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Section: Technologies of Geodesy and Cadastre

Classification of precise levelling instruments referring to the measurements of historic city centres

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Abstract

The inventory of the complexes of historic buildings requires, among others, surveying, based on which changes in time would be monitored, including the value of subsidence, inclination of walls, cracks, etc. The necessity of monitoring of dislocations and subsidence of the ground occurs in different centuries old cities in Poland. In Jarosław, the city in the Podkarpacie voivodeship, such necessity mainly occurs in the main square, because the location of the city centre on the scarp of the San River, which has the influence on the thickness and the kind of cultural layer, where the objects are placed. A significant reason for monitoring is also the presence of the underground historical cultural monuments occurring within the main square.

The carried out measurements of the subsidence of historical objects in the region of the old town, one should carry out with the use of proper sets for precise levelling. The equipment applied in this type of measurements should provide a proper accuracy, its class should, however, be justified economically.

In the Geodetic Metrology Laboratory of the Faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology in Krakow, the studies were carried out for two groups of levellers, precise and technical, as well as two types of levelling rods: invar and fibreglass rods. Precise levellers require different approach to the studies and classification other than technical levellers. The applied studies were carried out according to the standards BN-78/8770-07, ISO 12857-1 and ISO 17123-2. Based on the obtained results and table contained in standard BN-78/8770-07, the levellers were given proper classes. After the analysis of the results of the carried out measurements the optimal sets for this type of surveying were presented.

Keywords: checking; classification; levelling instruments; levelling rods; periodic monitoring.

1. Introduction

For the historic objects of the old town, such as in Jarosław, it is useful to carry out periodic inventory. Based on this inventory, it will be possible to define changes that, over the time, affect buildings and other objects in the area. From the point of view of surveying, one of the most important elements of such inventory is levelling, which leads to mark the values of dislocations and subsidence. The problem of this type of measurements takes a particular meaning due to the location of the town of Jarosław on the scarp of San and consequently on a given character of the cultural layer. A very important factor for the stability of the area is the presence of the historic objects in the underground in the centre of Jarosław.

The surveying leading to determine the values of the area of subsidence should be carried out with the levelling instruments optimal for this type of surveying. One should find a compromise between the required accuracy of instruments and economic aspect justifying its use. To achieve this accuracy studies and analyses were carried out for different groups of levelling sets and for different levelling rods. After the analysis of the results, the classification of levelling sets was proposed for the measurements in certain conditions, connected with the necessity of getting the required accuracy.

2. Geographic and geological conditions in Jarosław

The city of Jarosław is situated in the eastern part of the Sandomierz Valley (Kotlina Sandomierska) and the southern part of the community of Jarosław reaching the Carpathian Foothill (Pogórze Karpackie) in this part called Dynów Foothill (Pogórze Dynowskie). The area of the Sandomierz Valley is divided into several meso-regions. In the area of the

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community there are: the Rzeszow Foothill (Pogórze Rzeszowskie) and Tarnogród Upland (Płaskowyż Tarnogrodzki), divided by the Valley of the Lower San (Dolina Dolnego Sanu).

The Rzeszow Foothill, in this part called Jarosław Foothil, covers south-west part of the region. In this area there are small hills, making the transition area between the Sandomierz Valley and Dynów Foothill. The Rzeszow Foothill is built of several chains of hills up to about 230 m above the sea level. In many places there are deep gorges (ravines), here called wądoły, characteristic for loess soils.

Through the middle of the region from south-east to the north-west the river San flows, getting through the city of Jarosław. Alongside the river a wide erosion subsidence was formed, making meso-region of the Lower San Valley, formerly also called Nadsanie. In the relief of this valley, situated 175–190 m above the sea level, there are clearly seen two accumulation terraces: higher – Pleistocene and lower – Holocene. In the lowest terrace a flood terrace can be differentiated. They are built of gravel – sand and formations of marshy soils. The relief of the valley was formed as a result of numerous dislocations of the San riverbed, as the effect of which numerous oxbow lakes are formed, called Sanowiska. In the valley of the San River the city of Jarosław is formed [1].

