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# Satellite leveling as an alternative to classic height measurements for typical engineering problems

Mateusz Mszanik
Tadeusz Gargula✉ 0000-0003-3109-5922

Department of Geodesy, University of Agriculture in Krakow
✉ Corresponding author: tadeusz.gargula@urk.edu.pl

**Summary**

As part of this work, test measurements were carried out for the determination of the height of points by satellite levelling method with the use of real-time technology (RTK/RTN GNSS). The basis of the measurement was a specially set up (marked) grid of test points. Before starting the measurement, the satellite receiver was checked (for accuracy) on two nearby detailed matrix points. The satellite observations were repeated several times at each point in independent measurement sessions. For comparison purposes, height measurements of the test points were also taken using two classical methods: geometric levelling and trigonometric levelling. Then, based on the determined heights of the points (separately for each measurement method), the volume of earth masses was calculated for the solid formed by the test grid area and the adopted reference level. A further application of the determined point heights of the test grid was the drawing of contour lines. The criteria adopted in the comparative analysis of the obtained results were the deviation of the point height in relation to the base value (obtained from geometrical levelling), the difference in the volume of earth masses for individual measurement methods and the degree of similarity of the drawing of contour lines. Conclusions from the performed analysis will make it possible to assess the suitability of satellite height measurement using the RTK/ RTN technique for typical surveying tasks.

**Keywords**

height measurement • RTK/RTN GNSS measurement • satellite levelling • volume of earth masses

## 1. Introduction

Determining the height of a point is a basic task performed by surveyors. The choice of measurement method (geometric levelling, trigonometric levelling or satellite levelling) is decided by many factors, such as terrain, size of the area, required accuracy and access to the state geodetic control network. In order to control the results of the measurements, several independent methods can be used at the same time, for example: measuring points using the GNSS method, and then linking up with the state vertical control network using a total station or a leveller. This approach significantly reduces the possibility of coarse error, and thus mitigates the risk of incurring material costs that could result from erroneous documentation (e.g. design or inventory) and the associated consequences.

Determining the height is a very important stage in the construction process, among other things, affecting the positioning of the object in the right place in space - that is according to the design. A particularly critical topic is the determination of the height of engineering structures (viaducts, bridges) or elements of the land utility network in which the flow of materials is dependent on gravity (takes place without the participation of pumps). If the height of individual elements is not calculated correctly, the network may fail as a result of the inability of the matter to move inside the conduit, making it necessary to repair or, in the worst case, completely rebuild the structure. A definitely explicit provision regarding the responsibility for the correctness of the obtained measurement results is given by the Surveying and Cartographic Law [1989]: 'persons performing independent functions in the field of surveying and cartography are obliged to fulfil their tasks with due diligence, in accordance with the principles of contemporary technical knowledge and applicable legal regulations'.

Currently, many surveying tasks employ satellite-based methods, especially the measurement using the kinematic RTK GNSS technique. This method relies on the use of a phase measurement that is processed in real time, meaning that within a few seconds of measurement at a given point it is possible to unambiguously determine its position in three-dimensional space (e.g. plane coordinates *xy* and orthometric height *H*). The mobile receiver (positioned on the determined points) maintains communication with the stationary receiver (on a point with a known position). Determination of the position of the mobile receiver relative to the stationary receiver is possible by using observation data and corrections obtained at the reference station. The accuracy of RTK GNSS measurement decreases as the distance between the receivers increases. Another similar kinematic technique – RTN – exploits satellite signals from several fixed receivers (working on reference station points), from which a so-called virtual station (VRS) is created. The observation data or corrections are transmitted to a control and calculation centre, which automatically determines the position of the measuring receiver. Although the distance from the base stations is large (up to 80 km), the measurement results of the RTN technique do not differ in quality from those obtained with the RTK technique (at distances of less than 10 km [asgeupos.pl]). For this reason, the GNSS RTN technique is the most widely used satellite surveying method in geodesy [Ćwiąkała et al. 2015].

The role of base points when measuring with RTK/RTN techniques in Poland is usually fulfilled by reference stations of the ASG-EUPOS system [asgeupos.pl]. It is also possible to use other, commercial reference station systems. However, these systems must be part of the National Geodetic and Cartographic Resource (PZGiK) and meet certain accuracy requirements [Regulation 2020]. National reference stations are usually located on public administration buildings at voivodeship and county level, research facilities and educational buildings. They are evenly distributed across the country, with an average distance of about 70 km between them [asgeupos.pl].

The core element of the ASG-EUPOS system is the real-time provision of RTN network correction data. With their support, recipients of the service are able to make measurements in a reference system that is uniform for the whole country. Thanks to the use of various formats for the transmitted data, the system is compatible with many measurement instruments. Due to its high accuracy, the service is used for surveying, but also for the precise control of construction and agricultural machinery. On the website of the ASG-EUPOS system contractor [asgeupos.pl], there are information about the accuracy tests the system underwent. The results of these tests demonstrated that, under optimal measurement conditions, all types of correction data enable repeatability of results within ±0.03 m horizontally and ±0.05 m vertically.

