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LEVELLING WORKS AT THE JOINT ASTRONOMICAL, GEODETIC AND GEOPHYSICAL OBSERVATION STATION NEAR POLTAVA

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Problem in General Terms

Decision of many important problems of geodynamics requires a complex approach. It can be ensured by carrying out joint astronomical, geodetic and geophysical observations (JAGGO) in the same place. The station of joint observations in Stepanivka village was created for the fulfilment of wide range of research on geodynamics based on different type observations and for developing methods of combining these observations. Geometric levelling is one of the elements of determinations at the station.

Analysis of Recent Research and Publications

Creation of the experimental JAGGO-station in the Stepanivka village near Poltava and structure of its observation points are described in the works [1, 2]. The peculiarity of this station is that the results of different observations at its points in different epochs can be reduced to the same geometric centre. One of the types of geodetic observations at the station is geometrical levelling for elevation determination of the centres of points and bench marks. Appropriate technique of elevations transferring is used to reduce determined heights to the main geometric centre of the station [3]. Levelling and other determinations at the station of joint observations are briefly described in the work [4].

Formulation of the Problem

The purpose of this paper is a description of: local levelling network (LLN) created by us at the JAGGO-station in the Stepanivka village; levelling works executed by us as one of the types of geodetic determinations; results of geometric levelling for 2001-2014; comparison of the results of geometric and satellite levelling for two points of the network.

Local Levelling Network of the Station

The station of joint observations is in Stepanivka village of Poltava region, 20 km from Poltava in the north-easterly direction. It is based in laboratory building of Radio Telescope №2 of Ukrainian Radio Interferometer of Academy of Sciences (RT URIAS-2).

Usually local geodetic networks combine observation points in observatories [5]. There is such coordinate network in Stepanivka village [4]. We created local levelling network on its basis. These two networks overlap. LLN connects those points of the station on which heights or elevations are determined. These include marks of some observation points and network of wall elevation bench marks (see the figure):

MB4 is the eastern mark of the main base of the fundamental geodynamic point (which is equipped in the basement of the building of RT URIAS-2), the main coordinate centre of the station;

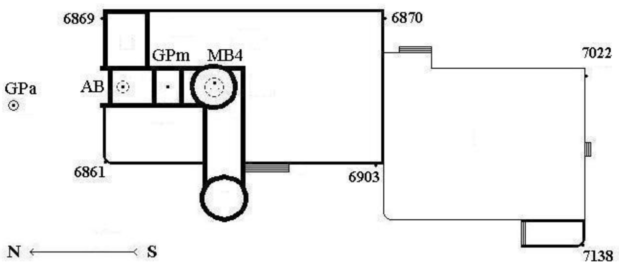
AB is the mark of the auxiliary base of the fundamental geodynamic point;

GPm is the mark of the main point of geodetic determinations (which is located in the iron-concrete plate above the third floor of the building on its load-bearing walls);

GPa is the mark of the azimuthal point of geodetic determinations (the ground elevation bench mark, it is located 383 m to the north from the main point);

wall elevation bench marks of the laboratory building (№№ 6870, 6869, 6861, 6903, 7138, 7022).

The figure (in the horizontal plane) shows: the three-story part of the building (in a very thick line), the two-story part of the building (in a thick line), the one-story part of the building (in a thin line), the projections of the bases that are in the underground floor of the building (in a dotted line), the marks and bench marks of the levelling network (in dots).



The Figure. The Scheme of the Local Levelling Network of the Station of Joint Observations in the horizontal plane (reference designations are given in the text)

The local levelling network is used to transfer heights of its marks to the main coordinate centre of the station, to control altitude stability of the marks and bench marks of the station. It has its own peculiarities. Almost all of its marks and bench marks are within the laboratory building of RT URIAS-2 which length is 46 m and width is 14 meters mainly. Only one mark of the network (GPa) is far from this building. The marks of the network are at three altitude levels, namely: under the surface of the ground (MB4, AB are at a depth of about 2 m), near the surface of the ground (wall elevation bench marks and GPa), above the surface of the ground (GPm is at a height of about 11.5 m).

