Koler, B., Jakljič, S., Breznikar, A. 2009. Analysis of different height systems along the Sava river. Geodezija ir kartografija / Geodesy and cartography 35, 3: 92 – 98.

http://versita.metapress.com/content/j10213049m243uq6/fulltext.pdf

GEODEZIJA IR KARTOGRAFIJA / GEODESY AND CARTOGRAPHY
2009
35(3): 92–98

UDK 528.375 doi: 10.3846/1392-1541.2009.35.92-98

ANALYSIS OF DIFFERENT HEIGHT SYSTEMS ALONG THE SAVA RIVER

Božo Koler[1], **Samo Jakljič**[2], **Aleš Breznikar**[3]

University of Ljubljana, Chair of Engineering Geodesy, Jamova c. 2, 1000 Ljubljana, Slovenia,
E-mail: [1]*bozo.koler@fgg.uni-lj.sl,* [2]*samo.jakljic@fgg.uni-lj.si,*
[3]*ales.breznikar@fgg.uni-lj.si*

Received 14 07 2008; accepted 15 06 2009

Abstract. The paper presents a project of renovating a levelling line from Hydroelectric Power Plant Medvode to Hydroelectric Power Plant Vrhovo. The levelling line is situated along the Sava River. A new height of benchmark was needed as a vertical reference system for the project building up a new HPP between the previously mentioned HPP. Further, the paper presents processing data on measurements (scale and temperature corrections). Gravimetric measurement was performed due to the determination of the geopotencial number and dynamic and normal heights. Slovenian official vertical system contains normal orthometric heights so we also calculated normal orthometric heights. Moreover, the article discusses the accuracy of measurements (levelling and gravimetric) and analyses height calculated in different vertical systems and vertical movements along the levelling line.

Keywords: bench mark, levelling, gravimetric measurement, geopotencial number, dynamic height, normal height, normal orthometric height, vertical movement.

1. Introduction

In Slovenia, preparations for constructing a continuous chain of run-of-river hydropower plants on the middle run of the Sava River have been launched. Next to the chain of HPPs on the Drava River, the finished chain of HPPs on the Sava River will furnish the electrical power system of Slovenia with a second strong production line of renewable energy. This chain of HPPs will become the main domestic renewable source of energy to be exploited for energy production.

As an EU member state, Slovenia is obliged to enforce the directives and objectives of energy policy and environmental protection in EU aiming at increasing the renewable sources of energy; as a signatory state of the Kyoto Protocol, it must reduce greenhouse gas emissions. Slovenia has adopted its national goal to increase the ratio of electric energy coming from renewable sources from 32% in 2002 to 33.6% by 2010.

The Sava River basin is the largest one in Slovenia. It comprises 10,746 km^2, that is, 53% of the surface area of Slovenia. The length of the river network is 13,950 km or 1.3 km/km2. There is an average of 1567 mm of precipitation in the Sava River basin, out of which 641 mm evaporates; the runoff coefficient is 59%. In the period from 1961 to 1990, the mean annual flow of the Sava River was 301 m^3/s. In the middle of the Sava River, nine dams are planned to be built between HPP Medvode and HPP Vrhovo. The concession awarded for exploitation the energy potential refers to the 117.0 m gross head between:

- tail water level of HPP Medvode planned at 308.0 m (upstream level of the concession) and
- tail water of the planned HPP Suhadol, being the last power plant on the middle Sava River at a level of 191.0 m (downstream level of the concession).

The gross hydro electric power potential of the middle Sava between the upstream and downstream level of concession was calculated from the period of 40 hydrological years (1961–1990) taking into account the average annual Sava River flow which is Eb = 1185 GWh/year.

In 2007, the Faculty of Civil and Geodetic Engineering of the University of Ljubljana was contracted by HSE Group, the leading Slovenian company in the power sector, to newly level the levelling line stabilised between HPP Medvode and HPP Vrhovo. Some parts of the line were levelled in 1971 (Medvode – Ljubljana and Zidani most – Vrhovo) and in 1988 (Ljubljana – Zidani most). The new levelling provided the determination of the height difference between the tail water level and the headwater level on HPP Medvode and HPP Vrhovo, ensured a unified height basis to perform all design works and future building of HPPs on the Middle Sava River and determined the potential vertical displacements of bench marks that were stabilised in the area (Fig. 1). The gravimetric campaign was performed to analyse point heights in different height systems.

