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APPLICATION OF DIGITAL AUTOMATIC LEVELS AND IMPACT OF THEIR ACCURACY ON CONSTRUCTION MEASUREMENTS

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ABSTRACT

Digital automatic levels are a precise instruments used for precise leveling. Operation of digital levels is based on the digital processing of video indications of a coded staff. At the beginning of measurement a visual pointing of the instrument into 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 information that saved in the memory of the instrument. The scope if this work includes resort of digital automatic levels and impact of their accuracy on construction measurements.

KEYWORDS

coded staff, digital leveling, levelling error.

1. 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 construction.

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 (Fig.1) 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, 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. Advantage: no readings required, no copying or writing down and no calculation by hand [1].

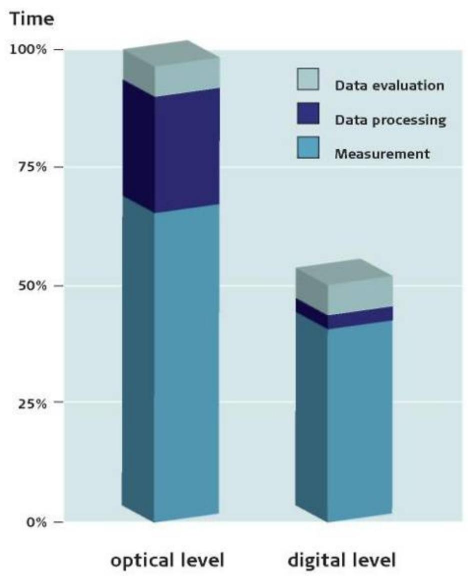

Figure 1. Work time saving with optical and digital levels

Digital automatic levels are precise instruments used for precise leveling. 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.

Precision investigations of a particular model of levels and coded staffs and digital leveling are necessary. The 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 construction measurements.

2. DETERMINATION OF THE COLLIMATION ERROR OF THE DIGITAL LEVELS

A digitals levels 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 CHECK&ADJUST. By setting up this program, readings are automatically compensated for the Earth curvature errors. Checking is made by repeating the leveling of a 45–50 m length site line AB, which is fixed by metal poles. The line is divided into three equal sections. The line contains points 1 and 2, which are locations of the leveling stations (Fig 2) [2-4].

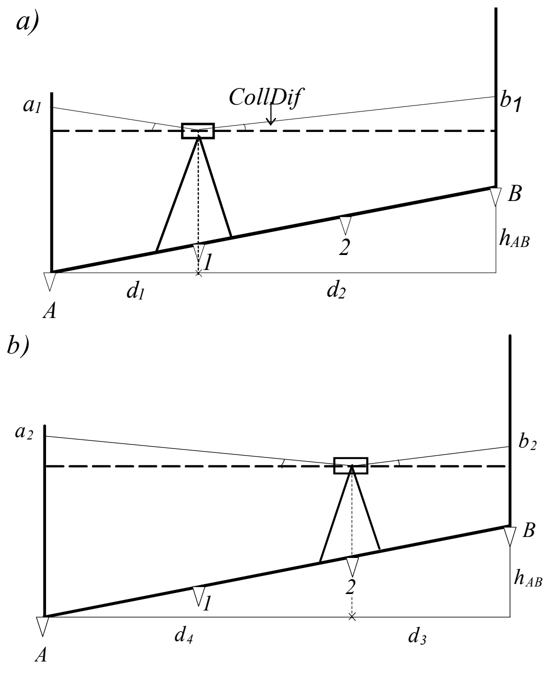

Figure 2. Checking of collimation error

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:

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

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

According to the sum of the expressions (6) and (7) are

$$collDif = \text{arctg}\ [(a1 - b1 + b2 - a2) / (d1 - d2 + d3 - d_4) \quad (3).$$

Starting the checking, i.e. putting into the program CHECK&ADJUST, *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 a2'. 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" [4, 5].