Additionally the influence on the subsidence of the area, covering the centre of the city of Jarosław, have underground chambers and corridors built covered with brick. In the old ages Jarosław was situated on the trade route and was famous from the fairs attended by the merchants from Europe and Asia. The cellars of Jarosław come from the 15th – 17th century. They were used to store goods in cold, vast and multi-level cellars. They are covered with brick, making 150–m long chain of chambers. The difference of levels between their points is about 8 metres. Nowadays these former cellars and merchant stores make a so-called Underground Tourist Route [2], [3].

From the above described reasons the historical city centre of Jarosław should be periodically surveyed, which will allow defining the stability of the area. The levelling measurements are the most important element of such monitoring in the determination of the area of subsidence. Thus the defining the class of sets for the levelling, useful in such type of measurements, becomes particularly important.

3. Methods of checking the technical conditions of levelling instruments

Every levelling instrument should be subdued to regular controls. The first condition, which should be fulfilled by levelling instruments is connected with the perpendicular situation of its vertical axis to tangent plane in the main point of the bubble level. The procedure of checking and rectification of the bubble level is commonly known and will not be the subject of this article.

All the digital levelling instruments are equipped with a compensator, the task of which is the correction of the inclination of the line of sight of the instrument. It is obvious that both intensive use of levelling instruments (in particular in extreme or changing physical and atmospheric conditions) and longer breaks in its use and transport conditions can disturb the work of the compensator. Thus one should temporarily check, especially after the transport of the instrument, if the compensator works in the whole plane of the horizon, within the established limits. The sample results of the examination of the work of the compensator of levelling instrument Trimble DiNi 0.3 mm (model with graphic screen replacing series DiNi11 and DiNi12) is presented in Figure 1. The study was carried out by the change of the position of the bubble level alongside the line of sight of the levelling instrument in both directions with the translocation of ½ of the range of the bubble level, making the control readings. Two foot screws were situated symmetrically to the line of sight of the telescope, while the change of levelling was made with the third screw. Because of the rotation of the foot screw the height of the line of sight of the levelling instrument, i.e. the readings from the rod will not be the same, but with the proper work of the compensator they should change linearly. Based on the analysis of the graph presented in Figure 1, it can be stated that in the studied levelling instrument Trimble DiNi 0.3 no. 734286 the compensator works correctly.

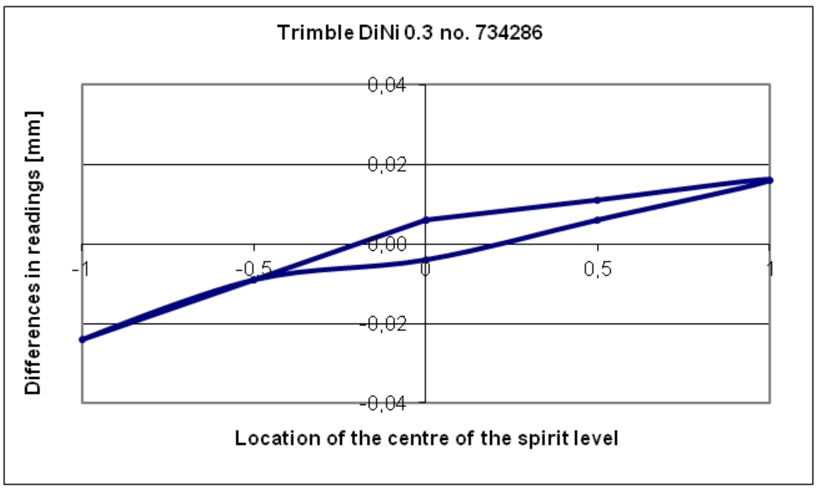

Fig. 1. The graph of the linearity of the work of the compensator of the levelling instrument Trimble DiNi 0.3 Source: authors' own work

The main condition of the proper work of the levelling instrument is connected with the proper compensation, generally connected with the correction of the inclination of the levelling instrument during the measurement. Possible correction is defined by the producers as justing of the line of sight. In levelling digital instruments the correction means marking the proper value of the compensator's correction, which is stored in the internal memory of the levelling instrument and used in the automatic correction of the reading from the rod. The producers of levelling digital instruments recommend one of four procedures in marking the values of the above mentioned correction [4]. For levelling instruments of a higher accuracy class, a so called Förstner's method, presented in Figure 2 is recommended.

