DETERMINATION OF THE DEFORMATION OF THE EARTH'S CRUST IN POLAND

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1. INTRODUCTION

It was within the framework of this project that an analysis was conducted of existing geodynamic networks with the aim of defining the potential for their use in undertaking studies tied with the deformation of the Earth's crust within the territory of Poland. It is as a part of this determination that the authors planned the identification of the primary zone of discontinuity of the deformation field within the framework of the Earth's crust throughout Poland. To provide for greater density in the existing network, supplementary observations were conducted at six points located in southeastern and northwestern Poland. Warping and deformation of the Earth's crust within Polish territory was determined on the basis of satellite observations.

2. AN OVERVIEW OF EXISTING GEODYNAMIC COORDINATE SYSTEMS

2.1. The IGS Network

The International GNSS Service (IGS) was established in 1990 during the 20th General Assembly of the International Union of Geodesy and Geophysics. The mission of the IGS is to provide high quality data and products as standards for GNSS systems as well as assistance in scientific studies of the Earth, interdisciplinary studies, and education. The IGS develops standards and specifications vital in international research.
IGS products are as follows:
- GPS and GLONASS satellite ephemerides,
- Earth rotational motion parameters,
- IGS station coordinated and velocities,
- Adjustment to GPS satellite and IGS station receiver clocks,
- Global troposphere parameters, and
- Global ionosphere maps.

A total of 383 stations are currently participating in the IGS, including three Polish stations—Józefosław, Borowiec, and Lamkówko.

2.2. The European Permanent Network

The EUREF Permanent Network (EPN) is made up of GPS and GPS/GLONASS stations throughout Europe delivering data to maintain the EUREF network. A part of the EUREF stations also participates in the IGS. Network organization is based on IGS standards. Currently, 192 stations, including nineteen Polish stations, are a party of the EPN.

2.3. ASG/EUPOS

The EUPOS system is made up of several segments, where the main one is the receiver segment. Its role is the collection of observation data from the GNSS satellites and relaying that data to the processing center in real time. The system also consists of evenly spaced GNSS reference stations throughout Poland and neighboring countries.

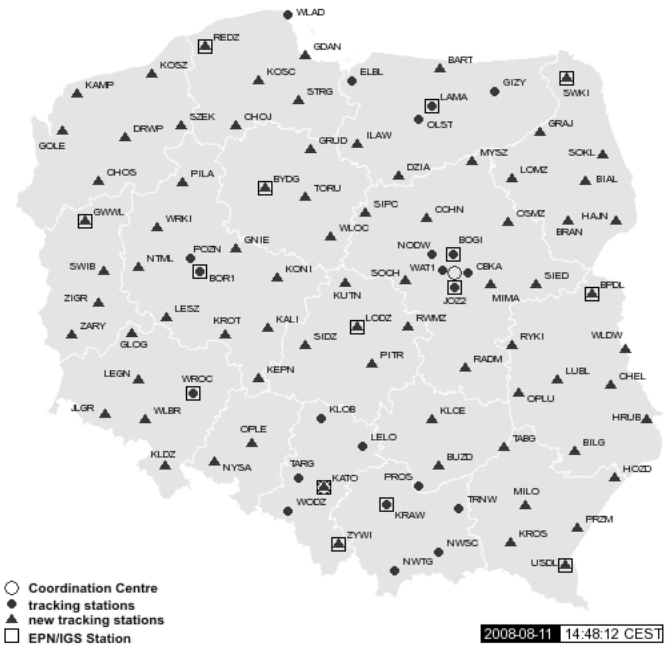

Fig. 1. Diagram of the AGS/EUPOS network.

Pursuant to the EUPOS standard, the following assumptions in building the receiver segment were made:

- The average distance between stations amounts to 70 km,
- Existing EPN and IGS stations are incorporated into the reference station network,
- Station coordinates are designated using the ETRS89 system as well as national systems,
- Only precision dual–frequency GNSS receivers are used at the reference stations, and
- Locations of reference stations are selected so as to guarantee convenient conditions for GNSS satellite observations.

