

# DETERMINATION OF ELEVATOR SHAFT UPRIGHTNESS APPLYING THE TERRESTRIAL LASER SCANNING METHOD

## URČOVANIE ZVISLOSTI VÝŤAHOVEJ ŠACHTY METÓDOU TERESTRICKÉHO LASEROVÉHO SKENOVANIA

*Ludovít Kovanič<sup>1</sup>*

<sup>1</sup> *Ing., PhD., Institute of Geodesy, Cartography and GIS, BERG Faculty, Technical University of Košice, Letná 9, Košice, Slovak Republic  
e-mail: ludo.kovanic@tuke.sk*

### Abstract

This paper presents the results obtained from geodetic measurements and processing the data with the objective to determine geometrical parameters of an elevator shaft applying classical as well as modern approaches for obtaining the measured data. The intention was to verify the possibility to apply the terrestrial laser scanning (TLS) method as a suitable, efficient and precise method for collecting spatial data.

### Abstrakt

V príspevku sú prezentované výsledky geodetického merania a spracovania údajov na určenie geometrických parametrov výťahovej šachty použitím klasických a tiež moderných prístupov získavania meraných dát. Zámerom je overenie možnosti využitia terestrického laserového skenovania ako vhodnej, efektívnej a detailnej metódy pre zber priestorových údajov.

**Key words:** elevator shaft, uprightness, terrestrial laser scanning (TLS)

## 1 INTRODUCTION

The activities to be accomplished by an authorized surveyor and cartographer in the process of building may be divided into several stages as follows:

- stage of background documents and project documentation preparation
- stage of building execution
- stage of building completion, approval and operation

Building objects differ in particular in shape and dimensions, as well as in type of construction. In all construction stages, the stress is placed on the accuracy of building object construction components for the building deviations should be less than the tolerances stated in standards or building project documentation.

In the building execution stage, the important part is to construct such staking grid of the building which meets, by its characteristics of positional and height accuracy, the requirements for the resultant accuracy of the detailed staking. The accuracy of staking alone depends on applied methods and the accuracy of instrumentation.

The requested accuracy of staking works is given as follows:

- directly – by maximum staking deviations of building objects which are given for example by standards,
- indirectly – by building deviations, from which the staking deviations are derived. As a rule, the building deviations are stated in technical standards depending on the type of construction of the building object.

When deriving staking deviations from building deviations, assuming that the effects of errors in staking, building and assembly works are of an equal value, the building deviation  $U_S$  is applied, which is considered to be the maximum error for the position of the point  $m_p$ . With the applied confidence coefficient  $t = 2$ , it holds:

$$U_S = t \cdot m_p = 2 \cdot m_p, \quad (1)$$

while:

$$m_p^2 = m_V^2 + m_m^2, \quad (2)$$

where:

$m_v$  - effect of errors in staking,

$m_m$  - effect of errors in building and assembly works.

If  $m_v = m_m$  than for the building deviation, it holds:

$$U_s = 2 \cdot \sqrt{(m_v^2 + m_m^2)} = 2 \cdot \sqrt{m_p^2} = 2,8 \cdot m. \quad (3)$$

The requested accuracy of staking works is then:

$$m_v = m_m = \frac{U_s}{2,8} = 0,36 \cdot U_s, \quad (4)$$

It follows from the above that the requested accuracy of staking and building and assembly works should not exceed 36 % of the building deviation. To calculate the accuracy, it is necessary to stress that:

$$m_v^2 = m_1^2 + m_2^2, \quad (5)$$

where:

$m_1$  - effect of errors in staking grid

$m_2$  - effect of staking errors, including e.g. the instrument centralisation on site, the effect of measurement of the instrument height error and the height of target in trigonometry measurements of heights and so on.

The accuracy of staking, building and assembly works is based on the equations (1) through (5) and must correspond to the building deviation which is given by the standard STN EN 13670 (732400) – “Execution of concrete structures” of 2010. The numerical value of the building deviation (tolerance) is  $\pm 25$ mm for the position of pillars and walls with regard to the straight line of the secondary top view scheme. Hence the resultant requested accuracy of staking works for the confidence coefficient  $t=2$  is about  $\pm 5$ mm.

During the building completion stage, the surveyor's major activities represent in particular checking measurements, and after implementation, setting the meterage for preparing as-built design documents. The objective of the geodetic part of as-built design documents is to determine positioning, shape and dimensions within binding (national) geodetic systems after the execution. The accuracy of measurements for the purpose of as-built design documents corresponds as a rule to the accuracy of staking. In case of the high rise buildings, the geodetic meterage of elevator shaft uprightness is its integral part along with the determination of deviations of the actual building object work in comparison with project documentation, or possibly with a relevant technical standard. To obtain the spatial data on the building object, it is possible to exploit several methods and procedures differing in accuracy, tediousness of measurement and availability of suitable measuring instruments.

## 2 BUILDING OBJECT, METHODS AND GOALS OF MEASUREMENTS

The object of experimental measurements was SO-03 Dwelling house HB3 at the construction “Košice bývanie - 1. etapa” at Ondavská street in Košice, in the stage of shell construction of monolithic reinforced concrete construction completion (Fig.1).



**Fig. 1** SO - 03 Dwelling house HB3 at the construction of “Košice bývanie -1.etapa”

The horizontal dimensions of the shell construction of the dwelling house are 21.70 m x 21.30 m, the construction height of the plate of the first storey is  $-0.15$  m (239,25 m asl) and that of the eighth storey is  $+20.68$  m (260.08 m).

The elevator shaft, which was the object of measurements, is located in the object core from the first up to eighth storey. It consists of carrier monolithic reinforced concrete walls with an entry opening at the west side. The construction dimensions of the shaft are 2.650 m x 1.650 m (Fig 2).



**Fig. 2** Object of measurements

At the time of measurements, the elevator shaft was ready to be handed over. It means that all sharp edges were smoothed at the contact between individual sections of casting, and its formwork was completely removed, including the temporary wooden safety and working floors at all the storeys. This fact was decisive for the selection of measuring method.

