GEOPHYSICAL TRANSACTIONS 1997
Vol. 40. No. 3-4. pp. 119–143

Hungary's new gravity base network (MGH-2000)

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The modernization of the Hungarian Gravity Base Network is being carried out in the framework of the establishment of the unified gravity network of the Central-European countries. The objective of former networks and the necessity for development are reviewed. The scale of the new network is guaranteed in the SI system by the numerous absolute gravity measurements carried out in recent years. The observation methods, data processing and adjustment procedures are presented. The results of the comparison of Czech, Slovakian and Austrian, Unified European gravity networks with the Hungarian network are discussed.

Keywords: gravity, network, absolute measurements, relative measurements, data processing, adjustment of gravity network

1. Introduction

One of the major consequences of the political changes in Hungary was the abolition of the secrecy of gravimetric information during the early 1990s. This made it possible for researchers to take part in the various international projects.

The International Union of Geodesy and Geophysics (IUGG) has long been planning to set up a unified scale and datum gravimetric network which could be applicable throughout the whole continent of Europe. Its conditions have now been established because several countries possess portable absolute

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Manuscript received: 30 April, 1996

gravimeters (AXIS, JILAG, etc.), providing a unified scale in accordance with the current accuracy specifications. At the same time the need for increasing the accuracy of global geodetic reference systems, and the solving of several geodynamic and geotectonic problems have brought about the realization of this objective as a daily routine.

As regards the number of absolute stations and point density (the number of 1st and 2nd order bases as well as their regional distribution), and also their accuracy, the gravimetric base networks of the individual European countries are somewhat heterogeneous. It seems both necessary and expedient to establish a unified network on the basis of the principles recommended at the joint conference of the Geodesy and Geophysics Working Group (GGWG) of NATO and the Mapping Services of East European Armies held in Budapest in collaboration with civilian experts in 1994. Its essence defines the creation of a network consisting of absolute points (zero order points) at a general distance of 100–150 km within which the 1st and 2nd order bases will need to be measured with modern relative gravimeters. It is advisable that the gravity value of the absolute points be checked in three year periods. At the same time it is deemed desirable that zero order points constitute an integrated network with the Hungarian GPS Base Network as well as increasing, where necessary, the number of gravimetric points within a suitable radius of integrated points.

The US Defense Mapping Agency (DMA) began to increase the accuracy of the WGS-84 reference ellipsoid in 1991 and substantially helped Hungary to establish both a Hungarian national Military GPS Network (KGPSH) and an absolute gravimetric base network [Ádám et al. 1994].

2. Antecedents

Hungary's first gravity network (MGH–50) covering the entire territory of the country was established by the Eötvös Loránd Geophysical Institute (ELGI) during the early 1950s. The measurements were carried out by a Heiland gravimeter [Renner, Szilárd 1959]. This network provided a sound basis for implementing a so called 'national reconnaissance gravity survey' launched at the time, but as a result of industrial and infrastructural developments during the 1960s, most of the base points established mainly along national roads were beginning to deteriorate or simply became unsuitable for their original purposes.

During the 1960s ELGI acquired geodetic type Sharpe gravimeters considered to be quite modern at the time, making it possible to re-measure and extend the 1st order network. In 1971 observations were carried out with three CG–2 Sharpe instruments transported by air to nineteen network points established at different airports. Network points were established in a formation so that their connecting sides could constitute triangled– and quadrangled-polygons and they were continually remeasured [Csapó, Sárhidai 1990a].

When the 'Hungarian First Order Levelling Network' was established during the 1970s, gravimetric observations had to be carried out for normal correction. At the same time this made it possible to establish a 2nd order gravimetric network by placing the basis points along the levelling lines in the gardens of long standing buildings such as churches or manor-houses. The base points are monumented by concrete blocks of 60 by 60 by 100 cm set up at ground level and a brass bolt is fixed in the middle of their top surface. The height of the points was determined in collaboration with the Institute of Geodesy, Cartography and Remote Sensing (FÖMI). The gravimetric measuring of the network was completed with two Sharpe CG–2 instruments and a geodetic type LaCoste–Romberg (LCR) between 1980 and 1989. The average distance between the points ranges between 10 and 20 km. The gravimeters and observers were transported by car. The network consists of consecutive triangles. The gravity difference (Δg) of each individual side was determined in the observation sequence A-B-A-B-A. The common adjustment of the measurement was carried out in 1971 and between 1980 and 1989, as well as compiling a catalogue of points was implemented in 1991. The standard deviation of the adjusted network of MGH-80 is ± 16 μGal** [Csapó, Sárhidai 1990b].

The objective of creating a unified gravimetric network which would cover a large territory was laid down in the cooperation projects of the geodetic surveys of the East Central European countries as early as the mid-1960s. The concept of this network was rather similar to the existing ones. Establishment of the first five absolute stations measured by Soviet made GABL absolute gravimeters [Csapó 1981] brought about the partial realization of this plan in Hungary just as a Unified Gravity Network of the

** $1 \mu\mathrm{Gal} = 10^{-8} \mathrm{ms}^{-2}$

Czech Republic, Hungary, and Slovakia (UGN) has been established by now. The observations needed to establish this common network had continuously been carried out by ELGI's experts in bilateral and multilateral forms of cooperation since 1972 [Csapó et al. 1994].

In 1992 and 1993 gravimetric measurements were carried out in the form of interconnecting measurements between Austria and Hungary within the framework of bilateral cooperation. This activity consisted of relative and absolute measurements. Relative measurements were carried out with 4–5 LCR gravimeter, whereas absolute measurements were carried out with a JILAG–6 absolute gravimeter [Csapó et al. 1993] by D. Ruess of 'Bundesamt für Eich- und Vermessungswesen' (BEV).

Implementation of the Unified European Gravity Network (UEGN) was commenced in 1993 in the East Central European countries under the auspices of the joint plan of the International Gravity Commission (IGC) and the Geodesy and Geophysics Working Group of NATO (GGWG) in the form of international cooperation. The reason for organizing an international project was that none of these countries possessed an absolute gravimeter. Absolute measurements were carried out in Hungary between 1993 and 1995 with the AXIS FG5 No.107 gravimeter of DMA and with JILAG–6 equipment of BEV [Friederich 1993, Spita 1994, Krauterbluth 1995]. The job was partly financed by the US-Hungarian Science and Technology Joint Fund (MAKA) under contract JF. No. 369 and it was implemented by the DMA expedition; part of the work was carried out by the Geological Survey of Austria on the basis of a scientific agreement between ELGI and the BEV.