Currently, this segment is made up of the following groups of reference stations:

- Eighty–four stations with a GPS module,
- Fourteen stations with a GPS/GLONASS module, and
- Up to thirty foreign stations.

The total number of stations incorporated into the system should not exceed 130. National reference stations are, for the most part, located on buildings belonging to voivodeship [provincial] and *admistrative district* [county] level public administration, research institutes, and educational facilities. It will be possible to utilize a part of the stations for geodynamic investigations following verification of the level of stability of the antenna positions.

2.4. The European Vertical GPS Reference Network

The European Vertical GPS Reference Network (EUVN) was established in 1997 as a network linking the height systems of the European countries. It was within the framework of this campaign that simultaneous measurements were taken at 196 points, including in Poland at four EUVN network points and EUREF permanent stations operating in the country (included in the EUVN network, giving a total of eight national points). A project increasing the density of this grid was implemented in 1999. Each of the designated points was subject to observations in twenty–four hour sessions. The coordinates of fifty–four new network points were designated in the campaign. Grid measurements were not repeated with the exception of primary points (four) measured in 1997 and 1999. The accuracy of the grid may be estimated for each of the ortho–Cartesian coordinates at a level of 2–3 mm.

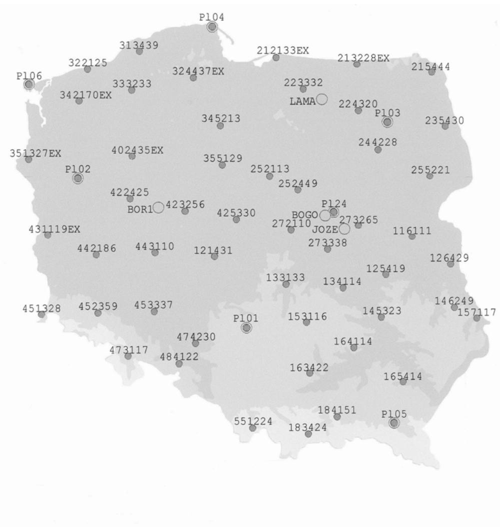

Fig. 2. Diagram of the European Vertical GPS Reference Network.

2.5. The Central Europe Regional Geodynamic Project

The Central Europe Regional Geodynamic Project (CERGOP) was initiated in 1994 as a network for regional geodynamic investigations and was coordinated within the framework of the Central European Initiative (CEI). The project is being continued as a European Union project under the name of CERGOP–2. The effect of work and research conducted within the framework of the two projects includes the Central European GPS Geodynamic Reference Network (CEGRN). Observation campaigns for the CEGRN were undertaken annually within the framework of the first program and every other year as a part of CERGOP–2. Each campaign had a duration of five days. The processing was the task of a minimum of three independent centres.

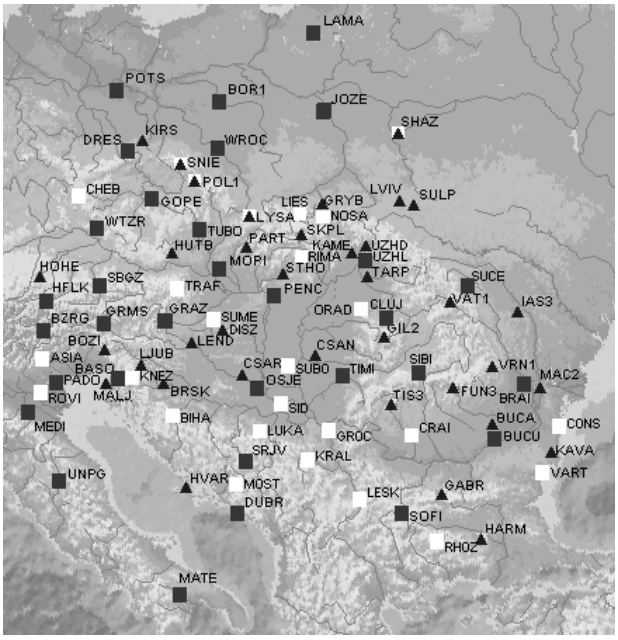

Fig. 3. Diagram of the CERGOP–2 geodynamic network.

