Project of the new gravimetric network and test survey in Slovenia

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Abstract: Based on analyses of old gravimetric surveys carried out in the territory of the Republic of Slovenia a project of the new gravimetric network was developed. The geological assessment of suitability of the preserved and new planned gravimetric stations was completed. Additionally, in the territory of Slovenia test gravimetric surveys with the relative gravity meter Scintrex CG-3M No. 10341 were performed. Test measurements were tied to the absolute gravimetric stations. The main aims of the test measurements included testing, trial operation of the instrument and acquisition of experience in measuring the first order gravimetric network. The measuring campaign was performed at the stations where gravity was previously measured. All readings were evaluated and a comparison with the previous gravity values in the surveyed stations was performed.

Key words: gravimetric network, project, test survey, SCINTREX CG-3M

1. Introduction

In Slovenia there is an existing zero order reference network, represented by 6 absolute gravimetric stations, where the absolute gravity was measured. The zero order gravimetric network will be updated into the first

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order gravimetric network, thus replacing the old Fundamental Gravimetric Network stabilized in the area of the former Yugoslavia. The basic goals that we want to achieve with the stabilisation and measurements of the first order gravimetric network are:

- connection of the relative gravimetric network to the zero order network (absolute gravimetric stations),
- closing of gravimetric polygons (triangles or quadrangles) in the territory of Slovenia,
- achieving accuracy in determination of gravity in first-order gravimetric stations within the limits of 10 μgal,
- ensuring quality basis for determination of the geoid in the territory of Slovenia and transition to an up-to-date height system,
- enabling successful inclusion into the EUVN (European Vertical Reference Network),
- acquisition of the basis for determination of vertical displacements and possibility of distinguishing displacements of the coast from the changes of the mean level of the sea.

The test measurements were performed, with several intermissions, between July 7, 2005, and October 13, 2005, in the territory of Slovenia. All measurements were performed with the relative gravimeter Scintrex CG-3M No. 10341, owned by the Surveying and Mapping Authority of the Republic of Slovenia (hereinafter called SMARS). The test measurements were connected to the absolute gravimetric stations and other stations that were previously connected to the absolute gravimetric stations. The basic aim of performing test measurements was testing, trial operation of the instrument and acquisition of experience in measuring the first order gravimetric network. The measurements were performed at the stations, where the gravity was measured in the past, thus enabling us to compare the results of measurements. On the basis of the comparison, potential gross and systematic errors could be detected. The test measurements included:

- gravimetric stations of the fundamental gravimetric network,
- bench marks of the Second Precise Levelling of Yugoslavia (hereinafter called: II NVN), performed in 1971,
- bench marks on which the 1995 gravimetric measurements were performed within the campaign of connecting the levelling networks of Slovenia and Austria,

- the gravimetric calibration line of Slovenia measured in 1998.

2. Project of the new gravimetric network of the Republic of Slovenia

Based on the review of the state of the fundamental gravimetric network of the former Yugoslavia, which was carried out by the SMARS in the spring of 2005, a new design of the new first order gravimetric network was drawn up. In determining the positions of the new gravimetric stations the following was considered:

- The gravimetric station must be positioned in the vicinity of levelling polygons of higher orders, since the gravimetric stations have to be connected to the levelling network. In this way the proper accuracy in determination of the height above the see level is achieved.
- The gravimetric station should be accessible by car. In this way a quick connection to the neighbouring stations is made possible, being an advantage when trying to determine the instrumental drift and enabling easier transport of the relative gravity meter to the station *(Torge, 1989)*.
- Ensuring homogeneous density of gravimetric stations in the territory of Slovenia.

3. Geological expertise on the suitability of positions of gravimetric stations

The design of the new gravimetric network of Slovenia has served as the basis for the making of the geological expertise regarding the suitability of stations of the fundamental gravimetric network in Slovenia *(Vrabec, 2005)*.

The geological expertise was drawn up for absolute gravimetric stations, preserved stations and planned new stations of the fundamental gravimetric network, that is, stations of the first order gravimetric network, based on the Basic Geological Map in a scale of 1 : 100.000.

It is evident from the expertise that the local geological stability was considered also with the original selection of locations for the existing stations. Thus, steep slopes, river banks, landslide-prone areas, marshes etc. were originally avoided. Two major criteria of stability were used in our analysis:

1. Stations located on alluvial deposits of gravel or silty loam can be prone to vertical displacements due to the oscillations of the groundwater level. These oscillations may be seasonal (that is, when the level of groundwater periodically changes with seasons) or completely random (related to the quantity of precipitation). To some extent, these effects can be avoided by repeated gravimetric measurements at approximately the same time of the year. Also, it would be advisable to record the groundwater level during measurements. The data could be obtained from piezometric boreholes, provided that they are located in the vicinity of the stations. However, the position of a station on the alluvial deposits does not necessarily imply that the location is not adequate, but this must be considered in the interpretation of results.