It must be noted, however, that optimum conditions rarely occur during measurements. For this reason, measurements made with a GNSS receiver may be subject to error, indicating the need to monitor the obtained results. Studies on the accuracy of measurements made using RTN and RTK methods have shown that they can reach a precision of ± 0.010 m for horizontal coordinates and ± 0.020 m for height [Siejka 2008, Uznański 2012]. Nevertheless, it is important to bear in mind that obtaining such accuracies depends on many factors, such as the number of used satellite systems [Tokura et al. 2014, Siejka 2015], or the distance from the reference station [McHugh et al. 2015]. The accuracy of measurements can also depend on the specific location where the measurement is taken [Bárta 2005, Tokura et al. 2014]. Extending the measurement time has been found to increase its accuracy, namely extending it from 5 to 10 seconds improves it by 10% and extending it to 60 seconds improves it by 30% [Plewako 2012]. Measurement errors can also stem from a lack of due diligence when taking measurements and from classic errors associated with RTK/RTN methods [Kowalczyk 2011, Gawronek et al. 2015]. Changes in the constellation of satellites during the day affect the accuracy of measurements, as illustrated by the PDOP parameter [Banachowicz et al. 2008]. It has been shown that satisfactory horizontal position results can be achieved for 83% of the day, with 43% of the results within 0.010 m of the central position, demonstrating the repeatability of RTN measurements. In order to ensure the highest accuracy, repeated measurements and averaging of results are crucial [Kudas et al. 2016]. In addition, the positioning model must work correctly to avoid residual errors due to atmospheric disturbances [Próchniewicz 2014].

The aim of this study is to assess the possibility of widespread use in typical surveying work, satellite-based (GNSS) height determination methods, using real-time kinematic techniques (RTK/RTN), as an alternative to classical (terrestrial) height measurement methods (trigonometric levelling, geometric levelling). The adopted criteria for comparison include the accuracy of the acquired data and the repeatability of the acquired results. The analysis will be carried out on the basis of the measurement of a test grid consisting of 20 marked points. Using the obtained heights of the points from the different methods, earth mass volume will be calculated and the drawings of contour lines will be generated. This will allow the evaluation of these measurement methods in terms of their suitability for typical surveying tasks.

The aim of the study outlined above enables the following research hypothesis to be formulated: height measurement using real-time kinematic techniques (RTK/RTN) may be insufficient in terms of the accuracy for the execution of certain surveying tasks.

## 2. Methods and equipment

### 2.1. Measurement methods

The test height measurement was carried out using three methods:

- the RTN kinematic method using a GNSS receiver (based on the ASG-EUPOS reference station system),
- the trigonometric levelling method (with reference to the detailed state control network),
- the geometric levelling method (with reference to the detailed state control network).

The PL-EVRF2007-NH height system was used during the measurements.

Geometric levelling involves determining the height differences between individual points by measuring the vertical distances from a horizontal reference plane built over the terrain being measured. A leveller and level staffs are used for the measurement. The use of this method of height measurements is limited to flat areas or slight slopes [Jagielski 2013].

Trigonometric levelling involves determining the height difference from the measurement (with a total station) of the vertical angle and distance. It is also necessary to identify the height of the instrument and the height of the prism. The calculated height difference is a function of all measured quantities, hence the final accuracy is slightly lower than in geometric levelling. Trigonometric levelling as a method of height measurement can be used in areas with varying terrain and steep slopes [Jagielski 2013].

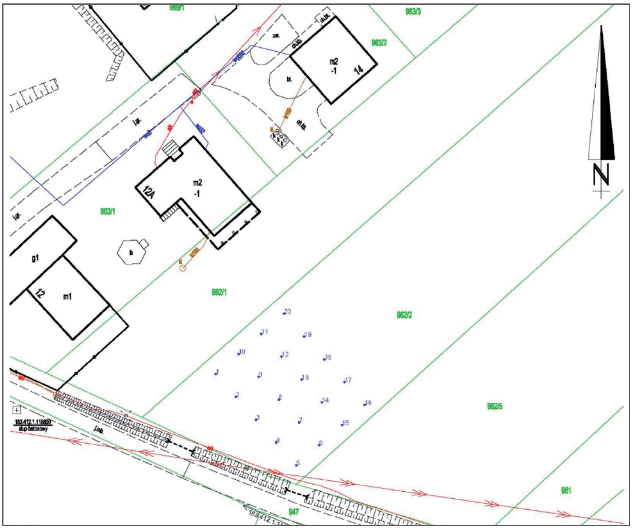
Satellite levelling is a calculation procedure leading to orthometric heights (referenced to a geoid) based on geometric heights (referenced to an ellipsoid) obtained from measurements with GNSS technique [Czarnecki 2010].

