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INTEGRATED ANALYSIS OF THE ENVIRONMENTAL MONITORING MEASUREMENTS IN THE GEODYNAMIC TEST NETWORK SÓSKÚT

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Abstract

The paper deals with an integrated analysis of the environmental monitoring measurements made in the Sóskút geodynamic test network of the Department of Geodesy and Surveying of Budapest University of Technology and Economics (BUTE) in a period of two years (1999–2000). The results of the deformation analysis of the network and a detailed gravimetric geoid computation are shortly summarized.

Keywords: crustal movement, geodetic and gravimetric measurements, GPS, deformation analysis.

1. Introduction

One of the first horizontal movement micronetworks in Hungary was established at near Sóskút village in 1984 (FÖLDVÁRY-VARGA et al., 1986). In this area there is a presumed fracture, therefore there are 3–3 points at both sides of the line (*Fig.1*) to detect horizontal and vertical movements.

Different qualities of geodetic measurements by using different EDM's, theodolites, electronic total stations and GPS observation campaigns with Geotracer and Trimble receivers were occasionally carried out in the frame of diploma and research works at BUTE (SZŰCS–TAKÁCS 1998; SZŰCS et al., 2000) since the establishment of the network. There were some levelling measurements in the network connected to different campaigns to detect the tilting of the pillars.

Within an academic project (contract No. AKP 98–68 2.5), in the years of 1999 and 2000 high precision geodetic (distance-, angle-, geometric levelling and GPS-) and gravimetric measurements were carried out in a co-operation between the

Budapest University of Technology and Economics (BUTE), Geodetic and Geophysical Research Institute (GGRI) of the Hungarian Academy of Sciences and Eötvös Loránd Geophysical Institute (ELGI) of Hungary (ÁDÁM et al., 2001).

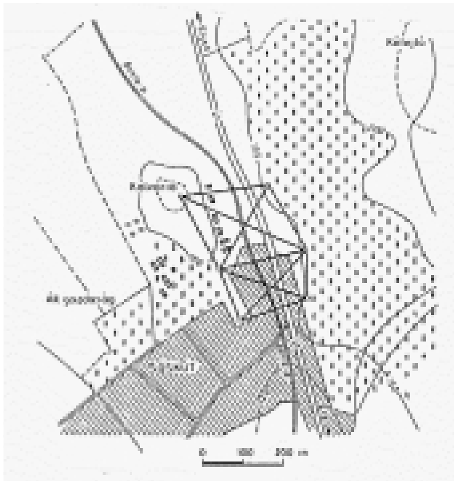

Fig. 1. The area of the network

Using the topographic and gravimetric data of high resolution, a detailed gravimetric geoid was computed in order to have geoid undulation with the highest possible precision at the network stations.

The results of the deformation analysis of the network carried out by using the traditional precise EDM distance and gravimetric measurements, as well as the local gravimetric geoid modelling in the Sóskút test area are summarized. The corresponding results of the GPS deformation measurements are given by ÁDÁM et al., (2002).

2. Interpretation of the Results

2.1. Distance Measurements

The deformation analysis of the Geodynamic Test Network Sóskút was carried out using the traditional precise EDM equipment (WILD/Leica DI2002). The instrument was compared to the Gödöllő Standard Baseline before the field measurements. The constant and scale biases of the instrument were determined using independent methods. The equality of the biases determined by different methods was investigated by statistical tests.

Since the Gödöllő Standard Baseline is longer than the longest distance in the Geodynamic Test Network Sóskút, therefore – according to the results of the comparison – the accuracy of the measurement (±0.2 mm +0.3 mm/km) is better than the official values given by the producer (±1 mm +1 mm/km). It was also confirmed by the differences between the distances measured in 1999 and 2000.

The measured slant distances were reduced to the average height of 164 m given in the Baltic system. The heights were determined by precise levelling. During the comparison and field measurements automatically registering meteorological devices were used to determine the corrections according to the formulas given by IAG.

The deformation analysis was carried out using the principle of the free network approach. In the first step the different measurement epochs were adjusted fixing the minimum number of unknowns and the outliers were investigated by τ-test. The equality of the a priori and the a posteriori standard deviation of unit weights were investigated by χ^2 -test. The stability of the network was investigated by the congruence analysis of the network between the two epochs. The square sums of the co-ordinate changes in the second epoch were minimised using the method of similarity transformation. The results of the graphic congruence analysis are summarized in *Fig. 2*, where the co-ordinate changes are smaller than the confidence ellipses referring to the 95% probability level. In spite of that the co-ordinate changes are not significant, according to the adjustment of the strain components, one of the principal strains became significant. Some components of the strain tensor are graphically summarised in *Fig. 3*.

