Effect of Ground Changes on the Reference Benchmarks in a Levelling Network of a Large City

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Key words: Benchmarks Displacement, GPS Levelling Network, Ground Deformation.

ABSTRACT

In the paper changes of reference benchmarks heights in levelling networks of the 1st, 2nd and 3rd order, during the 1968-1998 period, have been presented on the example of Wrocław.

Preliminary interpretation has shown that they are closely correlated with geological, tectonic conditions. The city of Wrocław is situated in the Odra River old valley that together with four other tributaries make up the so-called Wrocław Water Junction. This largely determines the mobility of the ground in the city area.

The problem of benchmarks catalogue heights credibility, which are the reference points for networks of the lower order and for deformations of engineering constructions in the city, has been raised. An attempt has been made to generalise the experiences obtained and apply them for modernisation of levelling networks and for design of geodetic networks that are to be connected with engineering projects

ZUSAMMENFASSUNG

Einfluss der Änderungen im Gebirge auf Bewegung der Höhenpunkte im Nivellementnetz des Grosstadtgebietes.

In der Bearbeitung wurden Änderungen der Höhenpunkten auf dem Gebiet der Stadt Wrocław in den Nivellementschleifen der I., II. und III. Klasse in den Jahren 1968-1998 dargestellt. Einleitende Analysen haben gezeigt, dass sie mit geologisch-tektonischen Bedingungen zusammenhängen.

Es wurde auch das Problem sowohl der Glaubwürdigkeit der Kataloghöhen der Höhenpunkte angedeutet, die als Bezugspunkte für Liniennetze niederen Grades dienen, aus auch der Deformationsmessungen von Bauobjekten im Stadtgebiet.

Es wird auch ein Versuch einer Verallgemeinerung der gesammelten Erfahrungen auf andere Stadtballungsgebiete durchgeführt und sowohl deren Einsatz bei Modernisierung von Höhenliniennetzen, als auch in Projekten von geodätischen Liniennetzen im Zusammenhang mit der Realisation von Bauinvestitionen.

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1. INTRODUCTION

Ground instability in large urban and industrial agglomerations results in changes of benchmark catalogue heights. The necessity of bringing them up to date arises from needs of surveying works associated with municipal and industrial enterprises. This is particularly important for cities, such as Wrocław (SW Poland), located in flat terrain and was demonstrated by the example of intercepting sewer construction (approx. 10 km long and 1,7% gradient) in the 80'ties of 20th century. Out-of-date, as was later established, benchmark heights (at the beginning and end of sewer) resulted in much higher, than planned, costs of this project.

In the article geometrical analysis of benchmark heights changes in levelling network of Wrocław in the course of 30-year period is presented. Height changes obtained from measurements performed in 1968 and 1998. Interpretation of these variations in relation to geological and tectonic structure, as well as, ground water level in the city area was also attempted.

2. CHARACTERISTICS OF LEVELLING NETWORK

Levelling network of 1968 based on 10 fundamental benchmarks regularly spaced around the city. Precise levelling lines of the 1st order propagated from W1 point towards city limits and continued on the perimeter to form nodes at fundamental benchmarks (fig. 1). Levelling lines of the 2nd and 3rd class augmented 1st order network. Mean error m_H of measurements was contained in the ±(0,9-2,6) mm per km limits.

Present (1998) shape of the levelling network has changed (fig. 2). Number of 1st order levelling lines changed course in some parts. Levelling lines of the same class extending on the perimeter have been replaced by 3rd class lines. Levelling lines measured with classical geometrical levelling method were augmented by precise measurements of height changes by satellite GPS technique. Measurements were performed on reference points at fundamental benchmarks and control points located outside city limits (20 to 30 km). Detailed information on this subject was presented by *Cacoń et al* (1999).

Accuracies of levelling line measurements obtained in 1998 are similar to those of 1968.

