Acta Geodyn. Geomater., Vol. 4, No. 4 (148), 133-140, 2007

QUASIGEOID ON CHOSE AREAS OF INVESTIGATIONS GEODYNAMICS

Piotr BANASIK

AGH University of Science and Technology (AGH-UST), Faculty of Mine Surveying and Environmental Engineering, Poland
Corresponding author's e-mail: pbanasik@agh.edu.pl

(*Received* May 2007*, accepted* September 2007)

ABSTRACT
In the paper a problem of elaboration and the use local quasigeoid on mining areas in south-eastern Poland is discussed. The models were elaborated within research projects carried by Institution of Geodesy and Cartography AGH in years 1996-2005 and related to mining caused terrain surface deformation problems. One part of the carried research was elaboration of quasi-geoid model that can be used in practical aspects of mine surveying. There is an example of this quasi-geoid model application in leveling surveys presented in the paper. Furthermore, discussed quasi-geoid models elaborated for small areas provide detailed information about the shape of this surface and they determine database completing existing country models as for example Leveling Geoid 2001 for area of Poland.

KEYWORDS: quasigeoid, geoid, GPS, levelling, geodynamic network

1. INTRODUCTION

The geoid surface is one of the basic that is used in geodesy. It is a reference surface in the orthometric height coordinate system. There is a quasi-geoid located close to geoid – one of surfaces of normal height coordinate system being in force in Poland. Both surfaces strongly differ in the aspect of physical attributes. Nevertheless the distance between them doesn't exceed a dozen millimeters on the most area of Poland. In many geometrical investigations, it can be considered that geoid and quasigeoid practically agree. Irregular shape of quasigeoid/geoid is determined in relation to a triaxial ellipsoid. Evaluation of undulation quasigeoid/geoid as a special model is a basic task of geodesy. One of the method of quasigeoid/geoid shape determination is an evaluation the distance between ellipsoid with the use normal (orthometric) or ellipsoidal heights of leveling network points by GPS surveys.

Actually, thanks to satellite techniques the task is carried with subcentimeterd accuracy. Derived local and regional, country models of quasigeoid/geoid are used for classical and satellite geodetic surveys techniques. Particular application is for mining areas, where geodetic especially leveling networks are losing their accuracy in quite short time due to deformations resulting from mining. It concerns especially leveling network connection on mining areas with the use of GPS and data information referred to local quasigeoid/geoid undulation. This connection should be carried to points located far away from areas affected by mining. It guarantees correct results of measured vertical displacements. Interesting areas for this research problem are Silesia and others southern parts of Poland, where geodynamical processes and phenomena result from both natural and anthropogenic causes.

There are precise geodetic networks established on these areas and designed for investigations of anthropogenic and natural geodynamical phenomena.

2. QUASIGEOID IN WIELICZKA AND KRAKOW AREA

In the scope of research carried in the years 1996-2006 on the Faculty of Mining Surveying and Environmental Engineering AGH University of Science and Technology there were several local model of quasigeoid elaborated. Areas studied in the investigations are presented in Figure 1. The main subject of the investigations carried in the mentioned above period was impact of mining activity on terrain surface. The research was focussed on southern areas of Poland (influenced by mining): eastern part of Upper Silesia Coal Basin (GOP) and Wojkowice, lead and zinc ore mining extraction area – Trzebinia, and salt mining – Wieliczka. There are next to antropogenic deformations natural geodynamical phenomena: suffosion, slides and tectonic. Geodynamic network was estabilished to observe (by geodetic or geophysic methods) effects of the mentioned processes.

Due to precise terrain deformation surveys several project integrated geodetic networks were established for displacement monitoring by GPS, precise leveling and gravimetry ("Research geodynamic network in area Wieliczka" – project KBN 9S60502807, "Research geodynamic network linked to the levelling network GIGANT and Active Geodetic Network ASG-PL" – project KBN 5T12E02323).

