*Fundamental gravity network of the Republic Croatia in the function of control and improving of national and European geoid model**

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Abstract: By demand for densification of EUVN_DA network with additional points on state territory, Republic Croatia is again activated in project EUVN_DA on national level in year 2005. During project EUVN_DA network is expanded from 8 existing points to 20 points. Difference between EGG97 and EUVN model showed possible errors on some areas or points (HR05 Split). Therefore, those errors were eliminated by measurements and results were free of errors from first EUVN campaign in year 1997. Differences between national model of geoid HRG2000 and EUVN show better adjustment of geoid surface for state area than continental EGG97 geoid. Therefore they are additional control in densification of EUVN_DA project. Result analysis along coast showed large differences between geoid models. From the old gravity network (84 gravity points) 25 gravity points were used. After stabilization of 11 new gravity points Basic Gravity Network comprises 36 gravity points. Finalization of establishment of the Fundamental Gravity Network of the Republic of Croatia is also planned to improve absolute national geoid orientation. As well, EUVN points in Croatia, based on Fundamental Gravity Network, will ensure better identification of geoid differences on continental level.

Keywords: EUVN (DA), GPS/levelling, gravity network, HRG2000, EGG06

1. INTRODUCTION

European vertical reference network (EUVN) project started for several reasons: establishing uniform European referent height system, acquiring new data for continental geoid model testing and calculating, and connecting continental seas tide gauges. Besides tide gauges connections, the different national height systems connections have also been realized.

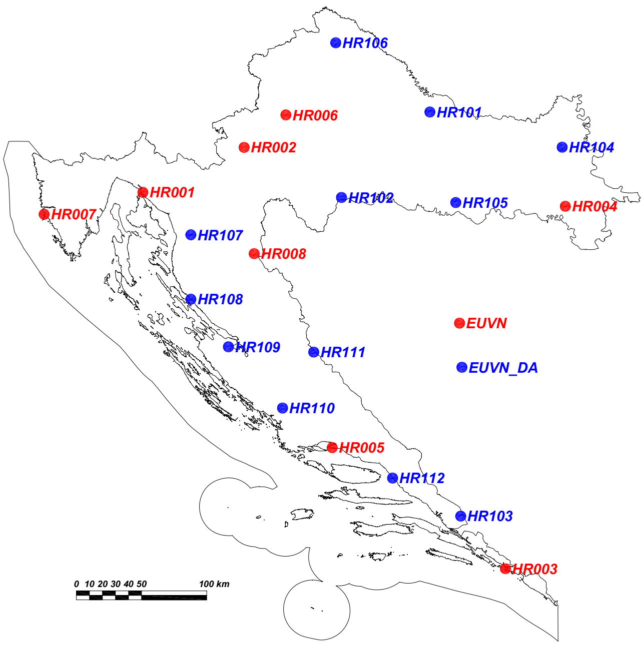

Figure 1.1. EUVN network in Croatia

EUVN1997 GPS campaign in Croatia had been conducted as part of EUVN project and 8 official points were defined (Marjanović, Rašić 1998). First discrepancy analysis of EGG97 and EUVN GPS/levelling undulations indicate some suspicious sites. In the year 2004 Croatian Geodetic Institute was activated in EUVN densification action (DA) in which besides revision on

8 points from 1997, 12 new points were defined. Today whole country is homogeneously covered with high accurate GPS/levelling EUVN points (fig. 1.1).
EUVN_DA project was completely leaned on 8 points from the first segment of the project. Due to the fact that some points, which were defined in 1997, did not obtain official status but all measurements were carried out on them, these points were added as densification points (HGI 2006).

2. CROATIAN GRAVITY NETWORK

The Republic of Croatia follows the unification trends of all geodetic networks at the European level, gravity networks as well. UNIGRACE project was the result of those trends. In two phases of that project Croatia acquired 6 absolute gravity points.
After the absolute points were set, all conditions for development of the first order gravity network were satisfied (fig. 2.1). After revision of the old gravity network state decision was that 25 of 84 old gravity points could be used in new first order gravity network. The network gets final look with 36 points after the installation of 11 new points (Bašić et al. 2004). After the gravity network had been measured in 2003 and the processing and adjustment had been done all gravity points got gravity values.