2.6. The "Tatry" Geodynamic Traverse

This is a sub–project undertaken within the framework of CERGOP–2. The Tatra Mountains network was established in order to study contemporary, local tectonic movements. Observations within the framework of this project are conducted using methods including GPS technology. The measurement campaigns are periodic (annual) in character. The network was established in 1998 and is presently made up of eleven GPS points (six points over the 1998–2002 period). Of the eleven points, seven are currently on the Slovakian side of the Tatra Mountains, with four on the Polish side. In the "Tatry" project, measurement campaigns have a duration of four days. The accuracy of determination of the positions of the points is assessed at less than 5 mm. A diagram of the Tatra Mountains network is found in Figure No. 4. The locations of the points were determined in terms of geological structure aspects.

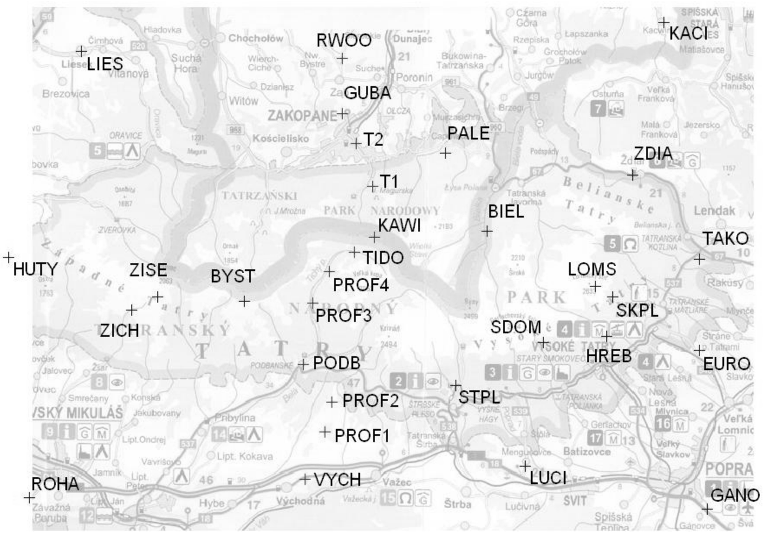

Fig. 4. Diagram of the "Tatry" network.

2.7. The “Pieniny” Geodynamic Traverse

The GPS satellite observations are being carried out in the area of the Pieniny Klippen Belt. Observation points were selected after careful geological analysis of the area encompassed by the work. The first efforts were commenced in 1977, preceding the application of satellite technology. GPS measurements were conducted each year over the 1994–1995 and 2001–2005 periods. The character of the measurements over the years 1994–1995 was applying short time intervals with repetition in various configurations. Starting with the year 2001, the principle assumed was that a few primary points are to be observed for at least three days. For the rest, two three–hour sessions were conducted in 2001, where for the successive two years a single six–hour session was conducted. All network points apply a system of forced centring as of 1994.

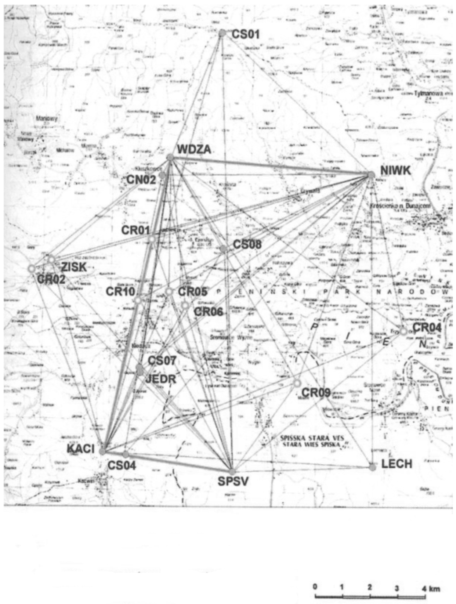

Fig. 5 Diagram of the geodynamic “Pieniny” network.