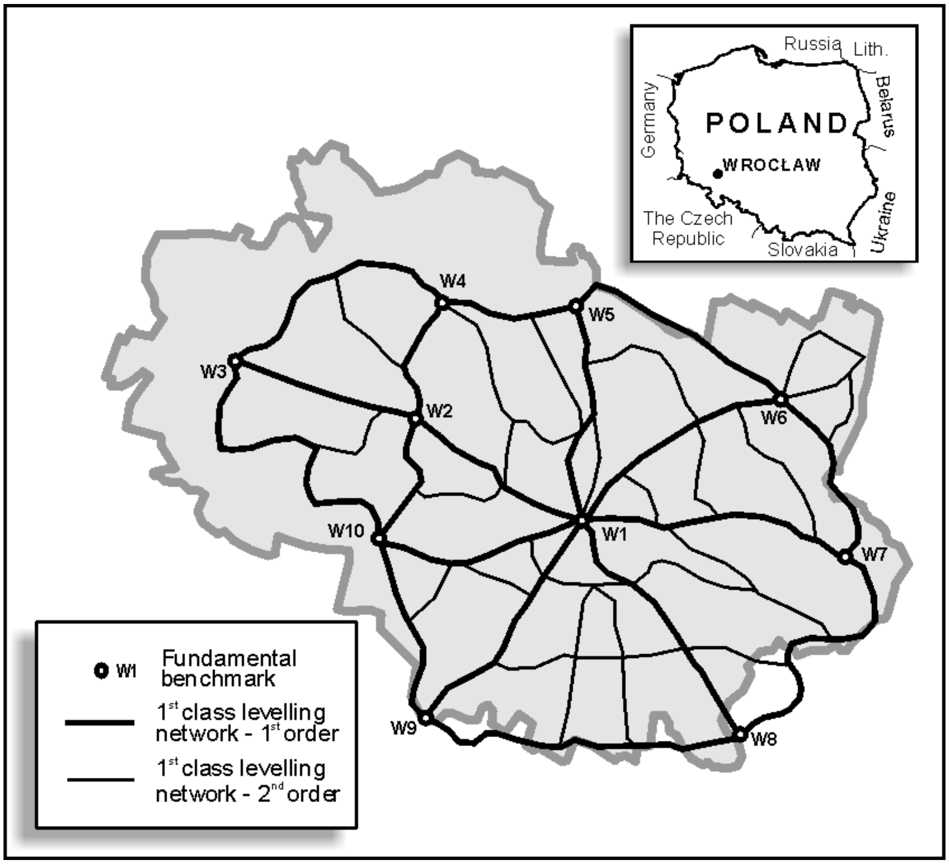

Fig.1. Levelling network of Wrocław in 1968

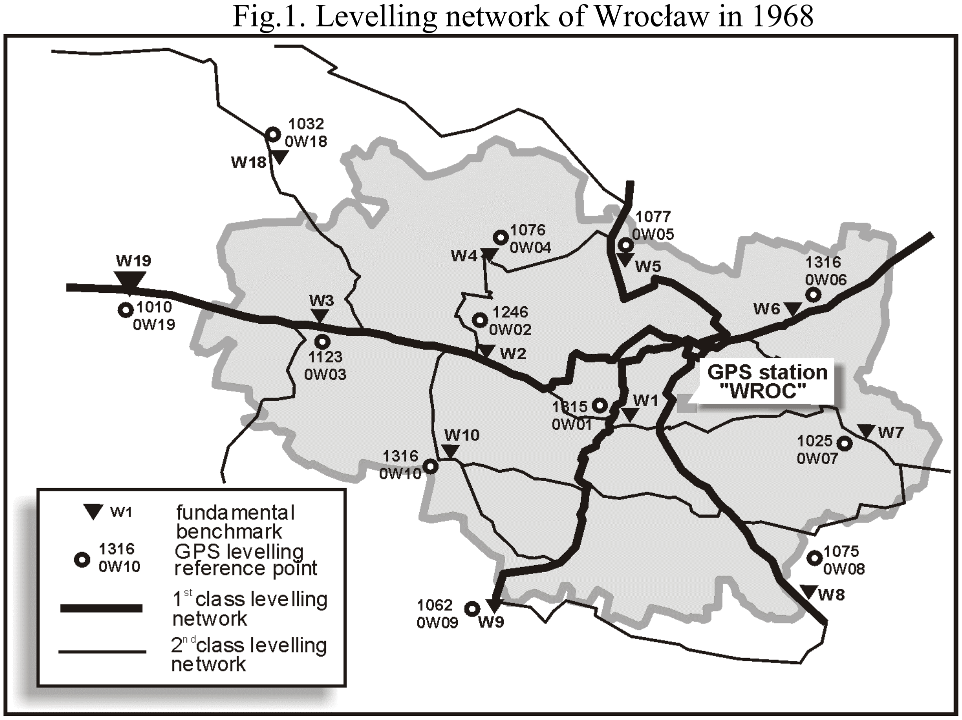

Fig.2. Levelling network of Wrocław in 1998

3. CHANGES OF BENCHMARK HEIGHTS IN ORDER LEVELLING LINES OF THE 1ST, 2ND AND 3RD

Displacements of benchmarks were calculated by independent adjustment of results from 1968 and 1998 (1st, 2nd and 3rd class). Points W9, W2 and W3 were identified as stable in relation to each other. Error-free identification of reference points was discarded during computation process. Displacements of fundamental benchmarks are presented in table 1. Values are within +22 to –31 mm limits at mean error value of ±(1,8 – 3,3) mm.