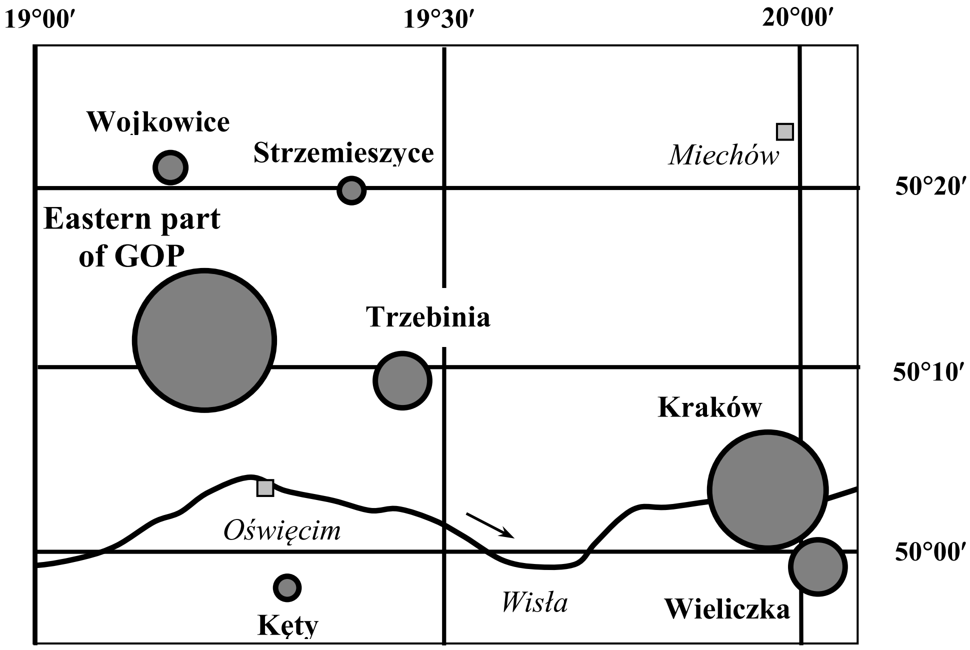


Fig. 1 Areas of the geodynamic surveys for determination of local quasigeoid model.

The geodetic coordinates B,L,h were determined with high accuracy on the network benchmarks (Góral and Zdunek, 1998). Existing points of country leveling and local networks were adopted for the network surveys needs.

The reference points so called "fiducial" were deeply grounded. Some of the points were grounded on crops of Triassic rocks. For GPS and leveling surveys selected points of POLREF network, first and second order leveling networks, ASG-PL were used. For GPS results elaboration algorithms were applied for minimizing disadvantageous influence of signal noises (disturbances) (Banasik et al., 1999). Thanks to that accuracy of horizontal and vertical coordinates amounted to few millimeters. The evaluated coordinates were applied for determination of quasigeoid undulations ζ that was referred to ellipsoid GRS-80 and component of deflections of the vertical (plumb line) ξ,η.

$$\zeta = h - H \tag{1}$$

$$\xi \cos A_{ij} + \eta \sin A_{ij} = -\frac{\Delta\zeta_{ij}}{s_{ij}} \tag{2}$$

$$\zeta = \zeta(x, y) \tag{3}$$

where: $\Delta\zeta_{ij}$ – quasigeoid udulation changes in directions i-j,
s_{ij} – distance i-j,
A_{ij} – azimuth a certain direction *i-j*.

The first studied object for quasigeoid location was Krakow and Wieliczka area. The main subject of geodynamic investigations was postmining ground and terrain deformation occurred there. The problem relates the Wieliczka and Bochnia mines, were next to typical phenomena of mining excavations compression, geological (postglacial and orogenic movements) and geomorphologic (landslides) processes. The areas are located on main tectonic Carpathian faults on two geological formations what is another cause of the rock mass instability. That's why the investigations are held there and carried for renovation work purposes and for minimizing effect of former mining activity.

The area covered by the surveys formerly covered 10 km × 10 km in the vicinity of Wieliczka. Results of precise leveling were used for a normal heights determination and they were carried on numerous on that area miming survey baselines and a vertical network. The benchmarks of the baselines were and single points of GPS surveys with 3 fiducial points made geodynamic study polygon (Góral and Zdunek, 1998), (Banasik et al., 2000b). Geodetic coordinates of the polygon points were evaluated in EUREF''89 system and normal heights in Kronsztadt'60 system.