### 2.2. Object of study

The site of the test measurements was a private land plot designated as registration parcel no. 962/2, located within the boundary of Grywałd (no. 121106_2.0001), Krościenko nad Dunajcem municipality (no. 121106_2). Krościenko nad Dunajcem is situated in the southern part of Poland, in Malopolska voivodeship, in Nowy Targ county. The surveyd site is not urbanised, and features slight slopes and open space (Fig. 1). There are no trees, bushes or other objects which could affect the results of the survey fieldwork.

Source: Authors' own study based on nowotarski.geoportal2.pl

**Fig. 1.** Location of the test site (red box) on parcel no. 962/2, m. Grywałd



Source: Authors' own study

**Fig. 2.** Situational drawing of the test grid

At the site selected for the survey, 20 points were marked with stakes to form a grid of 5 × 5 m squares; their location is shown in the drawing (Fig. 2).

### 2.3. Survey equipment, field work

The test measurements were taken using a NEDO F32 optical leveller, a Sokkia FX-103 electronic total station and a GNSS receiver called ComNav T300 with an R200 controller. The following is a brief description of each of these devices and the extent to which they were utilised in the test measurements.

The F serie F32 optical leveller from German company Nedo is a robust tool for precise measurements, particularly useful in demanding construction conditions. Its parameters (including accuracy per 1 km of double levelling: ±1.5 mm: compensator accuracy: ±0.3″) [sklepgeodety.pl] provide satisfactory measurement results.

The leveller was used to determine the base heights of the survey grid points. This stage of the fieldwork was completed using the forward geometric levelling method – the height of the target axis was acquired by reading the level staff set at the point of detailed control network PP1189 (Fig. 2). The measurement was carried out very carefully, for several independently set levelling heights, and the averaged heights of the control points were taken as comparative values for the results derived from the other measurement methods (trigonometric levelling, satellite levelling).

In 2016, the Japanese company Sokkia, drawing on years of experience and observation of the measuring equipment market, introduced a new line of instruments. Sokkia's state-of-the-art devices, including the FX-103 total station, feature adequate measurement accuracy (for angle: ±5″; for distance per prism: ±2 mm + 2 ppm) [xpert-surveyequipment.com], compatibility and robustness, proving perfect for tasks requiring precision.

The total station was used to determine the height of the control points by forward trigonometric levelling. The instrument was centred and leveled over the detailed control network point 183.412-118900. After carefully measuring the height of the instrument, a situational-elevation total station measurement (vertical angle, horizontal angle, distance, obliquity, signal height) was performed, covering the masked test points. Measurement alignment was accomplished by aiming the telescope at the detailed control network point 183.412-118800, and then at the subsequent points. The situational position of the test points was needed in order to carry out the planned analyses for the exemplary surveying tasks (calculation of earth mass volumes, generation of hypsometric layers).

The ComNav T300 GNSS receiver works with existing reference station networks using RTK and RTN technology. It can be operated both as a stand-alone base receiver and as a precision receiver for static measurements. Its parameters (e.g. positioning accuracy in RTK mode: horizontally approx. ±8 mm; vertically approx. ±15 mm) [geomatching.com] make it perfectly suited for typical surveying work. Additionally, the compact dimensions and low weight ensure high mobility and are important strengths of this device.

In accordance with the recommendation of the binding Regulation [2020], field work using a satellite receiver (RTN method) began with a control measurement of the detailed geodetic network no. 183.412-118900, which is located less than 7 km from the measurement site. It was found that the results of the control measurement did not exceed the permissible values ($dx \leq 0.12$ m and $dy \leq 0.12$ m and $dh \leq 0.09$ m). In order to obtain an additional control, another detailed geodetic network point no. 183.412-118800 was measured. In this case, the results were also within the acceptable range. Next, using the GNSS receiver with controller, a connection to the ASG-EUPOS correction service [asgeupos.pl] was established. The measurement length was selected to be 30 epochs in the device settings, and the measurement on each point of the test grid was also taken 30 times (in order to detect and eliminate possible coarse errors caused by satellite signal interference).

### 2.4. Desk studies

Prior to the start of the desk studies (involving calculation), the transmission of the measurement data from the individual instruments to the computer was completed. The measurement reports were saved in *html* and *txt* formats, which were used to create input files for the WinKalk programme [coder.pl]. The height calculations of the test grid points were performed independently based on:

- results of geometrical levelling (base data for comparing the results of the other two methods),
- trigonometric levelling results (for comparison with satellite levelling results),
- the results of the satellite levelling survey (the main survey being evaluated).

In the next stage of the desk study, the volume of earth masses was calculated based on the previously obtained heights, and the results were then analysed in terms of deviations from the base data.

The heights of the points were also used to generate sketches of the contour lines for the area covered by the test grid. Visualisation of the results made it possible to compare and evaluate the accuracy of satellite levelling in relation to classical methods.