Fig. 1. The levelling line and the planned sites of the new HPPs

2. Determination of Bench Mark Altitudes in the Newly Measured Levelling Line

The levelling campaign was connected to the bench mark of the state levelling network C36 in Medvode and HE8 Boštanj the height of which was determined within the renovation of the levelling network in the area of HPP Boštanj in 2003. Table 1 gives the basic statistical data on the levelling line. The line stabilised in the area is characterised by a very heterogeneous set of data, since the bench mark altitudes were determined within different campaigns and with different accuracy.

Table 1. Statistical data on levelling line

Number of stabilised bench marks (new ones)	155 (67)
Length of levelling lines	92.68 km
Average length of a levelling line	0.61 km

2.1. Instruments and Auxiliaries

The measuring campaign of levelling lines was performed using the Wild NA 3000 digital level enabling automatic registration of readings on the bar-coded invar staff. This is one of the most precise levels intended for levelling networks of higher orders, monitoring vertical displacements of structures, observing recent land displacements, and using in precise machinery work and other height deformation measurements. Bar-coded invar staffs with 3-kg levelling plates and a contact thermometer to measure the temperature of the invar strip were used within the campaign.

2.2. Preceding Data Processing

In preceding the processing of data obtained from the measurements, we must first obtain the raw data, containing information about the readings of levelling staff in each stand and information concerning the length of the line-of-sight. All levelling lines were measured following the rules of measuring a levelling network of high accuracy. We used compared invar levelling staffs and measured the temperature of the invar strip at the time of measurement. Levelling staffs were compared before and after the measurement using the comparator owned by the Faculty of Civil and Geodetic Engineering, the Chair of Geodesy. Based on data on the calibration of levelling staffs and temperature, we calculated the correction of the scale in a pair of levelling staffs, temperature correction and the base of levelling staffs. The corrections of the measured height differences are calculated using the following equation:

$$\Delta h = \Delta l_0 + \Delta h_0 [1 + (m_0^{para} + \alpha (T - T_0)) 10^{-6}], \qquad (1)$$

where: Δh – corrected measured height difference; Δl_0 – difference in the zero-point error of levelling staffs; m_0^{para} – the mean value of correcting the graduation of a pair of staffs; T – temperature of the levelling staff at the time of measurement; T_0 – temperature of the levelling staff during calibration; α – linear expansion coefficient of staff graduation.

Each levelling line was measured in both ways. Based on the corrected measured height differences, we calculated the misclosure of the double-run levelling line. The allowable misclosure of the double-run levelling line is calculated for high accuracy levelling lines using the equation (Pravilnik ... 1981):

$$\Delta_{allowable} = 2\sqrt{d + 0.04 d^2}, \qquad (2)$$

where: $\Delta_{allowable}$ – allowable misclosure in mm; d – the mean length of the levelling line in km

2.3. Accuracy Estimate of the Measured Height Differences

In precise levelling, the measuring accuracy of height differences can be measured based on different criteria. For levelled height differences, the following tests and accuracy estimates have been performed:

a) On the basis of the misclosure of the measured height differences of double-run levelling lines (marked as σL in Table 2).

In precise levelling, height differences are always measured in both ways. The misclosures obtained must be smaller than the allowable misclosure for the levelling line in one or another direction prescribed for levelling the levelling lines of high accuracy, as given in the equation above.

Standard levelling deviation is calculated using the equation (Table 2):

$$\sigma_L^2 = \frac{1}{4nL} \left[\frac{\rho^2}{d} \right], \qquad (3)$$

where: σL – standard deviation in levelling lines; nL – the number of levelling lines; ρ – the misclosure of the measured height difference of each levelling line in mm; d – the length of each levelling line in km.

b) Accuracy estimate based on the corrections of the measured height differences after adjustment (marked as σ_0 in Table 2).

The standard deviation of the measured height differences after adjustment is calculated using the following equation:

$$\sigma_0^2 = \frac{[pvv]}{r}, \qquad (4)$$

where: σ_0 – a standard deviation of unit weigh; r – the number of redundant observations; p – weight; v – the correction of the measured height difference after the adjustment.