## 2.1 Methodology of measurements

The methodology of measurements of elevator shaft uprightness was selected with regard to the requested accuracy and feasibility of measurements under actual conditions.

1. **Method of direct measurements of dimensions and distances of shaft walls from a fixated plummet** as the simplest measuring method. The plummet with a weight of about 1 kg was placed to a shaft wall corner of the elevator shaft on a bar suspension at the eighth storey of the object (Fig .3). It was fixated by immersing it in a tank filled with oil at the level of the first storey. The length of the hanging was about 25.5 m. The dimensions of the elevator shaft and the distance of the walls from the plummet hanging were measured directly using a measuring tape, and in case of non-accessible locations, using the manual laser telemeter Leica Disto A5. The average error of length measurements, declared by the instrument manufacturer, is  $m_d = \pm 1,5\text{mm}$ . The dimensions and the distances were measured at each storey at a height of 1.40 m above the level of the entry plane of the elevator.



**Fig. 3** Plummet hanging

2. **Polar method** with exploiting the UMS Leica TCRA 1201+, the average measuring error of vertical and horizontal angles  $m_a=m_z=\pm 1''$ , the mean error of length measurements with a prism  $m_d=\pm 1\text{mm}+1,5\text{ppm}$  and without a prism  $m_d=\pm 2\text{mm}+2\text{ppm}$ . The positions of the instrument were selected for each storey to be possible to measure the maximum number of points along the shaft circumference at a height of 1.40 m above the level of the entry plane of the elevator. During the measurements, the method of subordinate centring on tripods was applied. The determination of coordinates at each storey was executed in the coordinate system of a staking grid of the construction (S-JTSK). For the backward orientation of measurements always the same point at a distance of about 70 mm was used. At each storey, beside the visible edges without a prism, also the shaft walls were measured. The edges, which could not be measured directly from the site as they were in the obstruction of the walls, were constructed in the prolongation of the points on the walls as intersections of approximated lines of the flow-lines of the measured points. For the purpose of checking, also the plummet hanging was positional measured at each storey with the use of a reflection foil (Fig.8) and later on with the use of a 360° mini prism (Fig.9).



**Fig. 4** - TCRA 1201+

3. **Method of terrestrial laser scanning** with the use of TLS Leica ScanStation C10 (Fig.5). The mean error of determination of an individual point position  $m_p=\pm 6\text{mm}$ , the mean error of length measurements  $m_d=\pm 4\text{mm}$  (for the lengths up to 50 m), the mean error of measurements of horizontal and vertical angles  $m_a=m_z=\pm 12''$ , the accuracy of the modelled surface  $m_m=\pm 2\text{mm}$ . The instrument is furnished with a two-axis compensator with the accuracy of  $\pm 1,5''$  and a range of  $\pm 5'$  (Leica ScanStation C10 – data sheet). The measurements were conducted at the same time from one position at the lowest storey of the building object at the bottom of the elevator shaft. The horizontal and vertical density of the measured points was adjusted to 5mm per each 25m of length. The TLS method is an up to date and efficient method for collecting spatial data on objects (Gašinec et al., 2011, Gašinec et al., 2012).



Fig. 5 - TLS Leica ScanStation C10

## 2.2 Definition of objectives

The measurements of uprightness of an elevator shaft can be executed applying various methods, depending on available instrumentation, configuration and object accessibility, as well as requested accuracy (Erdélyi, et al., 2011, Erdélyi, et al., 2012).

The main objective was to confirm the method of terrestrial laser scanning as a suitable method from the point of accuracy and efficiency in comparison with the conventional measurement methods described in chapter 2.1.

The a priori estimation of the accuracy of this method results from the accuracy parameters of the applied instrument, when based on the expected accuracy of the modelled surface, the dimensions at a level of  $m_m = \pm 2\text{mm}$  were determined.

The partial tasks, with regard to the fact that the measurements were conducted from the bottom of the shaft whose height exceeded 20 m, were as follows:

1. Verify the accuracy effect of the compensator used for determining the uprightness
2. Verify the effect of the measured ray incidence under an acute angle at top storeys to determine the uprightness and the dimensions of the shaft compared to the checking direct measurements.

## 3 MEASUREMENTS AND PROCESSING THE RESULTS

The numerical and graphical processing of results for individual methods was carried out individually. **The direct measurement of dimensions and distances with a fixated plummet** was evaluated for each storey individually; the elevator shaft horizontal sections were drawn, and the measured values were inserted. The example of numerical and graphical evaluation for the first storey is given in Fig. 6

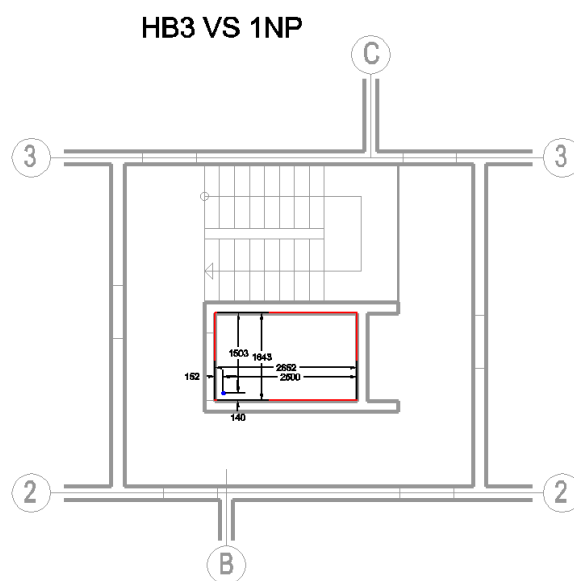
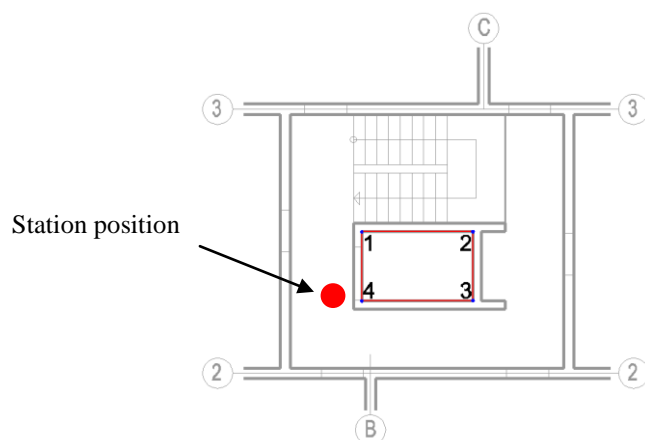


