ESTABLISHMENT OF GRAVIMETRIC NETWORK FOR THE AREA OF ZAGREB METRO

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Abstract

The paper offers the overview of the establishment of gravimetric network on the wider area of the City of Zagreb, the capitol of the Republic of Croatia. The network consists of 34 points the stabilization of which has been taken over from the previously established fundamental GPS network of the City of Zagreb. There is also the implementation of precise GPS, levelling and relative gravimetric measurements presented. In gravimetric measurements the relative gravimeter Scintrex Autograv CG-5 has been used. For the purpose of defining gravimetric datum two absolute gravimetric points were used. The relative gravimeter was calibrated on the part of the Gravimetric calibration base of the Republic of Croatia before and after the measurement. In the process of adjusting the gravimetric network, the input values were absolute values of gravity and gravity differences between the points that had been previously corrected for the height of instrument, the change of Earth pole position and for the air pressure, as well as for the instrumental drift. Standard deviations of gravity differences and the distance between points were used for weights. The obtained results of the gravity value, as well as their accuracy estimation indicate that there was extremely reliable gravimetric network established using applied methodology.

Key words: gravity, network, gravimeter drift, linear, quadratic

Introduction

In June 2005 the gravity network of the City of Zagreb was established at the wider territory of the City of Zagreb, as a part of the II. Order Gravity Network of the Republic of Croatia. The purpose of establishing the gravity network was to define precisely the values of gravity at the locations of selected points belonging to the previously defined GPS network of the City of Zagreb. The points needed to be connected with relative gravimetric measurements to absolute gravimetric points, and also to the nearest point of the I. Order Gravimetric Network. GPS-RTK technology was used in determining the positions of gravimetric points. The height component was determined with precise levelling connection to the bench marks of the II. NVT.

Revision of the geodetic base at the territory of the city of Zagreb

The 0. Order Gravity network of the Republic of Croatia consists of 6 points (Fig. 1 – red colour). At the territory of the City of Zagreb there are two absolute points, i.e.: AGT02 Maksimir and AGT03 Puntijarka (Fig. 2). The I. Order Gravity Network of the Republic of Croatia consists of 36 points (Fig. 1 – blue colour). The nearest I. Order point, GT117 was used in relative gravimetric measurement [1,2,4,6].

The fundamental GPS network of the City of Zagreb consists of 38 points. The majority of points are stabilised with concrete column 1,3 m high at the bottom of each point a chromium-plated bolt is installed (Fig. 3.). All relative gravimetric meausrements done refer to the bolt height. In GPS points, where it was not possible to do gravimetric measurements, adequate excenter was observed instead of them. Levelling survey required field reconnaissance to be carried out for the purpose of finding the most reliable II. NVT (highest order leveling network) bench marks. At the territory of interest there were altogether 5 bench marks found that levelling measurements were referred to.

Gravimetric, GPS and levelling measurements

Relative gravimetic measurement was done with relative gravimeter Scintrex AutoGrav CG-5. This is a quartz instrument controlled with microprocessor and highly automated. Operational range of the gravimeter is over 8000 mGal (1 mGal = 10^{-5} ms^{-2}), and standard gravimeter resolution is 1 μGal (1 μGal = 10^{-8} ms^{-2}). To be used in gravimetric measurement at the territory of the City of Zagreb, the gravimeter had been callibrated on the part of gravimteric callibration base of the Republic of Croatia [5]. For this purpose the points were used the values of which are more difficult to be known in absolute amount, i.e. in the points AGT03-Puntijarka and AGT02-Maksimir. On the basis of multiple measurements on the part of the calibration base between these two absolute gravimetric points and their adjustment, new scale changing factor was computed for the elative greavimeter CG-5 that was used in measurements. Table 1 provides the calibration factor that was used during the measurement.

