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Construction work starts and finishes with geodetic measurements, therefore geodetic measurements and labeling are the most important components of mounting and installation work in constructions and deformation observations. Modern constructions are distinguished by the size of construction objects, complexity of engineering structures and high precision of connectors and nodes of structural elements. These peculiarities and highly increased mechanization level caused changes in construction technology and character of engineering equipment of construction objects. Demand for precision has greatly increased. To reach a high precision of measurements, digital geodetic instruments are used. Large part of geodetic work in constructions is composed of leveling. This work contains investigations of leveling errors of digital levels. Changes in leveling methodology and sources of specific errors occur using digital levels for precise leveling. These changes can affect construction-engineering measurements. Precision investigations of a particular model of levels and coded staffs and digital leveling are necessary. Digital investigations of technical, geometrical and methodological parameters of instruments are also needed. The scope of this presentation includes resorting to digital automatic levels and impact of their accuracy on deformation and construction measurements.

KEYWORDS: coded staff, digital leveling, leveling error.

Introduction

Construction work starts and finishes with geodetic measurements, therefore geodetic measurements and labeling are the most important components of mounting and installation work in constructions and deformation observations. Modern constructions are distinguished by the size of construction objects, complexity of engineering structures and high precision of connectors and nodes of structural elements. These peculiarities and highly increased mechanization level caused changes in construction technology and character of engineering equipment of construction objects. Demand for precision has greatly increased. To reach a high precision of measurements, digital geodetic instruments are used. Large part of geodetic work in constructions is composed of leveling (Becker et.al. 1999).

The digital levels represented a breakthrough in levelling techniques using the innovative concept of reading a bar coded staff. Optical readings are not longer needed. Experience shows that with digital levels there is up to a 50% time saving when compared with conventional levels. The main reasons are the faster data capture as well as the shorter time and safer means of data processing,

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thanks to saving measured data on storage devices. Digital levels measure and save the height and the distance to the staff at the press of a button, and calculate the height of the point. The advantages include no readings required, no copying or writing down and no calculation by hand.

Operation of digital levels is based on the digital processing of video information from the coded staff. At the beginning of measurement a visual pointing of the instrument to the surface of leveling meter is performed. After that the instrument automatically points the focus of its optical system on the surface of the meter and then a rough correlation calculation is performed followed by the precise correlation. According to the data received in the processor of the instrument an exact distance from the axes of the instrument to the surface of the level meter is calculated. According to the information received by decoding the data from the photoelectric matrix the height of the level placing is calculated in the processor. During this operation the coded view of the meter is compared with that saved in the memory of the instrument. A true meter's height position is determined according to the shift of the image in the photoelectric sensor (pixels) matrix. (Aksamitauskas et.al. 2007) This work contains investigations of leveling errors of digital level Leica DNA03 (Fig.1)

Fig. 1

Digital level Leica DNA 03

Changes in leveling methodology and sources of specific errors occur using digital levels for precise leveling. These changes can affect construction-engineering measurements. Precision investigations of a particular model of levels and coded staffs and digital leveling are necessary. Digital investigations of technical, geometrical and methodological parameters of instruments are also needed.

The scope of this work includes resorting to digital automatic levels and impact of their accuracy on deformation and construction measurements.

Methods

Determination of the collimation error of the digital levels

A digital level automatically compensates for the collimation error digitally performing readings in coded staffs, if such error is defined and saved in the memory of the instrument. They have the absolute collimation error *absColl* and the variable error *collDif*, which depends on meteorological conditions. Initial value of the *absColl* set by a manufacturer is equal to zero seconds. The collimation error of these levels can be adjusted using maintenance program. By setting up this program, readings are automatically compensated for the Earth curvature errors. Checking is made by repeating the leveling of a 60 m length site line AB, which is fixed by metal poles. The line is divided into three equal sections, with two stations (Fig.2). The line contains points 1 and 2, which are locations of the leveling stations (Krikstaponis 2000, 2002).

In the station 1, reading a_1 and distance d_1 are set to the closer-standing staff. Then, reading a_2 and distance d_2 are set to the further-standing staff. Measurement sequence in the station is as follows: b_2, d_3 and a_2, d_4. If *absColl* = 0 and during the checking *collDif* = const ≠ 0, then two height differences can be calculated:

