A CONCEPT OF USING STATIC GPS MEASUREMENTS FOR DETERMINATION OF VERTICAL AND HORIZONTAL LAND DEFORMATIONS IN THE MAIN AND OLD CITY OF GDAŃSK

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The paper presents a project of a network of fundamental altitude points, which play the role of reference points and check points, stabilised in the area of the Main and Old City of Gdańsk, in order to determine horizontal and vertical land deformations with the use of static relative GPS measurements.

Key words:
GPS, altitude geodetic matrix

INTRODUCTION

In the years 1997 – 2001, Przedsiębiorstwo Geologiczno – Geodezyjne [the Geological and Geodetic Company] "Geoprojekt – Gdańsk" conducted precise levelling in the Main and Old City of Gdańsk (Fig. 1), which revealed the changes in the altitude of wall benchmark, ranging from 0.1 to 4.5 mm.
Four years of geodetic work also showed considerable changes in the altitude of adapted points of the basic altitude matrix of the first and second class (e.g.: first class point no. 60 – 4.5 mm, second class point no. 761 – 21.7 mm), which indicate a lack of stable points of control of precise altitude measurements. Maximum values of benchmark settlement in millimetres are shown in Table 1.

Table 1. Maximum values of benchmark settlement [mm]Source: Przedsiębiorstwo Geologiczno – Geodezyjne "Geoprojekt – Gdańsk".

	Rok obserwacji					Położenie reperu
Nr rep.	1997 obs. baz.	1998	1999	2000	2001	
26	0	-1,2	-1,7	-1,8	-2,9	Kościół św. Brygidy
33	0	1,3	-1,4	-1,5	-2,8	Kościół św. Mikołaja
34	0	-1.2	-1,4	-1,5	-3,2	Kościół św. Mikołaja
35	0	-2,3	-2,6	-3,1	-4,5	ul. Świętojańska 70/71
60	0	-1,5	-1,9	-1,8	-2,8	ul. Straganiarska 18/19
84	0	-1,3	-2,0	-2,2	-3,5	ul. Św, Ducha
89	0	-1,1	-1,6	-1,8	-3,2	Długie Pobrzeże 21
130	0	-0,3	-1,4	-1,5	-2,6	Skrz. Hodmurze i Latarniczej
131	0	-0,7	-1,3	-1,4	-2,4	ul. Podwale Staromiejskie
143	0	-1,0	1,4	-1,5	-3,0	ul. Ogarna (bud.nad.kan.Motławy)
144	0	-0,8	-1,2	-1,3	-2,3	ul. Powroźnicza

A set of altitude points included in the measurements, with highlighted points where the maximum increases in altitude were measured, is shown in Fig. 1.

