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NEW ELABORATION OF GRADIENT MAP OF VERTICAL CRUSTAL MOVEMENTS IN THE TERRITORY OF POLAND

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K e y w o r d s: vertical crustal movements, gradient map, precise leveling.

A b s t r a c t

The goal of this elaboration was to elaborate the map of vertical crustal movements gradients in the territory of Poland. This paper describes general characteristic of leveling data from last two leveling campaigns as well as the method of evaluation. Earlier gradient map from 1990 is also discussed. The map of gradients with an accuracy estimate is a result of this work.

NOWE OPRACOWANIA MAPY GRADIENTÓW PRĘDKOŚCI PIONOWYCH RUCHÓW POWIERZCHNI SKORUPY ZIEMSKIEJ NA OBSZARZE POLSKI

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S ł o w a k l u c z o w e: ruchy pionowe skorupy ziemskiej, mapy gradientów, niwelacja precyzyjna.

A b s t r a k t

Celem pracy było opracowanie map gradientów prędkości pionowych ruchów powierzchni skorupy ziemskiej na obszarze Polski. W artykule przedstawiono ogólną charakterystykę materiału niwelacyjnego z ostatnich dwóch kampanii niwelacji precyzyjnej oraz sposób opracowania map gradientów. Odniesiono się także do wcześniej opracowanej mapy gradientów z roku 1990. Efektem jest mapa gradnientów wraz z oceną błędów średnich ich wyznaczenia.

Introduction

First attempts to determine the vertical crustal movements in Poland were taken in the late fifties. This works resulted in three maps of vertical crustal movements (WYRZYKOWSKI 1971, 1985a, KOWALCZYK 2006a). The first vertical crustal movements elaboration in Poland was made in 1960 on the basis of common leveling lines from 1952–1958 (I i II order) and 1926–1937 (I order) campaigns. These lines did not create leveling loops (NIEWIAROWSKI, WYRZYKOWSKI 1961). The method used to obtain the vertical crust movement was based on the comparison of two adjusted networks fixed at the same point for which the height was assumed to be zero (NIEWIAROWSKI, WYRZYKOWSKI 1961).

Second and third attempt to derive vertical crustal movements in Poland was based on much larger data set, with different methods for movement speed computation. The comparison of this methods can be found in (KOWALCZYK 2006b).

The above works was published as an analog maps and model (KOWALCZYK 2006b). Vertical crustal movements were depicted using isolines. The other possibility to depict the movements is a map of gradients calculated for each leveling line with respect to it's direction. Until now in Poland only one map of gradients was published (Fig. 1) (WYRZYKOWSKI 1990). In this paper as well as in (WYRZYKOWSKI 1990) the all of the gradients are positive since their direction is depicted by arrows on the maps.

Gradients of vertical crustal movements speed distinctly depicts those lines for which the value of movement is equal. These values are expressed as a slope of the straight line in the unit of time. In this work unadjusted data was used for the computations, so called "observed" data (KAKKURI 1987). The distances were calculated on the basis of coordinates in 1992 coordinate system.

The information about gradients of vertical crustal movements can be used in scientific and practical tasks such as (WYRZYKOWSKI 1990):

– seismic regional assignment,

– micro seismic regional assignment of cities and large industrial facilities,

– research on earth crust,

– prospecting of natural resources,

– localization of large buildings and structures,

– evaluation of correlates between modern earth crust movements and geophysical fields,

– evaluation of the state of the art of leveling networks.

In particular the gradients can be used in the research on the correlation between vertical crustal movements and geophysical fields. The main reason for this is because on the large areas the errors are deforming the movements speed more then gradients (WYRZYKOWSKI 1990).