The results of standard deviations for levelling line campaigns are as follows in Table 2.

Table 2. Accuracy estimate of the levelling line

Standard deviation	
σ_L	0.441 mm/km
σ_0	0.073 mm/km

Table 2 shows that deviations from measuring levelling lines and the calculated accuracies of campaigns are within the expected limits, based on the instruments used and the precision of the level, as given by the manufacturer.

3. Gravimetric Survey on the Bench Marks of the Levelling Line

In spring 2007, we performed a relative gravimetric survey to determine gravitational acceleration in 45 bench marks of the levelling line. Based on changes in height difference and latitude, we proposed a gravimetric survey plan so that difference in gravitational acceleration between two bench marks was less than 2 mGal. The gravimetric survey was connected to elative gravimetric point FGG2 included into the gravimetric network of the 1st order of 2006 campaign (Kuhar *et al.* 2006). Gravitational acceleration for point FGG2 is: 980615670 μGal.

The relative gravimetric survey was performed using the relative Scintrex CG-3M gravity meter, No. 10341. Scintrex CG-3M is an automated gravity meter covering a range of over 7000 mGals without resetting 7000 mGal (1 mGal = 10–5 ms–2), meaning that it can be used almost on the entire Earth's surface. Due to its automatisation, the errors of the operator are eliminated. Gravity readings are stored into the internal memory of the gravimeter.

The relative gravity meter Scintrex CG-3M has a standard resolution of 1 μGal-a (1 μGal = 10–8 ms–2) with a standard deviation smaller than 5 μGal-a. The gravity meter continuously reads the data from the inherent tilt sensor. Based on this, it automatically performs the compensation of measurements due to the non-horizontal gravimetric sensor. Using the geographical position and time zone, the Scintrex CG-3M automatically performs corrections for tide errors in real time and for every reading.

The gravity meter displays and stores in the memory the following data: corrected measurement, standard deviation, tilt around x-axis and y-axis, sensor temperature, tide correction, duration of measurements, time of starting reading and basic information on reading parameters.

In the points of the levelling line, after the positioning and levelling of the instrument, 5 1-minute measurements were performed. To calculate the corrections of the measured values, we measured the height of the instrument and air pressure during. Air pressure was recorded using Meteo Station HM 30 by Swiss manufacturer REVUE THOMMEN AG with a resolution of 0.1 hPa and the standard deviation of 1 hPa.

Data Processing and Accuracy Estimate of the Gravimetric Survey

As many factors influence the measurement of gravitational acceleration, they either have to be eliminated or their influence reduced prior to data processing. Before calculating relevant corrections, we have to eliminate a periodic influence of the solid Earth tide calculated automatically using the Scintrex CG-3M gravity meter. The values of gravitational acceleration are either affected by the errors of the instrument or by external influences from the environment.

a) Instrumental errors

Instrumental errors are the consequence of the construction of the gravity meter. This includes the error of incorrect levelling, elastic hysteresis, instrumental tension instability and calibration function. In stationary and field work with the gravity meter, there occur changes in the balance of the system of springs. This results in changes in zero position, known also as gravimeter drift.

b) External influences from the environment

In processing data obtained during the relative gravimetric survey, we considered the influence of air pressure, the movement of Poles and short-time gravimeter drift influence. Data on the gravimetric survey were processed using the GravAP program (Schüler 2000).

c) Accuracy estimate

The accuracy of the gravimetric measurement can be estimated based on the average accuracy estimate calculated from the data on the accuracy of the performed gravimetric survey in each single point that was recorded in the memory of the instrument and determined based on the deviations of multiple measurements from the arithmetic mean or observation corrections obtained by data processing using GravAP program. The results are presented in the Tables 3 and 4 .