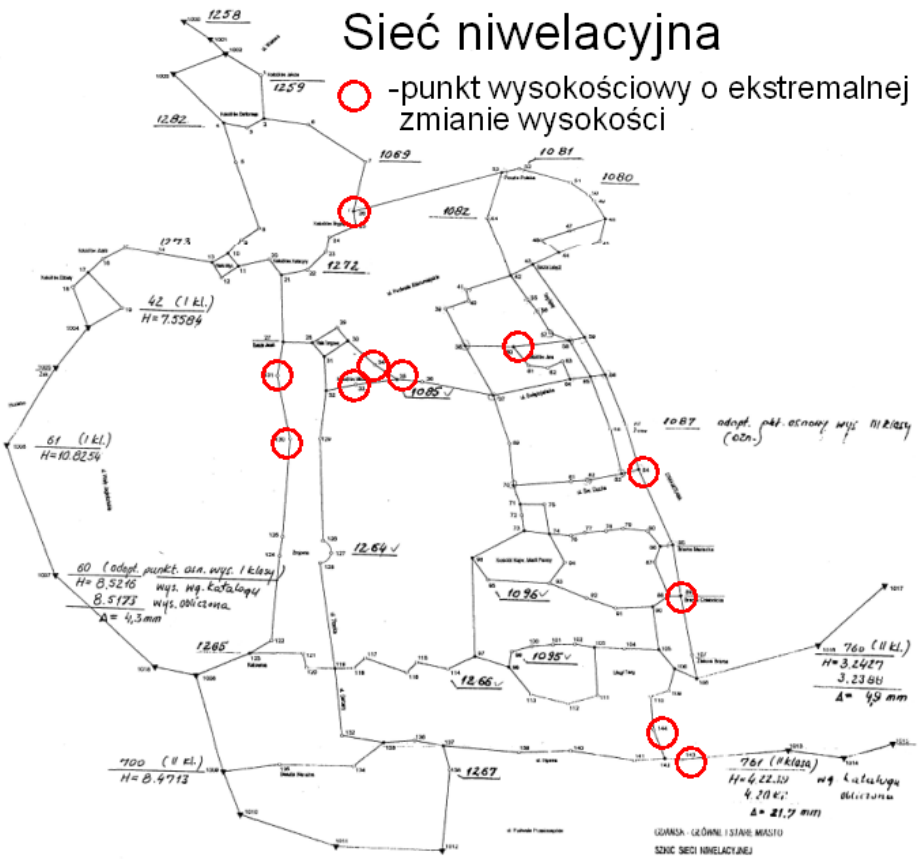

Fig. 1. An plan of deployment of points included in the measurements.

DEVELOPING A TECHNICAL PROJECT OF A NETWORK OF POINTS FOR EXAMINATION OLAND DEFORMATIONS IN THE MAIN AND OLD CITY OF GDAŃSK

The geodetic work conducted by the Przedsiębiorstwo Geologiczno – Geodezyjne has shown the permanent tendency of the buildings situated in the Main and Old City of Gdańsk to settle. However, the shifts discovered during the work are not connected with the vertical movements of the earth's surface in relation to a constant reference level (no guarantee of stability of the reference points). The points of the basic altitude matrix, fixed with the mural marks and situated in the vicinity of the points of settlement, cannot be adopted as reliable reference points for measurement of total absolute vertical movements of the earth's surface.

Consequently, the need arose to conduct long-term monitoring of vertical and horizontal movements of the earth's surface in the Old and Main City of Gdańsk, with the use of satellite measurement techniques and based on the reference points situated in a stable area, i.e. at a considerable distance from the area of settlement. In order to determine the vertical and horizontal movements of the earth's surface, the points had to be stabilised with underground fundamental altitude marks (check points), situated in the Old and Main City of Gdańsk and overground fundamental altitude marks (reference points), situated outside the area of deformations (Baryła R. et al., 2005).

The analysis of geological material (Fig. 1 and 2), field inspection and the adopted principles of planning the location of reference and check points provided grounds for the development of: "A Technical Project of Precise GPS Measurements and Scientific Research in order to determine precisely the vertical and horizontal deformations in the main and Old City of Gdańsk" (Baryła R. et al., 2005). The

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Technical Project adopts the optimum location of points in terms of the GPS observation conditions and the possibility of stabilising overground and underground fundamental marks.