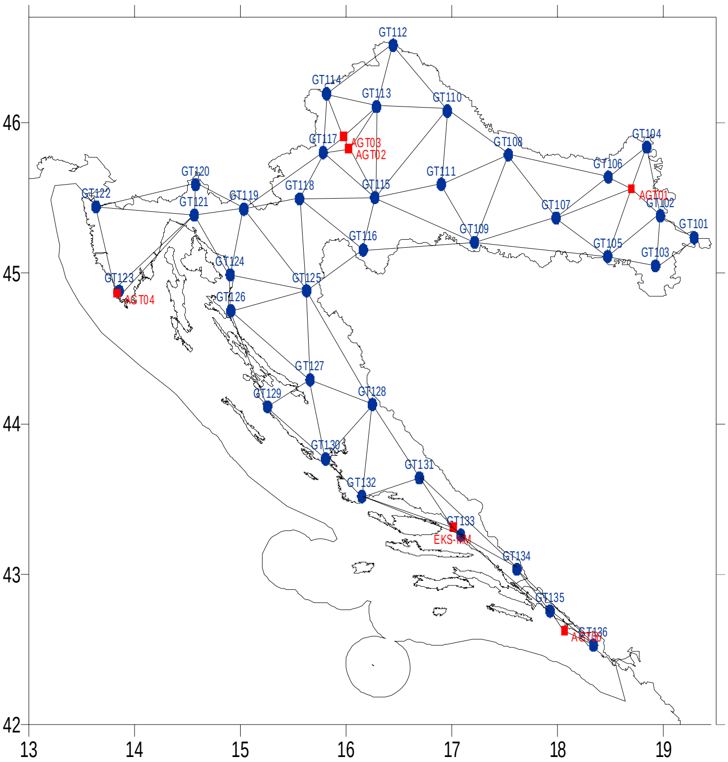

Figure 2.1.First order gravity network

Points of 1st order gravity network were determined under the project “Basic gravity network of the Republic of Croatia” by Institute of Geomatics, at Faculty of Geodesy in Zagreb, for the purposes of the State Geodetic Administration. The first phase of the project neglected precise position and height determination of the 0 and 1st order points due to the limited financial resource at that time. Position and height of the points were copied from the old field sheets and in small part they were taken as approximately values from the topographic maps of different scale or measured by less accurate handheld GPS equipment. It is evident that positions and heights accuracy is inadequate because of the fact that positions of the 1st order gravity points should be defined with accuracy better than a meter and height better than a centimetre (Torge 1989).

Good quality of point gravity, position and height are crucial not just for calculating of different gravity measurements corrections but also for acquiring of new point set for national geodetic infrastructure. That set is fundamental for numerous geodetic tasks.
Unsolved differences of some EUVN points and different geoid models lead to idea of using measurements of position and height on the 1st order gravity points in same way as in EUVN (DA) projects. With that approach gravity points with new measurements could be used for control of national and European geoid models and moreover for improving of absolute orientation of national geoid model. In addition, they could provide new input for the future models and in future as rich base for solving of different practical and scientific geodetic problems.

3. WORKS ON THE PROJECT OF FUNDAMENTAL GRAVITY NETWORK

One of the main tasks in the fundamental gravity network project was designing of preliminary plan with connections to nearest benchmarks, control points or permanent GNSS stations.
Activities in context of finishing 1st order gravity network next works were conducted:

- Project preparation,
- Assembling of field sheets and topographic maps of related benchmarks, gravity and control GPS points,
- Adaptation of database necessary for planning and completing the project,
- Finishing of the “Plan of 1st order gravity network - positional and vertical determination” (HGI 2006a).

After the Plan had been finished, accordingly to the settled goals in the Plan, next actions were conducting:

- Extra stabilization of gravity points,
- GPS measurements at the points, data processing and adjustment,
- Vertical connection to official benchmarks by precise spirit levelling, data processing and adjustment of levelling lines,
- Determination of absolute gravity points positions by combination of GPS and terrestrial methods (results are not prepared yet and data are not interpreted for the purposes of this paper),
- Processing and adjustment of terrestrial measurements,
- Calculation of geopotential heights,
- Calculation of normal heights in UELN95/98,
- Finishing of field sheets for all fundamental gravity points,
- Final report of 1st order gravity network - positional and vertical determination.

All field measurements were conducted according to technical aspects, and the main aim is fully satisfied – set of high precise points in positional, height and gravity matter, uniformly covering Croatian territory.

4. POSITIONAL DETERMINATION OF GRAVITY POINTS

Before gravity points were determined using terrestrial measurements, points had been extra stabilized by benchmarks (5-7cm length and 0.01m diameter). Extra stabilization was necessary to fix position and height with materialized mark.
Fundamental gravity network is not adjacent to existent positional network, so it was necessary to define all gravity points that had not been measured during earlier projects. Basic rule for GPS measurements was to calculate gravity points using at least two reference points. New points

were observed using static method to achieve relative accuracy of ±1cm+2ppm for position and ±2cm+2ppm for height.
As a result of time needed for height determination, method of height and position were measured simultaneously whenever it was possible.
To provide all GPS measurements during the project it was required to:

- use dual-frequency instruments,
- use same antenna type,
- use 15 second interval registration,
- use elevation mask above 10°,
- obtain GPS measurements for 2-4 hours per point, depending on levelling time
- set antenna to north, and measure height before and after measurement.

