Journal scientific and applied research, vol. 29, 2025
International Journal

ISSN 1314-6289 (Print)
ISSN 2815-4622 (Online)

Original Contribution

ERRORS WHEN USING TELESCOPIC SURVEY STAFF IN GEOMETRIC LEVELING

Ivan D. Ivanov

DEPARTMENT OF GEODESY, FACULTY OF TECHNICAL SCIENCES, KONSTANTIN PRESLAVSKY UNIVERSITY OF SHUMEN, SHUMEN 9712,115, UNIVERSITETSKA STR., E-MAIL: i.d.ivanov@shu.bg

ABSTRACT: *Geometric leveling is the most accurate method of determining the difference between two points used in surveying. By using calibrated equipment and applying the correct measurement methodology, accuracy can be achieved to a hundredth of a millimeter for individual measurement or to 0.2mm/km for double-run leveling. The equipment consists of a precision level (usually digital) and a surveying staff, which is often considered as auxiliary equipment, but in reality the surveying staff is no less important than the level itself [1]. Given the wear and tear and depreciation of the equipment, it should be periodically checked and, if necessary, calibrated. The results of the calibration allow correction of the raw data, and can also serve as a preliminary assessment and forecast of the achieved results.*

KEY WORDS: *Geometric leveling, Telescoping survey staff, Invar staff, Systematic errors.*

1. Introduction

The reason for writing this article was compromised results from geometric leveling, as the final accuracy of the results obtained differed several times compared to the error indicated by the manufacturer of the geodetic equipment. The result was established by conducting geometric leveling by two independent geodetic teams with different equipment, and at a distance of about 600 m and a displacement of about 20 m, a difference in the altitude of a single point of the order of **3.2 cm** was found with an error in the double run distance of ~2 mm (Fig. 1). These errors provoked doubts about the serviceability of the measuring equipment and necessitated some field inspections of the equipment, which can be carried out in the field, which should be carried out periodically in order to assess the condition of the measuring equipment and, above all, the condition of the telescopic code bracket, if such is used.