Table 3. Accuracy estimate of the gravimetric measurement

Estimate	Best (μGal)	Worst (μGal)	Average (μGal)
Scintrex CG-3M	10	219	50
GravAP	20	93	58

Table 4. Gravitational acceleration measured in the bench marks of the levelling line

Bench mark	g [μGal]	Bench mark	g [μGal]
FGG	980615670	HE21	980627431
V-Zg.v.	980612335	HE33	980629295
R-Sp.v.	980614348	5213	980631029
C36	980611986	MN-104	980627091
103	980615582	HE37	980633273
105	980614835	HE40	980633222
5910	980618287	HE42	980637069
43/14	980616223	HE44	980639759
43/15	980615441	HE46	980640394
44/16	980617733	5219	980644443

Table 4 complete

Bench mark	g	Bench mark	g
	[µGal]		[µGal]
43/11	980614365	HE48	980643515
PN1-210	980618812	HE49	980643742
CP412	980616686	HE55	980646410
2/12	980616047	HE58	980646624
2715	980614856	HE59	980645136
HM220	980614309	R8	980651666
MN-5982	980618525	VJ Sp.	980653010
CP239	980621054	OP904	980652393
MN-6000	980621058	VJ Zg.	980652509
189	980620309	MLXXVIII	980645195
HE1	980618305	5220C	980642146
MN-5976	980617281	HE53	980640297
MN-50/21	980622505	HE52	980644692
5207B	980623064	5220	980643477
5208B/1	980624842	HE36	980622800
5209E	980626766		

4. Calculating the Corrections of the Measured Height Differences in Different Height Systems

In Slovenia, the elevations of points are determined in the vertical datum Trst. To obtain comparable height above sea level of bench marks that would have a minimum deviation from the rest elevations in the state height system the levelling line was connected to the bench marks the height of which above the sea level is defined by the vertical datum Trst. The known bench marks were therefore bench mark C 36, stabilised in Medvode and bench mark HE8 in Boštanj. Through tying the levelling line to HE8 Boštanj, the heights above the sea level of tail water and headwater levels on HPP Boštanj are determined in the same vertical datum.

The height of a point can be given in different physical height systems. The bases of all physical height systems are geopotential numbers. These are determined based on the height differences and the data on gravitational acceleration. If we say that zero position height (of the geoid) equals 0, then the difference of potentials represents a natural physical unit for the elevation of points on the Earth's surface. The unit of geopotential numbers is also called GPU (geopotential unit) where 1 GPU = 1 kgalm = 10 Nm/kg = 10 m^2/s^2.

To obtain the height of points given in metres, the geopotential number has to be divided by gravitational acceleration. Based on the value of gravitational acceleration, different types of heights are obtained. If the geopotential number is dived by the constant value of gravitational acceleration, we obtain:

a) Dynamic heights

Dynamic height differences are obtained so that a dynamic correction is added to the measured height differences between two bench marks (Hofmann-Wellenhof and Moritz 2005):

$$DC_{ij} = \sum_{i=1}^{n} \frac{g-\gamma_0^{46}}{\gamma_0^{46}} \Delta h_{ij}, \tag{5}$$

where: g – average measured gravitational acceleration in bench marks i and j; γ_0^{46} – normal gravitational acceleration at the mean latitude of the levelling line (46° 05′ 42″) is 9,80719015ms^{-2}; Δh_{ij} – height difference.

Normal gravitational acceleration γ_0^{46} is calculated using the equation:

$$\begin{aligned}\gamma_0^{\varphi} &= 9{,}7803267715(1+5{,}2790414\cdot 10^{-3}\sin^2\varphi + \\ &2{,}32718\cdot 10^{-5}\sin^4\varphi + 1{,}262\cdot 10^{-7}\sin^6\varphi + \\ &7\cdot 10^{-10}\sin^8\varphi)ms^{-2}.\end{aligned} \tag{6}$$

b) Normal heights

Normal heights are obtained by adding a normal correction to the measured height difference using the equation (Hofmann-Wellenhof and H. Moritz 2005):

$$NC_{ij} = DC_{ij} + \frac{\overline{\gamma}_i - \gamma_0}{\gamma_0} H^i - \frac{\overline{\gamma}_j - \gamma_0}{\gamma_0} H^j. \tag{7}$$