GPS measurements were taken in period from 27.2. to 24.4.2007., and all gravity points were observed according to set criteria.

4.1. Processing of GPS measurements

During data processing next principles were used:

- GPS measurements were processed using commercial software,
- IGS final orbits and pole parameters were used,
- data were processed in actual ITRF2005 reference frame,
- elevation mask was set to 10°,
- registration interval was 15sec,
- troposphere model was standard (NEILL),
- processed data were adjusted using IGS stations in Dubrovnik and Osijek and IGS stations around Croatia, figure 4.1.1., left

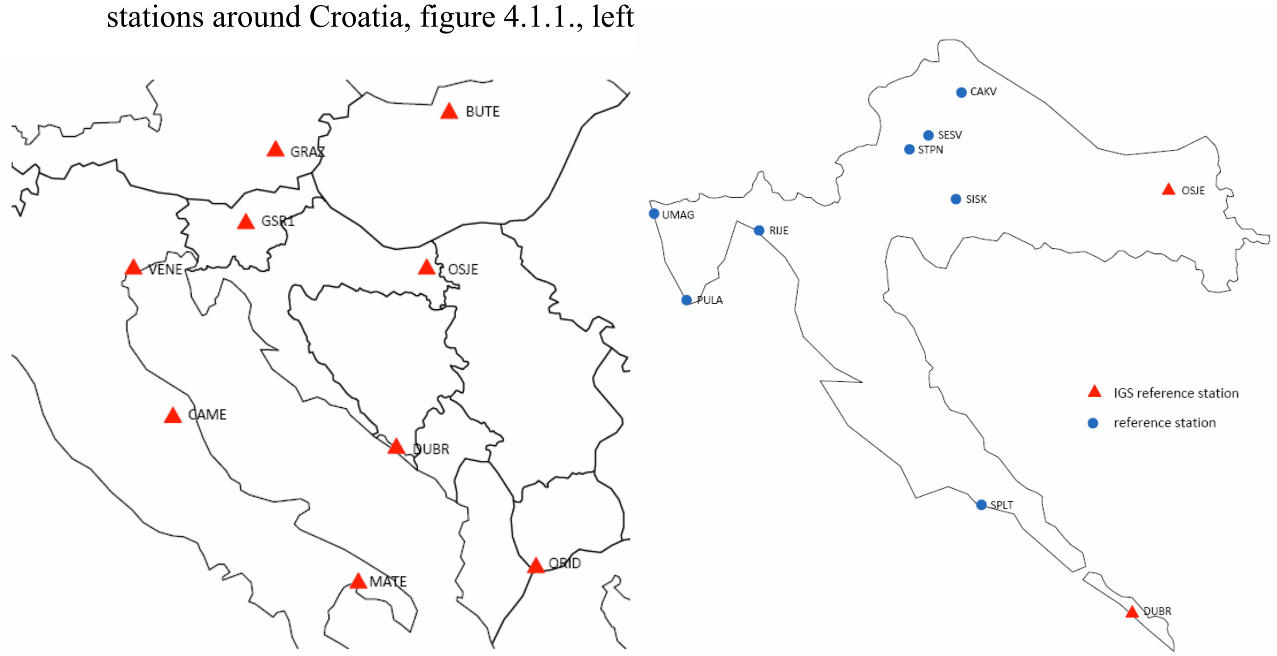

Figure 4.1.1. IGS and reference stations in Croatia used for data processing

During GPS data processing IGS stations were used as reference points. Reference station coordinates were transformed in datum ITRF2005 epoch 2007.24, when measurement were processed and adjusted. Central epoch is defined as a result of time when measurements started and ended.
In Republic of Croatia there are many reference stations owned by several private companies. Some of those stations were used for planning GPS measurements and with IGS stations in

Dubrovnik and Osijek formed quality foundation for positional and height definition of gravity points 0. and I. order, figure 4.1.1. right.
Preliminary data processing was obtained using Trimble Total Control software (TTC), ver.2.73. Single project was created, for all GPS measured gravity points and all observed data was imported.
After observation files were imported, data from field sheets (antenna height, point number) were inserted. Precise orbits were downloaded from Internet (*URL 1*) and imported directly in TTC, same as ionosphere model files (*URL 2*). Reference station coordinates were taken from EUREF official web page (*URL 3*) for recent observation period. During data processing default parameters were used for static measurements for long line-long occupation method of GPS observations. All possible baseline combinations were calculated. Measurements passed all statistical tests so additional vector optimization (satellite elimination, shortening of observation period, changing elevation mask) was not performed for purpose of calculating preliminary results. During processing, 2977 baselines were calculated and 68 points were adjusted.
After vector processing, because certain errors (gross errors) cannot be detected during baseline processing, figure closing was tested, which is one of TTC options.