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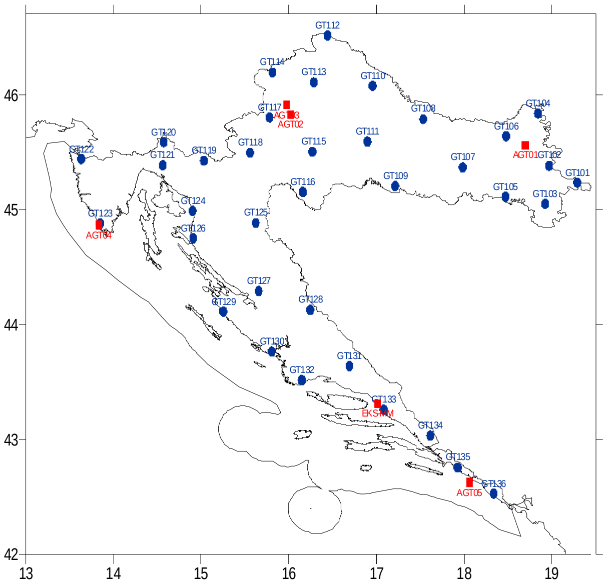

Figure 1. The 0. and I. Order Gravity Networks of the Republic of Croatia

Figure 2. Absolute gravity point AGT03-Puntijarka

Relative gravimetric measurements in the gravimetric network of the City of Zagreb were done in the period between 13th and 29th of June 2005. Depending on the measurement plan and field conditions, the star methods were used primarily in the measurement, and when necessary, a profile method. In the process of planning the measurement the economic efficiency, distance between points and reliable calculations of gravimeter drift were considered

Table 1. Calibration factor of the gravimeter Scintrex CG-5

	GCAL1 ($10^{-5}ms^{-2}$)	*K1*	*GCAL1' ($10^{-5}ms^{-2}$)*
CG-5	*8428,017*	*1,000071310*	*8428,618*

The calculation of linear and quadratic gravimeter drift was done always in the starting point of the gravimetric day. There are the measurement parametes given in the Table 2 that were used during the measurement in the Gravimetric network of the City of Zagreb.

Table 2. Parameters of gravimetric measurement in the network of the City of Zagreb.

Read time	60	*#of Cycles*	5	*Seizmic filter*	Yes
Auto reject	Yes	*Save raw data*	Yes	*Terrain corr*	No
Cycle time	77	*Start delay*	20	*Cont. tilt corr*	Yes
Tide correct	Yes	*Auto repeat*	No		

The instruments and additional equipment were transported with personal car. During the measurement 6000 km were made driving. There were altogether 54 gravimetric figures closed in the measurements of the Grvity Network of the City of Zagreb (Fig. 3) During the measurement in the gravimetric Network of the City of Zagreb the star method and the profile method were used. The mentioned methods were used for observing the closed figures, and the calculation of the daily gravimeter drift was taken into consideration. For that purpose the starting point was used that was observed in the middle of the day wherever it was possible, except as the final point.

Relative gravimeter Scintrex CG-5 has the possibility to yield measurement reductions immediately in the field. Gravimetric readings are in the instrument, in real time, reduced for the change of gravimeter reading scale referring to the calibraion constant, height of gravimeter, measuring sensor temperature and the Earth's tide waves [8,9].

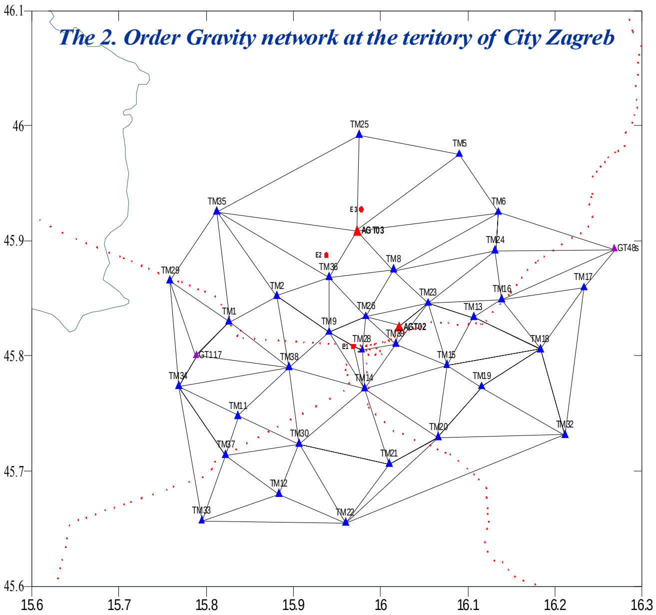

Figure 3. The part of II. Order Gravimetric network at the territory of the City of Zagreb