Calculations and graphs for the purposes of this study were made with the help of computer programs: Excel, Statistica, Qgis and GstarCAD 2021 [gstarcad.pl/gstarcad]. A more detailed description of the desk study and the tools employed can be found in [Mszanik 2024].

## 3. Analysis of results

### 3.1. List of point heights – deviation analysis

The results of the measurements taken using trigonometric levelling and satellite levelling methods (based on RTN GNSS measurements) were given a comparative analysis in relation to the base measurement (geometric levelling). The criterion for comparison was the height deviation (the difference between the obtained ordinate and the base value).

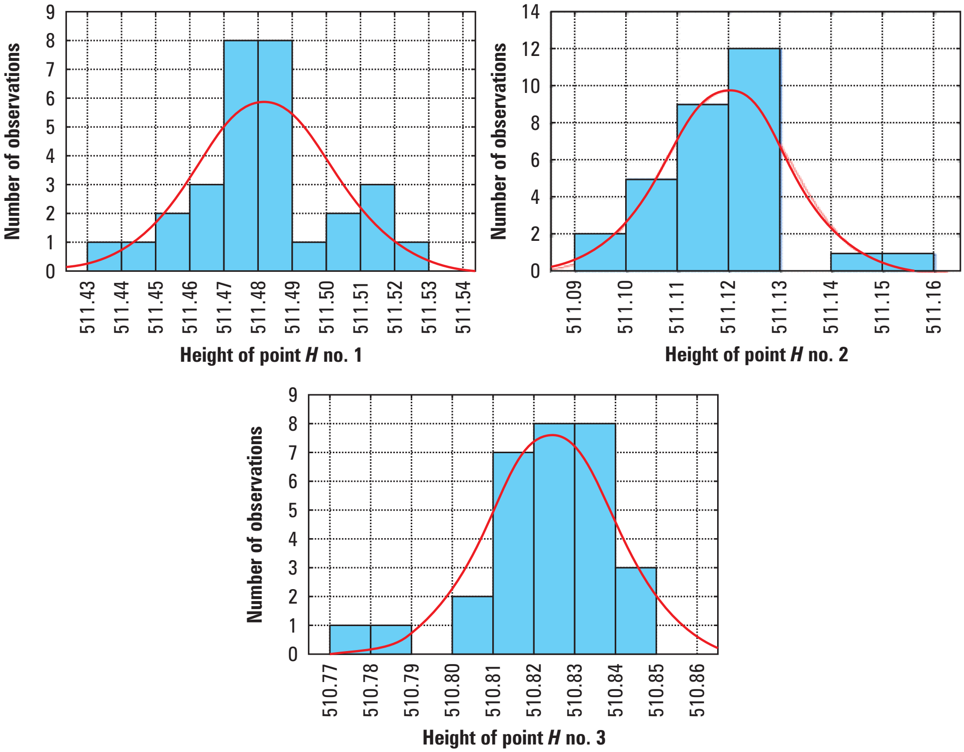
For the purpose of comparative analyses in this study, we will use a conventional definition of accuracy – understood as the value of deviation from the base results (in this case obtained by geometric levelling).

The height of each point of the test grid measured by the satellite levelling method was calculated as the average value from 30 independent measurements by a GNSS receiver. In the case there are no coarse errors in the satellite observations, the height ordinates obtained by this method can be treated as random variables - subject only to random errors. Such a thesis is confirmed by the normal (or approximately normal) distribution of heights obtained for individual points (Table 1, Fig. 3).