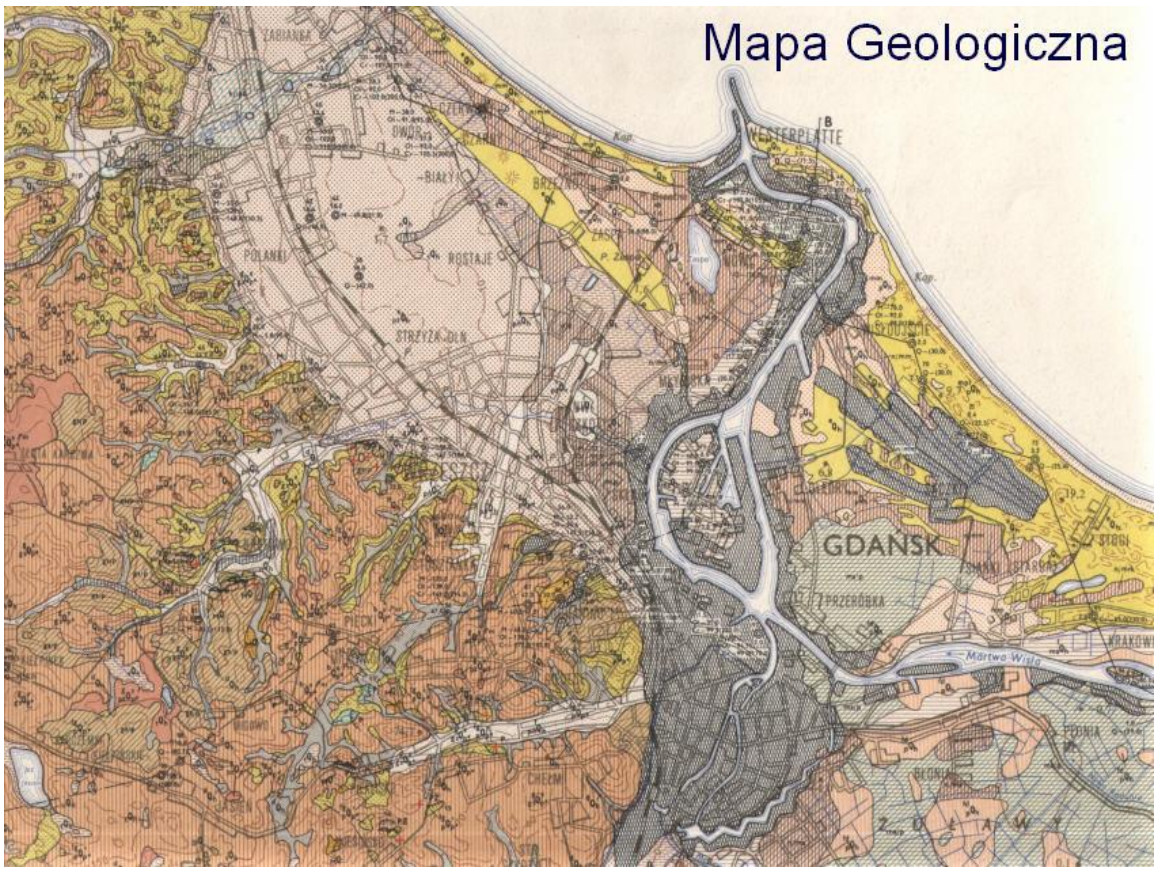

Fig. 2. Detailed geological map of the City of Gdańsk (Mojski J., 1977).