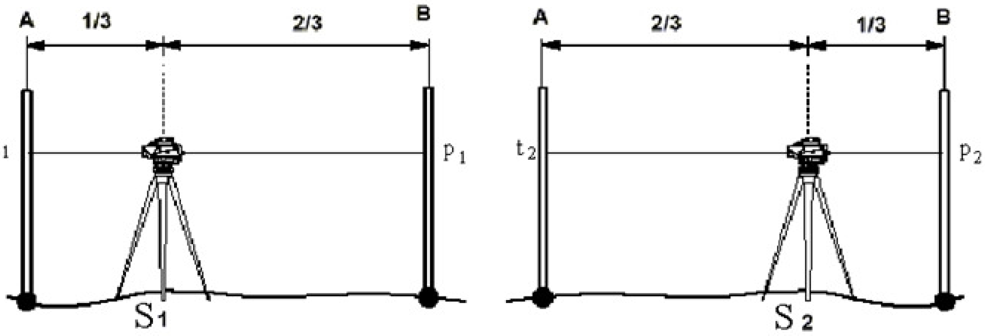

Fig. 2. Checking the compensation of the line of sight of the levelling instrument with the Förstner's method. Source: [4]

After putting the rods on stable points A and B, distant of about 45 m – 60 m from each other, one should divide this base into three parts, getting this way points S_1 and S_2, which will be the stands of levelling instruments (Fig. 2). The levelling instrument should be first put over the point S_1 and the measurement $\Delta h'_{AB} = t_1 - p_1$ is made. Then the levelling instrument is transferred over point S_2 and $\Delta h''_{AB} = t_2 - p_2$ is determined. The difference of calculation results makes base to determine the correction with the formulae contained in the programming of levelling instruments. Thus the correction of the reading from the rod is calculated from the formula:

$$v_0 = c\frac{\delta}{\rho''}, \tag{1}$$

where c is the length of the line of sight, $\rho = 206265''$ and

$$\delta = \frac{\Delta h''_{AB} - \Delta h'_{AB}}{c_{A-S_2} - c_{B-S_2}}\rho'', \tag{2}$$

where c_{A-S2}, c_{B-S2} are lengths of the lines of sights of the stands S_i of the levelling instrument to the rods put in points A and B.

After the end of the procedure to determine the compensation correction, the previous and new values of angle δ are shown and used in the calculations of the corrections of readings. If the difference between the previous and new value δ is big, the procedure should be repeated. After checking and accepting the new correction value, one should check the cross hairs (for classical observations). For this purpose, one should turn the rod into the metric division, make the reading and compare it with the one on the screen. If the difference exceeds 2 mm (for technical levelling instruments), one should correct the location of the cross hairs. In the end one should repeat the checking procedure. If the value of the compensation correction changes in short time intervals, the producers recommends giving the levelling of instruments to the service.

Some types of levelling instruments have only a strictly defined procedure of justing the line of sight available. For example in DiNi 20 only Förstner's method is available, for NA 3000 Näbauer's procedure was recommended, TOPCON for DL 103 recommends marking the correction with the levelling method from the centre, while for DL 101C and DL 102C Förstner's procedure is recommended. Sokkia for model SDL 30 proposed the levelling procedure from the centre, but the internal programming does not impose or control the lengths of the lines of sight, the user can also apply one of the three other procedures.