**Table 1.** Results from satellite levelling (for sample points 1, 2, 3)

| No. of point _ No. of measurement | $H$ [m] | $\delta H$ [m] | No. of point _ No. of measurement | $H$ [m] | $\delta H$ [m] | No. of point _ No. of measurement | $H$ [m] | $\delta H$ [m] |
|---|---|---|---|---|---|---|---|---|
| 1_01 | 511.506 | −0,024 | 2_01 | 511.152 | −0.032 | 3_01 | 510.835 | −0.011 |
| 1_02 | 511.473 | 0,009 | 2_02 | 511.143 | −0.023 | 3_02 | 510.834 | −0.010 |
| 1_03 | 511.487 | −0,005 | 2_03 | 511.104 | 0.016 | 3_03 | 510.846 | −0.022 |
| 1_04 | 511.478 | 0.004 | 2_04 | 511.103 | 0.017 | 3_04 | 510.846 | −0.022 |
| 1_05 | 511.477 | 0.005 | 2_05 | 511.107 | 0.013 | 3_05 | 510.839 | −0.015 |
| 1_06 | 511.473 | 0.009 | 2_06 | 511.107 | 0.013 | 3_06 | 510.835 | −0.011 |
| 1_07 | 511.472 | 0.010 | 2_07 | 511.103 | 0.017 | 3_07 | 510.829 | −0.005 |
| 1_08 | 511.478 | 0.004 | 2_08 | 511.115 | 0.005 | 3_08 | 510.814 | 0.010 |
| 1_09 | 511.475 | 0.007 | 2_09 | 511.115 | 0.005 | 3_09 | 510.831 | −0.007 |
| 1_10 | 511.475 | 0.007 | 2_10 | 511.122 | −0.002 | 3_10 | 510.835 | −0.011 |
| 1_11 | 511.465 | 0.017 | 2_11 | 511.129 | −0.009 | 3_11 | 510.820 | 0.004 |
| 1_12 | 511.450 | 0.032 | 2_12 | 511.129 | −0.009 | 3_12 | 510.825 | −0.001 |
| 1_13 | 511.458 | 0.024 | 2_13 | 511.130 | −0.010 | 3_13 | 510.830 | −0.006 |
| 1_14 | 511.484 | −0.002 | 2_14 | 511.118 | 0.002 | 3_14 | 510.828 | −0.004 |
| 1_15 | 511.493 | −0.011 | 2_15 | 511.116 | 0.004 | 3_15 | 510.839 | −0.015 |
| 1_16 | 511.489 | −0.007 | 2_16 | 511.126 | −0.006 | 3_16 | 510.846 | −0.022 |
| 1_17 | 511.470 | 0.012 | 2_17 | 511.130 | −0.010 | 3_17 | 510.840 | −0.016 |
| 1_18 | 511.439 | 0.043 | 2_18 | 511.125 | −0.005 | 3_18 | 510.817 | 0.007 |
| 1_19 | 511.463 | 0.019 | 2_19 | 511.120 | 0.000 | 3_19 | 510.790 | 0.034 |
| 1_20 | 511.456 | 0.026 | 2_20 | 511.123 | −0.003 | 3_20 | 510.812 | 0.012 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 1_21 | 511.484 | –0.002 | 2_21 | 511.120 | 0.000 | 3_21 | 510.827 | –0.003 |
| 1_22 | 511.483 | –0.001 | 2_22 | 511.119 | 0.001 | 3_22 | 510.809 | 0.015 |
| 1_23 | 511.484 | –0.002 | 2_23 | 511.127 | –0.007 | 3_23 | 510.824 | 0.000 |
| 1_24 | 511.484 | –0,002 | 2_24 | 511.125 | –0.005 | 3_24 | 510.825 | –0.001 |
| 1_25 | 511.484 | –0.002 | 2_25 | 511.128 | –0.008 | 3_25 | 510.827 | –0.003 |
| 1_26 | 511.501 | –0.019 | 2_26 | 511.114 | 0.006 | 3_26 | 510.814 | 0.010 |
| 1_27 | 511.519 | –0.037 | 2_27 | 511.126 | –0.006 | 3_27 | 510.811 | 0.013 |
| 1_28 | 511.522 | –0.040 | 2_28 | 511.112 | 0.008 | 3_28 | 510.808 | 0.016 |
| 1_29 | 511.517 | –0.035 | 2_29 | 511.099 | 0.021 | 3_29 | 510.811 | 0.013 |
| 1_30 | 511.520 | –0.038 | 2_30 | 511.100 | 0.020 | 3_30 | 510.780 | 0.044 |
| Average | 511.482 | | Average | 511.120 | | Average | 510.824 | |




Source: Authors' own study

**Fig. 3.** Distribution of observations (satellite levelling) for sample points 1, 2, 3

The results of the analysis involving the three measurement methods are summarised in Table 2. The satellite levelling method comes in two versions: 1) heights calculated based on 30 measurements; 2) heights calculated based on two random measurements (out of 30). The second version provides an answer as to whether it was useful to repeat multiple satellite observations on a given point. For each method (version), minimum and maximum values, median, average value, spread and standard deviation were calculated.

**Table 2.** Heights $H$ of the test points (determined by different measurement methods) and their deviations $\Delta H$ from the base level (geometric levelling)

