As-built documentation of anchor blocks of facade elements using TLS

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Abstract

The current trend of the construction of high-rise buildings is based on construction of a reinforced concrete frame and on subsequent mounting of a light curtain wall. Part of facades of buildings are also additional elements like balcony railings. The correct functionality, safety and also the aesthetic look of the facades depends on accurate fitting of these elements to the concrete frame. The facade elements are mounted (fixed) using anchor blocks, which are build-in the concrete frame.
The paper presents the procedure of as-built documentation of anchor blocks of the building complex Panorama City in Bratislava (Slovakia). The complex consists of two high-rise buildings with height of 110 m and a connecting part with height of 15 m. The as-built documentation was created for the facades of the high-rise buildings, on which more than 2 500 anchor blocks are situated.
Each anchor block consists of 4 threaded rods of type M20. The position of the anchors can be described by 4 points, defined by the intersection of the rod's main axis and the plane representing the part of the concrete frame. For determination of the position of anchor blocks, the threaded rods and the planes were modelled from TLS point cloud. The measurement procedure, data processing and results are described. Part of the paper is devoted to accuracy analysis and the analysis of limitations of TLS usage, also.

Key words: anchor block, facade, high-rise building, terrestrial laser scanning, as-built documentation

1 INTRODUCTION

Terrestrial laser scanning (TLS) is often used for data acquisition in cases, requiring 3D information with high resolution. Therefore, TLS is used in different surveying applications, even in as-built documentation of buildings or engineering structures. TLS allows non-contact documentation of the scanned structure (Vosselman, G. et al. 2011). The accuracy of determination of the 3D coordinates of single measured points by currently commercially available laser scanners is several millimetres. The precision can be increased using suitable data processing, when valid assumptions about the scanned surface are available (Wujanz, D. 2016), (Holst, C. et al. 2014). In this case the position of the monitored point is calculated from tens or hundreds of scanned points (Kašpar, M. et al. 2004).

The current trend of the construction of high-rise buildings is based on construction of a reinforced concrete frame and on subsequent mounting of a light curtain wall. The facade elements are mounted by anchor blocks (in most cases created by threated rods), which are build-in the concrete frame of the building. The functionality and the aesthetic look of the entire facade is conditioned by the proper fitting of the facade elements and the balconies' railings. Accurate determination of the position of anchor blocks, especially in the case of high-rise buildings places high demands on geodetic works.
The paper presents as-built documentation of anchor blocks of balconies' railing of the building complex Panorama City. The blocks are created by threated rods of type M20 (diameter 20 mm). The measurement procedure, data processing and results are described in the following chapters.

2 HIGH-RISE BULDING PANORAMA CITY

The building complex of Panorama City is situated on the waterfront of Danube river in Bratislava (the capital of the Slovak republic). The structure with 34 floors consists of 2 main parts, which form a polyfunctional complex (Fig. 1). The first part of the structure is the substructure with 1 underground and 4 overground floors. The high of the substructure is 15 m. In the interior of this part of the building shops and parking places are situated.
Two identical high-rise buildings are constructed on the substructure – Tower 1 and Tower 2. The towers have the shape of an equilateral triangle with side length of 51.34 m. In the both tower between the 5^{th} and the 33th floors apartment are situated. On the 34^{th} floor the technological equipment of the building is located. Total height of the building including the substructure is 110.65 m.

Fig. 1 Building complex Panorama City

The both towers are symmetrically oriented. One side of the towers is oriented to north, the second to south-east and the third side of the towers is oriented to south-west. The facade of the towers consists of light curtain wall with aluminium frame with glass fill and steel balcony railings. The balconies are situated in the corners of the towers and on the middle part of facades. On the south-west and the south-east facades 5 vertical columns of balconies are situated, while on the north facades are 4 of them.

