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GPS DEFORMATION MEASUREMENTS IN THE GEODYNAMIC TEST NETWORK SÓSKÚT

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Abstract

The Geodetic Institute of the University of Karlsruhe and the Department of Geodesy and Surveying of the Budapest University of Technology and Economics have been cooperating for 30 years in the field of deformation measurements and analysis. One of the common projects in this cooperation is related to the network of Sóskút which has been established to detect surface motions in the vicinity of a geological fracture. In the beginning terrestrial measurements have been carried out, while in recent years common GPS campaigns were organized in order to investigate the potential of the GPS technology in deformation measurements and analysis. The paper describes the development and the actual results of the joint project and points out the progress in methodology.

Keywords: GPS measurements, deformation analysis, geodynamic network.

1. Introduction

In the year 2000 the University of Karlsruhe and the Budapest University of Technology and Economics celebrate 30 years old cooperation. Collaboration in the field of Geodesy started in 1972, based on an agreement signed by Prof. Dr. Ákos Detrekői from the Department of Geodesy and Surveying of the Budapest University of Technology and Economics (BUTE) and by Prof. Dr. Eugen Kuntz from the Geodetic Institute of the University of Karlsruhe (GIK). After 1980 the partnership between both institutes has been financially supported by the German Academic Exchange Agency (DAAD), including a special agreement between Prof. Dr. Ferenc Sárközi (BUTE) and Prof. Dr. Eugen Kuntz (GIK), entitled 'Geodetic Deformation Measurements' in the years 1985–1988. In this phase of collaboration the main emphasis has been put on the application of terrestrial measurement procedures to several monitoring projects as well as on practical tests of the nearly developed approaches for deformation analysis. This period culminated in a seminar on Deformation Measurements held in Balatonfüred in October 1992 on the occasion of the 20th anniversary of the cooperation.

A new period started in 1997 when Prof. Dr. József Ádám (BUTE) and Prof. Dr. Bernhard Heck (GIK) signed an agreement for a project entitled 'A geodetic deformation measurement and analysis with special consideration of GPS observation procedures'. This special agreement has been sponsored by the DAAD during the years 1997–2000, allowing an exchange of scientists between both institutes (*Tab. 1*). This exchange could also be extended to students for the preparation of their diploma theses (three students of the BUTE, one student of the GIK).

Table 1. Exchange of scientists between BUTE and GIK within the special agreement 1997–2000

Date	from GIK to BUTE	Date	from BUTE to GIK
October 19–25 1997.	H. Haug (student) Dr. M. Kuhn	November 17–21, 1997.	Dr. K. Dede, L. Szűcs, E Papp, P. Bóna
November 8–14, 1998.	Dr. H. Kutterer, Dr. M. Kuhm	December 7–11, 1998.	Dr. K. Dede, L. Szűcs, E. Papp
October 3–9, 1999.	Prof. Dr. B. Heck, Dr. K. Seitz	November 22–26, 1999.	Dr. K. Dede, L. Szűcs
May 8–13, 2000.	Dr. H. Kutterer, Dr. K. Seitz	September 10–14, 2000.	Dr. K. Dede, L. Szűcs Sz. Rózsa, T. Tokos

As a central subject of the recent cooperation, GPS observation campaigns including GPS receivers of the GIK have been organized in the Sóskút network near Budapest in order to monitor potential deformations in this geodynamically active region. In the framework of the exchange programme the GPS observations have been processed, evaluated and integrated for the purpose of deformation analysis at the GIK.

2. The Geodynamic Network Sóskút

The geodynamic network Sóskút is located at the western side of the Buda Mountains in the Sóskút Plateau which is dissected by the Transdanubian fracture zone in NW-SE direction. For a description of the geology in this strongly eroded region see SZŰCS et al., (2000).

In 1984 the Department of Geodesy and Surveying of the BUTE established a small network consisting of six points to determine tectonic movements. The location of the sites has been fixed by inspecting aerial photographs taken along the fracture; all sites can easily be approached by car. For the location of the points in the Sóskút network see *Fig. 1*. The sites have been monumented by pillars consisting in reinforced-concrete material with special head units to guarantee precise force centering (*Fig. 2*). Three pillars are situated on the western and three ones on the eastern side of the fracture where a small river (Benta) has digged in this valley (FÖLDVÁRY–VARGA et al., 1986, BOTTKA et al., 1985).

