CONSIDERATIONS REGARDING ROMANIA'S LEVELING NETWORK

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The study aims to establish the degree of precision of altitude determination using the network of permanent stations managed by ANCPI in different areas of Romania.

The accuracy of determining the altimetric position in surveying works is ±5 - ±7 centimeters for the points in the geodetic network. For the Digital Terrain Model, the accuracy is ±20 - ±30 centimeters.

ANCPI through the ROMPOS application provides altitudes referenced to the nearest permanent station for any point within its range. In practice, on station the GNSS receiver on any point and get directly the altitude. The accuracy check is carried out by directly stationing the GNSS receiver on a point in the national leveling network and comparing the values: measured and from the inventory. If this is not possible, a nearby point is chosen. Here the elevation will be determined directly from the grid point by geometric or trigonometric leveling.

The purpose is to determine whether the accuracy of determining point attitudes differs from one area to another.

Key words: normal altitude, ellipsoidal altitude, geoid undulation

1. HISTORY

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Romania did not always have access to the Black Sea. Over time, the country was divided into three provinces: Wallachia, Moldova and Transylvania. The Danube was and is a transport corridor for goods from the Black Sea to Western Europe. A big part of the river is Romania's border with neighboring states. Navigators needed a system of altitudes that would allow them to constantly know the water level against a fundamental zero. Thus, the first initiative to establish a fundamental zero was taken by the European Commission of the Danube (CED) in 1586. Three hydrometric gauges were installed, two at the mouths of the river in the Black Sea Sulina and Sfântu Gheorghe and one in Tulcea .

Transylvania, which was under the rule of the Habsburg Empire, was connected to the zero level of the Adriatic Sea. Thus, in 1838, the first altitude referred to the Adriatic Sea was brought to the Danube port of Orșova. Later, in 1854, the altitude of Drencova port was also determined.

After 1877, when Romania became independent from the Ottoman Empire, it became a country bordering the Black Sea and owner of the mouths of the Danube, studies could be started to determine the zero altitude. The Military Geographical Institute installed a mean tide gauge in Constanța, near the Genovese Lighthouse. Based on two readings per day between 1896 and 1903, the average value of the level of the Black Sea was established, considered the zero level Constanța and reference plan for the general leveling of Romania.

In 1910, another tide gauge was reinstalled. Unfortunately in 1916 it was destroyed in the first world conflagration.

In December 1932 the Directorate of Marine Ports installed a margraph that still works today. This remained as the basis for establishing zero sea level by daily readings.

After 1955 the Black Sea datum was changed to the Kronstadt datum on the Baltic Sea. The reason was related to Romania's membership of the bloc of communist countries and the Warsaw Pact.

Since 1974, civil society has returned to zero on the Black Sea, the fundamental point of Constanța. The army, being in the Warsaw Pact, remained with the altitude system linked to the Baltic Sea.

2. ROMANIA'S LEVELING NETWORK

Between 1960 and 1965, the Military Topographic Directorate designed and carried out measurements in the leveling network. It was structured on four Orders, Order I being the most precise. The configuration of the First Order network is shown in figure 1. The tide gauge is the one installed in 1932. The altitude was transmitted to a landmark on the shore that became a fundamental point. Gravity measurements were also performed on the network to apply the correction.
The leveling network developed mainly along the railways because the slope of the land is constant and not very high, allowing longer stations. From the first-order network, developed along the railways, the second, third and fourth order networks were created, also along the railways or along the roads. The roads without high slope.