The steel structure of the balcony railings is mounted into the concrete skeleton of the building by anchor blocks, which are stabilized in the reinforced concrete slabs of the balconies (Fig. 2). Each anchor block is created by 4 threaded rods of type M20 (diameter 20 mm). The anchor blocks are divided into two pairs of rods with axial distance of 260 mm between them in horizontal direction. Each pair of rods are connected by steel plates embedded in concrete. The axial distance between the pairs of rods in vertical direction is 165 mm. The anchor blocks on the outer end of the corner balcony slabs were doubled (Fig. 2).

Fig. 2 Anchor blocks and balcony railing with mounting brackets

The facade design required tolerance in the position of the anchor blocks of ± 15 mm. The mounting brackets of the railings was designed with holes with diameter of 65 mm, which should have ensured the smooth and safe mounting of the structures. The contractor of the concrete skeleton has failed to meet the requirement mentioned, which complicated the construction of the facade. The differences between the designed and the as-built position of the rod pairs was several centimetres (in the extreme case up to 150 mm). Due to the fact, that the mounting using prefabricated brackets was practically not feasible, as-built documentation of anchor blocks was realized.

3 AS-BUILT DOCUMENTATION OF ANCHOR BLOCKS

For the above-mentioned reasons, as-built documentation of the anchor blocks of the balcony railings of buildings' facades was performed. The aim of the measurement was to determine the 3D coordinates of anchor rods of railings' mounting brackets. The measurement was done by terrestrial laser scanning. Threated rods of anchor blocks and facade elements near the balconies was scanned on the floors 5th to 33rd of both towers. At the request of the contractor of the facade, the position of only one of the pair of anchor rods connected by steel plates (chapter 2) was determined.

Since number of the points defining the position of anchor blocks is more than 5 000, special point IDs were used for exact identification of the measured points. The IDs of the measured points are created by an 8-character string (Fig. 3). The first 2 characters define the facade orientation (e.g. SE – south-east), the next two characters define the number of the vertical column of balconies, the following characters indicate the over ground floor's number and the last characters indicate the measured point's number within the balcony.

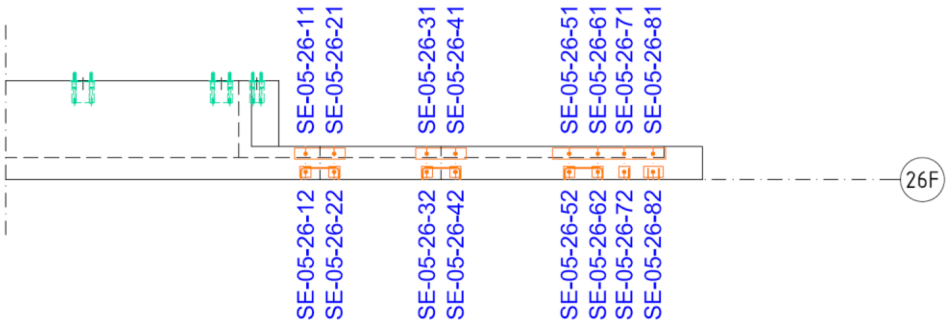

Fig. 3 Example of the measured points IDs

3.1 MEASUREMENT OF THE ANCHOR BLOCKS USING TLS

The measurement of the 3D position of measured points of the anchor blocks was performed by terrestrial laser scanning using Leica ScanStation2. The instrument is able to scan up to the range of 300 m with a scan rate up to 50,000 points / second. The accuracy of single point measurement is defined at level of 6 mm at 50 m range (one sigma) by the producer (Leica Geosystems).

The spatial shape of the buildings' skeleton in the place of balconies, the position of the threaded rods of anchor blocks and curtaining wall elements near the balconies were scanned. The positions of the instrument were situated on the roof of the substructure (5th floor) and around the towers at the street level outside the building site. The position of the instrument was chosen with respect to the measured facade. To ensure visibility of anchor rods, each column of balconies was scanned from a different position of the scanner (to minimize the cover of the rods each other). The maximum distance of measured points from the instrument was app. 120 m. The minimal point density was 3 mm x 3 mm on the surface of the scanned part of the structure.