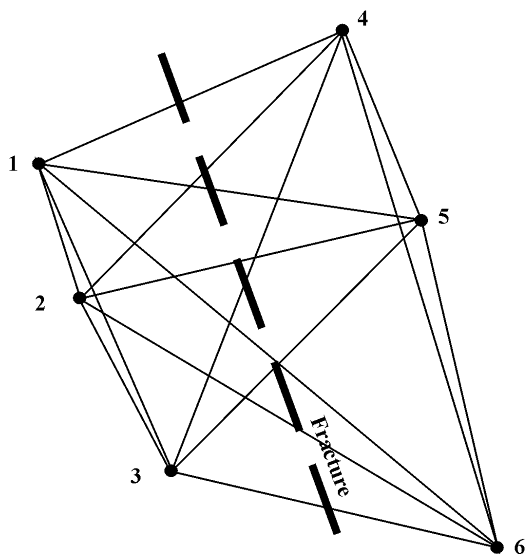

Fig. 1. The location of the points in the Sóskút network

At first classical terrestrial triangulation and trilateration have been applied for determining the horizontal positions of the points. Using WILD T3 theodolite a precision of $0''.1 - 0''.2$ for the horizontal directions could be achieved. The distances between the points of the network were measured by means of high precision electronic distance meters (SZŰCS–TAKÁCS, 1998), using the MEKOMETER ME 3000 (1985), the GEOMENSOR (1986) and the MEKOMETER ME 5000 (1991) in the framework of the BUTE-GIK cooperation. The height of the points has been controlled several times by precise levelling. Furthermore, local control levellings of the pillars have been made in order to detect the potential tilting of the pillars.

Since 1990 the GPS technology has been applied in the Sóskút network. The first campaign organized in April 1990 was the first GPS campaign in a local network in Hungary (FALUDI et al., 1990). An overview of the different GPS campaigns in the Sóskút network is provided in *Tab. 2*. Several observation designs and session

Fig. 2. Site pillar

lengths have been used in order to investigate the effects on the positioning results and to find an optimum. Since only one pair of receivers has been available, single baselines have been observed until 1997, while simultaneous observations on all six network sites could be carried out in 1998, 1999 and 2000. The four campaigns between 1997 and 2000 have been realized in the framework of the above mentioned BUTE-GIK project; in these campaigns a data rate of 15 s and a minimum elevation angle of 15 degrees have been used.

For the period 1999–2000 an integrated analysis of the environmental monitoring geodetic measurements was carried out within a project supported by the Hungarian Academy of Sciences, see ÁDÁM et al., (2002).

3. Deformation Analysis Based on GPS Observations 1997–2000

One of the main tasks performed in the framework of the special agreement between the BUTE and the GIK in the period 1997–2000 was the evaluation of the GPS observations for the purpose of deformation analysis. *Fig.3* illustrates the central problem of the geodetic deformation analysis: While the top-down path starts at the deformations of the earth's surface and ends in a straightforward way with the measured temporal variations of geodetic observations, the geodetic deformation analysis (bottom-up path) belongs to the class of inverse problems, since e.g. the

Table 2. GPS Campaigns in the Sóskút network

Date	Instrumentation	Frequencies	Logging time
Apr. 1990	2 GEOTRACER 100	L1	
Apr. 1996	2 TRIMBLE 4000SE	L1	
Oct. 1997	2 TRIMBLE 4000SSi	L1/L2	∼ 1 h
Nov. 1998	2 TRIMBLE 4800	L1/L2	∼ 3 h
	2 TRIMBLE 4000SSi		
	2 TRIMBLE 4000SSE		
Oct. 1999	2 TRIMBLE 4000SSi	L1/L2	∼ 6 h
	2 TRIMBLE 4800		
	2 TRIMBLE 4700		
May 2000	2 TRIMBLE 4000SSi	L1/L2	1^{st} session:
	2 TRIMBLE 4000SSE		24 h,
	2 TRIMBLE 4800		2^{nd} session:
	2 TRIMBLE 4700		6–8 h

impact of the atmosphere and observational errors cannot be fully modelled. This fact leaves some degrees of indeterminateness in the results of geodetic deformation analysis, suggesting the application of statistical procedures. It should be remarked that most types of geodetic observable phenomenons are influenced by the gravity field of the Earth. Temporal changes of the gravity field induced by geodynamic processes thus produce another component of deficiency in deformation analysis; this problem has been addressed to, e.g., by BIRÓ (1983), BIRÓ et al. (1986), and BIRÓ–HECK, (1986).

A deformation analysis on statistical basis has been developed at both institutes since the late seventies. The fundamentals of the procedure applied for the investigation of horizontal displacements and deformations are sketched in *Fig.4*; for details see, e.g., HECK (1983, 1989) and NKUITE (1998). A similar procedure is applied to the analysis of (one-dimensional) vertical displacements.