4.2. Adjustment of GPS measurements

For GPS measurement adjustment all reference stations coordinates were fixed in coordinate system ITRF'2005, 2007.24. Tau test has not detected "outliers", terefore all measurements were taken in adjustment.
Measurements were adjusted using TTC software and its Network Adjustment module.

- previously processed vectors were imported in adjustment,
- preliminarily adjustment was preformed using default parameters,
- measurements were adjusted in ITRF2005 reference frame for epoch 2007.24.

In the first phase local reference station coordinates were calculated using IGS stations as fixed. During second phase those coordinates were used for defining gravity point height and position. Having in mind the fact that most of gravity points were stabilized several decades ago and most of them were not adequate for GPS measurements, accomplished results are above expectations, figure 4.2.1. To control measurement quality, two second order GPS points on two locations were observed during the project.

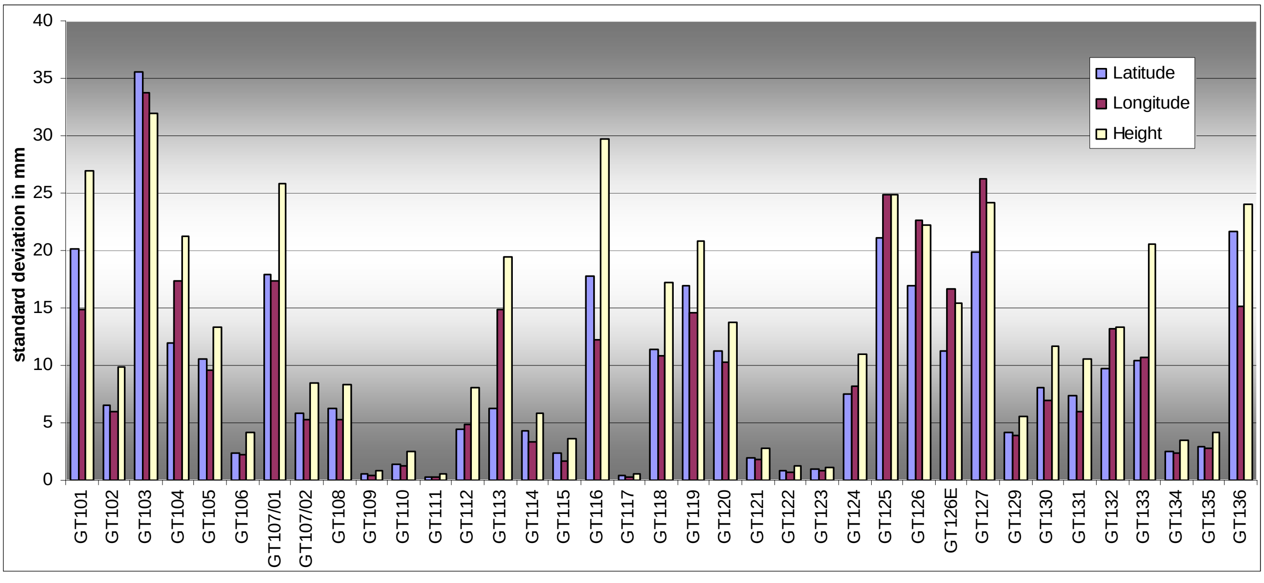

Figure 4.2.1. Position and height standard deviations - IGS and Croatian reference station are fixed

Also, all gravity point coordinates and Croatian reference stations were calculated as unknown, with IGS stations as fixed points. Results are shown on figure 4.2.2.