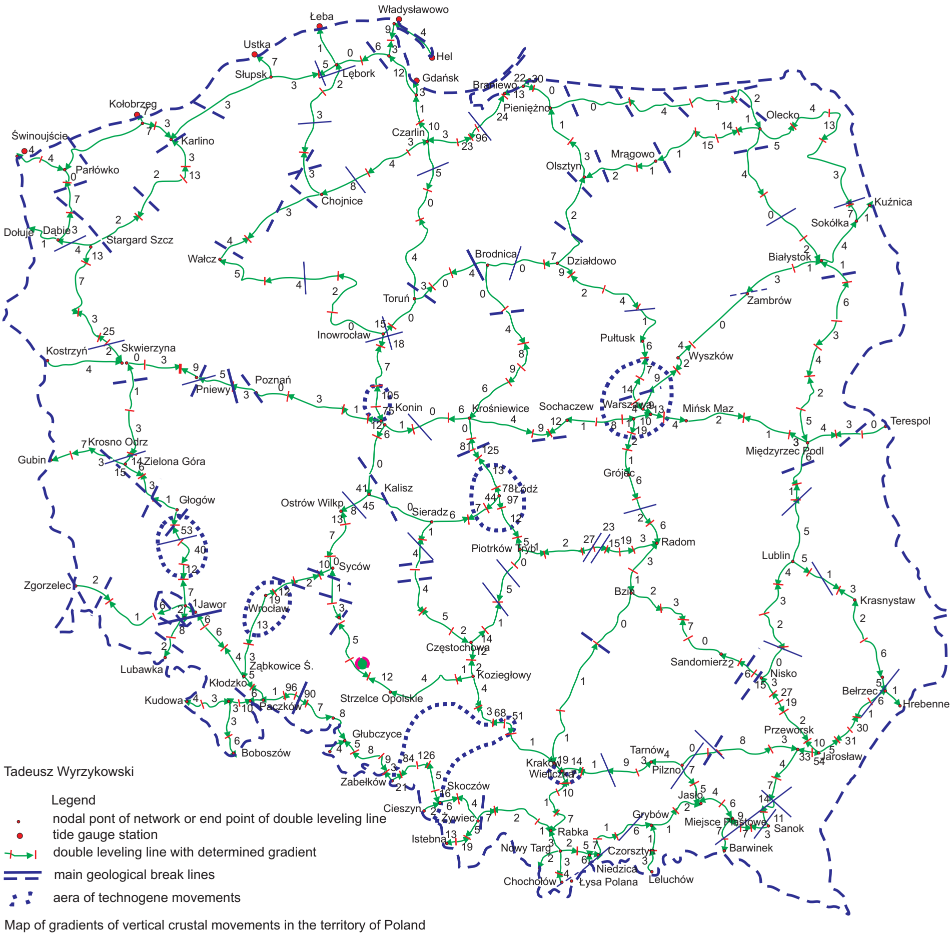

Fig. 1. Map of gradients of vertical crustal movements in the territory of Poland 1990

Leveling data used in elaboration

The first study of map of gradients of vertical crustal movements in Poland was performed on the basis of the double leveling of I order (1974–1979), which completly overlays with earlier I order leveling lines (1952–1955) and partially with 2 order 1 class lines (1955–1958). Total number of 141, 8411 km long lines, forming 23 closed polygons of double leveling were used. In these lines there were 5300 common benchmarks (WYRZYKOWSKI 1990). Average time between two consecutive epochs was 21 years. For the current study the unadjusted vertical crustal movements network was used as a source material (KOWALCZYK 2006a). This network was created on the basis of I order leveling data from 1974–1982 and 1997–2003. In general more then 360 lines of double leveling were used. In this lines almost 11 thousand common benchmarks were identified. Mean time difference between epochs was 22.5 year. Detailed description of materials used can be found in (KOWALCZYK 2006b, 2009).

Gradient determination

In (WYRZYKOWSKI 1990) gradients were calculated using two formulas:
– first, as a angular value of slope in time unit ("/year – seconds per year)

$$\mathrm{grad}V_1 = \frac{(V_2 - V_1) \cdot \rho"}{L} \text{ "/year} \tag{1}$$

where:
V_1, V_2 – speed of vertical crustal movement in first and last point of leveling line, for which the gradient is calculated in mm/year,
L – distance between points in mm,
$\rho"$ – ro sec. 206 265

– second, as a difference of vertical crust movement speed, calculated for 1 km long line (mm/rok/km).

$$\mathrm{grad}V_1 = \frac{(V_2 - V_1)}{L} \tag{2}$$

The dependency between these two equations can be denoted as (WYRZYKOWSKI 1990):

$$\mathrm{grad}V_1 \approx 5\mathrm{grad}V_1 \tag{3}$$

In this paper both equations (1 and 2) were used. The difference is that instead of speed differences in end points ΔV we have used unadjusted speed Δv on these lines.