Normal gravitational acceleration $\overline{\gamma}_i$ can be calculated as (Moritz 1988):

$$\begin{aligned}\overline{\gamma}_i &= \gamma_0^{\varphi} - 3{,}0877\cdot 10^{-6}(1-0{,}00139\sin^2\varphi)H_{ih} + \\ &0{,}72\cdot 10^{-12} H_i^2 [ms^2].\end{aligned} \tag{8}$$

c) Normal orthometric heights

In Slovenia, heights are determined in the height system of spheroidal (normal) orthometric heights. Spheroidal (normal) orthometric correction is calculated using the equation (Bilajbegović 1984):

$$NOC_{ij} = -0.000025707\, H_m\, \Delta\varphi, \tag{9}$$

where: H_m – mean height above the sea level between points P_i and P_j, in metres; $\Delta\varphi$ – differences in the latitude of points P_i and P_j, in seconds $(\Delta\varphi = \varphi_{Pj} - \varphi_{Pi})$.

The levelling line is stabilised between latitudes 46008′47″ and 46002′34″. Table 5 gives data on the size of corrections and input data.

Table 5. Values of known and calculated quantities

Value	*H* (m)	Δh (m)	$\Delta\varphi$	Corrections Δh (mm)		
				DC	NC	NOC
Minimum	188.9261	–21.18374	–57″	–1.72	–0.38	–0.20
Maximum	323.2304	19.44877	31″	1.68	0.33	0.30
Average	258.6433	3.24989	10″	0.30	0.08	0.06
Total		–134.30650		12.56	4.09	2.43

The table above shows that the corrections of the measured height differences are relatively small resulting from the east–west direction of the levelling line (the difference of latitudes is approx. 6′); the altitude of bench marks, measured height differences and changes in latitude among bench marks are also relatively small.

4.1. Deviations from the Measured Height Differences Compared to the Known Height Differences

Based on the corrected measured height differences, the mean value of the corrected height differences is measured. The total sum of the corrected values of the measured height differences and dynamic height differences is compared to the known value of height differences calculated from the differences of the known altitudes of bench marks. The difference between the measured and known height differences must be smaller than the allowed misclosure for levelling networks of the 1st order calculated using the equation:

$$\Delta_{allowed} = 1.5\sqrt{d + 0.04d^2}\,, \tag{10}$$

where: $\Delta_{allowed}$ – allowed misclosure in mm, d – the mean length of the levelling line in km.

The data on the known altitudes and measured height differences are provided in the table below. The altitudes of the known bench marks are presented in Table 6.

Table 6. Known, measured and height differences in different height systems in a levelling line

Known bench mark	Altitude			
	H^D		H^{NO}/H^N	
C36	323.2290 m		323.2304 m	
HE8 Boštanj	188.9332 m		188.9261 m	
From–to (C36-HE8)	Δh	Difference (Δh_{given}-$\Delta h_{i)}$)	d	$\Delta_{allowed}$
$\Delta h_{known(D)}$	−134.2958			
$\Delta h_{known(NO,N)}$	−134.3043			
$\Delta h_{levelling}$	−134.30650	−2.20 mm	92.68 km	± 20.89 mm
Δh_{DC}	−134.29394	1.86 mm	92.68 km	± 20.89 mm
Δh_{NO}	−134.30241	1.89 mm	92.68 km	± 20.89 mm
Δh_{NOC}	−134.30407	0.23 mm	92.68 km	± 20.89 mm

Table 6 shows that differences between the known and corrected measured height differences are small, which is to be expected, considering accuracy acquired in measuring height differences. Besides, it can be expected that there are no major differences in the size of vertical displacements between the known bench marks.

4.2. Height Deviations from the Determination of Tail Water Level in HPP Medvode and Headwater Level in HPP Boštanj

The basic aim of the new measurement of the levelling line between HPP Medvode and HPP Boštanj was to ensure adequate height basis used when performing works related to building new HPPs in the Middle Sava River, to guarantee the height connection of the known bench marks and to provide height designations (Fig. 2) in HPP Medvode and HPP Boštanj, thereby being able to determine tail water and headwater levels; the Table 7 shows data on bench mark heights before and after the levelling line campaign.