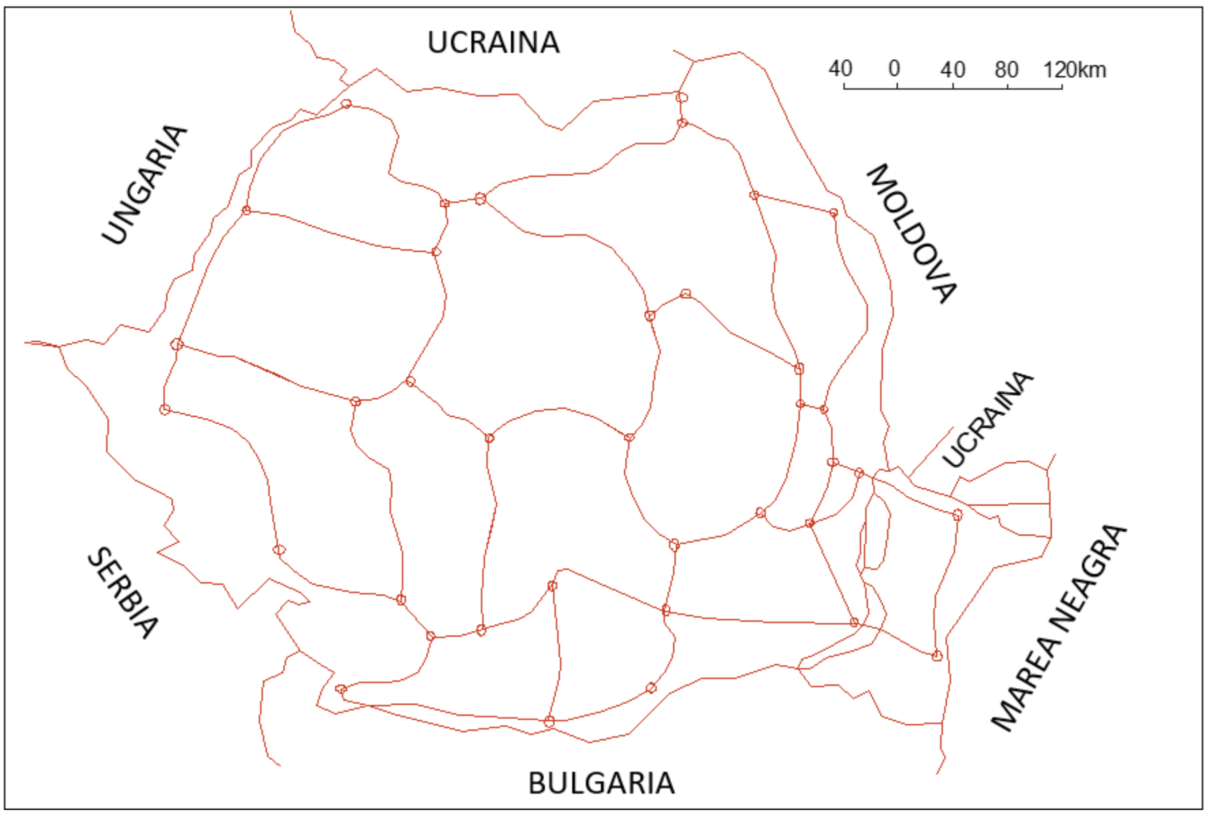

Figure 1 The leveling network of the first order in Romania

The network was compensated by the method of least squares, conditional measurements. Later the network was completed with measurements carried out by the Institute of Geodesy,

Photogrammetry, Cartography and Territorial Organization. A new offset was made resulting in the elevation of each point in the grid.
The height system is the Normal one, having as a reference surface the quasi-geoid represented by the Black Sea.
The altitude system is homogeneous and responds to the current works carried out on the territory of Romania. It is currently used and managed by the National Agency for Cadastre and Land Registration (ANCPI) through the National Cartography Center (CNC).