All points measured during the campaigns may be characterized as having errors, where the received coordinates worked out in both the individual campaigns and from repeated results over successive campaigns have errors at a level of 5 mm.

2.8. The Geodynamic Traverses in the Sudeten and Sub–Sudeten Mountains Area

The objective behind establishing geodynamic traverses in southwestern Poland is to study contemporary tectonic activities in the area of the Polish section of the Sudeten block as well as the pre–Sudeten block. Contemporary measurements are conducted using GPS technology. Work was commenced in 1992 and repeated annually. The range of the geodynamic traverses encompasses the Karkonosze Mountains, the Śnieżnik Massif, the Stołowe [Table] Mountains, and the Paczków Trench [Rów Paczkowa]. Selection of the points was dictated by the geological–tectonic structure of the examined area.

The traverses consist of twenty–seven points in the Śnieżnik Massif, ten points in the Stołowe [Table] Mountains, nineteen points in the Karkonosze Mountains, and fifteen points in the Paczkowski Trench. The GEOSUD research grid in 1996 was established.

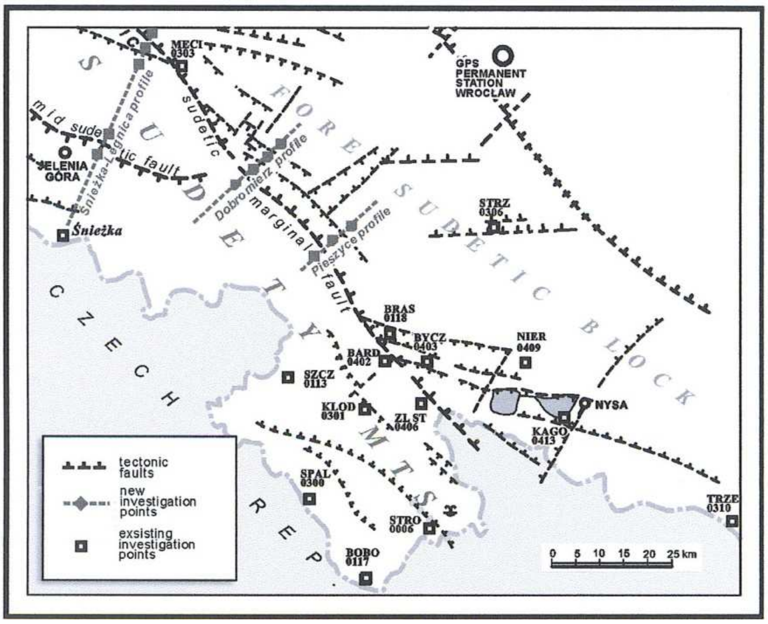

Fig. 6 Diagram of the geodynamic GEOSUD network.

The network was created using selected points from already existing geodynamic traverses as well as several new points. Starting with 1996, the measurement of this network is repeated annually in two–day observation campaigns. The coordinates of the points are defined with an accuracy of up to several millimeters.

2.9. The Polish Geodynamic Network

Work on establishing the Polish Geodynamic Network was taken up by the Institute of Geodesy and Cartography in 1992. It was decided that the core of the network being created was to consist of points located in astronomical–geodetic observatories. The remaining points would be points of the EUREF network found throughout the country as well as SAGET geodynamic traverse points taking part in several international programs. Locations of successive points, selected from the POLREF network, were consulted with Prof. R. Dadlez of the State Geological Institute (PIG). The basis for selection of the locations of these points was a map depicting the boundaries of the primary and secondary geological structures. This network matched perfectly the EUREF–POL permanent points as well as selected points of the POLREF network. The network was measured once, where comparison with the developed POLREF grid demonstrated significant systematic and random differences. Nevertheless, the method for stabilizing the points of this network recommends it for use in geodynamic work (repetition of measurements). Results of comparisons with the POLREF grid show centimetre differences in geodetic coordinates.
The main purpose for which the information procured from the above discussed grids is to be used, is the determination of stress in the Earth's crust. Since deformations within Poland are very small, the observation campaigns had to meet high requirements, including:
- Repeatability of measurements (numbers and duration of campaigns),
- Measurement quality and accuracy in defining coordinates,
- The range of the network and its cohesion with others (coordinate reference system).