Table 1: Displacements of fundamental benchmarks

Benchmark ID	Displacement [mm]	Mean error of displacement $\pm m_{DH}$ [mm]
W1	**-31**	1,8
W2	3	2,0
W3	**11**	2,7
W4	**13**	2,6
W5	-2	2,1
W6	**-19**	3,0
W7	**-18**	3,3
W8	**-11**	3,2
W9	-1	2,3
W10	**22**	2,7
Significant values of displacements at 95% confidence level are marked in bold		

Benchmark displacements in western parts of the city, in selected levelling lines of the 1st, 2nd and 3rd order are presented in fig. 3.

Mean errors of determined benchmark displacements in levelling lines are within ±(1,0 – 5,1) mm limits.

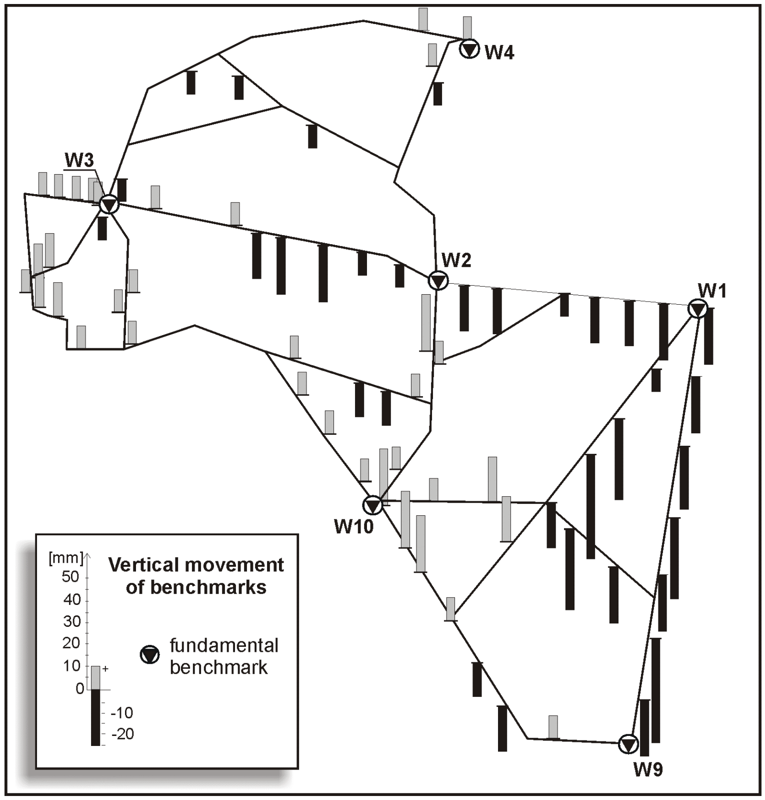

Fig. 3. Changes of benchmark heights in western parts of Wrocław

4. CHARACTERISTIC OF ENDOGENOUS FACTORS RELATED TO CHANGES OF BENCHMARK HEIGHTS

The city of Wrocław is located in a border zone between two large units of Pre-Cainozoic stratum: Fore-Sudetic Block and Fore-Sudetic Monocline separated by Middle Odra Fault System (*Buksiński, 1974*). Central part of the city lies in a zone of alluvial sediments deposited by the Odra River flowing across Wrocław. Odra and its tributaries: Oława, Ślęza, Bystrzyca, Widawa and dense network of canals form the so-called Wrocław Water Junction.

It is presumed that variations of ground water level correlated with surface water level and geological structure have the deciding effect on vertical changes of benchmark heads. Thickness of joint Tertiary and Quaternary formations in Wrocław area reaches 150 to 170 m.

Tertiary formations are represented as Neogene clays, muds and sands with thin (up to 2 m) brown coal intercalations (*Buksiński, 1974*). Thickness of Tertiary formations reaches approx. 170 m in SW part of the city and decreases in SE direction to approx. 85 m (fig. 4).