2. Stations positioned within fault zones of presumably active regional faults are considered as potentially unstable. In seismic and aseismic displacements along the faults within the fault zone, large vertical and horizontal surface deformations can occur. It should be noted that the data provided by GPS measurements indicate that the velocities of displacements along the faults in Slovenia are relatively small, within the size $\sim$1 mm/year *(Vrabec et al., 2006)*, so that from the point of view of station stability, the deformations can be considered negligible. It is worth mentioning that for most of the faults in Slovenia, there are no reliable data on their recent activity or lack of it. Mostly, we speak about their potential activity in relation to the orientation of the fault to the regional stress state and in relation to the indirect (e.g. geomorphologic) indicators *(Vrabec, 2005)*.

Based on the given criteria, the state for absolute gravimetric stations, preserved stations and new stations of the fundamental gravimetric network is the following *(Vrabec, 2005)*:

- Absolute gravimetric stations: stabilisation was performed in geologically suitable terrain.

- Preserved gravimetric stations of the basic gravimetric network: 10 stations (43%) out of 23 preserved stations have been stabilised in geologically suitable terrain. 9 stations (39%) have been stabilised in structures built on alluvium, where there may be vertical displacements present due to the oscillations in the groundwater level. The rest 4 stations (18%) have been stabilised in structures situated in the close proximity or within the potentially active fault.
- In selecting the micro locations of the new gravimetric stations the expertise of the geologist will be considered, thus estimating that the stations will be stabilised into structures built in geologically suitable terrain.

4. New first order gravimetric network in the Republic of Slovenia

In designing the gravimetric networks of lower orders usually the following density of gravimetric stations is considered *(Dichtl, 2000)*: first order: 1 station/1000 km^2, second order: 1 station/100 km^2, third order: 1 station/10 km^2.

In networks of the first order precise relative gravimetric measurements are performed, which are time-consuming. For this reason, the division of gravimetric networks in countries that are significantly larger than Slovenia seems legitimate. However, for Slovenia, which is of significantly smaller size, it is reasonable that with the first order gravimetric network a significantly larger network density is achieved, thus having the choice of replacing the measurements of gravimetric networks of lower orders or densifying the first order network with regional campaigns.

Based on the geological expertise, we proposed the design project of a new gravimetric first order network of Slovenia (Fig. 1). Into the gravimetric network all the preserved gravimetric stations of the fundamental gravimetric network (10) were included, which were stabilised in geologically suitable terrain. Due to the even distribution in the territory of Slovenia, the 9 preserved gravimetric stations were included. (stations Nos.: 8, 10, 11, 12, 21, 35, 37, 41, 44), which were stabilized in unstable areas, as well as 10 new gravimetric stations. The rest of the preserved gravimetric stations, which were not included into the new first order gravimetric network will