In spite of the high accuracy of EDM measurements (0.2 – 0.4 mm) no significant changes were experienced between the two epochs. If the tendency indicated by the principal strain is a real one it should be determined only with the continuation of the project.

2.2. Gravimetric Measurements

The gravimetry is a physical method. If for some reason a mass rearrangement is going on in the interior of the Earth, it will induce gravity variation on the surface. The mass rearrangement and the corresponding gravity variation, however, do not necessarily induce height variation on the surface. Therefore, the application of gravity measurements to the detection of vertical surface movements will only be successful if it is combined with other geometrical methods (GPS, levelling).

The detection of vertical surface movements by gravity method is a special case of the investigation of the secular variation of gravity. In this case, however, we try to harmonise the geophysical interpretation of gravity variations to the results of geometrical methods.

The object of the investigation is twofold, partly to determine the numerical value of the movements, partly to determine their territorial extent (local or regional). To separate the local component from the regional one the geological structure of the area should be taken into consideration. If two geological blocks are dislocated vertically to each other then the difference between gravity values observed on

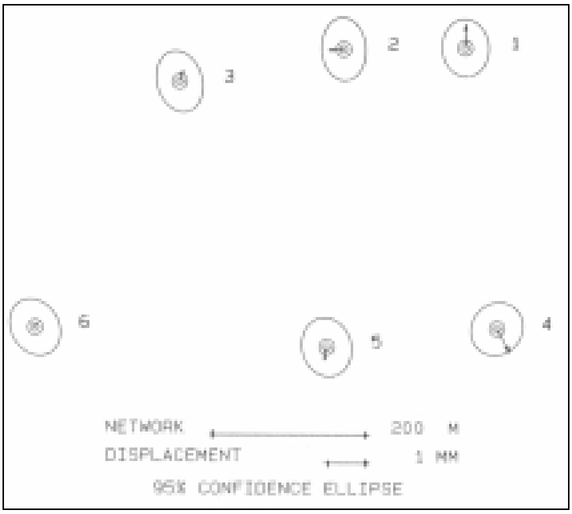

Fig. 2. Congruence analysis of the network (stations involved in the minimum norm are signed by double circles)

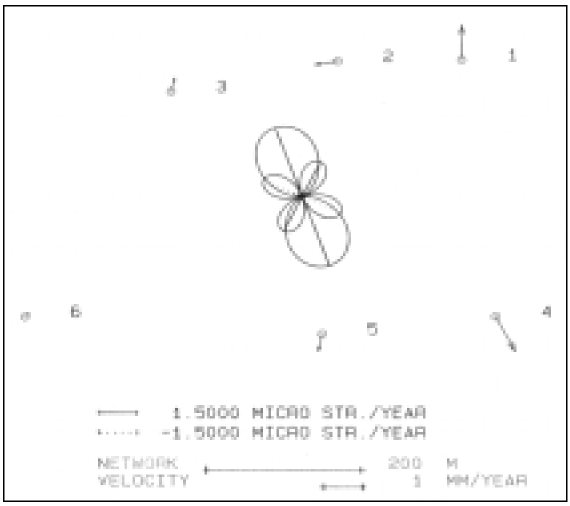

Fig. 3. Strain pedal curve, shear rosette and velocity vectors

stations located on the two different blocks will change. If we register the absolute gravity on both blocks, the difference between the two data sets will change in time. The standard error of absolute gravity measurements is about $\pm 2 - 3\ \mu$Gal

$(2 - 3 \times 10^{-8}\ ms^{-2})$. Converting this value to height difference we get about $\pm 6 - 9$ mm. If the height variations surpass this value, than we can detect the vertical movement by absolute gravimeters. The advantage of absolute gravity measurements is that their accuracy does not depend on station distance, so vertical movements of far away blocks can be investigated by them as well. To monitor local movements on small scale networks relative gravimeters are generally applied. But because of their lower accuracy ($\pm 5 - 10\ \mu$Gal), long observation series are needed in order to get reliable results.

The location of the gravity points and measurements relations are presented in *Fig. 4*. On both sides of the hypothetical fault, relative gravity stations were located and observed with two LCR–G gravimeters in 1999 and 2000. The measurements have been reported in detail by CSAPÓ (2000).