Elaboration of new map of gradients of vertical crustal movements in the territory of Poland

The map of gradients of vertical crustal movements speed was prepared as a digital model and its cartographic representation. Both model and map was prepared in 1992 coordinate system (Fig. 2).

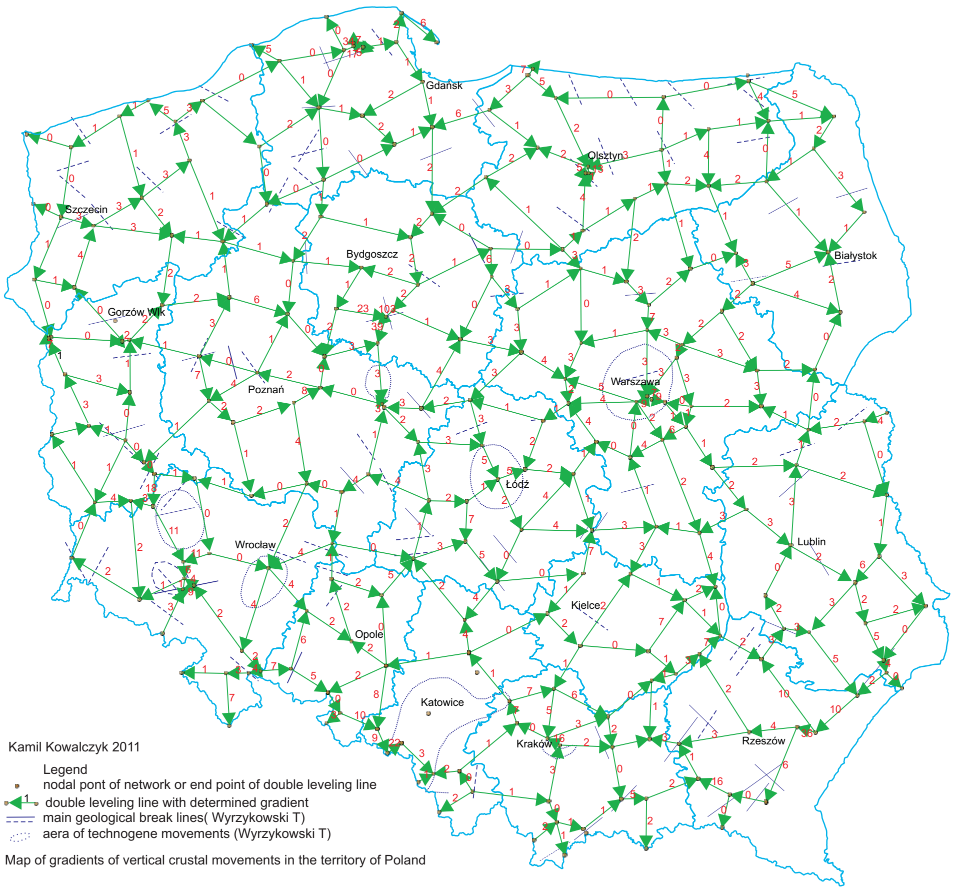

Fig. 2. Map of gradients of vertical crustal movements in the territory of Poland, year 2011

Additionally the map contains:

– the value of gradients in 0.001"/year (the choice of units was the same as in (WYRZYKOWSKI 1990), to allow comparison of both maps,

– the direction of unadjusted value of vertical crustal movement on the network lines,

– main lines of geological breaks from WYRZYKOWSKI 1990,

– major cities.

Analysis of gradient of vertical crustal movements distribution in the territory of Poland

To keep the ability to compare gradient map from 1990 and present map, the results were apprised statisticaly. Figure 3 presents the amount of determined gradients of vertical movements with resolution of 0.01”/year.