Fig. 6 Numerical and graphical evaluation of the results from direct measurements using the hanging plummet

The processing of measurements, applying the polar method using UMS Leica 1201+, was conducted through the comparison of the measured rectangular coordinates within the coordinate system of the staking grid of the building (S-JTSK), applying the method of laser scanning in a local coordinate system. The coordinates of inside points of the elevator shaft 1 through 4 were compared (Fig.7). These were numerically distinguished according to individual storeys, for example 101-104 for the first storey, 201 - 204 for the second storey and so on.



**Fig. 7** Designation of observed points

For the purpose of measurements, applying the **polar method using UMS Leica 1201+**, about 15 points were measured at each storey on inside walls of the shaft. The observed corners 2 and 3 were measured directly and the points 1 and 4, with regard to the position of the site outside the elevator shaft, were not measurable directly (Fig.7). These were constructed as intersections of lines led through the points measured on the inside walls of the shaft at a height of 1.40 m above the level of individual storeys. The plummet hanging was multiply focused at each storey as the controlling element to disclose the measurement errors. To determine its coordinates, measuring aids, inspired by the facility for the centric positioning of reflective prism on the hanging wire of the plummet, were experimentally exploited during connecting and regulation measurements under mining conditions exploited by the authors (Černota et al., 2011, Černota et al., 2012), as follows:

- The foil reflector with dimensions of 3 x 3 cm (Fig. 8) fixed on the plummet hanging by an adhesive tape. During the measurements, the adverse effect of its rotation along with the plummet hanging was observed, resulting in the prolonged period needed to its stabilisation when manually rotated into the direction perpendicular to the object,



**Fig. 8** Foil reflector fixed on plummet hanging

- The instrument 360° mini-reflector Leica GRZ 101 (Fig.9). Its advantage is the possibility of its centric positioning on the plummet hanging; movement to other height levels without the need to be disconnected using fixing screws; as well as the elimination of its rotation effect on the possibility to execute the measurements. The system ATR for automatic targeting the prism was exploited.



**Fig. 9** 360° mini-reflector Leica GRZ 101 fixed on plummet hanging

The evaluation of the relationship may be carried out based on the simple difference in coordinates of individual corners of the elevator shaft on condition that the directions of its walls are parallel with the direction of the applied coordinate system (most frequently the local one). In case of other coordinate system (S-JTSK), it is suitable to apply the analytical solution for determining the horizontal distance of the observed point from the vertical plane incorporating two points in 3D space. In this case, the points were located on the first storey of the object – the flow-line of the points 101 and 102 for the coordinate X, the flow-line of the points 102 and 103 for the coordinate Y, and so on.

### 3.1 The analytical solution for determining the horizontal distance of an observed point from the vertical plane incorporating two points in 3D space

The calculation of the distance between the point and the plane in analytical geometry consists of two steps:

- determine the general equation of the plane
- calculate the distance between the point and the plane

The plane in 3D space is expressed by the equation:

$$ax + by + cz + d = 0 \quad (6),$$

For the purpose of determining a deviation from the vertical plane, the reference plane is defined, which incorporates two points A, B and is upright. The vector  $\vec{u} = A - B$  is determined from the difference in coordinates of the above points. The vector  $\vec{v} = (0,0,1)$  is located on the vertical plane; it means that it is parallel with the axis Z. It is possible to define the reference plane in the direction of any coordinate axis or a general plane, when altering parameters of the vector. The general equation of a plane is unambiguously defined by one point located in the plane and a normal vector. The normal vector of the sought plane  $\rho$  may be determined by the vector product of the vectors:

$$\vec{u} \times \vec{v} = \vec{n} \quad (7),$$

The coordinates of this vector are calculated from:

$$\begin{aligned} n_1 &= u_2 v_3 - u_3 v_2 \\ n_2 &= u_3 v_1 - u_1 v_3 \\ n_3 &= u_1 v_2 - u_2 v_1 \end{aligned} \quad (8),$$

Then the coefficient  $d$  is calculated from the equation (6).

All tasks for the calculation of the distance between points, straight lines and planes are transferred into the task to determine the distance between two points. In case of the point and the plane, the formula for such distance calculation is derived. The plane  $\rho$  is specified by the general equation (6) and  $A[x_0, y_0, z_0]$  which is not located within the plane  $\rho$ . The distance between the point A and the plane  $\rho$  is equal to the distance between the point A and the foot of the perpendicular led from the point 1 to the plane  $\rho$ .

The vector  $\vec{u} = (a, b, c)$  is perpendicular to the plane  $\rho$  and parallel with the straight line  $k$ .