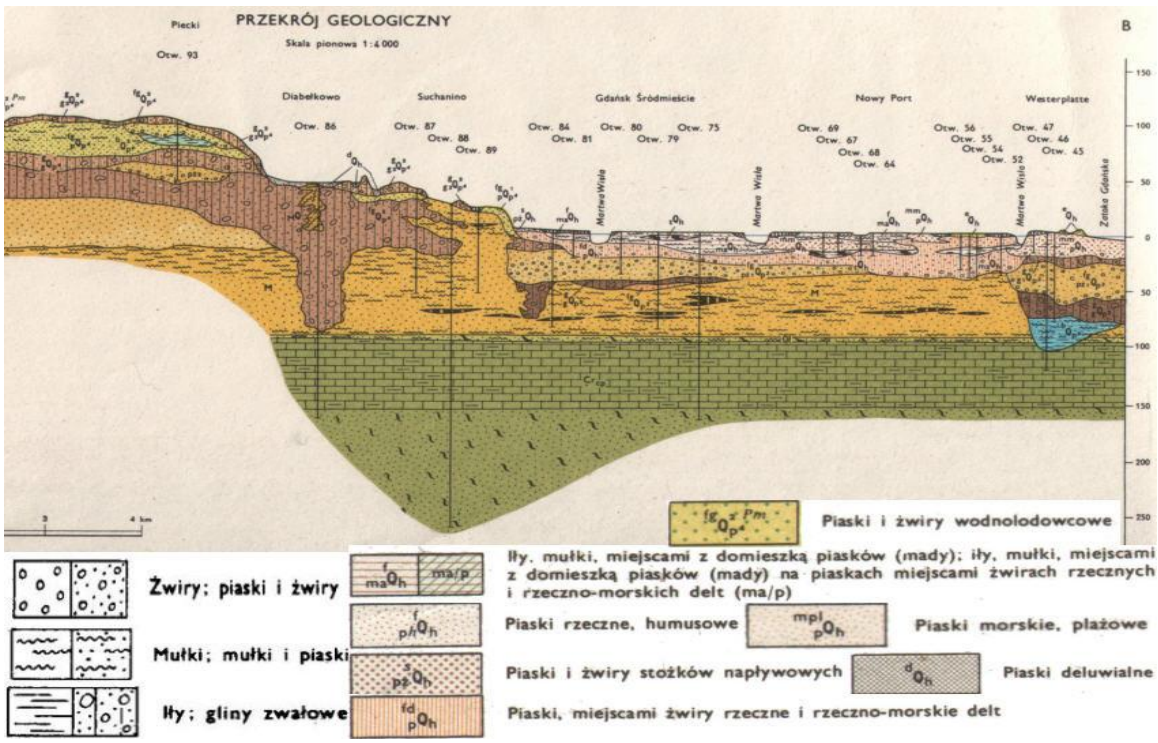

Fig. 3. Cross section of the detailed geological map of the City of Gdańsk (Mojski J., 1977).

Location of the Main and Old City of Gdańsk in the delta of the Vistula river is disadvantageous to the buildings situated there. The ground there consists of sandy

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and gravelly formations inter-layered with organic aggregate mud or peat. The physical surface is situated 2 to 8 m above the sea level. The ground of this composition with a high level of ground waters has variable load bearing capability for building foundations (Mojski J., 1979).

