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Determination of normal heights in the area of Polish Economic Zone

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ABSTRACT: The article presents a method of determining the level of the seabed in the Polish reference system. The authors show how to determine the ellipsoidal height of the seabed using GNSS measurements and single-beam echo sounders. The authors propose the transition to the system of normal heights referred to the average level of the North Sea as defined by the tide-gauge in Amsterdam to be made using the EGM 2008 model and data from the official Polish quasi-geoid model as well as data from another model distributed by GUGiK (Head Office of Geodesy and Cartography). The article presents also potential errors of the presented method.

1 INTRODUCTION

The determination of the height in the vertical reference frame in force in Poland is based both on national regulations (Council of Ministers Regulation, 2012) and on the resolution adopted by the EUREF subcommittee (EUREF Symposium, 2000). Currently, the PL-KRON86-NH vertical reference frame is in use in Poland – a normal height system referred to a quasi-geoid of the average level of the Baltic Sea determined by the zero level of the mareograph in Kronstadt. According to the Regulation, by the end of 2019, Poland will adopt the PL-EVRF2007-NH vertical reference frame, i.e. a normal height system referred to the average level of the North Sea defined by the zero level of the mareograph in Amsterdam. The ellipsoidal height of a point on the sea surface, for example on a drilling platform, can be determined using GNSS observations with the use of RTK network technology implemented on the ASG-EUPOS network. The evaluation of the potential use of this technique in the offshore area was the subject of prior research (Rogowski et al., 2015). The cited work involved a number of measurement experiments conducted to evaluate the usability of the ASG-EUPOS system with the use of RTK/VRS technology. Data for correction was obtained via the Internet from Orange mobile network. In the offshore area, discrepancies in the horizontal component reach up to 3 cm because the RTK/VRS correction is extrapolated. Since the height component is determined with an error twice as large, one can estimate that it will be determined with an error of up to 5 centimetres. Another problem is the range of mobile network which covers almost the whole Gulf of Gdańsk but in the coastal zone does not exceed 10 Mm. These are only estimates because, unfortunately, network administrators do not want to share any data. The transition to the normal height in the Amsterdam system requires the knowledge of the height anomaly obtained, as we propose, from the EGM 2008 geoid model and the correction of the quasi-geoid to the average North Sea level. For this purpose, we suggest to use data from the official Polish quasi-geoid model and data from another model distributed by GUGiK. The next step is to determine the height of a point above the sea floor. In this case, we can use an echo sounder or employ methods typical for underwater mining.

2 DESCRIPTION OF THE METHOD

2.1 *Geodetic height systems*

The fundamental concept in height systems applied is the so-called geopotential number **C**. It is equal to the difference between the potential of the geoid W_0 and of the point on the surface of the Earth W_P. The following relationship can be shown between the geopotential number **C**, gravitational acceleration **g** and the height **h**.

$$C = W_0 - W_P = \int_0^P g\,dh$$

Depending on the gravitational acceleration used to determine the height system, we may receive:

- H^{ort} – orthometric height system

$$H^{ort} = \frac{C}{\bar{g}}$$

where:
$\bar{g}$ – average value of gravitational acceleration between the geoid and the physical surface of the Earth.

- H^{nor} – normal height system

$$H^{nor} = \frac{C}{\bar{\gamma}}$$

where:
$\bar{\gamma}$ – the average value of normal gravitational acceleration along the vertical line of the normal gravity field.

- H^{dyn} – dynamic height system

$$H^{dyn} = \frac{C}{\gamma_0^{45^\circ}}$$

where:
$\gamma_0^{45^\circ}$ – the normal gravitational acceleration for latitude 45°.

The normal acceleration of gravity is related to the concept of equipotential ellipsoid that meets the following conditions:

- The size and shape of the ellipsoid correspond to the assumed ellipsoid that best approximates the geoid,
- The mass of the ellipsoid is equal to the mass of the Earth.
- The angular velocity of the ellipsoid spin ω corresponds to the velocity in the rotation of the Earth.
- The surface of an ellipsoid is by definition an equipotential surface with potential U_0. This potential is equal to the potential on the geoid W_0.

This condition is as follows:

$$U_0 = W_0 = const$$

Normal acceleration is equal to:

$$\gamma = gradU$$

The applicable global GRS 80 reference system can be represented by the following relationship:

$$\gamma = 9.780327 \cdot \left(1 + 0.0053024 \cdot sin^2\varphi - 0.0000058 \cdot sin2\varphi \ldots\right) ms^{-2}$$

where:
φ – latitude.

The vertical gradient of gravitational acceleration can be calculated using the formula:

$$\frac{d\gamma}{dh} = -\frac{\gamma}{a}\left(1 + f + q - 2fsin^2B\right)$$

where:
a – semi-major axis of ellipsoid,
f – flattening of the ellipsoid,
B – ellipsoidal width,

$$q = \frac{\omega^2 a^2 b}{GM}$$

3 THE PRINCIPLE OF DETERMINING THE NORMAL HEIGHT OF A POINT AT SEA LEVEL

The principle of determining the normal height of a point at sea level, e.g. a drilling platform, research vessel, etc. is shown in Figure 1.