In 1994 the linking of absolute stations with relative gravimeters was commenced with four LCR–G instruments transported by car. Hungary's absolute stations are situated at an average distance of 100 to 120 km, so 1st order and 2nd order points are used as tie points. The project is being financed by the National Commitee for Technological Development (OMFB) by means of contract No. MEC-94-0508. This job is backed by DMA too by their long-term loan to ELGI of two geodetic type LCR gravimeters.

3. Concept of the new base network (MGH-2000)

Previously the most important aspect of gravity base networks was to provide a unified framework for gravity surveys carried out by various institutes and companies for mineral exploration. It was necessary to have an appropriate number of base points for the economical completion of the work. Strangely enough the requirements for increasing the accuracy of measurements did not increase parallely with the development of the instruments. On the contrary, the requirements diminished as perfomance grew. For this reason, the improvement of the base network became of secondary importance as far as geophysics specializing in mineral exploration was concerned. However, during the course of the preparatory phase of 'International Gravimetric Calibration Polygon' (IGCP) which was launched to compile a unified geophysics map within the framework of cooperation between the Geodetic Surveys of the former Socialist Countries, including certain scientific projects launched by their respective academies of sciences, it turned out that the scale relations of the gravimetric base networks in this countries sometimes had a difference as big as 100–150 μGal. Such experiences led to the planning of the above mentioned unified network. However, its implementation was abandoned mainly for financial reasons in the second half of the 1980s.

As a matter of fact the number of geophysical measurements carried out for mineral exploration has decreased world-wide during the 1990s. At the same time the extension of cooperations requires unified measurements, geophysical maps, and databases in order to be able to resolve scientific as well as economic tasks covering entire continents. The 'advances' of military and civil spheres make it unnecessary to carry out parallel research in the same field. One of the prime examples is the useful cooperation between military and civil institutes in the GPS base network activities in Hungary.

When establishing Hungary's new gravimetric base network, we considered the following aspects important:

— The national gravimetric network should be regarded as a geodetic one, just as triangulation, levelling, or any GPS base network. The protection, maintenance and continuous development of networks should be undertaken by the government.

— Throughout the planning of the zero order base net (absolute stations) we attributed great importance to placing them evenly all over the country as well as setting them quite close to GPS geodynamic points — which had been established some time before — so that an economical system of integrated networks could be set up. We call these points integrated network points which means that the same point is a member of the base network of GPS, gravity, levelling, etc.

— When new points are established, or those that have deteriorated are replaced, one has to bear in mind the changes of ownership which are closely related to the protection of points.
— MGH–2000 is part of the above mentioned UGN, so the methods of modern network planning could partly be applied [CSAPÓ, SÁRHIDAI 1985, SÁRHIDAI 1986], because the joint form is basically determined by the previous and applicable parts of the networks of the three countries (Czech Republic, Hungary and Slovakia). In any case, we have experienced that the planning of networks for optimal network measurements can give rise to the necessity of establishing connections between far distant points. However, this might not be carried out (transporting instruments by planes) on account of Hungary's present financial situation.

4. Structure of MGH-2000

The network consists of zero order points as well as of points first order and second order (see the top of *Fig. 1*). In addition, the network contains 16 original, so called 'fundamental'. points established in 1954, so that the transformation equation could be given in relation to the old network and the new one while establishing the new network (one of them completely broke down during the past fifty years).

The zero order network

The use of such network is meant to establish the scale of the national (entire) base network as well as enabling the stability of gravity to be checked by repeated observations. The zero order network consist of 12 absolute stations (7750 km^2/point) whose locations are given in *Fig. 2* — including 5 foreign absolute stations near the borders. These points were placed at the ground level of important buildings whose survival and accessibility seem to be ensured well into the future (castles, stately homes, etc.). Monumentation was implemented by concrete blocks with the dimensions 120 by 120 by 100 cm. A brass bolt was fixed to the middle of the top of the block indicating

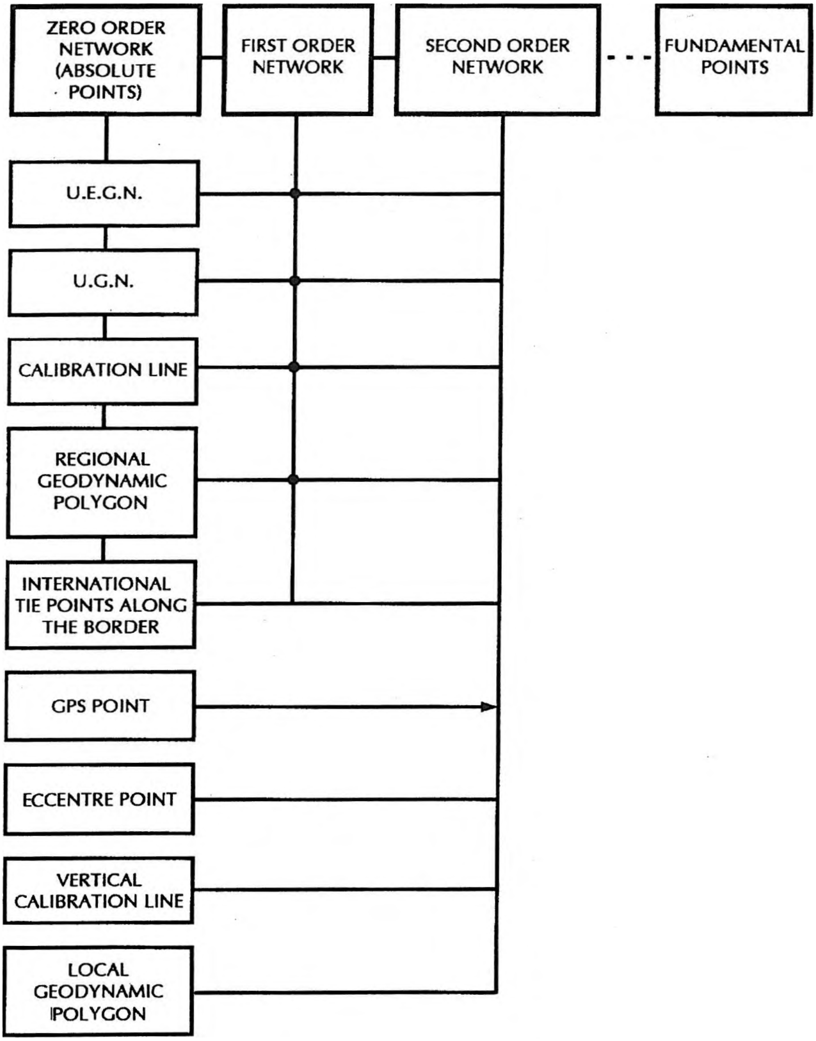

Fig. 1. The structure of MGH-2000
1. ábra. Az MGH-2000 szerkezeti felépítésének vázlata