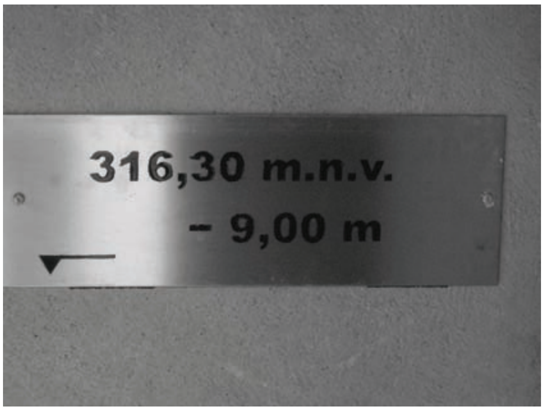

Fig. 2. Data on altitude and height difference in tail water level in HPP Medvode

Table 7. Data on the height of bench marks for determining water levels in HPP Medvode and HPP Boštanj

Bench mark	H_{2007} (m)	$H_{Befor\ 2007}$ (m)	Difference $H_{2007}-H_{Befor\ 2007}$ (cm)
HPP Medvode			
$VJ_{head\ water}$	329.22	329.22	± 0.0
$VJ_{tail\ water}$	316.19	316.30	−11.0
HPP Vrhovo			
$VJ_{head\ water}$	192.5115	192.4425	6.9
$VJ_{tail\ water}$	189.3467	189.2721	7.5

Based on data on the height of bench marks that were available at HPPs to determine low and high water levels, height difference prior to measurements was 123.86 m. After the levelling line campaign and determining the heights of bench marks in a unified height system and vertical datum, height difference was 123.68 m, that is, 18 cm less than the prior measuring campaign which cannot be considered negligible when designing HPPs in the Middle Sava River in the future.

5. Vertical Displacements of Bench Marks

Based on the previous measurement performed in 1988, it is possible to determine vertical displacements in the area under consideration (Table 8).

Table 8 shows maximum annual displacements in the range from −8.7 mm (5213a) to 8.7 mm (MN-181). Since the 1988 campaign was performed with a significantly lower accuracy (σ_0 = 1.94 mm/km and 2.08 mm < σH < 7.97 mm), these displacements cannot be considered as statistically significant because vertical displacements are within the limits of the accuracy determination of vertical displacements.

Table 8. Altitudes of bench marks, vertical displacements of bench marks and accuracy estimates

Bench mark	H_{1988}[m]	σ_H	H_{2007}[m]	σ_H	ΔH[mm]	$\sigma_{\Delta H}$ [mm]
MN–24/3	292,0897	2,21	292,0871	0,26	2,6	2,23
MN–24/4	294,1574	2,65	294,1541	0,26	3,3	2,66
MN–5976	293,6417	2,86	293,6431	0,80	–1,4	2,97
MN–5977	291,3639	3,44	291,3608	0,27	3,1	3,45
MN–180	290,8329	3,53	290,8286	0,27	4,3	3,54
MN–181	290,0298	3,85	290,0211	2,80	8,7	4,76
MN–5982	288,1111	4,11	288,1129	0,28	–1,8	4,12
MN–30/2	280,1613	4,26	280,1604	0,28	0,9	4,27
MN–5997	276,9461	4,78	276,9455	0,29	0,6	4,79
MN–190	278,3834	4,9	278,3824	0,29	1,0	4,91
MN–32/5	275,373	5,02	275,3694	0,29	3,6	5,03
MN–5998	276,5824	5,08	276,5824	0,29	0,0	5,09
MN–6000	274,5998	5,32	274,5991	0,30	0,7	5,33
MN–33/2	274,0686	5,77	274,0674	0,30	1,2	5,78
MN–50/23	267,8968	6,67	267,8978	0,32	–1,0	6,68
MN–50/21	264,9609	7,32	264,9647	0,32	–3,8	7,33
5206	260,7136	7,32	260,7221	0,33	–8,5	7,33
5206C	258,3181	7,44	258,3134	0,34	4,7	7,45
5207B	256,8067	7,52	256,8133	0,34	–6,6	7,53
5208A/2	254,0657	7,74	254,0630	0,34	2,7	7,75
5208B/1	251,7889	7,80	251,7876	0,34	1,3	7,81
5209E	246,5595	7,93	246,5561	0,34	3,4	7,94
5210c	241,5696	7,97	241,5705	0,34	–0,9	7,98
5211f	235,1657	7,96	235,1681	0,34	–2,4	7,97
5212d	233,4577	7,93	233,4632	0,34	–5,5	7,94
5213	233,8244	7,78	233,8272	0,34	–2,8	7,79
5213a	231,9782	7,76	231,9869	0,34	–8,7	7,77
5219	210,2855	5,12	210,2889	0,27	–3,4	5,13
5219d	203,9582	4,61	203,9529	0,27	5,3	4,62
5220	209,4168	4,03	209,4132	0,24	3,6	4,04
5220c	204,1924	2,83	204,1944	0,24	–2,0	2,84
5220e	202,4900	2,08	202,4850	0,21	5,0	2,09