3. SERVICE ROMPOS

In Romania there is the ROMPOS service, aligned to the EUPOS standards, through which users of GNSS receivers can benefit from obtaining the position in real time according to permanent stations. The distribution of permanent stations is uniform throughout Romania. Each permanent station provides services within a radius of about 50 kilometers. The number of permanent stations is 75.
Romania, through the National Agency for Cadastre and Land Registration, participates in a European project called EUPOS (European Position Determination System) which aims to implement standardized positioning services.
The EUPOS initiative belongs to an international group of experts and organizations from different fields (geodesy, navigation, research, cadastre, etc.).
Partners from 18 European countries came together with the aim of establishing an interoperable space infrastructure in their countries by using the Global Navigation Satellite Systems (GNSS) GPS, GLONASS, GALILEO and creating EUPOS national service centers
Permanent stations have determined their position in the WGS84 system by linking to the EUREF network. Romania made the connection to the EUREF network in 1994 determining the first 8 stations. Later, a program was created to transform the position from the WGS84 ellipsoid into the Stereographic 1970 plane system, based on the Krasovski ellipsoid (TRNSDAT.RO). The normal elevation of these permanent stations was transmitted by geometric and trigonometric leveling from points of the national leveling network.

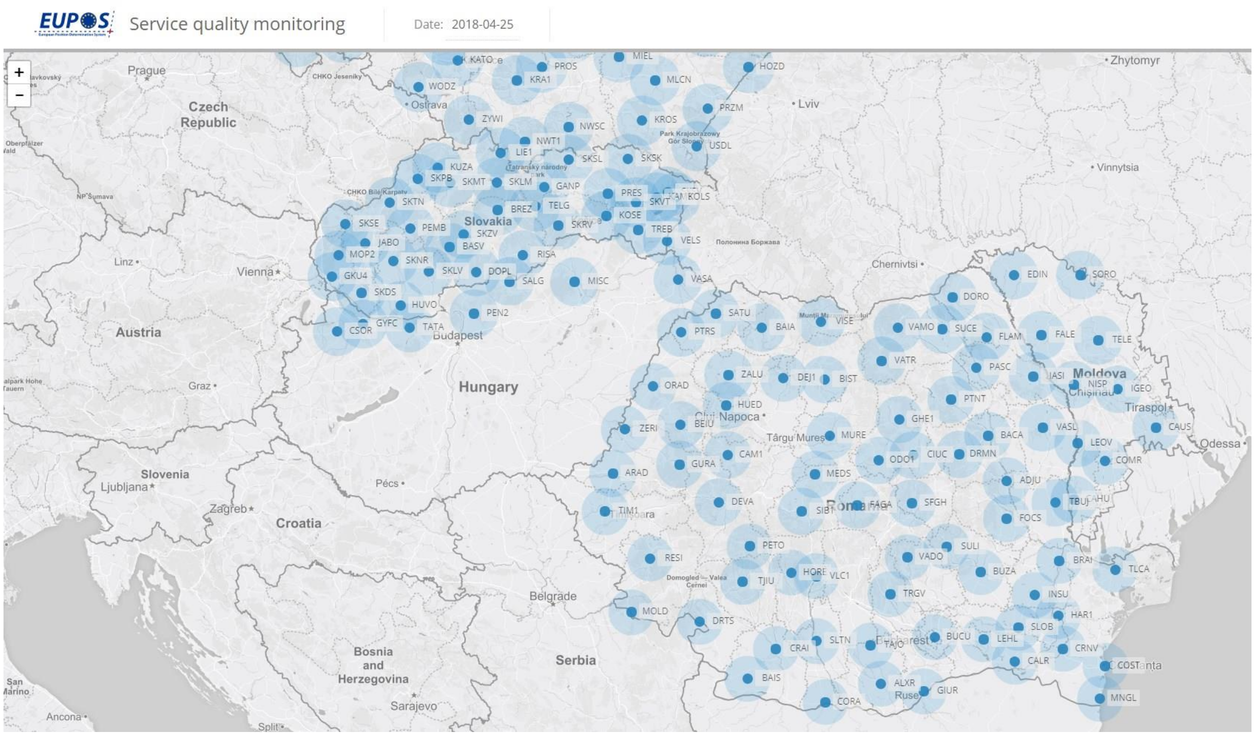

Figure 2 - ROMPOS network in Romania

Having made a geoid model, each GNSS receiver placed on a point whose position we need to determine receives the corrections of the satellites from the permanent stations for the planimetric position. The altimetric position is calculated by the program by interpolating the undulation of the quasi-geoid according to the planimetric position and the existing quasi-geoid model. In some areas this model is better, in others less accurate. This is because at this moment in Romania works are being carried out to determine the geoid. Where work has been completed the geoid model has good accuracy. Where it is not completed the accuracy is poorer.