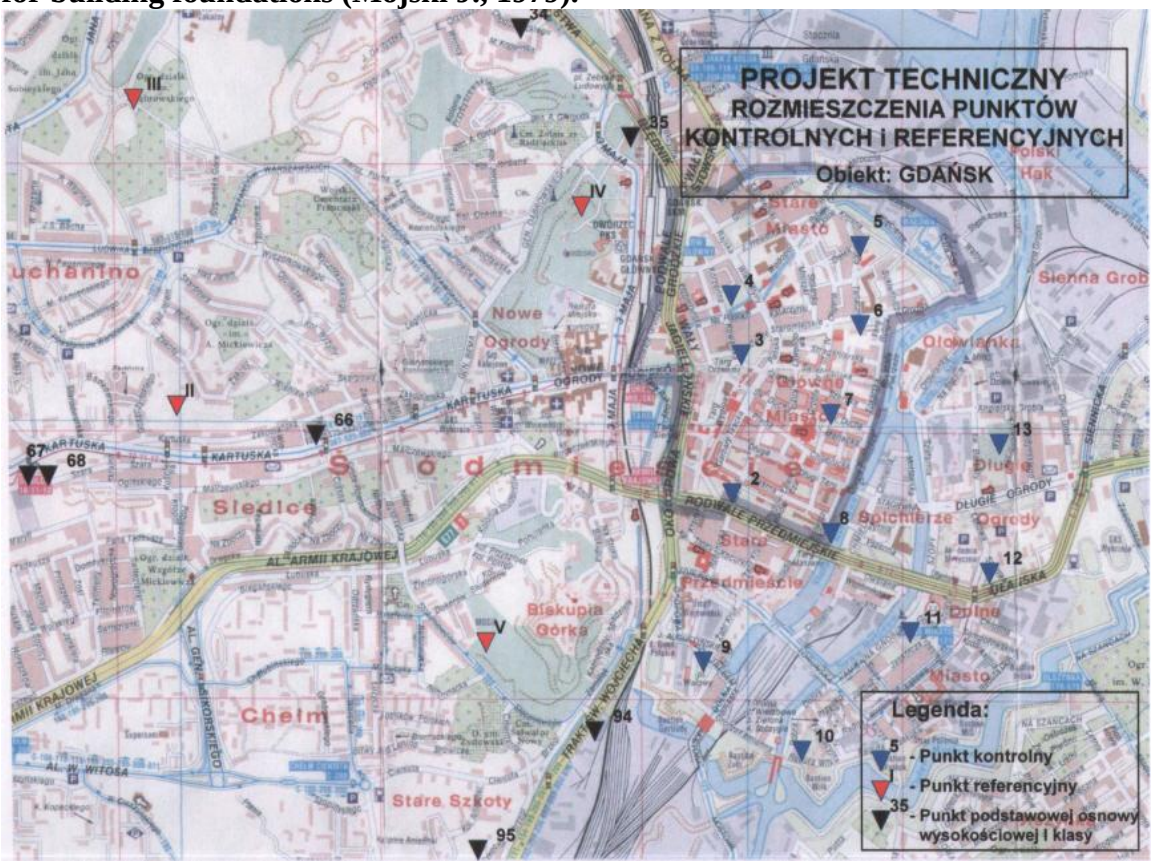

Fig. 4. The technical project of deploying check and reference points in the Main and Old City of Gdańsk (Baryła R. et al., 2005).

LOCATION OF THE GPS CHECK POINTS

Twelve check points, marked with underground fundamental marks type 71b, were to be deployed within the limits of the Main and Old City of Gdańsk (Fig. 5 and 6), according to the technical guidelines G – 2.1 "The basic altitude matrix", symmetrically in the area covered by this study. The following principles were taken into account when choosing the location of the check points:

- **a possibility of stabilising a ground altitude mark, type 71 b,**
- **conditions of conducting GPS observations (uncovered sky),**
- **obtaining a permit to install a geodetic mark at a specific point,**
- **stability of the mark (low risk of damage),**

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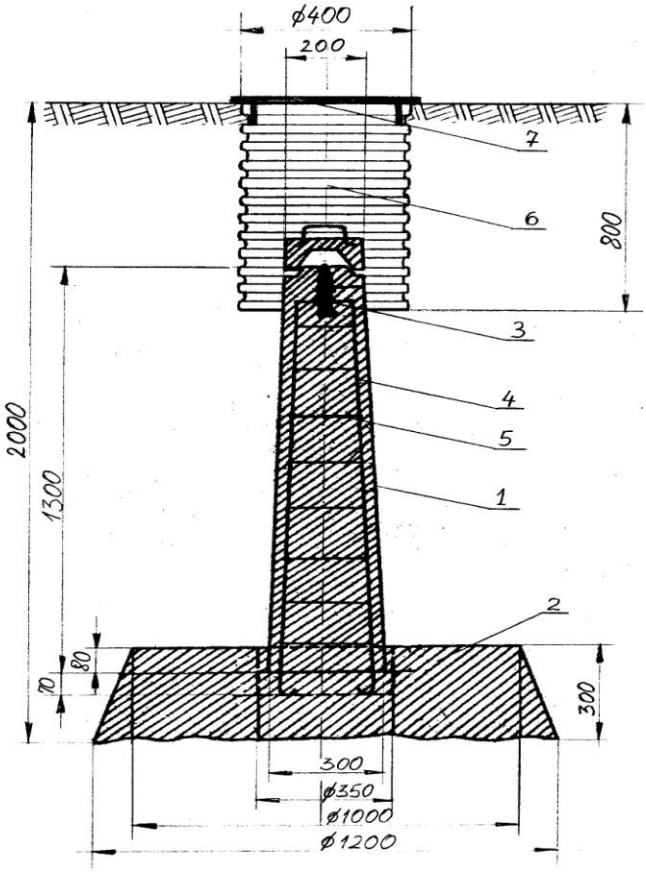

1 – reinforced post made as a pre-cast unit
2 – the mark foot, cast from concrete at the point of stabilisation
3 – bench-mark
4 – vertical reinforcement, Φ10x1400x4 pcs
5 – horizontal reinforcement, shackles Φ6 every 200
6 – draining well made of PVC
7 – draining well cover made of PVC

Fig. 5. An outline of a check point mark.