Regardless the presented above ways of checking the correctness of the work of the compensator, in surveying instruments (as well as levelling digital instruments), there is a problem of the instability of the line of sight, caused by the fact that the optic centre of the focusing lens can fail to move in a straight line in the whole range of the work. This can result in errors while reading from the rod, connected with the fact of the differentiation in the lengths of the lines of sights. Apart from the presented above questions, referring to checking levelling digital instruments, and also typical of conventional levelling optical instruments, in these instruments one important question is appearing, referring only to the levelling digital instruments: mounted in digital instruments CCD matrix is subdued to the process of „aging", causing changes in its scale and changing the scale of the readings. Thus, like in the case of rods, one should define the scale in the CCD matrix. Nowadays more and more common view is that the set of levelling instruments and the set of the rods makes an integrated measurement system, like in case of electronic total stations. Thus the calibration of the whole system is recommended, when the combined scale coefficient for the levelling digital instrument and the set of rods, making the measurement set is determined.

4. Classification levelling instruments

Every specimen of the levelling instrument that will be used for measurements should undergo periodic laboratory check-ups, to attribute it to an adequate class. This necessity is connected with its physical weariness, which can lead to diminishing its accuracy and it will be necessary to lower the class of the instrument. In Poland the levelling class of the instrument is defined based on the accuracy of the measurement of height differences and is marked with Roman numbers. Establishing the class is sometimes based on the producer's data, but the basic way of the classification are laboratory studies done in proper conditions and strictly according to the definite program.

According to the industry standard BN-78/8770-07 [6], in Poland four classes of accuracy are accepted for levelling instruments (Table 1). These classes are distinguished based on the calculated mean error $m_{\Delta h}$ of the measurement of the difference in the height between the points distant 1 km from each other, in the main and return direction:

$$m_{\Delta h} = \frac{1}{2}\sqrt{\frac{\sum (r_i)^2}{n \cdot L}} \text{ [mm/km]} , \tag{3}$$

where L is section length in km, $r_i = \Delta h_{i1} - \Delta h_{i2}$ is difference between the heights Δh measured in the main and return direction, and n is the number of the carried out measurements.

Table 1. Criteria of accuracy classes of levelling instruments. Source [5], [6]

Class	Mean error in the height difference of section $m_{\Delta h}$ [mm/1 km]
I	≤ ±0.5mm
II	(±0.5, ±2.0)
III	(±2.0, ±4.0)
IV	≥ ±4.0 mm

At the definition of the classes of levelling instruments, the mentioned earlier industrial standard [6], gives the recommended programme of measuring the difference in the height between points distant from each other of 1 km, with the application the method of the measurement „from the centre" (Table 2).

Table 2. Programme of measurements. Source [6]

Class of the levelling instrument	Number of stands	Length of the line of sight [m]	Number of measurements
I	14	40	10
II	12	50	9
III	10	60	8
IV	8	70	6

The way to determine the final value, necessary to determine the class of levelling instruments, is also defined by the international standard ISO 12857-1 [0]. According to this standard, one should four times measure the section of 1 km, in the main and return direction, putting the rods distant 50 m from each other (total 40 stands of levelling instruments).

The new standard ISO 17123-2 [0] made in 2001, introduced in Poland as PN-ISO 17123-2:2005, replacing standard ISO 12857-1:1989, which was corrected from technical point of view. Testing the levelling set, according to this standard requires two series of measurements. The first series means 20 measurements of difference in height Δh between points A and B (lines of sight 2–30 m). After each measurement the height of the levelling instruments changes only slightly. The second series is done in the same way, but the rods change their places. The analysis of the procedures recommended in individual standards indicates that the results of the studies of levelling sets obtained according to the schemes should be similar.

The classification procedure of levelling instruments is carried out in the Geodetic Metrology Laboratory located on a low level of the basement of the building of the Faculty of Mining Surveying and Environmental Engineering of the AGH University of Science and Technology in Krakow (GLM AGH). In the laboratory six levelling sets were tested: precise levelling instruments Zeiss/Trimble DiNi 11T, Zeiss/Trimble DiNi 12T, Trimble DiNi0.3, Leica NA 3003, Leica DNA03, with the sets of adequate code invar rods and one technical levelling instrument Leica Sprinter 150M, with the set of uniform fibreglass technical rods GSS113. After checking it was found that each instrument was in a proper shape and its mechanical parts worked properly, as well as the quality of optical elements was unquestioned, there was no damage or problems with work, as well all the axis-related conditions were fulfilled, such as: perpendicular situation of the tangent plane in the main point of the bubble level to the vertical main axis of the levelling instrument, perpendicular situation of the horizontal line to the main axis of levelling instruments, the horizontality of the line of sight and compensation of the inclination of levelling instrument occurs in the whole range of their activities. The rectification was not necessary.