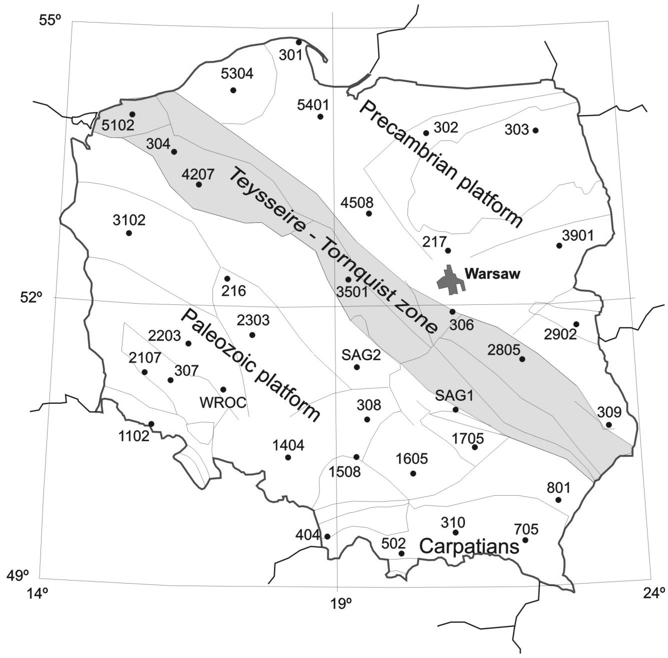

Fig. 7. Diagram of the geodynamic Polish Geodynamic Network.

As mentioned, the Polish Geodynamic Network was observed only once. It was decided to conduct supplementary measurements for six selected points of the network in order to utilize the existing stabilization as well as due to the good locations of the network points on geological structures. Three points were selected in north-west Poland and three in south-east Poland. Two campaigns were conducted as a part of this project in 2006 and 2007, five days each. The results of the observations were processed together with CERGOP and EPN observations.

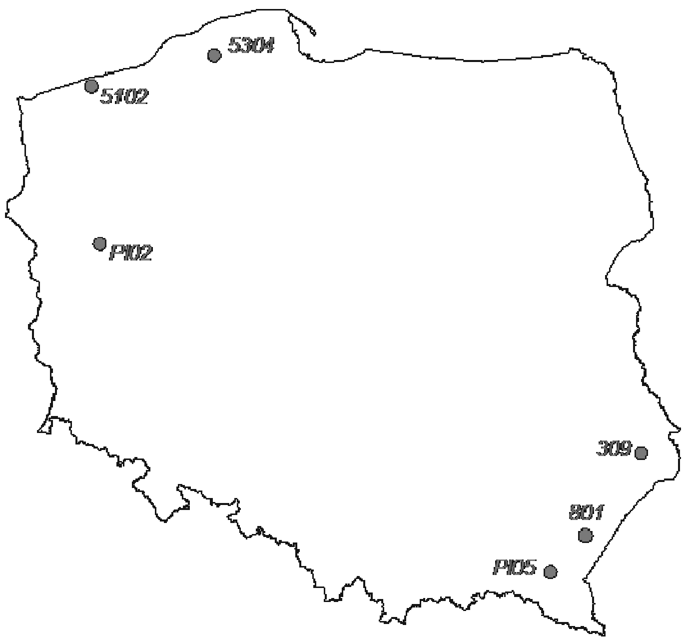

Fig. 8. Diagram of the supplementary network.

3. DETERMINATION OF VELOCITY VECTORS AND INTERPLATE SHIFTS

Polish Geodynamic Network was observed only once. Moreover, shifts (velocity vectors) were only determined for eight points of the CERGOP—four permanent stations and four for which observations are conducted periodically. Velocity vectors may be utilized to calculate interplate movements. Successive research into observations performed within the framework of the CERGOP campaign was used to calculate the velocity of stations taking part in this project. Three plate movement models were applied to determine the interplate shifts—the Eurasian APKIM 2000, APKIM 2005, and NUVEL 1A. Interplate shifts are presented in Figures No. 9, No. 10, and No. 11.