$$h_{AB} = (a_1 - b_1) - tgcollDif,(d_1 - d_2) \quad (1)$$

$$-h_{AB} = (b_2 - a_2) - tgcollDif,(d_3 - d_4) \quad (2)$$

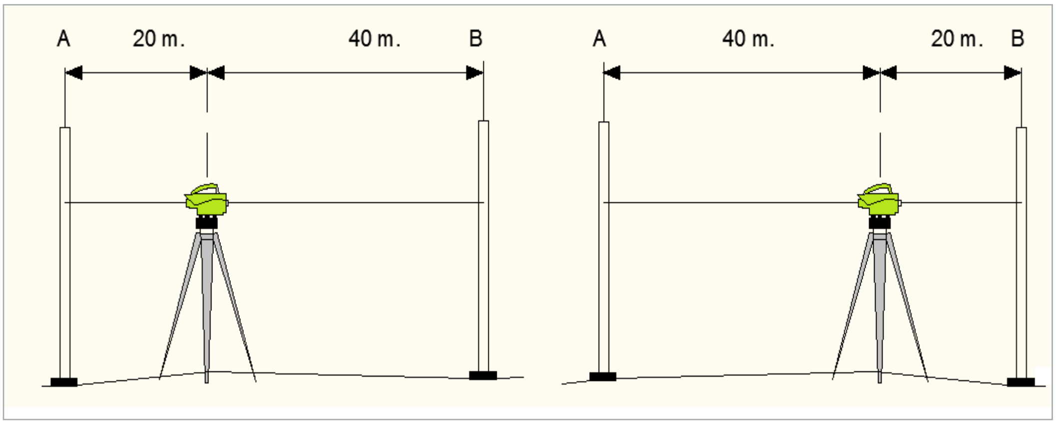

Fig. 2

The scheme of the measurements of the collimation error of the digital level DNA 03

Starting the checking *absColl* value from the memory of the level can be seen in the instrument display. After performing measurements in both stations, the variable collimation error *collDif* and the new absolute collimation error *absColl* are calculated. Both values, in seconds, are shown in the display. The new absolute collimation error is equal to the sum of the old and the newly determined variable collimation error. The absolute collimation error *absColl,* taking into account *collDif* value, can be set to a new value or left as the old value. If the *absColl* value is too large (>20"), it can be reduced or removed by adjusting the position of the middle horizontal reticle. After confirming the adjustment of the reticle position, the level calculates the correct reading a_2'. Visual reading to the staff with centimetric steps placed in point A is made without moving the level standing in the point 2. If the instrument is well adjusted, the calculated and the visually set readings are identical. If the difference between the readings is larger than 3 mm for the 30 m distance (*collDif* ≈20"), horizontal reticle should be adjusted. After the adjustment of the horizontal reticle, the collimation error is check again.

During the normal measurement conditions, standard deviation of the error is about ± 2" (Aksamitauskas *et al*. 2007). The *collDif* values are changing; therefore, if the surrounding air temperature changes, a new absolute collimation error *absColl* should be set and saved in the memory of the instrument. In order to reduce the impact of the collimation error for the measurement results, the error values should be set at temperature closest to an average air temperature at which the further measurements will be made. During the measurements in a station when all distances to the stuffs are absolutely equal and *collDif* value is stable, *collDif* does not have any impact on the measured height difference.

Reading system precision of the digital levels

Digital levels DNA03 can be used for a preferred number (1 to 99) of coded staff readings (Aksamitauskas *at al*. 2007). The final staff reading is based on these readings. It is unknown what number of readings is optimal and how a reading precision is changing depending on the number of readings (Krikstaponis 2001, Aksamitauskas *at al.* 2007). Reading system precision of the digital level DNA 03 was investigated using a 47 m long base fixed by temporal metal stakes. Readings were performed into two staffs set at distances. Using a measurement program MEASURE ONLY, ten measurements into the closer and further standing staffs were made. Each cycle contained different number of readings. Summarized precision indexes of the experimental measurements are provided in Table 1. The reading precision depends on the distance to a staff. Average precision results were calculated using the following weights (Krikstaponis 2001):

$$p_{\bar{\sigma}_i} = \frac{10^{-3}}{\bar{\sigma}_i^2}, \quad p_{m_{\bar{a}_i}} = \frac{10^{-3}}{m_{\bar{a}_i}^2}, \quad p_{m_{a_i}} = \frac{10^{-3}}{m_{a_i}^2}. \tag{3}$$

According to the weight average formula:

$$\tilde{\sigma} = \frac{\sum p_{\bar{\sigma}_i} \bar{\sigma}_i}{\sum p_{\bar{\sigma}_i}}, \quad \overline{m_{\bar{a}}} = \frac{\sum p_{m_{\bar{a}_i}} m_{\bar{a}_i}}{\sum p_{m_{\bar{a}_i}}}, \quad \overline{m_a} = \frac{\sum p_{m_{a_i}} m_{a_i}}{\sum p_{m_{a_i}}} \quad (4)$$

Table 1

Summarized precision indexes of the experimental measurements

n	d = 14.00 m			d = 33.00 m		
	$\bar{\sigma}$	$m_{\bar{a}}$	m_a	$\bar{\sigma}$	$m_{\bar{a}}$	m_a
2	0.03	0.022	0.031	0.03	0.044	0.03
3	0.023	0.018	0.018	0.05	0.043	0.06
4	0.038	0.022	0.045	0.06	0.034	0.068
5	0.02	0.014	0.03	0.03	0.036	0.068
6	0.02	0.016	0.04	0.03	0.028	0.062
7	0.03	0.012	0.033	0.025	0.016	0.041
8	0.02	0.012	0.035	0.026	0.016	0.041
9	0.01	0.013	0.04	0.01	0.016	0.042
	$\tilde{\sigma} = 0.001$	$\overline{m_{\bar{a}}} = 0.020$	$\overline{m_a} = 0.032$	$\tilde{\sigma} = 0.003$	$\overline{m_{\bar{a}}} = 0.094$	$\overline{m_a} = 0.107$

The performed investigation of the reading system precision of the levels DNA03 shows that the reading precision depends on the distance between the instrument and the staff. Digital levels DNA03 can be used for a preferred number (1 to 99) of coded staff readings, n. This investigation shows that the most precise indicators are obtained when n ≥ 7. When n > 7, an improvement of the precision results is insignificant. Therefore, the number of readings n should not be less then 7, although this would decrease the leveling efficiency.