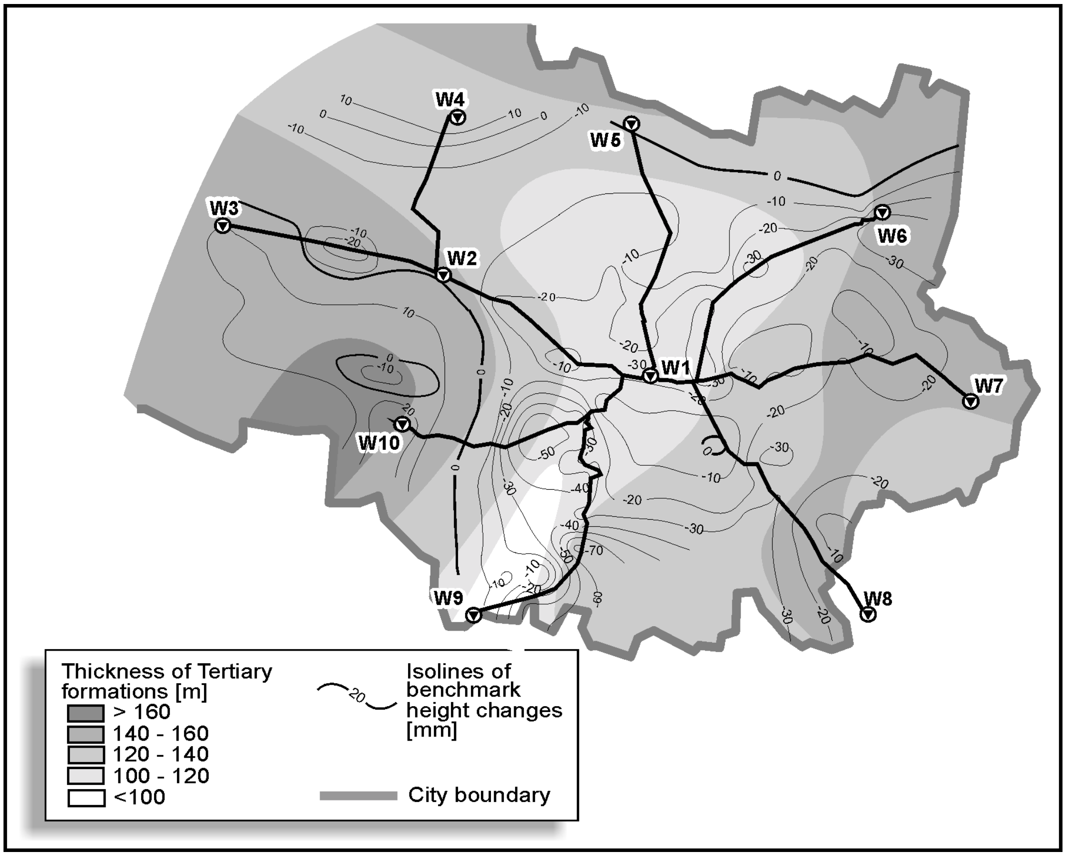

Fig. 4. Variations of ground level in Wrocław and thickness of Tertiary formations

Quaternary sediments are 57 m thick in central part of the area and shrink in W and SW direction, where they do not exceed 10 m (fig. 5).

Quaternary layer fills depressions that have formed in the roof of Tertiary bed levelling city's surface area lying at 110 m a.s.l. to around 130 m a.s.l. in its western part.

Figure 5 illustrates that ground settlement is higher in regions of deeper Quaternary formations than in other parts. In areas where thickness of Quaternary decreases and Tertiary formations approach surface, benchmark subsidence is reduced and uplifts are also registered. Displacements of benchmarks in relation to geological layers position along levelling lines extending to the W and SW from centre of the area are shown in figs. 6, 7 and 8.