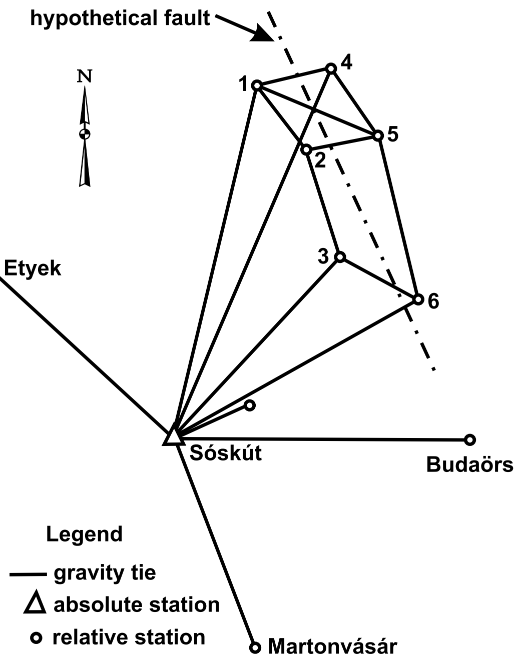

Fig. 4. The location of the gravity points and measurements relations

In *Table 1* the gravity values measured by No. 1919–G gravimeter and adjusted as a free network are presented. It can be seen that the deviations between the gravity values obtained in 1999 and 2000 are very low. The expected accuracy of these gravimeters is $5 - 10\ \mu$Gal, i.e. the equivalent of 15–20 mm height difference. This value can be regarded as the lower limit of height variation which can be detected by relative gravimeters.

In *Table 2* gravity values obtained by joint adjustment of the results of the two gravimeters are presented. The deviations are somewhat higher because of the summation of the random errors of the two gravimeters. Therefore, it is advisable

Table 1. Gravity values observed by No.1919–G gravimeter (M_0 = r.m.s. error of the adjusted network)

Point	1999		2000		Δ
	g (mGal)	r.m.s. (μGal)	g (mGal)	r.m.s. (μGal)	(μGal)
99	816.411		816.411		base
1	806.665	±2.5	806.663	±4.7	−2
2	809.734	±3.2	809.738	±5.2	+4
3	811.072	±2.9	811.082	±4.5	+10
4	808.068	±2.6	808.058	±4.6	−10
5	807.645	±3.0	807.629	±6.2	−16
6	808.313	±3.3	808.322	±4.6	+9
M_0	±3.2		±5.9		

to examine the results of the two gravimeters separately and compare the trend of the obtained differences.

Table 2. Gravity values after joint adjustment of the results obtained by two gravimeters

Point	1999		2000		Δ
	g (mGal)	r.m.s. (μGal)	g (mGal)	r.m.s. (μGal)	(μGal)
99	816.411		816.411		base
1	806.666	±2.9	806.694	±8.1	+28
2	809.729	±3.7	809.734	±9.3	+5
3	811.058	±3.4	811.080	±7.3	+22
4	808.070	±3.0	808.076	±8.8	+6
5	807.649	±3.5	807.659	±8.7	+10
6	808.321	±3.6	808.336	±6.4	+15
M_0	±5.2		±12.8		

In *Table 3* the observed vertical gradients are presented. Having seen the observed values it can be concluded that in the case of high precision gravity measurements the vertical gradient has to be determined and taken into account, because the anomalies of vertical gradients are influencing the final results (CSAPÓ, 1999).

3. Local Gravimetric Geoid Modelling in the Sóskút Test Area

A local gravimetric geoid solution is provided in order to have an independent control for our geoid heights calculated from GPS measurements and levelled heights.

Table 3. Observed vertical gradients

Point	LCR–1919	LCR–963	Mean	r.m.s.
	in Eötvös unit			in Eötvös unit
1	3617	3602	3599	±20
	3577	–		
2	3574	3699	3636	±88
3	3749	3861	3805	±79
4	3173	3205	3189	±23
5	3255	3151	3203	±74
6	3538	3580	3559	±30
99	with three gravimeters		2406	±20

In this calculation our latest gravimetric geoid solution for Hungary was applied as a reference (TÓTH–RÓZSA, 2000). This solution is based on $1' \times 1.5'$ mean free-air anomalies provided by the Loránd Eötvös Geophysical Institute (ELGI), and the EGM96 global geopotential model.

For our test area a more dense gravity database could be used:

- 1459 point gravity data from the database of the ELGI (free-air, and Faye anomalies),
- additional 151 point gravity measurements made in year 2000,
- point gravity data in the stations of the test network (6 stations).

In order to recover the high-frequency contribution of the terrain to our solution, we used a DTM with the resolution of 10 meters, provided by the Mapping Agency of the Hungarian Armed Forces. The DTM covered an area of 40 km by 40 km, around of our test network.