The deformation analysis of the GPS observations in the Sóskút network has been carried out along these lines of reasoning, after having partitioned the three-dimensional spatial Cartesian co-ordinates into two-dimensional horizontal and one-dimensional vertical components; the statistical information contained in the covariance matrix has to be transformed accordingly, using the law of covariance propagation. As a final result of the free network adjustments (step 1 in *Fig.4*) the horizontal and vertical point errors have been calculated for each epoch separately; the external precision of the epoch 1997 is worse than in the other campaigns by a factor of 2-3, which is due to the short occupation time and session length (generally less than one hour).

In step 2 of the deformation analysis the hypothesis of the whole congruence network for each pair of epochs is tested. Fixing the confidence level at 95% this hypothesis was not accepted for the comparison of the horizontal networks at

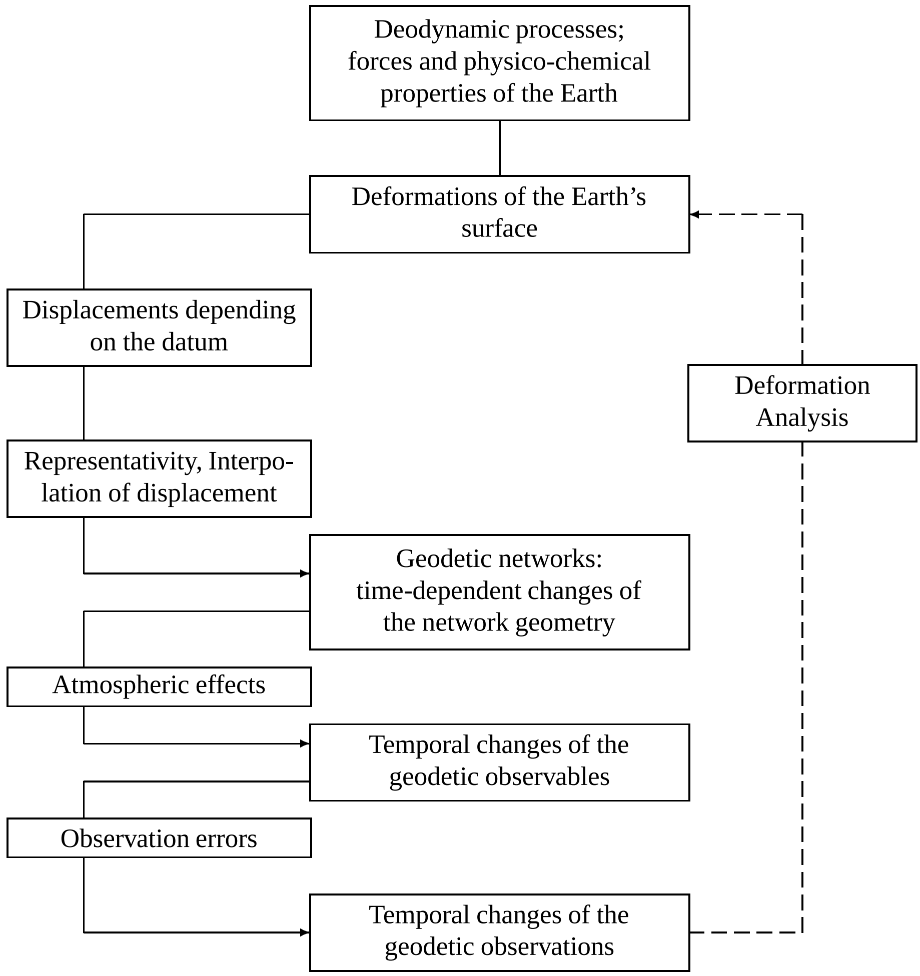

Fig. 3. Deformation analysis considered as an inverse problem

epochs 1999 and 2000. A point-by-point check for potential reasons proved that point no. 1 (see *Fig. 1*) might have moved; after eliminating this point from the set of reference points the congruence test was accepted. This result was corroborated by the succeeding single point tests performed in step 3. A graphical visualization of the tests for horizontal single point displacements of the points 1, 2, 3 with respect to the reference points 4, 5, 6 between the epochs 1999 and 2000 is provided in *Fig. 5* The displacement vectors of points 2 and 3 are completely included within the confidence ellipses, thus these points may be considered as stable; in contrast, the displacement of point 1 (3.5 mm) is weakly significant at the 95% confidence level. A further investigation of the behaviour of the point 1 by considering the control levellings pointed out that pillar 1 is tilting in the direction given by the displacement vector. This conjecture is corroborated further by the analysis of precise distance measurements carried out with MEKOMETER ME 5000.

The applying of the corresponding procedure to the analysis of the (ellipsoidal) heights resulted in statistically significant height changes of points 3 and 5 on the order of 1 cm. A further discussion showed that apparent height changes due to problems in measuring the antenna heights cannot be excluded, thus the vertical displacements in the Sóskút network are not fully conclusive yet.