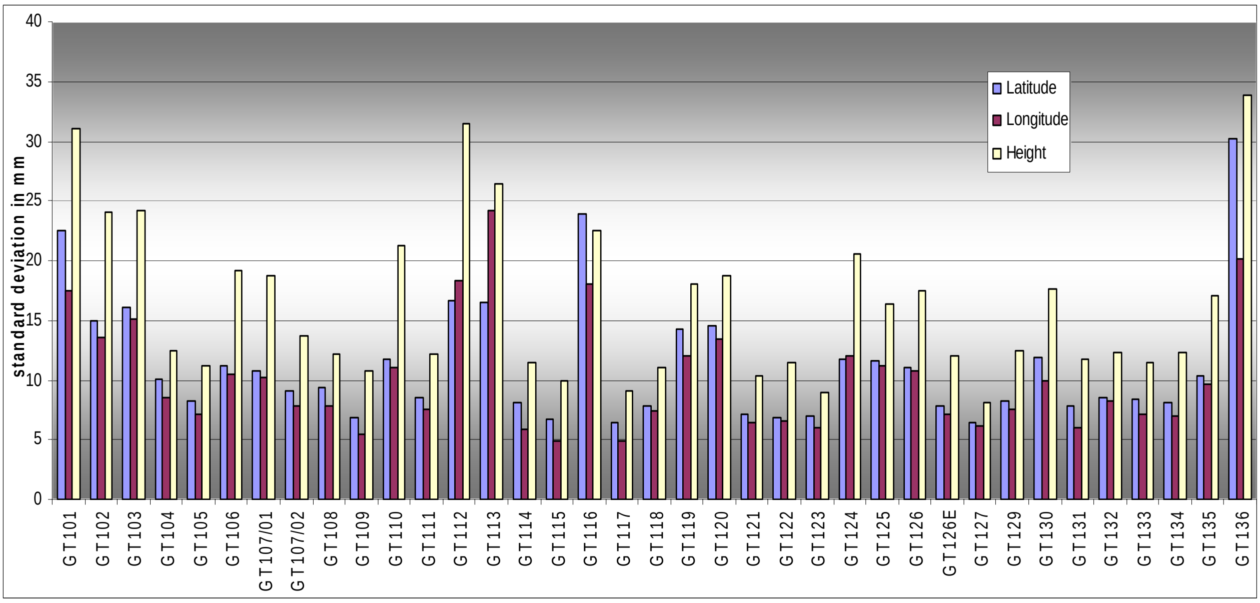

Figure 4.2.2. Position and height standard deviations - IGS are fixed

Comparing figures 4.2.1. and 4.2.2., it is possible to notice that new gravity point coordinates were calculated with high precision, according to measurement preconditions (length of GPS baselines, some old gravity points are not adequate for GPS measurements etc.)
After that gravity point coordinates were compared, figure 4.2.3.

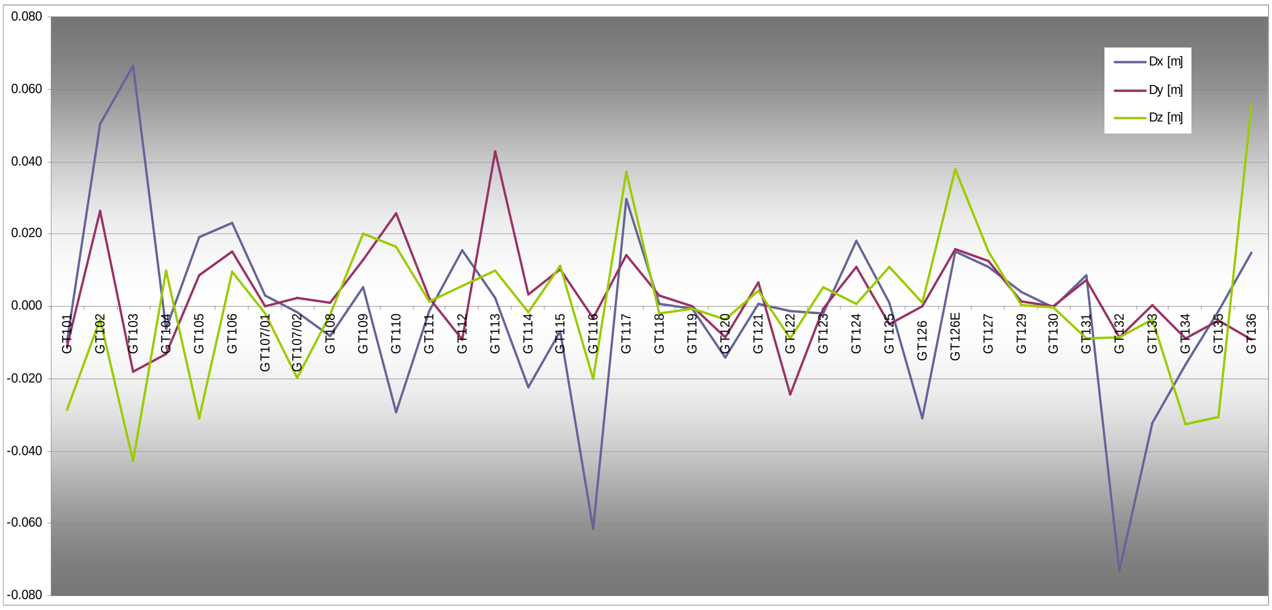

Figure 4.2.3. Gravity point coordinate comparison from two calculated models

After adjustment measurement accuracy and final result was given as standard deviations and error ellipses for 95% probability.
GPS measurements were adjusted in coordinate system ITRF2005, for epoch 2007.24. Coordinates of gravity points ITRF2005 were transformed in ETRS89 1989.0 and new Croatian datum HTRS96 (ITRF96 for epoch 1995.55). For transformation was used specialized software T7D developed on Faculty of Geodesy for State Geodetic Administration purposes, (Bašić et al. 2006).