The parametric equations of the straight line  $k$  are as follows:

$$\begin{aligned}x &= x_0 + ta \\y &= x_0 + tb \\z &= z_0 + tc\end{aligned}\quad (9),$$

It holds for the foot of the perpendicular:

$$a(x_0 + ta) + b(y_0 + tb) + c(z_0 + tc) + d = 0 \quad (10),$$

after the modification the following is valid:

$$ax_0 + by_0 + cz_0 + t(a^2 + b^2 + c^2) + d = 0 \quad (11),$$

because  $a^2 + b^2 + c^2 \neq 0$ , it can be written:

$$t = -\frac{ax_0 + by_0 + cz_0 + d}{a^2 + b^2 + c^2} \quad (12),$$

After the substitution for  $t$ , the coordinates of the foot of the perpendicular are obtained:

$$\begin{aligned}x &= x_0 - \frac{a(ax_0 + by_0 + cz_0 + d)}{a^2 + b^2 + c^2} \\y &= y_0 - \frac{b(ax_0 + by_0 + cz_0 + d)}{a^2 + b^2 + c^2} \\z &= z_0 - \frac{c(ax_0 + by_0 + cz_0 + d)}{a^2 + b^2 + c^2}\end{aligned}\quad (13),$$

The distance between the point and the plane is obtained from the difference in coordinates of the measured point and the foot of perpendicular to the plane:

$$v = \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2} \quad (14),$$

After the substitution and modifications, the following is valid:

$$v = \frac{ax_0 + by_0 + cz_0 + d}{\sqrt{a^2 + b^2 + c^2}} \quad (15),$$

The vector contains the distance between the measured point and the vertical plane (Gašinec et al., 2012).

### 3.2 Processing the data measured by TSL Leica ScanStation C10

The measurements were carried out with the parameters stated in Chap. 2.1. The measured data were in advance adjusted into the text set within the structure Y, X, Z – the spatial rectangular coordinates of measured points; I – the intensity of a reflected signal; R,G,B - the colour scale (Tab.1), and subsequently imported into the selected software application.

**Tab.1** The structure of the list of measured points coordinates in a text form

| Y          | X           | Z       | I  | R   | G   | B  |
|------------|-------------|---------|----|-----|-----|----|
| 264253.293 | 1226666.361 | 349.990 | 82 | 114 | 107 | 65 |

The program Trimble Real Works 6.5 was the major software tool exploited for modelling the walls, in particular with regard to the option of the program to work with a large number of points. The original set was reduced through the order “Spatial sampling” so that the spatial distance between the measured points was about



1cm. It holds mainly for the closest points to the scanner position. Out of this set of points, horizontal sections were created with a width of 10cm at height levels corresponding to the measurements carried out by the previously mentioned methods, i.e. 1.40 m above the level of the entry plane to the elevator on individual storeys. In such created sections, sets of measured points were created separately for each storey of the elevator shaft. The number of points in a section of each storey was about 2000. The fragments of the walls were formed individually by interlining the planes along the segmented points. The accuracy of the plane interlined by points is characterised by the parameter RMSD – a Root-mean-square deviation which is the mean square deviation of the distance between the points and the plane interlined through those. In case of all segments of the planes, its value was up to 1.5 mm. The corner points of the elevator shaft at each storey were constructed as intersections of these planes. The created 3D model was exported to CAD MicroStation V8 when the point markers were allocated to individual points of the shaft to obtain the list of coordinates for further evaluation (Fig.10 and details in Fig.11)

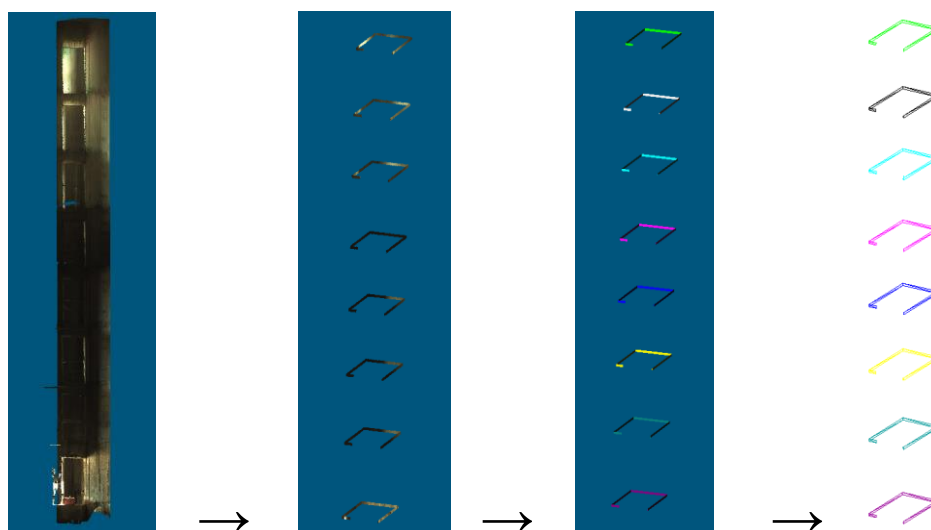


Fig. 10 Processing the data measured by TLS Leica ScanStation C10

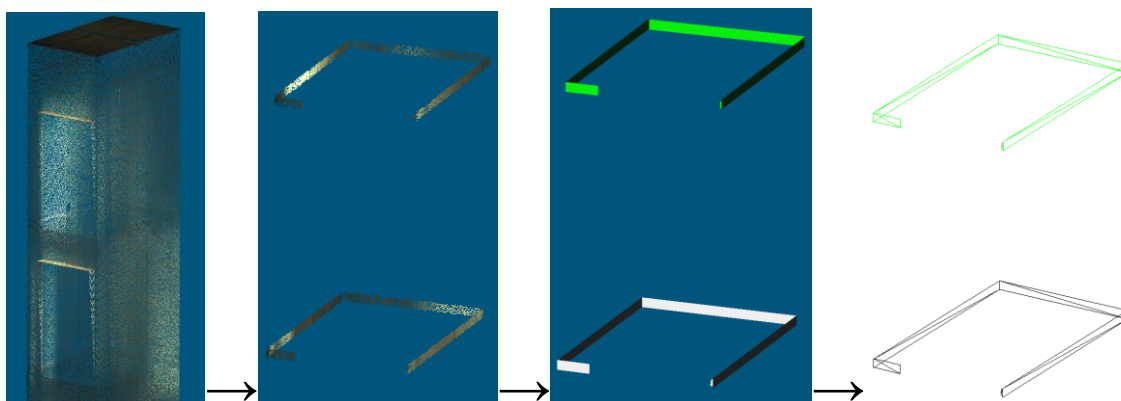


Fig. 11 Processing the data measured by TLS Leica Scan Station C10 - details

### 3.3 Numerical evaluation

The differences in uprightness for individual methods were estimated from the differences in the coordinates of the corners of the elevator shaft for UMS and TLS, and from the measured length differences for the method of direct measurements. The position of the corners of the elevator shaft on individual storeys in all applied procedures was compared with the position on the first storey of the object, which was selected as the starting one. Tab. 2 provides the numerical comparison of the results of uprightness determination by all methods and the differences in the position coordinates of the individual corners of the elevator shaft.