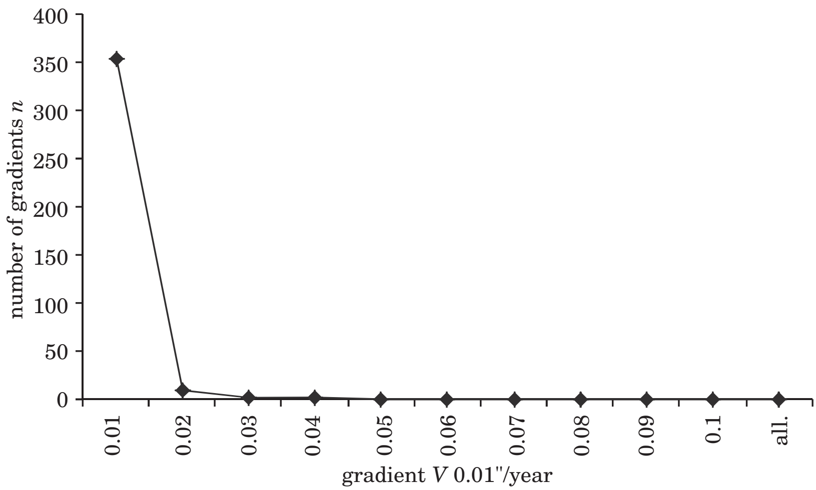

Fig. 3. The amount of determined gradients of vertical movements with resolution of 0.01”/year

From Figure 3 it is clear that 354, which is 96%, of overall vertical movement gradients are about 0.01”/year, in the range of 0.02”/year there is 98,5% of gradients.

For the further examination of the gradients distribution the more detailed figure within the range of 0.01”/year and resolution 0.001”/year is presented (Fig. 4).

In this case the distribution shows decrees of amount of gradients along with it’s size.

The assessment of mean error of modern vertical crustal movements gradient in the territory of Poland was made with reference to mean length of leveling line, which is 37 km.

The formula for the mean error can be denoted as:

$$m_{\mathrm{grad}v_{\acute{s}r}} = \frac{\rho”}{L_{\acute{s}r}} \sqrt{m^2_{\Delta v_{\acute{s}r}} + \frac{\Delta v^2_{\acute{s}r}}{L_{\acute{s}r}} m^2_L} \tag{4}$$

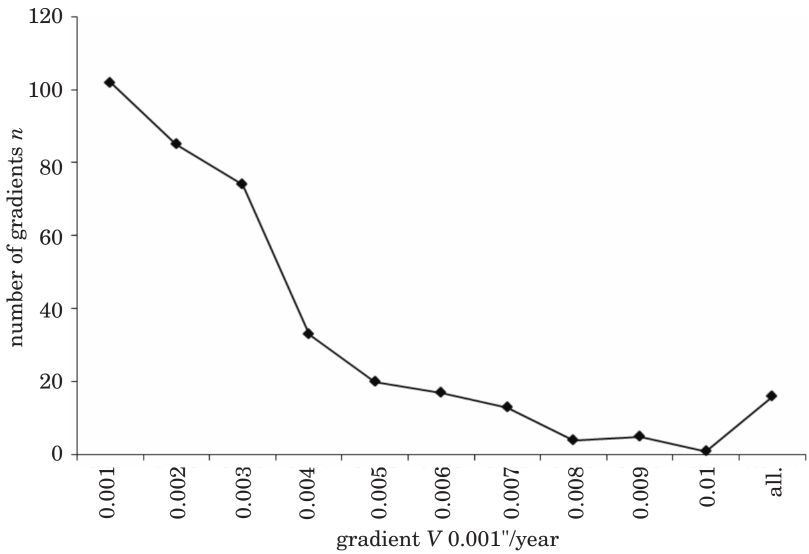

Fig. 4. The amount of determined gradients of vertical movements with resolution 0.001"/year

where:
$m_{\Delta v_{śr}}$ – mean error of vertical crustal movements on network line
$\Delta v_{śr}$ = 0.44 mm/year
m_L = 1 000 000 mm

In equation (4) the mean error of vertical crustal movements on network line remains unknown. To calculate this error one must start with the formula:

$$\Delta v = \frac{\Delta h}{\Delta t} \tag{5}$$

where:
Δh – the difference of height differences on the line of double leveling $(h_2 - h_1)$ in mm,
Δt – distance between epochs in years