| Measurement method → | Geometric levelling | Trygonometric levelling | | GNSS: average of 30 measurements | | GNSS: average of 2 random measurements | |
|---|---|---|---|---|---|---|---|
| Point no. | Base level [m] | $H$ [m] | $\Delta H$ [m] | $H$ [m] | $\Delta H$ [m] | $H$ [m] | $\Delta H$ [m] |
| 1 | 511.450 | 511.453 | –0.003 | 511.482 | –0.032 | 511.474 | –0.024 |
| 2 | 511.090 | 511.093 | –0.003 | 511.120 | –0.030 | 511.123 | –0.033 |
| 3 | 510.786 | 510.791 | –0.005 | 510.824 | –0.038 | 510.831 | –0.045 |
| 4 | 510.451 | 510.456 | –0.005 | 510.492 | –0.041 | 510.513 | –0.062 |
| 5 | 509.845 | 509.849 | –0.004 | 509.874 | –0.029 | 509.875 | –0.030 |
| 6 | 510.071 | 510.076 | –0.005 | 510.137 | –0.066 | 510.137 | –0.066 |
| 7 | 510.501 | 510.507 | –0.006 | 510.531 | –0.030 | 510.522 | –0.021 |
| 8 | 510.969 | 510.972 | –0.003 | 510.968 | 0.001 | 510.953 | 0.016 |
| 9 | 511.302 | 511.306 | –0.004 | 511.303 | –0.001 | 511.298 | 0.004 |
| 10 | 511.739 | 511.741 | –0.002 | 511.719 | 0.020 | 511.740 | –0.001 |
| 11 | 511.946 | 511.948 | –0.002 | 511.959 | –0.013 | 511.957 | –0.011 |
| 12 | 511.387 | 511.392 | –0.005 | 511.430 | –0.043 | 511.433 | –0.046 |
| 13 | 511.111 | 511.116 | –0.005 | 511.145 | –0.034 | 511.137 | –0.026 |
| 14 | 510.722 | 510.726 | –0.004 | 510.772 | –0.050 | 510.749 | –0.027 |
| 15 | 510.245 | 510.250 | –0.005 | 510.286 | –0.041 | 510.281 | –0.036 |
| 16 | 510.271 | 510.274 | –0.003 | 510.313 | –0.042 | 510.305 | –0.034 |
| 17 | 510.799 | 510.803 | –0.004 | 510.839 | –0.040 | 510.829 | –0.030 |
| 18 | 511.238 | 511.240 | –0.002 | 511.283 | –0.045 | 511.287 | –0.049 |
| 19 | 511.681 | 511.683 | –0.002 | 511.707 | –0.026 | 511.705 | –0.024 |
| 20 | 512.046 | 512.049 | –0.003 | 512.086 | –0.040 | 512.105 | –0.059 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Maximum | | –0.002 | | 0.020 | | 0.016 |
| Minimum | | –0.006 | | –0.066 | | –0.066 |
| Median | | –0.004 | | –0.036 | | –0.030 |
| Spread | | 0.004 | | 0.086 | | 0.082 |
| Standard deviation | | 0.001 | | 0.019 | | 0.021 |
| Average value | | –0.004 | | –0.031 | | –0.030 |

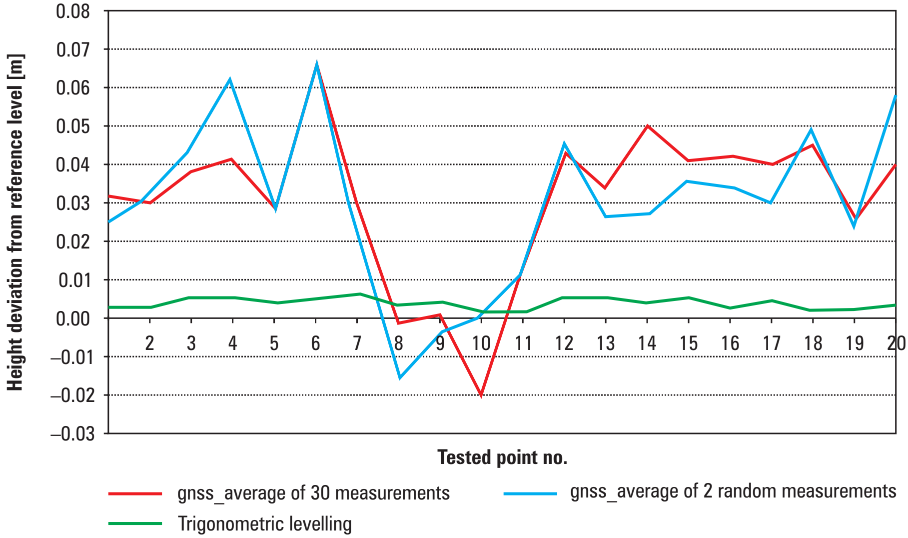
From the measurement carried out using the trigonometric levelling method (Table 2), it can be observed that the deviations Δ*H* (max = –0.002 m, min = –0.006 m) are at an acceptable level (considering the accuracy of the height measurement of the instrument reaching up to ±1 cm). What draws attention is the negative sign of the deviation at all test points, which may be related precisely to the error of the height measurement of the instrument. On the basis of the remaining parameters (range: 0.004 m, standard deviation: 0.001 m), it can be concluded that the trigonometric height measurement reaches satisfactory accuracy (compared with the results from geometric levelling).

Based on the measurement made with the GNSS receiver (average of 30 measurements), we can observe that the deviations of Δ*H* (max = 0.020 m, min = –0.066 m) are significantly larger (approx. 10-fold) than in the case of trigonometric levelling. The spread for the Δ*H* values compared above is also larger and stands at 0.086 m (approximately 20-fold increase). Similarly, the value of the standard deviation also increases (0.019 m). These analyses show that the height measurements using the GNSS receiver differ significantly from both the base measurement and the trigonometric levelling results. It should also be pointed out that some of the results do not meet the accuracy standards set by Regulation [2020].