Fig. 6. A view of a benchmark at a check point.

LOCATION OF THE GPS REFERENCE POINTS

The position of a reference point (overground fundamental mark) should remain unchanged for decades. The project provides for stabilising four reference points with modified, ground altitude marks, type 71 b (Fig. 7 and 8), located in the vicinity of the mural altitude points of the basic altitude matrix, first class, outside the Old and Main City of Gdańsk. The project also provides for adaptation of the existing ground altitude points. The following principles were taken into account when choosing the sites where the reference points are to be located:

- **appropriate ground stability,**
- **a possibility of stabilising the reference point,**
- **convenient GPS observation (no cover in the sky higher than 10º above the horizon,**

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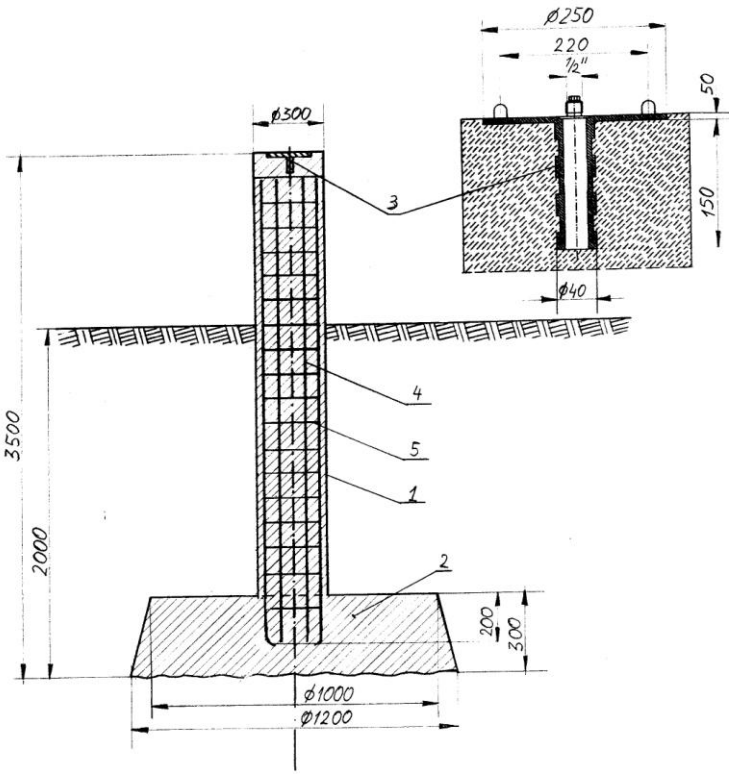
- **appropriate geometry of the reference and check point network,**
- **a possibility of obtaining a permit to install a geodetic mark at a chosen point,**
- **stability of the mark (low risk of damage),**



1 – reinforced post
2 – the mark foot, cast from concrete at the point of stabilisation
3 – head of the mark
4 – vertical reinforcement, Φ10x3400x6szt.
5 – horizontal reinforcement, shackles Φ6 every 250

Fig. 7. An outline of a reference point.

Fig. 8. A view of a reference point.

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SUMMARY

The data obtained in the precise levelling performed by the Przedsiębiorstwo Geologiczno – Geodezyjne „Geoprojekt – Gdańsk", as well as the material analyses, indicate the need to conduct further observations of dislocations in the Main and Old City of Gdańsk in the next years, in intervals of at least six months, controlled by independent fundamental altitude points.

The results of GPS static measurements at reference and check points, conducted during the first year, should be taken as reference values for the measurements conducted in subsequent years. The differences in the results from consecutive years will indicate the existence of vertical and horizontal movements of the earth's surface, where the City of Gdańsk is situated. The check points, stabilised with fundamental altitude points, will be used to monitor the settlement of historical tenement houses in Gdańsk.

Measurement of horizontal and vertical deformations of the earth surface in the areas where valuable objects of our cultural heritage are situated will make it possible to detect potential threats and to take action to prevent considerable damage.

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