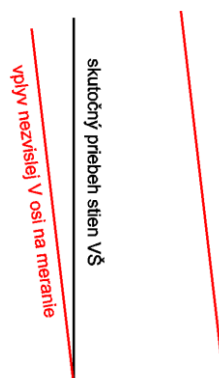
**Tab. 2** The comparison of the results of elevator shaft uprightness determination

|                 | Storey | Elevator shaft uprightness measured with hanging plummet |                 | Elevator shaft uprightness measured with UMS Leica 1201 + |                 | Elevator shaft uprightness measured with TLS Leica ScanStation C10 |                 |
|-----------------|--------|--|-----------------|---|-----------------|--|-----------------|
|                 |        | $\Delta y$ [mm]  | $\Delta x$ [mm] | $\Delta y$ [mm]   | $\Delta x$ [mm] | $\Delta y$ [mm]  | $\Delta x$ [mm] |
| <b>Corner 1</b> | 1      | 0  | 0               | 0   | 0               | 0  | 0               |
|                 | 2      | 4  | 8               | 6   | 13              | 7  | 8               |
|                 | 3      | 7  | 14              | 6   | 17              | 8  | 15              |
|                 | 4      | 11   | 18              | 10  | 21              | 15   | 19              |
|                 | 5      | 12   | 14              | -   | -               | 15   | 14              |
|                 | 6      | 10   | 0               | 9   | 5               | 13   | 0               |
|                 | 7      | 7  | 0               | 9   | 2               | 9  | 0               |
|                 | 8      | 7  | 1               | 9   | 3               | 13   | 0               |
| <b>Corner 2</b> | 1      | 0  | 0               | 0   | 0               | 0  | 0               |
|                 | 2      | 3  | 10              | 1   | 15              | 1  | 14              |
|                 | 3      | 3  | 12              | 0   | 16              | 4  | 14              |
|                 | 4      | 7  | 12              | 8   | 18              | 10   | 14              |
|                 | 5      | 10   | 13              | -   | -               | 11   | 15              |
|                 | 6      | 4  | 13              | 6   | 13              | 8  | 12              |
|                 | 7      | 3  | 7               | 4   | 4               | 3  | 6               |
|                 | 8      | 7  | -3              | 7   | -6              | 10   | -6              |
| <b>Corner 3</b> | 1      | 0  | 0               | 0   | 0               | 0  | 0               |
|                 | 2      | 6  | 15              | 5   | 13              | 6  | 10              |
|                 | 3      | 6  | 8               | 4   | 11              | 3  | 5               |
|                 | 4      | 3  | 8               | 3   | 12              | 2  | 5               |
|                 | 5      | 8  | 10              | -   | -               | 7  | 7               |
|                 | 6      | 8  | 7               | 6   | 8               | 8  | 6               |
|                 | 7      | 4  | -1              | 5   | -2              | 5  | -3              |
|                 | 8      | -1   | -6              | -2  | -7              | -3   | -10             |
| <b>Corner 4</b> | 1      | 0  | 0               | 0   | 0               | 0  | 0               |
|                 | 2      | 4  | 15              | 5   | 18              | 7  | 17              |
|                 | 3      | 4  | 17              | 0   | 20              | 2  | 16              |
|                 | 4      | 3  | 21              | 2   | 23              | 1  | 21              |
|                 | 5      | 3  | 18              | -   | -               | 6  | 17              |
|                 | 6      | 2  | 7               | 5   | 7               | 6  | 7               |
|                 | 7      | 3  | 5               | 3   | 5               | 2  | 5               |
|                 | 8      | -6   | 4               | -2  | 6               | -4   | 5               |

With regard to the results from the measurement stated in Tab. 2, it is possible to claim that they differ at the level of measurement accuracy depending on individual methods. The differences in determination of uprightness of the elevator shaft are caused mainly by the accuracy of measurements alone as well as different technology of each method.

### 3.4 Verifying the effect of TLS compensator error on measurement results

To confirm the definiteness of the results obtained by TLS, further independent measurements with an intentionally deviated compensator of the instrument were executed. When the vertical axis of the instrument is deviated from the vertical, the deformation of the results of uprightness determination is assumed, as shown in Fig. 12.



Effect of non-vertical axis V on measurements  
Actual behaviour of elevator shaft walls

**Fig. 12** The assumed effect of non-verticality of the instrument vertical axis on measurement results

TLS Leica ScanStation C10 is furnished with two axis balance with the accuracy of  $1.5''$  and a dynamic scope of  $\pm 5'$ . The verification of its function and effect on measurement results was carried out based on the experiment consisting in the execution of two independent scans and their comparison. In case of the first scan of the elevator shaft, the electronic builder's level was balanced as precisely as possible during the entire measurement. In case of the second one, it was declined from the central position to the limit of the compensator scope, i.e. by  $5'$ . The coordinates of elevator shaft corners obtained from these two scans were compared.