4. THEORETICAL CONSIDERATIONS

For current works, which do not need a precision below 3 - 5 centimeters, the determination of altitudes can be achieved by expeditious methods that ensure the required precision. Geometric leveling is a very accurate but expensive method. For this reason the combination of less expensive methods for determining altitudes is preferable.
As methods for determining altitudes, we can use geometric leveling, trigonometric leveling or GNSS technology. The first two, as I specified are expensive and additionally require a connection to a point of known elevation and a leveling trip.

The GNSS technology is the cheapest and most efficient, but there is the problem of determining the undulation of the geoid or the quasi-geoid, the quantities denoted by N and ξ – Figure 3.
Given these considerations and the fact that ANCPI does not assume the accuracy of the geoid (quasi-geoid) determination, we tried to find solutions so that the determination of the altitude of a point using GNSS technology was verified from at least two determinations.

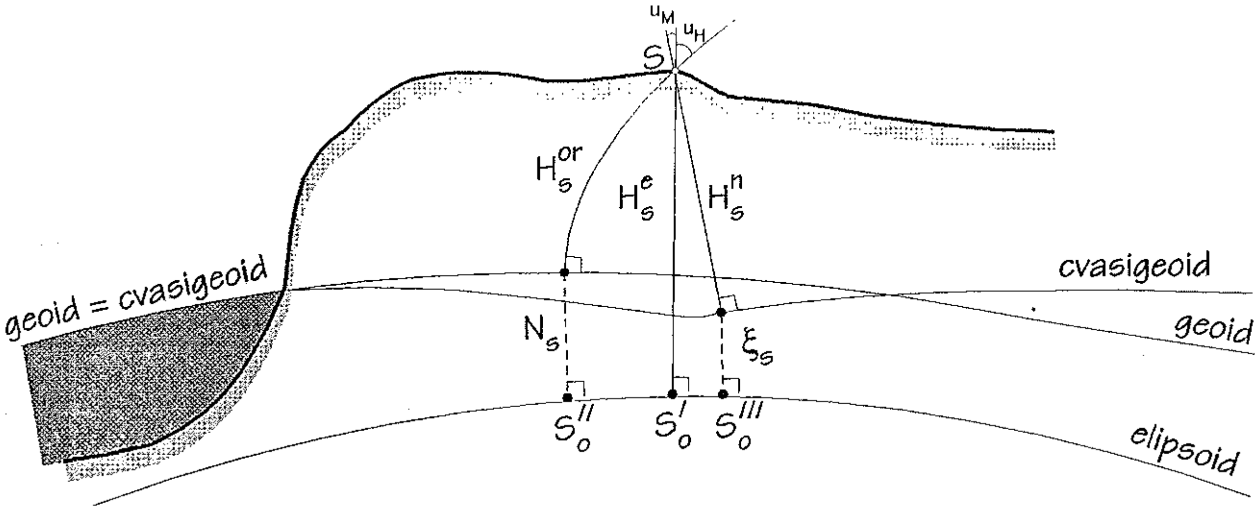

Figure 3. Altitude systems

The first solution is to perform point position determinations using dual-frequency GNSS receivers, the ROMPOS method. The planimetric position in the national Stereographic 1970 system is confirmed by ANCPI through CNC with a precision of ± 3-5 centimeters. The CNC specifies on the website that the accuracy of the normal altitude is about 20 centimeters. Following the measurement, we have confirmed the altitude referred to the WGS84 ellipsoid, with a precision usually below a centimeter.
In order to achieve better accuracy for normal altitudes than shown on the CNC site we will try to solve using real-time GNSS measurements combined with data from other sources.