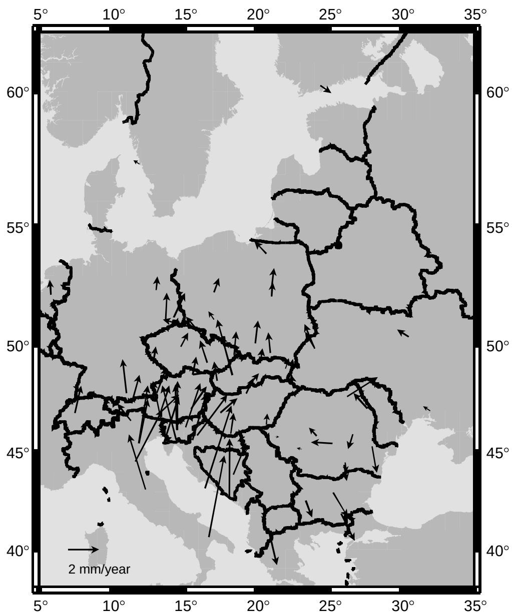

Fig. 9. Interplate velocity determined using the APKIM 2000 model.

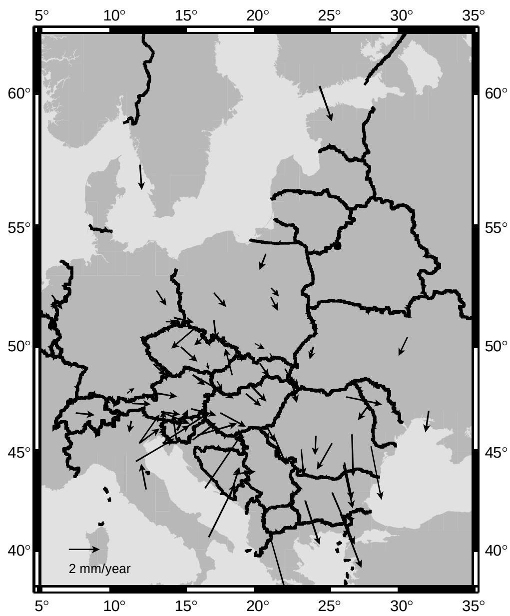

Fig. 10. Interplate velocity determined using the APKIM 2005 model.

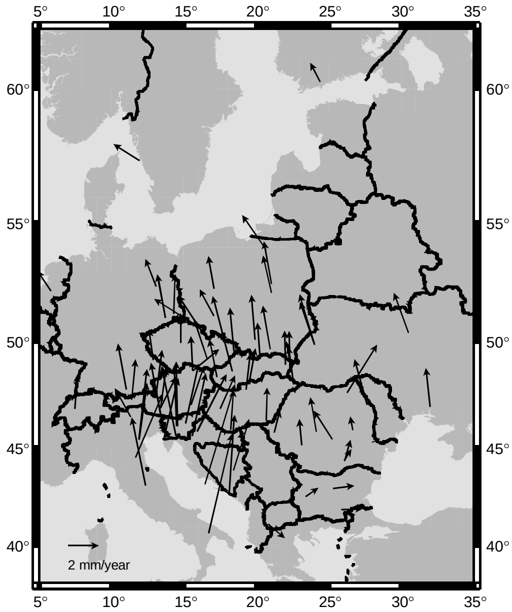

Fig. 11. Interplate velocity determined using the NUVEL 1A model.

Of significance are comparisons of the velocity of points taking part in the CERGOP campaign calculated using the three models of horizontal Earth crust movement— APKIM 2000, APKIM 2005, and NUVEL 1A. The values calculated for these three models are diametrically different, which actually has little impact on calculations of deformation axes using the Altiner method. The question of these differences should be the subject of further analysis. The determination of interplate velocities and deformation parameters was also conducted using observations at EPN stations in Poland and its immediate neighborhood. Measurement results of good quality for interplate velocities were achieved. They are a good match to the stress field models for this part of Europe.