The average density of points location on the study area was 1 point/km^2. There is the POLREF 1607 point in the central part of the area. The gravimetric results were used for evaluation of the distance between quasigeoid and geoid due to suugestions in (Barlik, 1996). Derived values of distance between the mentioned surfaces did not exceed 1 cm. It corresponds to global model on the area of Poland and specific, highland areas as well (Barlik, 1996). The distance between quasigeoid and

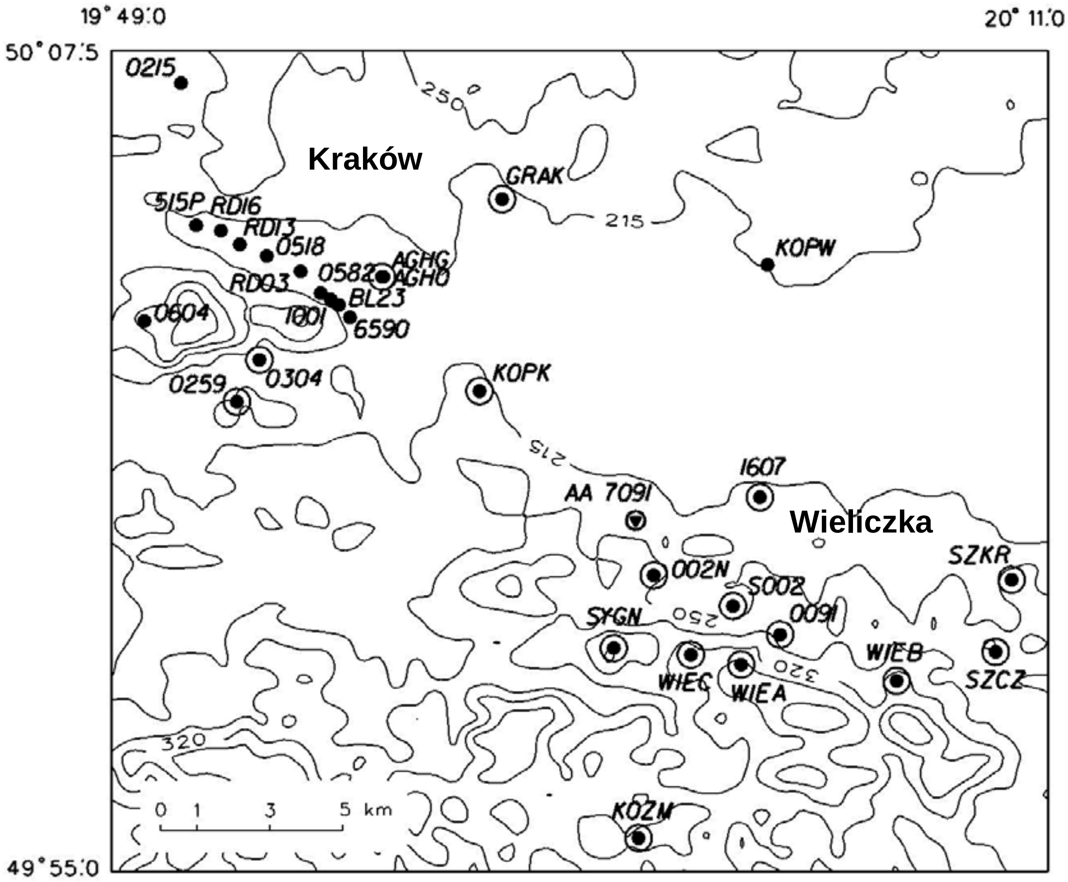


Fig. 2 Geodynamic polygon benchmarks on the area of Krakow and Wieliczkaon the background of the relief.

geoid was evaluated for research purposes. Some selected points from the nearby Krakow area were joined as well so the total area for quasigeoid undulation determination was double extended (Fig. 2).The normal heights most of the Krakow points were obtained in reference to national first and second order networks. The quasigeoid position was approximated with preceded analysis of polynomial order selection. The methods being robust for height errors influences were used in the analysis (Zhong, 1997). The optimal approximation polynomial was as follows:

$$\zeta_i = a_{00} + a_{10}x_i + a_{01}y_i \tag{4}$$

where: a_{00}, a_{10}, a_{01} – coefficients of the approximation polynomial,

Accuracy of the determined model called Quasi-Kr'99 was estimated as ±2 cm.