4.1 Using existing geoid models

Having the planimetric position obtained through real-time GNSS measurements, we can position the determined point on the EGM 2008 or EGM 96 international geoid map. Having the altitude referred to the WGS84 ellipsoid and the undulation of the quasi-geoid at that point, with the help of formula (1) we can determine the normal altitude of that point .

$$h_S^N = h_S^W + \xi_S^W \quad (1)$$

In which:

- h_S^N is the normal elevation of point S;
- h_S^W is the ellipsoidal elevation referred to the WGS84 ellipsoid of point S;
- ξ_S^W is the waviness of the quasi-geoid referenced to the WGS84 ellipsoid of the S point.

The h_S^W value is determined directly with the GNSS receiver and ξ_S^W is extracted from the international geoid map.

4.2 Using the quasi-geoid undulation difference

This approximation can be used on small areas, with a maximum radius of 10 kilometers because the difference in undulation would be more difficult to calculate.
The starting hypothesis is that at point S we know the undulation of the geoid with centimeter precision.
The basic idea is that the difference in level measured between two points is equal to the difference in altitude of the two points:

$$\Delta h_{SA}^N = h_A^N - h_S^N \quad (2)$$

In which:

- Δh_{SA}^N is the normal level difference between points S and A on the earth's surface;
- $h_A^N \, and \, h_S^N$ are the normal elevations of points S and A.

Given formula (1), the normal elevation of a point is equal to the ellipsoidal elevation of that point plus the undulation of the quasi-geoid of that point. In formula (2) we replace the normal altitude with formula (1).

Result:

$$\Delta h_{SA}^N = h_A^W + \xi_A^W - (h_S^W + \xi_S^W) \quad (3)$$

$$\Delta h_{SA}^N = h_A^W - h_S^W + (\xi_A^W - \xi_S^W) \quad (4)$$

We note:

$$\Delta h_{SA}^W = h_A^W - h_S^W \quad (5)$$

Where Δh_{SA}^W is the ellipsoidal level difference referenced to the WGS84 ellipsoid, calculated from the GNSS receiver measurements on the two points A and S.

From here it follows:

$$\xi_A^W - \xi_S^W = \Delta h_{SA}^N - \Delta h_{SA}^W \tag{6}$$

From here we can get an approximate value for the normal level difference between a permanent station and a point whose altitude we want to determine – point B:

$$\Delta h_{SB}^N = \Delta h_{SB}^W - (\xi_A^W - \xi_S^W) \tag{7}$$

On very small surfaces the difference in geoid undulations can be considered the same. For larger distances, i.e. over 1 kilometer, we can calculate the correct difference from the international geoid map.
Between the method described in the previous point and this one, there seem to be no differences because we still use the international geoid map. The difference is that we started from the idea that the undulation of the quasi-geoid at point S is very precisely known. Also, even if the absolute value of the undulation of the quasi-geoid on the international map is not very accurate, the difference in undulation between the two points is correct. The undulation difference can be determined from the values read on the international map and added to the ellipsoidal level difference on the WGS84 ellipsoid – formula (7). Or you can directly enter the value in formula (7) for the term $-(\xi_A^W - \xi_S^W)$.

Applying formula (7) to determine the altitude of a point, we will have:

$$h_B^N = h_S^N + \Delta h_{SB}^N \tag{8}$$

In which:
- h_B^N is the normal elevation of point B;
- h_S^N is the normal altitude of the permanent station S;
- Δh_{SB}^N approximate normal level difference between permanent station S and new point B.