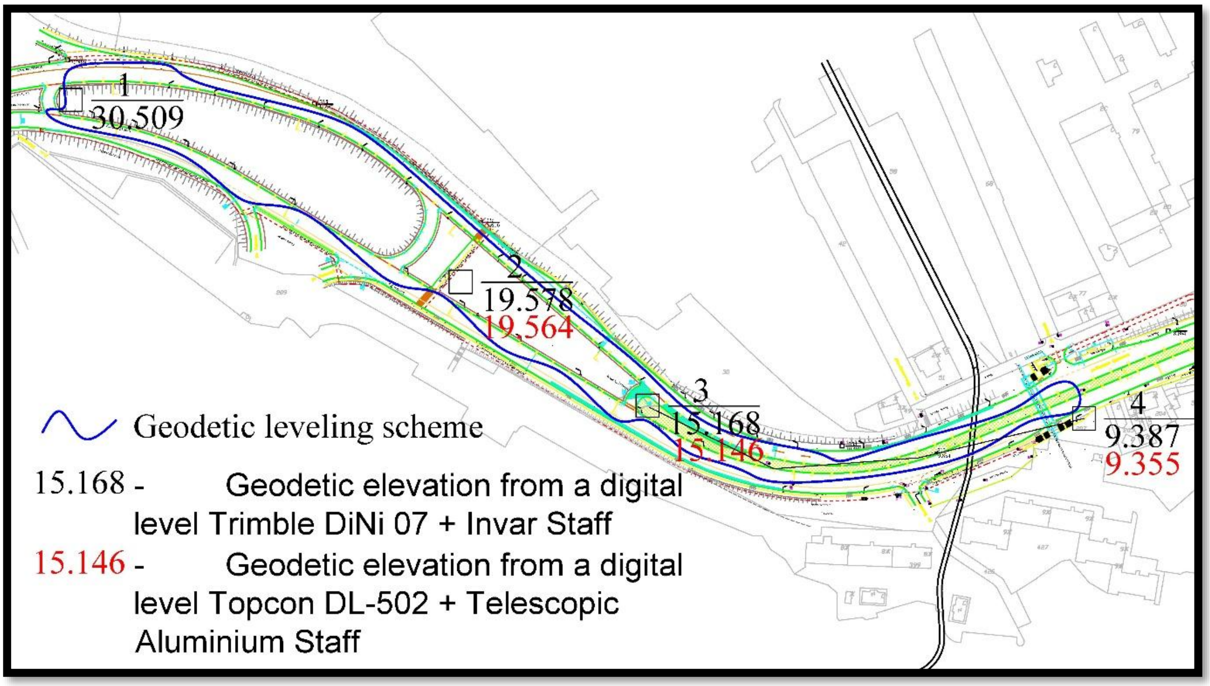

Fig. 1. Geodetic leveling scheme of an infrastructure project in the city of Varna, Bulgaria.

2. Types of errors in geometric leveling

In error theory, errors are divided not by sources, but by properties and regularities of occurrence. According to the latter signs, errors are divided into gross, systematic and random [6]. **Gross errors** have values that far exceed the expected and are mainly due to the experience and training of the operator. A typical example of this is the wrong recording of the report on the staff (changing the numbers or omitting one) or reading with an unleveled instrument. In modern digital levels, equipped with a CCD camera, allowing full automation of reading and recording of the values of the reports in the instrument's memory, this error is eliminated [5]. Despite technological progress and the digitalization of geodetic equipment, there are still modern digital levels that allow reading and recording of measurements with an unleveled instrument, which is an example of making a serious gross error when conducting geometric leveling.

Random errors have different magnitudes and signs even under relatively constant measurement conditions. These errors are due to the imperfections of the observer's senses, inaccuracies in the manufacture and adjustment of the measuring equipment, etc. [6]. As examples of random errors in geometric leveling, we can cite an error due to the different illumination of the staff [3,5], atmospheric influences, mechanical influences such as vibrations, poorly functioning compensator, etc. For random errors, the rule is also valid that their number increases proportionally to the number of stations, in contrast to systematic errors, which are proportional to the square of the number of stations

[4]. Equipment parameters indicating the achievable accuracy are usually obtained by processing numerous laboratory studies, so they also characterize the random error of the leveling equipment.

Systematic errors are those errors that, during the measurement process, retain their sign and value or change according to a certain law. Systematic errors with a constant value are detected and eliminated by changing the measurement instrument or methodology. Errors that vary according to periodic laws are eliminated by an appropriate method of measurement and/or by introducing corrections. However, some of the systematic errors are subject to very complex laws and their influence cannot be eliminated, especially in mass measurements. As examples of sources of systematic errors in geometric leveling, we can cite deformation of the parts of the staff, error of the staff spirit level, uneven base of the staff, errors in the graduation of the staff, etc. Systematic errors can also occur with a faulty level, but this is rather rare, because the malfunction of the level is more easily detected and predictable. Therefore, as the main source of systematic errors, we can point out the staff and the measurement methodology. In the methodology, the most common error is failure to comply with the basic rule in geometric leveling, which eliminates the systematic error of the level, namely - the readings from the stations in the leveling run should be at equal distances.

Leveling equipment is subject to calibration, which can correct some defects in the equipment or to derive corrections for the raw data. Calibration can be performed on the level only or on the entire equipment. When we talk about equipment calibration, this is usually the calibration of the digital level and the Invar staff, not the telescopic staff [1]. A detailed description and information on the subject can be found in [1,5,7,8,9].

In the past, leveling instruments were constructed much more simply, but with great care and precise mechanics. The users of these instruments knew more about the functioning of the instruments, and were able to quickly locate and sometimes even correct some imperfections in the leveling equipment. Today, these things are done only by the manufacturer or a licensed representative, and when imperfections are discovered and corrected, corrections are usually added to the measurement program, and the whole process remains secret, citing commercial reasons. The user in the field simply presses the button and gets “nice readings” without having the opportunity to control them. In the worst case, the user does not care about the correctness of these readings, which is indicative of the fact that levels and equipment need systematic calibration. [8].