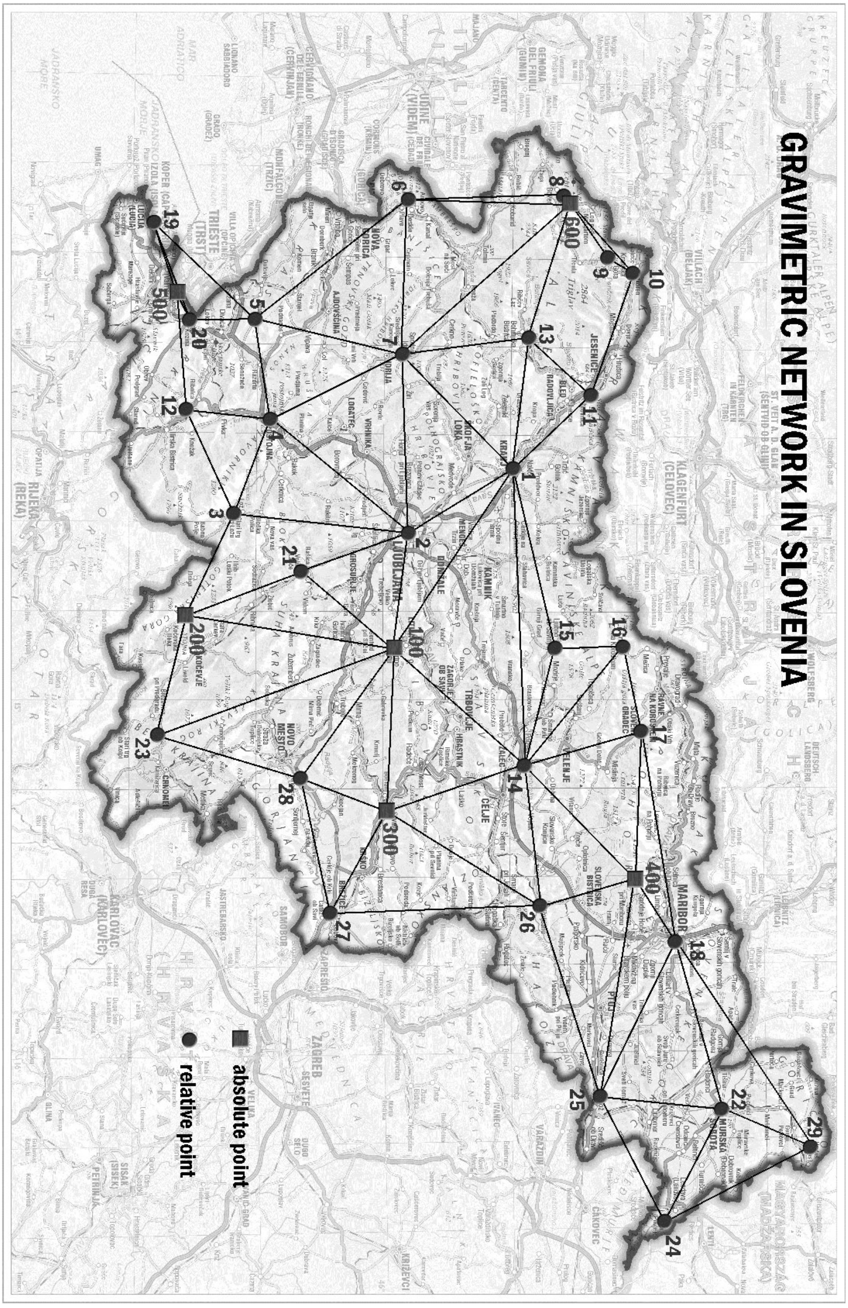

Fig. 1. Design project of the new first order gravimetric network in the Republic of Slovenia.

be included into the measurements of polygons in the area, where the stations were stabilised. These stations can be included with the step-method measurement or by the profile method.

5. Test gravimetric measurement in the area of Slovenia

The test gravimetric survey was performed by the relative gravity meter Scintrex CG-3M. The working range of the gravity meter (excluding resetting) is 7000 mGal-a (1 mGal $= 10^{-5}$ms^{-2}), meaning that the measurements can be performed almost anywhere on Earth. The measuring procedure is automated. In this way, the errors of the operator are diminished. The measurements are logged into the internal memory of the gravity meter. The relative gravity meter Scintrex CG-3M has a standard resolution of 1 μGal-a (1 μGal $= 10^{-8}$ms^{-2}) with the standard deviation of less than 5 μGal-a.

6. Measurement procedure and data post-processing

After the setting up and levelling of the instrument in the stations of the basic gravimetric network, the height of the instrument was measured three times (at each leg of the tripod – arithmetic mean value of the measured heights is considered in data post-processing). Due to the vibrations present during transport and carriage of the instrument, we waited for 10 minutes after the levelling of the instrument, to allow the measuring system to steady itself. After 10 minutes, we started to take the measurement. In the stations of the basic gravimetric network 5 measurements were performed.

In bench marks of the II NVN the height from the top of the instrument to the bench mark was taken only once, since the data about the measured g relate to the highest point of the bench mark. Since the previous surveys in the levelling bench marks of II NVN were given at an accuracy of 10 μGal, we performed 3 readings right after the setting up and levelling of the instrument.

In measuring the gravity, there are several contributing effects. These can be divided into two groups *(Torge, 1989)*:

1. Effects due to the imperfections of the instrument – instrumental errors;
2. Exterior influence of the surroundings.

Instrumental errors are attributed to the construction of the gravity meter. The rest of the effects are addressed with the introduction of adequate corrections. Prior to the calculation of the corrections required, the periodic influence of tides of solid Earth must be excluded from the results of the measurement.

In our case, the following corrections were considered.

1. Reduction due to the variations in atmospheric pressure. The atmospheric pressure at the station was measured with the Meteo Station HM 30 of the Swiss company REVUE THOMMEN AG. The resolution of the instrument is 0.1 hPa and the standard deviation is 1 hPa.
2. Reduction due to Polar Motion.
3. Effect of the residual drift of the instrument.

We distinguish between two kinds of instrumental drift:

- Long-term drift: as a result of spring aging, temperature changes and atmospheric pressure changes; the long-term drift ranges between 10 and 100 μGal per day and decreases with the aging of the instrument.
- Short-term drift: as a consequence of vibrations during transport. In this case, all the measurements were performed with the profile method. The modelling of the drift function was done with the polynomial functions of degrees 1, 2 and 3. Two characteristic cases of drift determination are given in Fig. 2. The left side shows the date of 15/07/2005, and the right side the date of 10/08/2005. Evidently, with the latter case the cubic function of the drift provides a better fit to the readings, however, due to the uneven temporal distribution of repeated readings in the stations the use of the linear drift is reasonable.