the height above sea-level based on the Baltic system. The points were tied to two or three points of the national levelling network, allowing ±5 mm confidence limit. The geographical coordinates of the stations were established on the basis of 1:10000 topographical maps with ±1 second confidence limit. Gravity acceleration relating to the reference heights of absolute gravimeters was determined with LCR gravimeters allowing 1.5–3 μGal

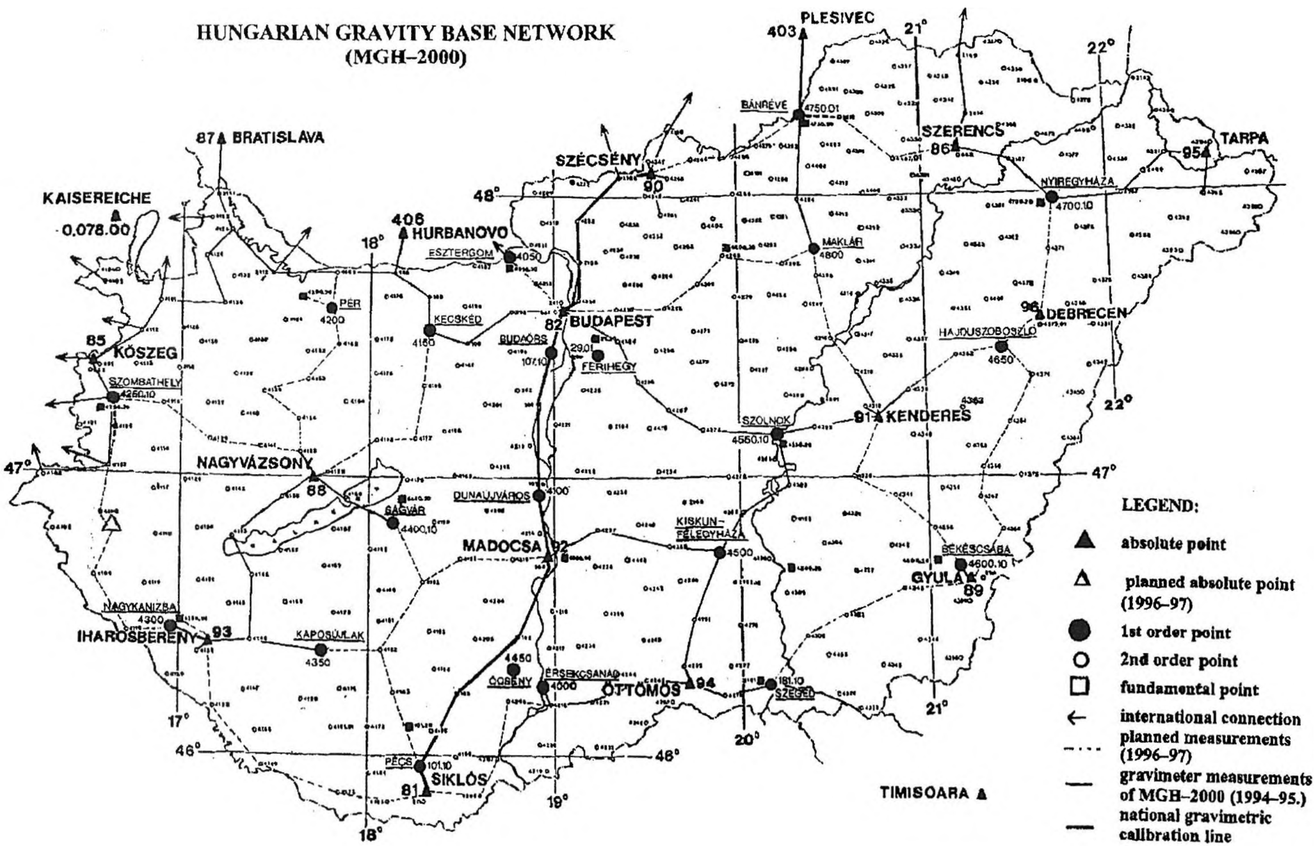

Fig. 2. The 'Hungarian Gravity Base Network' (MGH-2000)
2. *ábra.* A „Magyarországi Gravimetriai Hálózat" (MGH-2000) pontvázlata

confidence limit. The station established in Budapest is of extraordinary importance because measurements need to be repeatedly carried out on it with different types of absolute gravimeters every two or three years — as has in fact taken place since 1980. At most stations repetitive measurements have been carried out in the past three or four years as well. Each station has at least one so called 'eccenter point' which is fixed with a concrete block of 80 by 80 by 100 cm outside the building. The relative confidence limit of its 'g' value is better than 5 μGal. The most important parameters of the zero order network can be seen in *Table I.*

NUMBER	STATION	LATITUDE [° ' "]	LONGITUDE [° ' "]	HEIGHT [m]	DATE OF THE FIRST/ LAST OBSERVATION	GRAVIMETER
81	SIKLÓS	45-51-10	18-07-55	128.489	1978 / 1995.	GABL / JILAG-6
82	BUDAPEST	47-32-00	19-01-00	201.563	1980 / 1995.	GABL / AXIS FG5
85	KŐSZEG	47-23-24	16-32-33	284.461	1980 / 1993.	GABL / JILAG-6
86	SZERENCS	48-09-56	21-12-21	111.243	1980 / 1993.	GABL / JILAG-6
88	NAGYVÁZSONY	46-59-23	17-42-00	241.085	1993.	AXIS FG5
89	GYULA	46-38-42	21-17-14	89.053	1987 / 1995.	GABL / JILAG-6
90	SZÉCSÉNY	48-05-07	19-31-08	166.888	1993.	AXIS FG5
91	KENDERES	47-14-54	20-40-37	83.450	1993.	AXIS FG5
92	MADOCSA	46-41-19	18-57-40	93.758	1994.	AXIS FG5
93	IHAROSBERÉNY	46-21-48	17-06-17	203.898	1994.	AXIS FG5
94	ÖTTÖMÖS	46-17-04	19-40-47	124.042	1994.	AXIS FG5
95	TARPA	48-06-14	22-31-40	110.778	1995.	AXIS FG5