The value of the difference in corners uprightness of the elevator shaft between the first and the eighth storey should achieve, with the stated compensator accuracy, the value according to the relationship:

$$l = \Delta h \cdot \text{tg } \varphi \quad (16),$$

where:

$\Delta h$  - difference in super elevation between the first and the eighth storey,

$\varphi$  - angle from the vertical corresponding to the compensator accuracy

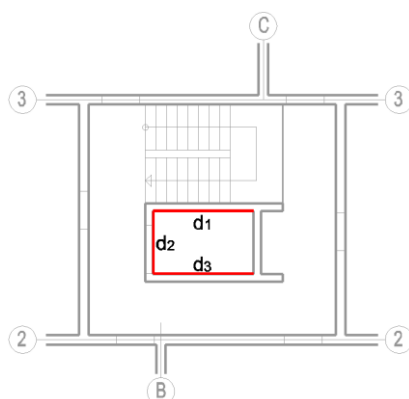
If the difference in heights between the first and the eighth storey is about 25m, excluding the consideration of further effects, this value is approximately  $\pm 0,2$  mm. In case of the value of the instrument vertical axis deviation at the level of the compensator scope when not functioning, the theoretical difference in uprightness is up to 60 mm. The values of the differences in elevator shaft uprightness and the differences in two independent measurements stated experimentally are given in Tab.3. The differences in uprightness determination, found out on the basis of two independent measurements (Tab.3), reach the level of the modelled surface accuracy given by the producer, therefore the influence of the compensator on results at the required level of accuracy was not significant.

**Tab. 3** The comparison of the results of uprightness determination from scans using the instrument TLS Leica ScanStation C10

|                 |               | Elevator shaft uprightness, 1 <sup>st</sup> measurement |                 | Elevator shaft uprightness, 2 <sup>nd</sup> measurement |                 | Measurement differences |            |
|-----------------|---------------|---|-----------------|---|-----------------|-------------------------|------------|
|                 |               | $\Delta y$ [mm]   | $\Delta x$ [mm] | $\Delta y$ [mm]   | $\Delta x$ [mm] | $\Delta y$ [mm]         | $\Delta x$ |
| <b>Corner 1</b> | <b>Storey</b> |   |                 |   |                 |                         |            |
|                 | 1             | 0   | 0               | 0   | 0               | 0                       | 0          |
|                 | 2             | 7   | 8               | 6   | 8               | 1                       | 0          |
|                 | 3             | 8   | 15              | 7   | 15              | 1                       | 0          |
|                 | 4             | 15  | 19              | 14  | 19              | 1                       | 0          |
|                 | 5             | 15  | 14              | 13  | 14              | 2                       | 0          |
|                 | 6             | 13  | 0               | 12  | 0               | 1                       | 0          |
|                 | 7             | 9   | 0               | 8   | 0               | 1                       | 0          |
|                 | 8             | 13  | 0               | 12  | 1               | 1                       | -1         |
| <b>Corner 2</b> |               |   |                 |   |                 |                         |            |
|                 | 1             | 0   | 0               | 0   | 0               | 0                       | 0          |
|                 | 2             | 1   | 14              | -1  | 14              | 2                       | 0          |
|                 | 3             | 4   | 14              | 2   | 14              | 2                       | 0          |
|                 | 4             | 10  | 14              | 8   | 14              | 2                       | 0          |
|                 | 5             | 11  | 15              | 9   | 15              | 2                       | 0          |
|                 | 6             | 8   | 12              | 6   | 12              | 2                       | 0          |
|                 | 7             | 3   | 6               | 2   | 6               | 1                       | 0          |
|                 | 8             | 10  | -6              | 8   | -6              | 2                       | 0          |
| <b>Corner 3</b> |               |   |                 |   |                 |                         |            |
|                 | 1             | 0   | 0               | 0   | 0               | 0                       | 0          |
|                 | 2             | 6   | 10              | 5   | 8               | 1                       | 2          |
|                 | 3             | 3   | 5               | 2   | 7               | 1                       | -2         |
|                 | 4             | 2   | 5               | 1   | 7               | 1                       | -2         |
|                 | 5             | 7   | 7               | 6   | 8               | 1                       | -1         |
|                 | 6             | 8   | 6               | 6   | 7               | 2                       | -1         |
|                 | 7             | 5   | -3              | 3   | -1              | 2                       | -2         |
|                 | 8             | -3  | -10             | -5  | -11             | 2                       | 1          |
| <b>Corner 4</b> |               |   |                 |   |                 |                         |            |
|                 | 1             | 0   | 0               | 0   | 0               | 0                       | 0          |
|                 | 2             | 7   | 17              | 5   | 18              | 2                       | -1         |
|                 | 3             | 2   | 16              | 3   | 16              | -1                      | 0          |
|                 | 4             | 1   | 21              | 2   | 21              | -1                      | 0          |
|                 | 5             | 6   | 17              | 6   | 18              | 0                       | -1         |
|                 | 6             | 6   | 7               | 7   | 8               | -1                      | -1         |
|                 | 7             | 2   | 5               | 3   | 5               | -1                      | 0          |
|                 | 8             | -4  | 5               | -3  | 5               | -1                      | 0          |

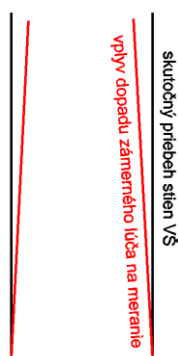
### 3.5 Verifying the effect of the observing ray incidence angle on the determination of uprightness and shaft dimensions

The elevator shaft dimensions were determined based on the model acquired applying the TLS method and the method of direct measurement. The directly measurable dimensions at individual storeys, marked in Fig. 13 as  $d_1$ ,  $d_2$ ,  $d_3$ , were compared.



**Fig. 13** Designation of the compared dimensions of the elevator shaft

The effect of the staking ray incidence under an acute angle on the measured plane with the resultant deformation of actual shaft dimensions was assumed, as shown in Fig.14.