Figure 4. Typical GPS pilar of the Zagreb network

Besides the mentioned reduction contained in the measurements in the field, the gravimetric readings should be additionally reduced for the influence of the instrument height, air pressure change and the change of Earth pole position, and finally for the gravimeter drift [3,7,11]. The time variation of gravimeter reading in the zero position of the instrument (drift) is given by the expression [10]:

$$D(t) = z(t_0) + d_1(t - t_0) + d_2(t - t_0)^2 + ..$$

where z(t0) is the gravimeter reading at the beginning of measurement *t0, d1* and *d2* are the drift parameters, and *t* is the moment of measurement. For the purpose of eliminating gravimeter drift and preparing the adjustment measurement, a daily linear and quadratic drift has been determined for CG-5 on the basis of the measuring method, i.e. of the repeated measurement in the point of origin. The example of determining the drift of CG-5 gravimeter is shown in Figure 5, for the 20th of June, 2005, where the drift is modelled on the basis of raw measurements as a linear – straight line with the corrected measurements obtained at the end (red), and guadratic – dash red line.

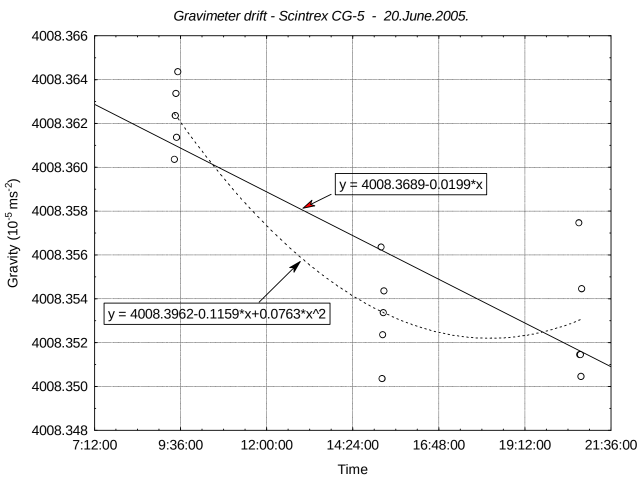

Figure 5. Linear and quadratic drift of the CG-5 gravimeter for the day 20.06.2005

For the purpose of determining the position of gravimetric points GPS-RTK method was used. Basic GPS points of the City of Zagreb were used as connection points. Official transformation parameters [1] were used for the transformation of coordinates from ETSR'89 system into Croatian Official Coordinate System. Thus obtained heights served for the comparison with orthometric heights obtained in levelling measurements.

Table 3. Statistics of levelling network adjustment

N = 34	Height (m)	St.dev. (m)
Mean value	187.3971	0.0132
St.dev.	116.0126	0.0081
Min.	102.3099	0.0055
Max.	601.9932	0.0333

Table 4. Statistics of height comparisong from GPS and levelling measurements

Total number of differences	21
Difference mean value	- 0.0118 m
Standard dev.	0.0244 m
Maximum difference	0.0400 m
Minimum difference	-0.0504 m

The height differences in the II. Order Gravity Network at the territory of the City of Zagreb were measured in one direction using digital levels Leica NA2000 and DNA03. Thus levelled height differences were controlled in closed figures of 3 or more points. There were altogether 20 figures levelled. The largest discrepancy of levelling with the length of levelling side being 1 km is 1.4 mm/1km. This discrepancy refers to the largest figure that is connected with the points on the southern and northern side, and its total length is 81.8 km. In the procedure of the levelling network adjustment the obtained mean reference error is m_0=1.44 cm.