Levelling for 2001-2014 years

Geometric levelling works are periodically performed by us since 2001. Their initial purpose was a need to monitor the laboratory building vertical stability after its commissioning at least at the level of IV accuracy class as it was known from geological research that this building was near the quicksand. Further goals have been expanded: altitude stability control of the observation points and laboratory building of the radio telescope, linking of the heights of the points and bench marks of the JAGGO-station to the main coordinate centre MB4. And since observations in the Global Navigation Satellite System (GNSS) are occasionally performed at the main and azimuthal points of geodetic determinations (GPm and GPa), the elevation changes between these points obtained by two methods are compared.

First, in 2001 we made linking LLN to the state levelling network with level H-3 and the standard three-meter levelling staffs from triangulation point of III class (levelling point of IV class), which is located 1.4 km east of the Stepanivka village and 0.3 km from forest belt in an ancient dug mound close to power line. Elevation of this point above the mark MB4 of the main base of the fundamental geodynamic point is +8.6564 m.

Later we have conducted seven series of levelling in the LLN. They were usually executed at the end of a year (some of them were at the end of one year and the beginning of another year), namely: in 2002/2003., 2004/2005., 2005, 2006, 2009, 2013, 2014. A level H-3 was used in the first four series, a level HB-1 was used afterward.

Levelling in the local levelling network was carried out by three separate traverses by a non-standard method:

● the first traverse between the wall elevation bench marks of the laboratory building (6870, 6869, 6861, 6903, 7138, 7022);

● the second traverse between the network of the wall elevation bench marks and the marks of the observation points MB4, AB, GPm;

● the third traverse between the network of the wall elevation bench marks and the mark of the azimuthal point GPa.

The length of the first traverse is 248 m, it is closed, the levelling was usually performed by the direct traverse, and in 2013 and 2014 also by the reverse one. Non-standard levelling staff of 1.355 m length was used, it is made by us based on a steel measuring tape. Precise level H-05 with the corresponding invar staff was used in 2002/2003 as an exception.

The total length of the second traverse is 175 m. It was performed as a direct and reverse one, based on one or two wall elevation bench marks. The only exception is the first series of levelling (direct open traverse).

The second traverse combines the marks and bench marks that are at three altitude levels, namely: in the basement of the laboratory building, near the surface of the earth, above the third floor of this building. It allows to link the heights of all marks and bench marks of the LLN to the main coordinate centre MB4.

To perform levelling in the second traverse in addition to our non-standard levelling staff steel measuring tapes that were fixed vertically and a vertical through-hole through all floors of the building above the auxiliary base were used. Initially two standard 50-meter steel measuring tapes and 5-meter one were applied. Herewith the process of levelling was delayed because of problems with fastening these tapes in appropriate places above the second and third floors of the building, and with attaching weights to their lower ends. These problems were eliminated in 2013, when we produced three special measuring tapes (from the ordinary steel ones) with the convenient means of fastening at their ends for hanging the tapes to brackets and hanging weights at their lower ends. This greatly accelerated levelling works in the second traverse.

The third traverse has a total length of 856 m, it was performed as a direct and reverse one, based on one wall elevation bench mark. The only exception is levelling in 2002/2003 (direct open traverse). Standard three-meter levelling staff (solid or sliding) was used. Levelling in the third traverse was not conducted in 2004/2005, 2005, 2014.

Works on geometric levelling were performed by Tyshchuk M.F. with the assistance of Gozhy A.V., Novikova Y.P., Borys'uk O.V., Babych T.M., Sharun D.I. in different years.

Results of the geometric levelling

Measured elevations between the marks and bench marks of the local levelling network were separately adjusted in three traverses. Characteristics of accuracy of these traverses are given in Table 1 in millimeters. The accuracy classes of levelling were determined in accordance with the received closure errors of the traverses [6].