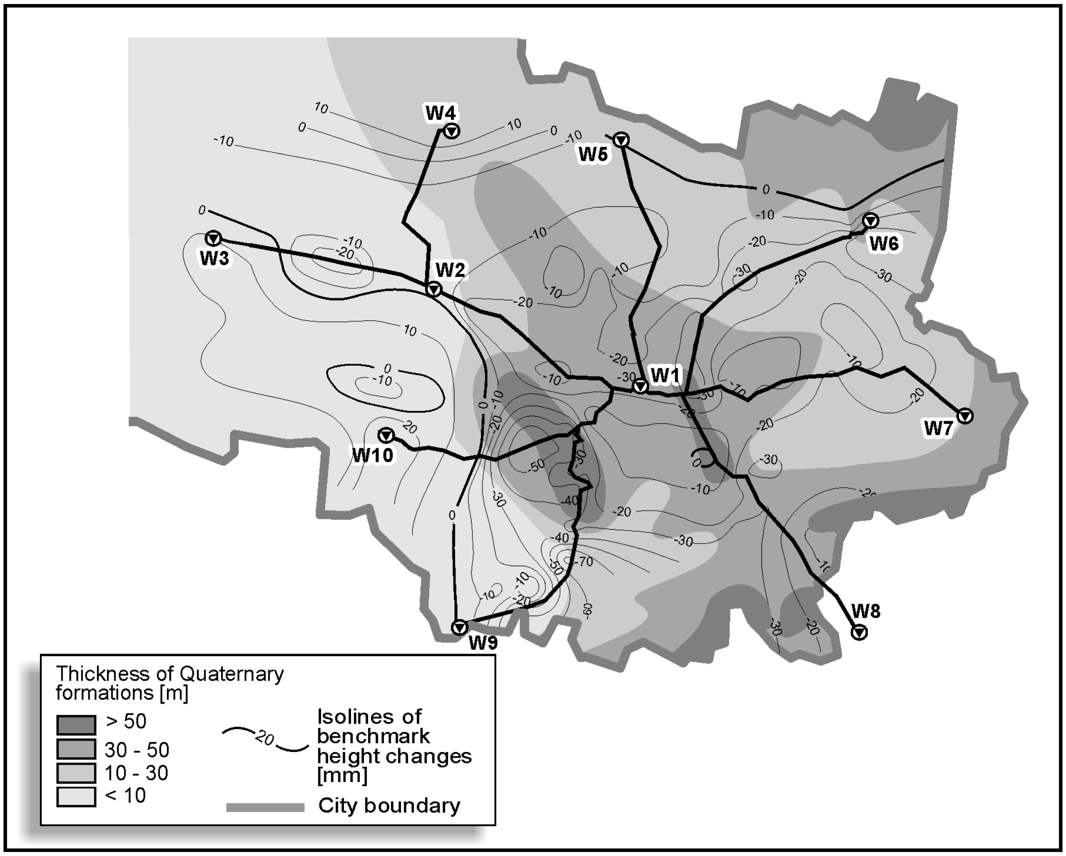

Fig. 5. Variations of ground level in Wrocław and thickness of Quaternary formations

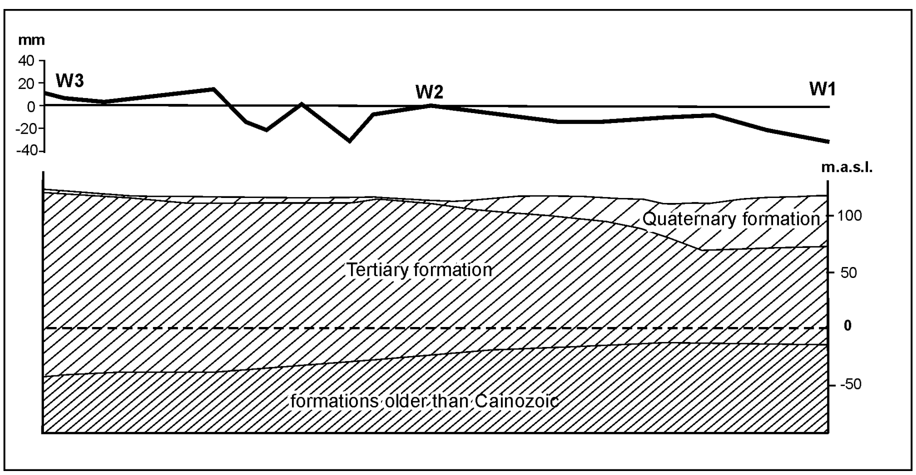

Fig. 6.Benchmark height changes against background of simplified geological cross-section along W3, W2, W1 levelling line