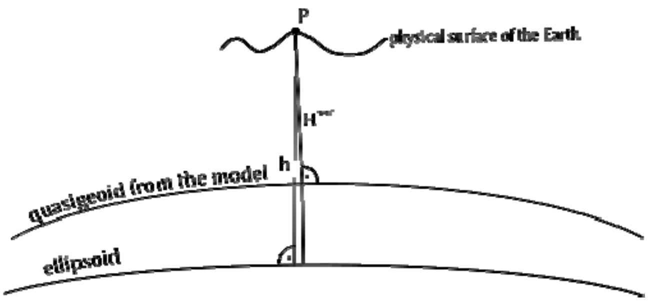

Figure 1 Determining the normal height of a point at sea level

As follows from the principle presented in Figure 1, the quasi-geoid model is required in order to determine normal height. We propose to use the EGM 2008 model. The official Earth Gravitational Model EGM2008 has been publicly released by the U.S. National Geospatial-Intelligence Agency (NGA) EGM Development Team. This gravitational consists of spherical harmonic coefficients complete to degree and order 2159, and contains additional coefficients extending it to degree 2190 and order 2159. For this model, there are online calculators available on the following websites: http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/, http://icgem.gfz-potsdam.de/ICGEM/, http://www.softpedia.com/get/Science-CAD/AllTrans-EGM2008-Calculator.shtml. These calculators allow you to determine the height of a quasi-geoid with a relatively high accuracy (3 – 5 cm) and grid resolution (1' x 1'). For the area we are interested in, we can create a map that can further be used to determine the value corresponding to the object position. An example of such a map for Gulf of Gdańsk is shown in Fig. 2 (Pałczyńska, 2017).

The fact that all of the above calculators use the WGS 84 ellipsoid proves to be problematic. A slight difference in the parameters of the WGS 84 and GRS 80 ellipsoids can be found in the data obtained from the abovementioned calculators.

Table 1.

Parameters	WGS 84	GRS 80
a	6 378 137	6 378 137
1/f	298.257 223 563	298.257 222 101

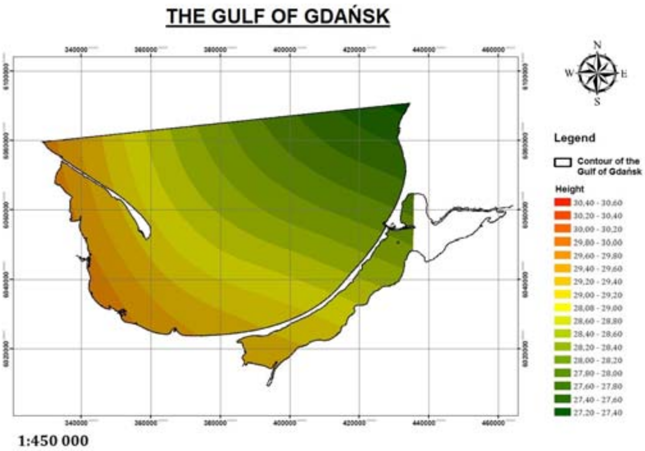

Figure 2 Map of EGM 2008 quasi-geoid for Gulf of Gdańsk (Pałczyńska, 2017)

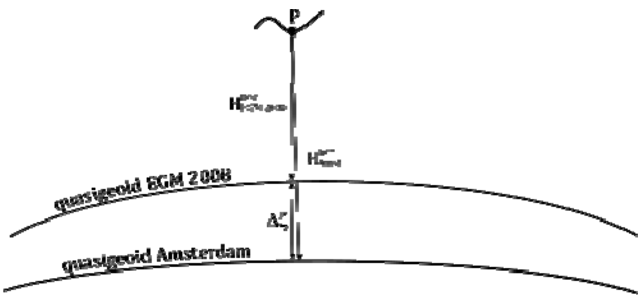

Figure 3 Normal height correction referred to the EGM 2008 quasi-geoid to the Amsterdam system.

Normal heights for the PL-EVRF2007-NH system can be determined using Δζ correction for data from the EGM 2008 model and data from official models published at http://www.gugik.gov.pl/bip/prawo/modele-danych. The transition from the normal heights referred to the EGM 2008 quasi-geoid to the quasi-geoid passing through the zero level of the mareograph in Amsterdam is shown in Figure 3.

Calculating the height of the sea floor requires the knowledge of the height difference between the position of the GNSS antenna and the seabed. It can be determined with an echo sounder or with other methods used in underwater mining.

4 SUMMARY AND CONCLUSIONS

The data necessary for the transition from PL-KRON86-NH high reference system to PL-EVRF2007-NH system is available on the website of the Head Office of Geodesy and Cartography at the following address: http://www.gugik.gov.pl/bip/prawo/modele-danych. The data to determine the correction to the EGM 2008 quasi-geoid in order to calculate a height in the PL-EVRF2007-NH system can be obtained through the comparison of the data from the Polish official quasi-geoid model available at http://www.gugik.gov.pl/__data/assets/text_file/0017/1844/gugik-geoid2011.txt and data from the EGM 2008 model. The authors estimate that the error in the determination of the seabed height in the PL-EVRF2007-NH frame amounts to about 10 cm.

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