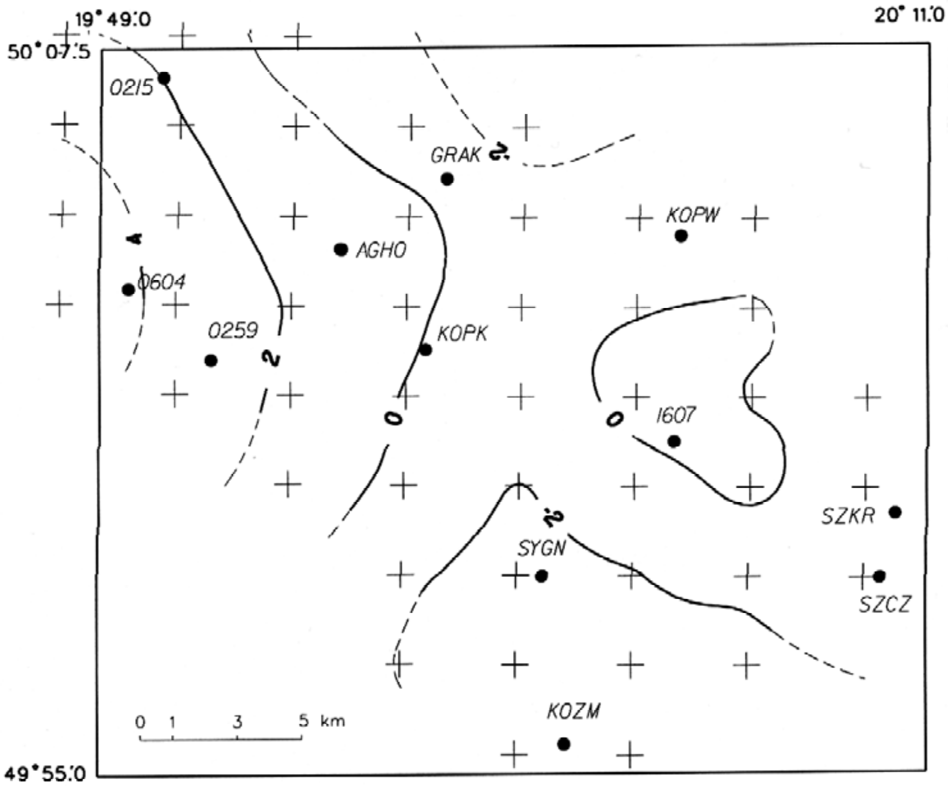
The distances for dozen control points (used for both GPS and leveling surveys carried within the scope of the investigation) were evaluated with this accuracy. Figures 3a and 3b present a isolines map illustrating distances between quasigeoid and ellipsoid GRS-80 and differences between the determined model and a national quasigeoid model Quasi'97b. The Quasi'97b model was discussed with details in (Łyszkowicz, 1998). The differences were calculated according to the formula:

$$R_{\zeta,i} = (\zeta_i^{Quasi-Kr'99} - \zeta_i^{Quasi'97b}) - \Delta\zeta_0 \tag{5}$$

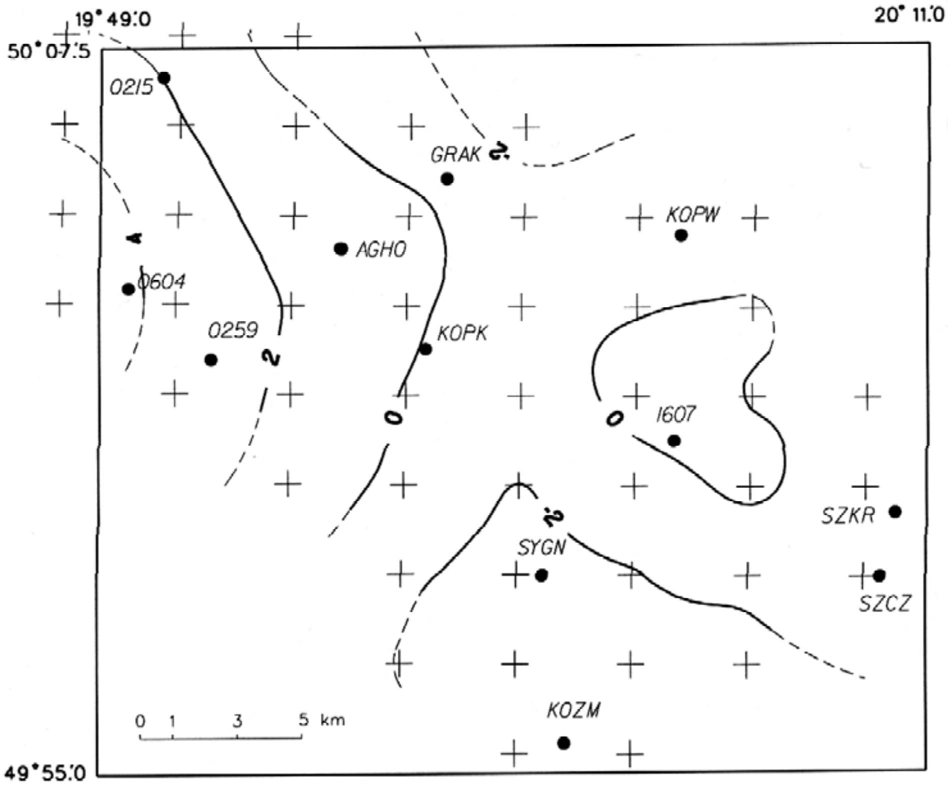
where $\Delta\zeta_0$ – a constant displacement between the models, derived as a average value of differences in every node of grid Quasi'97b model..

