objects nearby bridge (on base of the electricity pylon and on the retaining wall see Fig. 3.). The measurement is focused on the determination of vertical displacement of measured points, stabilized on the upper side of the deck and on the
foot of the pillars. Measured points on the structure are stabilized by ground benchmark (nails) and situated on the sidewalks on the both side of the deck. Measured points on the substructure are stabilized near the foot of pillars by wall benchmark.

![Fig. 3. Layout of reference and observed points.](image)

The results obtained by precise leveling reflect only the behavior of side beams. To obtain a complex picture of the behavior of the bridge, the measured points should be stabilized over each beam, therefore even in asphalt of traffic lines, which is not feasible in practical use. This shortcoming can be eliminated by measuring the bottom of the beams. The precise leveling is not applicable for this purpose, it was necessary to seek a new method for determination of bridge structure deformation.

4. PROPOSAL A NEW METHOD FOR DETERMINATION OF BRIDGE DEFORMATION

The above requirements imply that the new method of determination of bridge structure deformation must allow determining the heights of points on the bottom side of the deck. Considering the characteristics of the structure and requirements for determining the displacement was chosen the method of terrestrial laser scanning. It is a contactless and non-selective method of spatial data acquiring. TLS is currently one of the most effective methods of spatial measurement, it enables deformation measurement during the operation of bridge without need of signalizing the measured point, without the presence of a figurant nearby road. These properties of TLS increase the efficiency and safety of measuring and ultimately reducing the financial demands.
On 6.11.2010 was made the initial measurement of displacements using terrestrial laser scanner Leica ScanStation2. Heights of 196 measured points were determined in local coordinate system. The points were situated on the bottom side of reinforced concrete beams in profiles (11 in each profile) on the beginning, the centre and the end of each bridge section. Vertical displacements will be determined as the difference between the heights of measured points from the basic and the current epoch. The local coordinate system is defined by three reference points stabilized nearby bridge (on foot of electricity pylon and on retaining wall).

4.1. Scanning of the construction

Scanning of the No. M 137 bridge at Bojnická Street in Bratislava was made on 6.11.2010 using terrestrial laser scanner Leica ScanStation2.

The bottom side of whole construction was scanned from four positions of the scanner (see Fig. 4.) with spatial resolution 0.02 m x 0.02 m to 50 m. The results of scanning were four point clouds in different coordinate systems containing total 71 million points. To transform the clouds to a common coordinate system were used five control points signalized by Leica HDS Targets.

![Fig. 4. Layout of positions of scanner and of control points.](image)

The reference net is realized by three control points stabilized permanently using metallic fasteners. Before the measurement the targets are screwed into fasteners and thus define common coordinate system for each measurement epoch. The net was measured by a total station Leica TS30. The remaining two control points were stabilized and signalized on railway traction poles temporary using magnetic HDS targets. (Fig. 5.)
4.2. Data processing

Data processing contains from transformation of acquired data (point clouds) to a common coordinate system and from determination of heights of measured points in local coordinate system.

Results of scanning were four point clouds in coordinate system of the scanner in each position. The transformation of these point clouds to a common coordinate system was made in Cyclone software (Cyclone Register). The mean absolute error of transformation (Registration Error) was 3 mm.

Merged point cloud (Fig. 6.) was transformed to the local coordinate system realized by three permanently stabilized control points (HDS1-HDS3). The origin of the coordinate system is in point HDS2, y-axis is inserted into the line between points HDS2 and HDS3, z-axis is parallel with the vertical axis of leveled scanner realized by the dual-axis compensator of the scanner. The definition of local coordinate system allows determining the heights of measured points in the same parts of the construction in each epoch, despite these points are not signalized on the object.

Fig. 6. Merged point cloud of the bridge.

The next step of the data processing was determining the heights of measured points, respectively modeling the position of measured points and determining their z coordinates in the local coordinate system. The measured points are situated on the beginning, the centre and the end of each bridge section on the bottom of the reinforced
concrete beams. These points create 18 profiles with 11 points in each profile. Height of two points positioned in close proximity to the railway line could not be determined because a traction pole conceals that part of the construction.

The first step of modeling the position of measured points was creating of frames 0.2 m x 0.2 m, which were used to define the edges of the selection (fence) of points from the cloud. From selected points were created planar surfaces (planes) with dimensions 0.2 m x 0.2 m using function *Fit Patch To Cloud* of software CloudWorx in AutoCAD. The position of measured points is in the intersection of diagonals of planar surfaces (Fig. 7.).

![Fig. 7. Cross section of point cloud and the modeled planar surfaces.](image)

5. CONCLUSION

The paper presents the procedure of initial measurement of the No. M 137 bridge at Bojnická Street in Bratislava using terrestrial laser scanning method. The aim of measurement was to determine the height (z coordinates) of 196 measured points in local coordinate system. The measured points are situated on the beginning, the centre and the end of each bridge section on the bottom of the reinforced concrete beams. The position of points was obtained as the intersection of the diagonals of planar surfaces, modeled from the selected parts of point cloud. Vertical displacements will be determined as the difference between the heights of measured points from the basic and the current epoch.

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REFERENCES