Further on there is the comparison made of othometric heights obtained by means of levelling network adjustment and the heights in GPS network of the City of Zagreb. In order to carry out the comparison correctly, the difference of 17.2 cm related to the old system (Trieste) is added to the heights from the new height datum (HVRS71), and it was found out on the basis of the known heights of six bench marks in the old and new system and in this area. There were altogether 21 points compared with the existing heights and new height on the basis of the carried out leveling within the scope of this project. Table 4 gives statistical indicators of the comparison made.

Adjustement of gravity network

The measurements in the Gravimetric network for Zagreb area have included the total of 34 gravimetric points (2 absolute and 1 I. order points). The most probable values of gravity were obtained by means of adjustment using the least squares method. The connection between the measured and the requested values can be expressed with the correction equation [9]:

$$\Delta z_{i,j} + v_{i,j} = g_j - g_i \ ,$$

where $\Delta zi,j$ is the difference of gravimetric readings, vi,j is the accompanying correction of gravimetric reading, gi,j is the gravity in the points i i.e. j, at the moments of measurements ti,j.

The adjustment of gravity network has been carried out using the expression for immediate measurement. In the adjustment the a priori datum has been defined using the absolute gravity values in the points AGT02 Maksimir and AGT03 Puntijarka.

Table 5. Statistics of obtained st. dev. in linear and quadr. drift (only AGT03 defines the datum)

	CG5 – lin. drift		*CG-5 – guadr. drift*	
No. of meas. & st.dev.	139		139	
Min.($10^{-5}ms^{-2}$)	534.9096	0.0018	534.9108	0.0053
Max. ($10^{-5}ms^{-2}$)	674.3315	0.0036	674.3287	0.0109
St.dev. ($10^{-5}ms^{-2}$)	31.3981	0.0005	31.3977	0.0015
Mean ($10^{-5}ms^{-2}$)	646.5735	0.0027	646.5721	0.0080

Table 6. Statistics of obtained st. dev. in linear and quadratic drift for fixed network

	CG5 – lin. drift		*CG-5 – guadr. drift*	
No. of meas. & st.dev.	139		112	
Min.($10^{-5}ms^{-2}$)	585.3721	0.0019	585.3721	0.0019
Max. ($10^{-5}ms^{-2}$)	671.9375	0.0037	671.9375	0.0037
St.dev. ($10^{-5}ms^{-2}$)	18.0781	0.0006	18.0781	0.0006
Mean ($10^{-5}ms^{-2}$)	651.1326	0.0028	651.1326	0.0028

Apart from absolute values of gravity, the input values were the differences of gravity determined between two points. The gravity differences were obtained from arithmetic means of 60 second readings in five epochs in one point. On the basis of the reading there were also their belonging standard deviation determined, and the standard deviations of the gravity differences themselves were determined by applying the error growth law. Tables 5 and 6 give the overview of statistical indicators in the adjustment of free and fixed gravity network. In the free netowork the st. dev. is better as related to the network computed with square drift, and in fixed network the statistical indicators are ajusted due to the measurements eliminated in the network computed with quadratic drift.