Since the h_B^N value is determined from several permanent stations, the final value is the arithmetic mean, if it falls within a tolerance of ± 3 centimeters.
The final value is calculated with the formula:

$$h_B^N final = h_B^N + c \tag{9}$$

In which:
- $h_B^N final$ is the final elevation of the new point;

- c is the correction calculated by the international geoid map between point A and point B.

$$c = h_A^{N*} - h_B^{N*} \quad (10)$$

In which:

- h_A^{N*} is the normal altitude of point A, extracted from the geoid map;
- h_B^{N*} is the normal elevation of point B, extracted from the geoid map

4.3 Checking the two values obtained.

If they are close and fall within the tolerance of ± 7 centimeters, the average can be done.
Another check is the alignment against the value obtained by the ROMPOS service with the TRANSDAT program. If the point is in the geoid area determined by the CNC then the values should be close. If the point is in the working geoid area, then the obtained value is only informative.

5. CASE STUDY

GNSS measurements were made for two points in the first-order leveling network of Romania. The stay at each point was two hours. The distance between the points is 7.65 kilometers. The connection to the EUREF network was made through permanent ANCPI stations.

5.1 Reporting points on the international geoid map.

From Chapter 4.1 it follows that the two points, R07 and R08 are reported on the international geoid map and we obtain the altitude of the two points directly – Table 1.
Having the altitude of point R07 we can compare the result and correct the geoid undulation value with the resulting difference between the value taken from the map and the calculated value.

Table 1. The geoid separation value

Points Name	Latitude	Longitude	Ell. Height (m)	Elevation (m)	Geoid Separation (m)
7	46°34'02.00475"N	26°04'44.10912"E	755.866	718.577	37.290
8	46°31'47.43934"N	26°08'49.57318"E	682.197	645.222	36.975

Table 2 – Position of points R07 and R08 resulting from GNSS measurements and transformation to National Stereographic System 1970.

Point name	Normal height h^N (m) from the leveling network	Plane coordinates Stereographic 70/MN75 – calculated with TRANSDAT		Normal height h^N (m) calculated with TRANSDAT	Three-dimensional coordinates on the WGS 84 ellipsoid		
		X (m)	Y (m)	h(m)	Latitude	Longitude	h^W (m)

R07	718,7194	563629,792	582818,677	718,624	46°34'02.00476"N	26°04'44.10913"E	755,8664
R08	645,35142	559549,282	588104,932	645,25	46°31'47.43935"N	26°08'49.57318"E	682,1968

The geoid undulations calculated on the WGS84 ellipsoid have values of 37.290 and 36.975 meters for points R07 and R08.
Given the ellipsoidal altitude, we will calculate the anomalous altitude for the two points:

$$h_{R07}^{N} = h_{R07}^{W} + \xi_{R07}^{W} = 755{,}8664\text{m} + 37.290\text{m} = 718{,}5764\text{m}$$
(11)

$$h_{R08}^{N} = h_{R08}^{W} + \xi_{R08}^{W} = 682{,}1968\text{m} + 36.975\text{m} = 645{,}2218\text{m}$$
(12)

Comparing with the normal altitude determined by leveling we notice the difference:

$$h_{R07}^{N} din\ niv - \ h_{R07}^{N} din\ harta = 718{,}7194\text{m} - 718{,}5764\text{m} = 0{,}1430\text{m}$$
(13)

$$h_{R08}^{N} din\ niv - \ h_{R08}^{N} din\ harta = 645{,}35142\text{m} - 645{,}2218\text{m} \ = 0{,}1296\text{m}$$
(14)

From here it follows that between the altitude determined by geometric leveling and the altitude calculated from the result of GNSS technology, applying the undulation, we have a difference of about 13 cm.
The accuracy is at the lower limit.
Compared to the altitude achieved with the ROMPOS application, the differences are smaller and within the required tolerance.

$$h_{R07}^{N} TRANSDAT - \ h_{R07}^{N} from\ map = 718{,}624\text{m} - 718{,}5764\text{m} = 0{,}0476\text{m}$$
(15) (13)

$$h_{R08}^{N}\ TRANSDAT - \ h_{R08}^{N} from\ map = 645{,}25\text{m} - 645{,}2218\text{m} \ = 0{,}0282\text{m}$$
(16)

5.2 Use of formula (7).

Table 3 – Coordinates of the permanent stations from which points R07 and R08 were calculated