Investigations of *collDif* daily variations of the digital levels NA3003 No.92426 and No.92432 were performed at Vilnius Gediminas Technical University. Two instruments, previously used by Institute of Geodesy for the leveling of the geodesic vertical grid, were used for these investigations [6]. The methodology developed by Krikštaponis [4] was applied. A base AB of 45 m was selected. The end points of the base were fixed using metal stakes where coded staffs were fixedly (using supports) installed. The base was then divided into three equal sections. Both levels were placed at points 1 and 2. Measurements were performed every half an hour.

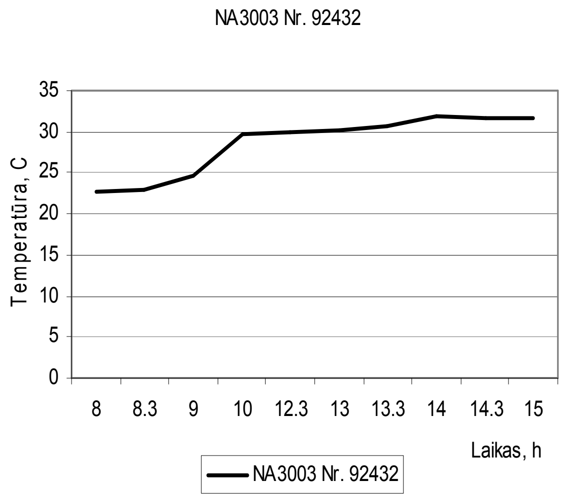

Figure 3. Temperature variations during *collDif* measurements by the level NA3003 No.92432

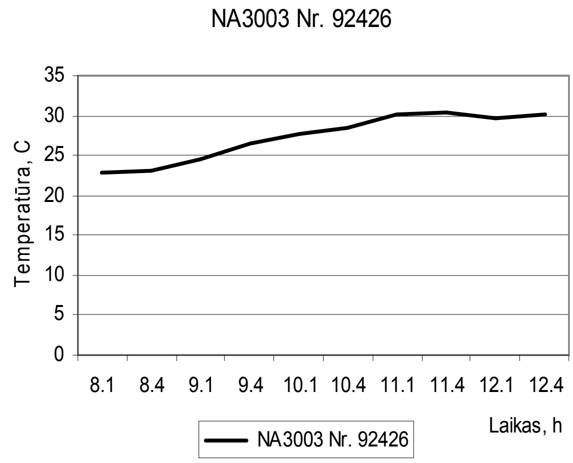

Figure 4. Temperature variations during *collDif* measurements by the level NA3003 No.92426

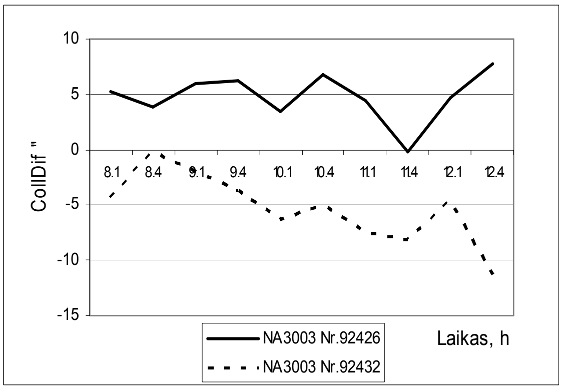

Figure 5. *collDif* variation during a day

Ten measurement cycles were made changing placement of the level without moving the tripod. Air temperature, measured in the shade by a thermometer H-200, varied up to 4 ºC. In order to achieve as uniform measurement conditions and objective results as possible, the measurements using both levels were performed sequentially at the same consistency. The measurements of one cycle by each level lasted about 5 minutes. The largest temperature variation during one cycle did not exceed 0.5 ºC.