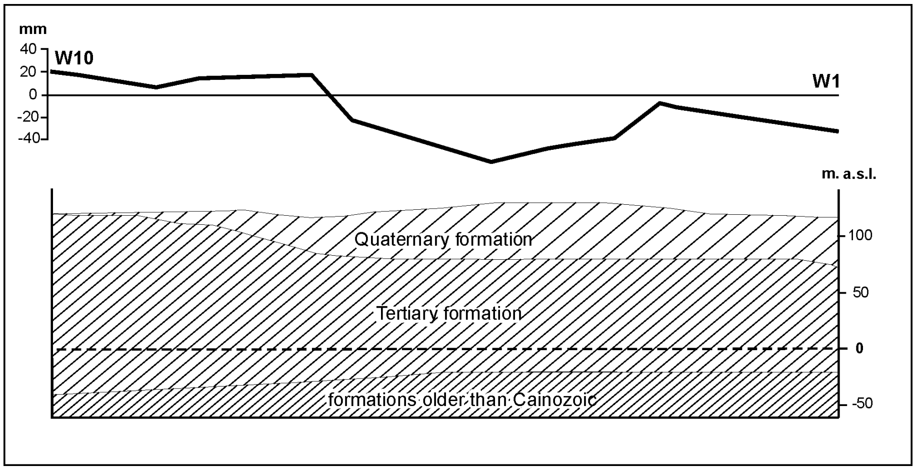

Fig. 7. Benchmark height changes against background of simplified geological cross-section along W10, W1 levelling line

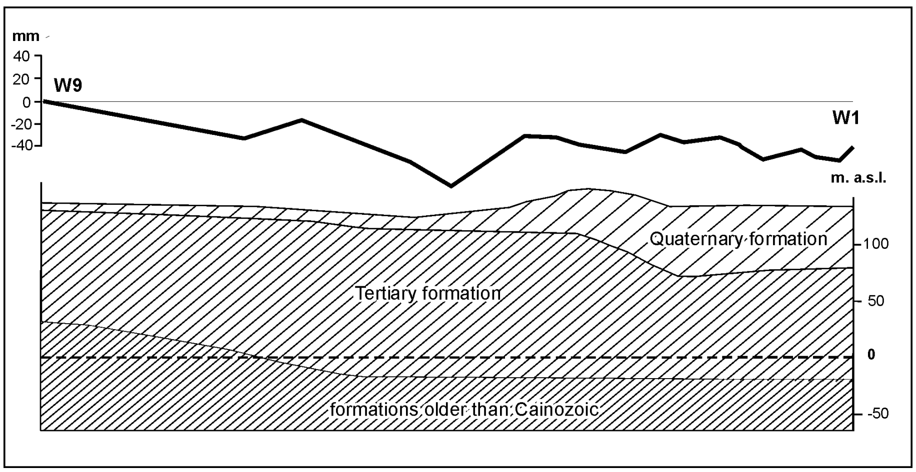

Fig. 8. Benchmark height changes against background of simplified geological cross-section along W9, W1 levelling line

Cross-sections presented indicate that decreasing thickness of Quaternary is correlated with reduced displacements of benchmarks. Detailed interpretation of benchmark height changes requires other factor to be also taken into consideration. These include: fluctuations of ground water level, location of benchmarks in relation to Wrocław Water Junction (rivers and canals), main communication routes and other exogenous factors. Above-mentioned problems will be subject of further studies to be carried out by the authors.

5. EFFECT OF BENCHMARK DISPLACEMENTS ON RESULTS OF SELECTED ENGINEERING SURVEYING IN THE CITY

The rate of vertical movements reaching up to –2 mm per year in some parts of the city results in catalogue heights of points becoming outdated in just a few years. Realisation of surveying works with control to benchmarks affected by vertical displacements has resulted in e.g. incorrect determination of intercepting sewer gradient. Results of analyses produced in chapter 3 indicate that even a system of reference points for leveling network, consisting of

10 deep-footed fundamental benchmarks, has not served the expected functions. Similar problem exists in small networks, among others for surveying of displacements on constructions and hydro-engineering installations. Displacement measurements of hydropower plant constructions in the area of Wrocław (*Cisek et all, 2000*) have revealed elevation of controlled points. However interpretation of these results has proved subsidence of local reference benchmark near above-mentioned constructions. Authors suggest that analysis of displacements on such objects be made only by the means relative measurements.

One must also take into account that displacements of benchmarks along leveling lines passing by these power plants reach values of –25 mm in the course of 1968 – 1998 period.

6. CONCLUSIONS

Presented considerations concerning changes of benchmark heights in an area of a large city such as Wrocław, have showed uneven changes occurring in the ground. Causes of benchmark heights changes are complex and influenced both by endogenous and exogenous factors. Bringing up to date heights of benchmarks by the means of new levelling measurements, should be performed more frequently than every 30 years. Conclusions drawn from analyses performed for the Wrocław area can also be related to other large agglomerations locate din flatlands.

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