Point name	Plane coordinates Stereographic 70/MN75		Normal height h^N (m)	Three-dimensional coordinates on the WGS 84 ellipsoid		
	X (m)	Y (m)	h(m)	Latitudine	Longitudine	h^W (m)
CIUC	540463,243	561782,523	690,9265	46°21'39.71650"N	25°48'05.20507"E	729,2185
DRMN	542054,572	614780,813	354,5119	46°22'06.48833"N	26°29'25.86080"E	389,5374

FAGA	482937,789	497685,845	435,9626	45°50'46.21364"N	24°58'07.15110"E	475,9779
NEHU	436102,969	602031,375	406,3186	45°25'01.99673"N	26°18'08.39192"E	440,7345
SFGH	485489,514	561313,704	542,9348	45°51'59.08747"N	25°47'17.78765"E	580,7151

Although both point R07 and R08 have the altitude determined by high-precision leveling because they are part of the national network of the First Order of leveling of Romania, we consider that only point R07 has the altitude determined by leveling. With the help of formulas 1 – 10 we will calculate the altitude of point R08.

Table 4 – calculation of the approximate normal Altitude h^N of point R08.

From - to	Normal level difference h^N (m)	Elipsoidal level difference h^W (m)	Geoid unulation difference $\xi_{R07}^W - \xi_S^W$ (m)	From - to	Elipsoidal level difference h^W (m)	approximate normal level difference h^N (m)	Approximate normal elevation h^N (m) of point R08
R07 - CIUC	27,9304	26,6801	1,2503	R08 - CIUC	-46,9787	-45,7284	645,0606
R07 - DRMN	364,3594	366,3785	-2,0191	R08 - DRMN	292,7163	290,6972	645,0572
R07 - FAGA	282,8744	279,8759	2,9985	R08 - FAGA	206,2221	209,2206	645,0656
R07 - NEHU	312,5304	315,1883	-2,6579	R08 - NEHU	241,4783	238,8204	645,0094
R07 - SFGH	175,8824	175,1874	0,695	R08 - SFGH	101,5204	102,2154	645,0524

The average of the values is 645.0490 m. The accuracy is ± 2.4 centimeters.
The result obtained in chapter 5.1 shows the correction value for determining the normal altitude of point R08.

$$c = 0{,}319\ meter \quad (17)$$

The value of the normal altitude of point R08 according to formula (9):

$$h_{R08}^N final = h_{R08}^N + c = 645{,}049 + 0{,}319 = 645{,}368\ m \quad (18)$$

Comparing with the R08 altitude value from Table 1, determined by geometric leveling, namely 645.35142 meters, a difference of 1,6 cm.

5.3 Altitude determination using TRANSDAT

The elevation of points R07 and R08 was calculated from the data taken with the GNSS receiver, the static method, relative to the permanent stations, using a general quasi-hygoid model by ANCPI.
The altitude values of the two points are:

h_{R07}^{N}= 718,624 meters

h_{R08}^{N}= 645,250meters

6. CONCLUSIONS.

All three variants of the case study provide sufficient accuracy for current work. These works can be cadastre, photogrammetry, LiDAR, etc.

Table 5 – normal altitude values for points R07 and R08

	Geometric leveling	Variant 5.1	Variant 5.2	Variant 5.3
R07	718,7194	718,5764		718,624
R08	645,35142	645,221	645,368	645,25

Considering the value obtained by geometric leveling as the correct one, we calculated the differences between this value and the other calculated values.

Table 6. The difference in altitude values

	Geometric leveling minus version 5.1	Geometric leveling minus version 5.2	Geometric leveling minus version 5.3	Version 5.1 minus version 5.3
R07	0,143		0,0954	-0,0476
R08	0,13042	-0,01658	0,10142	-0,029

The values closest to the normal altitudes determined by geometric leveling are those from version 5.2. These are within tolerance. The difference being 1.6 centimeters, the method can be used for any type of work.

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