For coordinate transformation in one datum (period is different) geologic plate velocities were applied (model NNR_NUVEL1A), i.e. their rotation around global Cartesian axis on GRS'80 reference ellipsoid. In Republic of Croatia EURA has been used as reference geologic plate.

5. LEVELING MEASUREMENTS

Gravity points were connected to closest benchmark using method of geometric levelling (precise levelling) in period from February 27th to April 29th 2007. Where it was possible, control measurements were taken. Data were processed and adjusted using least square adjustment method.

Results demonstrated that all points, except gravity point GT126, satisfied precise levelling criteria according to proposal of Geometric Levelling Regulations (Klak, Feil, Rožić 1993). Height differences after precise levelling should be corrected with normal orthometric corrections

Normal orthometric correction (NOC) may be calculated as follows (Bilabejgović 1984):

$$NOC_{GT,R} = -0,000\,025\,685\ H_S\ \Delta\varphi''\ [mm],$$

where

$$H_S = \frac{H_{GT} + H_R}{2} = H_R - \frac{\Delta h_{GT,R}}{2},$$

$$\Delta\varphi = \varphi_R - \varphi_{GT},$$

therefore normal orthometric height difference is

$$\Delta h_{GT,R}^{NO} = \Delta h_{GT,R} + NOC_{GT,R}$$

Measured and calculated height differences provided final heights of gravity points, table 5.1.

Table 5.1. Normal orthometric heights of gravity points

POINT	benchmark	height HVRS71	distance	allowed difference	Δh	$\sigma_{\Delta h}$	NOC	**H_{GT} (HVRS71) (H_R - Δh)**
(from)	(to)	[m]	[km]	[mm]	[m]	[mm]	[mm]	**[m]**
GT101	BV10753	86.2570	0.09	±1.20	2.33729	0.09	0.00	**83.91971**
GT102	20260	88.8984	1.32	±4.60	1.24297	0.07	-0.09	**87.65543**
GT103	20352	82.7295	1.81	±5.38	2.40842	0.40	0.03	**80.32108**
GT104	C-437	92.1345	0.15	±1.53	1.98740	0.19	-0.01	**90.14710**
GT105	CP-388	87.1042	1.72	±5.25	1.00604	1.77	-0.11	**86.09816**
GT106	22343	89.6021	0.04	±0.80	1.33432	0.01	0.00	**88.26778**
GT107	2	183.3837	0.49	±2.80	3.60915	0.55	-0.06	**179.77455**
GT108	C-143	117.3205	0.67	±3.27	4.05992	0.31	0.06	**113.26058**
GT109	EP 467	102.7883	0.48	±2.77	2.28862	0.26	-0.04	**100.49968**
GT110	DCCLXIV	134.5135	1.22	±4.42	-3.36427	0.80	-0.11	**137.87777**
GT111	35	125.0973	0.70	±3.34	11.66834	0.86	-0.05	**113.42896**
GT112	31128	167.3064	0.02	±0.56	1.15725	0.02	0.00	**166.14915**
GT113	D72	164.2396	0.18	±1.71	-3.42547	0.22	0.02	**167.66507**
GT114	10	192.7440	0.60	±3.10	-3.29061	0.42	0.02	**196.03461**
GT115	CP 724	115.0645	1.00	±4.01	11.86811	0.13	0.05	**103.19639**
GT116	22374	307.7942	1.21	±4.40	-68.414941		0.15	**376.20914**
GT117	14348 A	146.0196	1.24	±4.45	16.61353	0.18	0.04	**129.40607**
GT118	61	111.8835	0.14	±1.50	0.01902		0.01	**111.86448**
GT119	31165	522.9966	9.65	±12.42	-46.59901	1.07	2.16	**569.59561**

POINT	benchmark	height HVRS71	distance	allowed difference	Δh	$\sigma_{\Delta h}$	NOC	**H_{GT} (HVRS71) (H_R - Δh)**
(from)	(to)	[m]	[km]	[mm]	[m]	[mm]	[mm]	**[m]**
GT120	31334	767.3994	0.31	±2.24	-2.70583	0.02	-0.01	**770.10523**
GT121	70	308.0421	6.66	±10.32	-293.29821	0.79	0.33	**601.34031**
GT122	MP 280	114.4081	0.46	±2.72	1.46759	0.06	0.03	**112.94051**
GT123	99	31.0083	0.44	±2.65	17.44388	0.23	0.01	**13.56442**
GT124	A-339	3.2067	0.20	±1.80	-5.75947	0.11	0.00	**8.96617**
GT125	67	578.3569	0.00	±0.00	0.00000	0.00	0.00	**578.35690**
GT126	MP-183	253.7016	1.48	±4.87	20.83132	4.30	-0.33	**232.87028**
GT127	MCDXCI	1017.8575	1.08	±4.16	-29.97537	0.06	0.29	**1047.83287**
GT128	56	362.3857	0.20	±1.79	0.08336	0.10	-0.04	**362.30234**
GT129	11	12.3320	0.63	±3.18	7.00407	0.02	0.00	**5.32793**
GT130	NP-85	37.9228	0.00	±0.00	0.00000	0.00	0.00	**37.92275**
GT131	EP-162	665.7109	0.98	±3.95	8.49133	0.04	-0.27	**657.21957**
GT132	BP-174	9.0973	0.52	±2.88	0.52156	1.36	0.00	**8.57574**
GT133	22467	262.5828	1.59	±5.05	-38.39798	1.38	-0.30	**300.98078**
GT134	MCXCIV	6.5674	0.12	±1.39	2.42980	0.22	0.00	**4.13760**
GT135	59	367.4176	0.52	±2.89	-20.55617	0.31	-0.14	**387.97377**
GT136	BP-200	59.7929	1.14	±4.27	-3.25313	0.09	0.03	**63.04603**
AGT05E	28	6.7207	0.14	±1.48	-1.38014	0.27	0.01	**8.10084**