3. Leveling equipment

For this experiment, a Trimble DiNi 07 digital level complete with an invar staff and a Topcon DL-502 digital level complete with an aluminum telescopic staff and an invar staff were used (Fig. 2). According to a specification given by the manufacturer, the Trimble DiNi 0.7 achieves an accuracy of 0.7mm/km using an invar barcode staff and 1.3mm/km using a standard telescopic barcode staff. The analogous data for the Topcon DL-502 are 0.6mm/km using an invar barcode staff and 1.0mm/km using a standard telescopic barcode staff.

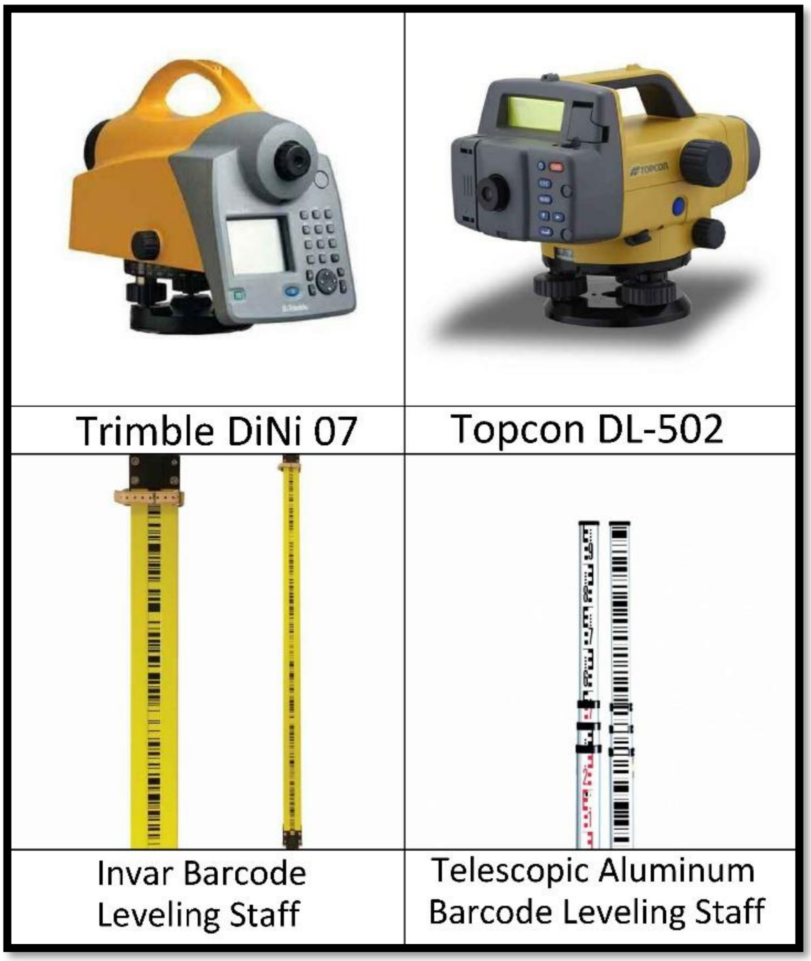

Fig. 2. Geodetic equipment used in this study.

The digital levels have been checked and calibrated annually. The telescopic staff has been stored properly in its transport case and has been used non-daily for about a year. It has not been checked until the results described in this article, although there were no visible defects or remarks on it.

