DETERMINATION OF VERTICAL MOVEMENTS IN WARSAW AND SURROUNDING REGIONS

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INTRODUCTION

The aim of the research was to establish vertical movements in the Warsaw region and surrounding regions, based on measurements of the 1st class national precision leveling network, conducted as part of the 2nd, 3rd and 4th leveling campaigns. As the examined fragment of the national leveling network is not a networked linked directly with any level of reference, the indicated vertical movement values are relative in nature and describe only structure deformations. The boundaries of the region, with a span of approx. 100 km, were the leveling lines of the towns of Sochaczew, Wyszogród, Płońsk, Pultusk, Wyszków, Niegów, Mińsk Mazowiecki, Stara Wieś, Góra Kalwaria, Grójec and Mszczonów. The paper includes an outline of source materials, algorithms and results of the reference point database search as well as a summary of the interpretation of the causes of vertical movements.

1. CHARACTERISTICS OF THE RESEARCH SUBJECT

The area over which the researched network is spread out is entirely located on the East European Precambrian platform, and its south-western border is located very close to the Teisseyre-Tornquist zone, an intermediary zone between the Precambrian platform and the Variscan orogeny. The location of the researched area in connection with other tectonic units in Poland is shown on Fig. 1. Most of the region is located within a unit called the coastal basin; the Warsaw Basin to be exact. This structure is unique as it has the greatest thickness of the entire coastal basin region. The regions surrounding Żyrardów, Sochaczew and Wyszogród are located where the crystalline basement is situated the deepest (approx. 1400 m). The basement is situated slightly further up near Grójec and Płońsk (1000-1100 m), while in Warsaw this depth is only 900 meters. (Mizerski, 2009). Additionally, the Włocławek-Płońsk fault runs through the Płońsk region, while shallower faults run through Grójec and Góra Kalwarii and tectonic graben are located north of Warsaw.
Fig. 1. A sketch of the network on a schematic map featuring main tectonic units.

A schematic view of the longitude section through the artesian basin, formed in the depression of the Warsaw basin, is shown on Fig. 2. The image clearly illustrates the mechanism of the formation of hydrostatic pressure on the bottom of the basin, under the impermeable cover of Pliocene clay. Water filling the Oligocene and Miocene sands on the bottom of the basin is fed in places where the layer of tertiary sands nears the surface. In the Warsaw Basin, the areas where the artesian waters are fed are located on the northern and north-eastern edge of the basin, along a wide strip connecting the Radom, Dęblina and Kock regions.

Fig. 2. Section of the Warsaw Basin according to J. Lewiński (source: Kostrowicki J. Środowisko Geograficzne Polski, PWN, Warsaw 1968, p. 265)

1–quaternary, 2–a) mottled Pliocene clay, b) coal-bearing Miocene, 3–Oligocene sands, 4–chalk marl.

The upper layer of the artesian basin is composed of sand, clay and clay mineral quaternary formations, mainly linked with the activities of the Scandinavian iceberg.
2. DISCUSSION AND UNIFICATION OF RESEARCH MATERIALS

Analyzed fragments of the 1st class of the 3rd and 4th measurement campaigns are almost identical in shape and are composed of 22 leveling lines, formed in 8 polygons containing 767 benchmarks from the 3rd campaign and 836 benchmarks from the 4th campaign, of which 21 are fundamental marks. The path of these lines has changed from 1978 to 2002 only very slightly. The network class of the 2nd campaign is, by comparison, much poorer, and is composed of only 5 leveling lines with two junction points (Fig. 3). Thus in order to unify the shape of the network for all three measurements, 7 lines of the present 2nd class first category network were added to the oldest 1st class network measurement.

![Diagram](image1)

Fig. 3. Shape of the analyzed leveling network fragment: left image – from the 2nd campaign, right image – from the 3rd and 4th campaigns (source: CODGiK archive).

This way a network of 12 leveling lines was formed, creating 4 closed polygons containing 438 points of various types of stability. All data was obtained from the Main Geodetic and Cartographic Documentation Centre (CODGiK) archives.

In order to obtain fully uniform measuring material, the normal correction was eliminated from elevations obtained as part of the 2nd and 3rd campaigns, and elevation errors were assumed to be higher during the 2nd campaign, as no tidal corrections or thermic corrections were introduced.

After the combination and interpretation of common points for the campaigns the following results were obtained, in relation to the points in campaign III:

- 292 common points for campaigns II and III – 38% in relation to campaign III (Fig. 4);
- 645 common points for campaigns III and IV – 84% in relation to campaign IV (Fig. 6).