Table I. Most important parameters of the zero order network
I. táblázat. A nulladrendű hálózat legfontosabb paraméterei

First order network

The 21 points included in Fig. 2 are, by and large, the same as the bases of MGH–80 placed at airports [Csapó, Sárhidai 1990b]. The distance varies between 50 and 70 km and the density of points is 4400 km^2/point. Bigger point monuments (100 by 100 by 100 cm) were placed exactly beside the MGH–80 points before UGN measurements started in Hungary in 1982, so that several gravimeters could be set up at the same time by the staff of air expeditions. Determination of the geographical coordinates of the points was similar to the methods described in the section on zero order points. Levelling (altitude determination) between the individual points and the national levelling base points was performed by the Budapest Geodetical and Cartographical Enterprise and by ELGI, with 1–10 mm confidence limit.

Second order network

As has already been mentioned, these points were established by ELGI in the 1970s. The distance between the individual points is 10 to 15 km in hilly areas whereas it ranges from 15 to 25 km in the plains. The average density of points is 220 km^2/point. We have replaced a couple of dozen points which were destroyed during the last twenty years and have integrated them into MGH–80. The new network contains 430 2nd order points.

5. Division of network points according to function

The use of network points is shown in the vertical column of Fig. 1. Not only do zero order points make it possible to deduce the scale of the national network, but they also have a similar role in the establishment of continental and regional networks (UEGN, UGN) too [Boedecker et al. 1994].

Testing of the scale is done by repeated absolute measurements. The calibration factor of the relative gravimeters has to be determined and to be checked from time to time on calibration lines. It means that before and after the field work (normally in spring and in autumn), high precision gravity measurements are carried out at the points of a calibration line regarded as standard.

The fundamental points of regional gravimetric lines (i.e. Carpathian polygon) established to observe the non-tidal changes of gravity field and tie points between the gravimetric networks of neighbouring countries are as far as possible absolute stations. As shown in Fig. 2, absolute points along the borders (border region points) served this purpose during the measurements of MGH–2000 and UGN.

1st order points are meant to create ties between absolute stations placed at greater distances. Their high accuracy enables them to be used as absolute points during gravimetric measurements as well.

2nd order bases are used more extensively than high grade network points because they are directly used for detailed gravity surveys. These bases are used as eccentric high order points, vertical bases, and as local points of deformation study lines (Debrecen) in Hungary.

The geodynamic points of the National GPS Network have a special status within Hungary's gravimetric base network because gravimetry aspects did not enjoy any priority in the selection of their location. The applicability of GPS technique and some geological considerations have to be reckoned with. For this reason, it has been made possible by applying an appropriate survey mark to carry out relative gravimetric measurements on them too and they were integrated into the MGH–2000 network. With regard to the fact that these points were generally placed on sparsely surveyed highland regions, they can serve as local bases for detailed gravity surveys.

6. National gravimetric calibration line

An outline of the National Gravimetric Calibration Line is given in *Fig. 3*; its location within the country can be seen in Fig. 2. Its present form has been undergoing development by ELGI since 1969. There are four absolute stations within the 210 mGal range of the line (the highest Δg value is 250 mGal between the base points of the country). The other points of the calibration line are 1st and 2nd order points at an average distance of 30 km from each other. Δg values between the points were previously determined with Askania Gs–12, GAG–2, Sharpe, Worden, then LCR gravimeter groups. The vertical gradients of the points were determined by a group of LCR instruments with an accuracy of 4–7 μGal, and with standard A-B-A-B-A-B observation sequence [CSAPÓ 1987]. The relative accuracy of each point is 7–12 μGal. The calibration line is part of UGN, and the section of

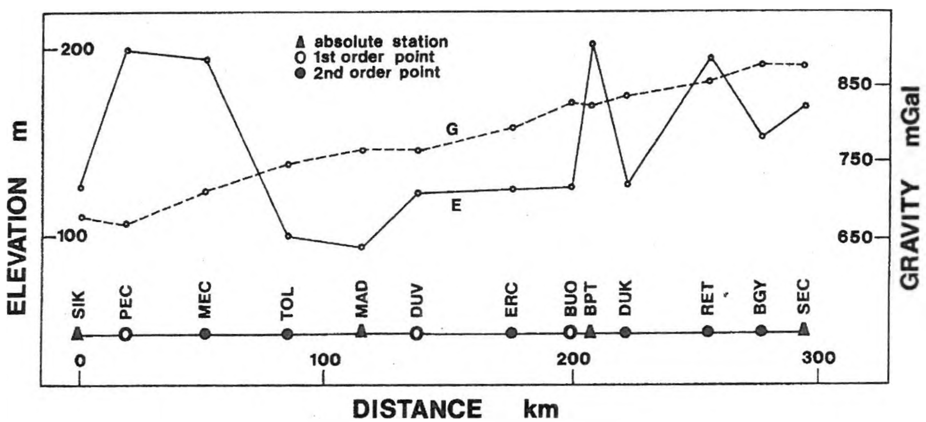

Fig. 3. Sketch of national gravimetric calibration line

3. ábra. A nemzeti gravimetriai hitelesítő alapvonal vázlata

Siklós–Budapest is the southern part of the 'Carpathian Polygon'. The Carpathian Polygon was established by ELGI in collaboration with Czech, Polish, and Slovak partners in 1973 to monitor the non-tidal variations of the gravity field in the Carpathian Basin (the line starts from Siklós absolute point then goes via Budapest, Zilina, Zakopane to Cracow). It was reobserved in 1978–79 and 1988–89, but the latest (planned) observation campaign was not launched on account of ELGI's financial difficulties.

Calibration of gravimeters

The present form of the calibration line shown in Fig. 3 was finalized by ELGI in 1985. The former calibration line was based on the 'Potsdam Gravimetric System'. The first absolute station was established on the former line at Budapest in 1980. It is also part of the new calibration line. ELGI carries out measurements twice a year on the line. The scale of gravimeters can also be checked by adjustment of the measurements carried out between two absolute points. Such a version was also prepared for adjusting MGH-2000.