For the transformation of the coordinates of the anchor rods to the coordinate system of the facade design, reference points were selected on curtain wall elements. These are situated in the bottom corner of the aluminium strip near the measured balcony (Fig. 4).

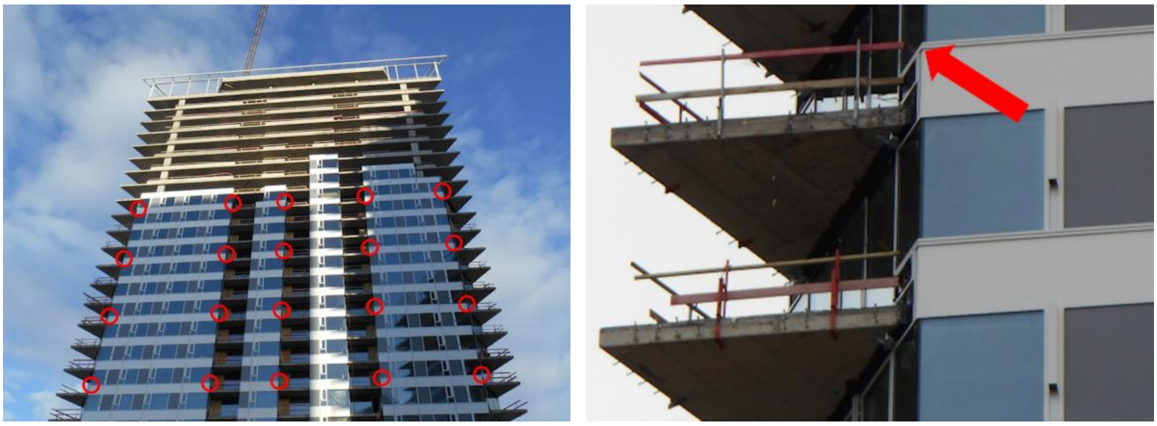

Fig. 4 Reference points on curtain wall – Tower 1 SE (left), detail of reference corner (right)

3.2 DATA PROCESSING – MODELLING OF THE ANCHOR RODS

The results of scanning were point clouds of each balcony column (Fig. 5). The aim of data processing was to determine the 3D coordinates of one of the pair of anchor rods connected by steel plates embedded in concrete. The data processing and the determination of the 3D position of measured points (treaded rods of anchor blocks) consisted of:

- modelling of regression planes from the point cloud of the front of concrete slabs of balconies in the place of threaded rods of anchor blocks,
- modelling of regression cylinders from the point cloud of the treaded rods,
- determination of the 3D coordinates of measured points as the centre of the intersecting ellipses of cylinders and planes,
- modelling of reference points as the bottom corner of the aluminium strip of curtain wall (Fig. 4),
- transformation of the coordinates into the coordinate system of the facade design according to the reference points.

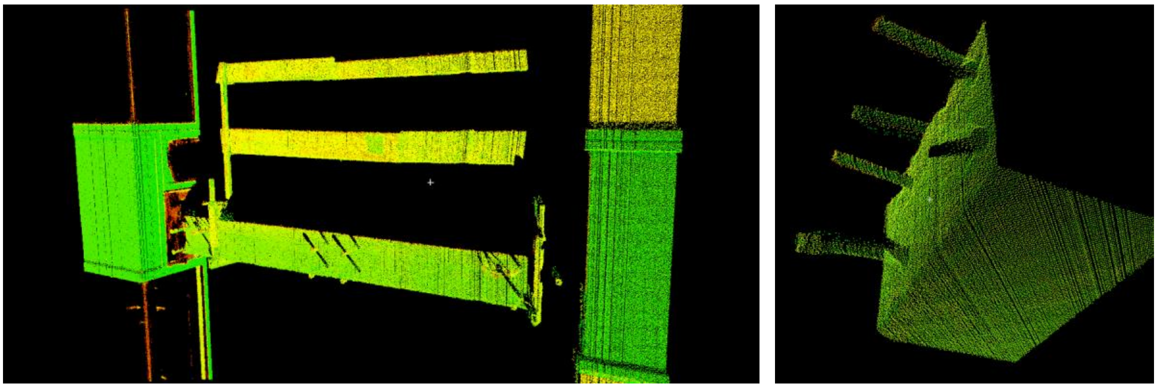

Fig. 5 Point cloud of balcony and part of curtain wall (left), anchor rods (right)