4. HORIZONTAL DEFORMATIONS OF THE EARTH'S SURFACE

All CERGOP campaigns and the three models of interplate movement—APKIM 2000, APKIM 2005, and NUVEL 1A—were used in calculating interplate velocities. Deformations in the area encompassed by the CERGOP project were determined on the basis of these vectors.

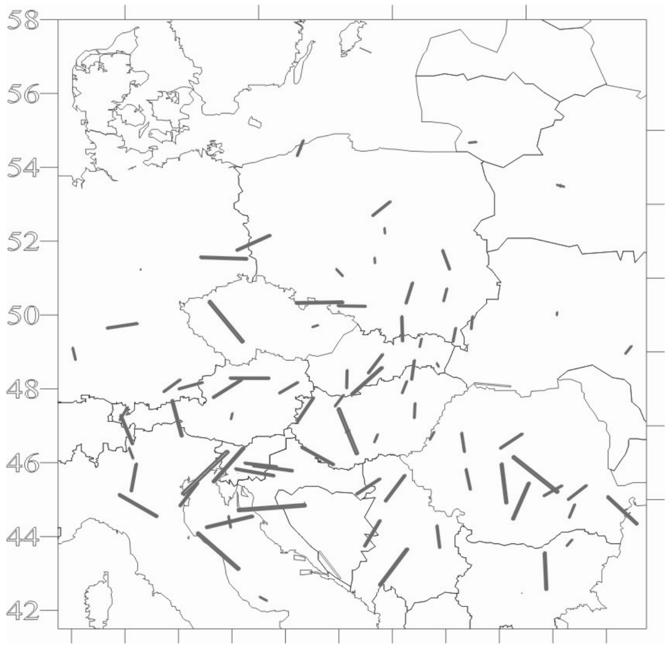

Fig. 12. Contraction directions.

The orientation of the axis of greatest torsion demonstrates certain significant similarities in terms of the directions of stress axes. The results of calculations demonstrate that the pervading direction of contraction in south-eastern Poland is close to longitudinal, with a deviation that is north–north-east. In south-western Poland, the contractions are almost exactly perpendicular to the former and their values are relatively greater. The picture for the Balkans is not uniform and, at locations such as the Alpine area, difficult to explain from the point of view of geodynamics. Since deformation calculations are strongly influenced by errors in determining vector velocities, the interpretation of calculation results in terms of the geodynamics of the area is still premature. What should be done, is to wait for more precise measurement results as well as to avoid artefacts as deformation calculations can only use carefully selected permanent measurement points. In spite of the fact that the received deviation axes disclose a certain similarity with stress directions, greater agreement is seen in interplate shift directions adjusted for APKIM 2000.

5. CONCLUSIONS

- The analysis conducted on the existing GNSS network demonstrates that the network that best meets the needs of geodynamic research is the Polish Geodynamic Network because of the location of points and their stability.
- Experience gained over the course of work on this project as well as acquired during work related to the CERGOP and CERGOP–2 projects allows the statement that the procurement of results permitting good modelling of the kinematics and dynamics of the Earth's crust is possible only after conducting several (4–5) measurement campaigns annually or biannually.
- The optimum solution is the use of permanent stations of the GNSS network for research into the kinematics and dynamics of the Earth's crust.
- Permanent points for geodynamic studies must meet stabilization criteria as defined within the framework of the CERGOP project as well as defined in the initial IGS documents.
- Some of the Polish points of the EPN network and a substantial majority of ASG–PL points fail to meet these criteria.

- Results received as a part of this project demonstrate an agreement between geodynamic phenomenon taking place on the Earth's surface (from geodetic measurements) and phenomena occurring in the Earth's crust (measurements of stresses in the deep boreholes).
- It is necessary to design a new network of permanent stations, supplementing the EPN and ASG–PL stations, for geodynamic research that meets the location and stability criteria for this project.
- Also, the possibility of using the Polish Geodynamic Network in the discussed studies should be reanalyzed.

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