ELGI has built laboratory calibration equipment [Csapó, Szatmári 1995] for the calibration of LCR gravimeters with feedback electronics. With the help of this equipment the possible time variations of the calibration factor of LCR gravimeters can be studied as well [Meurers 1994].

7. Data preparation

For the formerly mentioned reasons the observed data of MGH–2000 contain data obtained from outside the country (absolute measurements, polygons, tie measurements along the borders, etc.) as well. Three databases have been compiled for the processing of field records.

Catalogue of points

This contains the numbering of points, names, geographical coordinates according to a Gauss-Krüger projection system and Baltic heights, preliminary gravity values and their reliability obtained from adjustments in the eighty character records. The number of the 1:10000 scale topographic maps of the Unified National Mapping System and a four digits information code are given as well. This data file contains 600 records.

Catalogue of instruments

Information is given on the relative gravimeters applied (9 Sharpe gravimeters, 3 Worden, and 10 LCR gravimeters). The catalogue contains the make, type, registration number, original calibration tables and coefficients, as well as the corrections needed on account of the periodic errors of the measuring system, including other data (barometric correction factors, the operating temperature of thermostat, etc.) which were taken into account in the processing of observations.

Field records

The field records contain the observed data in analogue form. These records are stored in computer files consisting of eighty character records for each instrument. The field records contain both numeric and alphabetical data, such as name of the tie, catalogue number of the points, date of observation, time zone, dial and voltmeter readings, local time of readings, daily conversion factor of galvanometer reading to μGal (mVolt/μGal), instrument heights above the bench mark or ground, meteorological data and method of gravimeter reading (optical, CPI, FB), the name of the observer, and data on the transporting vehicle.

Data files are arranged in a library so that the field records observed in different years can easily be identified, and complemented (i.e. BASE-LINE\SIKLÓS\1994\LCR–963).

8. Data processing

Absolute measurements

Table I shows that during the last one and half decades absolute measurements were carried out in Hungary with three different types of instruments. It was noted that some differences appeared during the course of the data processing as well as during the application of corrections. In view of this, it was necessary to reprocess all observations on the basis of a unified approach. Instrument corrections as given by the observers were accepted. It has recently turned out that the observed values are dependent on the light intensity of laser fringes. Should the (old ADM 686) fringe detector be replaced in an equipment by a new AD 9696, different gravity data can be obtained in a given light intensity range (D. RUESS, personal communication). This is what happened when the AXIS FG5 No. 107 instrument was used, DMA is due to reprocess all its data obtained after 1993. The possible corrections are not included in the present adjustment.

The calculation of tide correction was based 505 tidal waves. The parameters used in the calculations are given in *Table II*. The parameters were compiled on the basis of the data of Pecný (Czech Republic) tide registration station [HOLUB et al. 1986]. Ocean tide was disregarded.

WAVE	DELTA	KAPPA	AMPL. CORR.	PHASE CORR.
Q1	1.1525	-0.28	1	0
O1	1.1486	-0.03	1	0
M1	1.1391	0.45	1	0
K1	1.1362	0.10	1	0
J1	1.1542	-0.20	1	0
OO1	1.1565	0.08	1	0
2N2	1.1586	0.85	1	0
N2	1.1781	1.43	1	0
M2	1.1848	1.03	1	0
L2	1.1554	-0.16	1	0
S2	1.1861	0.30	1	0
M - S0	1.0000	0.00	1	0
SSA	1.1600	0.00	1	0
MM	1.1600	0.00	1	0
MF	1.1600	0.00	1	0
MTM	1.1600	0.00	1	0
M3	1.0775	-0.22	1	0

Table II. Parameters of tidal waves used for the processing of MGH-2000

II. táblázat. Az MGH-2000 mérési eredményeinek feldolgozásánál figyelembe vett árapály hullámok paraméterei

Correction due to polar motion. The observed gravity is corrected for changes in the centrifugal acceleration due to the variation of the distance of the earth's rotational axis from the gravity station. The following formula was used in the calculations:

$$\Delta g_{pm}=1.164\ \omega^2 R\ \sin2\varphi\ (x\ \cos\lambda - y\ \sin\lambda)\ \mathrm{ms}^{-2}$$

where:

ω = 7.292. 10^{-5} rad/s = angular velocity of the Earth's rotation

R = 6.371. 10^6 m= mean radius of the Earth

φ, λ = geographical coordinates of the absolute station

The value of correction in μGal:

Δg_{pm} = -19.1·sin2φ (x''cosλ - y''sinλ)

the actual values for x and y can be found in the Annals of the International Earth Rotation Service (IERS).

Correction due to the changing atmospheric masses. Only the local part of the atmospheric effect was taken into consideration. The relation is given by the standard of DIN 5450 of 1968 and with the following empirical coefficient:

$$c = 0.30\ \mu\mathrm{Gal/hPa}$$

The local part of the correction compensates for 80% of the total atmospheric effect.

Reduction of gravity value to the bench mark. In the adjustment the gravity values relevant to bench marks were used. Therefore, the results of the absolute measurements which are related to a certain height depending on the type of the equipment (850-1300 mm) were referred to the bench marks. The vertical gradients (i.e. the Δg between two points by 1 m vertically apart) were determined by a group of gravimeters. The vertical gradients of Hungary's absolute stations can be found in *Table III*. The vertical gradients measured between 1979 and 1994 at the Budapest absolute point are presented in *Fig. 4*. The vertical gradients as a function of height — determined at the absolute point of Budapest — are presented in *Fig. 5*.