The anchor rods had diameter of 20 mm (type M20). During the data processing, regression cylinders were modelled from the point cloud of rods. The diameters of modelled cylinders varied from 20 mm to 15 mm. The diameters were influenced mainly by the noise of the cloud which increased by the distance of the measured points from the instrument. The laser

spot size in the distance of 120 m was app. 10 mm. The noise of the point cloud had random character, therefore was assumed that the centreline of the modelled cylinders is identical with the centreline of the rods in the reality. The accuracy of the results was checked by modelling the randomly selected pairs of the rods on every second floor, whose axial distance was 260 mm. The modelled axial distance differed from the designed within ± 3 mm.
Ellipses were calculated as intersection of cylinders and regression planes in close surroundings of the rods. The position of the measured points was in the centre of these ellipses (Fig.6).

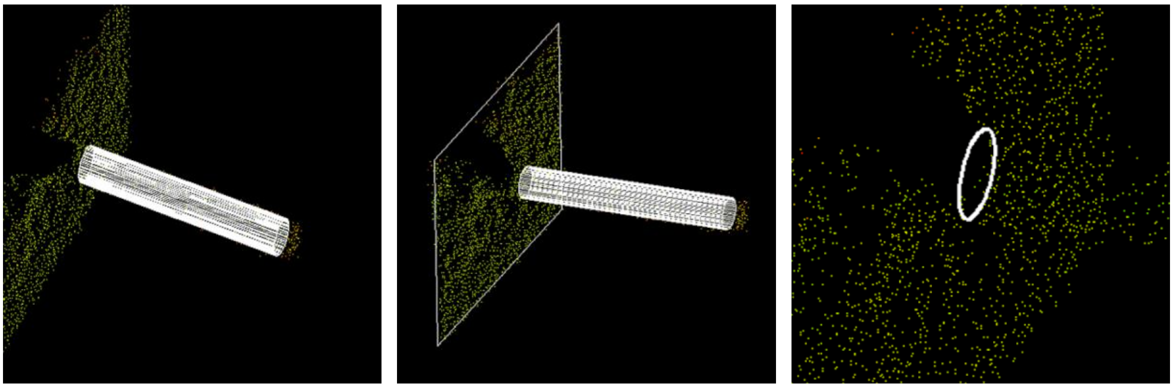

Fig. 6 Procedure of modelling the anchor rods' position

The bottom corners of aluminium strips of curtain wall elements were modelled as intersection of 3 regression planes. The corners defined the reference points needed for data transformation. At least 8 reference points were determined in each column of balconies.
The result of modelling was coordinates of points, defining the position of anchor rods in the coordinate system of the instrument in each position. The last step of data processing was the transformation of the data into the coordinate system of the facade design. Each facade had its own 2D cartesian coordinate system. The axis X of the coordinate system was oriented into the plane of the facade and the axis Y was vertical compared to 3D space. The accuracy of the transformation was given by the differences ΔX, ΔY between the identical reference points (modelled and designed corners of the facade elements) after the transformation. The transformation error was calculated as a quadratic mean of these differences. The error contains the accuracy of the reference points modelling and the construction deviation. The values of the transformation error were from 4 mm to 6 mm in any cases.