Based on calculated levelling data, analysis of the field measurements was made, table 5.2.

Table 5.2. Information about levelled gravity points

total distance in one direction:	*39020 m*
average distance:	*1060 m*
min. distance:	*0 m*
max. distance:	*9650 m*
min. height difference:	*0 m*
max. height difference:	*293.298 m*

6. ANALYSIS OF GEOID MODEL DIFFERENCES

The Republic of Croatia has unfavourable geographical shape for geoid modelling on state borders. Adriatic coast is also unhelpful for geoid modelling because of high mountains near coast that provide large vertical gradients on geoid surface. After researches that had tested adaptation of Croatian territory to global geoid, and detailed analysis of available gravity data, new Croatian geoid HRG2000 was calculated and connected to old height system with origin in Trieste (Bašić 2001).

Difference between preliminary geoid model EGG_06 and EUVN (difference between UELN normal height and GPS height) based on 20 EUVN points with expanded set of 34 first order gravity points, demonstrate evident shift in height direction for EGG06 geoid model (figure 6.1). Compared with that, HRG2000 coincides tightly to reference height surface, but standard deviation values shows that EGG_06, with eliminated 43cm shift, has slightly better characteristics then national model. To compare it with EGG_06, heights had to be transformed into UELN height system. It was done preliminarily, so all HVRS71 heights were decreased for 33cm – average difference between UELN and HVRS71 height systems; for whole country differences are about 32-35cm **(URL4)**.

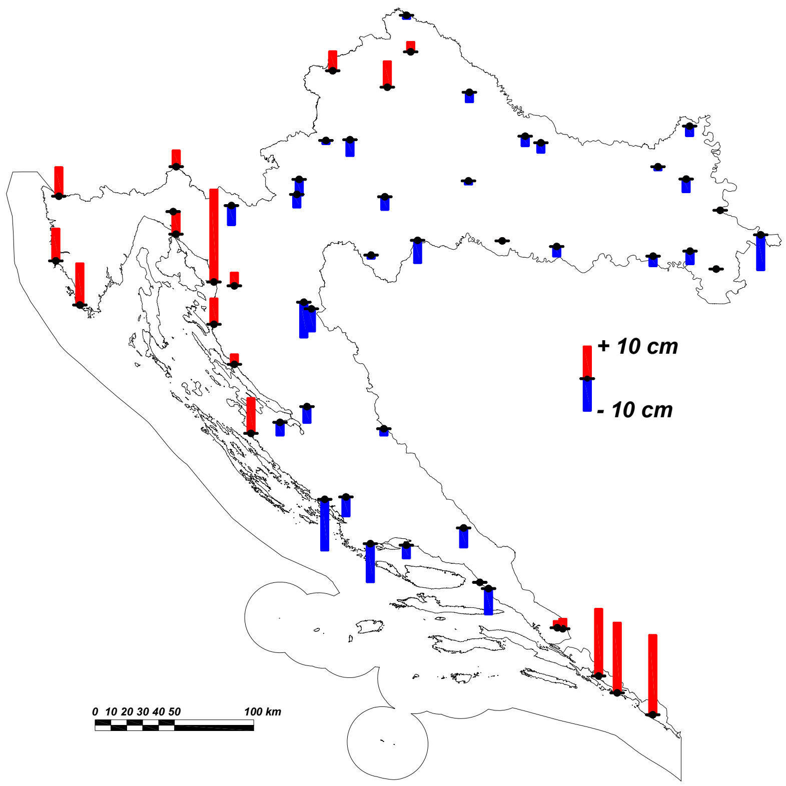

Figure 6.1. EGG_06 and EUVN geoid model differences with eliminated shift of 44cm

Differences between HRG2000 geoid model and EUVN founded on extended set of points,which includes EUVN and first order gravity network, show some problematic zones on national geoid model around the GT120 near the border with Republic of Slovenia, figure 6.2.