Effect of staking ray incidence on measurements  
Actual behaviour of elevator shaft walls

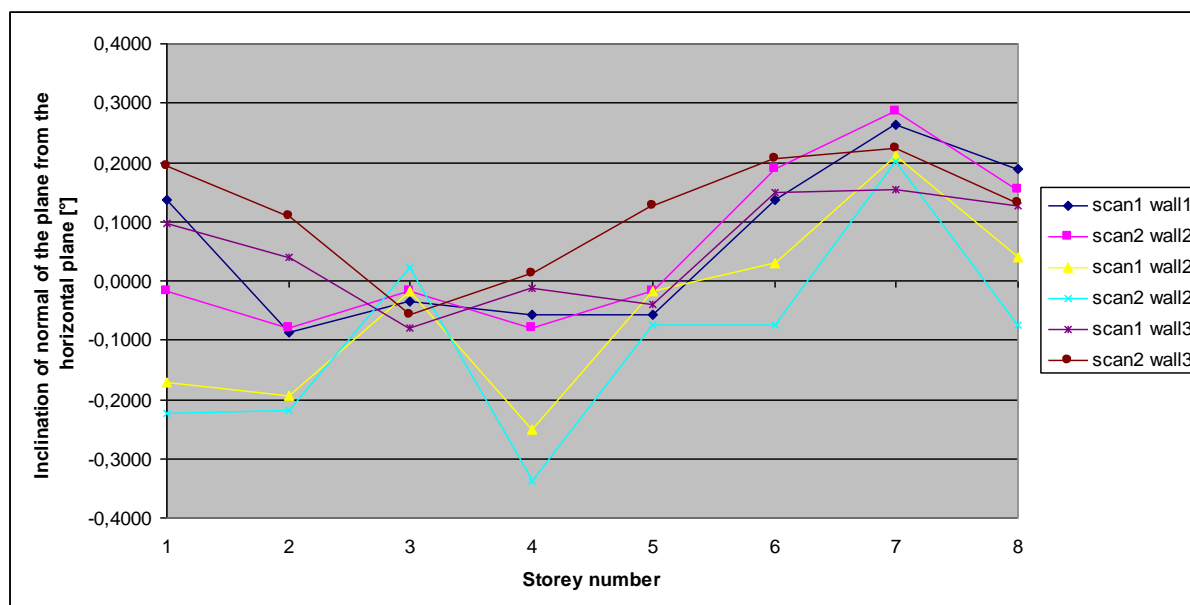
**Fig. 14** The assumed effect of the staking ray incidence under an acute angle on measurement results

The internal elevator shaft dimensions, derived from the model obtained applying the TLS method, were compared with the direct measurements at individual storeys. The results are given in Tab.4.

**Tab. 4** The comparison of the results obtained from the uprightness determination from two scans applying the instrument TLS Leica ScanStation C10

| Storey | TLS           |               |               | Direct measurement |               |               | Dimension difference |                      |                      |
|--------|---------------|---------------|---------------|--------------------|---------------|---------------|----------------------|----------------------|----------------------|
|        | $d_1$<br>[mm] | $d_2$<br>[mm] | $d_3$<br>[mm] | $d_1$<br>[mm]      | $d_2$<br>[mm] | $d_3$<br>[mm] | $\Delta d_1$<br>[mm] | $\Delta d_2$<br>[mm] | $\Delta d_3$<br>[mm] |
| 1      | 2642          | 1644          | 2645          | 2643               | 1645          | 2647          | 1                    | 1                    | 2                    |
| 2      | 2648          | 1653          | 2645          | 2648               | 1652          | 2647          | 0                    | 1                    | 2                    |
| 3      | 2647          | 1647          | 2645          | 2646               | 1649          | 1646          | 1                    | 2                    | 1                    |
| 4      | 2647          | 1646          | 2644          | 2647               | 1648          | 2645          | 0                    | 2                    | 1                    |
| 5      | 2646          | 1648          | 2645          | 2645               | 1650          | 2647          | 1                    | 2                    | 2                    |
| 6      | 2647          | 1651          | 2644          | 2646               | 1649          | 2646          | 1                    | 2                    | 2                    |
| 7      | 2648          | 1649          | 2643          | 2648               | 1650          | 2645          | 0                    | 1                    | 2                    |
| 8      | 2645          | 1648          | 2645          | 2645               | 1649          | 2647          | 0                    | 1                    | 2                    |

It is possible to determine the inclination of partial planes on individual storeys based on the results obtained from processing the 3D model of the elevator shaft and based on the angles to their normal. The elevation angles of the normal to the surfaces are presented in the graph in Fig. 15.



**Fig. 15** The elevation angles of the normal to the surfaces from the horizontal plane from the model measured with TLS Leica ScanStation C10

#### 4 CONCLUSIONS

The goal of the experimental measurements was to confirm the method of terrestrial laser scanning (TLS) for its application to determine the uprightness and dimensions of an elevator shaft as a suitable, satisfactory accurate, fast and detailed method as compared with conventional geodetic measuring procedures.

The evaluation of the achieved accuracy of the TLS method may be seen in Tab. 2 where the differences in determined uprightness of individual corners of the elevator shaft, set by three independent methods, are within the scope of the a priori estimated accuracies of the exploited method, the value of which is about  $\pm 3\text{mm}$  in all cases, as the outmost differences in uprightness differed by 5mm as maximum.

The definiteness of the results of repeated measurements exploiting the TLS method is apparent from Tab. 3 where the differences in determination of elevator shaft corners uprightness were up to  $\pm 2\text{mm}$ . This corresponds to the accuracy declared by the manufacturer of the modelled surfaces. In spite of the fact that in case of the second type of measurements, when an electronic builder's level was applied, intentionally deviated from the central position toward the limit of the compensator scope, i.e. by  $5''$  with the objective to verify the effect of the unbalanced instrument on results, the determined values of the uprightness differences differed mutually up to  $\pm 2\text{mm}$ .