Relative measurements

The computer stored field records were processed by a program developed in ELGI. Processing steps:

- conversion of the readings to mGal
- correction calculations (tidal, height, barometric and periodic error corrections)
- calculation of the corrected relative gravity values
- drift calculations

NUMBER	STATION	LAST VALUE (mGal)	N_{VG}	VERTICAL GRADIENT (eötvös)
81	SIKLÓS	980678.327	22	3407 ± 16.0
82	BUDAPEST	980824.294	50	2509 ± 9.7
85	KŐSZEG	980784.713	22	2661 ± 23.9
86	SZERENCS	980872.789	51	2969 ± 11.4
88	NAGYVÁZSONY	980765.818	18	2565 ± 12.3
89	GYULA	980766.404	29	2913 ± 10.5
90	SZÉCSÉNY	980873.111	15	3059 ± 17.8
91	KENDERES	980810.283	12	2662 ± 23.7
92	MADOCSA	980761.777	8	2560 ± 17.1
93	IHAROSBERÉNY	980699.028	19	2805 ± 9.7
94	ÖTTÖMÖS	980725.926	17	2634 ± 10.0
95	TARPA	980880.426	15	2712 ± 20.0

Table III. Vertical gradients of the Hungarian absolute stations
(N_{VG} — number of determinations)

III. táblázat. A magyarországi abszolút állomások vertikális gradiens értékei
(N_{VG} = mérések száma)

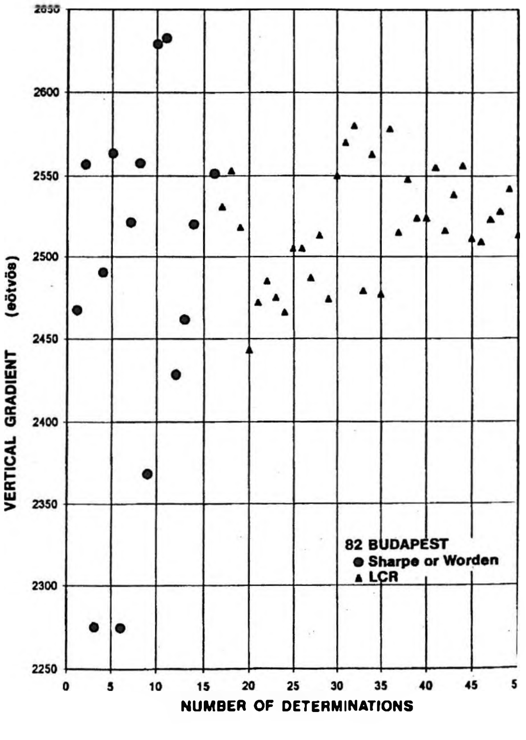

Fig. 4. Vertical gradients obtained between 1979 and 1994 at the Budapest absolute station

4. ábra. A budapesti abszolút állomáson 1979–94 között végzett vertikális gradiens mérések eredménye

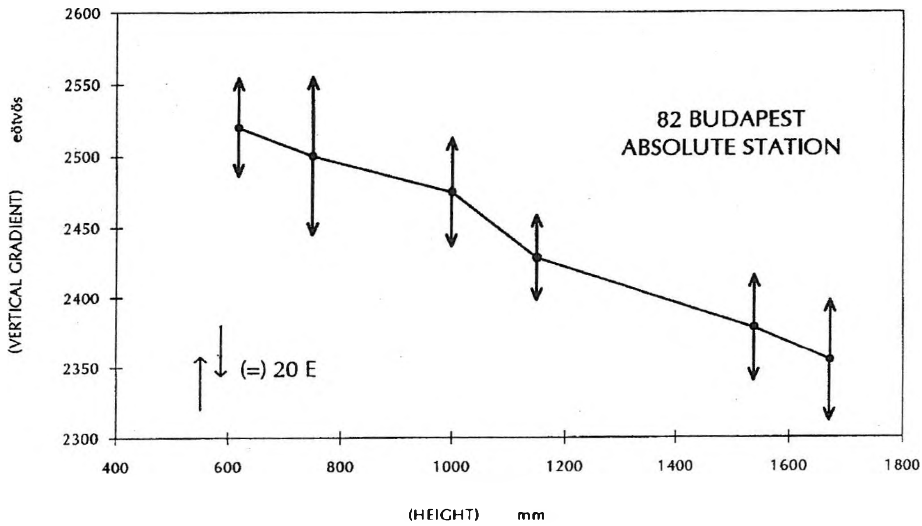

Fig. 5. Vertical gradient as a function of height — at the absolute station of Budapest
5. ábra. A vertikális gradiens értékének magasságfüggése — Budapest abszolút állomáson

— calculations of drift corrected relative gravity values
— Δg calculation
— error calculations

A total of 9100 measuring sections were processed for adjusting MGH-2000 (and UGN).

9. Adjustment of measurements

The observed data were adjusted by the least squares method as a constrained network. The fixed points of the network were the latest results of absolute determinations. The mean values of the observed gravity differences (Δg) observed in the A-B-A-B-A system by one gravimeter (which means the average of the four observed differences) were taken as one individual measurement. The adjustment procedure was reviewed in detail in a former paper [CSAPÓ, SÁRHIDAI 1990b]; here only the weight determination is discussed. To decrease the effect of relatively large errors in the adjustment their weight should be decreased, but before the adjustment the errors are not known. This contradiction can be solved by an iteration

('Danish method'): in the first step ($j=1$) all observed data have equal weight ($p=1$), in the further steps the weight will be:

$$p_{ij}=1/1+a_k \cdot v^2_{j-1}$$

where j represents the actual iteration step. The a_k coefficient is correct if $p \leq 0.25$ for the erroneous measurement [SOHA 1986]. The threshold of errors can be taken as the function of the errors of unit weight, then:

$$a_k=3/v^2_k$$

where

$$v_k=3\mu_0 \quad \text{if} \quad v_{max}>3\mu_0$$

$$v_k=2\mu_0 \quad \text{if} \quad 2\mu_0<v_{max}<3\mu_0$$

$$v_k=\mu_0 \quad \text{if} \quad \mu_0<v_{max}<2\mu_0$$

The erroneous measurements will get less weight with each subsequent iteration step. The iteration should be continued until the error of unit weight decreases to a considerable extent. In the adjustment of MGH-2000, two iteration steps proved to be sufficient. Adjustments were carried out on two different data sets and both of them in two versions.

The first data set consisted of the measurements of EGH and all Hungarian data except the measurements of the 2nd order net of MGH-80 (9400 ties, 621 points, 19 absolute points as fixed values).

The second data set consisted of all the measurements of MGH-2000, absolute points near to the border in the neighbouring countries, and connecting ties across the borders; all together 8464 individual observed gravity differences and their corrections, 561 unknowns (point values and scale factors of gravimeters) 16 absolute points, 539 gravimeter points including 8 Austrian and 42 Slovakian ones.

The adjustments provided a possibility for comparing the results obtained from two data sets having different homogeneity, and a comparison of adjustments carried out by ELGI and Czech and Slovak partners with basically different methods.