The distribution of differences demonstrates a minimal dip of both surfaces, the results from higher degree density of the Quasi-Kr'99 local model in compare with Quasi'97b. Calculated due to Bouguer anomaly distance between geoid and quasigeoid did not exceeded 1 cm.

There were investigations carried for determination of the terrain relief influence for the direction of the vertical in the vicinity of the benchmark 604 (Fig. 2). Gravitational effect of topographic mass resulting from the located there a hill with height over 150 m was analyzed in two perpendicular profiles. The numeric terrain model with resolution 50 m × 50 m was used for the analysis.



a)



b)

Fig. 3 Model local quasigeoid Quasi-Kr'99 on the area of Krakow and Wieliczka evaluated in Kronsztadt'60 and EUREF'89 systems:
a) quasigeoid undulation contours [m],
b) differences in relation to Quasi'97b model [cm].

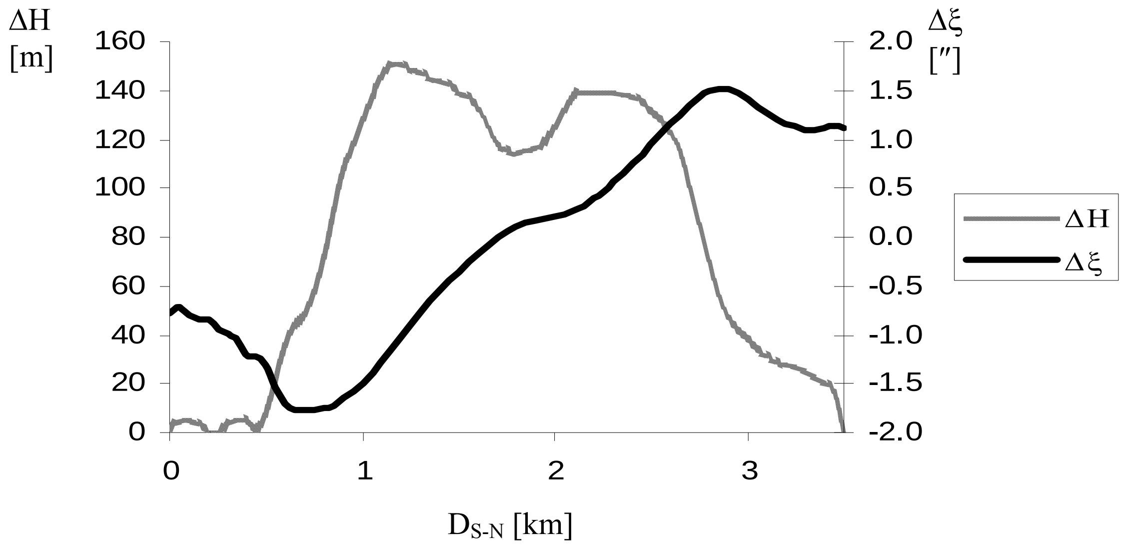


Fig. 4 Changes of verticality line in S-N direction and relief profile.

The path of deflections of the vertical along meridian profile is presented in Figure 4. Maximum values of ξ component occur in northern and southern slope of the hill and they amount to ±2″. The values of the vertical on that area were confirmed by direct evaluations both components of deflection of the vertical (Banasik, 1999). Obtained results suggest the necessity of investigations in deflections of the vertical on the area of diverse relief and consideration them in precise angle and leveling surveys.

3. THE LOCAL QUASIGEOID ON THE PART OF GOP

The experiences in the geodynamic polygon project and elaboration of local quasigeoid model for Krakow and Wieliczka were used in elaboration of successive local models for mining areas in Jaworzno, Trzebinia and Wojkowice (Banasik et al., 2000a; Banasik, 2001). The location of these areas is presented in (Fig. 1).