262 common points shared by campaigns II and IV were also interpreted, comprising 90% of the set of common points from campaigns II and III (Fig. 5)
3. DETERMINATION OF THE VERTICAL MOVEMENTS

3.1. Identification of reference benchmarks

Identification of the reference base was conducted with the help of the reduction method in the iterative process of movement calculation. In the first iteration movements are calculated in relation to a base composed of all potential reference points, and during following iterations subsequent points of the base are eliminated; those that indicated movements exceeding the specified stability criterion. The algorithm utilizes the criterion of the double value of the average error of movement allocation. The iteration process indicates the proper reference base, which fulfills accuracy requirements. The movement values obtained as a result of the final iteration are final. Point leveling differences were calculated with the help of a geodesic movement mapping method – the ordinate difference method with the use of a flexible reference layout. The flexible reference layout model proved to be adequate, as it allows fragmentary movements on reference points, which in turn allows for the incorporation of the limited precision of calculations. In this model the reference level is “fixed into” the value of base point movements (Prószyński, Kwaśniak, 2006).

For 1st and 2nd campaign measurements, relating to the years 1956 and 1987, as well as the 2nd and 4th campaign measurements (1956 and 2001), the set of potential reference points was composed of 10 fundamental benchmarks. The proper reference base for the years 1956-1978 was obtained during five iterations of the movement calculation process, and for the years 1956-2001 – during six iterations. One common reference base was formed based on both identified bases, which was assumed to be final. It was composed of five points. For 3rd and 4th campaign measurements the number of analyzed potential reference points was somewhat larger and was composed of 15 fundamental marks. The proper reference base was obtained during the fourth iteration of the movement calculation process, after eliminating only three points. It is composed of 13 benchmarks.

3.2. Record of vertical movements

In total, 292 network points were examined for the years 1956-1978; 262 points for the years 1956-2001, while as many as 645 points were examined for the years 1978-2001. The average accuracy of determined level changes for those years was, accordingly: 7.1 mm, 8.3 mm and 4.4 mm. The average error of determined movement speed was accordingly: 0.3 mm/year, 0.2 mm/year and 0.2 mm/year. Significant vertical movements (exceeding double the value of the average error of movement allocation) were recorded for: for the years 1956-1978 – 55 points, for the years 1956-2001 – also 55 points, and for the years 1978-2001 – 216 points. A map of movement speeds was elaborated based on calculation results – for each pair of compared measurements. These maps are presented on figures 4, 5 and 6. The figures show that during the years 1956-1978 the examined region strongly settled in its central portion, while the edges of the region remained practically without change (Fig. 4).
Fig. 4. Map of leveling point movements between 1956 and 1978, expressed in mm per year, with sketch of local urban agglomerations and the Zegrzyński Lake.

Fig. 5. Map of leveling point movements between 1978 and 2001, expressed in mm per year.
The years 1978-2001 show the opposite tendency for the region. Comparisons of the 3rd and 4th campaigns show a settlement tendency in the western region of the network, with a speed of over a millimeter in the region of Sochaczew. Eastern regions remained without change during this period or underwent only small, local elevations (Fig. 6).

An interesting phenomenon could be observed during this period: an increase of demotions in the western part of the network. This could have been caused by tectonic movements near the Teisseyre-Tornquist zone and the settlement of earth masses down the slanting bottom of the cretaceous Warsaw basin. The vertical movements portrayed with the help of figures 4, 5 and could be compared to Wyrzykowski’s study (Wyrzykowski, 1985) and that conducted by Kowalczyk (Kowalczyk, 2008). There are many similarities. The shape of isolines is similar (the spatial differentiation of movement speeds), while the absolute movement speed values themselves differ. It can be assumed that these differences are the result of the choice of different reference levels, as the movements illustrated on these figures are local in nature.

4. INTERPRETATION OF VERTICAL MOVEMENTS

4.1. Tetrogenic factors

The indicated movement values for the years 1956-1978 showed significant settling of the central part of the examined network, which includes regions of the Warsaw agglomeration. As it turns out these movements could have been caused by human activity, mainly the load of newly constructed urban structures, as well as the drying of the Mazowiecka basin due to excessive exploitation of artesian waters. The intensificat-
ion of construction work between the 1950s and 1970s in Warsaw explains the settlement of the central part of the precision leveling network for the years 1956-1978. The settlement could have been caused by the extra load on the land. Another phenomenon, also linked with ground humidity, is the intensive exploitation of artesian waters, contained in the Oligocene and Miocene formations of the Mazowiecka Basin. Since Oligocene water was discovered in 1896, over 200 wells were drilled in Warsaw over a period of 100 years, while over 300 wells were drilled in the artesian basin area (Stempień-Salek, 2005).