Investigation of the incomplete tilt compensation of the digital level

Incomplete compensation of a level was examined leveling the same station with lying and angled levels. For this purpose the level was placed strictly in the middle between the staffs that were fixed on built poles, and the height difference was measured at the following bubble position of the spherical level. (Fig.3)

The Δh of the averages of height differences for the level used in the first class leveling should not exceed 0.5 mm or 0.05 mm per level tilt minute (Krikštaponis 2001). Incomplete compensation of the level tilt was investigated when the distance between the staffs was 15 m. A reading obtained by digital levels is an average of several (in this case 5) readings. In this investigation, four measurement sections were made in total while changing the level height with each section. The results of the measurements are given in Table 2 and Table 3. The averages of the height differences and the differences of these averages Δh from the average of the height difference obtained at the bubble position in the middle of the level ampoules were calculated (Krikstaponis 2002).

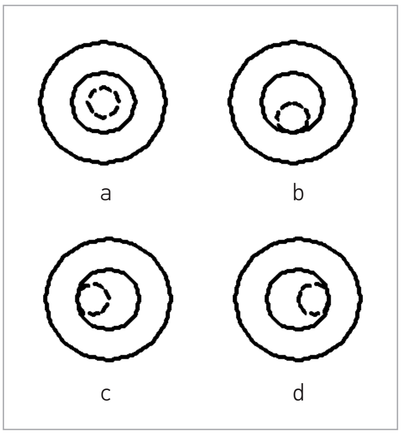

Fig 3

Positions of the spherical level bubble while testing a level compensator: A – bubble in the middle of the ampoule, b and c - at the longitudinal inclination, d and e - at the transverse inclination

Also incomplete compensation of the level tilt was investigated when the distance between the staffs was 30 m. A reading obtained by digital levels is an average of several (in this case 5) readings. In this investigation, four measurement sections were made in total while changing the level height with each section. The results of the mea-

Section No.	Height differences				
	Bubble in the middle of the ampoule	At the longitudinal inclination		At the transverse inclination	
		−5	+5	−5	+5
	Leica DNA03 Nr. 01632145 S = 15 m				
1	0,25984	0,25984	0,25991	0,25989	0,25982
2	0,25986	0,25982	0,25994	0,25986	0,25982
3	0,25984	0,25981	0,25987	0,25987	0,25982
4	0,25988	0,25980	0,25986	0,25990	0,25982
5	0,25989	0,25983	0,25984	0,25990	0,25987
average	0,25986	0,25982	0,25988	0,25988	0,25983
h (mm)		0,00004	-0,00002	-0,00002	0,00003

Table 2

Investigation of the incomplete tilt compensation of the digital level when distance is 15 m

	Leica DNA03 Nr. 01632145 S = 30 m				
1	0,21132	0,21132	0,21135	0,21135	0,21138
2	0,21132	0,21134	0,2114	0,21132	0,21141
3	0,21132	0,21132	0,21137	0,21139	0,21143
4	0,21132	0,21132	0,21142	0,21139	0,21144
5	0,21133	0,21132	0,21143	0,21135	0,21142
average	0,21132	0,21132	0,21139	0,21136	0,21142
h (mm)		0,00000	-0,00007	-0,00004	-0,00010

Table 3

Investigation of the incomplete tilt compensation of the digital level when distance is 30 m

surements are given in Table 3. The same, like in previous example the averages of the height differences and the differences of these averages *Δh* from the average of the height difference obtained at the bubble position in the middle of the level ampoules were calculated.

During investigation of the incomplete tilt compensation it was found that these digital levels meet the requirements for the first-class instruments. The obtained *Δh* of the averages of height differences did not exceed 0.5 mm or 0.05 mm per level tilt minute.

Conclusions

The *collDif* values are changing; therefore, if the surrounding air temperature changes, a new absolute collimation error *absColl* should be set and saved in the memory of the instrument. In order to reduce the impact of the collimation error for the measurement results, the error values should be set at temperature closest to an average air temperature at which the further measurements will be made. During the measurements in a station when all distances to the stuffs are absolutely equal and *collDif* value is stable, *collDif* does not have any impact on the measured height difference.

The performed investigation of the reading system precision of the levels DNA03 shows that the reading precision depends on the distance between the instrument and the staff. Digital levels DNA03 can be used for a preferred number (1 to 99) of coded staff readings, n. This investigation shows that the most precise indicators are obtained when n ≥ 7. When n > 7, an improvement of the precision results is insignificant. Therefore, the number of readings n should not be less then 7, although this would decrease the leveling efficiency.

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