Table 1

Accuracy characteristics of levelling (mm)

Date	Closure error of traverse	Allowable closure error	Class of levelling
first traverse			
2002/3	-2.4	3.5	III class
2004/5	-9.0	10.0	IV class
2005	+5.5	10.0	IV class
2006	+5.9	10.0	IV class
2009	+1.7	2.0	II class
2013	+1.4	2.0	II class
2014	-1.5	2.0	II class
second traverse			
2002/3	wasn't determined	-	-
2004/5	+3.6	8.4	IV class
2005	+0.2	0.8	I class
2006	-0.2	0.8	I class
2009	+1.3	1.7	II class
2013	-0.4	0.8	I class
2014	+0.2	0.8	I class
third traverse			
2002/3	wasn't determined	-	-
2004/5	-	-	-
2005	-	-	-
2006	+16.0	18.5	IV class
2009	+9.0	18.5	IV class
2013	-4.9	6.5	III class
2014	-	-	-

Best accuracy was achieved in the second shortest traverse as seen from Table 1. Since 2009 accuracy had been significantly improved in the first traverse. Although accuracy is growing in the third longest traverse, but errors remain significant. Therefore we plan to do all levelling on a level of first class in the future.

Elevations of the points of the LLN above the main coordinate centre MB4, the average values of seven series of levelling Δh_{mean} and standard deviations $\sigma_{\Delta h}$ were calculated from adjusted elevations in the three traverses (Table 2).

Table 2

Elevations of the marks and bench marks of the LLN above the main coordinate centre MB4 (mm)

Date	Names of centres, elevations		
	first traverse		
	bm 6870	**bm 6869**	**bm 6861**
2002/3	3294.5	3194.4	3325.6
2004/5	3293.4	3193.9	3324.9
2005	3294.5	3195.5	3326.0
2006	3293.5	3192.2	3323.9
2009	3293.8	3193.0	3324.8
2013	3292.9	3192.8	3324.9
2014	3293.8	3193.5	3325.8
Δh_{mean}	**3293.8**	**3193.6**	**3325.1**
$\sigma_{\Delta h}$	**±0.58**	**±1.10**	**±0.73**
	first traverse		
	bm 6903	**bm 7138**	**bm 7022**
2002/3	3319.4	2684.3	2673.7
2004/5	3318.9	2682.9	2672.4
2005	3320.0	2683.5	2674.0
2006	3318.5	2682.0	2672.0
2009	3319.6	2682.1	2672.3
2013	3319.6	2681.4	2671.4
2014	3319.9	2682.9	2672.4
Δh_{mean}	**3319.4**	**2682.7**	**2672.6**
$\sigma_{\Delta h}$	**±0.53**	**±0.97**	**±0.92**
	second traverse		*third trav.*
	AB	**GPm**	**GPa**
2002/3	-78.5		-939.6
2004/5	-78.8	13565.1	-
2005	-79.5	13565.5	-
2006	-80.2	13565.9	-938.8
2009	-78.7	13565.0	-937.0
2013	-78.9	13567.2	-936.7
2014	-79.4	13566.4	-
Δh_{mean}	**-79.2**	**13565.9**	**-938.0**
$\sigma_{\Delta h}$	**±0.58**	**±0.84**	**±1.40**

Despite some significant closure errors in the levelling traverses (Table 1) the range of deviation of the elevations relative to the main coordinate centre MB4 of the station for the points of the local levelling network during 2002-2014 was within 1.5-3 mm, and standard deviation was 0.5-1.4 mm (Table 2).

For the most points of the network the trend of height change is not clearly manifested. Only the azimuthal point of geodetic determinations (GPa) has a clear tendency of its height increasing. So, to identify the direction of height changes of the LLN-points relative to MB4 we performed linear approximation of the levelling results and obtained their trends for the period 1.01.2002-31.12.2014 (Table 3).

As seen from Table 3 height trends of the eastern and southern wall elevation bench marks are negative within 1-2 mm, the north-western one is close to zero, the western one is positive and less than 1 mm. Main and azimuthal centres of the geodetic point have positive trends of about 2mm and 3.5 mm respectively, and the centre of the auxiliary base has the trend close to zero.