In the first version of adjustment the yearly scale factor was determined for each gravimeter separately. Then the obtained scale factors were included in the final adjustment.

In the second version of adjustment one scale factor was determined for each gravimeter for the whole time interval (1969–95) of measurements so that the scale factors were taken as unknowns in the adjustment.

Iterations were carried out in both versions and with both data sets. The best results were obtained in all cases when one scale factor was determined for each gravimeter for the whole time interval of the observation campaign. This version was accepted as the final adjustment of MGH-2000.

10. Conclusions

Table IV. contains the scale factors and the mean errors of the gravimeters. Comparison of the standard errors gives information about the quality

I	Gravimeters	Calibration factor	Number of observations	Mean error (mGal)
1	LCR–D 9	1.000181	24	0.009
2	LCR–G 176	0.996145	2	0.001
3	LCR–G 220	0.996926	116	0.017
4	LCR–G 625	0.999996	24	0.014
5	LCR–G 779	1.001211	16	0.014
6	LCR–G 821	1.000654	85	0.017
7	LCR–G 919	1.000916	234	0.020
8	LCR–G 963	1.000724	449	0.019
9	LCR–G 1011	1.003474	6	0.010
10	LCR–G 1919	1.000370	2198	0.015
11	Sharpe 174	1.000306	189	0.020
12	Sharpe 176	1.000867	44	0.019
13	Sharpe 181	0.999468	1887	0.020
14	Sharpe 184	0.999510	3	0.009
15	Sharpe 197	0.999682	117	0.024
16	Sharpe 228	0.999932	27	0.014
17	Sharpe 253	1.025750	42	0.017
18	Sharpe 256	1.000104	1931	0.017
19	Sharpe 280	0.999739	200	0.018
20	Worden 961	0.999628	135	0.026
21	Worden 971	0.997728	557	0.031
22	Worden 978	0.998789	178	0.021
Σ			8464	

Table IV. Calibration factors and RMS errors of adjustment for gravimeters applied in the MGH-2000 network

IV. táblázat. Az MGH-2000 méréseinél alkalmazott graviméterek kiegyenlítésből származó méretarány-tényezői és átlagos mérési hibái of instruments but it must be taken into account that the numbers of observations carried out with the individual gravimeters are significantly different. *Figure 6* represents the histogram of the corrections; it can be seen that 90 % of them are less than 40 μGal and only 2 % higher than 100 μGal, but the weight of this latter 2 % is so small that it hardly influenced the

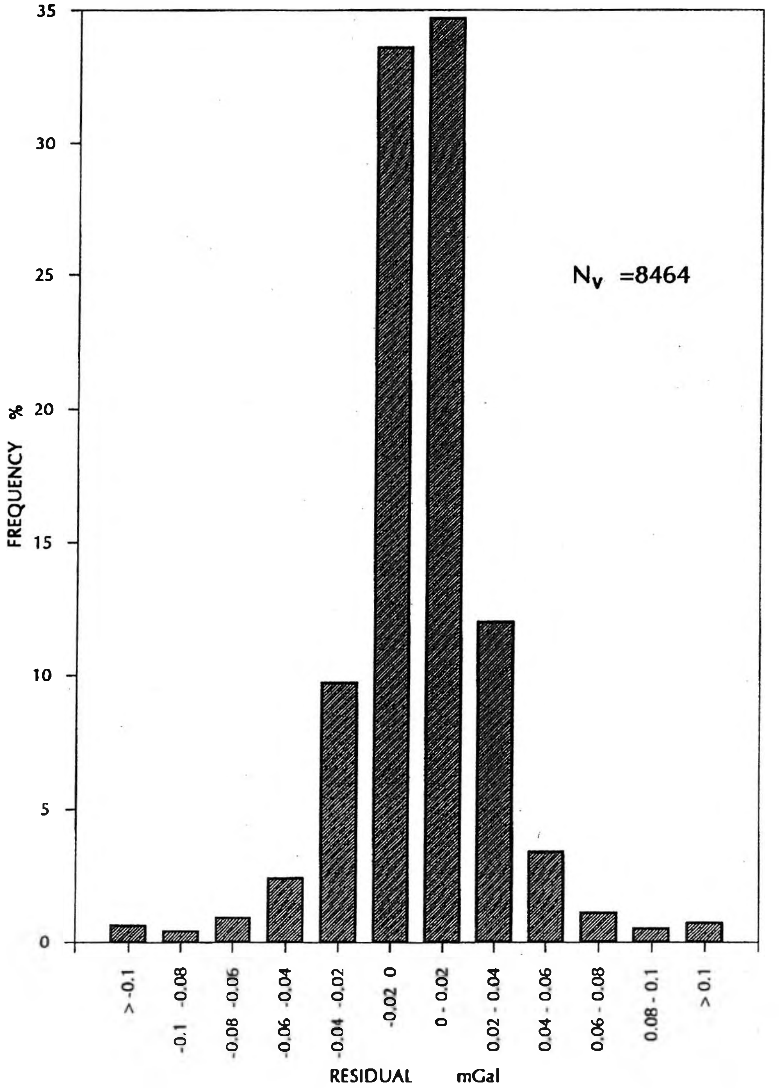

Fig. 6. Histogram of residuals

6. ábra. A mérési javítások hisztogramja adjusted values. In *Fig. 7* the errors of the adjusted gravity are presented. Most of the points are in the 6–10 μGal error interval, but for those points where the number of measurements are small greater errors are obtained. The error of unit weight of the adjusted network is ±20 μGal.