The analysis of the satellite levelling results for the average of two random measurements shows very similar accuracy statistics to the previous case – that is the average height calculated from 30 measurements. It follows that repeated satellite observations for a given point do not entail a significant increase in accuracy.

The graph (Fig. 4) shows the height deviations between the different methods and the base measurement.

It can be inferred from the graph that, while the trigonometric method was able to achieve satisfactory accuracy on each occasion, the measurements with the GNSS receiver saw deviations for only a few test points (8, 9, 10) taking values below ± 0.020 m. In most cases, the differences oscillated between 0.025 m and 0.050 m. It is also worth noting that the GNSS measurement results differ significantly from each other (for individual points), even though they come from the same measurement session. The above analysis leads to the conclusion that the accuracy of real-time GNSS height measurements is not yet sufficient to abandon classical surveying methods.




Source: Authors' own study

**Fig. 4.** Overview of height deviations for each measured point

### 3.2. Comparison of earth mass volumes

Based on the measured heights and base data, the volumes of earth masses were calculated, and the results compared in several versions (depending on the source of the measurement data). The adopted reference level for all versions was $H = 508.000$ m. The total station survey data was used to calculate the X, Y coordinates (PL-2000 system). Table 3 shows an exemplary report on the earth mass calculation. The final results for comparative analysis are summarised in Table 4.

**Table 3.** Report on the calculation of the volume of earth masses: GNSS measurement (with 30 measurements)

| Pt no. | $X$ [m] | $Y$ [m] | $H$ [m] |
|---|---|---|---|
| 1 | 5478603.09 | 7456008.34 | 511.482 |
| 2 | 5478599.31 | 7456011.61 | 511.120 |
| 3 | 5478595.55 | 7456014.96 | 510.824 |
| 4 | 5478591.79 | 7456018.23 | 510.492 |
| 5 | 5478588.08 | 7456021.54 | 509.874 |
| 6 | 5478591.37 | 7456025.29 | 510.137 |
| 7 | 5478595.12 | 7456022.03 | 510.531 |

| | | | |
|---|---|---|---|
| 8 | 5478598.84 | 7456018.68 | 510.968 |
| 9 | 5478602.64 | 7456015.36 | 511.303 |
| 10 | 5478606.4 | 7456012.06 | 511.719 |
| 11 | 5478609.71 | 7456015.84 | 511.959 |
| 12 | 5478605.92 | 7456019.10 | 511.430 |
| 13 | 5478602.19 | 7456022.44 | 511.145 |
| 14 | 5478598.44 | 7456025.72 | 510.772 |
| 15 | 5478594.70 | 7456029.05 | 510.286 |
| 16 | 5478598.04 | 7456032.76 | 510.313 |
| 17 | 5478601.75 | 7456029.47 | 510.839 |
| 18 | 5478605.48 | 7456026.17 | 511.283 |
| 19 | 5478609.23 | 7456022.83 | 511.707 |
| 20 | 5478612.98 | 7456019.53 | 512.086 |
| Reference level: | | | 508.000 m |
| Volume: | | | 904.89 m$^3$ |
| Oblique surface area: | | | 300.4899 m$^2$ |
| Ring road area: | | | 298.9537 m$^2$ |
| Sum of areas of triangles: | | | 298.9421 m$^2$ |
| Approximate control*: | | | 858.70 m$^3$ |

* – Area multiplied by the average height of the figure

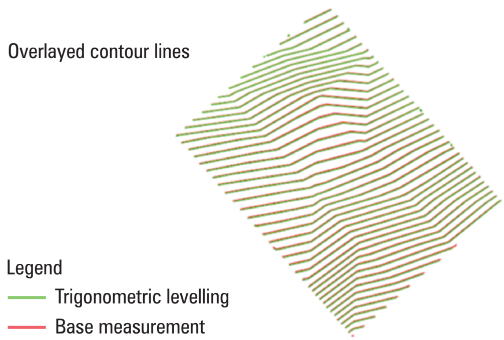
**Table 4.** Summary of earth mass volumes

| Height data source | Volume [m$^3$] | Deviation [m$^3$] | Deviation [%] |
|---|---|---|---|
| Pomiar bazowy (niwelacja geometryczna) | 896.39 | – | – |
| Trigonometric levelling | 897.56 | −1.17 | 0.13 |
| GNSS – average of 30 measurements | 904.89 | −8.50 | 0.95 |
| GNSS – average of 2 random measurements | 903.81 | −7.42 | 0.83 |

Based on a comparison of the summarised results (Table 4), it can be concluded that the closest volume to the base value is provided by the trigonometric measurement method (the deviation is slightly more than 1 m$^3$, which is about 0.1% of the total volume). In contrast, the result obtained from GNSS measurements shows a rather large difference with respect to both classical height measurement methods (approximately 8 m$^3$, almost 1% of the total volume). However, taking into account the size of the test grid, it appears that this difference translates into about 1.5 centimetres of soil on the surface of the entire grid. On the basis of this analysis, it can be concluded that, for earthworks not requiring high precision, all the analysed methods can be applied and a satisfactory accuracy of the results can be achieved.