6. Conclusions

Based on the analysis of the corrections of the measured height differences in various height systems, it can be established that the size of dynamic corrections is not large. The size of normal corrections is comparable to normal orthometric corrections that were taken into account in the height system of Slovenia. These results were expected considering the fact that the levelling line runs in the east–west direction and that there are no large height differences between the bench marks and bench marks on high altitudes. Considering the size of corrections, it is safe to say that for designing and performing geodetic works in building, new satisfactory results on HPPs could be acquired by adjusting the measured height differences.

The new campaign of the levelling line from HPP Medvode to HPP Boštanj gave an appropriate height basis for performing all geodetic works related to the preparation of design projects and performance of geodetic works in each HPP. Also, within a unified system, we defined the bench marks for establishing the water levels on HPP Medvode and HPP Boštanj as well as height difference between the bench marks. Height difference in 18 cm must, certainly, be of significant importance during the design. Of similar importance is also the lack of large-scale vertical displacements in the area, although this analysis was performed based on measurements, which cannot be comparable regarding their accuracy.

References

Bilajbegović, A.; Feil, L.; Klak, S.; Sredić, S. 1984. *Comparison of levelling lines connecting tide gauges and normal benchmark in Maglaj*. Faculty of Geodesy, University of Zagreb, Proceedings. D. 5 (in Croatian).

Hofmann-Wellenhof, B.; Moritz, H. 2005. *Physical Geodesy*. Springer, Wien, New York.

Kuhar, M.; Medved, K.; Barišić, B.; Liker, M.; Koler, B. 2006. *Izmera gravimetrične mreže Slovenije* [Measurement of Slovenian Gravimetric Network]. Raziskave s področja geodezije in geofizike, Ljubljana (in Slovenian).

Moritz, H. 1988. Geodetic Reference System 1980, *Bulletin Geodesique, the Geodesists Handbook*. International Union of. Geodesy and Geophysics, 348–358.

Pravilnik o tehničnih normativih za mreže temeljnih geodetskih točk. Republiška geodetska uprava, Ljubljana, 1981 (in Slovenian).

Schüler, T. 2000. *Conducting and Processing Relative Gravity Surveys*. Institute of Geodesy and Navigation. University FAF Munich.

Božo KOLER. Assist. Prof., Doctor. University of Ljubljana, Faculty of Civil and Geodetic Engineering, Chair of Engineering Geodesy, Jamova c. 2, 1000 Ljubljana, Slovenia. Ph +386 1 476 8640, Fax + 386 1 4250 681, e-mail: bozo.koler@fgg.uni-lj.si.

Co-author pars of two monographs and the author of more than 20 scientific papers. Participated in a number of international and national conferences.

Research interests: levelling, gravimetric measurement, height system.

Samo JAKLJIČ. Technical Co-worker. University of Ljubljana, Faculty of Civil and Geodetic Engineering, Chair of Engineering Geodesy, Jamova c. 2, 1000 Ljubljana, Slovenia. Ph +386 1 476 8630, Fax + 386 1 425 0681, e-mail: samo.jakljic@fgg.uni-lj si.

Aleš BREZNIKAR. Assist. Prof., Doctor. University of Ljubljana, Faculty of Civil and Geodetic Engineering, Chair of Engineering Geodesy, Jamova c. 2, 1000 Ljubljana, Slovenia. Ph +386 1 476 8643, Fax + 386 1 425 0681, e-mail: ales.breznikar@fgg.uni-lj.si.

Co-author pars of one monograph and the author of more than 20 scientific papers. Participated in a number of international and national conferences.

Research interests: calibration of geodetic instruments, adjustment of geodetic network, engineering geodesy.