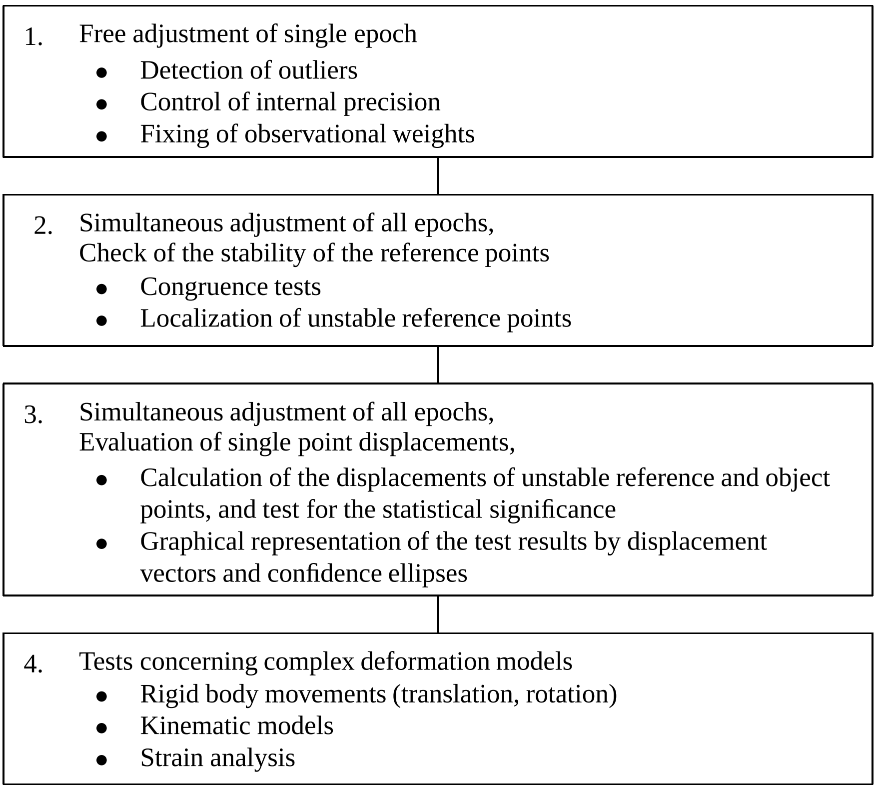

Fig. 4. Deformation analysis of horizontal deformation networks

4. Results and Recommendations

The efforts which have been undertaken in the past years into monitoring deformations in the Sóskút network have resulted in a strongly improved observation design for GPS measurements. In this way it was possible to increase the detectability of horizontal point displacements from about 2 cm in 1997 to about 5 mm in 2000. Similarly, the detectability of vertical displacements has improved from about 2–3 cm in 1997 to better than 1 cm in 2000; the precision obtainable now is still influenced by the problem of antenna calibration and the insufficient measurement of antenna heights.

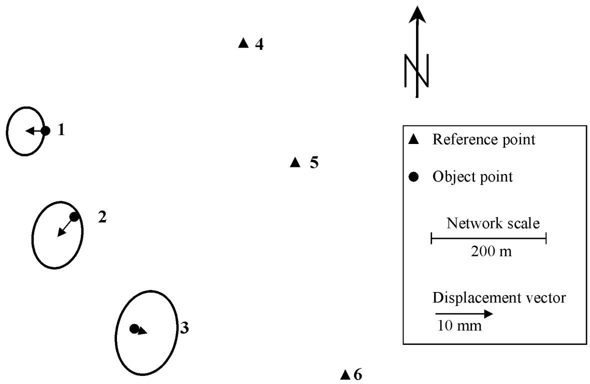

Fig. 5. Test for single point displacements in horizontal direction with respect to the reference points 4,5,6 between 1999 and 2000

Precise distance measurements in the Sóskút network can be considered as an external reference for comparing GPS results. It becomes clear from this data source that potential point displacements amount up to 1 mm maximum within 10 years, this order of magnitude is situated quite below the limit of detectability using GPS observations. On the other hand, the project has affected an important progress in methodological respect: The experience and the know-how gained in the Sóskút control network can easily be transferred to other local GPS networks installed for engineering of geodynamic purposes.

Both institutes plan to continue the successful co-operation, that has been lasting since more than 25 years, in the new millennium. The geodetic deformation analysis will still form an important topic in the future work of the Department of Geodesy and Surveying at the Budapest University of Technology and Economics and the Geodetic Institute at the University of Karlsruhe.

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