4. Experiment

The experiment in this article was carried out due to the differences in the elevations of the working points obtained by two independent teams with different leveling equipment. The first team, in which the author participated, used a Topcon DL-502 digital level complete with a telescopic aluminum barcode staff, and in the control team - a Trimble DiNi 07 digital level complete with an invar staff. The distance from the starting point No. 1 to the end point is approximately 600m. When conducting the leveling, the discrepancy for the leveling stroke was 2.7mm for the double-leveled distance with the Topcon DL-502 digital level and 2.4mm for the double-leveled distance with the Trimble DiNi 07 digital level, respectively. Although the achieved error was higher than that described in the characteristics of the two digital levels (1.0mm/km for the Topcon DL-502 with a standard telescopic barcode staff and 0.7mm/km for the Trimble DiNi 07 with an invar barcode staff), the resulting error corresponded to the accuracy tolerance of this type of geodetic work.

As a result of the uniform increase in the difference between the obtained elevations from the two runs, it was assumed that there was a systematic error. Given the use of only the same staff in both runs – for the Topcon DL-502 an aluminum telescopic barcode staff, and for the Trimble DiNi an invar barcode staff, the check was mainly focused on the digital levels and the measurement methodology, respectively, compliance with the basic rule.

At the beginning, the digital levels were checked for the presence of a collimation error in the horizontal sighting axis. A detailed description of the verification and calibration methodology with the built-in programs of the digital levels is discussed in [7]. In our case, after the check, we established a collimation error for the Topcon DL-502 digital level within ≈9" and, respectively, for the Trimble DiNi 07 digital level within ≈7". With this collimation error, the above-described leveling run was performed, and according to the values before calibrating the instruments, we can assume that the error is not too large and would not affect the differences in the elevations of the points to such a large extent.

Then, the leveling run and the reports made from the two separate runs were examined in detail. The reports on the battens of both runs were also reviewed, with all reported excesses being within 0.45-2.81m. The check was also carried out in order to assess compliance with the main condition of geometric leveling, namely - the distance between the reports back and forward should be equal. The value of this error can be estimated using the formula:

$$\Delta = \frac{\delta}{p}\Delta S \quad (1)$$

where ΔS is the difference in the distances to the staffs, δ is the collimation value of the instrument, and p is a multiplier that converts the angle from radians to seconds (206265) [6]. In the leveling runs carried out, a maximum difference between the distances from a single station of the order of 5m was found in places. If we apply the above-quoted formula and calculate the error considering the collimation of the digital levels (we will use the more inaccurate and larger error of the Topcon DL-502 - 9"), we obtain an error for one measured excess of ≈0.22mm. Given the distance between the geodetic points and the slope of the terrain (≈5%), the distances of the reports to the staffs are mostly about 20m, and the number of stations for the entire leveling run is ≈30. Even if we assume that in one of the two runs (in this case for the Topcon DL-502 leveling run) all the distances between the back and forward reports differ by 5m (which is not the case in practice), the error for the entire run caused by the collimation would be ≈**7mm**, which is well below the obtained value of 32mm.

Another serious source of systematic error is the curvature of the Earth. Many modern digital levels have software that takes into account and corrects the influence of the curvature of the Earth. Trimble DiNi 07 also has such software, while Topcon DL-502 does not have a function for correcting the curvature of the Earth. This type of error is characterized by the fact that it is the same in both directions (in both reports - forward and backward), respectively, if the basic rule is followed, the error is compensated. The error can be calculated by the following formula:

$$\varDelta = \frac{S_1^2}{2R} - \frac{S_2^2}{2R} = \frac{\varDelta S(S_1 + S_2)}{2R} \tag{2}$$

where S_1 and S_2 are the lengths of the sight lines and R is the value of the Earth's radius.

For a difference between the 5m readings, the error in the excess would be ≈**0.002mm** without taking into account the value of the Earth's refraction, which reduces the effect of the Earth's curvature. Even if we assume that this error is allowed at all 30 stations, the total value would be ≈**0.06mm**.

After this general check of the condition of the digital levels, the methodology and the measurement values, we turned our attention to the staffs used. The suspicion of an error in the staffs used comes from the fact that for each telescopic staff there is a characteristic gap in the push buttons of the individual parts (Fig. 3).