Table 3. Results of the calculations for all the levelling instruments. Source: Authors' own work

Levelling instrument	mΔh [mm/km]	s0 [mm/km]	Producer's value [mm/km]	Class
Zeiss/Trimble DiNi 11T	0.1	0.1	0.3	I
Zeiss/Trimble DiNi 12T	0.2	0.1	0.3	I
Trimble DiNi 0.3	0.2	0.1	0.3	I
Leica NA 3003	0.4	0.3	0.4	I
Leica DNA03	0.2	0.1	0.3	I
Leica Sprinter 150M	1.2	1.2	2.0	II

After making the measurement necessary to calculate mean error $m_{\Delta h}$ (according to standard BN-78/8770-07) and the standard deviation s_0 (according to standard ISO 12857-1) double levelling for 1 km, individual values were calculated to define the class of every levelling instrument. The obtained results were calculated according to standard BN-78/8770-07 and ISO 12857-1 and are similar. For all the instruments the mean error $m_{\Delta h}$ and standard deviation s_0 are smaller or equal to those given by the producer. Based on the obtained results and table contained in standard BN-78/8770-07, the levelling instruments were given respective classes (Table 3).

Taking into account all the types of levelling instruments and the rods matching them, one can put the optimal combinations of equipment in terms of both price and quality. With the levelling instruments of Leica DNA03, DNA10 and NA3003 invar rods GPCL3 lub GPCL2 can be used and fibreglass rods GKNL4M, 4 metres long, consisting of three segments. In fibreglass rods there are rapid changes in scale on joints, up to 0.3 mm, while errors of division are up to 50 µm. In the levelling instruments Trimble DiNi invar rods LD13 and rods can be used and folded plywood rods 3×1 m (one-metre sections are joint). The accuracy of code lines is similar as in case of fibreglass rods of Leica, while translocations on the joints are of about 50 µm. Additional parameter of the assessment of the usefulness of the studied levelling instruments can be results of measurements made on similar objects in cities of similar historic origin and similar structure of buildings. The measurements of the subsidence in the old town historic objects were made, among others in the area of Krakow in 1970–2003 [0]. The changes in the height of node marks of the state observation line I, II and III class were analysed. The obtained values of subsidence, mean errors of levelling can be used in the assessment of the usefulness of a given levelling set. Apart from accuracy parameters economic factors are also important.

5. Conclusions

Based on results of the studies for levelling made in GLM AGH the recommendations connected with their later use and applications are formulated. The sets with invar rods are universal, but expensive. The alternative could be applied such as cheaper fibreglass or plywood rods, but they have serious limitations. Translocations on joints cause systematic errors, depending in a linear way on height difference between node marks. Rods, in which rapid changes on joints do not prevent from achieving the catalogue accuracy of levelling in the flat area, while the measurement, where significant de-levelling of the area occur (e.g. terraces of the Lower San Valley), the levelling instrument should be the most accurate from the offer of the given company, with invar rods in the set. Transferring it to the conditions of Jarosław one can state that in the area of the old town one can use the levelling instrument Leica DNA10 with fibreglass rods Leica Sprinter 150M with rods GSS113, Trimble DiNi 0.7 (DiNi22) with plywood rods or the one of equivalent accuracy of another company with similar instruments with similar equipment. The reference to constant points and levelling scarps in the direction of the San Valley should be made with sets allowing higher accuracy, for example Leica DNA03 or Trimble DiNi 0.3 (DiNi11, DiNi 12), with invar rods. The elements of the levelling set should be subdued to constant field control (rectification of the main condition) and in the laboratory before and after the measuring season.

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