The terrain deformations resulted from mining activity are monitored there. The observations are carried usually by spirit leveling surveys on so-called “baselines”. The reliable results of the surveys strictu depend on correct connections to reference points of national leveling network. Due to distances of monitored area the connection lines amount to even a dozen kilometers. It makes the surveys time-consuming and expensive. So, the investigations on quasigeoid/geoid were incensed to make possible application of the surface for connection a mining leveling network by GPS. The benchmarks of second order leveling network (GIGANT) was used in experiments in Jaworzno. Several benchmark located on quasigeoid isolines with distances approximately 5 km (Fig. 5) were chosen fort the surveys. The direction of the isolines (azimuth ≈132°) was determined with use of the Quasi’97b model (Łyszkowicz, 1998). There is equal value for normal ΔH and ellipsoidal height changes on this direction according to the following formula:

$$\Delta H = \Delta h + \Delta\zeta \qquad (6)$$

where Δζ - undulation difference, which in minimal quasigeoid dip to ellipsoid direction is close to zero.

Statistic GPS observation in 2 hours sessions were carried on the benchmarks. The ellipsoidal height differences were compared with normal ones. Obtained minimal values Δζ do not exceed ±3mm/km.

This is a value compared with accuracy of the third order network leveling surveys. This is a sufficient accuracy for the most of leveling surveys carried on mining areas. The connection by this method is more economical. The possibilities of the method application on mining areas were studied in details in Banasik et al. (2000a) and Banasik (2001).

The geodynamic network created in the years 2002-2005 on the eastern part of GOP (Jaworzno, Chrzanów, Chełmek, Lędziny) enables investigations of natural and induced by mining geodynamic phenomena (Góral, 2002). The surveys area covers mining areas of 6 coal mines and one lead and zinc ore mine. Due to vicinity of their location there is a superposition of phenomena causing the terrain deformations. Moreover there are several faults located on the area affecting additionally the forming process of post mining subsidence basins. The features of the phenomena were discussed widely in (Góral et al., 2005). The main goal of establishment of precise leveling network was a possibility for complex and precise monitoring of terrain deformations. Established geodynamic network involves a dozen

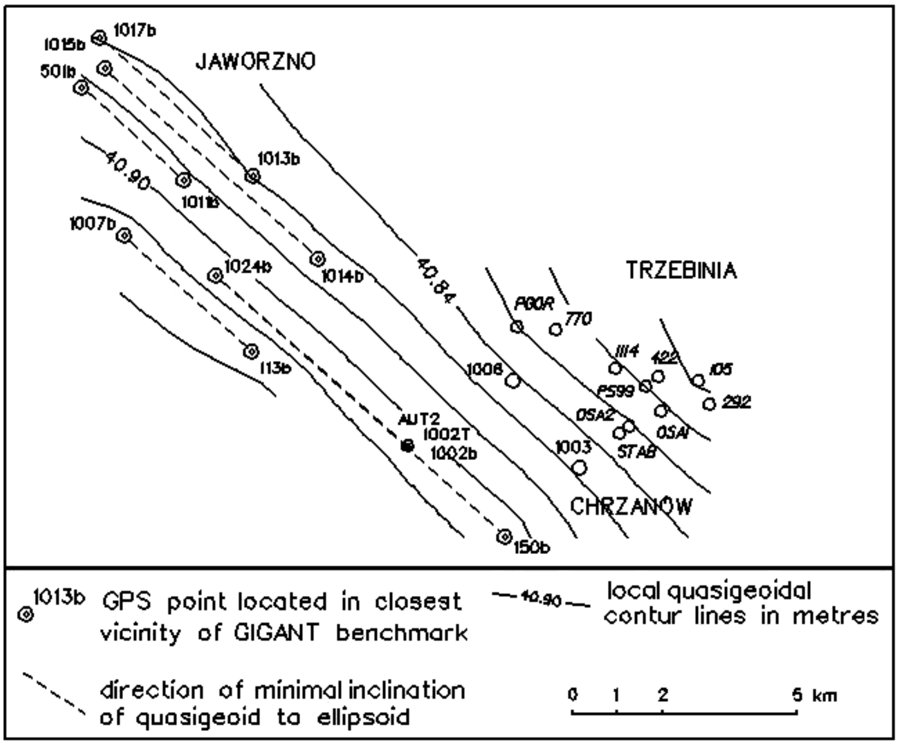


Fig. 5 Isolines of the quasigeoid elevations of the part Upper Silesian Coal Basin (GOP) area.