3. READING SYSTEM PRECISION OF THE DIGITAL LEVELS

Digital levels NA3003 can be used for a preferred number (1 to 99) of coded staff readings [7, 8]. 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 [4, 5]. Reading system precision of the digital level NA3003 No. 92426 was investigated using a 47 m long base fixed by temporal metal stakes. Readings were performed into two staffs set at distances of 14 m and 33m. Air temperature in the shade was measured by a thermometer. Using a measurement program MEASURE ONLY, ten measurements into the closer and further standing staffs were made. Each cycle contained different number of readings for, *n*, which was altered from 2 to 9. The measurement data was automatically corrected for the Earth curvature error. On the following day, the second cycles of measurements were calculated.

Summarized precision indexes of the experimental measurements are provided in Table 1 and 2 and Figures 6, 7, 8 and 9.

The reading precision depends on the distance to a staff [5]. Average precision results were calculated using the following weights [4]:

$$p_i = \frac{m_0^2}{m_i^2}. \tag{1}$$

Table 1. Summarized precision indexes of the experimental measurements (first day)

n	d = 14,00 m			d = 33,00 m		
	$\overline{\sigma}$	$m_{\bar{a}}$	m_a	$\overline{\sigma}$	$m_{\bar{a}}$	m_a
2	0,03	0,022	0,031	0,03	0,048	0,067
3	0,01	0,018	0,018	0,07	0,044	0,077
4	0,05	0,042	0,084	0,06	0,034	0,072
5	0,02	0,014	0,030	0,04	0,036	0,081
6	0,02	0,016	0,040	0,03	0,028	0,069
7	0,03	0,012	0,033	0,01	0,016	0,041
8	0,02	0,012	0,035	0,02	0,016	0,045
9	0,01	0,014	0,043	0,01	0,016	0,047
	$\tilde{\sigma} = 0{,}002$	$\overline{m_{\bar{a}}} = 0{,}028$	$\overline{m_a} = 0{,}037$	$\tilde{\sigma} = 0{,}004$	$\overline{m_{\bar{a}}} = 0{,}096$	$\overline{m_a} = 0{,}112$

Table 2. Summarized precision indexes of the experimental measurements (second day).

n	d = 14,00 m			d = 33,00 m		
	$\overline{\sigma}$	$m_{\overline{a}}$	m_a	$\overline{\sigma}$	$m_{\overline{a}}$	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
	$\tilde{\sigma} = 0{,}001$	$\overline{m}_{\overline{a}} = 0{,}020$	$\overline{m}_a = 0{,}032$	$\tilde{\sigma} = 0{,}003$	$\overline{m}_{\overline{a}} = 0{,}094$	$\overline{m}_a = 0{,}107$

Assume that $m20$ is equal to 0.0001. Then corresponding weights are:

$$p_{\overline{\sigma}_i} = \frac{10^{-3}}{\overline{\sigma}_i^2},\ p_{m_{\overline{a}_i}} = \frac{10^{-3}}{m_{\overline{a}_i}^2},\ p_{m_{a_i}} = \frac{10^{-3}}{m_{a_i}^2}. \qquad (2)$$

According to the weight average formula:

$$\tilde{\sigma} = \frac{\sum p_{\overline{\sigma}_i}\overline{\sigma}_i}{\sum p_{\overline{\sigma}_i}},\ \overline{m}_{\overline{a}} = \frac{\sum p_{m_{\overline{a}_i}} m_{\overline{a}_i}}{\sum p_{m_{\overline{a}_i}}},$$

$$\overline{m}_a = \frac{\sum p_{m_{a_i}} m_{a_i}}{\sum p_{m_{a_i}}} \qquad (3)$$

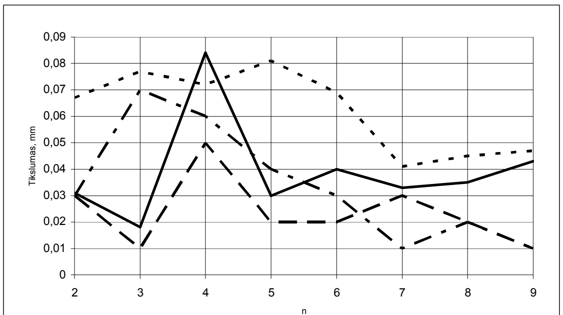

Figure 6. Graphical expression of summarized precision indexes of the experimental measurements (first day)