The equation for the mean error of vertical crustal movement on network line can be written as:

$$m_{\Delta v_{śr}} = \frac{1}{\Delta t_{śr}} \sqrt{(m^2_{\Delta h_{śr}} + \Delta v^2_{śr} + m^2_{\Delta t_{śr}}} \tag{6}$$

where:
$m_{\Delta t}$ = 0.12 – mean error of epoch distance determination
$\Delta t_{śr}$ – mean distance between epochs (22.5 year)

Mean $\Delta h_{śr}$ error calculated using formula:

$$m_{\Delta h_{śr}} = \sqrt{(m_{h_1}^2 + m_{h_2}^2) \cdot L_{śr}} \qquad (7)$$

The value of mean errors of the double line leveling $m_{h_1}^2$ i $m_{h_2}^2$ were obtained from WYRZYKOWSKIEGO (1985b) and GAJDEROWICZA (2005), and are equal to

$$m_{h_1}^2 = 0.55 \text{ mm/km}$$

and

$$m_{h_2}^2 = 0.52 \text{ mm/km}$$

Substituting the above values to equation (7) the value of mean error is $m_{\Delta h_{śr}} = 4.60$ mm.

Substitution to equation (6) will result in the final value of mean error $m_{\Delta v_{śr}}$ of vertical crustal movement speed on the leveling line. In our case it was 0.21 mm/year. Substituting the above values to equation (4), the mean error of gradient of vertical crustal movement speed in the territory of Poland for the mean line length is $m_{\text{grad}v_{śr}} = 0{,}0012''$/year.

To analyze the mean gradient, the ratio between each gradient and the entire network mean error is necessary. Simplified formula presented by (WYRZYKOWSKI 1990) was used to calculate mean error of each gradient:

$$m_{\text{grad}v} = \frac{\rho'' \cdot m_{\Delta h}}{\Delta T \cdot L} \qquad (8)$$

The results were divided into 4 ranges (Tab. 1).

Table 1

Ratio between each gradients and the entire network mean error in percents

Ranges	Amount of occurence	Value %
0–1	123	33.2
1–2	106	28.7
2–3	60	16.2
More	81	21.9

Looking at Table 1 it is clear that in 62% of cases the calculated ratio between each gradient and the entire network mean error is smaller then twic the value of the mean error. It means that the gradient is correct. The ratio is more then triple mean error happened in 22% of cases, which is a half of the number obtained in (WYRZYKOWSKI 1990). Fifty percent of this cases happened on the technogene areas, remaining values only slightly exceeds the triple mean error.

Conclusions

In most cases the same methods that were used for the evaluation of vertical crustal movements map in the territorz of Poland (KOWALCZYK 2006a) were used to determine the gradients. However the change of the Baltic sea level is not taken into consideration in gradients determination. Therefor the gradients are free from the sea level errors. Each of the gradients of vertical movement speed is determined independently.

The largest gradient is observed on the Inowrocław – Szadłowice line – 0,103”/year with mean error 0,005”/year. Other large values of gradient were observed in the vicinity of Inowrocław, Jarosław and Łęczyce.

In the remaining area the value of gradients is smaller than 0,010”/year. The largest errors of gradients were on the short lines Kostrzyń 1 – Kostrzyń 2 (0,019”/year), Jaroty – Bartąg (0,016”/year), Godętowo – Łęczyce (0,016”/year), Konin 2 – Konin 1 (0,013”/year). Other large errors are also on the short lines.

The mean error of gradient of vertical crustal movement speed for the mean line length is $m_{\mathrm{grad}v_{\mathrm{sr}}}$ = 0,0012”/year. 78% of calculated gradients to mean error ratio is smaller than triple mean error. The results were 20% better than in previous elaboration. It can be caused by the use of more precise leveling equipment as well as the choice of data used for the calculations – only data from first class network was used. It is also confirmed by the mean errors of height determination mh for campaign #2 – 0,7 mm/km, # 3 – 0,55 mm/km, # 4 – 0,52 mm/km respectively. The mean value of gradient is grad_v = 0.003”/year.

With reach and systematic leveling data available (KOWALCZYK, BEDNARCZYK 2009) the elaboration of gradients for each line of double leveling can be performed. This kind of research would show for which of leveling network nodes the change in its heigt is significantly different from the avarege.

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