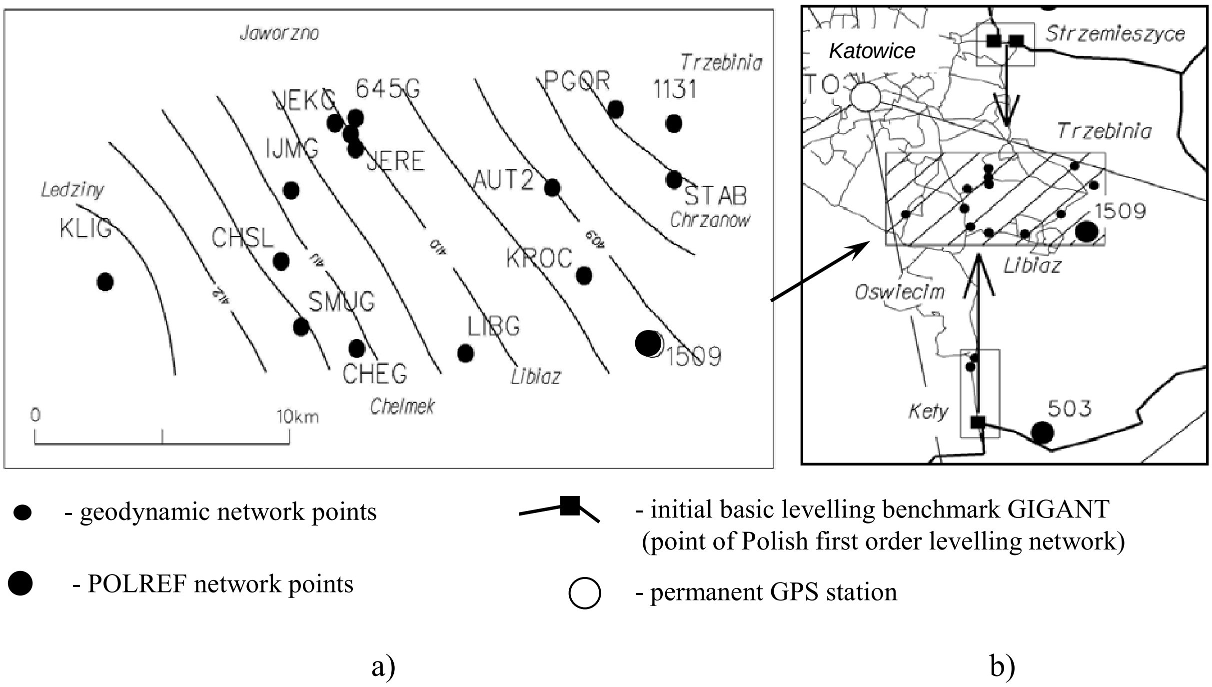


Fig. 6 Research geodynamic network on the eastern part of GOP:
a) Quasigeoid on the area of geodynamic network in EUREF'89 and Kronsztadt'86 systems,
b) scheme of leveling reference carried out by GPS surveys and use of guasigeoid local model information.

benchmarks usually grounded on rock crops. Their localization satisfied both research and practical application by mining surveyors. The GPS, leveling, gravimetric surveys were carried on the benchmarks (Góral et al., 2005). The ellipsoidal coordinate (B, L, h) were determined in EUREF'89 system and it was referred to permanent stations ASG-PL. Precise ellipsoidal heights were obtained thanks to application of special elaborated algorithms that eliminated disadvantageous troposphere refraction effect to GPS signals (Góral et al., 2005). Normal heights were derived by precise leveling surveys in reference to second order leveling network (GIGANT) in Kronsztadt'86 system. The g-force values were calculated in reference to gravimetric national network in IGSN'71 system. High accuracy of coordinates enabled elaboration precise centimeter moel of quasigeoid and geoid (Góral et al., 2005) (Fig. 6a). The model was compered with national quasigeoid model of all Poland Leveling Geoid 2001 (Pażus et al, 2002).

The distance ζ between quasigeoid and ellipsoid was determined on several network points on the area of Strzemieszyce and Kęty. These points are located close to reference benchmarks of GIGANT leveling network to first order leveling network (Fig. 6b). The aim of mentioned surveys was a possible elaboration of this type connection by GPS surveys and with use of elaborated model of quasigeoid in future.

4. CONCLUSION

There are on the areas affected by geodynamic phenomenon established networks for precise surveys. The particularly interesting in this case are mining areas, were intensive extraction is carried by underground, open and drilling mining. The natural resources extraction process results in terrain deformation, mainly due to a post mining excavation forming and hydrogeological regime changes. Of course it is difficult to analyse the resulting from mining deformations of the geodetic network on the area of the study and such an investigation require repeated observations. Thus the presented surveys are basic and important for mining deformation performance. A superposition of man induced phenomenon in natural caused phenomenon as tectonic on faulted areas or landslides. The elaboration of geodynamic networks has to monitor mentioned phenomenon and protection against their negative influence.