In general, telescopic battens, even when brand new, have a characteristic gap in the area around the push buttons, which increases with time and depreciation of the staff. This fact is known to all users of leveling equipment, although almost no one pays attention to it. To check the serviceability of the telescopic staff, we conducted an experiment by stabilizing three metal nails on steps at different levels (Fig. 4). The levels of the nails were adjusted so as to obtain reports on the individual parts of the telescopic staff. The results are described in the diagram in Fig. 4 and are, to put it mildly, catastrophic considering that the telescopic staff was stored correctly and used for about a year. An error was noted in determining the excess between the first and second parts of the staff by 1.3mm, and between the second and third – 1.4mm.

Fig. 3. Push button lock for aluminium leveling staff

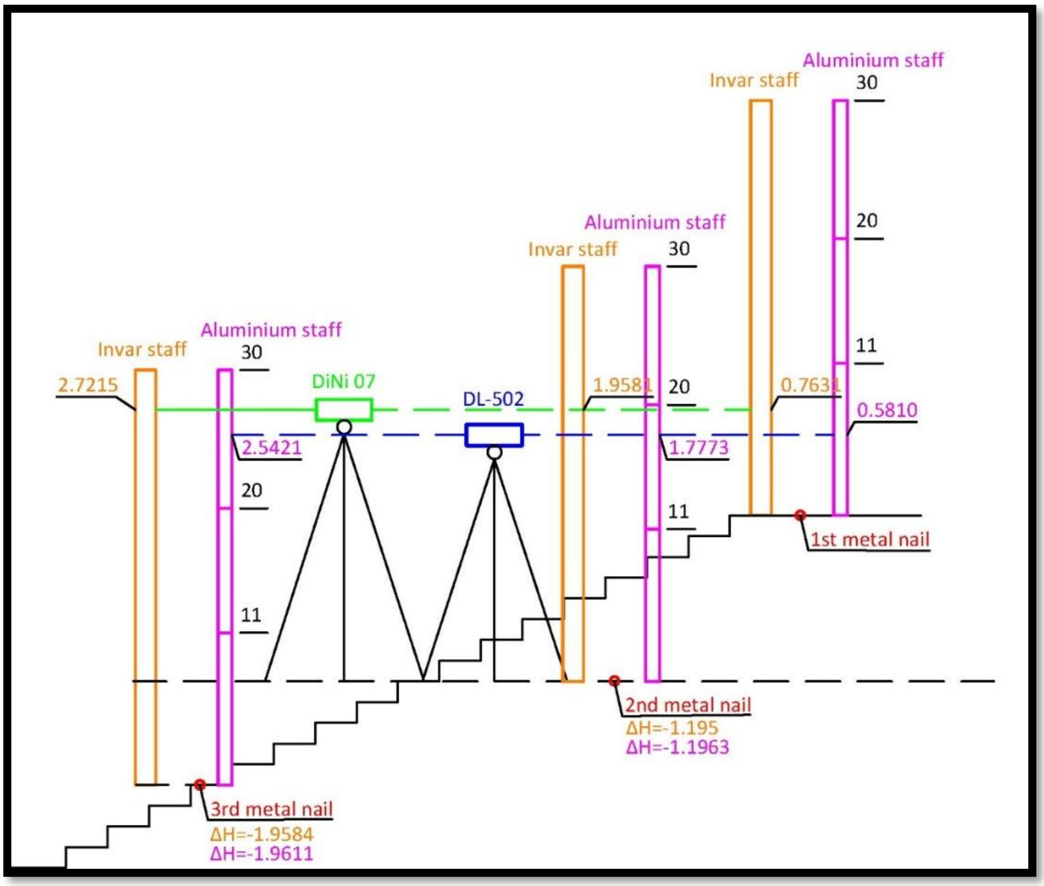

Fig. 4. Scheme of the inspection performed

The elevations of the telescopic staff are visibly increased, which leads to the conclusion that there is subsidence between the individual parts in the area of the push buttons, which is why during the leveling stroke from the higher to the lower geodetic point there was a smooth "sinking" in the elevations of the points. Since the performed leveling stroke is closed and half of the elevations are opposite, the effect of the deformation of the telescopic staff is eliminated and in practice independent control cannot be performed. As we pointed out at the beginning, the discrepancy for both leveling strokes is almost identical (2.4mm and 2.7mm), which creates the illusion that the results obtained with the telescopic staff are reliable.