7. Results of the surveys and comparison with previous gravimetric surveys

The surveys helped to establish the gravity in 8 stations of the former basic gravimetric network of Yugoslavia and in more than 60 bench marks

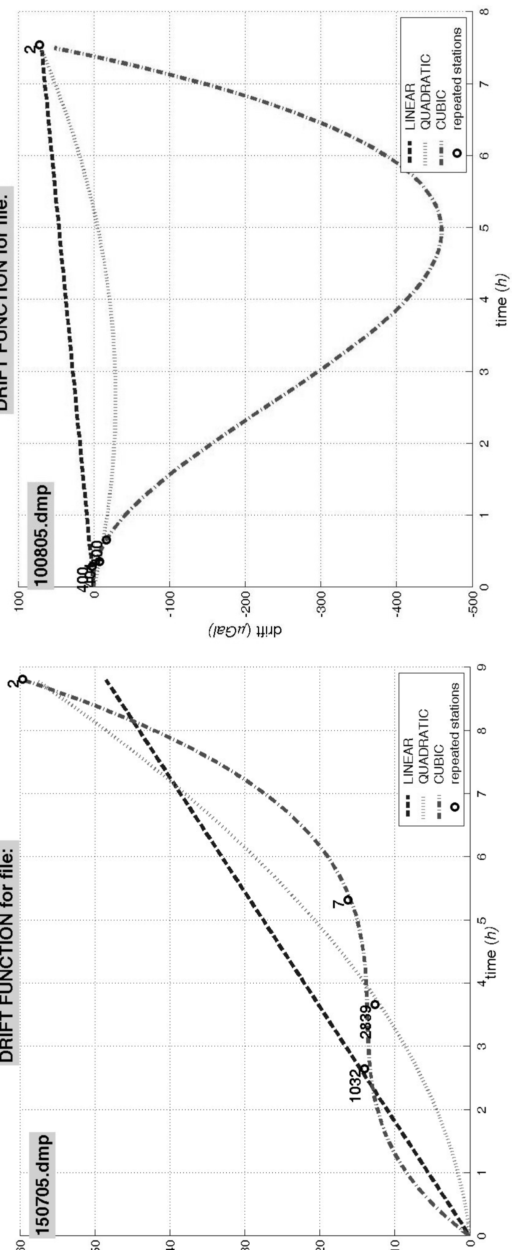

Fig. 2. Function of the instrumental drift for 15/07/2005 and 10/08/2005.

of II NVN. Table 1 gives the absolute gravity values in the stations of the fundamental gravimetric network of 2005 and those of 1967 in the Potsdam system, and the differences between them.

Between system IGSN71 and the Potsdam system of gravity an offset of −14 mGal was determined. However, based on subsequent surveys in the territory of the former Yugoslavia, performed in Belgrade and Zagreb, the offset ranged between −15.13 mGal and −15.10 mGal, corresponding to the differences based on the test gravimetric survey *(Milovanović, 1984)*.

When comparing the measured values of gravity in bench marks of II NVN performed in 1971 and our test survey, the differences were estimated at about −1100 μGal. Regardless of the fact that the compared surveys were performed within the IGSN71 system, the difference mentioned resulted from the fact that with the gravimetric survey of II NVN the difference between the Potsdam system and the IGSN71 system at a value of −14 mGal was considered *(Bilajbegović et al., 1986)*.

Table 1. Results of gravity survey in stations of the basic gravimetric network of Yugoslavia

STATION	Gravity – system IGSN71 [μGal]	Gravity – Potsdam system [μGal]	Differences between the 2005 and 1967 [μGal]
	2005	**1967**	
GT19	980661757	980676854	- 15097
GT20	980547723	980562846	- 15123
GT348	980573154	980588193	- 15039
GT6	980630888	980645657	- 14769
GT21	980558032	980573321	- 15289
GT39	980678011	980693177	- 15166
GT43	980701702	980716566	- 14864
GT44	980715784	980730865	- 15081

8. Conclusions

The project of the new gravimetric network represents the basis for the stabilisation of new gravimetric stations and planning of the survey. Besides, the new gravimetric network of Slovenia will provide the basis for all further gravimetric surveys in the territory of Slovenia. The gravimetric network will be further connected to the levelling network of the Slovenia. This will give us a basis for determination of heights of stations in the new height system.

Test gravimetric surveys performed in the entire territory of Slovenia in 12 working days have fully completed our expectations. We were provided with many data, which will enable further analyses related to the scale of the instrument (repeated survey of calibration basis of the Republic of Slovenia) and determination of the instrumental drift function. The selection of the instrumental drift function has the most significant influence, since the procedure itself has been automated. The gravity meter Scintrex Autograv CG-3M has proven as a reliable and easy-to-use instrument.

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