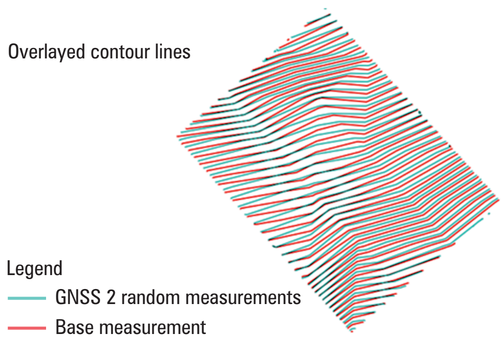
### 3.3. Comparison of contour line maps

Using the measured heights of the test points, drawings of contour lines were generated for the grid area. The necessary X, Y coordinates of the test points were calculated from the tachymetric measurement. Figures 5–7 show a comparison of the generated contour lines for the different measurement methods. A contour cut of 0.05 m was used when creating the contour lines.




Source: Authors' own study

**Fig. 5.** Comparison of contour lines for the trigonometric levelling method



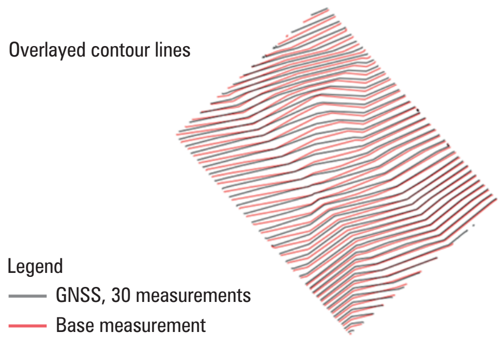

Source: Authors' own study

**Fig. 6.** Comparison of contour lines for GNSS method (average of 2 random measurements)

For the contour lines obtained with trigonometric levelling, slight differences from the base drawing can be observed (Fig. 5). However, these are not significant enough to really affect the terrain model.

In Figure 6, in contrast to the previous example (Fig. 5), a significant difference can be seen between the surveyed measurement (GNSS method, average of two random measurements) and the base measurement. It can be concluded that there is a shift of about half of the value of the contour cut.

For the GNSS version of the survey, which draws the average of 30 observations (Fig. 7), a significant difference can also be noted between the studied measurement and the base measurement. The shift of the contour lines is even greater here, and even contours with different features overlap.




Source: Authors' own study

**Fig. 7.** Comparison of contour lines for the GNSS method (average of 30 measurements)

The analyses showed that the results of the GNSS measurements deviate quite considerably from those derived from classical height determination methods. The average height deviations are about 3 centimetres, but there are also results deviating by up to 6 centimetres. Similar results were found in the studies conducted by Wyczałek [2012] and Żychowski [2011] (the results of measurements by the GNSS method also deviated from the catalogue coordinates). Thus, based on the conducted analyses, it can be argued that the levelling method using a GNSS receiver (RTK/RTN) is still not as accurate as classical measurement methods.

## 4. Summary and conclusions

The conducted studies and analyses made it possible to compare different geodetic methods of determining the height of points. Measurements made with the geometric levelling method, the trigonometric levelling method and levelling with a GNSS receiver revealed that while the first two methods practically coincide, the results obtained from measurements with a GNSS receiver differ significantly from classical measurements.

Measurements by trigonometric levelling provided satisfactory results. However, the disadvantages of this method (as well as geometric levelling) are that at least two people have to take the measurements, and a reference to a geodetic network point is required.

Some satellite measurement results exceeded the values declared by the producer of the receiver as well as by the contractor of the ASG-EUPOS system. This leads to the conclusion that the GNSS receiver is not yet able to provide satisfactory results in real-time, especially with regard to the height measurement. Moreover, the acquisition of these results took significantly longer than with the other two methods. It should also be noted that the pre-measurement check of the GNSS receiver at the detailed geodetic network point indicated deviations that were within the applicable standards [Regulation 2020]. In favour of this method is the possibility for a single person to carry out the measurement.

The result of the satellite measurements could have been influenced by interference from the ionosphere occurring at the time the measurement was taken. In order to obtain a higher accuracy of measurement, it would be necessary to use a static method of measurement. However, the increase in accuracy would have been at the expense of the time needed for the measurement itself and for postprocessing.

In conclusion, levelling with a GNSS receiver (in real time) is suitable for measurements not requiring an accuracy of more than about 5 centimetres. Under such initial conditions, satellite measurement is able to provide satisfactory results. However, if higher accuracies of the determined heights of points are required, one of the classical height measurement methods – geometric levelling or trigonometric levelling – will be the appropriate measurement method.

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