Slight bight changes resulted from geodynamic processes can be monitored by leveling or GPS periodic surveys. For the integration both techniques quasigeoid/geoid information is essential for a survey area.

The sense of this integration was explained in (Banasik et al., 2005). The information about point's ellipsoidal coordinates and normal heights makes excellent opportunities for determination of quasigeoid or geoid undulation. Presented local quasigeoid models are examples of carried works on the area of GOP and Wieliczka. Evaluated model scan be used by mining surveyors to increase efficiency of observations carried on mining areas. It is especially important for areas where terrain deformations make geodetic networks false. Another interesting application of the quasigeoid model is a reference of mining observation baselines to leveling network. The test procedure carried on Jaworzno area proved the sense for practical application such a method of leveling networks connection. It concerns especially regions where this connection is too far or it passes adverse terrain conditions for spatial leveling surveys.

Discussed in the paper models of quasigeoid is the first elaboration for the Silesia region. These models must be verified during the coming surveys campaigns carried on established geodynamical networks. Anyway just now it is possible to adapt the quasigeoid model by mine surveyors on those areas.

Local quasigeoid/geoid created with the use of precise geodetic surveys in the points of geodynamical network perform usually higher accuracy and resolution than country or regional models. Hence another new model after suitable adaptation should complete country model.

ACKNOWLEDEMENT

The research has been supported by the AGH-UST in Krakow in frame of the project No. 11.11.150.478.

REFERENCES

Banasik, P: 1999, Influence of the relief of terrain on the change of vertical line on the example of hill Sowiniec in Krakow. Scientific Bulletins of the University of Mining and Metallurgy, Geodesy, Vol. 5, No. 2, Krakow, 1999, 189-194, (in Polish).

Banasik, P., Góral, W. and Maciaszek, J.: 1999, Precise control network in the Eastern Part of the Upper Silesia Industrial Area. Scientific Bulletins of the University of Mining and Metallurgy, Geodesy, Vol. 5, No. 2, Krakow, 1999, 195-205, (in Polish).

Banasik, P., Góral, W., Maciaszek, J. and Szewczyk, J.: 2000a, Monitoring of large-area surface changes in Upper Silesia Industrial area (GOP) with application of modern measurement technologies. 11 th International Congress of the International Society for Mine Surveying, Vol.1, Krakow, 2000, Poland.

Banasik, P., Góral, W., Kudrys, J., Maciaszek, J. and Szewczyk, J.: 2000b, Precise GPS network in Krakow area. 6th Geodetic Millenium Meeting Poland-Italy, Reports on Geodesy, No. 8(54), Warsaw, 2000.

Banasik, P: 2001, Utilization of quasi-geoid in levelling measurements. Scientific Bulletins of the University of Mining and Metallurgy, Geodesy, Vol. 7, No. 2, Krakow, 2001, 141-149, (in Polish).

Barlik, M: 1996, Applying of the gradiometric measurements to determination of the geoid to quasigeoid separation . Reports on Geodesy, No. 6(24), Institut of Geodesy and Geodetic Astronomy, Wars. Univ. of Technol., Warsaw.

Góral, W. and Zdunek, R.: 1998, The geodynamical polygon in Wieliczka and Krakow area. Scientific Bulletins of the University of Mining and Metallurgy, Geodesy, Vol. 4, No. 1, Krakow, 1998, 13-18, (in Polish).

Góral, W.: 2002, A concept of research geodynamical network in the area limited by Silesian Active Geodetic Network and permanent station KRAK. Scientific Bulletins of the University of Mining and Metallurgy, Geodesy, Vol.8, No.1, Krakow, 2002, 19-25, (in Polish).

Góral, W., Banasik, P., Maciaszek, J. and Szewczyk, J.: 2005, Research geodynamic network in eastern part upper Silesian Coal Basin, UWND AGH, Krakow, 2005, (in Polish).

Łyszkowicz A.: 1998, The gravimetric quasi-geoid model QUASI97B and the leveling system Kronsztadt'60, VI Symposium. Actual problems of basic geodetic networks, Warszawa, (in Polish).

Pażus, R., Osada, E. and Olejnik, S.: 2002, Leveling Geoid 2001, Surveyor, No.5/2002, Warsaw, (in Polish).

Zhong, D.: 1997, Robust estimation and optimal selection of polynomial parameters for the interpolation of GPS geoid heights. Journal of Geodesy, No.71, 552-561.