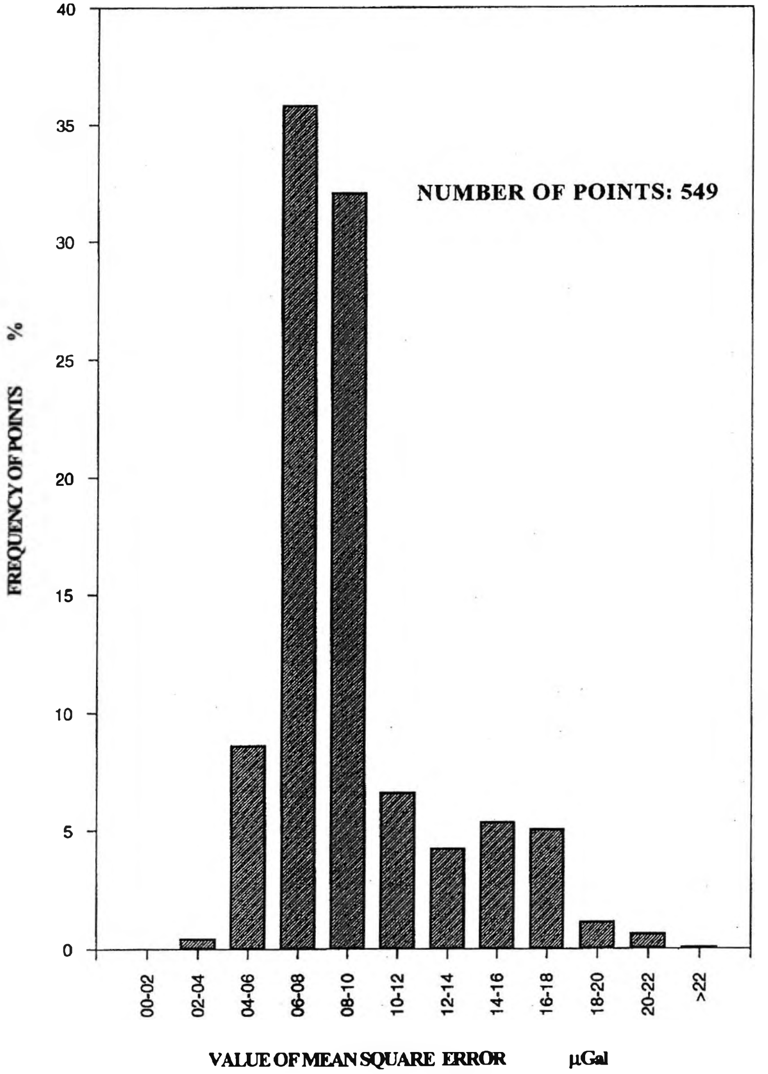

Fig. 7. Histogram of mean square error frequency of adjusted gravity

7. ábra. A kiegyenlített nehézségi értékek középhibáinak hisztogramja

To check the quality of the adjustments two comparisons were carried out. **In the first** one we compared the adjusted values of identical points obtained from the two different data sets (EGH and MGH) calculated by the second version of ELGI adjustment, the deviations between the adjusted values were from 1–3 μGal only, in spite of the different number of observations, different extent of area involved and different number of gravimeters in the calculations. The small values indicate that the national gravity scale depends mainly on the absolute points, and relative measurements of the country and far away points do not influence the results in a perceptible way.

In the second comparison the results of the Czech and Slovakian free adjustments and the Hungarian constrained adjustment were involved. The deviations on the Hungarian base points between the three adjustments were in the 0–20 μGal interval. The result is very satisfying, taking into account the different size of data sets involved and the different methods ('free' and 'constrained') of adjustments. Significant deviation was not experienced between the datum levels. From the 105 compared points only three (Esztergom, Kunhegyes, Nyiregyháza) differed by more than 30 μGal.

A similar comparison was carried out between the Austrian and Hungarian gravity datum. Based on 8 points the Hungarian datum proved to be higher than the Austrian by 18 μGal.

In the adjustment of the 'Unified European Gravity Network' 94' five Hungarian base points were involved [BOEDECKER et al. 1994]. Based on the five points the Hungarian datum is higher by 14 μGal than the international one (see *Table. V*).

UEGN' 94	**MGH–2000**	**UEGN'94**	**MGH–2000**	**difference in microgal**
number and	**name of point**	**gravity value**	**in microgal**	
1835 FRTOD	4111 Fertőd	980824222 ± 8.0	980824234 ± 4.9	12
1836 HGYEHAL	4122 Hegyeshalom	980844449 ± 12.0	980844460 ± 7.0	11
1837 KESZG	85 Kőszeg	980784705 ± 15.0	980784713 ± 5.0	8
1838 SPRO	4105 Sopron	980808350 ± 14.0	980808375 ± 5.4	25
1839 VELCJ	4112 Völcsej	980802189 ± 14.0	980802203 ± 4.1	14

Table V. Comparison of UEGN' 94 and MGH-2000 networks based on identical Hungarian points

V. táblázat. Az UEGN'94 és az MGH-2000 hálózat összehasonlítása a közös magyarországi pontok alapján

11. Plans for the near future

— Based on the plans of the International Gravity Commission two more absolute gravity points will be measured in Hungary during 1996–97 (Debrecen és Zalalövő).
— The next adjustments of the Unified European Gravity Network will be carried out in 1998 [BOEDECKER et al. 1994]. Since Hungary's intention is to join the European Network the relative gravity measurements between the absolute points should be concluded in 1997 (see Fig. 2).
— A further task is to connect the new and the old networks in order to have the transformation equation between them.
— It is important to provide maintenance and restoration of the gravity base points, and to ensure the necessary funds for the three yearly reobservation of the absolute points.

Acknowledgement

The author wishes to express his gratitude to the National Committee for Technological Development (OMFB) and the U.S.–Hungarian Science and Technology Joint Fund (MAKA) which organizations supported the measurements of MGH-2000 (MEC-94-0508 and JF-369 contracts). Their financial assistance rendered possible the completion of the project. Special gratitude is due to DMA for their support of ELGI. He is indebted to D. RUESS for carrying out the absolute measurements with the JILAG-6 gravimeter, to A. SÁRHIDAI for the adjustments, and to all local and foreign partners who assisted in his work with advice and discussions.

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Az új magyarországi gravimetriai alaphálózat (MGH–2000)

CSAPÓ Géza

A közelmúltban fejeződtek be a közép-európai országok közös gravimetriai hálózatának kialakítására végzett munkák, amelyek keretében a magyarországi alaphálózatot is korszerűsítették. Ismertetésre kerülnek a korábbi hálózatok, azok feladata és a fejlesztés szükségszerűségének okai. Az új hálózat méretaránya az SI mértékrendszerben adott; ezt nagyszámú abszolút állomás telepítésével és mérésével biztosították. A szerző bemutatja az alkamazott gravimetriai módszereket, az adatfeldolgozás és kiegyenlítés folyamatát, majd összehasonlítást végez a cseh, a szlovák, az osztrák és az „Egységes Európai Gravimetriai Bázishálózat", valamint a magyar hálózat között.