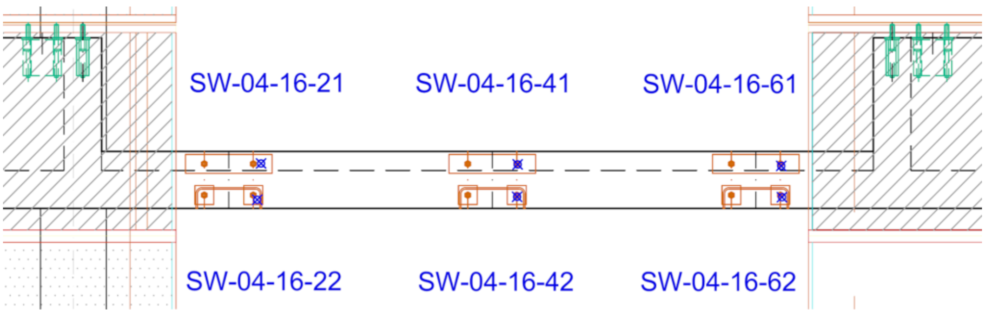

Fig. 7 Designed and as-built position of anchor blocks of the 4th balcony on the 16th floor of south-west facade of Tower 2

The as-built documentation of the anchor blocks contained drawing of the facade design in which the as-built positions of anchor rods were drawn (Fig. 7). Part of the documentation were the calculated deviations of the position of the anchor rods from the design also.
The tolerance in the position of the anchor blocks required by the design (± 15 mm) was not kept. The differences reached several centimetres. The deviation was less than ± 15 mm only in 10 % of cases, in app. 40 % of rods was less than ± 30 mm and in some cases, was more than ± 100 mm.

4 ACCURACY ANALYSIS

The accuracy of the results can be expressed in different ways. It can be assessed based on known parameters of the measured object such as, e.g., the position of the structure's parts and their dimensions. These can be compared with the modelled parameters. This approach provides a complex picture about the accuracy of scanning, eve. modelling, because it also contains the influence of systematic errors (Erdélyi, J. et al. 2017).
The second approach is to calculate the precision of the regression entities used for modelling (regression planes and cylinders). In case of application of orthogonal regression, this can be calculated from the distances of the points of point cloud from the modelled surface. The resulting precision in this case is influenced by the noise of the point cloud as well as by physical properties of the scanned surface (e.g. roughness).
Each column of balconies of the building complex Panorama City was scanned from different position of the instrument (to minimize the cover of the rods each other). Due to the limitations of the space around the building complex the maximum distance of the scanned part of the structure from the instrument was app. 120 m. Using the instrument Leica ScanStation 2 that means a laser spot size more than 10 mm. This fact strongly affected the cloud noise on the surface of the anchor rods, especially on the upper floors of the building. The accuracy of single point measurement is defined at level of 6 mm at 50 m range (one sigma) by the instrument producer. The use of orthogonal regression increases the precision of the results. The diameters of modelled anchor rods varied from 20 mm to 15 mm. Assuming that the noise of the point cloud has random character, the axis of the regression cylinders were considered to be identical to the axis of the threaded rods.
Relative accuracy check was performed by measuring the distance between randomly selected pairs of rods (connected by steel plate) on every second floor. The axial distance between these rods according to the design was 260 mm. The modelled axial distance differed from the designed within ± 3 mm. The transformation error, described in the chapter 3.2, was less than 6 mm in any cases. Applying the uncertainty propagation law was calculated the uncertainty in position of the anchor rods at the level of ± 7 mm.
In addition to this analysis, in 3 height levels (lower floors, middle of the facades, upper floors) distances between the anchor rods were measured along the balconies by measuring tape. The difference between the measured and the modelled distances was less than ± 5 mm.

5 CONCLUSION

As-built documentation of the anchor blocks of the facade of the building complex Panorama City was performed using TLS. The towers have the shape of an equilateral triangle with side length of 51.34 m. Total height of the building including the substructure is 110.65 m. The as-built documentation was created for the facades, on which more than 2 500 anchor blocks are

situated. To increase the accuracy of the results, the anchor rods were approximated by fitting geometric primitives to subsets of the point cloud. The uncertainty of position determination of the anchor rods was less than ± 7 mm.
Deviations of the position of the anchor rods from the design of the facade were calculated. These reached several centimetres. The deviation was less than ± 15 mm only in 10 % of anchor blocks, in app. 40 % of rods was less than ± 30 mm and in some cases, was more than ± 100 mm.

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