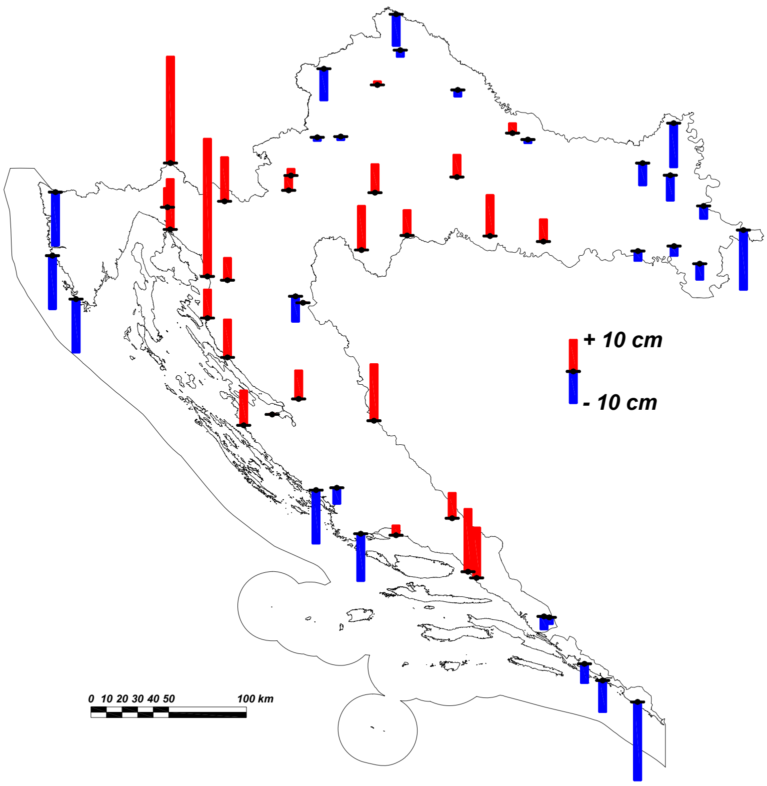

Figure 6.2. HRG2000 and EUVN geoid model differences based on expanded set of points (EUVN and gravity points)

Founded on 20 EUVN points and 34 first order gravity points on Croatian territory, comparison between EUVN, EGG_06 (Denker 2007) and national HRG200 geoid model was made, table 6.1.

Table 6.1.EUVN and EGG_06 and HRG2000 geoid model differences

	n=54 points		n-1 points	n-2 points
	EGG_06 - GPS/levelling (EUVN, GT) [cm]	HRG2000 - GPS/levelling (EUVN, GT) [cm]	EGG_06 - GPS/levelling (EUVN, GT) [cm]	HRG2000 - GPS/levelling (EUVN, GT) [cm]
STDEV	9	13	8	11
AVERAGE	-43	1	-44	0
MIN	-60	-25	-60	-25
MAX	-15	45	-19	20
RANGE	45	70	41	45

Since the point GT124 manifests a slightly larger deviation for EGG06 and national geoid model assumption is that there was made a fault during identification of benchmark. Big deviation on the point GT120 is largely a result of incorrect height from the Republic of Slovenia which was used for modelling the national geoid. Therefore, in the right part of Table 6.1. statistical analysis of differences of geoid models without those points is demonstrated. After those points were removed the statistical analysis shows much better characteristics.

Expanded set of points can be additional control for EUVN network densification project to check for some large errors and quality check for new European EGG_06 geoid model. In addition, it can be used for definition of new national geoid HRG2007.

7. CONCLUSION

Realization of EUVN network densification project (EUVN_DA) with new set of coordinates was result of systematic preparatory works.

With defining, obtaining, processing and adjusting GPS and level measurements for Croatian Fundamental Gravity Network, Croatia gained good foundation of points with defined gravity, position and height that will provide their application in different geodetic works. After finalization of Fundamental Gravity Network and result interpretation, need for realization of basic gravity network was satisfied, that will serve as foundation for densification with second order gravity network, and approach to European standards.

During project realization, better absolute orientation of national geoid model was significant for preparations for realization of height datum decimetre precise connections that will obtain, with future European geoid model, analysis of European and national levelling networks. Homogenous GPS/level/gravity point network is obtained with project realization, and will provide control and improvement of geoid model on territory of Republic of Croatia.

Project realization and newly defined points provide systematic quality control of EGG06 geoid model for Croatian territory.

Achieved results confirm appropriate participation of the Republic of Croatia in international projects with expanded set of national data.

The authors would like to thank M. Denker who gave us the preliminary results of EGG06 geoid model.

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