Such a large and concentrated water yield from a poorly renewable Oligocene basin caused a decrease of the water level. At first the water level (drilled at a depth of 230-250m) stabilized at approx. 100 m above sea level. A drop to approx. 60 m above sea level was observed in the 1960s, as well as the formation of depressions reaching a level of 40 meters. Hydrostatic pressure, at first 23 atm., which caused water to pour out from the drill point to a height of a dozen or so meters above ground level, decreased to such an extent that water usually does not gush to the surface on its own. The basin is dry to such an extent that, in connection with the additional load, it was most likely the main reason behind the indicated settlement in the Warsaw agglomeration region. A second source of such strong settling which can be seen on the movement map could be the region of the Zegrzyński Basin, which was created in 1963 after the construction of a dam on the Narwia River. Indicated settling could have been caused by the load of water accumulated in the reservoir.

The Zegrzyński Basin (Fig. 4) was formed in 1963 after the stream channel of the Narwia River was partitioned in Dębe. The area of the formed reservoir is currently 3030 ha; its length along the Narwia River – 41 km, its width – approx. 3.5 km, and its volume – 94.3 million m$^3$, while the water level maintains a height of 79 m above sea level. An amount of water equal to 95·10$^6$ m$^3$ has a mass of approx. 95·10$^6$ tons, which, with a basin the surface of 3030 ha, exerts the pressure of over 30 kN/m$^2$. Thus the area must bear a significant load. The formation of such a strong stimulus in the 1960s had to have caused deformations. In summation, the intensification of construction work and excessive utility of water resources in the 1960 is clearly correlated with the settlement during the years 1956-1978.

An analysis of movements during the years 1978-2001 does not show a clear relationship with human activity. An examination of the movement of points in the Warsaw region of the 1$^{st}$ class network shows only that more settling took place in the western part of the city. Significant settling was observed in the Ochota district and the Bielany district near the Młocinńskiego Park. Weaker settling occurred along Wolska Street and further on Połczyńskiej Street, as well as along Aleja Krakowska Street. On the eastern side of the Vistula River positive vertical movements dominate, and settling can be observed practically only by the shore. Spatial distribution and scale of vertical movements in Warsaw do not indicate the presence of technogenic movements during this time.
4.2. IMPACT OF POINT STABILIZATION TYPE

The size and direction of indicated movements of specific points is undoubtedly affected by stabilization type. As it turns some types of marks can be affected by the amount of time that has elapsed since settlement. An analysis of the results of point movements during the years 1956-1978 shows that all type I points (Technical Guidelines G-1.9) showed significant settling. Four of five of these points are located within the territory of Warsaw; the entire region settled quite significantly during this time (Fig. 4). These marks were laid out mostly during the 1950s, right before the 2nd campaign measurements, settled during the years 1956-1978, and are only now stabilizing, as during the years 1978-2001 they were completely stable. The movement of points of the 3rd type also changed in nature during the years 1956-1978-2001. During the first period all of them settled slightly, while later they settled and were elevated in the same degree. Type IV points were stable, only 5.6% significantly moved during the years 1956-1978, and in later years the significant ratio of movements was below 30%. These movements were systematic, as they underwent only settling, both during the years 1956-1978, and during 1978-2001. Type V points also showed great stability. During the years 1956-1978 only 13% moved significantly, while during the years 1978-2001 only 25%. As far as the direction of recorded movements is concerned, type V points were the only ones to become elevated during the first period, in over 25% of cases. In later periods elevations composed only 6% of significant movements. Type VI wall marks exhibited the most movement; 26% during the first period and during the second period even 40% showed significant movement. It is difficult to establish patterns in these movements, as they depend on the stability of the structure they were marked upon.

The technogenic causes of height changes are a dominating factor. Technogenic factors are understood as the effect of loads on the earth’s surface caused by structures or investments and factors linked with underwater reservoir exploitation. Due to a relatively small area with dominating technogenic factors, an analysis based only on local point movements does not show any clear tendencies, thus making the an attempt to explain the movements of the points in a broader geological context difficult.

REFERENCES