After this incident, we decided to conduct another experiment by purchasing brand new staffs (one invar staff and two telescopic aluminum staffs) for the Topcon DL-502 digital level. Before they were put into operation and amortized, we repeated the same experiment. The results are summarized in figure 5.

№	Invar Staff	Telesc. Staff - 1	Telesc. Staff - 2
1	0.7120	0.7120	0.7120
2	1.7487	1.7484	1.7486
3	**2.4836**	**2.4842**	**2.4841**

Fig. 5. Results of an experiment with brand new equipment

It is noticeable that there is no error from the zeros of the staffs, but there are differences in the readings of the second and third parts of the telescopic staff. In general, the second telescopic staff shows better results, but the error in the range of the third part (2 – 3m) of both telescopic staffs is ≥**0.5mm**, which in the event of a leveling run would be of a systematic nature. This requires an adequate preliminary assessment when conducting a leveling run using a telescopic aluminum staff, because the value of the random error presented by the manufacturer (in this case **1.0mm/km**) is much lower than a possible final error. On the other hand, in a closed leveling run, the error in the elevations of single points may remain hidden, as in the example from this study.

5. Conclusion

This article focuses on a possible problem with aluminum telescopic staffs in general, **not just those used in this article**. Preliminary evaluation and verification depending on the task at hand is advisable when using telescopic battens in order to ensure acceptable end results, especially some more specific tasks such as those described in [2].

Acknowledgments

This scientific article under project number RD-08-117/06.02.2025 „Application of a specialized geographic information system for solving problems in the field of cadastre“ is funded.

References:

[1] Baričević, Sergej & Staroveški, Tomislav & Barković, Đuro & Zrinjski, Mladen. (2023). Measuring Uncertainty Analysis of the New Leveling Staff Calibration System. Sensors. 23. 10.3390/s23146358. doi.org/10.3390/s23146358.

[2] Dobrev, S. Analisys of the geodetic methods for research of deformations of hydrotechnical instalations. MATTEX 2018. Collection of scientific papers. Volume 2. Konstantin Preslavsky University of Shumen. p. 147-156. ISSN 1314-3921.

[3] Ingensand, H., 1999, The evolution of digital leveling techniques-limitations and new solutions. In Lilje, M. (ed.) The importance of heights. FIG, Gävle, Sweden: 59-68. 236.

[4] Izvoltova, Jana & Chromčák, Jakub & Smrčková, Daša. (2024). The Effect of Critical Distance in Digital Levelling. EISSN: 2079-3197 DOI:10.20944/preprints202402.0338.v1.

[5] Ježko J. (2014). Calibration of surveying instruments and tools – means to the quality increase of deformation measurements. Journal of Sustainable Mining, 13(4), 17–22. doi: 10.7424/jsm140404.

[6] Mazdrakov M., Ivanova, I. Geodesy. 2014. Publishing House of the Konstantin Preslavsky University of Shumen. ISBN: 978-954-577-987-9

[7] Rekus, Donatas & Aksamitauskas, Česlovas & Giniotis, Vytautas. (2008). Application of digital automatic levels and impact of their accuracy on construction measurements. DOI:10.3846/isarc.20080626.625.

[8] Takalo, M., Rouhiainen, P. On System Calibration of Digital Level. Ingenieurvermessung 2004 14th International Conference on Engineering Surveying Zürich, 15. - 19. März 2004. https://www.iv2004.ethz.ch/programm/poster/p_12_iv2004.pdf.

[9] Wasmeier, P.; Foppe, K. A new CCD-based technique for the calibration of levelling rods. In Proceedings of the XXIII International FIG Congress, Munich, Germany, 8–13 October 2006.