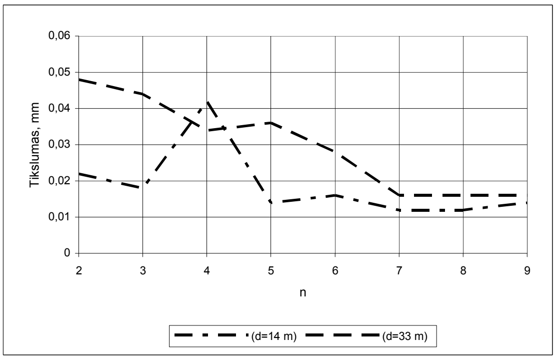

Figure 7. Graphical expression of summarized precision indexes of the experimental measurements (first day)

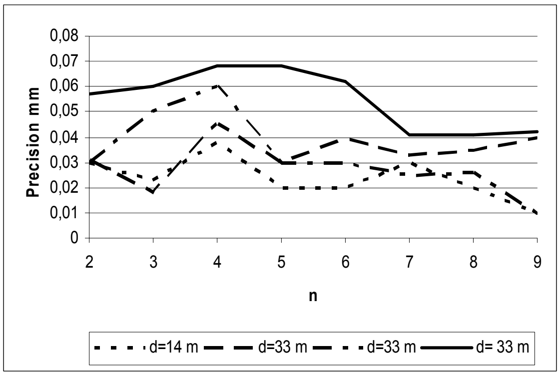

Figure 8 Graphical expression of summarized precision indexes of the experimental measurements (second day)

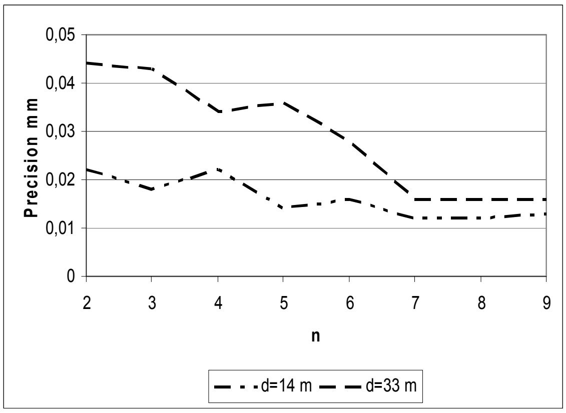

Figure 9 Graphical expression of summarized precision indexes of the experimental measurements (second day)

Results of a research based on a similar methodology are published by Krikstaponis [4]. Operation efficiency depended on the work duration in a leveling station, which, in turn, depended on the selection of optimal number of readings in a coded staff. No direct dependency between the number of readings and reading precision was observed. The reading precision depended on the distance to a staff. A correlation between a standard deviation of the reading average obtained by the digital level Wild NA3003 and the number of readings was week. Based on that, it was suggested that reading number exceeding five is unnecessary. Based on our two days researches (Figs 3-8), the best precision results are obtained when $n \geq 7$. When $n > 7$, then an improvement of the precision results is insignificant. Therefore, the number of readings of n should not be less then 7, although this would decrease the leveling efficiency. [4-6]

CONCLUSIONS

The performed investigation of the reading system precision of the levels NA3003 shows that the reading precision depends on the distance between the instrument and the staff. Digital levels NA3003 can be used for a preferred number (1 to 99) of coded staff readings of n. This investigation shows that the most precise indicators are obtained when $n \geq 7$. When $n > 7$, then an improvement of the precision results is insignificant. Therefore, the number of readings of n should not be less then 7, although this would decrease the leveling efficiency.

The variability profile of *collDif* for both instruments, i.e. NA3003 No.92432 and NA3003 No.92426, was similar, although the angle values differed up to 6". A slight impact from air temperature for *collDif* variations was also observed.

The *collDif* values change; 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 staffs are absolutely equal and *collDif* value is stable, *collDif* does not have any impact on the measured height difference.

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