The effect of staking ray incidence under an acute angle on the surface of top storeys on the results of uprightness of elevator shaft measurements is not significant, as can be seen in Tab. 2. According to the values provided in Tab. 3, the angle of incidence of the observing ray has no significant effect on the determination of horizontal dimensions of the elevator shaft. The differences in dimensions determined from the 3D model, obtained when applying the TLS method, are up to  $\pm 2\text{mm}$  in comparison with the direct measurement.

While considering the height of a storey to be 3m and the building deviation (tolerance)  $\pm 25\text{mm}$  for the positions of pillars and walls on adjacent storeys with regard to the straight line of the secondary top view scheme, the tolerable inclination of the elevator shaft wall from the vertical is  $\pm 0.48^\circ$ . The values of the elevation angle of the inclination of normal to the partial surfaces from the horizontal surface, stated in Tab. 4 and Graph 1, are up to  $\pm 0.34^\circ$  which corresponds to their actual inclination and is within the tolerance scope of the building deviation.

The method of acquiring the data exploiting TLS may be characterised as the fast one with regard to the measuring period of about 30 minutes. However, the administration of the measured data is more demanding as it lasts about 1 day. Its advantage, along with the speed of work in situ, is the high precision and complexity of

spatial data as it allows to evaluate the parameters of an elevator shaft at any location of its height, and even to construct its complex 3D model.

## REFERENCES

- [1] ČERNOTA, P. STAŇKOVÁ, H., & GAŠINCOVÁ, S., 2011: Indirect Distance Measuring as Applied upon both Connecting Surveys and Orientation One, *Acta Montanistica Slovaca*, Vol. 16 (2011), no. 4, p. 270-275 ISSN 1335-1788.
- [2] ČERNOTA, P., STAŇKOVÁ, H., POSPÍŠIL, J. & MATAS, O., 2012: Nová metoda pozorování kyvů pro určení správné polohy olovnice v tížnici při připojovacím a usměrňovacím měření. In *Geodézia, kartografia a geografické informačné systémy*. Tatranská Lomnica 24. – 25. 10. 2012, Košice, TU, FBERG, ÚGKaGIS, 2012. ISBN 978-80-553-1173-9.
- [3] ERDÉLYI, J., LIPTÁK, I., 2011: Monitoring mostného objektu technológiou TLS. In: 47. *Geodetické informační dny : Sborník přednášek*. Brno, ČR, 8.-9.11.2011. – Brno, Český svaz geodetů a kartografů, 2011. - ISBN 978-80-02-02350-0. - p. 58-63
- [4] ERDÉLYI, J., LIPTÁK, I., KYRINOVIČ, P. & KOPÁČIK, A., 2012: Určovanie posunov a pretvorenie železobetónových konštrukcií pomocou TLS. In: *Geodézia, kartografia a geografické informačné systémy 2012: VII. vedecko-odborná medzinárodná konferencia*, Tatranská Lomnica, SR, 24.-25.10.2012. - Košice : Technická univerzita v Košiciach, 2012. – ISBN 978-80-553-1173-9.
- [5] GAŠINEC, J., GAŠINCOVÁ, S., ČERNOTA, P. & STAŇKOVÁ, H., 2012: Zastosowanie naziemnego skaningu laserowego do monitorowania logu gruntowego w Dobszyńskiej Jaskini Lodowej, *Inżynieria Mineralna*. Vol. 13, no. 2 (30) (2012), p. 31-42. ISSN 1640-4920
- [6] GAŠINEC, J., GAŠINCOVÁ, S., 2012: Modelovanie deformácií rovinných plôch. In *Geodézia, kartografia a geografické informačné systémy*. Tatranská Lomnica 24. – 25. 10. 2012, Košice, TU, FBERG, ÚGKaGIS, 2012. ISBN 978-80-553-1173-9.
- [7] GAŠINEC, J., GAŠINCOVÁ, S., ČERNOTA, P. & STAŇKOVÁ, H.: Možnosti použitia terestrického laserového skenovania pri dokumentovaní ľadovej výplne Dobšinskej ľadovej jaskyne a riešenie súvisiacich problémov v programovacom jazyku Python. In *SDMG 2011: sborník referátů 18. konference: Praha, 5.-7. října 2011*. Ostrava : VŠB-TU, 2011 p. 51-59. - ISBN 978-80-248-2489-5.
- [8] Leica ScanStation C10 – technický list. Dostupné na internete: [http://www.geotech.sk/downloads/Laserove-skenery-HDS/Leica\\_ScanStation\\_C10\\_Brochure\\_sk.pdf](http://www.geotech.sk/downloads/Laserove-skenery-HDS/Leica_ScanStation_C10_Brochure_sk.pdf)

## RESUMÉ

Stavebné objekty sa od seba odlišujú najmä ich tvarom a rozmermi a tiež druhom konštrukcie. Vo všetkých etapách výstavby je kladený dôraz na presnosť zhotovenia konštrukčných častí stavebného objektu, tak aby stavebné odchýlky boli menšie ako je ich tolerancia udávaná normami, alebo projektovou dokumentáciou stavby. Vo fáze ukončovania stavby sú hlavnými činnosťami geodeta najmä kontrolné merania a porealizačné zameranie na vyhotovenie dokumentácie skutočného vyhotovenia stavby (DSVS). Pri výškových budovách je jej súčasťou aj geodetické zameranie zvislosti výťahových šacht (VŠ) s určením odchýlok skutočného vyhotovenia stavebného objektu voči projektovej dokumentácii, prípadne príslušnej technickej norme. Na získanie priestorových údajov o stavebnom objekte je možné použiť viac metód a postupov, ktoré sa od seba líšia presnosťou, časovou náročnosťou merania a tiež dostupnosťou vhodných meracích prístrojov. Cieľom experimentálnych meraní prezentovaných v článku bolo potvrdenie metódy terestrického laserového skenovania pre jeho aplikáciu na určenie zvislosti a rozmerov výťahovej šachty ako vhodnej, dostatočne presnej, rýchlej a detailnej pri porovnaní s bežnými geodetickými meračskými postupmi.