Due to the fact, that we could use a reference geoid solution for the test area, we calculated corrections for this reference surface caused by refined input data. The calculations were based on the following equation:

$$N = N_m + dN_{dg} + \delta N_{\delta N_{\text{ind}}}, \tag{1}$$

that is the geoid undulation can be calculated using the geoid undulation of the reference model (N_m), and adding the correction based on the refined gravity measurements (dN_{dg}), and the difference of the indirect effects ($\delta N_{\delta N \text{ind}} = \delta N_{\text{ind}} - \delta N_{\text{ind(m)}}$) to this. In the equations here m denotes the reference model.

In *Eq.* (1) dN_{dg} can be calculated by the well-known Stokes integral. In order to be able to calculate this integral, we have to determine the difference dg of the refined and reference Faye anomalies. This can be done, with the following formula:

$$dg = \Delta g - \Delta g_m + \delta g_{TC} - \delta g_{TC(m)}, \tag{2}$$

where Δg and Δg_m are the refined and reference Faye anomalies, δg_{TC} and $\delta g_{TC(m)}$ are the refined and reference terrain corrections. For the evaluation of the Stokes integral we have interpolated the dg differences for a 100 m-resolution grid.

The corrections of the reference geoid model (i.e. the effect of the refined data) can be seen in *Fig* 5.

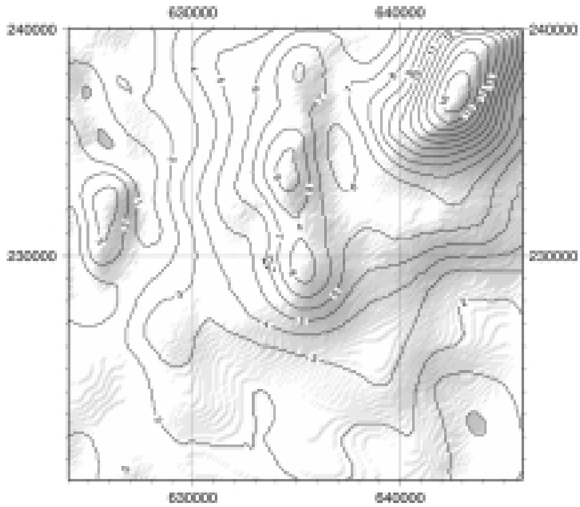

Fig. 5. The corrections of the geoid undulation for the test area [mm]

With the help of gravimetric geoid undulations we can control our height determination using spirit levelling and GPS, and vice versa. The gravimetric geoid undulations for our stations can be seen in *Table* 4, while the differences of the gravimetric solution and the GPS/Levelling measurements are shown in *Table* 5.

Table 4. Gravimetric geoid undulations in the stations of the test area [m]

Station No.	1	2	3	4	5	6
Undulation	43.8654	43.8635	43.8595	43.8643	43.8610	43.8540

The comparisons in *Table* 5 show very strange values. From the results it can be seen, that the GPS/Levelling measurements show a strong E-W tilt between the stations on the east side of the network (1,2,3) and the west side of the network (4,5,6). This tilt reaches the level of 2 cm/100 m, i.e. 40′. Since this tilt can be caused by a horizontal gravitational anomaly of the magnitude of 200 mgal, the results can hardly be explained by physical, gravitational reasons. According to our opinion, the GPS measurements could be distorted by multi-pathing effects, which can be the reason for the tilt. However, this question should be further investigated.

Table 5. The difference of the gravimetric solution and the GPS/Levelling measurements [cm]

Station /Year	1997	1998	1999	2000
1	14.7	16.5	16.1	16.4
2	13.8	15.4	14.9	15.1
3	12.3	12.7	12.9	13.8
4	9.3	9.3	9.3	9.3
5	7.0	9.0	7.8	7.4
6	5.8	6.7	5.7	6.1

Our geoid calculations showed, when suitable gravity data and a reference geoid solution is available, the refined measurements can be introduced very easily into geoid modelling. In the Sóskút area, the corrections caused by the refined gravity and DTM data reached the level of a few millimetres on the stations of the network. The calculations proved, that an independent control for the GPS/Levelling measurements is required in order to achieve precise height determination. In this way the overall accuracy of the methods, not only the inner accuracy can be calculated.

4. Conclusions and Recommendations

The measurements and computations have not yet shown any significant movements of the network points, however, there are some certain indications on them. Therefore, this micronetwork of the BUTE will be remeasured with high precision and the corresponding investigations will be continued in accordance with other domestic research projects (GRENERCZY et al., 2001 and JOÓ, 1998).

Acknowledgements

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