Table 3

Linear trend of the LLN-points relative to MB4 for the period 2002-2014 (mm)

first traverse			
Bench marks	**bm 6870**	**bm 6869**	**bm 6861**
Trends	-1.0	-1.5	+0.1
first traverse			
Bench marks	**bm 6903**	**bm 7138**	**bm 7022**
Trends	+0.7	-1.9	-1.8
	second traverse		*third trav.*
Marks of points	**AB**	**GPm**	**GPa**
Trends	-0.2	+1.9	+3.5

Comparison of results of geometric and satellite levelling

Several series of GNSS-observations were conducted at the main and azimuthal points of geodetic determination. Today we have the results of two of them.

The first campaign to determine coordinates of the points in Stepanivka village was held 11-13.10.1999. Two-day observations were performed by specialists of the Ukrainian State Aerogeodetic Enterprise (Kyiv) Rudenko S.S., Mel'nyk V.L., Haruta B.E. under the direction of Antoshchuk A.O. and Zagoruyko V.O. with our participation. The GNSS-receivers Trimble 4000 SSE were used.

Another campaign was held 30-31.10.2012. Daily observations were performed at the point GPm, four-hour and five-hour observations were performed at the point GPa. The set of GNSS-receivers Trimble 5700 with antennas Zephyr Geodetic and Zephyr was used. The work was carried out in collaboration with the State Scientific and Production Enterprise "Poltava Geodetic Center" (Poltava), the primary observer was its worker Stakhiv D.V.

Observational data of the GNSS-campaign 2012 were transferred to the Research Institute of Geodesy and Cartography (Kyiv) for processing. Together with the data of 2012 the data of 1999 were also processed there in the IGS08 coordinate system. We refined values of reductions of the GNSS-determinations in 2012 at the point GPm and made appropriate corrections of the results. So, from the satellite observations we received geodetic elevations of the points GPm and GPa relatively geocentric ellipsoid GRS80. Elevations between these points on the dates of the satellite observations are presented in Table 4.

We have obtained the normal elevations of the same points in the Baltic height system 1977 from geometric levelling. But the dates of GNSS-observations do not coincide with the time limits of executed geometric levelling. Therefore, we extrapolated the results of linear approximation of classical levelling for the points GPm and GPa on the date of the first GNSS-campaign and interpolated on the date of the second GNSS-campaign and got elevations between these points for the period of satellite observations (Table 4).

The results of GNSS-levelling in these two epochs showed a decrease of the elevation between the points GPm and GPa by 5.3 mm, the results of classic levelling showed a decrease of the elevation by 1.6 mm. The elevations between these points, obtained by different methods, differ by about 10 and 7 mm. Of course, here we have some difference between the results of classical and satellite levelling. But it should be noted for example, that a daily session of GNSS-levelling gives an error of elevation between points 7-8 mm compared with geometric levelling [7]. Therefore such differences in the results of levelling by two methods can be permissible.

Table 4

Elevations between the points GPm and GPa from satellite and geometric levelling for the period 1999-2012 (mm)

Date of GNSS-observation	GNSS-levelling	Geometric levelling	Difference of the methods
1999	14515.2	14504.8	10.4
2012	14509.9	14503.2	6.7
(2012-1999)	-5.3	-1.6	

Conclusions and perspectives

1. The local levelling network was created at the station of joint observations.
2. Linking LLN to the state levelling network was made.
3. Geodetic determinations of elevations by geometric levelling are periodically performed.
4. Transmission of altitude component of coordinates of the observation points and elevations of the bench marks to the main coordinate centre of the JAGGO-station is provided.
5. The levelling works testified altitude stability of the observation points and laboratory building of the radio telescope.
6. Comparison of the results of geometric and satellite levelling for two points was done.

Determination of elevations by geometric levelling in the local levelling network will be continued in parallel with other types of observations at the station to ensure its comprehensive operation. Herewith our efforts will be aimed at the accuracy improvement of the levelling works and the expansion of the LLN.

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Levelling works at the Joint Astronomical, Geodetic and Geophysical Observation Station near Poltava

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The local levelling network of the joint observation station in Stepanivka village is described. Linking this network to the state levelling network is made. The results of seven series of geometric levelling in the network during 2002-2014 years are given. The comparison of the results of geometric and satellite levelling for two points is carried out.