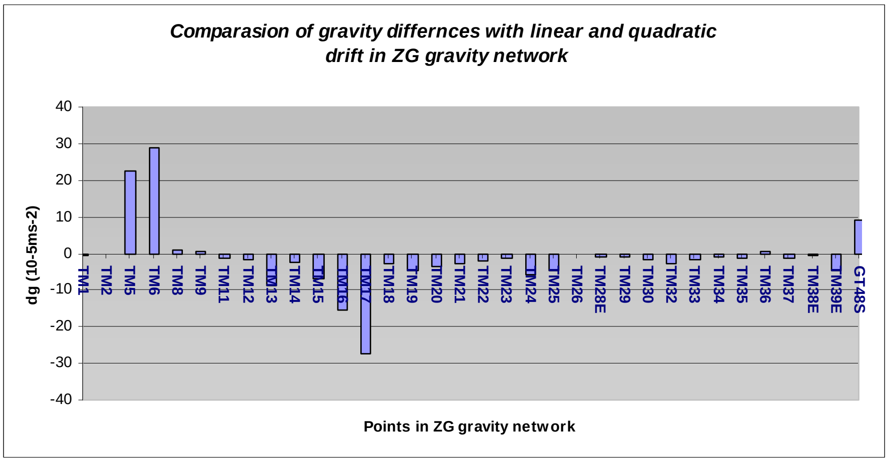

Figure 6. Gravity differences obtained between the adjustment with linear and the adjustment with quadratic drift in the Zagreb Gravity Network

Figure 6 presents graphic comparison (differences) of gravity values obtained by means of the adjustment with linear and quadratic model of gravimeter drift. There are some deviations noticed in four points (TM5, TM6, TM16 and TM17), that are grouped at the western edge of the gravity network and were observed during two gravimetric days when the gravimeter drift was somewhat bigger.

Conclusion

On the basis of the procedures applied in measuring the gravity differences as well as the height differences between the points of the gravity network of the City of Zagreb as a part of the future II. Order Gravity Network of the Republic of Croatia, and of the processing and adjustment of gravimetric, GPS and levelling measurements it can be concluded that extremely reliable gravity network has been established with equally reliable heights. It can be seen from the mean standard deviation of the heights being 1.32 cm, and the minimal value of the standard deviation is 0.55 cm, and the maximal is 3.33 cm. Regarding the gravity, the mean standard deviation is $2.45 \times 10^{-8} ms^{-2}$), which corresponds excellently with the adjustment obtained with the reference error of $2.30 \times 10^{-8} ms^{-2}$, the minimal value of standard deviation is $1.15 \times 10^{-8} ms^{-2}$, and the maximum value is $4.85 \times 10^{-8} ms^{-2}$.

References

1 Bašić, T. (2004): Inserting GPS points homogeneous field of the GPS network of the City of Zagreb into the Croatian State Coordinate System. Technical Report for the Department for Cadastral and Geodetic Affairs of the City of Zagreb, 1-180, Zagreb.
2 Bašić, T., Markovinović, D. (2002): Gravimetric network and Calibration base of the Republic of Croatia. The Proceedings of the Faculty of Geodesy, University of Zagreb – on the occasion of 40. anniversary of its independent activity (1962.-2002.), Ed. T. Bašić, 81-93, Zagreb.
3 Bašić, T., Markovinović, D., Rezo, M. (2004): Basic Gravimetric Network of the Republic of Croatia, Reports of State Geodetic Administration on Scientific and Professional Projects in 2002, Ed. I. Landek, 51-65, Zagreb.
4 Bašić, T., Markovinović, D., Rezo, M. (2006): Basic Gravimetric Network of the Republic of Croatia. Geodetski list, 1-16, Zagreb
5 Hećimović, Ž., Markovinović, D. (2003): Calibration of the Relative Scintrex CG-3M gravimeters HGI-1 and HGI-2. Geodetski list, 3, 161-166, Zagreb.
6 Markovinović, D. (2001): The I. order Gravimetric Network and Gravimetric Calibration Base of the Republic of Croatia. (Master thesis), Faculty of Geodesy, University of Zagreb.
7 Schüler, T (2000): Conducting and Processing Relative Gravity Surveys. Institute of Geodesy and Navigation. University FAF Munich, Germany.
8 Scintrex Limited (2002): Scintrex CG-5 Autograv Automated Gravity Meter. Operation manual, Scintrex Limited, Canada.
9 Torge, W. (1989): Gravimetry. Walter de Gruyter, Berlin-New York.
10 Torge, W. (2001): Geodesy. Walter de Gruyter, Berlin-New York.
11 URL1: International Earth Rotation Service (IERS), http://hpiers.obspm.fr/eoppc/bul/bulb/. (30.05.2005.)